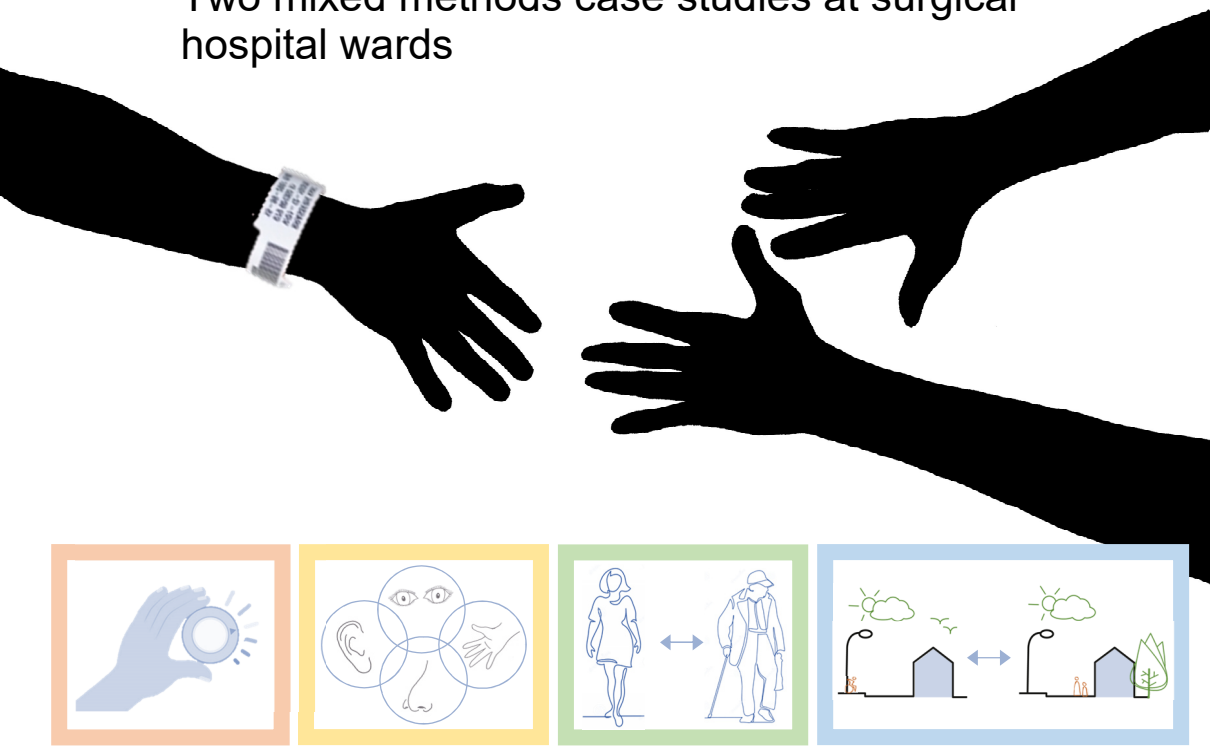
KU LEUVEN

ARENBERG DOCTORAL SCHOOL
FACULTY OF ENGINEERING SCIENCE

Reducing the gap between predicted and experienced indoor environmental comfort

Two mixed methods case studies at surgical hospital wards



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Prof. dr. ir. arch. Ann Heylighen
Co-supervisor:
Prof. dr. ir. arch. Dirk Saelens

Dissertation presented in partial fulfilment of the requirements for the degree of Doctor of Engineering Science (PhD): Architecture

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TWO MIXED METHODS CASE STUDIES AT SURGICAL HOSPITAL WARDS

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One of the participants during previous research gave me a great goal and I hope that I can partly fulfil it with this work.

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Sara Willems
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Abstract

The design of healthcare environments can have an impact on patients' emotions. These emotions can influence their comfort and health, and interlink with adaptation, i.e. the response to restore comfort when discomfort occurs. Adaptation affects energy use. In that context, researchers seek to develop models that predict comfort (MCP) or adaptations of indoor conditions (MAP); or try to understand the roles of the built environment (RBE) in experiences.

In MCP research, discrepancies are observed between predicted and experienced (dis)comfort; in MAP research, between predicted and actual adaptations of indoor conditions. In RBE research the roles of the built environment in experiences are not yet fully understood. More attention is needed for *interactions (1) between people and indoor conditions* through perceived control and adaptation, and *(2) between the different indoor environmental quality (IEQ) factors* in experience, as well as for *differences (3) between people and (4) between settings*.

This research addresses these four points of attention. It focuses on the question: How do hospitalized patients' experiences of their patient room's indoor environment relate to measureable values of IEQ parameters (e.g. temperature)? This with the objective to explore whether integrating RBE, MCP, and MAP research enables improving the understanding of the four points of attention described above.

MCP, RBE and MAP research were integrated. This integration occurred through two mixed methods case studies in surgical wards of two Belgian hospitals. The data collection included: interviews with 16 (case 1) and 19 (case 2) patients; self-documentation by eight patients (case 1); sensor measurements of IEQ parameters (mainly noise, light, and indoor air temperature levels) (case 1 and 2); questionnaires with 84 (case 1) and 238 (case 2) patients as well as simulations of the free-running temperature, the total short-wave solar radiation through the windows and the heat demand. During data analysis and interpretation, quantitative and qualitative data were integrated via joint displays, and figures were combined with an explanation based on the interviews. Implications were discussed with engineers, architects and nurses.

Five adaptation strategies were identified in the interactions between patients and indoor conditions. When participants perceive control, they adapt

(1) indoor conditions, (2) sensations (e.g. hot or cold) or the environmental information (e.g. heating or incident sunlight), (3) or their position; or (4) they adapt to indoor conditions by choice. In the absence of perceived control (5), the adaptation feels imposed. The first three strategies seem to support both hedonic (i.e. pleasure) and eudaimonic well-being (i.e. a sense of functioning well), the fourth and sometimes the last only eudaimonic well-being. There is a tendency towards more neutral or more preferable sensations and higher satisfactions when participants adapt indoor conditions or have no wish to do so than when they adapt by choice or when adaptation feels imposed. Since differences in experience do not correspond to those noticed in values of IEQ parameters, the strategies seem to influence experience in a psychological way.

More insight was gained into how IEQ factors interact in experience. The overall assessment of the comfort in the room correlates with the assessment of the individual IEQ factors and that of different IEQ factors correlate with each other. Interactions are observed between satisfaction with one IEQ factor and variations in IEQ parameters associated with another IEQ factor or in satisfaction with these IEQ factors. Interactions seem to occur because sensations are experienced simultaneously as well as objects and events.

A better understanding was obtained of how thermal and visual comfort and adaptation differ between patients and settings. Three scenarios were identified: (1) situations in which experienced comfort and adaptation are similar, (2) in which adaptation differs and experienced comfort is similar, or (3) in which experienced comfort differs and indoor conditions are similar. In addition, eleven models of thermostat adaptations in patient rooms were set up and their strengths and weaknesses with respect to three design purposes compared: for energy-sensitive design, for obtaining robust designs, or for attending to the simultaneity of energy use. Which model performs best seems to depend on the application purpose. In general, models that take differences in thermostat adaptations between days, interactions between characteristics related to patients and their setting that can impact on the adaptations, and the stochasticity of these adaptations into account, seem best suited for the three design purposes.

The positive influence on patients' experience when they adapt indoor conditions suggests to design adaptable building characteristics that align with various competences of patients, and patient room designs that support autonomy. This design strategy is expected to increase comfort while reducing the percentage of time that the heating or lighting are working. The insights can increase designers' understanding of patients' adaptation strategies and provide researchers with a basis for improving models that predict comfort or adaptation. The insights from this research can support the design of more comfortable patient rooms, with a reduced gap between experienced and predicted indoor environmental comfort.

Beknopte Samenvatting

Het ontwerp van zorgomgevingen kan impact hebben op emoties van patiënten. Deze emoties kunnen hun comfort en gezondheid beïnvloeden en hangen samen met aanpassing, d.w.z. de reactie om comfort te herstellen wanneer discomfort zich voordoet. Deze aanpassing beïnvloedt het energieverbruik. In die context stellen onderzoekers modellen op die comfort voorspellen (MCP); anderen die de aanpassingen van binnencondities voorspellen (MAP). Andere onderzoekers trachten de rollen van de gebouwde omgeving in ervaringen (RBE) te begrijpen.

In MCP onderzoek tonen zich discrepanties tussen het voorspelde en ervaren (dis)comfort; in MAP onderzoek, tussen voorspelde en werkelijke aanpassingen van binnencondities. In RBE onderzoek worden rollen van de gebouwde omgeving in ervaring nog niet helemaal begrepen. Meer aandacht is nodig voor *interacties (1) tussen mensen en binnencondities* via ervaren controle en adaptatie, en *(2) tussen factoren van de kwaliteit van de binnenomgeving* (IEQ) in ervaring; en voor *verschillen (3) tussen mensen en (4) tussen contexten*.

Dit onderzoek behandelt deze vier aandachtspunten. Het richt zich op de onderzoeksvraag: Hoe verhouden ervaringen van patiënten van de binnenomgeving in hun ziekenhuiskamer zich tot meetbare IEQ parameters (e.g. temperatuur). Dit met als doel te onderzoeken of de integratie van RBE, MCP en MAP onderzoek het mogelijk maakt om de vier hierboven beschreven aandachtspunten beter te begrijpen.

RBE, MCP en MAP werden geïntegreerd. Dit gebeurde via twee casestudies met gemengde methoden in chirurgische afdelingen van twee ziekenhuizen in België. De dataverzameling omvatte: interviews met 16 (case 1) en 19 (case 2) patiënten; zelfdocumentatie door acht patiënten (case 1); sensormetingen van IEQ parameters (voornamelijk geluid, licht, en de binnenluchttemperatuur) (case 1 en 2); enquêtes met 84 (case 1) en 238 (case 2) patiënten alsook simulaties van de vrije temperatuur, de totale kortgolvige zonnestraling door de ramen en de warmtevraag. Tijdens de analyse en interpretatie werden kwantitatieve en kwalitatieve data geïntegreerd via tabellen en figuren, en figuren gecombineerd met een toelichting op basis van de interviews. Implicaties werden besproken met ingenieurs, architecten en verpleegkundigen.

Vijf aanpassingsstrategieën werden in de interacties tussen patiënten en binnencondities geïdentificeerd. Wanneer participanten controle waarnemen

passen ze (1) binnencondities, (2) sensaties (bv. warm/koud), de omgevings-informatie (bv. verwarming of invallend zonlicht), (3) of hun positie aan; of ze (4) kiezen om zich aan te passen aan de condities. Wanneer ze geen controle waarnemen (5) voelt het aanpassen gedwongen. De eerste drie strategieën lijken hedonisch (i.e. plezier) en eudaimonisch welbevinden (i.e. een gevoel van goed functioneren) te ondersteunen; de vierde en soms de laatste enkel eudaimonisch welbevinden. Wanneer participanten binnencondities aanpassen of er geen wens toe hebben, hebben sensaties de tendens om neutraler of verkieslijker te zijn en tevredenheden hoger dan wanneer ze kiezen om zichzelf aan te passen of de aanpassing opgelegd voelt. Vermits de verschillen in ervaring niet overeenstemmen met deze in waarden van IEQ parameters, lijken de strategieën de beleving op een psychologische manier te beïnvloeden.

Meer inzicht werd verworven in interacties tussen IEQ factoren in ervaring. De algemene comfortbeoordeling van de kamer correleert met de beoordeling van IEQ factoren en deze van de factoren onderling. Interacties tonen zich tussen tevredenheid met één IEQ factor en variaties in IEQ parameters die geassocieerd worden met een andere IEQ factor of in de tevredenheid met deze IEQ factoren. Interacties lijken op te treden omdat sensaties tegelijkertijd ervaren worden, evenals objecten en gebeurtenissen.

Ook werd een beter beeld gevormd van hoe thermisch en visueel comfort en aanpassing verschillen tussen patiënten en contexten. Drie scenario's werden geïdentificeerd: situaties waarbij het ervaren comfort en aanpassing gelijkaardig zijn, waarbij aanpassing verschilt en het ervaren comfort gelijkaardig is, of waarbij het ervaren comfort verschilt en binnenomstandigheden vergelijkbaar zijn. Bovendien werden elf modellen van thermostaataanpassingen opgesteld en hun geschiktheid voor drie ontwerpdoelen vergeleken: het toepassen van energie-sensitief ontwerp, het verkrijgen van robuuste ontwerpen, of het letten op de gelijktijdigheid van energieverbruik. Welke modellen het beste presteren lijkt af te hangen van het ontwerpdoel. In het algemeen lijken deze die verschillen in thermostaataanpassingen tussen dagen, interacties tussen kenmerken van patiënten en hun context die de aanpassingen beïnvloeden, en de stochasticiteit van de aanpassingen meenemen, het meest geschikt voor de drie ontwerpdoelen.

Dat het zelf aanpassen van binnencondities de ervaring van participanten positief beïnvloedt, suggereert om aanpasbare gebouwkenmerken te ontwerpen die aansluiten bij de competenties van diverse patiënten en patiëntenkamers die hun autonomie ondersteunen. Verwacht wordt dat dit het comfort verhoogt en tegelijk de duur van verwarmen en verlichten reduceert. De inzichten kunnen het begrip van ontwerpers voor aanpassingsstrategieën van patiënten verhogen en aan onderzoekers een basis bieden voor het verbeteren van comfort- en adaptatiemodellen. Dit leidt mogelijk tot comfortabelere en energiezuinigere patiëntenkamers, met een gereduceerde kloof tussen het voorspelde en het ervaren comfort van de binnenomgeving.

Glossary

Action	Something done or performed, a deed, an act (Oxford University Press, 2022).
Experienced indoor environmental (dis)comfort	The experience (including assessment) of indoor conditions by people.
Adaptable building characteristic	Building characteristic, such as the heating or lighting, of which the state can be changed.
Adaptation of indoor conditions	An action that changes the state of indoor conditions.
Adaptive opportunity	The possibilities offered to people by contextual factors to adapt behaviourally (e.g. adaptable building characteristics or dress codes) (Nicol & Humphreys, 2002).
Affection	The state of the mind as regards some specific object; disposition towards something (Oxford University Press, 2022).
Affordance	The possible facilitations or hindrances provided by the substances, surfaces, objects and other living creatures surrounding a person in the immediate context of its current activity (Gibson, 1979, p. 127, 1968, p. 68; Ingold, 2011a, pp. 77–78).
Building	The material structure of the built environment, including its layout, furniture and finishing (Miedema, 2020).
Built environment	Buildings, spaces, and products that are created or significantly modified by people (Schulz & Northridge, 2004; Miedema, 2020).
Cognition	The action or faculty of knowing (Oxford University Press, 2022).

Environment	A particular set of surroundings or conditions which something or someone exists in or interacts with (Oxford University Press, 2022).
Experience	The fact of being consciously the subject of a state or condition, or of being consciously affected by an event; a state or condition viewed subjectively (Oxford University Press, 2022).
Hospital	Institution for the nursing patients (Van Dale Uitgevers, 2022).
Indoor environment	The environment inside a building.
Indoor environmental conditions	Intangible features of the indoor environment.
Indoor environmental parameters	Measurable quantities of indoor environmental conditions like the sound, light, temperature, humidity, or CO_2 level (Bluyssen, 2009).
Indoor environmental factor	Constructs such as thermal, visual and acoustic comfort and indoor air quality (Bluyssen, 2009). They can be assessed by people or estimated based on one or more IEQ parameters.
Indoor environmental quality	The quality of indoor conditions. The experienced indoor environmental quality refers to people's experience or assessment of indoor conditions, or to how indoor conditions impact on people's health, productivity and well-being; the predicted indoor environmental quality to the quality predicted by the use of indoor environmental quality models.
Indoor environmental quality model	A function or model developed by researchers to predict the indoor environmental quality based on values of parameters, such as indoor environmental quality parameters.
Material environment	The tangible features of the environment.
Perceived control	People's belief about the influence on an outcome via changing the world or themselves to fit in with the world (Bryant, 1989; Chipperfield et al., 2012). In this work, it refers to the control people can perceive over adaptable building characteristics that can influence indoor conditions (e.g. the heating).

Perception	The process of becoming aware of physical objects, phenomena, etc., through the senses (Oxford University Press, 2022).
Physical environment	Both the built and the natural environment (Schulz & Northridge, 2004; Miedema, 2020).
Predicted (dis)comfort	The (dis)comfort predicted through indoor environmental quality models.
Senses	Abilities to absorb external stimuli, such as hearing, sight, smell, taste and touch (Van Dale Uitgevers, 2022).
Setting	The combination of the natural, social and built environment, and the complex and dynamic interaction among them (Miedema, 2020).

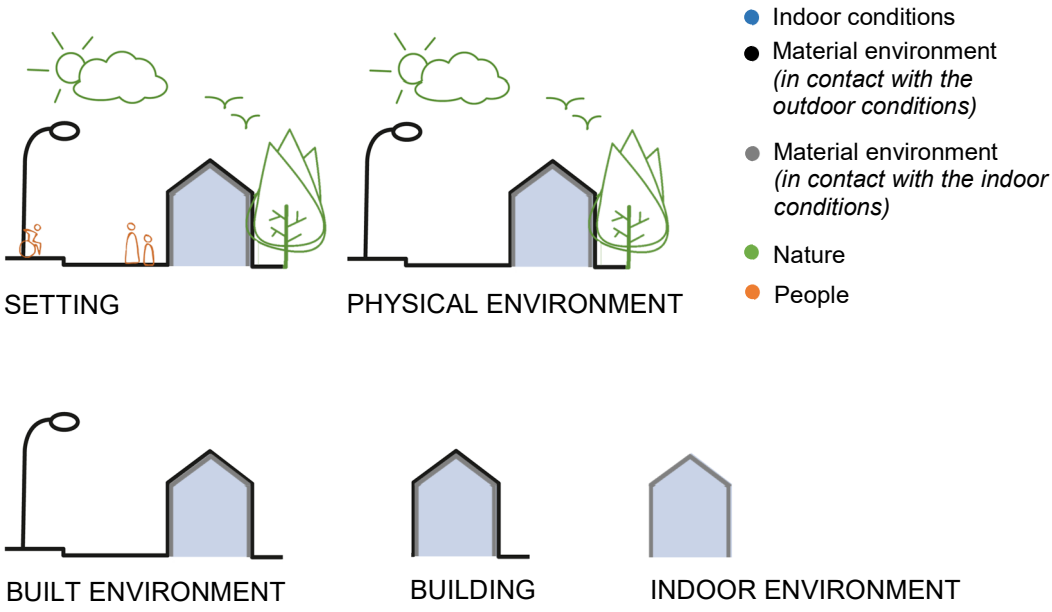

Figure G.1 Visualization of the differences between the concepts setting, physical environment, built environment, building and indoor environment (Based on: Miedema, 2020).

List of Abbreviations

1p	Single room
2p	Double room
AIC	Akaike information criterion
AUC	Area under the ROC curve
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BEPS	Building energy performance simulation
c.	Corridor side
EBC	Energy in Buildings and Communities
EN	European standard
h.	During the heat wave
IAQ	Indoor air quality
IEA	International Energy Agency
IEQ	Indoor environmental quality
ISO	International Organization for Standardization
LAeq	A-weighted equivalent continuous sound level
LED	Light-emitting diode
MAP	Models for predictions of adaptations of indoor conditions
MCP	Models for comfort predictions
n_i	Number of interviewees
n_s	Number of respondents
NA	Not applicable
NE	Northeast
n.h.	During other days of the fieldwork than the heat wave
n.s.	Not significant
NW	Northwest
PA	Point of attention
PMP	Performance Measurement Protocols
PMV	Predicted mean vote
PPD	Predicted Percentage Dissatisfied
q5	5th percentile
Q1	First quartile
Q3	Third quartile

Q95	95th percentile
QUAN	Quantitative
QUAL	Qualitative
QUAGOL	Qualitative Analysis Guide of Leuven
RBE	The roles of the built environment in experiences
ROC	Receiver operating characteristic
RQ	Research question
SA	Satisfaction with the indoor air quality
SE	Southeast
SET	Standard effective temperature
SV	Satisfaction with the visual comfort
SS	Satisfaction with the acoustic comfort
ST	Satisfaction with the thermal comfort
SW	Southwest
w.	Window side
WHO	World Health Organization

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Chapter 1: **Introduction**

1. Background and scope

Hospitals are one of the building types for which the improvement of comfort through the indoor environment is of importance. Due to the different ways in which the indoor environment and people interrelate, which will be discussed below, hospitals rated with a high indoor environmental quality (IEQ) enhance patients' healing process (Nimlyat & Kandar, 2015). The length of patients' hospital stay was for example found to reduce when they experience the indoor environment as satisfactory (Nimlyat & Kandar, 2015; Choi et al., 2012). Moreover, patients' length of stay was related to the window orientation, view on nature, and illuminance level in studies of Benedetti et al. (2001), Choi et al. (2012) and Ulrich (1984). Mortality was affected by, for example, window orientation, the direction of air flow, and the filtration of air in studies performed by Beauchemin and Hays (1998), Leaf et al. (2010), Shirani et al. (1986), and Passweg et al. (1998). In this work the focus is on patient rooms as hospitalized patients spend much of their time there.

The indoor environment and people interrelate in different ways. Within this interrelation, the design of indoor environments can have an impact on people's emotions, and these emotions, in turn, can affect their indoor environmental comfort (Ortiz et al., 2017). Despite differences in its definition, comfort refers across studies to subjective experiences, affected by various factors (e.g. physical, physiological, psychological) that result from the interrelation between people and their environment (e.g. Ortiz et al., 2017; de Looze et al., 2003; Vink, 2005, p. 14). Moreover, comfort can be understood as a fully specifiable optimal condition or as a social construct (Ortiz et al., 2017; Chappells & Shove, 2005). For example, from a biological perspective, comfort can be considered the maintenance of homeostasis – a reaction to the environment indicating the absence of environmental stressors (Ortiz et al., 2017). Similarities between people as a species may lead to similar comfort requirements. However, it can also be argued that what is considered comfortable reflects the beliefs, values, expectations and aspirations of those who construct comfort (Cooper, 1982, p. 270; Chappells & Shove, 2005). In this

work it is assumed that comfort can be specified due to similarities between people, but only with approximation as it is also partly a social construct.

Supporting indoor environmental comfort through positive emotions can also have a positive impact on health. For example, positive emotions have been associated with lower blood pressure levels, reduced inflammatory processes and neuroendocrine, cardiovascular and immune strengthening, while negative emotions can cause stress, anxiety, depression, and eventually damaging changes in the cardiovascular system (Ortiz et al., 2017). Moreover, the maintenance of homeostasis is not only related to comfort but also to health. Note that the indoor environment has also an impact on health independently from comfort. Indoor conditions can limit physical stressors causing infirmity, disease and years of potential life lost (Rohde et al., 2020). Given our interest in the interrelation between the indoor environment and subjective experiences, we focus in this research on patients' indoor environmental comfort.

Furthermore, people are not passively exposed to the indoor environment. Emotional responses to the indoor environment are related to adaptation (Ortiz et al., 2017). Adaptation refers to people's reaction to restore their comfort when a change occurs that causes discomfort (Nicol & Humphreys, 2002). People can adapt in different ways. Based on the literature, de Dear and Brager (1998) distinguished between behavioural, physiological and psychological adaptation. The purpose of behavioural adaptation is to eliminate or reduce negative stimuli of the environment (Ortiz et al., 2017). It may also be applied to obtain positive ones (Rohde et al., 2020).

In order to ensure that the indoor environment is comfortable in buildings, several researchers aim to understand what a comfortable indoor environment is (e.g. Andrade & Devlin, 2015; Fanger, 1970). Other researchers focus on understanding how people behave in a setting (e.g. Stazi et al., 2017). Influenced by differences in the research objective(s), applied research approaches of these studies differ. Researchers take other ontological (i.e. how researchers assume the nature of reality) and epistemological positions (i.e. assumptions about the origin, limits and nature of knowledge), which connect with researchers' theoretical lens, methodology and methods (Creswell & Plano Clark, 2018, p. 35). Some examples are given below.

To start with, the objective of studies differs. For example, some researchers try to understand different roles that the indoor environment plays in experiences (e.g. Annemans et al., 2018a; Jellema et al., 2020). Other researchers try to understand *the* role of the indoor environment in experience (e.g. Andrade & Devlin, 2015; Andrade et al., 2017). Other researchers develop models that enable predicting (dis)comfort or adaptation based on values of IEQ parameters, sometimes in combination with occupant- and building-related parameters. IEQ parameters are measurable quantities of indoor environmental conditions like the sound, light, temperature, humidity, or CO_2 level. Examples of occupant- and building-related parameters are needs for privacy or the window

orientation (e.g. Stazi et al., 2017; Fabi et al., 2012; Inkarojrit, 2005). Often these researchers set up models that predict comfort with respect to separate IEQ factors. IEQ factors are constructs that can be assessed by people or estimated based on one or more IEQ parameters. Most often thermal, visual and acoustic comfort, and indoor air quality are considered as the main IEQ factors (Nimlyat & Kandar, 2015). Models that predict adaptation are often set up with respect to separate actions towards adaptable building characteristics, such as thermostat adaptations (e.g. see Carlucci et al., 2020 for an overview).

Different worldviews are adopted as well. For example, some researchers have adopted constructionism as worldview (e.g. Annemans, 2015; Jellema, 2020); other researchers naïve realism (e.g. Fanger, 1970; Parkinson et al., 2020; Andrade & Devlin, 2015; Andrade et al., 2017). On the ontological level, researchers supporting constructionism believe that reality is an internal construction where individuals assign meaning to events and ideas (Major & Savin-Baden, 2013, p. 63). They also view reality as multiple. Participants have multiple perspectives (Creswell & Plano Clark, 2018, p. 36). Papert developed constructionism based on Piaget's constructivism (Ackermann, 2001). Constructionism, in contrast to constructivism, attends to how people form and transform knowledge within specific contexts and how it is shaped and expressed through different media (Ackermann, 2001). Epistemologically research with constructionism as worldview has a subjective element in it (Searle, 2001, p. 54–56). Knowledge about the meaning of phenomena, formed through participants and their subjective views, is created by researchers rather than discovered (Creswell & Plano Clark, 2018, p. 36). In contrast, researchers supporting naïve realism search epistemologically objective knowledge, within a certain probability, about how the world 'really' is. They assume at an ontological level that mind-independent events and objects exist. According to them people perceive these events and objects; these perceptions are not representations of reality; and the items a subject perceives constitutively shape the perception's phenomenology (Beck, 2019). At an epistemological level, therefore, perception enables people to think about reality, and to know what is objectively the case. The emphasis on using validated instruments and avoiding bias shows researchers' wish to understand the world as it 'really' is.

Different ways of reasoning are also applied. For example, some researchers apply deduction (e.g. Andrade & Devlin, 2015; Andrade et al., 2017), others induction (e.g. Annemans, 2015; Jellema, 2020). In deductive reasoning, a hypothesis is evaluated (Åsvoll, 2014). In inductive reasoning, empirical data is used to identify a pattern from which to make a general statement (Flick, 2018, p. 51).

Different theoretical lenses are taken. Kano's satisfaction model, developed originally in the context of marketing, has been applied in some studies (e.g. Kim & de Dear, 2012b; Dace et al., 2020). Kano (1984) assumes in his model of customer satisfaction that different qualities or factors impact overall customer

satisfaction in different ways: some in a positive way, some in a negative way, and some in both directions. Other studies are based on post-phenomenology (e.g. Dorrestijn & Verbeek, 2013). Post-phenomenologists conceive technology as mediators of human experience. They try to understand how technology shapes the connection between people and the world. Other studies build on Gibson's theory of affordances (e.g. van Dijk & Rietveld, 2017). Affordances are defined by Rietveld et al. (2018) as "*relations between (a) aspects of the sociomaterial environment in flux and (b) abilities available in a 'form of life'*". Other studies have their basis in multisensory anthropology (e.g. Pink et al., 2022). They attend to how perceptual systems are emplaced in a particular setting (e.g. cultural context), and the mediating rather than representing role of them (Serres, 2008; Howes, 2006, p. 7, 2019; Pink, 2009, p. 25; Duncum, 2012). Perceptual systems are various combinations of the senses that function to pick up information about affordances from the environment rather than sensations (Gibson, 1968, p. 5, pp. 47-49).

The methodology and the corresponding methods vary too. Methods applied for data collection are, for example interviews (e.g. Annemans et al., 2018a; Jellema et al., 2020), sensor measurements (e.g. Nicol & Humphreys, 2002), the documentation of building characteristics (e.g. Eijkelenboom & Bluyssen, 2020), and/or questionnaires addressing one (e.g. Khodakarami & Knight, 2008) or more IEQ parameters or factors (e.g. Fransson et al., 2007), long-term or right-now assessments (e.g. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), 2010; Kim & de Dear, 2012a; Kim & de Dear, 2012b), and comfort or adaptation (e.g. Deme Belafi et al., 2018). Methods applied for data analysis are, for example, statistical analyses such as multivariate regression (e.g. Ncube & Riffat, 2012; Eijkelenboom et al., 2021), or the grounded theory approach (i.e. the aim is to systematically generate a substantive theory grounded in empirical data (Walker & Myrick, 2006)) (e.g. Annemans, 2015).

The research objective seems to influence choices regarding the research approach. This can be illustrated with some examples. Constructionism is for example appropriate when the objective is to understand roles of the built environment in experiences. Both inductive and deductive reasoning can be applied. The former can be applied when one wants to describe different roles of the built environment in experiences (e.g. Annemans et al., 2018a); the latter when one wants to improve an existing theory about its roles (e.g. Andrade et al., 2017; Andrade & Devlin, 2015). In contrast to the latter case, in the former case no theoretical lens is adopted prior to the research. In the former case, methods that enable gaining an in-depth understanding of participants' experience are necessary as one wants to understand differences in the meaning given. Qualitative methods can be used (e.g. interviews and the grounded theory approach) (Johnson & Gray, 2010). Some researchers also collect quantitative data to better understand the meaning of phenomena (e.g. Venter et al., 2014;

Annemans et al., 2020). In the latter case, both qualitative as quantitative methods can be applied as well (e.g. questionnaire).

Naïve realism is for example appropriate when one aims to develop a guideline or a model that can predict indoor environmental comfort or the corresponding adaptation. It is assumed that the guideline or model is applicable in general, for a particular user group, or in a particular setting. Both inductive and deductive reasoning can be applied. The former can be applied, for example, when the objective is to identify variables and their associations in order to develop a predictive model (e.g. Roussac et al., 2011), the latter to test hypotheses or a model (e.g. Verheyen et al., 2011). The theoretical lens adopted reflects the assumptions made regarding the associations between variables (e.g. Kano's satisfaction model (Kano, 1984)). Methods that enable identifying variables and their associations are applied. Quantitative methods are typically associated with naïve realism (e.g. sensor measurements, questionnaires and statistical analyses) (Johnson & Gray, 2010). However, some researchers gather qualitative data within a naïve realist worldview (e.g. Roussac et al., 2011). The qualitative data are used, for example, to determine which variables should be included in their 'general' or 'covering laws'.

2. Problem statement

First, discrepancies are observed between predicted and experienced (dis)comfort (e.g. Burge, 2004; de Dear & Brager, 1998; Nenonen et al., 2013; Nicol & Humphreys, 2002). This gap is indicated by research with the objective to set up models for comfort predictions (MCP). MCP research includes studies on which the threshold values for IEQ factors in current standards and guidelines are based (e.g. Bureau for Standardisation, 2003; Bureau for Standardisation, 2005; Berglund et al., 1999), as well as follow-up research on them (e.g. Parkinson et al., 2020 for the adaptive thermal comfort model).

Second, it is not completely understood yet which roles the indoor environment plays in patients' experiences. Understanding in depth the roles of the indoor environment in occupants' experience (RBE) is the objective of RBE research. The setting focused upon in this research are healthcare settings (e.g. Annemans et al., 2018a; Annemans et al., 2018c; Douglas & Douglas, 2004; Anaker et al., 2019; Jellema et al., 2020; Nielsen & Overgaard, 2020).

Third, people adapt indoor conditions to improve their indoor environmental comfort. Researchers who quantify buildings' energy use usually observe a discrepancy between the predicted and actual one (e.g. Zou et al., 2018). It is argued that not including people's adaptations of indoor conditions accurately in energy use predictions is one of the main reasons that causes this discrepancy (Stazi et al., 2017). Therefore, some researchers have the objective to set up models for predictions of adaptations of indoor conditions (MAP) that

can be included in building energy performance simulations (e.g. see Carlucci et al., 2020 for an overview). Further research is needed on how these models can be refined (Yan et al., 2017).

To reduce these gaps, a better understanding seems needed of *interactions (1) between people and indoor conditions*, e.g. through perceived control and adaptation, and *(2) between the different indoor environmental quality (IEQ) factors* in experience, as well as of *differences (3) between people and (4) between settings* in indoor environmental comfort and adaptation. How a better understanding of these four points of attention (PA) can reduce the gaps described above is discussed in more detail below.

2.1. Interactions between people and indoor conditions through perceived control and adaptation (PA.1)

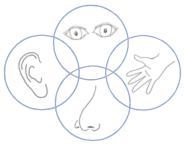


One reason given for discrepancies between predicted and experienced (dis)comfort in MCP research is that predictions do not (sufficiently) take into account the positive influence of perceived control on how indoor conditions are experienced (de Dear & Brager, 2001; Nicol & Humphreys, 2002). It is observed that perceived control over indoor conditions improves people's experience of them as it supports adaptation (e.g. in offices: Boerstra et al., 2013; Brackley et al., 2021; Sakellaris et al., 2019, in schools: Yun, 2018, and in residential buildings: Brown & Gorgolewski, 2014; Luo et al., 2014; Xu & Li, 2021). Taking this influence into account requires a better understanding of how people interact with the indoor environment through perceived control and adaptation, as well as how it influences their comfort.

In RBE research a better understanding is needed of the different ways in which patients adapt and adapt to indoor conditions, and the roles of the built environment therein. According to Ulrich (1991), patient's lack of control is a major problem in healthcare settings. Ulrich's theory of supportive design advances three properties of healthcare settings that support patients' wellness: positive distractions, social support, but also perceived control over the material and social environment. However, the role of perceived control in patients' experience is not clearly understood yet (e.g. Andrade et al., 2017; Andrade & Devlin, 2015). In a study with orthopaedic patients, questionnaire respondents' stress - which can be caused by negative emotions - was predicted not by how much control they indicated to perceive over the lighting, temperature, windows, and refrigerator, but by positive distraction and social support (Andrade et al., 2017). Andrade et al. (2017) have argued that the expected positive effect on the stress level of patients with a high desire for control may be cancelled out by the absent of an effect for patients with a low desire. Distinguishing between adaptation strategies might thus be needed to improve the understanding of the role of perceived control in patients' experience.

A better understanding of how people interact with the indoor environment through perceived control and adaptation may also enable refining models of adaptation. In models set up within MAP research the focus is currently only on adaptations of indoor conditions.

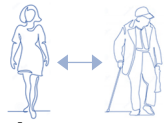
2.2. Interactions between IEQ factors in experience (PA.2)



One reason given for discrepancies between predicted and experienced (dis)comfort in MCP research is that most predictions do not take into account that people's experience of the indoor environment is multi-sensory (e.g. Liu et al., 2018). Taking into account that people's experience is multi-sensory requires a better understanding of how IEQ factors interact in experience. In MCP research, relationships between values of IEQ parameters and the assessment of IEQ factors are searched for. The focus is most often on an individual IEQ factor (e.g. Fanger, 1970; Carlucci et al., 2015). These factors relate to different sensations. Attention can indeed facilitate processing relevant stimuli and suppress processing irrelevant ones (Zimbardo & Gerrig, 2002). It is however observed that different IEQ factors have a combined effect on people's overall experience (Heinzerling et al., 2013; Nimlyat & Kandar, 2015), and that people have difficulties to isolate one sensory quality from another (Fransson et al., 2007). For example, thermal conditions were found to be significantly correlated with satisfaction with the indoor air quality in an experiment in a laboratory configured to emulate an open-plan office (Tang et al., 2020), and for patients and employees in a hospital (Fransson et al., 2007). Interactions between IEQ factors occur. Insight into these interactions needs to be improved.

The need to better understand interactions between IEQ factors in experience is also indicated within MAP research. It is one of the topics to which the International Energy Agency (IEA) via the Energy in Buildings and Communities' (EBC) Annex 79 wants to contribute (O'Brien et al., 2020). It is advanced that a more in-depth understanding of occupants' experience and adaptation as well as buildings' energy use under multi-domain exposure situations is needed in order to predict buildings' energy use more accurately.

2.3. Differences between people in comfort and the corresponding adaptation (PA.3)



One reason given for discrepancies between predicted and experienced (dis)comfort in MCP research is that predictions do not sufficiently take into account that which indoor conditions people find comfortable can differ among them. Taking these differences into account to a larger extent requires that these differences are better understood. In MCP research, the same relationships between IEQ parameters and IEQ factors and the same threshold values often apply for people in general (e.g. Parkinson et al., 2020) or the different occupants

of the same type of room (e.g. Bureau for Standardisation, 2003; Bureau for Standardisation, 2005; Berglund et al., 1999). When threshold values focus on a specific type of room, it can be questioned whether the threshold values and the corresponding relationships have been identified based on fieldwork with the user groups that occupy this type of room. Threshold values for the A-weighted equivalent continuous sound level (LAeq) and the maximum instantaneous A-weighted sound pressure level, measured on fast response (LAmax, fast) for example do take patients' limited ability to cope with stress into account (Berglund et al., 1999). Note that this work does not focus on threshold values of material characteristics of patient rooms that impact acoustic comfort. However, the relationship between IEQ parameters and thermal comfort in Fanger's thermal comfort model is based on research in climate chambers with healthy adults (Fanger, 1970). The relationship is fixed, but the value of the metabolic rate and clothing insulation can be specified. In this way, some distinction can be made between specific user groups. Note however that values of the metabolic rate and clothing insulation are costly and difficult to obtain in real-world settings and, therefore also often assumed or simplified (Kim et al., 2018). Moreover, in determining the threshold values for the illuminance level specified in NBN EN 12464-1 (Bureau for Standardisation, 2003), the tasks and activities that take place in patient rooms were taken into account. It can be questioned whether, when determining the threshold values, the activities were taken into account independent of the setting, or whether the threshold values are based on research with patients performing different activities in a patient room. When assuming that the same relationships or threshold values apply for different people, indoor environmental comfort for an 'average' person is pursued (Bluyssen, 2020). However, what patients experience as comfortable may, for example, differ from healthy people. In addition, differences in comfort requirements may exist between patients. This work focuses on differences between patients.

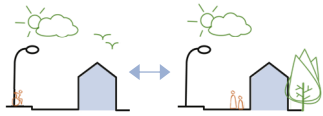
In addition, the accuracy with which MAP research's models of adaptations of indoor conditions include differences in these adaptation between people needs to be improved (e.g. Stazi et al., 2017). The extent to which models include differences in adaptation between people depends on their complicatedness. The complicatedness of a model is related to three distinctive features of occupant behaviour that different models take into account differently: it is stochastic, divers and complex (Yan et al., 2017). Stochasticity refers to the fact that, unlike machines, people do not strictly repeat their behaviour, for example, from day to day. Diversity refers to the many different people who reside in an indoor environment and who can adapt indoor conditions in a different way. Differences may arise due to, for example, deviating tolerances and comfort requirements. Complexity implies that occupant behaviour has complicated underlying mechanisms. To refine the models, more insight is needed into the mechanisms

that explain differences in indoor environmental comfort and the corresponding adaptation between people.

The understanding of the different roles the indoor environment plays in different patients' experiences needs to be improved as well according to RBE research. Attention for differences between patients resonates with the paradigm shift from a biomedical perspective towards a person-centred perspective that took place in health care (Lines et al., 2015; Annemans et al., 2018b). With regard to the indoor environment, it raises the question how a person-centred hospital building can be designed (Lawson, 2010; Annemans et al., 2018b). More insight into differences in comfort and the corresponding adaptation between patients are expected to contribute to the understanding of what a person-centred hospital building can be.

Note that in general researchers have already indicated that various characteristics of people or of patients in particular can influence the experience of the indoor environment. In general, people's experience of the indoor environment can differ due to demographics, physiological characteristics, social aspects and previous experiences and exposures (Bluyssen, 2014). Individuals' preferences and needs may vary over time as well, due to differences in the activities, clothing, health state or other personal factors (Heerwagen, 1998). In particular for patients, birth sex and age (Sattayakorn et al., 2017), as well as their disease and vulnerability (Eijkelenboom & Bluyssen, 2022) are found to impact their experience. Furthermore, different moods, recent negative and positive events, patients' length of stay, the familiarity with the hospital building, and whether the hospital stay was planned in advance or not may impact patients' experience as well (Annemans, 2015). In addition, indoor environmental comfort and needs for privacy vary between hospital wards (Barlas et al., 2001; Maben, 2016; Pease & Finlay, 2002; Wang & Pukszta, 2017; Andrade et al., 2017; Becker & Douglass, 2008; Hweidi, 2007; Leather et al., 2003; Eijkelenboom & Bluyssen, 2022).

2.4. Differences between settings in comfort and the corresponding adaptation (PA.4)



One reason given for discrepancies between predicted and experienced (dis)comfort in MCP research is that predictions do not sufficiently take into account that which indoor conditions people find comfortable can differ among settings (e.g. Hwang et al., 2007). Taking these differences into account to a larger extent requires that they are better understood. Threshold values for IEQ factors and IEQ parameters are often established for combinations of building types, climate zones, and/or populations (e.g. Fanger, 1970; Carlucci et al., 2015). At the same time, properties of the relationships (e.g. coefficients) are fixed by the original dataset, and cannot be updated to reflect the characteristics of a particular setting (Kim et al., 2018). For example, NBN EN 15251 (Bureau for

Standardisation, 2005) formulates threshold values for the operative temperature for different types of rooms, but not for patient rooms, based on Fanger's thermal comfort model. For the value of the insulation of the clothing, a distinction is made between summer and winter, for the activity on the basis of the room type. In adaptive thermal comfort models, threshold values vary with the outdoor temperature (Carlucci et al., 2018). In determining threshold values for the LAeq and the LAmax, fast, events and properties specific to patient rooms were taken into account: sleep disturbance, annoyance, and communication interference, including interference with warning signals (Berglund et al., 1999). As described above, threshold values for the illuminance level focus on the tasks and activities that take place in patient rooms (Bureau for Standardisation, 2003). Each of the threshold values therefore takes into account certain characteristics of the setting. It should be investigated whether discrepancies reduce when characteristics of the setting are taken into account more accurately.

In addition, the accuracy with which MAP research's models of adaptations of indoor conditions include differences in these adaptations between settings needs to be improved. To improve the models of MAP research more insight is needed into the mechanisms that explain differences in indoor environmental comfort and the corresponding adaptation between settings. A focus on hospitalized patients is valuable in this regard. To the author's knowledge, models of adaptations of indoor conditions in patient rooms do not exist. Only Niu et al. (2022) provided information on window opening behaviour in a maternity ward to inform the development of such models.

3. Research objective and research questions

In addressing the need for an improved understanding of indoor environmental comfort and the corresponding adaptation, this research aims to explore whether integrating RBE, MCP, and MAP research enables improving the understanding of *interactions (1) between people and indoor conditions* through perceived control and adaptation, and *(2) between the different IEQ factors* in experience, as well as of *differences (3) between people and (4) between settings* in indoor environmental comfort and adaptation.

To gain more insight into the four points of attention described above, we see potential in integrating RBE, MCP and MAP research. By integration we mean bringing together and comparing results that can be associated with these three types of research, and interpreting the combined results (Creswell & Plano Clark, 2018, pp. 221-234). In this way a synergy may be created between the three types of research. We see potential in integrating RBE, MCP, and MAP research because they focus on other parts of what Chemero (2009, p. 111) refers to as

the symmetry principle (see also Shaw & McIntyre, 1974). MCP and MAP researchers focus on how the state of the indoor environment, sometimes in combination with the one of other characteristics (e.g. occupant-related), results in an assessment of it or a certain behaviour. MCP research enables predicting (dis)comfort at an aggregated level and with, most often, a focus on individual IEQ factors; MAP research adaptations of indoor conditions at an aggregated level with, most often, a focus on separate actions. At the same time, RBE researchers focus on how people actively construct their experience of the indoor environment. They focus on a person's active exploration and experience of that indoor environment. Moreover, they view reality as multiple. They actively look for multiple perspectives from participants in different settings. An in-depth understanding of people's experience of the indoor environment and differences therein is obtained.

Furthermore, we see potential in integrating them at a substantive level. First, an integration of MCP and RBE research may improve the understanding of indoor environmental comfort; of MAP and RBE research the understanding of indoor environmental adaptation; and of MCP, MAP and RBE research of how comfort and adaptation interrelate. Second, while sensations are given the main attention by MCP researchers (e.g. Sakhare & Ralegaonkar, 2014), RBE researchers most often focus on experiences of objects (e.g. adaptable building characteristics) and events (e.g. people talking in the corridor) as well as how these experiences influence sensations (e.g. Annemans et al., 2018a). With respect to the latter, Annemans et al. (2018a) refer for example to Louise's experience of sounds of televisions at a nephrology hospital ward. The sounds of televisions are distinguished from other sounds that this patient will probably hear. The sounds of televisions are pleasant for several patients between 7 and 10 p.m., but annoy Louise afterwards because she wants to keep her door open. An understanding of both sensations and sense perception seems necessary. Objects and events often influence different sensations. At the same time, a sensation is often influenced by different objects and events. The meaning given to an object or event may therefore influence the experience of sensations, while a sensation may influence how the different objects that relate to that sensation are experienced.

Moreover, combining the methods of MCP, MAP and RBE research seems valuable. Sensor measurements, for example, can add to the wealth of the data collected by RBE researchers. It can improve the in-depth understanding of people's experience and behaviour. At the same time, interview data, for example, can support determining which variables should be included in the models to predict comfort or adaptation. In addition, in-depth insights resulting from a qualitative analysis can be further investigated in a quantitative way, while the in-depth insights may help to explain quantitative results at the same time.

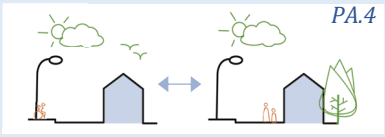
Strengths of the research approaches, substantive focus, and applied methods of RBE, MCP and MAP research therefore seem complementary. Combining the strengths of RBE, MCP and MAP research may thus enable to better understand mechanisms underlying comfort and the corresponding adaptation with a focus on the four points of attention described above.

To address the research objective, the following research question (RQ) was central to the research. This research question was subdivided into five sub-questions, each addressing points of attention described above.

RQ: How do hospitalized patients' experiences of their patient room's indoor environment relate to measureable values of IEQ parameters?

RQ.1: How does patient room design influence patients' comfort through its impact on their adaptation of, and to, indoor conditions via their perceived control?

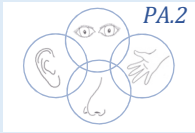




RQ.2: How does distinguishing between hospitalized patients' adaptation strategies inform about reasons for discrepancies between predicted and experienced indoor environmental (dis)comfort?



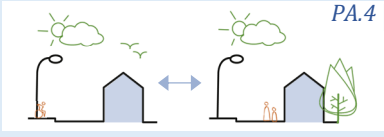
RQ.3: How does understanding interactions that occur between IEQ factors and parameters in patients' experience inform about reasons for discrepancies between predicted and experienced (dis)comfort?



RQ.4: When and why do thermal and visual[1] comfort and adaptation differ among hospitalized patients?

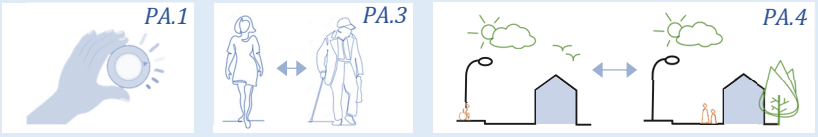






[1] A focus on thermal and visual comfort and adaptation was chosen because more as well as more reliable sensor measurements were conducted with regard to these IEQ factors than with regard to acoustic comfort. Moreover, next to closing and opening the room's door, patients had no control over the indoor air quality (IAQ). As a result, little diversity in the applied adaptation strategies can occur among patients.

RQ.5: What are strengths and weaknesses of different deterministic and probabilistic models of thermostat adaptations in patient rooms?



RQ.1 to RQ.4 had the highest importance within this study. RQ.5 is an additional, but within this study less important, follow-up question. Answering RQ.5 allowed going a step further in the exploration of how findings can be valorised within MAP research.

4. Research approach

This section provides a general overview of the research approach of this study. More detailed information about the methods used to answer the research sub-questions individually can be found in the results chapters. Since the results chapters are based on individual articles, published or about to be submitted, there is some overlap between what is described in this introduction and in the individual chapters.

4.1. Worldview

As described above, this work integrates three types of research on indoor environmental comfort and the corresponding adaptation. The worldview of these types of research differs. MCP and MAP research adopt naïve realism, RBE research constructionism. Naïve realism and constructionism are incompatible worldviews in themselves. Therefore they could not simply be merged. To merge them, critical realism is taken as worldview. Within critical realism, strengths of both worldviews can be brought together in a way that is in line with the objective of this research.

First, critical realism integrates a realist ontology – meaning that a real world exists independently from our perceptions, theories and constructions - with a constructionist epistemology[2] – meaning that our understanding of this world is inevitably a construction built from our own standpoint (Creswell & Plano Clark, 2018, pp. 40–41; Khanna, 2019). The focus is on ontology. At ontological level, it supports a stratified emergent generative ontology (Clark et al., 2008). It distinguishes between various 'strata' (i.e. layers) in the natural and social worlds (Gorski, 2013). For example, visual light and persons are

[2] Note that sometimes it is indicated that critical realism is compatible with a constructivist epistemological framework; sometimes with a constructionist epistemological framework. As constructionism is a descendant of constructivism (Ackermann, 2001), and constructionism plays a more important role in this work, we refer to constructionism.

ontological, not epistemological, different. Visual light may not have thoughts and intentions, but persons do not have a wavelength. They occupy different strata of reality. Reality is also emergent. The combination and interaction of entities and properties at one stratum of reality generates 'emergent' entities and properties at others (Miller & Page, 2009; Gorski, 2013). For example, indicators of how well a building performs in terms of indoor environmental comfort (e.g. Rohde et al., 2020) are dependent on people being social beings, which is dependent on people being psychological beings, which is dependent on people being biological beings. At the same time, it depends on the indoor environment. Moreover, each of these strata have their own characteristics. For example, indoor environmental comfort is people's evaluation of the indoor environment. The same evaluation can be given in different situations. For example, the same evaluation can be given when the outdoor air temperature is lower than the indoor air temperature, the window is open and more clothes are put on, as when the window is closed and less clothes are worn. A clear example of how each stratum has its own characteristics can also be found in another context. Water tends to extinguish fires. Its constituents, hydrogen and oxygen, tend to accelerate them (Gorski, 2013). The ontological difference between strata leads to epistemological differences. For example, we can only observe social structures via the activities and constructs of people or the material artefacts they generate. Unlike natural reality, social reality is not independent of human minds. Note that the social reality is independent of any particular human mind.

Second, a critical realistic worldview supports addressing the research objective to improve the understanding of the four points of attention mentioned earlier. Within a critical realist worldview, the focus is on explaining mechanisms underlying events instead of events themselves. Bhaskar, the initiator of critical realism, introduced a distinction between three 'ontological domains' to clarify this focus: the 'real', the 'actual', and the 'empirical' (Gorski, 2013). The domain of the real consists of all the mechanisms that exist in the world; of the actual of all mechanisms that have been activated; of the empirical of all mechanisms that have been activated and observed. The goal is to understand the real as well as possible based on the empirical. In this work, the objective is to better understand how adaptation, interactions between IEQ factors in experience, differences between patients, and differences between settings influence the relationship between patients' experience of the indoor environment and measurable values of IEQ parameters.

Third, reality is considered as a complex, open system, as distinct from the much more 'closed' conditions characterizing the parts of reality focused on in the natural sciences (Fleetwood, 2017; Næss, 2004). Reality is somewhere in the middle between chaos and uniformity. Many factors come together to cause an event in the real world. A small change in one of these factors can result in a big change in the events that happen. For example, with respect to the four points of

attention focused upon in this work, changes in which adaptable building characteristics are provided, in sources that affect the state of different IEQ parameters simultaneously, in occupants and in the setting can lead to differences in indoor environmental comfort and the corresponding adaptation. Therefore, the focus is on identifying demi-regularities, i.e. "the occasional, but less than universal, actualization of a mechanism or tendency, over a definite region of time-space" (Lawson, 1997, p. 204). As a result of this perspective, several researchers supporting critical realism show a pronounced scepticism about the possibility of predicting social phenomena (Danermark et al., 2019; Lawson, 1997). However, this work follows Næss's (2004) argumentation, which is based on Sayer's (1992) work, that predictions that can be made about social phenomena are of the crude 'rule of thumb' type. They are qualitative impact assessments with modest statements about the direction of the influences and maybe their order of magnitude. It is impossible to make exact, quantitative estimates of social phenomena, such as of indoor environmental comfort and the corresponding adaptation. This is due to the non-exact nature of our knowledge as well as the continual processes of social change (e.g. due to learning). Moreover, it are predictions at the aggregate level, not at the individual level that can be made (Næss, 2004). Even though people may have highly different and unstable wishes and preferences within a certain cultural and social context, there will nonetheless be a range of wishes and preferences shared by several people. In terms of people's sensory experience, there are for example similarities between the senses of people, which change very slowly through evolution. Changes in the mentality and culture of a population usually take place very slowly as well (Lundmark, n.d. in Næss, 2004).

4.2. Methodology

The methodology is illustrated in Figure 1.1. It consists of a main and a secondary research. The main research contains the mixed methods case studies at one or two hospital wards of two Belgian hospitals and their cross-case analysis. It is indicated in the light blue rectangle in Figure 1.1. The secondary research refers to interviews with architects and engineers throughout the research. It is indicated in the red rectangle in Figure 1.1. The two parts informed each other. The Social and Society Ethics Committee of KU Leuven approved the fieldwork with patients at the hospital wards (G-2018 08 1304).

4.2.1. Main research

4.2.1.1. Overview of the methodology

The empirical research is set up as a multiphased case study, mixed methods design (Guetterman & Fetters, 2018). *Case studies* allow investigating a contemporary phenomenon in an intensive, detailed, in-depth way through exploring one or more cases over time in a real-world context within a bounded

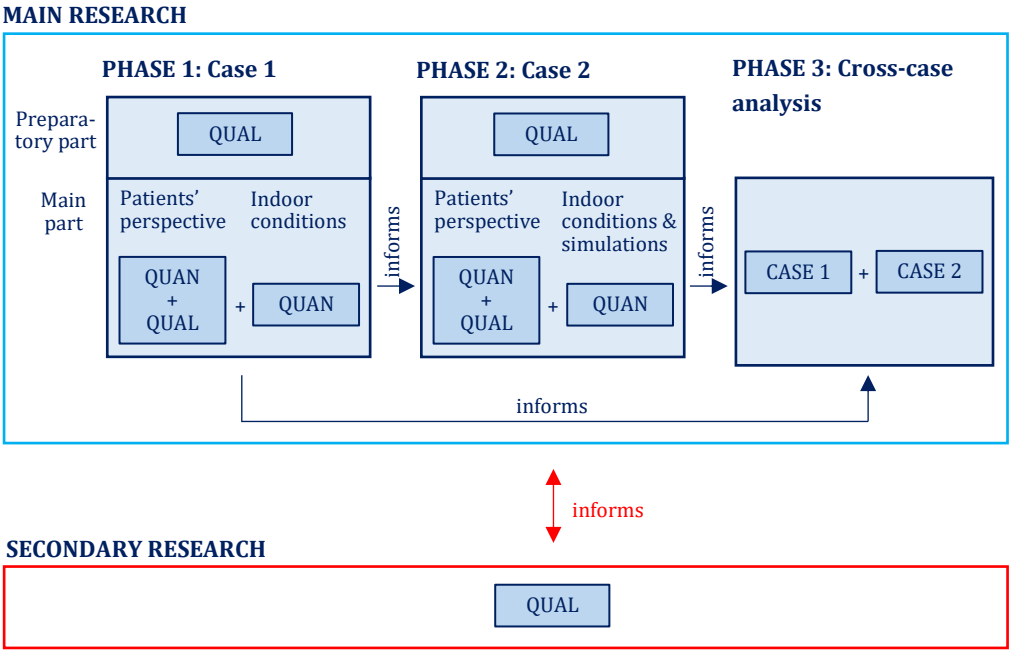


Figure 1.1 Overview of the methodology.

system (Yin, 2003; Ritchie & Lewis, 2003). This results in a holistic and meaningful, context-constituted understanding of real-life events (Yin, 2003), which corresponds with the research objective. Each case comprised one or two hospital wards, including the patients residing in these wards. Furthermore, *mixed methods case studies* are chosen. After all, this study attempts to improve the understanding of indoor environmental comfort through the integration of RBE and MCP research. Integrating RBE and MCP research involves the integration of qualitative and quantitative data - the defining feature of mixed methods research (Creswell & Plano Clark, 2018; Greene, 2006; Johnson et al., 2007). The two mixed methods case studies as well as the cross-case analysis are visualized with separate rectangles in Figure 1.1. The research has a *multiphased design* as the first case study also acted as a pilot study to inform the data collection and analysis of the second case study. The analysis of both cases informed the cross-case analysis. This is indicated by the blue arrows in Figure 1.1.

Both individual case studies consisted of two parts: a preparatory and main part, as visualized in Figure 1.1. The *preparatory part* consisted of qualitative methods: a focus group interview with nurses and short observations in the hospital ward. These informed about positions for sensor measurements and gave a first impression about how patients experience the indoor environment

of their patient room. At both cases, three nurses were selected for the interviews by the head nurse based on their availability.

During the *main part*, qualitative and quantitative data were collected and, for case study 2, quantitative building simulations were conducted. This enabled building a comprehensive understanding of the two cases. Each individual case study has a *convergent parallel design*. This is indicated with the rectangles indicating the quantitative (QUAN) and qualitative (QUAL) strand as well as the plus in Figure 1.1. A convergent design was chosen for case study 1 and case study 2 because it allowed collecting a lot of data in an efficient way. For case study 2, this efficiency was important because of the COVID-19 pandemic. After all, it was uncertain how long it would be allowed to collect data in the hospital wards. Integration of quantitative and qualitative strands occurred at several levels, namely at the level of study design, sampling, data collection, data analysis and interpretation, and reporting. Despite quantitative and qualitative data had been gathered at both cases, not all research questions asked for an analysis of both. Under the subsection 'data collection' and in each of the results chapters, it is explained on which case and data the findings are based.

4.2.1.2. The cases

In line with 'purposeful maximal sampling', two cases were selected that show different perspectives on the phenomenon (Creswell, 2013). First, regarding the indoor environment, differing Belgian hospital buildings were chosen. A mixed-mode hospital building built in 1984 and renovated in 2010, and a hospital building finished in 2018 with mechanically regulated indoor conditions and with an architectural design that is based on concepts of healing environments were selected. More detailed information about the (indoor environmental) design of the patient rooms can be found in the results chapters.

Second, regarding *outdoor conditions*, maximum difference between the cases was searched as well. The first case study was conducted in spring and summer. The second case study was conducted in autumn and winter.

Third, regarding *patient characteristics*, similarity was searched for between the cases. It was hypothesized that indoor environmental comfort is most important for those patients who stay for a long-term period in the hospital, and that complying with their comfort requirements will likely result in comfort for other patients as well. Moreover, patients' longer hospital stay enabled conducting follow-up interviews. Patients in the wards also had to be able to participate in interviews and to complete the questionnaire. Based on these criteria, surgical wards were chosen in consultation with hospital staff. The focus was on one traumatology ward of the oldest hospital building and one ward for abdominal surgery, urology and gynaecological surgery; and one for neurosurgery, plastic surgery, and ear, nose and throat of the newest hospital building.

4.2.1.3. Data collection

Quantitative (sensor measurements, simulations of indoor conditions and the heating demand, and questionnaires) and qualitative data (face-to-face semi-structured interviews, self-documentation via probes, and a walk-along interview) were gathered concurrently. Sensor measurements provided quantitative data about indoor conditions, simulations quantitative data about adaptations of indoor conditions in patient rooms, and questionnaires quantitative data about patients' first reaction towards the indoor environment. The face-to-face semi-structured interviews and self-documentation via probes fit within ethnographic research. Ethnography allows providing rich, holistic insights into people's experience and the nature (e.g., views, sounds) of their environment (Reeves, 2008). Below a general description is given of these different data collection methods. Detailed information about which data were gathered with each of the methods (e.g. topic guide of the semi-structured interviews) can be found in the result chapters.

- Sensors measured IEQ parameters. The measured IEQ parameters were chosen based on the NBN EN 15251 (Bureau for Standardisation, 2005) standard and the ASHRAE PMP (ASHRAE, 2010; Hyojin, 2012). The sensor measurements of IEQ parameters inform about the indoor conditions and how they vary in time and space. The sensors were placed near patients' heads when they were lying in their bed. One could compare sensors located near patients with their senses as passive receptors, each responding to the appropriate form of stimulus energy.
- The free-running temperature (i.e. the indoor temperature when the heating or cooling system are not in use and the air change rate is kept at its nominal value (natural or mechanical ventilation without any air conditioning) (Inard et al., 2011)), the total short-wave solar radiation through the external windows and the heating demand were simulated in TRNSYS17 (2019). The former two inform about indoor conditions in patient rooms without the influence of adaptations of indoor conditions. Comparing the simulated values with actually measured values enabled estimating when the lighting and heating were on in patient rooms.
- The questionnaires were paper-based and self-reported. The questionnaire was inspired by the one of the Center for the Built Environment (American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2010; Hyojin, 2012; Peretti & Schiavon, 2011), and adapted to hospitals based on insights from evidence-based design research in this setting (e.g. Huisman et al., 2012; Ulrich et al., 2008). Based on case study 1, the questionnaire was improved for case study

2. The questionnaire of case study 1 can be found in Appendix A; the one of case study 2 in Appendix B. The questionnaire was not validated. Likert scales and multiple choice options were given as answer possibilities. Some open questions were included as well. The questionnaire was part of a survey. A survey enables gathering data from (a sample of) entities in a systematic way in order to construct quantitative descriptors of the attributes of the larger populations of which the entities are members (Groves et al., 2004). In the remainder of the work, only the word 'questionnaire' is used. The term 'respondents' will refer to questionnaire participants.

- Face-to-face semi-structured interviews allow gaining rich, detailed answers from participants giving in-depth insight into their individual story (Ritchie & Lewis, 2003), while the prepared protocol allows for comparisons across participants. Since interviews were conducted face-to-face, social cues (e.g., the interviewee's voice, intonation, body language) could give extra information beyond the verbal answer to a question (Opdenakker, 2006). The protocol was partly set up such that it enables participants to become aware of their subjective experience and to describe it with great precision. After all subjective experience lies underneath representations, beliefs, judgements and comments (Petitmengin, 2006). To this end, the interview method presented by Petitmengin (2006) was applied to make interviewees describe the most important moment(s) during their previous days in the hospital. The interviews were conducted twice with all participants of case 1 and 10 of case 2; once with participants who left the hospital earlier than expected. The interviews were transcribed verbatim. 'Interviewees' refers to participants of the interviews in the remainder of this work.
- Patients were asked to self-document experiences and their adaptation via probes. Probes are a form of self-documentation that provokes people to reflect and express their experiences, feelings, attitudes, actions and setting in creative ways (Yuan & Dong, 2014). They allow expressing thoughts in other ways than verbally (Lange-Nielsen et al., 2012). They aim to understand the participants in their own context, empathically rather than intellectually (Mattelmäki, 2005; Lange-Nielsen et al., 2012; Boehner et al., 2007; Gaver et al., 2004). During case study 1 the first five interviewees were given a diary and the other interviewees a timeline to document their experiences over time. This change came about because the timeline elicited a more detailed description of experiences, as documenting experiences at different times of the hospital stay. The documentation over time allowed linking experiences to the continuous sensor measurements. Moreover, one patient carried light, sound, indoor air temperature, relative

humidity and vibration sensors while making a movie with a GoPro of routes that he took through the hospital in between the two interviews. The movies were discussed during a follow-up interview.

- During case study 1 one walk-along interview was conducted while I carried light, sound, indoor air temperature, relative humidity and vibration sensors. During a walk-along interview, the researcher walks together with the interviewee through their environment (Carpiano, 2009). It enables obtaining contextually based information about how people experience their environment. Given that the sensors did not adapt quickly enough to the indoor conditions at different locations passed through, the data of the walk-along interview and the data collected by the patient while he was walking through the hospital were not used. Furthermore, as it was not possible to position sensors everywhere along the route, a focus on patient rooms was chosen.

Integration during data collection occurred by connecting and building. Integration through connecting means that one type of data links with another through the sampling frame (Fetters et al., 2013). In our study, some interviewees, including those who participated in the self-documentation, constitute a subsample of the respondents of the questionnaire, further referred to as 'respondents'. Furthermore, some of the sensor measurements were conducted in the room of interviewees and respondents. Integration through building means that results from one data collection method inform the data collection of another method (Fetters et al., 2013). In our study, values measured by sensors in between the two interviews and the probe were discussed with interviewees during the second interview.

4.2.1.4. Data analysis

The different types of data were first analysed separately. *Interviews* were analysed qualitatively. Qualitative analysis was chosen as the purpose was discovery, not hypothesis testing (Corbin & Strauss, 2008, p. 317). Grounded theory was taken as approach: the aim was to generate systematically a substantive theory grounded in empirical data (Walker & Myrick, 2006). The data were analysed roughly following the Qualitative Analysis Guide of Leuven (QUAGOL) (Dierckx de Casterlé et al., 2012). QUAGOL is inspired by the constant comparative method of the Grounded Theory Approach (Corbin & Strauss, 2008; Dierckx de Casterlé et al., 2012). It supports researchers in qualitative data analysis without imposing a rigid, detailed step-by-step plan (Dierckx de Casterlé et al., 2012). QUAGOL was followed roughly since the different steps were taken more iteratively than described in QUAGOL, and steps such as a narrative interview report were not explicitly written down. For the separate analysis of the interviews, QUAGOL was followed until a conceptual understanding of the research data as a whole was obtained. The other steps of QUAGOL were taken when the qualitative and quantitative data were interpreted in an integrated

way. This will be described later. The interviews and their qualitative analysis allowed understanding patients' experience and how they construct comfort in depth, which is typical of RBE research.

Questionnaires were analysed using descriptive and subsequently inferential statistics. The data were first analysed in general, and subsequently for different situations (e.g. for single and double rooms separately). The open questions included in the questionnaire of case study 1 were not analysed. When entering the answers in Excel, it was observed that the answers contain little depth. Through the interviews, a more in-depth understanding of the experience of patients could be gained. With the exception of one general open-ended question at the end, these questions were therefore omitted from the questionnaire of case study 2. The statistical analyses of the questionnaire provided insight into patients' assessment of their indoor environmental comfort, which is typical of MCP research.

Sensor measurements of IEQ parameters were in first instance analysed by visually looking at their variations over time, by transforming them to IEQ factors by the use of IEQ models (e.g. Fanger's thermal comfort model) and by comparing values of IEQ parameters and factors with their corresponding threshold values. Moreover, based on the measurements, models were set up of patients' thermostat adaptations. The measurements thus provided insight into comfort when considered as a specifiable optimal condition and into comfort predictions, which is typical for MCP research, as well as in patients' adaptations of indoor conditions, which is typical for MAP research.

To answer RQ.1 (Chapter 2), RQ.2 (Chapter 3) - although based only on quantitative data -, RQ.3 (Chapter 4) and RQ.4 (Chapter 5), the separate analyses were followed by an integrated analysis and interpretation. Achieving integration ensures in mixed methods research that together the different types of data can produce more insight into the phenomena studied than what the data of the applied methods could offer in isolation (Morgan, 1998). The integration allows that the strengths of one method offsets the limitations of another one and that a more complete understanding of the research problem can be gained (Morgan, 1998; Creswell & Plano Clark, 2018). Note that only the quantitative data from the measurements and the questionnaire were used to answer RQ.2, but these data were integrated as well.

At the analysis level, the 'following a thread technique' was applied to obtain integration (Moran-Ellis et al., 2006). Based on an initial, separate analysis of each data type, key themes and questions requiring further exploration were identified. A theme or question was then picked from one dataset, and was followed across the others, which Moran-Ellis et al. (2006) call the thread. To answer RQ.1 (Chapter 3), RQ.2 (Chapter 3) and RQ.4 (Chapter 5), the following a thread technique to data integration was then combined with joint displays. When being integrated through joint displays, data are brought together through a visual means (Fetters et al., 2013). This supports drawing out new insights

beyond the information gained from the findings of the separate quantitative and qualitative data. Inspiration to do so was found in (Bustamante, 2019; Guetterman et al., 2015; Johnson et al., 2019). To answer RQ.1 (Chapter 2) and RQ.4 (Chapter 5) data were combined within a table, and for RQ.2 (Chapter 3) in a graph.

Via integration at the interpretation level it could be investigated in an in-depth way and highlighted when results are congruent (i.e., findings from each method agree), complementary (i.e., they clarify, explain, or more fully elaborate the results of analyses), discrepant (i.e., contradict each other) (Creswell & Plano Clark, 2018; Fetters et al., 2013; O'Cathain et al., 2010; Sandelowski, 2000), or when silence (i.e. a concept present in one data set is not in another one) occurred (O'Cathain et al., 2010; Uprichard & Dawney, 2019). This informed about discrepancies between predicted and experienced (dis)comfort, and improved the understanding of mechanisms underlying indoor environmental comfort and the corresponding adaptation. To answer RQ.1 (Chapter 2) and RQ.4 (Chapter 5), the coding process of QUAGOL was roughly followed to convert the insights about which findings were congruent, complementary, discrepant or showed silence into an empirical framework.

The approach applied for reporting was the weaving approach (Fetters et al., 2013). It involves writing both qualitative and quantitative findings together on a theme-by-theme basis.

Lastly, to valorise answers to RQ.1 to RQ.4 (Chapters 2 to 5) in the light of RQ.5 (Chapter 6), quantitative models of patients' adaptations of indoor conditions were set up based on measurements and simulations. A detailed overview of the models is given in Chapter 6.

4.2.2. Secondary research

As to the implications for design practice, intermediate results were discussed with architects and engineers during several semi-structured interviews throughout the study and two focus group interviews towards the end of the study. Nurses were present as well during the focus group interviews. For both types of interviews, purposive sampling was applied. Participants provided informed consent. Table 1.1 gives an overview of the methods for data gathering and analysis applied, the people participating, and the moment of the interview.

Two semi-structured interviews were conducted online, the others face-to-face. One architect and three engineers participated. Questions were asked about the design process, and, for the architects, about design concepts. The semi-structured interviews were audio-recorded. To analyse them, they were replayed several times. Some participants of the semi-structured interviews also participated in the focus group interviews.

A focus group interview allows multiple stakeholders to share their, possibly contradictory, visions and experiences in an open, interactive

discussion (Mortelmans, 2011). Since this brings views to the surface more easily, it can enhance data quality (Greenbaum, 2000). During the focus group interviews, main results of the research were presented in four parts. In between the parts, the participants were asked about possible implications of the results. The focus group interviews were conducted online. They were recorded and transcribed verbatim.

The interviews mainly served to keep an understanding of what is going on in practice and to receive advice on possible implications of the research results. This helped to formulate implications for practice in discussion sections of individual results chapters and the 'Discussion' chapter. Only from the focus group interview specific results are reported. These results are included in the 'Discussion' chapter.

Table 1.1 Overview of the architects, engineers and nurses participating in individual semi-structured and focus group interviews, and the moment of the interview.

Method	Type of participant(s)	Date
Individual semi-structured interviews	Engineers: 3	22/02/2021; 09/08/2021; 26/08/2021
	Architects: 1	25/09/2020
Focus group interview 1	Engineers, working as staff for a hospital: 3	7/02/2022
	Engineers: 1	
	Architects: 2	
	Nurses: 2	
Focus group interview 2	Engineers, working as staff for a hospital: 1	10/02/2022
	Engineers: 1	
	Nurses: 1	

4.3. Trustworthiness of the research

The trustworthiness of the research was assessed by continuously reflecting on concepts formulated by Guba and Lincoln (1994), the practical guidance to qualitative research of Korstjens and Moser (2018), the guidance to quantitative research of Heale and Twycross (2015), and the overview of critical appraisal frameworks developed to evaluate mixed methods research articles by Heyvaert et al. (2013) as well as the mixed methods appraisal tool of Hong et al. (2018).

First, the trustworthiness of the qualitative research was taken into account. Strategies applied to enhance the credibility of the developed empirical frameworks are (1) prolonged engagement, (2) triangulation, and (3) persistent observation.

(1) Spending several periods of the day at case 1 and many full days at case 2 - as the questionnaire was distributed in the morning, afternoon and evening - increased my familiarity with both settings. In addition,

interviewing participants twice enabled building trust and obtaining a better view on how they experienced their patient room.

(2) Methods triangulation and theoretical triangulation were applied. The rich mix of data collection methods (interviews, self-documentation via probes, observation during walk-along interviews, questionnaires and sensor measurements) allowed me to approach the research questions from different theoretical lenses and triangulate findings.

(3) Analysing several types of data and integrating the findings until both an integrated approach as well as substantive contributions were achieved, in combination with co-analysis with my supervisors enhanced the possibility to grasp the essence of the data and to obtain well-considered insights.

Statements about the transferability of the empirical frameworks can be made on the basis of (1) the descriptions provided, (2) a master thesis student's research in student libraries, and by (3) experiences of a nurse who has working experiences in wards which were not part of the cases studied.

(1) The participants, the case(s), and the research process are described in detail in the results chapters. Readers can judge for themselves on the basis of these descriptions whether the findings can be transferred to other settings.

(2) A thesis student conducted a similar study in student libraries (Willems, 2021). She identified similar adaptation strategies. Moreover, her study showed that students adapt their position, an adaptation strategy which was not identified for patients at that moment yet. That similar adaptation strategies were identified suggests a certain transferability of the results of this study.

(3) A nurse, not working at the cases studied, expressed that the empirical frameworks were recognizable, while at some wards the implementation of the framework may differ (e.g. for patients in source isolation or at an oncology ward).

The description of the research steps taken allow assessing the dependability of the empirical frameworks. The confirmability of the empirical frameworks was enhanced by (1) using audio-recordings of the interviews, (2) discussing research findings with my supervisors and nurses working at the ward of case study 1, and (3) bracketing (Fischer, 2009).

(1) Audio-recordings guaranteed a substantive degree of inter-subjectivity.

(2) Co-analysis with my supervisors mitigated the risk of misinterpretations. Nurses working at the ward of case study 1 identified the empirical frameworks presented during the focus group interviews as recognizable.

(3) Comparing my hospitalisation before and the one during the research made me aware of my own point of view on patients' experience and adaptation, as well as how it changed throughout the research. Being a

patient made me aware that I as a researcher have a better overview of how indoor conditions differ over the ward while patients are mainly aware of the indoor conditions in their specific room. However, it is through my research that I became more aware of the control patients actually have over indoor conditions, and therefore how perceived control can differ between patients.

Second, the trustworthiness of the quantitative research was taken into account. To enhance the validity, measured IEQ parameters were selected based on NBN EN 15251 (Bureau for Standardisation, 2005) and ASHRAE's Performance Measurement Protocols (ASHRAE, 2010; Hyojin, 2012). Furthermore, the questionnaire was based on the one of the Center for the Built Environment (ASHRAE, 2010; Hyojin, 2012; Peretti & Schiavon, 2011). However, the questionnaire was adapted to align more with the intended use. To improve the validity, three questionnaires were completed orally by patients while I accompanied them during case study 1.[3] Inspired by the cognitive interview technique – a method that can be easily applied to evaluate a questionnaire - this enabled exploring whether respondents' interpretations of self-reported items are consistent with the intended meanings (Ryan et al., 2012). Cognitive interviews inform about problems that occur in the underlying cognitive processes through which respondents generate their answers to a questionnaire (Tourangeau, 2003; Ryan et al., 2012). Furthermore, to obtain a sense of the internal validity of the quantitative findings and predictive models, the influence of some confounders on the findings was verified (e.g. whether it are the same patients who are dissatisfied with the different IEQ factors). However, only variables that were observed directly could be verified in this way.

Rather than aiming for generalizability of the findings, obtaining in-depth understandings was pursued.

To enhance the reliability, the accuracy of the sensor measurements was taken into account when selecting appropriate equipment with respect to the intended use. As several IEQ parameters were measured at several locations, inexpensive sensors were used. To enhance the reliability, all sensors were calibrated. The reliability of the adapted questionnaire was not formally checked.

The objectivity of the quantitative research was enhanced by applying continuous sensor measurements at the same location in each patient room, and by letting respondents fill in the questionnaire independently from the researcher.

Third, the trustworthiness of the mixed methods research was taken into account. Quality criteria for mixed methods research are less well established than those of qualitative and quantitative research. Heyvaert et al. (2013) and Hong et al. (2018) ask attention for the following.

[3] These questionnaires were excluded from the analyses that intended to answer the research questions. After all, my presence may have influenced their answers.

A rational for conducting mixed methods research needs to be provided. This is given in the 'problem statement' section.

The mixing and integration of the quantitative and qualitative data asks careful consideration. This is discussed in general in this 'Methodology' section and in detail in the individual result chapters.

The findings of the integration of qualitative and quantitative data need to be interpreted carefully. This interpretation can be found in the 'Results' and 'Discussion' sections of chapters that will follow (Chapters 2, 4 and 5).

Discrepancies between quantitative and qualitative findings need to be addressed adequately as well. How observed discrepancies are addressed can be found in the 'Results' sections of individual chapters (Chapters 2, 4 and 5), and a reflection on it in the 'Discussion' chapter.

The added value and limitations of this integration need to be addressed. These are elaborated upon in the 'Discussion' chapter of this work.

5. Outline

Apart from this introduction, this work consists of five results chapters, followed by a discussion and a conclusion chapter. Each of the results chapters focusses on one of the research sub-questions. The four points for attention that were described earlier are addressed across the five chapters. Which point of attention is addressed by answering which research sub-question is indicated in the 'Research objective and research questions' subsection of this chapter. As indicated above, Figure 1.1 visualizes the research methodology. Each chapter focusses on a part of it. The contents of the chapters and their methodological focus is described in more detail below.

Chapter 2 addresses RQ.1 in the light of the research objective. In this chapter attention is given to interactions between people and indoor conditions and to differences in these interactions between settings.[4] A contribution is thus made to addressing the 1st and 4th point of attention for an improved understanding of indoor environmental comfort and the corresponding adaptation. The chapter integrates insights from MCP and RBE research. Methodologically, it focusses on case study 1, case study 2, and their cross-case analysis. These three phases of the research each had a valuable substantive contribution in the light of answering the research question. Different types of data are brought together via joint displays. Substantively, it advances the understanding of how patient room design influences patients' comfort through its impact on their adaptation of, and to, indoor conditions via their perceived control. Linking well-being to comfort and health, linking well-being theories to the state-of-the-art in MCP and RBE research, and elaborating these links via

[4] see RQ.1 in the section 'Research objective and research questions'

observations from the two mixed methods case studies improves the understanding of the adaptation strategies surgical patients adopt.

Chapter 3 addresses RQ.2 in the light of the research objective. In this chapter attention is given as well to interactions between people and indoor conditions.[5] A contribution is thus made to addressing the 1st point of attention for an improved understanding of indoor environmental comfort and the corresponding adaptation. This chapter quantifies results from Chapter 2. Methodologically, it focusses on the quantitative data of case study 2. Case study 2 was chosen because, for this case study, the questionnaire was improved based on case study 1, more patients completed the questionnaire, and measurements were conducted in more patient rooms. The chapter shows how measured values of IEQ parameters, and sensation, preference and satisfaction votes can be analysed simultaneously in a visual way while at the same time a distinction can be made between the adaptation strategies adopted. Substantively, it describes observed tendencies in how the different adaptation strategies, identified in Chapter 2, influence the experience of indoor conditions differently.

Chapter 4 addresses RQ.3 in the light of the research objective. In this chapter attention is given to interactions that occur between IEQ factors in patients' experience.[6] A contribution is thus made to addressing the 2nd point of attention for an improved understanding of indoor environmental comfort and the corresponding adaptation. In this chapter insights from MCP and RBE research are integrated. Methodologically, it focusses on mixed methods case study 1. Case study 1 was chosen because indoor conditions vary more in this older hospital building. This made combinations of and interactions between IEQ factors in experience clearer. In-depth understandings of patients' experience enable explaining observations that are part of MCP research. Substantively, the chapter improves the understanding of combinations and interactions between IEQ factors and parameters in patients' experience. This improved understanding informs about reasons for discrepancies between predicted and experienced (dis)comfort.

Chapter 5 addresses RQ.4 in the light of the research objective. The chapter builds on the mixed methods approach of Chapter 2 and substantive insights about patients' adaptation strategies described in Chapter 2 and 3. In this chapter attention is given to interactions between people and indoor conditions, and differences between people and between settings.[7] A contribution is thus made to addressing the 1st, 3rd, and 4th point of attention for an improved understanding of indoor environmental comfort. In this chapter, insights from MCP, MAP and RBE research are integrated. Methodologically, the chapter focusses on mixed methods case study 2. This choice was made as well because

[5] see RQ.2 in the section 'Research objective and research questions'
[6] see RQ.3 in the section 'Research objective and research questions'
[7] see RQ.4 in the section 'Research objective and research questions'

of the improved and larger amount of quantitative data collected within this case study. It analyses data gathered during the fieldwork and dynamic simulations. Joint displays, similar as the ones for Chapter 2, were set up. Substantively, it is investigated whether differences in characteristics of the patient, patient room and outdoor conditions relate to differences in patients' visual and thermal comfort and their adaptation of and to visual or thermal conditions.

Chapter 6 is an additional chapter. It addresses RQ.5 to explore how results of the research can contribute to MAP research. Similar as how Chapter 3 quantifies results from Chapter 2, this chapter quantifies results from Chapter 5. It valorizes insights into interactions between people and indoor conditions, and differences between people and between settings.[8] Methodologically, eleven models of thermostat adaptations in patient rooms of case study 2 are set up. In this chapter, the choice to focus on case study 2 was made as well because of the improved and larger amount of quantitative data collected within this case study. The models enable simulating patient rooms' heating demand. Substantively, the chapter gives some preliminary insights about which models are appropriate for different design purposes within design practice.

The discussion is presented in **Chapter 7**. It elaborates on the main contributions of the study, limitations and suggestions for future research, and implications for design practice.

Chapter 8 contains the conclusion. An answer is formulated to the main research question and sub-questions.

[8] see RQ.5 in the section 'Research objective and research questions'

Chapter 2: **Patient Comfort, Adaptation of and to Indoor Conditions, and Patient Room Design: Two Mixed Methods Case Studies**

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Abstract

Research indicates that perceived control influences how people experience the indoor environment, and that the indoor environment influences both adaptation, via perceived control, and well-being. Their interlinkage is, however, not well understood. Therefore, we investigated how the design of patient rooms can contribute to patients' well-being by supporting their adaptation of and to indoor conditions via perceived control. Two mixed methods case studies were conducted at hospital wards in Belgium, each concurrently collecting qualitative and quantitative data. These included interviews with 16 (case 1) and 19 (case 2) patients, self-documentation by 8 patients (case 1), sensor measurements of indoor environmental quality parameters (e.g. sound, light, and temperature levels) (cases 1 and 2) and questionnaires among 84 (case 1) and 238 (case 2) patients. Focusing on the indoor environment's role in adaptation allows characterizing known adaptation strategies in more detail. When perceiving control over adaptable building characteristics, patients can adapt indoor conditions or adapt to indoor conditions by choice. When not perceiving such control, they may still adapt sensations or their position. Without any perceived control, adapting to indoor conditions is imposed. The indoor environment can support patients' adaptation by supporting their autonomy and competences. In this way it seems to foster both patients' eudaimonic as well as their hedonic well-being.



1. Introduction

Hospitals' indoor environment affects patients' comfort, health, and well-being. The indoor environment can trigger positive emotions (Ortiz et al., 2017; Altomonte et al., 2020; Roskams & Haynes, 2021; Woo et al., 2021). When patients experience positive emotions, their comfort is higher and health supported. Given our interest in the interrelation between the indoor environment and subjective experiences, we focus in this chapter on patients' indoor environmental comfort and how it links with well-being.

Although it is recognized that the indoor environment plays a role in comfort and well-being, its role is not well understood yet (Altomonte et al., 2020; Andrade et al., 2017; Hanc et al., 2019). Researchers have often focussed on how the indoor environment can help alleviate discomfort and provide comfort by assuming that it and/or its indoor conditions are given to people (e.g. Candido & de Dear, 2012; de Dear, 2011; Rohde et al., 2020). However, when a change occurs that causes discomfort, people adapt, i.e. they react to restore their comfort (Nicol & Humphreys, 2002). This adaptation is affected by the indoor environment. Both are linked via perceived control, i.e. people's belief about the influence on an outcome via changing the world or themselves to fit in with the world (Bryant, 1989; Chipperfield et al., 2012).

Little is known about how people adapt and adapt to indoor conditions, how this adaptation influences their comfort and well-being, and how it is influenced by the indoor environment via perceived control. The need to improve this understanding is especially emphasized in research with the objective to set up models for comfort predictions (MCP). MCP researchers try to set up relationships between IEQ parameters and people's assessment of IEQ factors. IEQ parameters are measurable quantities of indoor conditions such as the indoor air temperature. IEQ factors are constructs such as thermal comfort that can be assessed by people or estimated based on one or more IEQ parameters. MCP researchers have observed that perceived control and adaptation positively affect people's comfort. Some researchers have referred to the positive effect of perceived control (e.g. in offices: Boerstra et al., 2013; Brackley et al., 2021; Sakellaris et al., 2019, in schools: Yun, 2018, and in residential buildings: Brown & Gorgolewski, 2014; Luo et al., 2014; Xu & Li, 2021), others to that of adaptation (e.g. de Dear & Brager, 1998; Parkinson et al., 2020). This positive effect allows extending the range of indoor conditions in which people feel comfortable.

Two knowledge gaps require further attention in this regard. First, more insight is needed into the different adaptation strategies that people adopt. De Dear and Brager (1998) took the first steps in this regard. Based on the literature, they have distinguished three adaptation strategies: behavioural, physiological, and psychological. Despite this distinction, researchers have tended to treat these strategies as similar by treating adaptation as a 'black box' (e.g. Parkinson

et al., 2020), or have attended to differences between them based on a limited understanding (Schweiker & Wagner, 2015, 2016).

Second, more insight is needed into how the setting influences adaptation and perceived control. Some researchers have already indicated, based on field studies, how perceived control and/or adaptation are influenced by the setting (e.g. spatial layout) (Schweiker & Wagner, 2016; Marín-Restrepo et al., 2020a, 2020b). However, despite that adaptive opportunities, i.e. contextual factors that offer possibilities to adapt behaviourally (such as adaptable building characteristics or dress codes) differ between settings, most researchers have treated different settings as being similar to one another. An example of this is that the same threshold values for IEQ factors and IEQ parameters, developed by the use of sensor measurements and questionnaires, are often applied to different settings (e.g. Fanger, 1970; Lazarov & Stranger, 2017).

To contribute to reducing both gaps, we see potential in integrating the strengths of MCP research with those of research with the objective to understand in depth the roles of the built environment in experiences (RBE) (e.g. Annemans et al., 2018a; Douglas & Douglas, 2004; Anaker et al., 2019; Nielsen & Overgaard, 2020). MCP research allows predicting (dis)comfort. However, these predictions do not take into account how adaptation strategies influence experiences. RBE research allows gaining an in-depth understanding of how experiences differ between situations, and what role adaptation and the indoor environment play in this. Moreover, combining their methods may support gaining this in-depth understanding. Sensor measurements provide, for example, insight into the indoor conditions, interviews and multiple choice options in questionnaires into which meaning is given to the indoor environment, partly by adaptation, and questionnaires and measurements into which adaptation strategy is adopted. These three findings are needed to identify and understand adaptation strategies.

Furthermore, a focus on hospitalized patients is valuable. According to Ulrich (1991), patients' lack of control is a major problem in healthcare settings, which increases stress and anxiety in patients. Ulrich's theory of supportive design advances three properties of healthcare settings that support patients' well-being: positive distractions, social support, but also perceived control over the material and social environment. Huisman et al.'s (2012) systematic literature review indicates that patients' control over indoor conditions can be enhanced by providing them with control over the temperature (air conditioning and heating), sound (music and television), lighting (including dimmers) and natural light. However, despite the above observations, in a study by Andrade et al. (2017) and Andrade and Devlin (2015), questionnaire respondents' stress was predicted not by how much control they indicated to perceive over the lighting, temperature, windows, and refrigerator, but by positive distraction and social support. Andrade et al. (2017) have argued that the expected positive effect on the stress of patients with a high desire for control may be cancelled out

by the absence of an effect for patients with a low desire. Distinguishing between adaptation strategies may therefore be needed to improve the understanding of the roles of perceived control in patients' comfort.

In view of these observations, we aim to identify patients' adaptation strategies, how these strategies influence their comfort, and how it is influenced by hospital room design via perceived control. Central to this chapter is the following research question: how does hospital room design influence patients' comfort through its impact on their adaptation of, and to, indoor conditions via their perceived control? We address this question by linking well-being to comfort and health, well-being theories to the state-of-the-art in MCP and RBE research, and by further elaborating these links via observations from two mixed methods case studies that combined the approaches of MCP and RBE research. Note that because we take into account both research approaches, we adopt critical realism as worldview. Moreover, we use the term indoor conditions to denote characteristics of the indoor environment that can be quantified in terms of IEQ parameters as well as that provide people information about the setting via their senses (e.g. whether it is day or night).

The remainder of this chapter is structured as follows. Section 2 describes links between well-being theories to the state-of-the-art in research on indoor environmental comfort. Section 3 describes the methodology. Section 4 presents the results. In Section 5 links between the results and well-being theories, hospital rooms influence on patients' well-being, and limitations of the study are discussed.

2. Linking well-being to comfort and health, as well as well-being theories to the state-of-the-art in MCP and RBE research

2.1. Relationships between well-being, comfort and health

'Comfort' has been defined differently across studies (Ortiz et al., 2017). However, there is a common basis in the definitions: 'comfort' refers to subjective experiences, affected by various factors (physical, physiological, psychological) that result from the interrelation between people and their environment (e.g. Ortiz et al., 2017; de Looze et al., 2003; Vink, 2005, p. 14). Specifically in MCP research it is defined as the 'condition of mind that expresses satisfaction with the environment and is assessed by subjective evaluation' (ASHRAE, 2017). Comfort partly overlaps with health. The Constitution of the World Health Organization (WHO) has defined health as 'a state of complete physical, mental, and social well-being not merely the absence of disease…' (World Health Organization, 2020). To distinguish health from comfort, indoor environmental health can be understood as the indoor environmental conditions that limit physical stressors causing infirmity, disease and years of potential life

lost (Rohde et al., 2020). Given our interest in the interrelation between the indoor environment and patients' subjective experience, we focus on comfort and its links with well-being. Figure 2.1 visualizes links between well-being, comfort and our focus on comfort (Figure 2.1: small blue rectangle within the big blue rectangle).

The term well-being lacks a clear definition in research, and there is no agreement yet on how it relates to other concepts such as comfort and health (Pinto et al., 2017; Watson, 2017; Rohde et al., 2020). In literature on the indoor environment, well-being is used (1) as a synonym of comfort or health (e.g. Xie et al., 2017; Huisman et al., 2012), (2) to refer to the combination of comfort and health (e.g. Bluyssen, 2010; Ortiz et al., 2017) (Rohde et al., 2020), (3) as a broader concept than comfort and health (e.g. Steemers & Manchanda, 2010), or (4) as a distinct concept from comfort and health (e.g. Watson, 2017; Rohde et al., 2020). In the first view, comfort, health and well-being seem to be used interchangeably. In the fourth view, comfort is associated with a 'feeling of neutrality'. Rohde et al. (2020), for example, consider well-being as positive emotional responses, and therefore as a counterpart to the neutral or negative stimuli of the comfort domain and as the positive psychological counterpart to the physiological stressors of the health domain. In the third view, comfort is not necessarily associated with a 'feeling of neutrality'. However, it is distinguished from happiness. Steemers and Manchanda (2010), for example, consider health, comfort and happiness as lying on a well-being spectrum. This spectrum ranges from the directly measurable (e.g. symptoms including body temperature or blood chemistry), to the intersection between quantifiable parameters (e.g. temperature) and qualitative experiences (e.g. thermal comfort), to the 'unmeasurable' (e.g. quality or delight). What is understood as happiness in the third view, belongs to comfort in the second view.

In this work we support the third perspective. We are interested in how well-being theories that focus on happiness provide more insight into indoor environmental comfort. Since we assume a spectrum between comfort and happiness, we expect that insights about happiness also apply to comfort. Moreover, comfort is considered part of well-being.

2.2. Linking well-being theories to the state-of-the-art in MCP and RBE research

Well-being, comfort, adaptation, and the indoor environment with its indoor conditions are linked (Figure 2.1). To gain more insight into how not only the indoor conditions, but also adaptation can influence comfort, inspiration can be found in the distinction psychologists make between two well-being perspectives: hedonic well-being and eudaimonic well-being (light and dark blue zone in Figure 2.1) (Delle Fave et al., 2010; Hanc et al., 2019). Both perspectives focus on happiness. The former focuses on people's subjective belief about

whether their life is desirable, pleasant, and good (Diener, 2009); the latter on functioning well. Eudaimonia is concerned with living in a way, and within an environment, that aligns with one's daemon or true self (i.e. congruent with deeply held values), and that encourages expressing one's full potential (Ryan & Deci, 2001; Ryff & Singer, 2008; Waterman, 1993). From this perspective, not all pleasure producing desires would yield well-being when fulfilled, as some outcomes may harm people (Ryan & Deci, 2001). Ryff and Keyes (1995), who have adopted the eudaimonic perspective, have defined well-being in terms of six aspects. Related to adaptation is the aspect labelled as 'environmental mastery', which denotes the ability to manage effectively one's life and the surrounding world. It parallels psychological constructs like 'sense of control' and 'self-efficacy', but unlike these it emphasizes finding or creating a surrounding context that suits one's personal needs and competences (Ryff & Singer, 2008). 'Competence' refers to the feeling of being competent and confident to achieve valued goals (Carver & Scheier, 1999; McGregor & Little, 1998). A higher challenge to achieve the goal, whether the goal activities are characterized by an approach rather than an avoidance motivational system, and the more goals and motives are aligned, the higher well-being (Ryan & Deci, 2001). The self-determination theory by Ryan and Deci (2001) defines three basic needs to foster well-being: autonomy, competence, and relatedness. 'Autonomy' refers to how autonomous one is in pursuing goals (Ryan & Deci, 2001). According to the self-determination theory only self-endorsed goals will enhance well-being. 'Relatedness' refers to warm, trusting, and supportive interpersonal relationships (Ryan & Deci, 2001). It includes attachment security and intimacy (i.e. the quality of relatedness). The self-determination theory posits that fulfilling these three basic needs typically fosters both hedonic and eudaimonic well-being.

Researchers investigating indoor environmental comfort have adopted perspectives related to hedonic and eudaimonic well-being. Most often their perspective links to hedonic well-being: indoor conditions can alleviate discomfort and provide pleasure (Candido & de Dear, 2012; de Dear, 2011; Rohde et al., 2020; Annemans et al., 2018a) (Figure 2.1: blue arrow in the light blue zone). Indoor conditions can also be linked to eudaimonic well-being: more perceived control has been considered to explain why people are satisfied with more variable and a wider range of indoor conditions in some situations (de Dear & Brager, 2002; Leaman & Bordass, 1999; Nicol & Humphreys, 2002; Zhang et al., 2011). More psychological adaptation occurs (Figure 2.1: orange arrow). When perceiving control over building characteristics, people can also adapt indoor conditions (Nicol & Humphreys, 2002). This behavioural adaptation can reduce discomfort and increase pleasure, and thus foster hedonic well-being (Figure 2.1: purple arrow).

Adaptation links comfort with indoor conditions not only to both well-being perspectives but also to the material environment (Figure 2.1: red colour).

The material environment affects the indoor conditions in the room (e.g. Carlucci et al., 2015; Rasmussen, 2017), and the indoor conditions affect whether a wish for adaptation is likely to arise (Figure 2.1: red frame around indoor conditions). The material environment also influences to what extent control is perceived, and thus behavioural and/or psychological adaptation occurs (Figure 2.1: red frame around people) (Hummelgaard et al., 2007; Kim & de Dear, 2012a; Leaman & Bordass, 1999; Nicol & Humphreys, 2002).

Linking well-being theories to the state-of-the-art in MCP and RBE research highlights the need for investigating how the indoor environment influences comfort through its impact on adaptation of and to indoor conditions via perceived control. As indicated in the introduction, we investigated this influence with a focus on patients. Via two mixed methods case studies the observed links were further elaborated into links between patients' comfort and well-being, their adaptation strategies, and patient room design via the control they perceive.

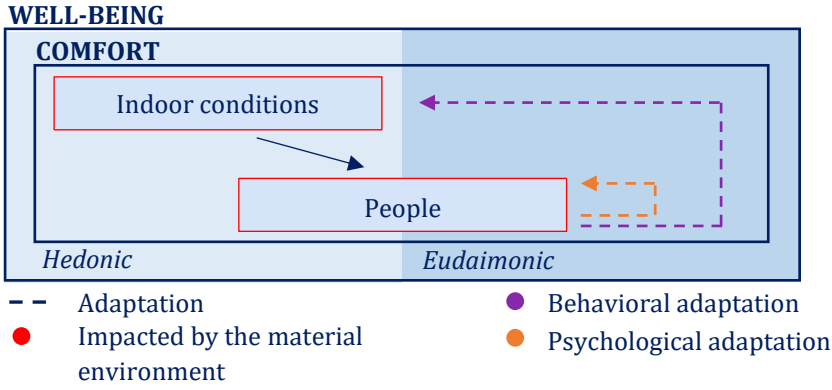


Figure 2.1 Adaptation model: links between well-being, comfort, adaptation and the indoor environment with its indoor conditions found in literature.

3. Methodology

3.1. Overview

We conducted two mixed methods case studies in hospital wards. Quantitative and qualitative methods from MCP and RBE research were combined to gain more profound insight than each can offer in isolation (Creswell & Plano Clark, 2018; Fetters et al., 2013). Integration occurred at the level of the research approach, case study design, methods, interpretation, and reporting (see Fetters et al., 2013 for further discussion). Figure 2.2 presents the different levels where integration occurred. The research was approved by the Social and Society Ethics Committee of KU Leuven (G-2018 08 1304).

The two case studies were combined within a multiphase design, with each case study covering one phase of the research and the cross-case analysis the third phase (Figure 2.2: links between rectangles). Case study 1 improved our understanding of adaptation, which allowed informing and improving data collection for case study 2. The findings of both case studies informed the cross-case analysis.

Each individual case study has a convergent parallel design (Figure 2.2: big and small rectangles for case 1 and 2). Quantitative and qualitative data were gathered concurrently. Integration at the methods level occurred during data collection and analysis. We collected quantitative (questionnaires) and qualitative (interviews and self-documentation) data focusing on patients' perspective, and quantitative data about the state of indoor conditions (sensor measurements). Integration during data collection occurred by connecting the methods to obtain qualitative and quantitative data. In our study, some interviewees, including those who participated in the self-documentation, constitute a subsample of the respondents of the questionnaire, further referred to as 'respondents'. Furthermore, some of the sensor measurements were conducted in the room of the interviewees and respondents. In the first instance, the different types of data were analysed separately. Results from the separate quantitative and qualitative analyses were given equal priority, and integrated during the overall data analysis via merging (i.e. bringing together the two strands for analysis and for comparison (Fetters et al., 2013)). For reporting, we adopted the weaving approach, writing out findings from the qualitative and quantitative analyses together on a theme-by-theme basis.

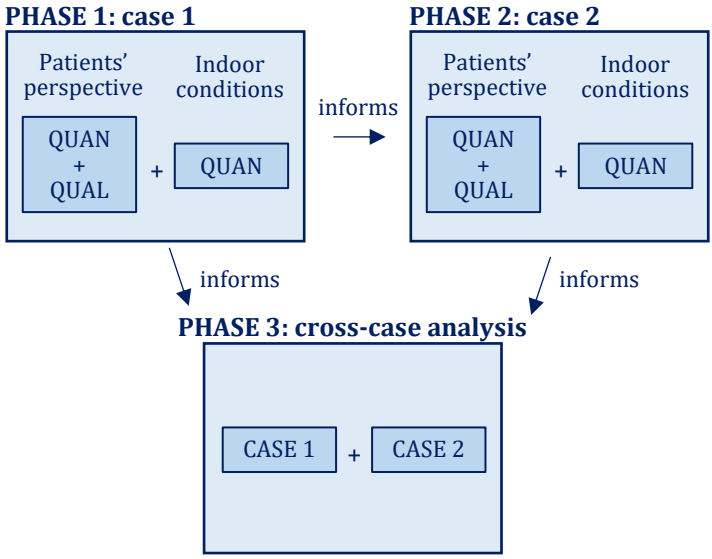


Figure 2.2 Visualization of the methodology.

3.2. The cases

The cases are located in Belgium. In consultation with hospital staff, we chose surgical wards as patients on those wards were expected to stay for several days and be physically and cognitively able to participate. Case 1 concerns a traumatology ward in a hospital building originating from 1984, and which was refurbished in 2010. Indoor conditions in patient rooms were regulated by mechanical ventilation (70 m^3/h in all rooms, supply temperature at outdoor air temperature during data collection), operable windows, operable indoor and outdoor shading devices (except for northeast oriented windows), individual fans, radiators with a thermostat knob, and lighting without dimmers. Case 2 comprised two wards in a building originating from 2018: one for abdominal surgery, urology and gynaecological surgery; and one for neurosurgery, plastic surgery, and ear, nose and throat. Patient rooms were equipped with mechanical ventilation (100 m^3/h in single room, 200 m^3/h in double room, supply temperature at 21°C), operable windows which were locked, a fixed external louvre system as sun shading, radiators with a thermostat knob, and lighting with dimmers. Except from top-cooling in summer at case 2, there was no cooling system in any of the patient rooms. Figure 2.3 shows the floor plans and the layout of a double room. For case 1 data were collected from May 14 to 30 and 9 July to 1 August 2019; for case 2 from 29 September to 30 October 2020 and 8 December 2020 to 8 January 2021.

3.3. Data collection

First, a self-reported paper-based questionnaire quantitatively gauged patients' assessments, causes of (dis)comfort, perceived control and, for case 2, states of adaptable building characteristics. Since we consider positive experiences as belonging to comfort, different levels of dissatisfaction as well as satisfaction were questioned with regard to the assessments via Likert scales. The questionnaire was inspired by the one of the Center for the Built Environment (American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), 2010; Hyojin, 2012; Peretti & Schiavon, 2011), and adapted to hospitals based on insights from evidence-based design research in this setting (e.g. Huisman et al., 2012; Ulrich et al., 2008). For case 2, questions about patients' well-being were added, inspired by the World Health Organization's (WHO) Quality of Life Questionnaire (WHOQOL-BREF) (De Vries & Van Heck, 1996). We turned the questionnaire into a right-now questionnaire inspired by NBN EN ISO 28802 (2012), removed questions unrelated to IEQ parameters (e.g. about wayfinding), added questions about IEQ factors (e.g. patients' preferences and sensations), reformulated questions about IEQ parameters to questions about IEQ factors for uniformity and to reduce response burden (e.g. thermal environment instead of indoor temperature), and added questions about causes of comfort and the state of adaptable building characteristics. Table 2.1 presents

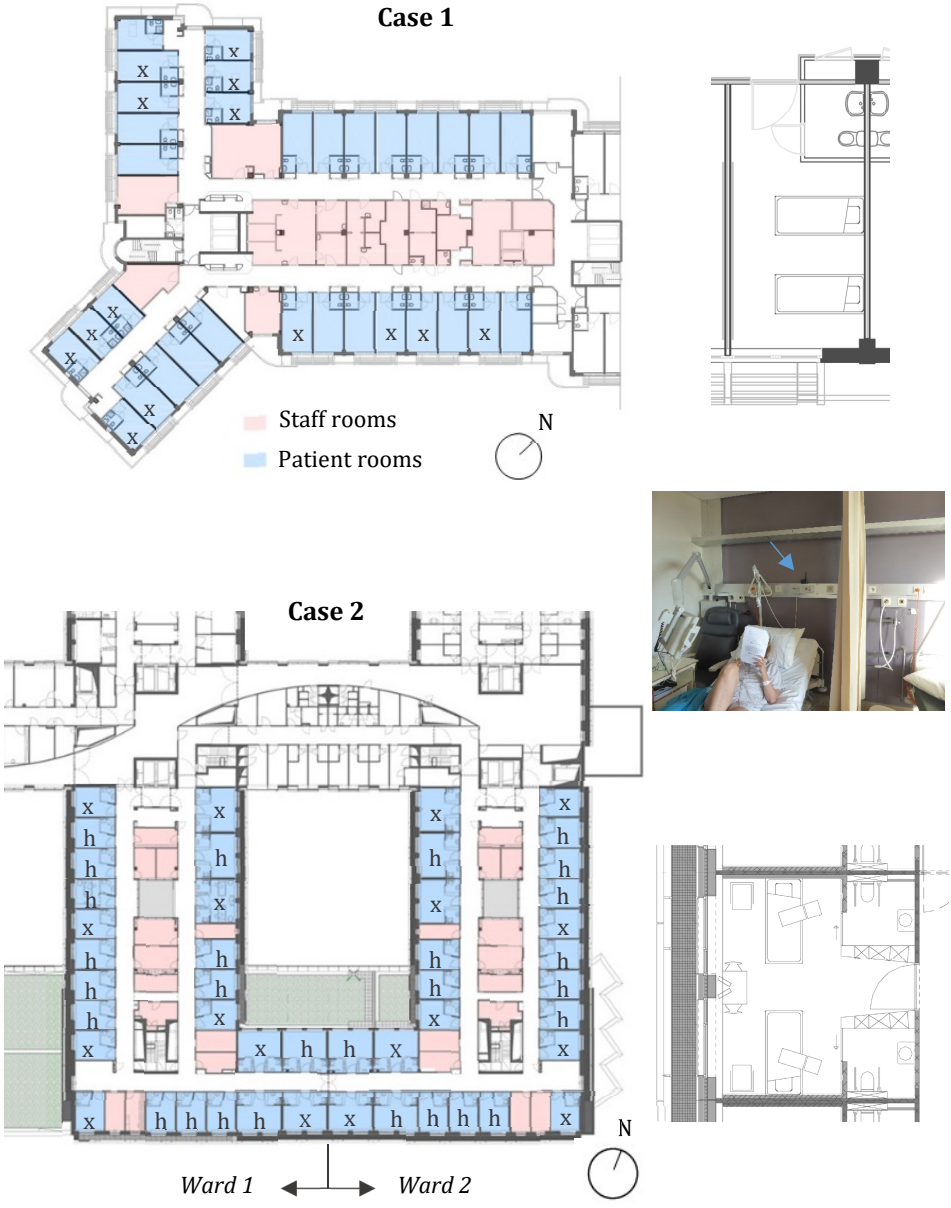


Figure 2.3 Floor plans of the wards where research was conducted for case 1 (top) and case 2 (bottom), and a picture of a respondent with in the background a VersaSense Wireless Device. The 'x' on floor plans indicates rooms where HOBO's and VersaSense sensors were located during interviewees' hospital stay for case 1 (top) and permanently during case study 2 (bottom); 'h' indicates those with only a HOBO (Plans case 1: based on the plan of the hospital's infrastructure planning department; plans case 2: based on the design of VK Architects & Engineers. Permission was obtained to publish the plans.)

the components this research focused on, the type of questions, the questions asked, the types of answer options, and the percentages of missing values per question. The full questionnaires can be found in the Appendix (Appendix A and B).

Within the wards, simple random sampling was applied. I was at the ward one or two days a week to invite randomly selected (case 1) or all patients (case 2) to participate. In total 84 (case 1) and 238 (case 2) agreed to participate, provided informed consent, and responded. Table 2.2 lists the number of respondents, the percentage of them answering all questions, their personal and room characteristics, and dates the questionnaire was distributed.

Second, to gain an in-depth understanding of patients' experience, perceived control, and adaptation, semi-structured face-to-face interviews were conducted, and, for case 1, self-documentation by patients. The interviews addressed how interviewees experienced their hospital stay, especially related to their comfort with indoor conditions and their actions to adapt them. Experiences in general, but also specific positive and negative experiences were questioned. Table 2.3 presents the topic guide. In between the interviews, interviewees could complete the questionnaire or participate in the self-documentation. The latter consisted of a probe – a form of self-documentation that invites interviewees to express e.g. experiences and actions they might not think of during an interview (Gaver et al., 2004). It had the form of a timeline or booklet for taking notes and focused on interviewees' experience and adaptations of and to indoor conditions.

Convenience sampling was adopted. Interviewees were selected by nurses based on their ability and willingness to participate. They were interviewed until saturation in data collection was reached (i.e. new data repeat what was expressed in previous data (Saunders et al., 2018)). Interviews were conducted with 12 respondents and 4 others for case 1, and 15 respondents and 4 others for case 2. Eight interviewees participated in the self-documentation. All interviewees provided informed consent. All interviewees of case 1 and 10 of case 2 were interviewed twice, with about 3–4 days in between. Table 2.2 lists the number of interviewees, the number of them participating twice, their personal and room characteristics, and dates of participation.

Third, sensors measured IEQ parameters in order to understand which indoor conditions patients were experiencing, assessing, adapting, and adapting to. Table 2.4 lists sensors used, the IEQ parameters measured and their unit, their accuracy or sensitivity, the sampling rate, their location in the ward, and position in the room. Figure 2.3 presents for case 1 the rooms of interviewees where measurements took place during their hospital stay, as well as fixed sensor locations in patient rooms for case 2. For case 1, among the patients the nurses considered eligible for an interview during the days I was at the ward, we picked out patients who stayed in different room types (i.e. single versus double room and different window orientations) to maximize variety in measurement

locations. For case 2, measurement locations were chosen so as to obtain an even spread in both single and double rooms at each of the window orientations. To improve the measurements' reliability, sensors in patient rooms were calibrated for case 2 and HOBO's for case 1. For case 1, the minimum adjustment needed to calibrate case 2's light sensors was applied for all light sensors and only four different light and sound sensors were used.

3.4. Data analysis

Data were grouped according to differences in characteristics related to the setting. Attention was given to differences in characteristics related to the material environment (e.g. single versus double rooms) and conditions outside the room (e.g. regular weather versus an official heat wave (22/07/2019 and 26/07/2019)), as both turned out to influence patients' adaptation. For two opposing groups, we then compared experiences, causes of (dis)comfort, perceived control, satisfaction votes, and measured values of IEQ parameters.

Quantitative analysis of questionnaire responses and sensor measurements, using the software RStudio (RStudio, 2021) combined descriptive and inferential statistics. The questionnaire informed about responses at an aggregated level for each group. Mann–Whitney U tests and Kruskal Wallis tests allowed comparing satisfaction votes between groups. The significance level (α) was taken equal to 0.1 because of the limited number of respondents per group for case 1. The extent to which multiple-choice options were chosen was compared between groups via percentages. We considered only options chosen by at least 10% of the respondents in one of both groups, and with a difference between both groups of at least 5%. The statistical methods applied work with unequal sample sizes. Only the non-missing values were analysed.

Measured values of the IEQ parameters were grouped in two steps.

(1) For each interviewee (case 1) or respondent (case 2), the distribution of measured values (mean, 1st quartile, 3rd quartile, 5th percentile, and 95th percentile) was calculated per 10-minute interval for the values measured in their room and during their hospital stay. This grouping ensured that the measurements associated with each participant were given equal weight in the grouping of the second step.
(2) The measurements grouped for each interviewee or respondent were then grouped according to differences in building characteristics and conditions outside the room. For these grouped measurements, the distribution was again calculated per 10-minute interval.

The same process was undertaken to group measured outdoor air temperatures and global radiations. Influenced by the sampling rate, we used

Table 2.1 Overview of the questionnaire components this chapter focuses on, incl. type of questions, questions asked, response scale, and percentages of missing values per question when relevant. For case 2, questions ended with 'right now'. (Not applicable (NA)).

Component	Type of questions	Case 1	Case 2	Response scale[1]	Case 1: % missing values	Case 2: % missing values
Room characteristics		Room number, single or double room, window or corridor side	Room number, side of the window (left or right)	Open questions and multiple choice	1 %/0 % /0 % (question filled in by first author)	4 %/5 %
Personal characteristics		For example: age, nationality, expected length of stay (case 1) or moment of arrival and expected moment of leave (case 2), weight, length		Open questions and multiple choice	0.08 %-23 %/0 %/0 %/30 %/30 %	0.8 %/0.4 %/0.4 %/19 %/3 %/5 %
Self-rated well-being		NA	How do you find your state of physical well-being?	Likert scale: 1-7 (very bad - very good)	NA	0.40 %
			How energetic are you feeling?	Likert scale: 1-7 (not at all- very much)		0.40 %
			How much pain do you have?	Likert scale: 1-7 (a lot of pain - no pain)		0.40 %
			How satisfied are you with the amount of sleep and rest that you had?	Likert scale: 1-7 (very dissatisfied - very satisfied)		3 %

[1] Likert scales from 1-7 were used since people tend to indicate positive values more quickly than negative values. During data analysis, the values were transformed to the commonly used values ranging from -3 to +3.

			How do you find your state of psychological well-being?	Likert scale: 1-7 (very bad - very good)		0.80 %
			To what extent do you have negative feelings such as blue mood, despair, anxiety, depression?	Likert scale: 1-7 (very much - not at all)		1 %
			To what extent do you have positive feelings?	Likert scale: 1-7 (not at all - very much)		2 %
IEQ factors						
Overall comfort in the room	Satisfaction	How satisfied are you with the comfort of the room?		Likert scale: 1-7 (very dissatisfied - very satisfied)	10 %	6 %
		NA	How satisfied are you with the IEQ (thermal comfort, visual comfort, acoustic comfort, and IAQ) of the room?	Likert scale: 1-7 (very dissatisfied - very satisfied)	NA	7 %
Thermal comfort	Perceived control[2]	Which of the building features below can you adjust in the room yourself? (Please indicate all aspects that apply.)		Multiple choice, including the possibility to indicate options themselves	NA	NA
	State of adaptable building characteristics	NA	What is the state of the building features below?	Multiple choice, including the possibility to indicate options themselves	NA	NA

[2] To reduce response burden, perceived control possibilities are questioned once when they influence more than one IEQ factors.

	Satisfaction	How satisfied are you with the temperature in your room?	How satisfied are you with the thermal environment?	Likert scale: 1-7 (very dissatisfied - very satisfied)	7 %	3 %
	Moment of discomfort	[Which of the following aspects leads to less satisfaction with the temperature in your room?] When is this usually a problem?	NA	Multiple choice, including the possibility to indicate options themselves	NA	NA
	Causes of comfort	NA	How would you describe the cause of thermal comfort?	Multiple choice, including the possibility to indicate options themselves	NA	NA
	Causes of discomfort	How would you describe the cause of thermal discomfort?		Multiple choice, including the possibility to indicate options themselves	NA	NA
Indoor air quality	Satisfaction	How satisfied are you with the indoor air quality in your room (e.g. stuffy/ stale air, cleanliness, humidity, odours)?		Likert scale: 1-7 (very dissatisfied - very satisfied)	7 %	6 %
	Causes of comfort	NA	Which of the following aspects contribute to satisfaction with air quality?	Multiple choice, including the possibility to indicate options themselves	NA	NA
	Causes of discomfort	Please rate each of the following problems: the air stuffy/stale air, not clean, too dry / to humid , smells bad (odours)		Likert scale: -6-0 (big problem - no problem)	19 %/23 %/20 %/21 %/20 %	8 %/8 %/6 %/8 %/8 %
		Which of the following aspects result in odour problems?		Multiple choice, including the	NA	NA

				possibility to indicate options themselves		
Visual comfort	Perceived control[2]	Which of the following control options do you have over the lighting in your room?		Multiple choice, including the possibility to indicate options themselves	14%	6%
	State of adaptable building characteristics	NA	What is the state of the building features below?	Multiple choice, including the possibility to indicate options themselves	NA	NA
	Satisfaction	How satisfied are you with the amount of light in your room?	How satisfied are you with the visual environment (i.e. amount of light, glare, reflections, contrast)?	Likert scale: 1-7 (very dissatisfied - very satisfied)	8%	5%
		How satisfied are you with the visual environment (i.e. glare, reflections, contrast)?		Likert scale: 1-7 (very dissatisfied - very satisfied)	8%	
		How satisfied are you with the view out through the windows in your room?		Likert scale: 1-7 (very dissatisfied - very satisfied)	8 %	8 %
	Causes of comfort	NA	Which of the following aspects contribute to satisfaction with the visual environment?	Multiple choice, including the possibility to indicate options themselves	NA	NA
	Causes of discomfort	Which of the following aspects result in less satisfaction with the visual environment?		Multiple choice, including the possibility to	NA	NA

				indicate options themselves		
Acoustic comfort[3]	Satisfaction	How satisfied are you with the amount of sound in your room?	How satisfied are you with the sounds in your room?	Likert scale: 1-7 (very dissatisfied - very satisfied)	10 %	6 %
		How satisfied are you with the amount of tranquility in your room?		Likert scale: 1-7 (very dissatisfied - very satisfied)	10 %	8 %
		How satisfied are you with the amount of sound privacy in your room (i.e. the ability to have conversations without others overhearing it and vice versa)?	NA	Likert scale: 1-7 (very dissatisfied - very satisfied)	12 %	NA
	Causes of comfort	Which of the following aspects contribute to satisfaction with the acoustic comfort?	Which of the following aspects contribute to satisfaction with the acoustic comfort?	Multiple choice, including the possibility to indicate options themselves	NA	NA
	Causes of discomfort	Which of the following aspects result in less satisfaction with the acoustic comfort?		Multiple choice, including the possibility to indicate options themselves	NA	NA
Layout of the room	Satisfaction	How satisfied are you with the privacy in your room?		Likert scale: 1-7 (very dissatisfied - very satisfied)	4 %	6 %

[3] As mentioned before, IEQ factors are questioned at case 2 instead of IEQ parameters. The question about the amount of sound and sounds is distinguished from the one about the degree of tranquillity. They refer respectively to how quiet it is, the acoustic comfort and how peaceful it is. The degree of sound privacy was not questioned in case 2 as it overlaps with the degree of privacy.

		How satisfied are you with the way in which you can have social contact with others?		Likert scale: 1-7 (very dissatisfied - very satisfied)	17 %	10 %
	Causes of comfort	NA	Which of the following aspects contribute to satisfaction with the privacy in your room?	Multiple choice, including the possibility to indicate options themselves	NA	NA
	Causes of discomfort	Which of the following aspects result in less satisfaction with the privacy in your room?		Multiple choice, including the possibility to indicate options themselves	NA	NA

Table 2.2 Overview of interviewed and questionnaire participants, their personal and room characteristics, and dates of participation.

Case & type of data	Case 1, interviews	Case 1, questionnaire	Case 2, interviews	Case 2, questionnaire
Dates of participation	May: 14, 17, 21, 24, 27, 30; July: 9, 11, 12, 15, 16, 19, 20, 22, 26, 30; August: 1	May: 14, 21, 24, 27, 30; July: 9, 10, 11, 12, 15, 19, 22, 25, 26, 29	September: 29; October: 2, 6, 9, 13, 16, 20, 23, 27, 30; December: 8, 11, 15, 18, 29; January: 5	September: 29; October: 2, 6, 9, 13, 16, 20, 23, 27, 30; December: 8, 9, 11, 15, 18, 30; January: 2, 5, 8
Number of participants	16	84	19	238
Number of participants participating in two interviews/answering all questionnaire questions (excl. multiple choice questions)	16	58%	10	50 %
Birth sex: % woman	31 %	35 %	74 %	59 %
Age [years]: mean, sd	57.93; 14.48	53.6; 17.23	46.73; 35.27	52.58; 22.76
Nationality: % Belgian	88 %	100 %	100 %	97 %
Length of stay [days]: mean, sd	7.31; 6.54	5.36; 4.92	7.25; 6.96	3.83; 3.17
Self-rated well-being: % >= neutral	NA	NA	100 %	74 %
Number of previous hospitalisations: mean, sd	5.75; 3.28	5.36; 4.92	9.62; 7.95	9.20; 5.31
Type of room: % single room	50 %	25 %	47 %	59 %
Window or corridor side (only double rooms): % window side	44 %	45 %	NA	NA
Window orientation	NE: 19 %; E: 13 %; SE: 31 %; NW: 0 %; W: 25 %; SW: 13 %	NE: 16 %; E: 21 %; SE: 34 %; NW: 29 %; W: 8 %; SW: 26 %	NE: 21 %; SE: 32 %; SW: 32 %; NW: 16 %	NE: 34 %; SE: 22 %; SW:32 %; NW: 12 %
Zone of ward	quiet: 50 %; neutral: 25 %; noisy: 25 %	quiet: 37 %; neutral: 33 %; noisy: 30 %	quiet: 68 %; noisy: 32 %	quiet: 62 %; noisy: 38 %
Outdoor conditions: % heat wave (case 1)/cold days (case 2)	19 %	20 %	47 %	24 %
Outdoor conditions: % sunny days			20 %	27 %

Table 2.3 Topic guide of the semi-structured interviews.

Topic guide interviews		
Interview 1	**Introductory questions**	Introduction of themselves
	Transition questions	Positive experiences of the room
		Negative experiences of the room
		Meaning given to the room
	Main questions	Overall comfort
		experiences
		preferences
		IEQ factor which has the main importance
		assessment
		Thermal comfort
		experiences (incl. variations over time and space)
		sources that impact it
		actions to improve it
		preferences
		assessment
		Acoustic comfort (subtopics idem thermal comfort)
		Visual comfort (subtopics idem thermal comfort)
		IAQ (subtopics idem thermal comfort)
		Other factors that the participant experiences as important
		Comparison of the room's IEQ with that in other contexts: why would it be experienced similarly or different?
		Most important characteristics of the IEQ in a patient room
		If a new hospital were built: which characteristics of the room or IEQ would the patient certainly keep or change?
	Concluding questions	What is the most important topic addressed during the interview according to the participant?
		Which factor of the indoor environment does the participant find the most important?
		Additional comments from the participant
Interview 2	**Introductory questions**	How did the participant experience the past few days in the hospital?
	Transition questions	Experiences of the IEQ during the previous days
	Main questions	Discussion of the most important moments during the previous days, and (implicitly) how the indoor environment influenced these moments
		Discussion of the probe if the participant filled it in
		Discussion of the measurements during the previous days, and actions taken which impact on the measured values
		Additionally: discussion of separate IEQ factors
	Concluding questions	Idem interview 1

Table 2.4 Overview of the sensor measurements.

Sensor	IEQ parameter(s) [measurement unit]	accuracy/ sensitivity	sampling rate [min.]	Location case 1	Location case 2	Position in room
HOBO prov2	air temperature [°C]	± 0.21	10	Interviewees' room	all rooms	1.50 m from floor level, behind patient
VersaSense Edge Gateways	NA	NA	NA	staff room	two staff rooms	NA
VersaSense Wireless Devices	ambient illuminance level [lx]	± 0.01	1	Interviewees' room	per ward: 9 patient rooms	1.50 m from floor level, behind patient (light sensor pointed to ceiling)
	sound level [%, with 0 % = 40 dB and 100 % = 80 dB]	noise detection level: approx. equivalent to a finger-click at 1 meter	1	Interviewees' room	9 patient rooms, period at ward 1: 29/09 to 20/10 & 15/12 to 08/01, ward 2: 20/10 to 15/12	1.50 m from floor level, behind patient
Weather station	outdoor temperature [°C]	Case 1: ±(0.226 - 0.0028 × temperature); Case 2: ± 0.2	Case 1: 1; Case 2: 15	3km from hospital	at hospital	NA
	global radiation [W/m2]	Case 1: ± 10 %; Case 2: 5 %				
Gossen Mavolux 5032B illuminance measurer	Illuminance level [lx]	0.01 lx	2006	NA (only used for calibrating the VersaSense sensors)	NA	NA

10-minute intervals for case 1 and 15-minute intervals for case 2. Unless mentioned otherwise, measurements during the heat wave (case 1) were excluded from the groups, as this situation influenced the values considerably and was unevenly distributed over groups. The impact of differences in window orientations (see captions of Figures 2.5–2.7) and seasons was taken into account during data interpretation. The threshold values in Table 2.5 gave an indication of how differences in measured values were expected to be experienced.

Table 2.5 Threshold values from norms, standards and guidelines.

Indoor air temperature (Flemish Indoor Environment Decree (Lazarov and Stranger, 2017))			
Cold half of the year	20 °C <= T < 24 °C		
Warm half of the year	22 °C <= T < 26 °C		
Illuminance level (NBN EN 12464-1 (2003))[12]			
General lighting	100 lx		
Reading lighting	300 lx		
Simple examination	300 lx		
Examination and treatment	1000 lx		
View out (NBN EN 12464-1 (2003) NBN EN 17037 (2019))	Horizontal sight angle	Outside distance of the view	Layers
Minimum	>=14 °	>=6 m	landscape layer
Medium	>=28 °	>=20 m	landscape layer and one additional layer
High	>=54 °	>=50 m	sky, landscape (urban and/or nature) and ground layer

Interviews were audio-recorded and transcribed. Transcriptions were analysed qualitatively, together with the data of the self-documentation, questionnaires and sensor measurements, roughly following the Qualitative Analysis Guide of Leuven (Dierckx de Casterlé et al., 2012) and using NVivo software (NVivo, 2021). Interviews were analysed per interviewee and per group. They informed about what the social construct 'comfort' means. During data analysis, relevant concepts were looked up in literature: spheres of attention (Arvidson, 2006), perceived control (Bryant, 1989; Chipperfield et al., 2012; Rothbaum et al., 1982), adaptive preferences (Bovens, 1992; Bruckner, 2009; Teschl & Comim, 2005) and theories about satisfaction (Oliver, 1980). Insights from literature informed the adaptation model presented in the Results section. Quotes reported were translated to English by the authors.

[12] Threshold values apply for the illuminance level at floor level. Aiming to understand patients' experience of ICs, we measured illuminance levels at patients' eye height. We assumed that the same threshold values were applicable.

The integrated analysis was conducted iteratively with separate quantitative and qualitative analyses. For each of the compared groups, findings of the separate quantitative and qualitative analyses were merged via a joint display to draw out new insights beyond those gained from the separate analyses (see for instance Tables 2.6–2.8 and Figures 2.5–2.7). Joint displays were set up for the analyses of the individual cases as well as for the cross-case analysis. When silence occurred during merging (i.e. findings about a certain theme were not present in a data set (O'Cathain et al., 2010; Uprichard & Dawney, 2019), we first verified whether we overlooked something during the separate analysis. During the integrated analysis, attention was given to whether findings of the quantitative and qualitative data were congruent (i.e. correspond), complementary (i.e. clarify, explain, or more fully elaborate each other), or discrepant (i.e. contradict each other).

4. Results

Merging data from interviews, questionnaires, and sensor measurements offered insight into how participants adapt and adapt to indoor conditions, as well as how their adaptation is influenced by the indoor environment. Figure 2.4 builds on Figure 2.1. It summarizes the interlinkages observed and will be referred to in the two sections below.

4.1. Patients' adaptation of and to indoor conditions

The adaptation process observed is visualized in Figure 2.4. Some indoor conditions catch participants' attention via sensations and environmental information they transfer. Participants attribute meaning to these indoor conditions. Experiencing indoor conditions that deviate from their preference in that situation can trigger a wish for adaptation. When participants have a wish for adaptation, they can either perceive control to reduce the deviation or do not perceive such control. How patient room design affects participants' adaptation of and to indoor conditions via its influence on perceived control will be discussed later. For now, the focus is on the different ways in which participants adapt and adapt to indoor conditions. When participants perceive possibilities to reduce the deviation, i.e. when they perceive control, they adapt behaviourally or psychologically. Four adaptation strategies are identified, of which the first three are forms of behavioural adaptation. These are presented by the rectangles at the bottom right of Figure 2.4. Each strategy reduces the deviation in a different way, which is indicated by the purple and orange arrows on Figure 2.4. Participants

(1) adapt indoor conditions in the room (arrow pointing to indoor conditions);

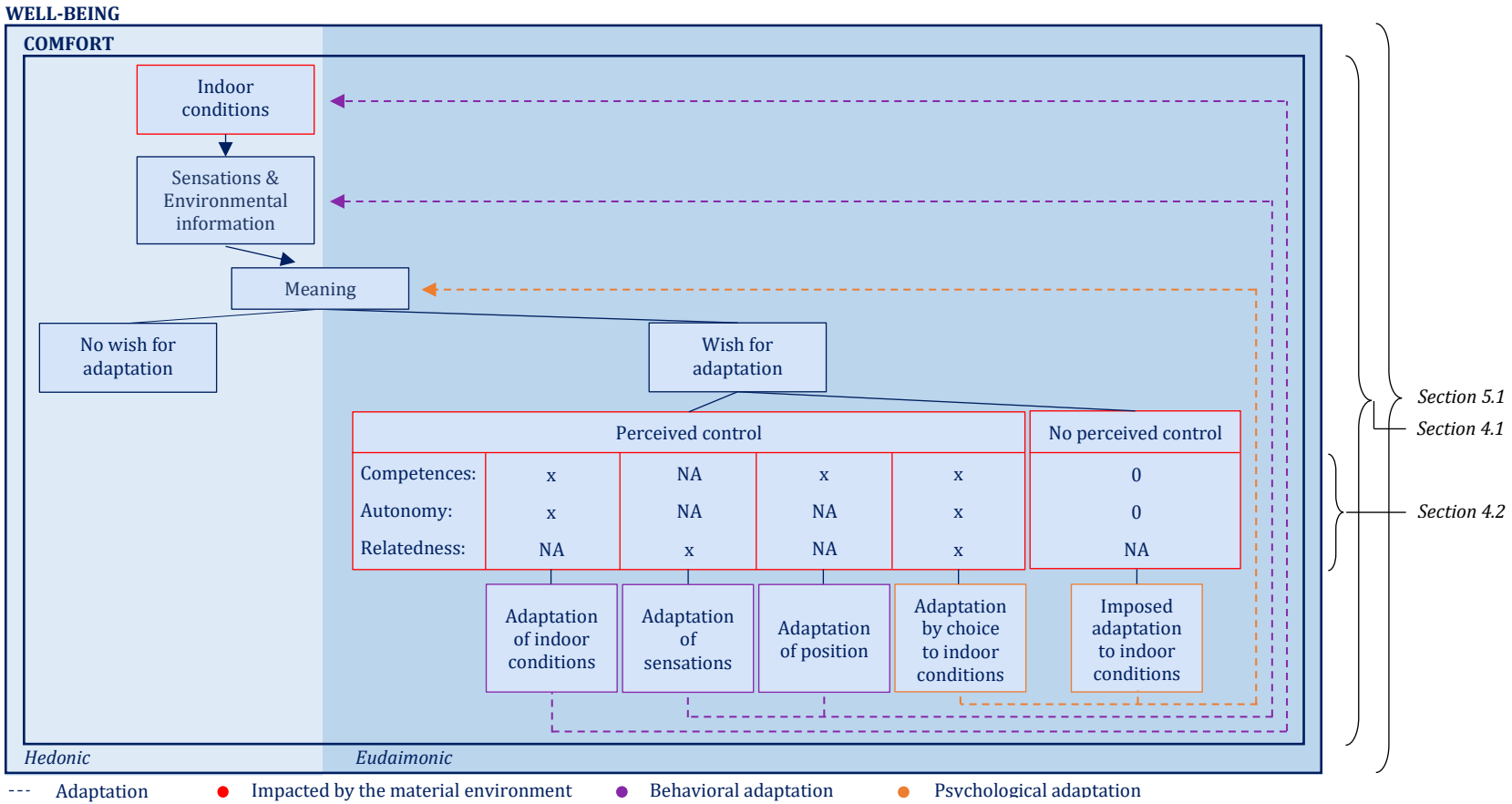


Figure 2.4 Adaptation model: the interplay between a patient and indoor conditions through perceived control and adaptation as well as its link with comfort, influences of the indoor environment on patients' adaptation of and to indoor conditions, and how both link to well-being. [An 'x' indicates that competences, autonomy, or relatedness should be supported or is often supported by the indoor environment when the corresponding adaptation strategy is adopted; an '0' that it is not supported; and 'NA' that whether it is supported or not does not seem to play an important role in whether the corresponding adaptation strategy is adopted.] [Note that the link with well-being will be described in the 'Discussion' (Section 5.1).]

(2) adapt sensations or the experienced environmental information via physical means (e.g. changing clothing) (arrow pointing to sensations and environmental information);
(3) adapt their position by moving to more comfortable indoor conditions (arrow pointing to sensations and environmental information); or
(4) adapt by choice to indoor conditions through choosing themselves to alter the attention given and meaning attributed to indoor conditions (arrow pointing to meaning). Adaptation by choice to indoor conditions occurs in two types of situations: when contextual factors take priority over comfortable indoor conditions, or when some IEQ factors take priority over others because the most comfortable condition of individual factors cannot exist simultaneously.

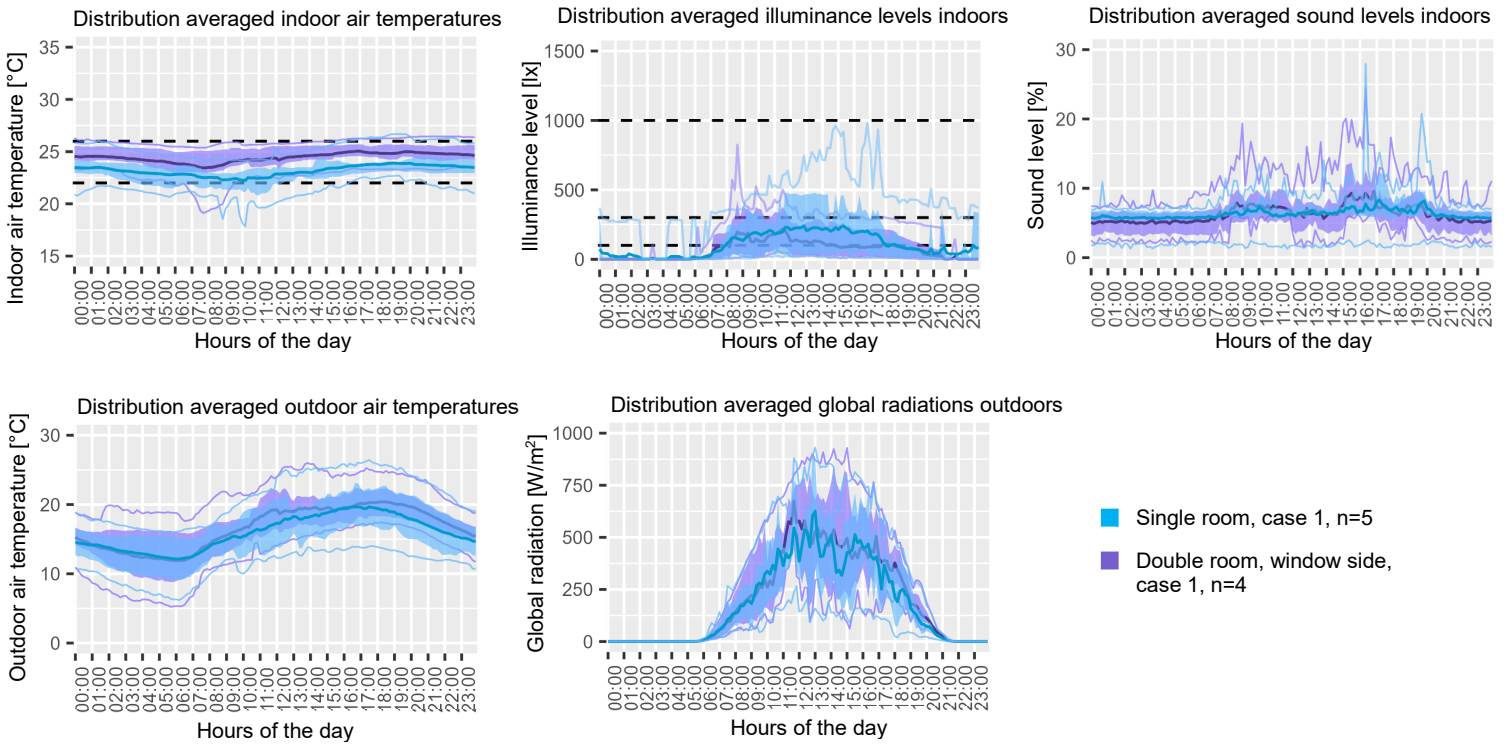
When perceived control is lacking, participants are

(5) imposed to adapt to indoor conditions through altering the meaning and attention given to indoor conditions (arrow pointing to meaning). This occurs in two types of situations: when actions taken to adapt indoor conditions do not suffice, or when no action can be taken.

4.1.1. Adaption of indoor conditions

Perceived control and actions interviewees and respondents take, seem to affect how they experience indoor conditions positively. Figure 2.5 shows the distribution of indoor and outdoor air temperatures, and illuminance, global radiation, and sound levels in single and (at the window side of) double rooms or outdoors during the hospital stay of interviewees (case 1, top) and respondents (case 2, bottom). Table 2.6 presents interview quotes, causes of (dis)comfort, perceived control, satisfaction votes, and characteristics of the measured values. This section focuses on the findings from case 1. Rather than by the extent to which measured values of IEQ parameters meet threshold values (Table 2.6: threshold values), (the absence of) differences in reported satisfaction between single rooms and at the window side of double rooms can be explained by the fact that interviewees and respondents in single rooms perceive more control over indoor conditions (e.g. have more privacy or control over sources that influence indoor conditions) (Table 2.6: interview quotes and causes of (dis)comfort), perceive more control over building characteristics (Table 2.6: perceived control) and adapt indoor conditions more (Figure 2.5). How this shows for thermal, visual, and acoustic comfort is explained in more detail below.

First, the lower indoor air temperatures, at similar outdoor temperatures, indicate that the window is more often open in single rooms (Figure 2.5). Although these lower indoor air temperatures comply less with threshold values, satisfaction is not significantly different (Table 2.6: satisfaction votes and threshold values).


Distribution averaged indoor air temperatures
Indoor air temperature [°C]
35
30
25
20
15
Hours of the day
Distribution averaged illuminance levels indoors
Illuminance level [lx]
1500
1000
500
0
Hours of the day
Distribution averaged sound levels indoors
Sound level [%]
30
20
10
0
Hours of the day
Distribution averaged outdoor air temperatures
Outdoor air temperature [°C]
30
20
10
0
Hours of the day
Distribution averaged global radiations outdoors
Global radiation [W/m²]
1000
750
500
250
0
Hours of the day
Single room, case 1, n=5
Double room, window side, case 1, n=4

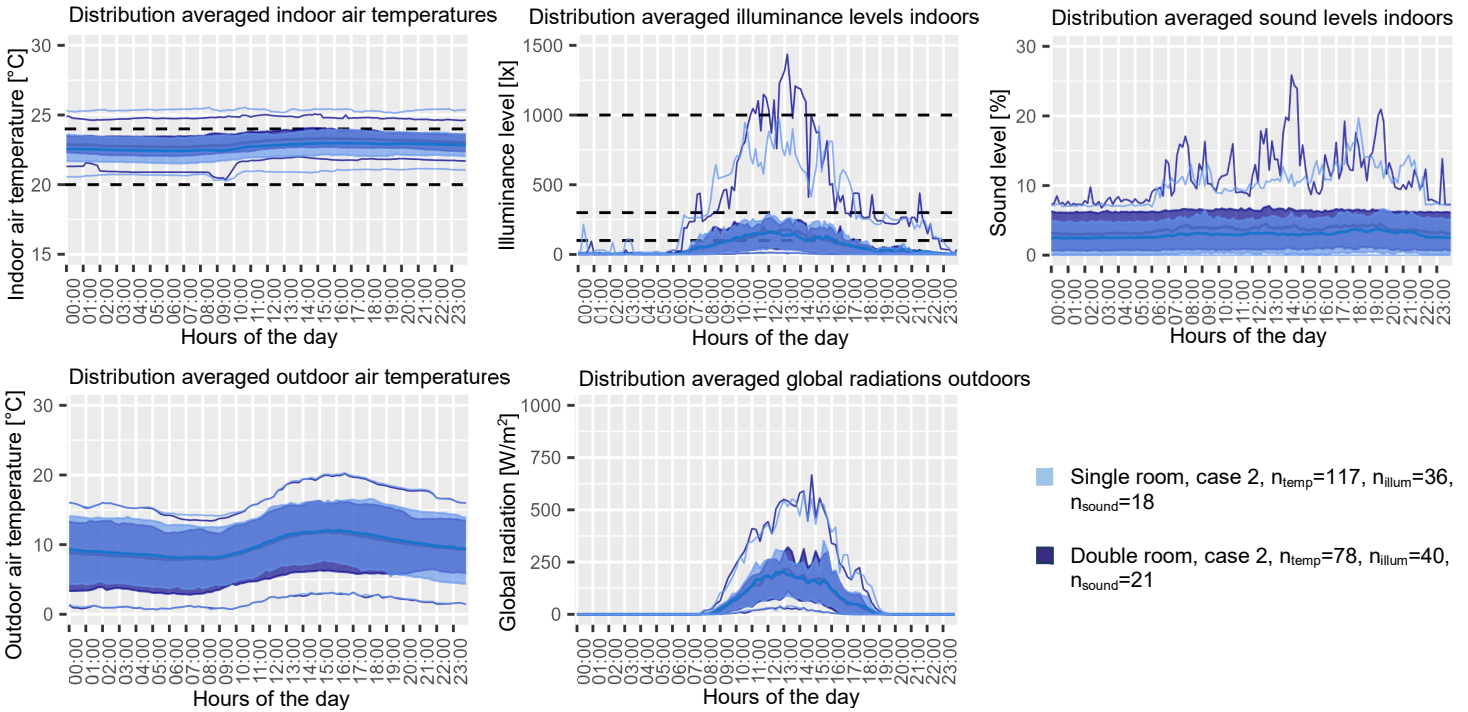


Figure 2.5 The (10 min average) mean, 1st quartile, 3rd quartile, 5th percentile and 95th percentile of the indoor air temperature (top left), illuminance level (top middle), and sound level at patients' bed (top right), and outdoor air temperatures (bottom left) and global radiation outdoors (bottom right) over the hours of the day during interviewees' (case 1) and respondents' (case 2) hospital stay in single or (at the window side of) double rooms. In case 1 window orientations are distributed as follows: 1x northeast, 1x east and 3x west for single rooms; and 4x southeast for double rooms. This difference explains the lower illuminance levels in the afternoon in double rooms. Horizontal dotted lines refer to threshold values of the Flemish Indoor Environment Decree (top left) and NBN EN 12464-1 (2003) (top middle). (n: number of participants for which the measurements are included).

Table 2.6 Interview quotes, causes of (dis)comfort, perceived control, satisfaction votes and characteristics of the measured values for interviewees and respondents residing in single (1p) and (at the window side of) double rooms (2p) of case 1 and 2. The first part of the table focusses on case 1; the second part on case 2 and the cross-case analysis. (number of interviewees (n_i), number of respondents (n_s), not significant (n.s.)).

TYPE OF SPACE:	**Single room, case 1 (n_i=7, n_s=21)**	**Double room, window side, case 1 (n_i=4, n_s=62)**
EXPERIENCE	**Interview quotes**	
Autonomy	"I think something to always keep in mind is to allow people to have enough space they can control themselves around themselves to keep their own privacy." (participant 2)	-
	"In the morning, for example, that was very good. I opened the window a little. Then fresh air comes in. I like that. [...] And straight from outside. Not artificially through an air conditioning system that most likely uses filters that are not clean and bring bacteria in." (participant 16)	-
Autonomy and relatedness	"Other people eat their food, they have their biscuits, chips, crisps, coffee, thee. They have their body odours, their perfumes. They might use desinfactance. This all together creates a mix of smells which is probably different from what one, oneself kind of does as an effect of one's activities. This is something I don't like. It is a degree of intimacy which I don't appreciate so much." (participant 2)	"Then it started to get a bit warm. Well [...] for me it was fine without a fan. But [the other patient in the room] suffers more from it than I do. But he is also farther away from the window than I am. [...] . It was [kind of] 'pleasant'. [But] then you hear that noise from the fan." (participant 11)
	-	"But then at night. [...] The neighbour here [...] is a demented lady. She started to be very restless. They couldn't calm her down. She was shouting. There's another shouter. Then there's another one. [...] They started against each other. Like with children. when one shouts, the next one starts

		shouting too and after a while everyone is shouting." (participant 9)
	Causes of (dis)comfort [%]	
Causes of thermal comfort	NA	NA
Causes of thermal discomfort	-	Incoming sun (1p: 25 %, 2p: 35 %)
		Drafts from windows (1p: 0 %, 2p: 17 %)
Causes of visual comfort	NA	NA
Causes of visual discomfort	-	-
Causes acoustic comfort	Music (1p: 50 %; 2p: 14 %)	People talking in neighbouring rooms (1p: 6 %, 2p: 18 %)
	The control over television programs (1p: 44 %; 2p: 29 %)	
	Interactions with people in my room (1p: 31 %; 2p: 21 %)	
	The silence (1p: 25 %; 2p: 21 %)	
Causes acoustic discomfort	Monitors (1p: 13 %; 2p: 4 %)	Noise and crying, snoring and shouting from other patients (1p: 19 %; 2p: 43 %)
		Sound of devices (1p: 19 %, 2p: 39 %)
		People talking in neighbouring rooms (1p: 13 %, 2p: 26 %)
		People who can overhear private conversations (1p: 6 %; 2p: 26 %)
		People who can overhear conversations with staff about delicate and personal topics (1p: 13 %; 2p: 22 %)
		Carts (1p: 0 %, 2p: 22 %)
		Sounds of TVs (1p: 6 %, 2p: 17 %)
		Mechanical noise (e.g. heating, air conditioning an d ventilation system) (1p: 0 %, 2p: 13 %)
		Excessive echo of voices or other sounds (1p: 6 %, 2p: 13 %)

Causes of comfort with IAQ	NA	NA	
Causes of discomfort with IAQ	Air is stuffy/stale (1p: 43 %, 2p: 30 %)	Air is not clean (1p: 19 %, 2p: 26 %)	
	Air is humid (1p: 14 %, 2p: 9 %)	Food (1p: 10 %, 2p: 22 %)	
		Smell of urine or feces (1p: 10 %, 2p: 22 %)	
		Cleaning products (1p: 5 %, 2p: 13 %)	
Causes of comfort related to the room's layout	NA	NA	
Causes of discomfort related to the room's layout	-	High density: too little space between people (1p: 13 %, 2p: 48 %)	
		Partitions between people do not provide enough visual privacy (1p: 13 %, 2p: 43 %)	
		Conversations are discouraged because they interfere with other patients (1p: 0 %, 2p: 17 %)	
		There are no spaces to talk to visitors in a pleasant way (1p: 0 %, 2p: 13 %)	
	Perceived control [%]		
	Light switch (1p: 93 %, 2p: 52 %)	Air conditioning (1p: 7 %, 2p: 13 %)	
	Windows opened/closed (1p: 87 %, 2p: 78 %)		
	Shading device - for visual comfort (1p: 60 %, 2p: 43 %)		
	Desk fan (1p: 40 %, 2p: 30 %)		
	Light dimmer (1p: 40 %, 2p: 9 %)		
ASSESSMENT	**Satisfaction votes [Q1/median/Q3 votes]**		**p-value: 1p verus 2p case 1**
Thermal comfort			
Temperature	-1 1 3	-1 1 2	n.s.
Visual comfort			
Amount of light	0 2 3	0 2 3	n.s.
Visual comfort	0 2 3	0 1 2	0.02
View out	-2 1 3	0 1 2	0.03

Acoustical comfort			
Amount of sound	0 2 3	0 1 2	0.02
Degree of tranquility	0 2 3	0 1 2	0.009
Degree of sound privacy	0 2 3	-1 0 1	<0.001
IAQ			
IAQ	0 2 3	1 2 2	n.s.
Room's layout			
Degree of privacy	1 2 3	0 1 2	0.002
Way of social contact	0 2 3	1 2 2	n.s.
Overall satisfaction with the room	0 2 3	1 2 2	0.004
SENSOR MEASUREMENTS	**Threshold values [% of time]**		
Thermal comfort			
Indoor air temperature	22 °C <= T < 26 °C: 63 %	22 °C <= T < 26 °C: 88 %	
Visual comfort			
Illuminance level (case 1: 6h-21h; case 2: 8h-18h)	> 100 lx: 42 %	> 100 lx: 37 %	
	Measured values		
Acoustic comfort			
Average sound level for day/night	7.29/6.32	7.36/6.07	
Average of the q95 sound level per room	9.14	9.46	

TYPE OF SPACE:	Single room, case 2 (n_i=9, n_s=134)	Double room, case 2 (n_i=10, n_s=93)
EXPERIENCE	**Interview quotes**	
Autonomy	"But for me personally, I prefer to be alone. [...] Then I'm free in my doings. [...] Because then it is quiet and you can turn on the TV for music or something else. Yes, I think that's better." (participant 8)	-
Autonomy and relatedness	-	"When we have a conversation, you have someone in front of you instead of next to you. For example, if you can't turn, [having someone next to you during a conversation is] a little more difficult. And if you want some privacy, then here's that curtain. Then you still have your own bubble let's say." (participant 4)
	-	"You can adapt [the artificial lighting] yourself. […] We prefer it that way." Her roommate: "We agree on that. […] You take each other into account. [...] You ask can the curtain between us open, does that disturb? Some people prefer that it's always closed." Participant: "That situation once happened to me […]. I [prefer an open curtain]. That curtain was always closed." (participant 1)

	-	"That night I woke up two times from noise from the corridor. [...] I kept the door to the hallway open because she liked it so much and I think she suffers more than I already have here, so I follow her in that. [...] And for me that makes, well, you can have a preference, but if you don't have [your preference], it is not that then everything is screwed up. It's just like, I'll adapt. You close your eyes anyway. It's not that [the open door] prevents me from sleeping. That's just a habit I've adopted in life that everything has to be closed at night." (participant 11)
	Causes of (dis)comfort [%]	
Causes of thermal comfort	Clothing policy and the use of bed sheets and blankets is flexible (1p: 67 %, 61 %)	-
	I can control the temperature myself (1p: 32 %, 2p: 11 %)	
	Heating/cooling system responds quickly en ough to the thermostat (1p: 27 %, 2p: 20 %)	
	Thermostat is accessible (1p: 26 %, 2p: 14 %)	
Causes of thermal discomfort	Thermostat is inaccessible (1p: 11 %, 2p: 5 %)	-
Causes of visual comfort	Sufficient windows (1p: 55 %, 2p: 50 %)	-
	Attractive view through the windows (1p: 34 %, 2p: 23 %)	
	Incomming sun (1p: 21 %, 2p: 15 %)	

Causes of visual discomfort	-	Unattractive view through the windows (1p: 12 %, 2p: 18 %)
Causes acoustic comfort	Sounds of TVs (1p: 52 %, 2p: 31 %)	Interactions with people in my room (1p: 11 %, 2p: 48 %)
	Music (1p: 29 %, 2p: 24 %)	The silence (1p: 42 %, 2p: 48 %)
	Carts (1p: 12 %, 2p: 4 %)	Interactions with other patients in my room (1p: 2 %, 2p: 25 %)
		Interactions with visitors in my room (1p: 16 %, 2p: 21 %)
Causes acoustic discomfort	Carts (1p: 28 %, 11 %)	Noise and crying, snoring or shouting of other pat ients (1p: 2 %, 2p: 15 %)
	Sound of devices (1p: 16 %, 2p: 7 %)	People listening when you talk with staff about de licate and personal topics (1p: 1 %, 2p: 10 %)
Causes of comfort with IAQ	Cleaning products (1p: 29 %, 2p: 21 %)	-
	Disinfecting alcohol gel (1p: 24 %, 2p: 18 %)	
	Sources from outdoors (1p: 15 %, 2p: 7 %)	
Causes of discomfort with IAQ	-	-
Causes of comfort related to the room's layout	Not many people come into my room (1p: 50 %, 2p: 42 %)	There is enough space between people (1p: 18 %, 2p: 70 %)
	Nursing staff cannot easily see inside (1p: 28 %, 2p: 13 %)	The number of people per room is pleasant (1p: 34 %, 2p: 69 %)
		Partitions between people provide enough visual privacy (1p: 11 %, 2p: 63 %)
Causes of discomfort related to the room's layout	-	-

	Perceived control [%]				
	Light switch (1p: 87 %, 2p: 79 %)	Curtain between patients (1p: 4 %, 2p: 58 %)			
	Door to indoor area (1p: 50 %, 2p: 42 %)				
	Thermostat (1p: 25 %, 2p: 11 %)				
	Heating (1p: 23 %, 2p: 17 %)				
ASSESSMENT	**Satisfaction votes [Q1/median/Q3 votes]**		**p-values**		
			1p case 2 versus 2p case 2	1p case 1 versus 1p case 2	2p case 1 versus 2p case 2
Thermal comfort					
Temperature	1 2 3	1 2 3	n.s.	n.s.	n.s.
Visual comfort					
Amount of light	NA	NA	NA	NA	NA
Visual comfort	1 2 3	2 2 3	n.s.	n.s.	0.004
View out	0 1 3	0 1 2	n.s.	n.s.	n.s.
Acoustical comfort					
Amount of sound	0 2 3	0 2 3	n.s.	n.s.	n.s.
Degree of tranquility	1 2 3	2 2 3	n.s.	n.s.	0.04
Degree of sound privacy	NA	NA	NA	NA	NA
IAQ					
IAQ	1 2 3	0 2 3	n.s.	n.s.	n.s.
Room's layout					
Degree of privacy	2 3 3	1 2 3	0.02	n.s.	0.03

Way of social contact	0 2 3	1 2 3	0.046	0,03	n.s.
Overall satisfaction with the room	2 3 3	2 3 3	n.s.	n.s.	<0.001
SENSOR MEASUREMENTS	**Threshold values [% of time]**				
Thermal comfort					
Indoor air temperature	20 °C <= T < 24 °C: 86 %	20 °C <= T <24 °C: 84 %			
Visual comfort					
Illuminance level (case 1: 6h-21h; case 2: 8h-18h)	> 100 lx: 32 %	> 100 lx: 27 %			
	Measured values				
Acoustic comfort					
Average sound level for day/night	3.43/2.31	3.36/2.96			
Average of the q95 sound level per room	8.49	8.2			

Second, as the global radiation outdoors is similar, higher illuminance levels in single rooms result from more actions on the lighting (Figure 2.5). This is supported by the horizontal patterns in the illuminance level and higher 95th percentile values during the night. Through the actions taken, compliance with threshold values is higher (Table 2.6: threshold values). Congruent with the higher compliance rate, satisfaction with the visual comfort is significantly higher ($p = 0.02$) (Table 2.6: satisfaction votes).

Third, as causes of acoustic (dis)comfort, the respondents in single rooms mention more sources controlled by themselves, while those in double rooms mainly mention uncontrollable sources (Table 2.6: causes of (dis)comfort). In single rooms sound levels are slightly lower during the day, and slightly higher during the night (Table 2.6: measured values, Figure 2.5). Discrepant with this limited difference in measured values, respondents in single rooms are significantly more satisfied with the amount of sound ($p = 0.02$), degree of tranquillity ($p = 0.009$), degree of sound privacy ($p < 0.001$), and degree of privacy ($p = 0.002$).

Not only the possibility to adapt indoor conditions, but also the state of the indoor conditions after they have been adapted, support patients' comfort. It shows in respondents' higher satisfaction with the acoustic comfort in single rooms and the more positive experience of sound sources they can control (Table 2.6: satisfaction and causes of (dis)comfort) as well as interviewees' enjoyment of indoor conditions that are adapted by themselves (Table 2.6: interview quotes).

4.1.2. Adaptation of sensations and environmental information

Having the possibility to adapt sensations or experienced environmental information seems to foster comfort. Some interviewees preferred it to be slightly too cold instead of too warm so that they can adapt their clothing.

The findings suggest as well that adapting sensations or experienced environmental information fosters comfort. Interviewees wear ear plugs to avoid annoying sounds, adapt clothing to increase thermal comfort, and, when the air feels dry, drink more, and use moistening lotion, anti-dandruff shampoo and, especially those wearing contact lenses, eye drops.

4.1.3. Adaptation of position

Having the possibility to adapt one's position seems to foster comfort. Figure 2.6 shows for case 1 the distribution of illuminance and global radiation levels at the window and corridor side of double rooms during interviewees' hospital stay. Table 2.7 presents interview quotes, causes of (dis)comfort, perceived control, satisfaction votes and characteristics of the measured values. Several interviewees residing at the corridor side of double rooms move to the window when there is a nice view out. Having this possibility is expected to explain why

respondents residing at the corridor side are significantly more satisfied with the view out than those residing at the window side of double rooms (p = 0.02) (Table 2.7: satisfaction votes). This observation is discrepant with NBN EN 17037's (2019) indication that the view out scores lower at the corridor side (Table 2.7: threshold values).

Participants' comfort would seem to be fostered as well at moments when they adapt their position. Interviewees residing at the corridor side refer with more enthusiasm to views on helicopter landings or the atmosphere at the window in the corridor (Table 2.7: interview quotes).

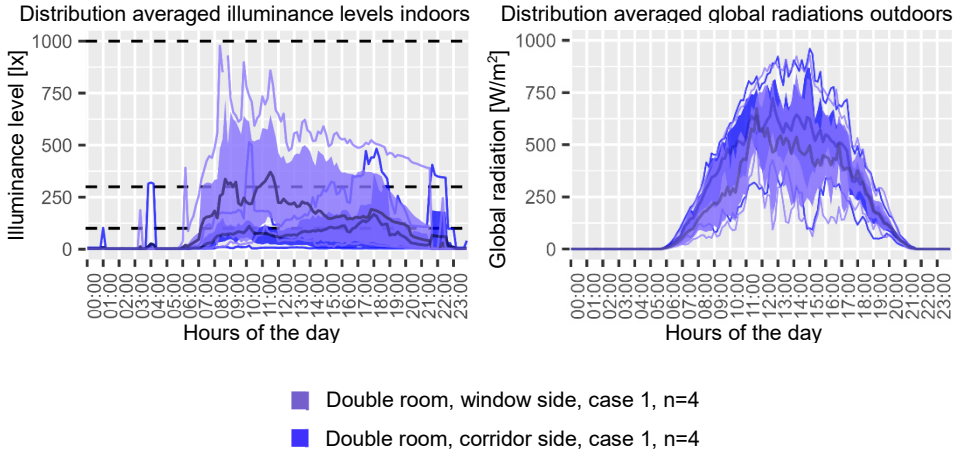


Figure 2.6 The (10 min average) mean, 1st quartile, 3rd quartile, 5th percentile and 95th percentile of the illuminance level at the patients' bed (left), and the global radiation outdoors (right) over the hours of the day during interviewees' hospital stay at the window or corridor side of double rooms of case 1. The window orientations are distributed as follows: 4x southeast for the window side, and 2x southwest, 1x southeast, and 1x east for the corridor side. As the illuminance levels at the corridor side stay below those at the window side in the afternoon and evening, differences in window orientation do not cause bias in the interpretation of the measurements. Horizontal dotted lines refer to threshold values of NBN EN 12464-1 (2003).

Table 2.7 Interview quotes, causes of (dis)comfort, perceived control, satisfaction votes and characteristics of the measured values for interviewees and respondents residing at the window (w.) or corridor side (c.) of double rooms of case 1.

TYPE OF SPACE:	**Double room, window side, case 1 (n_i=4, n_s=28)**	**Double room, corridor side, case 1 (n_i=4, n_s=34)**
EXPERIENCE	**Interview quotes**	
(Lack of) autonomy	"When [the window] was open, fresh air came in. That was good too. I do think it's good if you lie at the window. If you lie [at the corridor side], that's less good, I think." (participant 9)	"Yes, but unfortunately I'm lying here in the warmest corner. But if that person has it cold, I can hardly expect that person [to open the window and] to have it cold because I am here." (participant 12)
Competences	"Here is also a landing place for helicopters. But that hasn't happen often. That has happened twice now. [not very enthusiastic]" (participant 9)	"Actually, I've never seen a helicopter standing on the ground like this. An airplane yes, but a helicopter no. Only in the air. So I was really, I have to see that." (participant 10)
	Causes of (dis)comfort [%]	
Causes of thermal discomfort	Incoming sun (w.: 35 %, c.: 11 %)	My area is hotter or colder than other areas (w.: 0 %, c.: 7 %)
	Drafts from windows (w.: 17 %, c.: 7 %)	
Causes of visual discomfort	Too bright (w.: 4 %, c.: 0 %)	Reflections on screens, e.g. TV screen or computer screen (w.: 9 %, c.: 14 %)
	Too much daylight (w.: 4 %, c.: 0 %)	Not enough daylight (w.: 0 %, c.: 4 %)
Causes acoustic comfort	People talking in neighbouring rooms (w.: 18 %, c.: 6 %)	Control over television programs (w.: 29 %, c.: 38 %)
		Music (w.: 14 %, c.: 29 %)
Causes acoustic discomfort	Noise and crying, snoring or shouting of other patients (w.: 43 %, c.: 14 %)	
	Sound of devices (w.: 39 %, c.: 25 %)	
	People talking in neighbouring rooms (w.: 26 %, c.: 4 %)	
	People listening to my private conversations (w.: 26 %, c.: 18 %)	
	Sound from TVs (w.: 17 %, c.: 0 %)	

	Mechanical noise (e.g. heating, air conditioning and ventilation system) (w.: 13 %, c.: 0 %)		
Causes of discomfort with IAQ	Air is stuffy/stale (w.: 3 0%, c.: 21 %)		
	Air smells bad (odours) (w.: 30 %, c.: 14 %)		
	Air is not clean (w.: 26 %, c.: 14 %)		
	Food (w.: 22 %, c.: 4 %)		
	Cleaning products (w.: 13 %, c.: 4 %)		
Causes of discomfort related to the room's layout	High density: too little space between people (w.: 48 %, c.: 32 %)	My room is difficult to find for visitors (w.: 9 %, c.: 14 %)	
	Partitions between people do not provide enough visual privacy (w.: 43 %, c.: 21 %)		
	Conversations are discouraged because they interfere with other patients (w.: 17 %, c.: 7 %)		
	There are no areas to gather with other patients (w.: 13 %, c.: 4 %)		
	Perceived control [%]		
	Windows opened/closed (w.: 78 %, c.: 46 %)		
	Shading device - for thermal comfort (w.: 57 %, c.: 29 %)		
	Bedside lamp (w.: 57 %, c.: 42 %)		
	Shading device - for visual comfort (w.: 43 %, c.: 33 %)		
	Door to indoor area (w.: 30 %, c.: 21 %)		
	Door to outdoor area (w.: 27 %, c.: 21 %)		
	Thermostat (w.: 22 %, c.: 8 %)		
	Heating (w.: 22 %, c.: 4 %)		
ASSESSMENT	**Satisfaction votes [Q1/median/Q3 votes]**		**p-value**
Thermal comfort			
Temperature	0 2 3	-1 1 2	n.s.
Visual comfort			
Amount of light	0 2 3	0 2 3	n.s.

Visual comfort	0 1 2	0 2 2	n.s.
View out	-1 0 1	0 2 3	0.02
Acoustical comfort			
Degree of sound privacy	-1 0 2	-1 1 2	0.08
SENSOR MEASUREMENTS	**Threshold values [% of time]**		
Thermal comfort			
Indoor air temperature	22 °C <= T < 26 °C: 88 %	22 °C <= T < 26 °C: 87 %	
Visual comfort			
Illuminance level (6h-21h)	> 100 lx: 37 %	> 100 lx: 9 %	
View out	medium/minimum	minimum (horizontal sight < 28 °)	
	Measured values		
Acoustic comfort			
Average sound level for day/night	7.10/5.90	7.59/6.22	
Average of the q95 sound level per room	9.46	10.19	

4.1.4. Adaptation by choice to indoor conditions

Adapting by choice to indoor conditions seems to foster comfort. This shows, for instance, when certain IEQ factors take priority over others. Figure 2.7 shows for case 1 the distribution of indoor and outdoor air temperatures, and illuminance and global radiation levels during a heat wave and on other days during interviewees' hospital stay. Table 2.8 presents interview quotes, causes of (dis)comfort, perceived control, satisfaction votes and characteristics of the measured values. During the heat wave interviewees' and respondents' attention goes mainly to the heat and their main priority is keeping it outside (Table 2.8: experiences, causes of (dis)comfort, and perceived control). Although the actions they take reduce comfort with other IEQ factors, the number of complaints about these is limited, as shown in more detail below.

First, interviewees and respondents close the shading devices during the heat wave (Table 2.8: interview quotes and perceived control) and use more lighting, as indicated by the horizontal patterns in the illuminance levels and the higher illuminance levels with similar to lower global radiation outdoors (Figure 2.7). One would expect complaints about the visual comfort during the heat wave as daylight and a view out are appreciated by interviewees on other days. Discrepant with this expectation, respondents do not complain more about causes of visual discomfort (Table 2.8: causes of (dis)comfort). They are not significantly less satisfied with the amount of light, visual comfort or view out (Table 2.8: satisfaction votes). An interviewee explains that, although he prefers a view out and daylight on other days, he accepts their reduction as this is the result of his own choices (Table 2.8: interview quotes). Neither did he consciously notice that during the heat wave the lighting was on while before he complained about its intensity and atmosphere.

Second, interviewees and respondents perceive more control over the window and the room's door during the heat wave (Table 2.8: interview quotes and perceived control). An interviewee closes the window to keep the heat out and opens the door to have some air circulation. Keeping the window closed, he explains, involves accepting by choice that the indoor air cannot be refreshed with outdoor air, while keeping the door open involves accepting by choice the reduced privacy. Discrepant with possible complaints that thus can arise, during the heat wave respondents do not complain more about the amount of privacy, and they are not significantly less satisfied with the degree of sound privacy and privacy (Table 2.8: causes of (dis)comfort and satisfaction votes). They do complain more about causes of discomfort with the indoor air quality (IAQ), yet they are not significantly less satisfied with it (Table 2.8: causes of (dis)comfort and satisfaction votes).

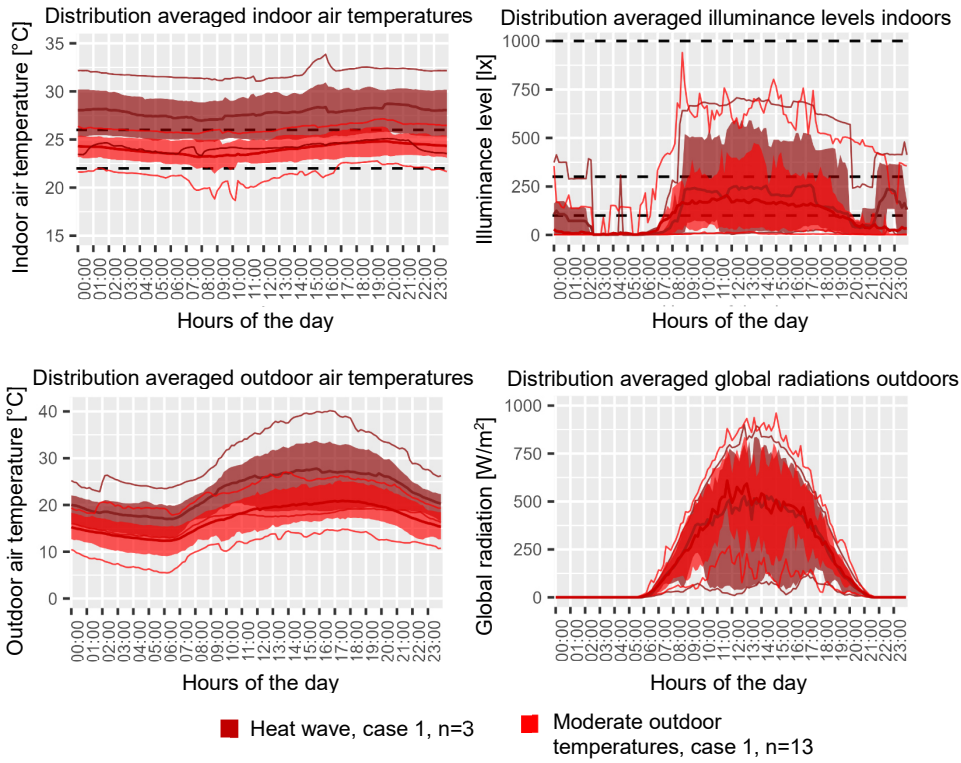


Figure 2.7 The (10 min average) mean, 1st quartile, 3rd quartile, 5th percentile and 95th percentile of the indoor air temperature (top left), and illuminance level at patients' bed (top right), and outdoor air temperatures (bottom left), and global radiation outdoors (bottom right) over the hours of the day during interviewees' hospital stay for those of case 1 who experienced the heat wave and the others. The window orientations are distributed as follows: 1x northeast, 2x east, 5x southeast, 2x southwest, and 3x west during moderate outdoor temperatures, and 2x northeast and 1x west during the heat wave. Horizontal dotted lines refer to threshold values of the Flemish Indoor Environment Decree (top left) and NBN EN 12464-1 (2003) (top right).

Table 2.8 Interview quotes, causes of (dis)comfort, perceived control, satisfaction votes and characteristics of the measured values of interviewees and respondents hospitalized in case 1 during the heat wave (h.) and during other days of the fieldwork (n.h.).

TYPE OF SPACE:	**Before and after heat wave, case 1 (n_i=13, n_s=67)**	**During heat wave, case 1 (n_i=3, n_s=17)**
EXPERIENCE	**Interview quotes**	
(Lack of) autonomy		"[The temperature], that's very bad eh. [...]" (participant 15)
Competences	"I really like the temperature. You can dress for it." (participant 4)	"[Closing the blinds] was for the warmth. For the light, that is less pleasant. [It was] more important to keep the heat out than to let the light in. [...] I mainly [put the artificial lighting on] when there is nursing, when doctors come in here and they need to see a little more, or to look to the wound. But otherwise I'll leave [the artificial lighting] out, because that's a bit too bright. [The sensor measurements showed that the artificial lighting was on during the heat wave] No, no, that was on all day actually. I shouldn't have done that, because it also gives heat." (participant 13)
	"To go [to the window], with that leg. [...] I've put [a blanket] on [my feet] now because I was kind of cold […]. Otherwise I have to put on socks. […] To reach my feet, that is not possible anymore" (participant 6)	"I knew it was going to get hot. If I'm prepared for that, then I can endure it." (participant 13)
	Causes of (dis)comfort [%]	
Causes of thermal discomfort	The clothing which I have to wear is not flexible (n.h.: 4 %, h.:0 %,)	The sun shining into the room (n.h.: 22 %, h.: 47 %)
	The thermostat is not accessible (n.h.: 4 %, h: 0 %)	There is too little air movement (n.h.: 4 %, h.: 35 %)
		Heat of devices in the room (n.h.: 3 %, h.: 12 %)

Causes of visual discomfort	Reflections on screens (n.h.: 9 %, h.: 0 %)		
Causes of discomfort with IAQ	Smells of urine or feces (n.h.: 16 %, h.: 6 %)	The air is stale (n.h.: 25 %, h.: 41 %)	
		The air is dry (n.h.: 30 %, h.: 41 %)	
		Bad smells (n.h.: 21 %, h.: 29 %)	
Causes of discomfort related to the room's layout	High density: too little space between people (n.h.: 33 %, h.: 24 %)		
	Partitions between people do not provide enough visual privacy (n.h.: 27 %, h.: 12 %)		
	Perceived control [%]		
	Windows opened/closed (n.h.: 68 %, h.: 53 %)	Desk fan (n.h.: 32 %, h.: 59 %)	
	Door to outdoor area opened/closed (n.h.: 23 %, h.: 6 %)	Shading device - for thermal comfort (n.h.: 47 %, h.: 59 %)	
	Thermostat (n.h.: 16 %, h.: 6 %)	Door to indoor area opened/closed (n.h.: 29 %, h.: 35 %)	
		Air conditioning (n.h.: 11 %, h.: 24 %)	

ASSESSMENT	**Satisfaction votes [Q1/median/Q3 votes]**		**p-value**
Thermal comfort			
Temperature	0 1 2	-2 -2 -1	<0.001
Visual comfort			
Amount of light	1 2 3	0 2 2	n.s.
Visual comfort	0 2 2	0 2 2	n.s.
View out	1 2 3	0 1 2	n.s.
Acoustical comfort			
Degree of tranquility	1 2 2	0 0 1	0.02
Degree of sound privacy	-1 1 2	0 1 2	n.s.
IAQ			
IAQ	1 2 2	0 1 2	n.s.
Room's layout			
Degree of privacy	0 1 2	0 2 2	n.s.

Way of social interactions	1 2 3	0 1 2	0.02
Overall comfort	1 2 2	0 1 2	0.07
SENSOR MEASUREMENTS	**Threshold values [% of time]**		
Thermal comfort			
Indoor air temperature	22 °C <= T <26 °C: 87 %	> 26 °C: 100 %	
Visual comfort			
Illuminance level (6h-21h)	> 100 lx: 32 %	> 100 lx: 35 %	
	Measured values		
Acoustic comfort			
Average sound level for day/night	7.26/6.20	7.56/6.09	
Average of the q95 sound level per room	9.36	10.05	

4.1.5. Imposed adaptation to indoor conditions

Sometimes adapting to indoor conditions is imposed. Patients' comfort seems to be supported when they tolerate the imposed adaptation. This shows itself during the heat wave. During the heat wave, the indoor air temperature exceeds the threshold values of the Flemish Indoor Environment Decree more (Figure 2.7). Congruently, interviewees and respondents refer more to causes of discomfort related to the heat and perceive control over adaptable building characteristics that allow reducing it (Table 2.8: interview quotes, causes of (dis)comfort, and perceived control). The actions they take do not allow creating thermal comfort. They are significantly less satisfied with the indoor temperature ($p < 0.001$) (Table 2.8: satisfaction votes). An interviewee explains, however, that he knew in advance a heat wave was coming, and that this helps him to cope with the heat (Table 2.8: interview quotes).

4.2. How patient room design affects patients' adaptation of and to indoor conditions

The experienced level of autonomy, competences, and relatedness influence to what extent participants perceive control and which adaptation strategies they apply. The indoor environment impacts the experienced level of autonomy, competences, and relatedness via its adaptable building characteristics and spatial layout. How patient room design affects patients' adaptation of and to indoor conditions through its impact on the experienced level of autonomy, competences and relatedness is explained in more detail below. Figure 2.4 presents these influences via the two red rectangles on the right side of the figure.

(1) Adapting indoor conditions is stimulated when the indoor environment supports autonomy and competences to do so.
(2) Adapting sensations and environmental information can occur independently from the indoor environment. However, it is stimulated when a feeling of autonomy over indoor conditions and of competences to adapt indoor conditions are lacking, or when relatedness takes priority over using this autonomy or these competences.
(3) Adapting one's position asks for competences to move.
(4) Adapting by choice to indoor conditions is stimulated when the indoor environment supports autonomy and competences to adapt indoor conditions, but also relatedness with others.
(5) Imposed adaptation to indoor conditions is needed when the indoor environment does not support a feeling of autonomy over indoor conditions and of competences to adapt indoor conditions and when sensations or the experienced environmental information cannot be adapted in another way.

4.2.1. Autonomy

The impact of the indoor environment on the degree of autonomy, and its influence on the degree of perceived control and the extent to which behavioural adaptation is exercised, shows when one compares findings in single and double rooms in cases 1 and 2. In this comparison it is the material environment that influences the experienced degree of autonomy, rather than the number of patients in the room. In double rooms, participants reside next to each other in case 1 and face-to-face in case 2 (Figure 2.3). Interviewees and respondents experience more autonomy in single rooms in cases 1 and 2 and double rooms in case 2 than at the window side of double rooms in case 1 (Table 2.6: interview quotes and causes of discomfort related to the room's layout). When they experience more autonomy, their perceived control – which, as indicated in the introduction, refers to their belief about the influence on an outcome by changing the state of adaptable building characteristics - seems higher as well as the extent to which this influence is exercised.

Differences in the experienced degree of autonomy do not only align with differences in the degree of perceived control and number of adaptations of indoor conditions, but also with differences in satisfaction when single and double rooms of both case studies are compared. For case 1 differences in perceived control (Table 2.6: perceived control) and adaptations of indoor conditions (Figure 2.5) have been discussed earlier. For case 2 differences between both room types are less outspoken. Here still more control is perceived in single rooms, but the difference between both types of rooms is smaller compared to case 1 (Table 2.6: perceived control). Indoor air temperatures and (95th percentile values of) the illuminance level are more similar between both types of rooms (Figure 2.5). Satisfaction with the visual comfort, tranquillity, and overall comfort differ significantly between single rooms and the window side of double rooms in case 1, and between the latter and double rooms in case 2, but not between single and double rooms in case 2 or between single rooms at both cases (Table 2.6: satisfaction votes).

These differences in perceived control, actions, and satisfaction can be explained by differences in the experienced degree of autonomy, rather than by differences in the number of patients in the room or differences in indoor conditions. If the number of patients in the room would have played the most important role, differences in perceived control and satisfaction would be found between single and double rooms for each of the case studies. Moreover, differences in indoor conditions do not provide an explanation for differences in perceived control and satisfaction either. The illuminance and sound levels differ more between the cases than between the two types of rooms per case (Figure 2.5). Taking into account the uneven distribution of window orientations of double rooms of case 1, we can assume that illuminance levels and the number of daylight hours are lower in case 2 due to seasonal differences. Sound levels

are lower in case 2 in both single and double rooms (Figure 2.5). This can be partly explained by the fewer activities in the wards in case 2 due to the COVID-19 pandemic.

Note that similar influences of the indoor environment on the experienced degree of autonomy and perceived control could be observed in other compared situations, but that this influence does not always results in differences in satisfaction. In double rooms in case 1, more autonomy and perceived control could also be noted at the window side than at the corridor side (Table 3.7: experiences and perceived control). Interviewees residing at the window side enjoy this control. However, in this case no differences in the number of experienced causes of visual and thermal discomfort and only a slightly higher satisfaction with the indoor temperature could be identified (Table 3.7: causes of discomfort and satisfaction votes).

4.2.2. Competences

The impact of the indoor environment on the experienced degree of competences, perceived control, and actions taken shows through situations in which participants are imposed to adapt to indoor conditions because competences are lacking. An interviewee in case 2 complains about looking straight at a slat of the sun shading while being unable to adapt position. Furthermore, patients' physical and cognitive competences influence the extent to which they can use adaptable building characteristics to adapt indoor conditions. An interviewee who is unable to leave his bed adapts himself to the lower amount of daylight when the shading devices are down although he prefers them to be open. Another interviewee does not understand how to turn the lighting off and thus leaves it on during the night, although he prefers darkness.

4.2.3. Relatedness

Even when having autonomy and competences to adapt indoor conditions, in some situations participants give priority to their experience of relatedness. As discussed for the adaptation of indoor conditions, fewer actions are taken in double compared to single rooms, especially in case 1. Table 2.6 shows that interviewees and respondents residing at (the window side of) double rooms are more aware of other people's presence in their room (Table 2.6: interview quotes and causes of (dis)comfort). When interviewees in double rooms perceive control over adaptable building characteristics, several of them hesitate to adapt indoor conditions and choose to adapt sensations or the experienced environmental information or adapt by choice to indoor conditions (Table 2.6: interview quotes). For instance, an interviewee of case 2 chooses to wear an eye mask as her roommate prefers to keep some light on during the night. Several interviewees in case 1 hesitate to ask nurses to close the door during the night

when they lack the competence to leave the bed. They do not want to disturb the nurses. Some find it more important to take others into account than to experience more comfortable indoor conditions.

5. Discussion

5.1. Linking adaptation strategies to psychologists' well-being perspectives

The adaptation strategies seem to impact comfort in two ways. These two ways can be linked to the distinction psychologists make between hedonic and eudaimonic well-being.

First, having the ability to influence the experience of indoor conditions through adaptation seems to support comfort. This influence can take place through behavioural or psychological adaptation. When patients have the possibility to adapt indoor conditions, sensations and the environmental information, or their position, they can influence their experience in a behavioural way; when they can adapt by choice or when they have the ability to adapt when it is imposed, they can influence their experience in a psychological way. Similarities are seen between this form of comfort and how eudaimonic well-being is defined (Figure 2.1: dark blue zone). When patients have the ability to influence their experience, they seem to function well. The strongest link can be found with how Ryff and Keyes (1995), and Ryff and Singer (2008) define 'environmental mastery'. Having the ability to influence the experience of indoor conditions can be considered as an ability to manage effectively one's life and the surrounding world. Adapting behaviourally or psychologically enables creating a surrounding context that suits one's personal needs and competences (Ryff & Singer, 2008). In the remainder of the Discussion section we will refer for this form of comfort to 'eudaimonic comfort'.

Second, the indoor conditions that are experienced as a result of the adaptation of indoor conditions, sensations and the environmental information, or position seem to support comfort as well. Similarities are seen between this form of comfort and how Diener (2009) understands hedonic well-being (Figure 2.1: light blue zone). The more pleasant experience of the indoor conditions that results from these forms of behavioural adaptation can be considered as a part of people's subjective belief about whether their life is desirable, pleasant, and good. In the remainder of the Discussion section we will refer for this form of comfort to 'hedonic comfort'.

This distinction suggests that eudaimonic comfort is supported when participants adapt indoor conditions, adapt sensations and the environmental information, adapt position, adapt by choice, or tolerate the imposed adaptation (Figure 2.4: adaptation strategies within the corresponding zone). The former three adaptation strategies seem to support hedonic comfort as well (Figure 2.4:

arrows pointing to the corresponding zone). Positive experiences of indoor conditions are obtained and negative ones avoided.

Furthermore, in the context of hospitalized patients' adaptation, 'competences' can be understood as patients' abilities to adapt; 'autonomy' to how autonomous a patient is in choosing the indoor environment of the patient room; and 'relatedness' to the interpersonal relationships with other people in the patient room. Similar as how actual control may differ from perceived control, patients' actual competences, autonomy and relatedness may differ from their experienced ones. As described in Section 4.2, the indoor environment influences the degree of competences, autonomy, and relatedness via its adaptable building characteristics and spatial layout. This may impact the experienced degree of competences, autonomy, and relatedness. This, on its turn, may impact the degree of perceived control. Links can be found between these observations and the self-determination theory of Ryan and Deci (2001). This theory posits that the basic needs for well-being are competences, autonomy, and relatedness. According to Ryan and Deci (2001), fulfilling the basic needs typically fosters both hedonic and eudaimonic well-being.

5.2. Limitations

The adopted methodology has shortcomings due to its explorative character. Part of the research was to investigate how RBE and MCP research can be integrated, both methodologically and substantively. Although this was demonstrated, limitations on resources and time need to be acknowledged.

Regarding data collection, the questionnaire's construct validity and reliability should be verified via further research. The questionnaire evolved during our study as our understanding of patients' comfort, perceived control and adaptation grew. Moreover, future research can include questions about hedonic and eudaimonic well-being in the questionnaire. This may enable to quantify how the different adaptation strategies contribute to well-being. Inspiration to do so can, for example, be found in Diener (2009, pp. 14-24) and Cooke et al. (2016). Note that these questionnaires do not focus on the built environment. The representativeness of the sample can also be improved as several patients with low cognitive competences or who did not feel well refused or were unable to participate in this research. Selecting those participants for (short) interviews or interviewing them together with an assistant (e.g. a nurse or guardian) can be a direction for the future. Next to improving the sampling procedure, the sample size should be increased in order to improve the generalizability for surgical wards. Patients at other wards and people in other contexts should also be included to investigate whether the presented adaptation model is transferable to other contexts, each with their own specificities, and whether additional adaptation strategies can be identified. We hypothesize that similar adaptation strategies will be found, but that the extent

to which each of the adaptation strategies is applied may differ. Furthermore, physiological adaptation (i.e. adaptation via the regulator subsystem (Whittemore & Roy, 2002)) could be taken into account simultaneously. Inspiration can be found in Goodhew et al. (2020). We can improve the mixed methods approach by selecting the interviewees from the respondents using purposive sampling. To do so, online questionnaires are likely to be more convenient as, due to patients' short length of stay, purposive sampling should occur immediately after the questionnaire has been filled in.

Regarding data analysis, groups were made based on one variable (e.g. single versus double rooms). An increased sample size would enable controlling for different variables simultaneously. We assumed that patients with different personal characteristics are randomly distributed across the compared groups. The season during which data were collected differs between both cases. Only single and double rooms were compared across both cases, and the difference in season was taken into account during interpretation. Comparing the two wards of case 2 suggests that differences in assessments, experiences, and indoor conditions between patients who undergo different types of surgery are limited.

5.3. Suggestions for future research

Some topics for future research can be suggested. First, future research is needed on whether a distinction can be made between hedonic and eudaimonic comfort, similar as the distinction that is made between hedonic and eudaimonic well-being.

Second, the theories related to hedonic and eudaimonic well-being focus on psychological well-being. However, in the context of the indoor environment, Gibson's (1968) theory about affordances and further elaborations of it by other authors (e.g. Baggs and Chemero, 2021) seem interesting to include in the theoretical framework in the future. These theories point to the interrelationship between an occupant and the occupant's environment. According to Gibson (1979, p. 127, 1968, p. 68), the fundamental constituents of the environment when studied from the point of view of 'behaving' people are 'affordances'. Affordances, in their original meaning, are the possible facilitations or hindrances provided by the substances, surfaces, objects and other living creatures surrounding people in the immediate context of their current activity (Gibson, 1979, p. 127, 1968, p. 68; Ingold, 2011a, pp. 77–78). Rietveld et al. (2018) defined it more recently as "*relations between (a) aspects of the sociomaterial environment in flux and (b) abilities available in a 'form of life'*". Affordances are properties of the environment taken with reference to a person, but not properties of the person's experience exclusive of the environment. Such interrelationships came up as well in this study. In this study it was for example observed that patients' competences influence whether they can make use of adaptable building characteristics to adapt indoor conditions. Conversely, it can

be stated that adaptable building characteristics should be aligned with the diverse competences of patients. The latter is what designers can take into account. Presumably, insights into affordances can therefore provide additional insights into how hospital room design can influence patients' comfort through its impact on their adaptation of, and to, indoor conditions via their perceived control.

Third, future research should investigate how designers can deal with the various competences of patients. Moreover, future research can try to understand in depth how patients' sense of autonomy and relatedness are influenced by the socio-material environment.

5.4. Implications for design practice

How can patient room design foster patients' comfort in relation to indoor conditions? In case future research confirms that a distinction can be made between hedonic and eudaimonic comfort, two perspectives can be distinguished from this research.

First, architects and engineers can foster patients' hedonic comfort by alleviating patients' discomfort and increasing pleasure. Understanding how architects and engineers can achieve this goal has traditionally been pursued separately by RBE and MCP research. A downside of this way of designing is that avoiding discomfort often results in neutral indoor conditions. Also, pleasure is reduced. Compared to case 2, we found more variation in experiences, causes of (dis)comfort, perceived control, satisfaction votes and measured values in case 1. This more outspoken variation is reflected in the findings discussed. In general, the lower variation in indoor conditions in case 2, which is influenced by both the indoor environment and the limited number of activities in the wards during the COVID-19 pandemic, has the advantage that participants perceive more control over sensations and the environmental information experienced, but it can result in boredom too. Other MCP researchers have voiced similar concerns (e.g. Candido & de Dear, 2012; de Dear, 2011; Rohde et al., 2020). They have argued that besides avoiding negative stimuli, one should provide positive stimuli. Theoretical frameworks and literature reviews by RBE researchers offer insights into how to do so (e.g. Andrade & Devlin, 2015; Huisman et al., 2012; Ulrich, 1991). For example, Beauchemin and Hays (1996, 1998) found that patients had shorter hospital stays when staying in sunny rooms compared with dimly lit rooms.

Another downside is that what causes discomfort or pleasure can differ between patients. If there were no difference, adaptation by choice would, for instance, be less present in double rooms. Several other authors found differences between people as to which indoor conditions they experienced as comfortable (e.g. Bae et al., 2020, 2021; Haddad et al., 2019; Teli et al., 2015). Designing indoor environments with indoor conditions that contribute to

hedonic comfort for all, might thus be impossible without providing adaptive opportunities, and thus without acknowledging that an approach that only aims to alleviate discomfort and increase pleasure via indoor conditions does not suffice.

Second, architects and engineers can foster eudaimonic comfort via design, with possibly a positive effect on hedonic comfort. From this perspective, the material environment can be designed as a means that patients can use to influence indoor conditions, and in this way, their own comfort; in addition to a provider of indoor conditions that contribute to hedonic comfort. More variable indoor conditions can be combined with adaptive opportunities. The latter should be selected consciously. Perceived control needs to be restricted when indoor conditions can harm patients (e.g. their health), while support is needed for environmental mastery, one of the six dimensions of eudaimonic well-being (Ryff & Singer, 2008). To enable such mastery, the indoor environment has to fulfill via its adaptable building characteristics and spatial layout basic needs to foster eudaimonic well-being indicated by the self-determination theory: autonomy and competences (Ryan & Deci, 2001). Taking this perspective allows paying attention to our observations and those from existing fieldwork in offices, schools, and dwellings (e.g. Brackley et al., 2021; Xu & Li, 2021; Yun, 2018) that perceived control influences comfort with indoor conditions positively.

Furthermore, this second perspective enables attending to differences in settings and people. The self-determination theory states that, when basic needs are fulfilled, people can choose how they influence their well-being (Ryan & Deci, 2001). Patients are given an active role in influencing the indoor conditions within the possibilities offered to them. They can choose which of the feasible indoor conditions align best with the true self. These can be those which foster hedonic comfort, but not necessarily. Fulfilling the basic needs allows in this way accommodating differences in contextual, cultural and developmental factors, e.g. in the context we studied differences in outdoor conditions, self-rated well-being, length of stay, or personal preferences.

While the second perspective seems promising, how to translate it into practice requires further research. The following two questions may help to guide future research, design practice, and hospital management.

Question 1: how to support autonomy? Differences found in the experienced level of autonomy between single and double rooms in case 1, for instance, align with observations that people of single offices perceive more control and/or adapt indoor conditions more than those in shared office spaces (Haldi & Robinson's, 2010; Marín-Restrepo et al., 2020a, 2020b; Schweiker & Wagner, 2016). Differences in the experienced level of autonomy between the window and corridor side of double rooms align with observations in shared office spaces that the distance between an employee and adaptable building characteristics affects perceived control (Marín-Restrepo et al., 2020a). Future research should try to better understand patterns in the relation between

(adaptable) building characteristics and autonomy. Hospital management needs to consider how much autonomy patients should be given.

Question 2: how to support competences? The findings indicate that adaptable building characteristics should be aligned with patients' physical and cognitive competences. Differences between patients may exist in terms of both. The current MCP approach has been criticized for designing for the 'average' person (Bluyssen, 2020). In line with this critique, we advocate for designing for those with the most limited competences, without reducing the comfort of others. Hospital policy can consider this as an important value. Future research should investigate similarities and differences in perceived control over indoor conditions when competences vary as well as why these similarities and differences are shown. This will provide insight into who has the least competences in certain situations, and when possible conflicts arise in the competences of different patients.

6. Conclusion

Combining two mixed methods case studies in hospital wards in a multiphase design provided insight into how patient room design may influence patients' comfort through its impact on their adaptation of and to indoor conditions via perceived control.

Well-being was linked to comfort and health, and well-being theories were linked to the state-of-the-art in RBE and MCP research. By empirical work, an adaptation model was set up. The model clarifies the relationships between the indoor environment, perceived control, adaptation strategies, and indoor environmental comfort and well-being that were identified based on an integrated analysis. Subsequently, the model was relinked to well-being theories.

Focusing on the indoor environment's role in perceived control and adaptation enabled characterizing known adaptation strategies in more detail. Strategies with perceived control were identified as adaptation (1) of indoor conditions, (2) of sensations or the environmental information, (3) of position, and (4) by choice to indoor conditions; and without perceived control: (5) imposed adaptation to indoor conditions. Via its adaptable building characteristics and spatial layout, the indoor environment affects which adaptation strategy is or has to be adopted. Both affect patients' autonomy over the experienced indoor conditions, competences to adapt and relatedness with others with whom the indoor conditions are shared.

Both having the ability to influence the experience of indoor conditions through adaptation and the more preferable indoor conditions that can be obtained through adaptation seem to support comfort. Links could therefore be identified between how the adaptation strategies impact comfort and the distinction psychologists make between hedonic and eudaimonic well-being.

The behavioural adaptation of the first three adaptation strategies, described above, seems to contribute to both hedonic and eudaimonic well-being. The psychological adaptation of the fourth adaptation strategy seems to contribute to eudaimonic well-being. For the latter strategy, patients seem to experience eudaimonic well-being only if they are able to adapt psychologically themselves. Moreover, the way the indoor environment affects adaptation corresponds with the basic needs for well-being according to the self-determination theory. Further research into the links between comfort and hedonic and eudaimonic well-being are needed.

To support patients' comfort, designers can pay attention to how they can increase patients' autonomy and competences to adapt indoor conditions or position. Our observations suggest that the indoor environment should be designed as a means that patients can use to influence indoor conditions, next to an environment that aims to provide comfortable indoor conditions.

Chapter 3: **Discrepancies Between Predicted and Experienced Indoor Environmental (Dis)comfort: the Role of Hospitalized Patients' Adaptation Strategies**

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Abstract

Hospitals' indoor conditions affect patients' comfort. Comfort is predicted based on threshold values for indoor environmental quality (IEQ) parameters, but discrepancies with experienced (dis)comfort occur. Current prediction methods ignore the role of patients' adaptation or treat it as a 'black box'. Therefore, we investigated how distinguishing between adaptation strategies may help explain discrepancies. We combined sensor measurements of IEQ parameters (sound, light, temperature) at two hospital wards with a questionnaire among 238 patients. After grouping respondents according to their adaptation strategy, we investigated whether tendencies could be observed in how the adaptation strategy adopted, respondents' experiences of indoor conditions and measured values of IEQ parameters relate to each other. Experiences seem to differ when respondents' adaptation strategy differs. There is an indication that satisfaction votes are higher when sensation votes are more neutral or more as preferred. This seems to occur when respondents adapt behaviourally (i.e. adapt indoor conditions) or do not wish to adapt indoor conditions (e.g. adapt sensations), rather than when they adapt psychologically (i.e. by choice or imposed). Adaptation strategies influence measured values differently, but this cannot explain differences in experiences. Adaptation strategies therefore seem to influence experiences in a psychological way, which current methods cannot predict. Attending to how adaptation influences experiences of indoor conditions and how this differs between adaptation strategies, may thus contribute to reducing discrepancies.

PA.1



1. Introduction

The quality of the indoor environment is known to affect patients' comfort, well-being and even healing (e.g. Nimlyat & Kandar, 2015; Ulrich, 1984). Indoor environmental quality (IEQ) parameters inform about this quality. These parameters relate to indoor conditions and can be expressed in terms of values (e.g. temperature, illuminance and sound level), building characteristics (e.g. orientation of windows, spatial layout or the possibility for the growth of fungi) or characteristics of people (e.g. heat, tiredness or infection incidence related to the physical environment) (Bluyssen, 2010; Eijkelenboom & Bluyssen, 2019). Eijkelenboom and Bluyssen (2019) present the state-of-the-art of how indoor conditions and building characteristics affect patients.

Research with the objective to set up models for comfort predictions (MCP) aims to understand what comfortable and healthy environments are. Relationships between values of IEQ parameters and people's assessment are sought for different IEQ factors (i.e. constructs such as thermal comfort that can be assessed by people or estimated based on one or more IEQ parameters) (Bluyssen, 2010). To guarantee that a minimum number of people feel comfortable and the environment is healthy, threshold values have been developed for values of IEQ parameters corresponding to each IEQ factor.

When these threshold values are used to predict (dis)comfort, discrepancies occur with experienced (dis)comfort (Burge, 2004; de Dear & Brager, 1998; Nenonen et al., 2013; Nicol & Humphreys, 2002). Discrepancies are observed, for example in research about hospitalized patients' comfort that uses on-site sensor measurements and questionnaires. Lo Verso et al. (2016) and Verheyen et al. (2011) observed a higher satisfaction than expected based on threshold values with, respectively, the illuminance levels and the thermal environment. Hwang et al. (2007) observed that the predicted mean vote (PMV) model, which is developed based on the thermal comfort experience of healthy, young adults, overestimated patients' sensitivity to variations in the thermal environment. Hwang et al. (2007) and Verheyen et al. (2011) argued that patients are less sensitive to indoor conditions than the healthy population. Although Verheyen et al. (2011) themselves do not establish the link, the discrepancy observed in their study might also be explained by behavioural adaptation. A high percentage of patients indicated in the questionnaire that they did not need help from nursing staff to adapt clothing, bedding or the thermal environment by adjusting for example windows, heating and cooling; nobody indicated being unable to adapt sensations or indoor conditions. Lo Verso et al. (2016) observed on the other hand that patients' main complaints related to a lack of perceived control, namely inadequate or lacking control systems to manage shading systems and the lighting. Bliefnick et al. (2019) focused on identifying IEQ parameters linked to patients' experience of hospitals' acoustic environment. They observed that the A-weighted equivalent continuous sound

level (LAeq) showed some association with subjective experiences of quietness, but insufficient to be statistically correlated. They attributed the absence of a statistically significant correlation partly to behavioural adaptation as well. In the best-rated ward, measurements predicted a lower acoustic comfort due to in-room patient noise at night. Bliefnick et al. (2019) indicate that auditory stimuli were possibly used as an aid to sleep. On the other hand, they observed that the quietest ward in terms of LAeq was rated as average, likely due to significant low-frequency noise measured in the unit. We assume that the low-frequency noise (e.g. caused by ventilators, air-conditioning or traffic) might have been out of patients' control.

A common explanation for discrepancies is that current models to predict (dis)comfort fail to accurately account for (1) the positive influence of perceived control and adaptation on how indoor conditions are experienced and (2) the negative influence of their absence (e.g. Boerstra et al., 2013; de Dear & Brager, 1998, 2002; Leaman & Bordass, 1999; Nicol & Humphreys, 2002; Yun, 2018). Adaptation refers to people's reaction to restore their comfort when a change occurs that causes discomfort (Nicol & Humphreys, 2002). Perceived control is defined by psychologists as one's beliefs about the influence on an outcome via changing the world or oneself to fit in with the world (Bryant, 1989; Chipperfield et al., 2012). It has a positive effect on the experience of indoor conditions as it allows for adaptation. The indicated influences of adaptation and perceived control on how indoor conditions are experienced also seem to explain discrepancies in the studies in hospitals described above.

Current methods to predict (dis)comfort either do not include the influence of adaptation on how indoor conditions are experienced or treat adaptation as a 'black box'. Examples of the former are threshold values for Fanger's PMV (International Organization for Standardization (ISO), 2005; Bureau for Standardisation, 2005), the illuminance level (Bureau for Standardisation, 2003), the LAeq (Berglund et al., 1999) or the CO_2-level (Bureau for Standardisation, 2010; Bureau for Standardisation, 2005). Examples of the latter are threshold values of the adaptive thermal comfort model (Boerstra et al., 2015; De Dear et al., 2020). We hypothesize that not distinguishing between adaptation strategies in (dis)comfort predictions can be a reason for discrepancies.

Moreover, little is known about different ways in which people adapt, and whether and how they influence the experience of indoor conditions differently. Based on the literature, de Dear and Brager (1998) distinguished between behavioural, physiological and psychological adaptation. Based on two mixed methods case studies with hospitalized patients, five adaptation strategies were identified among participants showing a wish for adaptation, as described in Chapter 2. Four strategies were identified among participants who perceived control to align indoor conditions with their preferences: (1) behaviourally adapting indoor conditions, (2) behaviourally adapting sensations or the

experienced environmental information (i.e. changing sensations without changing indoor conditions, e.g. by adapting clothing), (3) behaviourally adapting position (i.e. moving to more comfortable indoor conditions) and (4) psychologically adapting by choice to indoor conditions (i.e. altering the meaning and attention given to indoor conditions despite the perceived possibility to adapt them); and one among participants who perceived no control to bring indoor conditions in line with their preferences: (5) imposed psychologically adapting to indoor conditions (i.e. being imposed to adapt the meaning and attention given to the indoor conditions, as no control is perceived to bring the indoor conditions in line with their preference).

In view of these observations, this chapter aims to improve the understanding of why discrepancies occur. It builds upon existing research in order to understand the influence of adaptation and perceived control on how indoor conditions are experienced (e.g. Humphreys et al., 2013; Marín-Restrepo et al., 2020a; Marín-Restrepo et al., 2020b; Schweiker & Wagner, 2016). More specifically, it aims to contribute to filling the knowledge gap about whether and how different adaptation strategies influence the experience of indoor conditions differently. It centres around the following research question: how does distinguishing between hospitalized patients' adaptation strategies inform about reasons for discrepancies between predicted and experienced indoor environmental (dis)comfort? The reasons for discrepancies we identify and the ways in which we explore them are expected to fuel future research. In addition, this chapter informs about how patients' comfort can be fostered by supporting adaptation strategies that contribute to a more positive experience of indoor conditions.

The remainder of this chapter is structured as follows. Section 2 describes the methodology. Section 3 reports the results. It focusses on whether tendencies could be noted between the adaptation strategy adopted and experiences of indoor conditions, the adaptation strategy adopted and measured values of IEQ parameters, and measured values of IEQ parameters and experiences of indoor conditions. In Section 4 the main observations, implications of the observations, suggestions for future research and limitations are discussed. Section 5 contains the conclusions of this chapter.

2. Methodology

2.1. Overview

To gain insight into whether and how different adaptation strategies influence the experience of indoor conditions differently, and how this informs about reasons for discrepancies when existing methods to predict (dis)comfort are applied, we conducted a case study at two hospital wards. Figure 3.1 gives an overview of the data collection and analysis. Inspired by the studies in hospitals

referred to in the introduction, we collected data through a questionnaire and on-site sensor measurements of IEQ parameters. The research was approved by the Social and Society Ethics Committee of KU Leuven (G-2018 08 1304). Data analysis consisted out of three steps. (1) Per respondent we linked the measured value of IEQ parameters, their sensation, preference and satisfaction votes, perceived control and the state of adaptable building characteristics. (2) We grouped respondents per adaptation strategy. (3) We analysed whether tendencies could be identified in how the adaptation strategy adopted, the experience of indoor conditions, and measured values of IEQ parameters relate to each other. Below we provide a more detailed description of the case, data collected and the way in which the data were analysed.

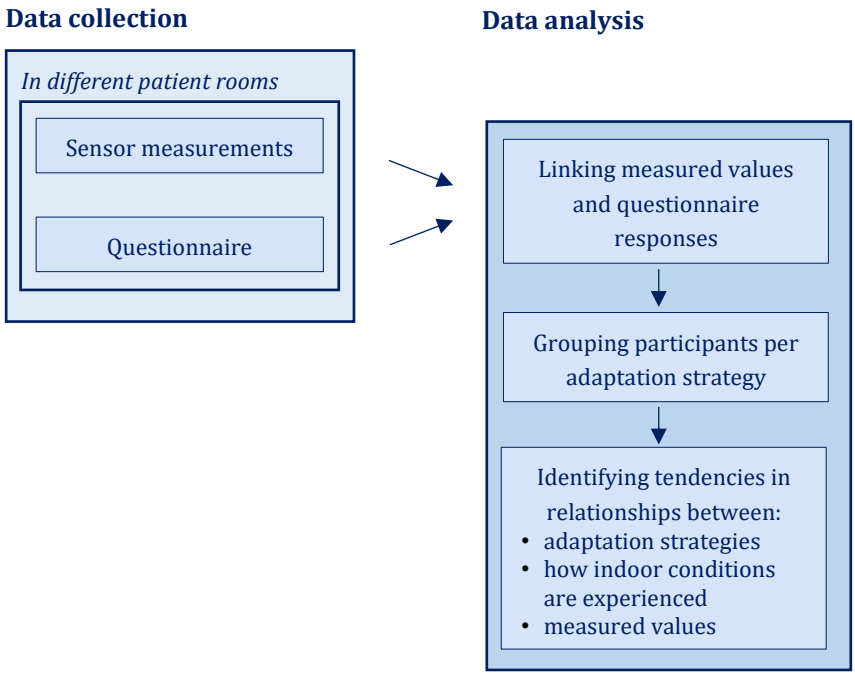


Figure 3.1 Visualization of the methodology.

2.2. The case

The hospital building is located in Belgium and was put into use in 2018. Together with hospital management and staff, we chose two surgical wards as surgical patients stay for several days and were expected to be able to participate. Figure 3.2 presents a floor plan of the wards and a picture of a patient room. Patient rooms were partly conditioned: they were equipped with mechanical ventilation (100 m^3/h per patient in the room, supply temperature at 21°C and top-cooling in summer), operable windows which are locked and a fixed external louvre system for shading. Patients could also adapt indoor

conditions in various ways: through radiators with a thermostat knob; window curtains; the room's door; a curtain between the patient beds in double rooms and Light-emitting diode (LED) lighting (consisting of a main (dimmable) lighting above the patient bed and a small light behind it in all rooms, plus an additional atmospheric light in single rooms and an additional main light in double rooms, all with a light switch).

Data were collected in autumn and winter, more specifically from September 29 to October 30, 2020 and from December 8, 2020 to January 8, 2021. The end date was determined by the weather. At the beginning of January, there were still a few cold days. Warmer weather was forecast for the following days. For days with moderate outdoor temperatures, saturation in data collection was reached (i.e. new data repeat what was expressed in previous data (Saunders et al., 2018)).



Figure 3.2 Floor plan of the wards and a picture of a patient with in the background a VersaSense Wireless Device and a HOBO (white arrows). The 'x' on the floor plan indicates rooms where HOBO's and VersaSense sensors were located; 'h' indicates those with only HOBO's. (Plan: based on the plan of VK Architects & Engineers).

2.3. Data collection

2.3.1. Questionnaire

The questionnaire was inspired by the questionnaire of the Center for the Built Environment (American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), 2010; Hyojin, 2012; Peretti & Schiavon, 2011), adapted to hospitals based on insights from evidence-based design research in this setting (e.g. Huisman et al., 2012; Ulrich et al., 2008) and turned into a right now

questionnaire inspired by NBN EN ISO 28802 (2012). In this research, we focused on the questions asked about sensations, preferences and satisfaction with IEQ factors, perceived control, the state of adaptable building characteristics and patients' activity and clothing. Note that questions about sensations addressed how one feels (e.g. hot); those about preferences how one wishes the indoor conditions to be (e.g. warmer) and those about satisfaction how satisfied one is with these conditions (e.g. very satisfied). These questions probe into different things. If respondents rate a sensation for example 'slightly warm', this does not indicate whether or not they wish it was warmer or how satisfied they are (Bureau for Standardisation, 2012). Moreover, we focused on questions related to thermal, visual and acoustic comfort. Very few odour problems were reported, and patients had little control over the indoor air quality (IAQ) (i.e. locked windows and mechanical ventilation). Table 3.1 provides more detailed information about the questionnaire. The full questionnaires can be found in the Appendix (Appendix B).

As respondents, we selected a simple random sample of the patients admitted to the wards during the fieldwork. During two days a week, the first author asked all patients in the wards to participate. In total 238 provided informed consent and responded. Table 3.2 contains more information about the sampled respondents.

2.3.2. On-site measurements

Values of IEQ parameters were measured in patient rooms. The IEQ parameters measured were chosen based on NBN EN 15251 (Bureau for Standardisation, 2005) and ASHRAE's Performance Measurement Protocols (ASHRAE, 2010; Hyojin, 2012). Measurement locations were chosen so as to obtain an even spread across single and double rooms at each of the window orientations. Table 3.3 provides more information about the sensor measurements. Sensors' location and position are also indicated in Figure 3.2.

2.4. Data analysis

2.4.1. Linking measured values of IEQ parameters, sensation, preference and satisfaction votes, perceived control and the state of adaptable building characteristics

To start with, we linked the measured values of IEQ parameters in respondents' room to their sensation, preference and satisfaction votes, the control they perceived over adaptable building characteristics and the state of these characteristics at the moment they completed the questionnaire.

We established the links for those respondents who had responded to all questions analysed. If illuminance or sound levels were not measured in their room, we estimated the values of these IEQ parameters. In case the respondent

Table 3.1 Overview of the type of questions, questions asked, response scales and percentages of missing values per question of the questionnaire.

Component	Type of question	Question	Response scale	% missing values
IEQ factors				
Thermal comfort	Perceived control[1]	Which of the building features below can you adjust in the room yourself? (Please indicate all aspects that apply.)	Multiple choice: window blinds or shades; operable window; thermostat; portable heater; permanent heater; air conditioning in the room; portable fan; adjustable air vent in wall, ceiling or floor; door to interior space; none of the above; other:…	12 %
	State of adaptable building characteristics[2]	What is the state of the building features below right now?	Multiple choice: permanent heater on/off/NA; air conditioning in the room: on/off/NA; portable heater: on/off/NA; door to corridor: open/closed/NA; thermostat: self-adjusted/not self-adjusted	17 %
	Sensation	On the scale below, circle the number that represents how you feel right now?	Likert scale: 1-7 (very cold - very warm) [3]	3 %
	Preference	How would you prefer the thermal environment right now?	Likert scale: 1-7 (much colder - much warmer)	5 %

[1] To reduce response burden, perceived control over the room's door and whether it was open or closed was not questioned again for acoustic comfort.
[2] To reduce response burden, whether the window blinds or shades were open or closed was only questioned for visual comfort.
[3] Likert scales from 1-7 were used since people tend to indicate positive values more quickly than negative values. During data analysis, the values were transformed to the commonly used values ranging from -3 to +3.

	Satisfaction	How satisfied are you with the thermal environment right now?	Likert scale: 1-7 (very dissatisfied - very satisfied)	3 %
	Activity	Please indicate below what you are doing as an activity right now.	Multiple choice: lying down; sitting; reading or writing; typing; watching television; other:...	3 %
	Clothing	Please indicate below which clothing you are wearing right now.	Multiple choice: shorts and short sleeve t-shirt; shorts and long sleeve t-shirt; long pants and short sleeve t-shirt; long pants and long sleeve t-shirt; long pants and sweater; nightgown up to the knee with short sleeves; nightgown up to the knee with long sleeves; nightgown up to the ankles with short sleeves; nightgown up to the ankles with long sleeves; skirt up to the knee with short sleeves; skirt up to the knee with long sleeves; skirt up to the ankles with short sleeves; skirt up to the ankles with long sleeves; other:...	4 %
		Please indicate below with what your body is additionally covered right now.	Multiple choice: sheet, only on feet; sheet, half body covered; sheet, full body covered; blanket, only on feet; blanket, half body covered; blanket, full body covered; nothing	16 %

Visual comfort	Perceived control	Which of the following control options do you have over the lighting in your room? (Please indicate all aspects that apply.)	Multiple choice: light switch, light dimmer, window curtains, curtain around patient bed, window blinds or shades, none of the above, other:…	6 %
	State of adaptable building characteristics	What is the state of the building features below right now?	Multiple choice: main lighting on/off; bedside lamp on/off; window blinds or shades open/closed; window curtains open/closed; curtain around patient bed open/closed/NA; other:…	11 %
	Sensation	How bright do you find your environment right now?	Likert scale: 1-7 (very dark - very light)	6 %
	Preference	How would you prefer your visual environment right now?	Likert scale: 1-7 (much darker - much lighter)	11 %
	Satisfaction	How satisfied are you with the visual environment (i.e. amount of light, glare, reflections, contrast) right now?	Likert scale: 1-7 (very dissatisfied - very satisfied)	5 %
Acoustic comfort	Sensation	How do you find the sound level of your environment right now?	Likert scale: 1-7 (very quiet - very loud)	7 %
	Preference	How would you prefer the sound right now?	Likert scale: 1-7 (much quieter - much louder)	6 %
	Satisfaction	How satisfied are you with the sounds in your room right now?	Likert scale: 1-7 (very dissatisfied - very satisfied)	6 %

Table 3.2 Overview of the dates the questionnaire was distributed, the percentage of the respondents answering all questions, and their personal and room characteristics. (northeast (NE); southeast (SE); southwest (SW); northwest (NW)).

Dates of participation	September: 29; October: 2, 6, 9, 13, 16, 20, 23, 27, 30; December: 8, 9, 11, 15, 18, 30; January: 2, 5, 8
Number of respondents answering all questions of the questionnaire (excl. multiple choice questions)	50 % (56 % excl. question about date of leave)
Number of respondents answering all questions of the questionnaire focused upon in this article (excl. multiple choice questions)	82 %
Birth sex: % woman	59 %
Age [years]: mean, sd	52.58; 22.76
Nationality: % Belgian	97 %
Days in hospital at moment of the questionnaire [days]: mean, sd	3.83; 3.17
Self-rated well-being: % >= neutral	74 %
Number of previous hospitalizations: mean, sd	5.25; 4.70
Type of room: % single room	59 %
Window orientation	NE: 34 %; SE: 22 %; SW:32 %; NW: 12 %
Zone of ward	Quiet: 62 %; Neutral: 38 %

indicated that the window curtains were open and the lighting off, we took as representative values illuminance levels measured in rooms in the same ward, with the same window orientation, and of the same room type (single versus double). For a sample, it was checked that the window curtains were indeed open and the lighting off in the representative room. In case respondents indicated that the lighting was on or the window curtains closed, a room with illuminance levels that could represent this situation was searched manually. As representative values for the sound levels, we took those measured in rooms of the same type and with a similar relation to other rooms in the ward.

To link questionnaire responses with measured values of IEQ parameters, we used mean values of the indoor air temperatures and illuminance levels measured in respondents' rooms during the hour before they started completing the questionnaire; and the background sound level measured during the 24 hours before the start. In the analysis, we chose to use as representative value the background sound level for the following reasons. The only adaptable building characteristic we considered as allowing patients to adapt the sound level in their room is the room's door. Opening and closing the door, we assumed, impacts mainly on the background sound level. Peaks in the sound level were, on the other hand, largely the result of own activities in the room. The 1st quartile of the measurements in percentages showed to be representative for the background sound level.

Table 3.3 Overview of characteristics of the sensor measurements. (Not applicable (NA)).

Sensor	IEQ parameter(s) [measurement unit]	accuracy/sensitivity	calibration year	sampling rate [min.]	Location	Position in room
HOBO prov2	Air temperature [°C]	± 0.21	2019	10	All rooms	1.50m from floor level, behind patient
VersaSense Edge Gateways	NA	NA	NA	NA	Two staff rooms	on desk
VersaSense Wireless Devices	Ambient illuminance level [lx]	± 0.01	2021	1	Per ward: 9 patient rooms	1.50m from floor level, behind patient (light sensor pointed to ceiling)
	Sound level [%, with 0%=40dB and 100%=80dB]	Noise detection level: approx. equivalent to a finger-click at 1 meter	2021	1	9 patient rooms, period at ward 1: 29/09 to 20/10 & 15/12 to 08/01, ward 2: 20/10 to 15/12	1.50m from floor level, behind patient
Gossen Mavolux 5032B illuminance measurer	Illuminance level [lx]	0.01lx	2006	NA (only used for calibrating the VersaSense sensors)	NA	NA

2.4.2. Grouping respondents per adaptation strategy

In a second step, respondents were grouped according to the adaptation strategy they apply. The grouping was based on respondents' questionnaire responses about their preferences, perceived control and the state of adaptable building characteristics. A detailed overview of how respondents were grouped is given in Table 3.4. The grouping built on the adaptation strategies identified in Chapter 2 and mentioned in the introduction but differs slightly from it. We focused only on adaptation strategies that differ in how patients interact with indoor conditions via adaptable building characteristics. Therefore, we grouped respondents who have no wish for adaptation with those who adopt adaptation strategies that lead to indoor conditions they prefer and that do not involve adaptations of indoor conditions (i.e. adaptation of sensations and environmental information or of position), and refer to them as respondents who have 'no wish to adapt indoor conditions'. Next to this, within the group of respondents who are imposed to adapt to indoor conditions, we distinguished those who are imposed to adapt after having already taken action from those who did not take action. The former include, for example, respondents whose lighting is on and window curtains are open, who still prefer more light and who do not perceive a possibility to further increase it; the latter include respondents who prefer more light but do not perceive control over available adaptable building characteristics to increase it. Measured values of IEQ parameters were expected to differ in both situations.

When grouping respondents, we had to make some assumptions. First, respondents sometimes perceived control over adaptable building characteristics they actually did not have control over. For example, some patients perceived control over the window while these were locked. Although the control is actually lacking, it might be perceived and this perception can influence how indoor conditions are experienced. In grouping respondents, we therefore included patients who perceived control over adaptable building characteristics and those who perceived control over building characteristics that were not adaptable but who indicated a plausible state of the building characteristic. Patients who perceived control over building characteristics that were not adaptable and who indicated an impossible state of the building characteristic were excluded. For example, windows are locked so perceived control over the window and a closed window was possible, while perceived control over the window and an open window was not.

Second, overlaps occurred between the group of respondents who took action to increase an IEQ factor and those who took action to decrease it. We assumed that for each IEQ factor, respondents could apply only one adaptation strategy at the moment they completed the questionnaire. It seemed most plausible that a respondent who adjusted the thermostat turned the heating on, and to assign respondents who used the heating while their door was open or

Table 3.4 Overview of how respondents were grouped per adaptation strategy based on their questionnaire responses, the number of respondents per adaptation strategy and the number of respondents removed from a group due to overlaps with another group.

IEQ factor	Adaptation strategy	Preference	Groups within adaptation strategy	Perceived control	State of adaptable building characteristic	Number of participants	Number of removed participants due to overlaps
Satisfaction thermal comfort	**Adaptation of indoor conditions**	According to preference	Actions to increase	Thermostat	Thermostat: adjusted	54	NA
				Permanent heater	Permanent heater: on		
				Permanent heater	Thermostat: adjusted		
				Thermostat	Permanent heater: on		
				Door to interior space	Door to interior space: closed		
			Actions to decrease	Air conditioning in the room	Air conditioning in the room: on	22	-15 (overlap with actions to increase)
				Door to interior space	Door to interior space: open		
	No wish to adapt indoor conditions	According to preference		NOT (perceived control over the thermostat AND thermostat: adjusted) AND NOT (perceived control over the permanent heater AND permanent heater: on) AND NOT (perceived control over the permanent heater AND thermostat: adjusted) AND NOT (perceived control over the thermostat AND permanent heater: on) AND NOT (door to interior space) AND NOT (perceived control over the air conditioning in the room AND air conditioning in the room: on)		43	NA

	Adaptation by choice to indoor conditions	Prefer more		Thermostat OR permanent heater	Thermostat: not adjusted AND permanent heater: not on	27	NA
				Door to interior space	Door to interior space: open		
		Prefer less		Air conditioning in the room	Air conditioning in the room: off	2	NA
				Portable fan	Portable fan: off		
				Operable window			
				Window blinds or shades	Window blinds or shades: open		
				Door to interior space	Door to interior space: closed		
	Imposed adaptation to indoor conditions	Prefer more	With action	Thermostat OR permanent heater OR door to interior space	Thermostat: adjusted AND door to interior space: closed; OR permanent heater: on AND door to interior space: closed	12	NA
			Without action	NOT (thermostat) AND NOT (permanent heater)		14	NA

				AND NOT (door to interior space)			
		Prefer less	With action	Air conditioning in the room OR door to interior space	Air conditioning in the room: on AND door to interior space: open AND permanent heater: off	1	NA
				Door to interior space	Door to interior space: open AND permanent heater: off		NA
			Without action	NOT (air conditioning in the room), AND NOT (door to interior space)		1	NA
Satisfaction visual comfort	**Adaptation of indoor conditions**	According to preference	Actions to increase	Light switch OR light dimmer	Main lighting: on OR bedside lamp: on	112	NA
				Window curtains	Window curtains: open		
			Actions to decrease	Window curtains	Window curtains: closed	2	-4 (overlaps with actions to increase)
	No wish to adapt indoor conditions	According to preference		NOT ((light switch OR light dimmer) AND main lighting: on) AND NOT ((light switch OR light dimmer) AND bedside lamp: on) AND NOT (window curtains)		14	NA
	Adaptation by choice to	Prefer more		Light switch OR light dimmer	Main lighting: off AND bedside lamp: off	30	NA

	indoor conditions			Window curtains	Window curtains: closed		
		Prefer less		Light switch OR light dimmer	Main lighting: on OR bedside lamp: on	4	NA
				Window curtains	Window curtains: open		
				Window blinds or shades	Window blinds or shades: open		
	Imposed adaptation to indoor conditions	Prefer more	With action	Light switch OR light dimmer OR window curtains	Main lighting: on AND window curtains: open; OR bedside lamp: on AND window curtains: open	16	NA
			Without action	NOT (light switch) AND NOT (light dimmer) AND NOT (window curtains)		10	NA
		Prefer less	With action	Window curtains	Main lighting: off AND bedside lamp: off AND window curtains: closed	0	NA
			Without action	NOT (light switch) AND NOT (light dimmer) AND NOT (window curtains)		0	NA
Satisfaction acoustic comfort	**Adaptation of indoor conditions**	According to preference	Actions to increase	Door to interior space	Door to interior space: open	42	NA
			Actions to decrease	Door to interior space	Door to interior space: closed	24	NA

	No wish to adapt indoor conditions	According to preference		NOT (door to interior space)		65	NA
	Adaptation by choice to indoor conditions	Prefer more		Door to interior space	Door to interior space: closed	0	NA
		Prefer less		Door to interior space	Door to interior space: open	13	NA
	Imposed adaptation to indoor conditions	Prefer more	With action	Door to interior space	Door to interior space: open	1	NA
			Without action	NOT (door to interior space)		3	NA
		Prefer less	With action	Door to interior space	Door to interior space: closed	10	NA
			Without action	NOT (door to interior space)		19	NA

lighting while the window curtain was closed to the group of respondents who took action to increase the warmth or amount of light. As patients did not have control over an air-conditioning or the ventilation system, a respondent who had a closed door and indicated that the air-conditioning was on, was included in the group of respondents who took action to increase the warmth.[4] The overlaps were excluded manually. The number of respondents who were removed from a group is mentioned in Table 3.4.

2.4.3. Identifying tendencies in how the adaptation strategy adopted, the experience of indoor conditions, and measured values of IEQ parameters relate to each other

In a third step, we analysed per IEQ factor whether tendencies could be noted in how the adaptation strategy that respondents adopt relates to how indoor conditions are experienced, how the adaptation strategy that respondents adopt relates to measured values of IEQ parameters, and how measured values of IEQ parameters relate to how indoor conditions are experienced. These tendencies were investigated in three ways. These three ways are explained in more detail below.

First, the tendencies were analysed for individual respondents by visually representing respondents' votes and values of IEQ parameters measured in their room, and by interpreting this representation. Figure 3.3 (see Results) was set up to this end. This figure shows per adaptation strategy and per IEQ factor the relationship between (a) the measured value of the IEQ parameter in respondents' room (x-axis) and (b) their satisfaction with the IEQ factor (y-axis) in combination with (c) a visual representation of their sensation and preference votes.

We made each row of Figure 3.3 correspond to an adaptation strategy: adapting indoor conditions (row 1), no wish to adapt them (row 2), adapting by choice to them (row 3) and imposed adaptation to them (row 4 and 5), with a distinction between imposed adaptation after action to adapt them (row 4) and without action (row 5). We made each column of Figure 3.3 correspond to an IEQ factor: thermal comfort (column A), visual comfort (column B) and acoustic comfort (column C).

For each graph in Figure 3.3, the big dots, rectangles and triangles refer to respondents applying the corresponding adaptation strategy for a certain IEQ factor. The small dots refer to the respondents who apply another adaptation strategy for that factor. By showing all respondents together, we seek to facilitate the comparison between strategies.

[4] Some respondents were interviewed, but results of the interviews are not focused on in this chapter. However, note that several interviewees refer to the ventilation system as 'air conditioner', so they seem to assume that the ventilation system cools the air of the room.

We also aimed to represent sensation and preference votes, as well as how respondents adapted indoor conditions in order to align them with their preferences, simultaneously with the measured values (x-axis) and satisfaction votes (y-axis). Sensation votes are represented by the colour of the big dots, squares and triangles. Whether preference votes are 'as preferred' or not is indicated by the points' shape. Rectangles and dots refer to IEQ factors that are as preferred, with the squares' rotation representing the direction of the action that led to the IEQ factor becoming as preferred. A rhombus refers to actions that change the value of an IEQ parameter in order that sensations become warmer, lighter or louder, and a square to those actions that let sensations become colder, darker or quieter. Triangles refer to IEQ factors that are not as preferred, with triangles pointing up when respondents prefer warmer, lighter or louder indoor conditions, and down when they prefer colder, darker or quieter ones. The extent to which indoor conditions deviate from respondents' preferences is shown by the triangles' size.

To allow comparing experienced and predicted (dis)comfort, threshold values of existing prediction methods were presented through dotted lines. These threshold values are also summarized in Table 3.5.

Second, as the number of respondents per adaptation strategy is limited, we checked visually whether adaptation strategies differ in terms of how measured values and (sensation, preference and satisfaction) votes are distributed (i.e. mean, 1st and 3rd quartile, 5th and 95th percentile). To this end Figure 3.4 (see Results) was set up and interpreted. Figure 3.4 presents the distribution of measured values and (sensation and satisfaction) votes per adaptation strategy and per IEQ factor.

Third, we analysed whether strategies differ significantly in terms of their distribution of measured values, and sensation and satisfaction votes. Neither measured values nor votes are normally distributed. Therefore, we performed Kruskal–Wallis tests ($\alpha = 0.1$) as well as pairwise Mann–Whitney U tests with Benjamini and Hochberg's (1995) adjustment method as post hoc pairwise test. We took the significance level alpha (α) equal to 0.1 as the number of respondents per adaptation strategy is limited (Table 3.4).

Table 3.5 Threshold values.

Indoor air temperature (Flemish Indoor Environment Decree (Lazarov and Stranger 2017))	
Cold half of the year	20 °C <= T < 24 °C
Illuminance level (NBN EN 12464-1(2002))[5]	
General lighting	100 lx
Reading lighting	300 lx
Simple examination	300 lx
Examination and treatment	1000 lx

3. Results

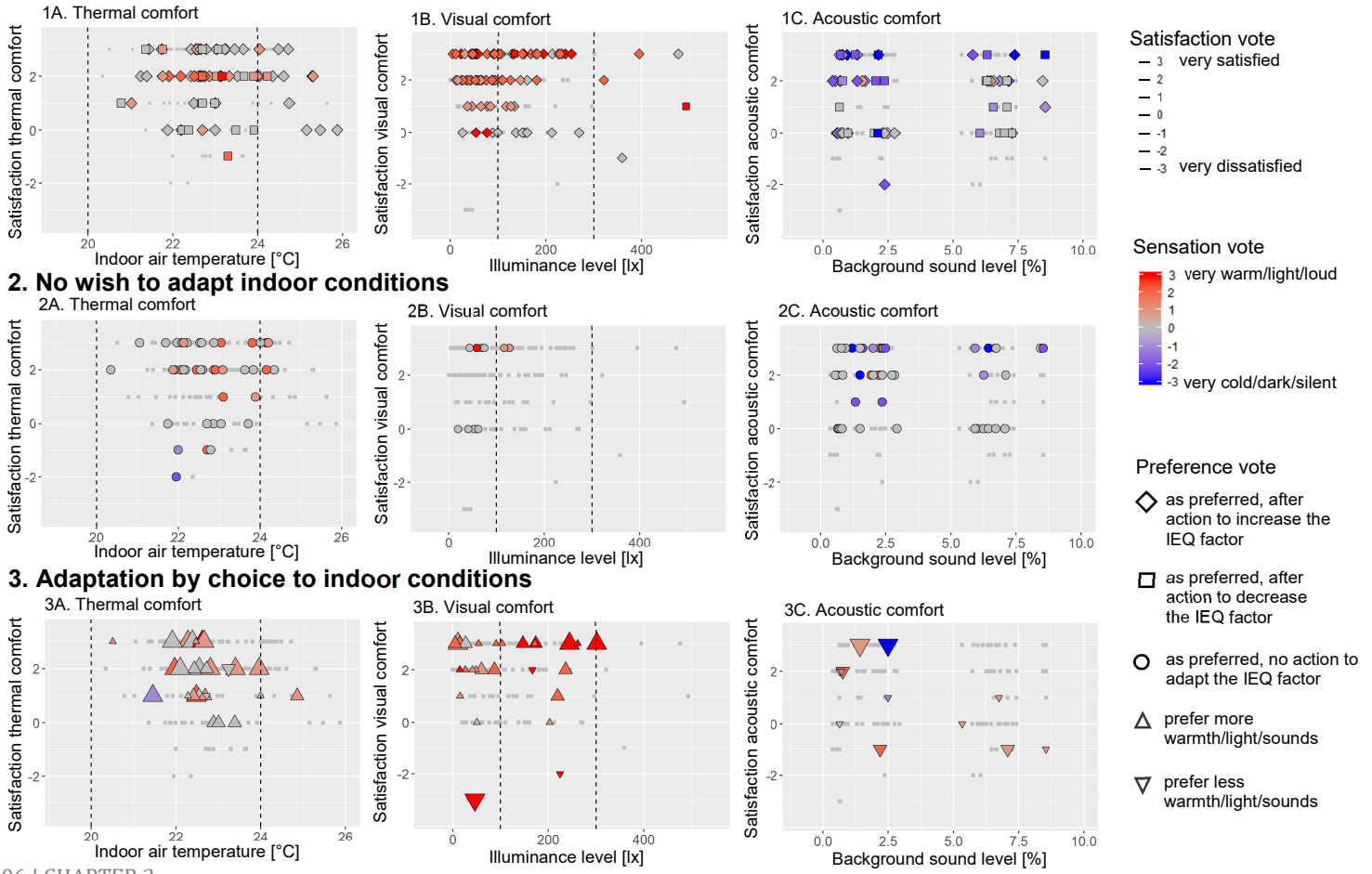
This section describes the observed tendencies in how the adaptation strategy adopted relates to how indoor conditions are experienced, how the adaptation strategy adopted relates to measured values of IEQ parameters, and how measured values of IEQ parameters relate to experiences of indoor conditions. This provides initial indications about whether different adaptation strategies influence experiences of indoor conditions differently.

3.1. Adaptation strategies and experiences of indoor conditions

To start with, a tendency can be noted in how the adaptation strategy adopted relates to how indoor conditions are experienced.

Figure 3.3 gives a slight indication that dissatisfaction, i.e. a satisfaction vote lower than neutral, is more common for visual and acoustic comfort when respondents choose or are imposed to adapt to indoor conditions (Figure 3.3, 3B, 3C, 4B, 4C, 5B, 5C) compared to when they adapt indoor conditions or have no wish to adapt them (Figure 3.3, 1B, 1C, 2B, 2C). More specifically, within this limited group of respondents who choose or are imposed to adapt and are dissatisfied, dissatisfaction is most often observed in situations when the visual or acoustic sensation vote contrasts with the preference vote (e.g. a sensation of very light and a preference for much darker) (Figure 3.3, 3B, 3C, 4B, 4C, 5C). The highest dissatisfaction occurs most often for the largest differences between sensation and preference votes (Figure 3.3, 3B, 4B, 4C). When respondents are imposed to adapt without taking an action, dissatisfaction occurs also when the sensation vote aligns with the preference vote (e.g. a sensation of slightly light and a preference for more light in Figure 3.3, 5B) (Figure 3.3, 5B, 5C). For thermal comfort, a similar tendency can be noted (Figure 3.3, 5A). However, with respect to thermal comfort, several respondents are dissatisfied as well when having no wish to adapt indoor conditions (Figure 3.3, 2A). Within this group of

[5] Threshold values apply for the illuminance level at floor level. Aiming to understand patients' experience of indoor conditions, we measured illuminance levels at patients' eye height. We assumed that the same threshold values were applicable.


1. Adaptation of indoor conditions
1A. Thermal comfort
Satisfaction thermal comfort
Indoor air temperature [°C]
1B. Visual comfort
Satisfaction visual comfort
Illuminance level [lx]
1C. Acoustic comfort
Satisfaction acoustic comfort
Background sound level [%]
2. No wish to adapt indoor conditions
2A. Thermal comfort
2B. Visual comfort
2C. Acoustic comfort
3. Adaptation by choice to indoor conditions
3A. Thermal comfort
3B. Visual comfort
3C. Acoustic comfort
Satisfaction vote
3 very satisfied
2
1
0
-1
-2
-3 very dissatisfied
Sensation vote
3 very warm/light/loud
2
1
0
-1
-2
-3 very cold/dark/silent
Preference vote
as preferred, after action to increase the IEQ factor
as preferred, after action to decrease the IEQ factor
as preferred, no action to adapt the IEQ factor
prefer more warmth/light/sounds
prefer less warmth/light/sounds

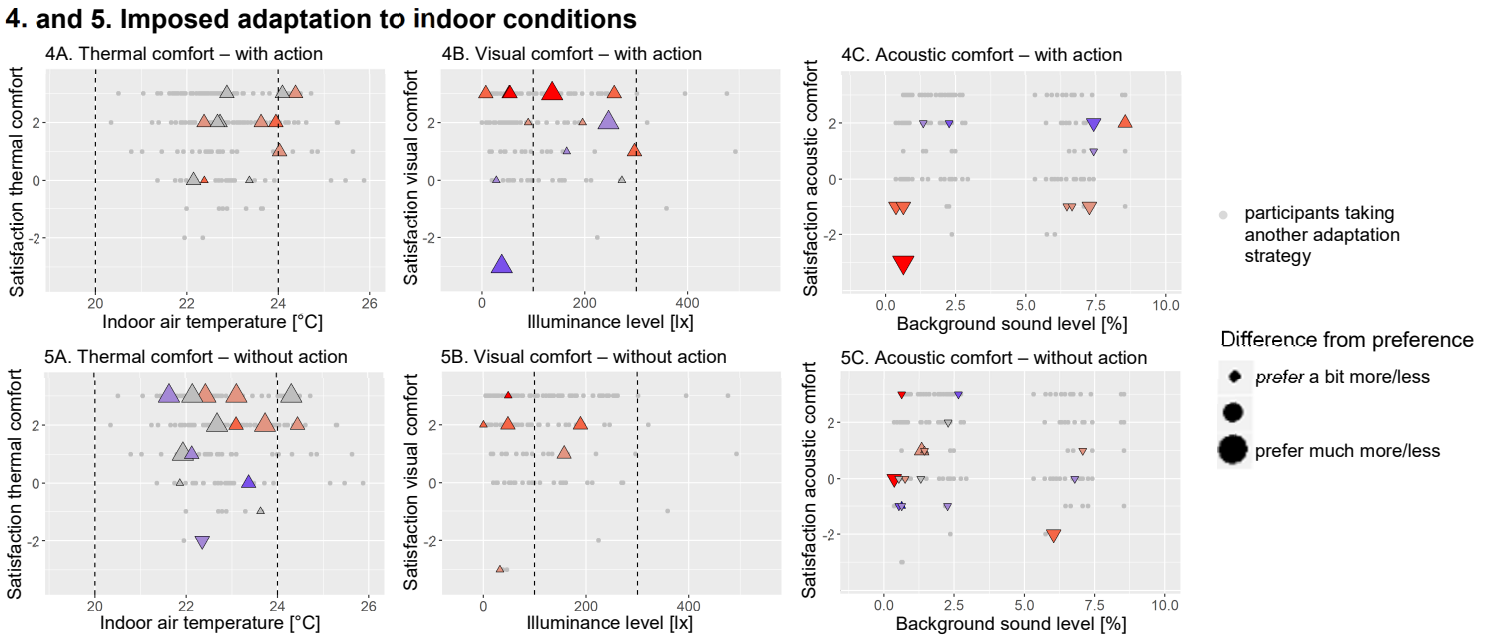
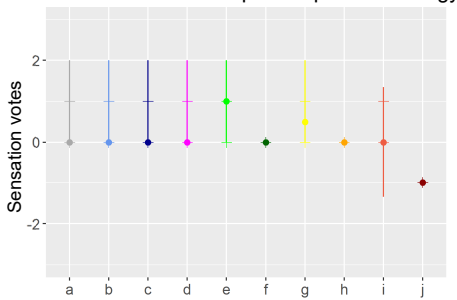


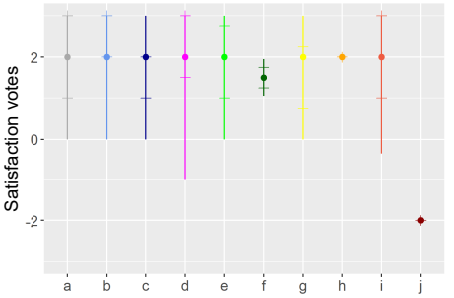
Figure 3.3 Satisfaction with the thermal (A), visual (B) and acoustic comfort (C) in relation to the measured value of a corresponding IEQ parameter for different adaptation strategies: adaptation of indoor conditions (first row), no wish to adapt indoor conditions (second row), adaptation by choice to indoor conditions (third row) and imposed adaptation to indoor conditions (fourth and fifth row). For each graph, the big points refer to respondents adopting the corresponding adaptation strategy; the small light grey ones to the respondents adopting other ones. Sensation votes are represented by the big points' colour; preference votes and, when relevant, how this preference is obtained or the extent to which sensations differ from the preferred ones by the points' shape and size. Dotted lines refer to the threshold values summarized in Table 3.5.

1. Thermal comfort

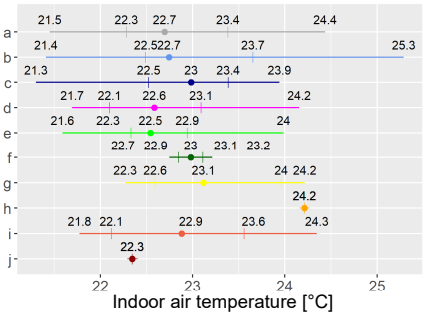
1A. Sensation votes per adaptation strategy



1B. Satisfaction votes per adaptation strategy



1C. Measured values per adaptation strategy



Sensation vote

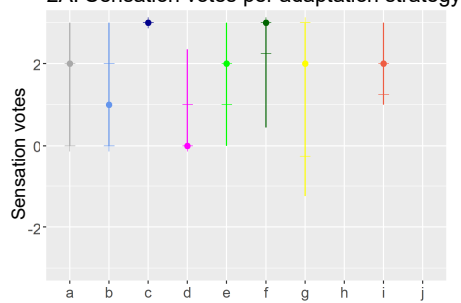
- 3 very warm/light/loud
- 2
- 1
- 0
- -1
- -2
- -3 very cold/dark/silent

Satisfaction vote

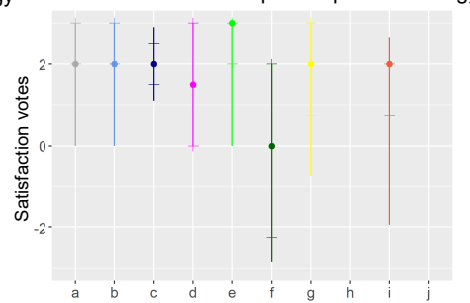
- 3 very satisfied
- 2
- 1
- 0
- -1
- -2
- -3 very dissatisfied

2. Visual comfort

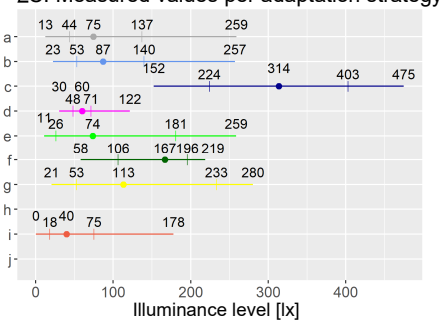
2A. Sensation votes per adaptation strategy



2B. Satisfaction votes per adaptation strategy



2C. Measured values per adaptation strategy



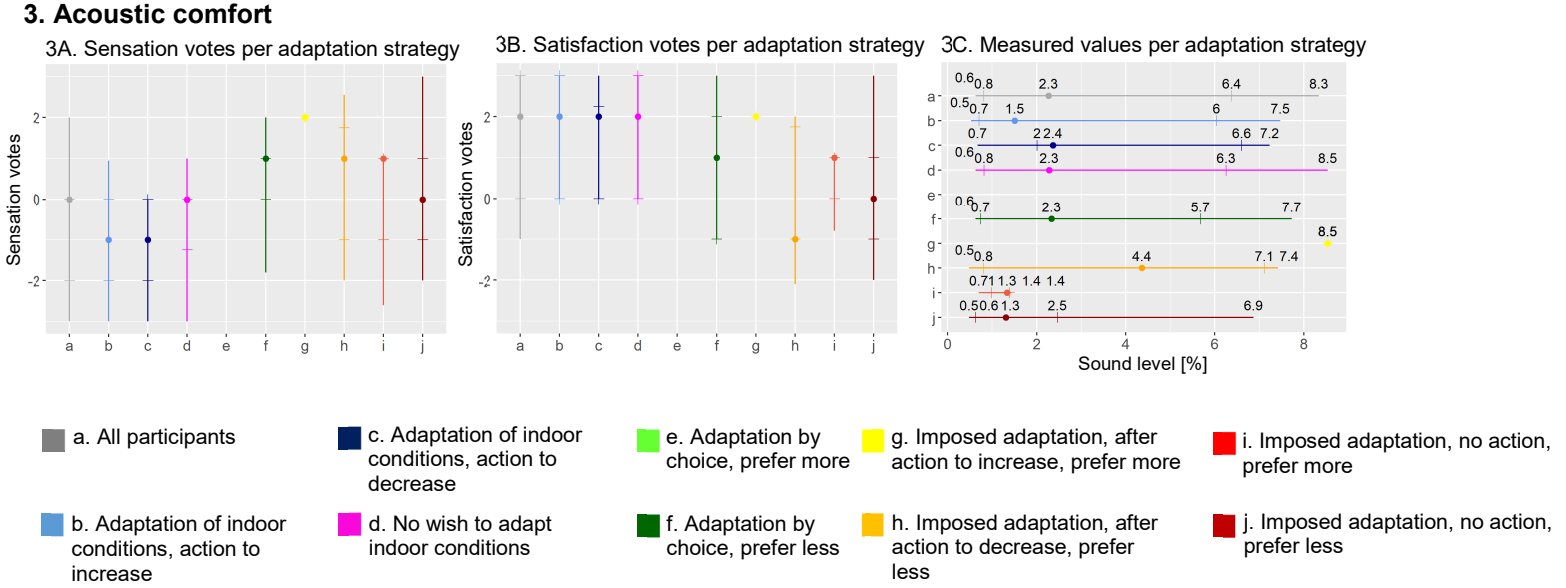


Figure 3.4 The distribution (mean, 1st and 3rd quartile, 5th and 95th percentile) of sensation votes (left), satisfaction votes (middle) and measured values (right) per adaptation strategy and separately for the thermal (top), visual (middle) and acoustic comfort (bottom).

dissatisfied, sensation votes vary (Figure 3.3, 2A). The reason for dissatisfaction and differences in sensations cannot be explained by differences in respondents' activity, clothing or use of the bedding, and does not seem to relate to whether or not they have the possibility to adapt clothing.[6]

Figure 3.4[7] suggests that the tendency that was observed for visual and acoustic comfort applies not only for the extent to which dissatisfaction occurs but also for the distribution of the votes in general. Satisfaction votes are generally more distributed towards being satisfied (i.e. higher than neutral) when sensation votes are distributed more towards neutral (i.e. equal to zero) or the preference. This occurs more when respondents adapt indoor conditions or have no wish to adapt them. For these respondents, thermal and visual sensation votes are often more distributed towards neutral, and acoustic sensation votes more towards quiet sensations (i.e. lower) than for those choosing or being imposed to adapt (Figure 3.4, 1A: b, c, d; 2A: b, d and 3A: b, c, d). For the former two groups of respondents satisfaction votes are shifted towards high satisfaction (Figure 3.4, 1B, 2B, 3B: b, c, d).[8] On the other hand, sensation votes are generally more distributed towards a sensation of warm, light or loud (i.e. above neutral), for those who choose or are imposed to adapt to indoor conditions (Figure 3.4, 1A: e, g, i,; 2A: e, f, g, i; and 3A: f, h, i, j). When these respondents also prefer it to be warmer, lighter or colder, satisfaction votes are distributed more in the direction of being satisfied (i.e. higher than neutral) (Figure 3.4, 1B: e, g, i; 2B: e, g i; and 3B: i). An opposite trend can be noted for those who prefer colder, darker or quieter (Figure 3.4, 1B: f; 2B: f; and 3B: f, h, i).

Table 3.6 lists the adaptation strategies for which these differences in sensation and satisfaction votes are significant. The upper part shows that the mean ranks of acoustic sensation and satisfaction votes differ significantly ($p < 0.001$). Pairwise comparison between adaptation strategies reveals that the mean ranks of sensation votes often differ significantly between respondents who adapt indoor conditions with an action to increase or decrease the sound level or have no wish to adapt it, and those who choose (Table 3.6: $p = 0.008$,

[6] The respondent with the warmest sensation vote wears the fewest clothes and uses the bedding the least; for the one with the coldest sensation vote, the opposite holds. One of the sitting respondents has it warm, one slightly cold; one of the lying respondents finds the thermal environment neutral, one has it cold. Differences in activity or clothing thus do not help explain the observed differences in satisfaction and sensation votes. Two of the respondents are wearing a nightgown up to the knee with short sleeves – possibly an operation shirt – while the other two certainly chose their clothes themselves. A lack of perceived control over the clothing therefore does not help explain the dissatisfaction either.

[7] Adaptation strategies to which only 1 respondent belongs were not included in the analysis (Figure 3.4, 1A, B, C: h, j; and 3A, B, C: g).

[8] As mentioned before, some respondents were interviewed, but results of the interviews are not focused on in this chapter. However, note that most interviewees seem to prefer quietness in their room. Moreover, little questionnaire respondents prefer louder indoor conditions. Therefore, acoustic sensation votes that are distributed towards a sensation of quiet can be considered as a situation in which sensations differ in the direction of the overall preference.

0.008 and 0.008) or are imposed to adapt after (Table 3.6: p = 0.008, 0.008 and 0.02) or without action (Table 3.6: p = 0.08 and 0.06). Pairwise comparison shows also that the mean ranks of satisfaction votes differ significantly between those who adapt indoor conditions with an action to increase or decrease the sound level or have no wish to adapt it, and those who are imposed to adapt after (p = 0.003, 0.01 and 0.002) or without action (p = 0.01, 0.02 and 0.01). The lower part of Table 3.6 shows that the mean ranks of visual sensation votes differ significantly between adaptation strategies (p = 0.07). Pairwise comparison between the strategies shows significant differences between respondents having no wish to adapt the amount of light and those who are imposed to adapt without action while preferring more light (p = 0.08).

Table 3.6 IEQ factors for which sensation and satisfaction votes differ significantly between the adaptation strategies when compared together and in pairs (α = 0.1). The table displays the obtained p-values. (not significant (n.s.)).

Acoustic comfort				
Sensation votes		*<0.001*		
Satisfaction votes		*<0.001*		
Pairwise comparison:				
Sensation votes		**Adaptation of indoor conditions** According to preference, after action to increase	**Adaptation of indoor conditions** According to preference, after action to decrease	**No wish to adapt indoor conditions** According to preference
Adaptation by choice	Prefer less	*0.008*	*0.008*	*0.008*
Imposed adaptation	Prefer less, after action to decrease	*0.008*	*0.008*	*0.02*
Imposed adaptation	Prefer less, no action	*0.08*	*0.06*	*n.s.*
satisfaction votes				
Imposed adaptation	Prefer less, after action to decrease	*0.003*	*0.01*	*0.002*
Imposed adaptation	Prefer less, no action	*0.01*	*0.02*	*0.01*
Visual comfort				
Sensation votes		*0.07*		
Pairwise comparison:				
Sensation votes				**No wish to adapt indoor conditions** According to preference
Imposed adaptation	Prefer more, no action to increase			*0.08*

3.2. Adaptation strategies and measured values of IEQ parameters

In addition to the tendency that seems to be present in how the adaptation strategy respondents adopt relates to how they experience indoor conditions, two opposite tendencies can be noticed between how the adaptation strategy adopted and measured values of IEQ parameters relate to each other.

On the one hand, adaptations of indoor conditions result sometimes in high or low values of IEQ parameters. In these situations, the adaptations of indoor conditions are reflected in measured values. Figure 3.3 shows that the percentage of rooms with indoor air temperatures higher than 24 °C and illuminance levels higher than 100 lx is higher when respondents increase the indoor temperature or the amount of light (Figure 3.3: 1A: 22 %; 4A: 25 %; 1B: 34 %; 4B: 44 %) than when they have no wish for adaptation or prefer more warmth or light but adapt without taking action (Figure 3.3: 2A: 12 %; 3A: 4 %; 5A: 14 %; 2B: 14 %; 3B: 33 %; 5B: 20 %). The differences between adaptation strategies in the actions that are taken are sometimes also reflected in differences in the distribution of measured values. This is most apparent for thermal comfort. Figure 3.4 indicates that indoor air temperatures are higher in rooms where respondents adapt indoor conditions with an action that increases the temperature (Figure 3.4, 1C: 3rd quartile and 95th percentile values of b, g), that these temperatures are sometimes more moderate where no action is taken (Figure 3.4, 1C: 1st quartile of d, e and i, and mean of d, e), and that the lowest ones occur where action is taken to decrease them (Figure 3.4, 1C: 5th percentile value of c).

On the other hand, actions seem to be taken in order to bring high or low values of IEQ parameters to a more 'moderate' state, and adaptation strategies that involve psychological adaptation seem to be adopted to deal with situations in which IEQ parameters have a rather high or low value. In these situations, actions taken to adapt indoor conditions are not reflected in (the distribution of) measured values. Figure 3.3 indicates that sound levels are similar in rooms of respondents who take actions that decrease the sound level (Figure 3.3: 1C: minimum of 0.6 %; 4C: minimum of 0.4 %) compared to those where respondents have no wish to adapt them, or prefer a lower sound level and adapt by choice or imposed to it without an action (Figure 3.3: 2C: minimum of 0.56 %; 3C: minimum of 0.6 %; 5C: minimum of 0.4 %). The same holds for rooms of respondents who take actions that increase the sound level (Figure 3.3: 1C: maximum 8.5 %; 4C: maximum 8.5 %) and rooms of those who do not wish to adapt or who prefer a higher sound level but adapt by choice or imposed to it (Figure 3.3: 2C: maximum 8.5 %; 5C: maximum of 1.4 %). At the same time, the distributions of illuminance and background sound levels presented in Figure 3.4 indicate that actions that increase these levels or adaptation strategies with preferences for more warmth, light or sounds are adopted more when they are lower. Moreover, actions to reduce them or adaptation strategies with

preferences for less warmth, light or sounds seem to be adopted more when they are higher (Figure 3.4, 2C and 3C: b compared to c; 1C and 2C: e compared to f; and 3C: i compared to j).

Only for visual comfort the mean ranks of the measured values differ significantly ($p = 0.08$). However, we could not identify any pairs of adaptation strategies for which a significant difference occurs.

3.3. Measured values of IEQ parameters and experiences of indoor conditions

Across adaptation strategies, no tendency could be identified based on our data in how measured values of IEQ parameters relate to differences in how indoor conditions are experienced.

First, the individual data points do not show a clear relationship between measured values, and sensation and satisfaction votes. For thermal comfort, indoor air temperatures not complying with threshold values are experienced as satisfactory (Figure 3.3, 1A: 24.0–25.9 °C). Those experienced as dissatisfactory can be found within threshold values (Figure 3.3, 1A: 23.3 °C; 2A: 21.9– 22.8 °C and 5A: 22.3 °C, 23.6 °C). These temperatures are experienced as warm, neutral and cold. For visual and acoustic comfort, measured values for which dissatisfaction occurs vary (Figure 3.3, 1B: 359 lx; 3B: 46 lx, 224 lx; 4B: 38 lx; 5B: 32 lx and 1C: 2.4 %; 3C: 2.2 %, 7.1 %, 8.5 %; 4C: 0.4–7.3 % and 5C: 0.5–6.0 %). Some of these values are below the minimum threshold value of 100 lx, others higher. The illuminance levels are experienced as light, neutral and dark, sound levels as both quiet and loud.

Second, Figure 3.4 suggests that differences in the distribution of measured values between adaptation strategies do not align with differences in the distribution of sensation and satisfaction votes. For thermal comfort, mean values of the indoor air temperature are for example higher, while mean sensation votes are more neutral and 1st quartile values of satisfaction votes higher when respondents take action to increase the indoor air temperature than when they adapt by choice and prefer a higher indoor air temperature (Figure 3.4, 1A, 1B and 1C: b versus e). Similar situations can be observed for visual (Figure 3.4, 2A, 2B and 2C: b versus e, and e versus f) and acoustic comfort (Figure 3.4, 3A, 3B and 3C: d versus f).

4. Discussion

4.1. Main observations

This chapter explored how distinguishing between patients' adaptation strategies may explain discrepancies between experienced (dis)comfort and (dis)comfort as predicted based on existing methods. A possible reason for

discrepancies is that indoor conditions seem to be experienced differently when patients adapt behaviourally or have no wish to adapt indoor conditions compared to when they adapt psychologically. This observation provides a possible explanation for discrepancies between hospitalized patients' predicted and experienced (dis)comfort as observed in MCP research that uses on-site measurements and questionnaires.

First, as a reason for discrepancies, MCP researchers refer to the positive influence of perceived control on how indoor conditions are experienced as it enables adaptation (e.g. Boerstra et al., 2013; de Dear & Brager, 1998; Nicol & Humphreys, 2002; Yun, 2018). Its positive influence allows explaining discrepancies between predicted and experienced (dis)comfort in Verheyen et al.'s (2011) and Bliefnick et al.'s (2019) research. A lack of perceived control also seems to influence experiences in a negative way and provides a possible reason for discrepancies in Lo Verso et al.'s (2016) and Bliefnick et al.'s (2019) research. However, differences we observed in how indoor conditions are experienced rather align with the distinction between behavioural and psychological adaptation de Dear and Brager (1998) refer to. Adaptation strategies that seem to be experienced more positively are adopted when control is perceived and this can suggest that the presence of perceived control positively influences the experience of indoor conditions.

Second, in our study, respondents are satisfied with indoor temperatures that fall outside threshold values when they adapted the temperature themselves. This aligns with Bliefnick et al.'s (2019) assumption that patients are satisfied with higher sound levels during the night when they used auditory stimuli as sleep aid.

Third, in our study, dissatisfaction seems to be more common when respondents adapt psychologically to indoor conditions than elsewise. At the same time, observations for visual and acoustic comfort suggest that when adapting psychologically, several respondents are satisfied with measured values that fall outside threshold values.[9] Our results thus do not necessarily conflict with the observation of Verheyen et al. (2011), Lo Verso et al. (2016) and Hwang et al. (2007) that patients are in general less sensitive to indoor conditions and variations therein than healthy people.

4.2. Limitations

During analysis, adaptation came to the fore as a possible reason for discrepancies between predicted and experienced (dis)comfort. Since the data were not originally collected to understand adaptation, there are shortcomings in the questionnaire and measurement procedure.

[9] Sound measurements in dB(A) with a XL2 Sound Level Meter in nine patient rooms indicated that the sound level exceeded the threshold values of Berglund et al. (1999) in all these rooms.

The questionnaire can be improved in several ways. First, some questions should be asked differently. Perceived control should be questioned independently from the IEQ factors as actions to adapt indoor conditions often impact on several IEQ factors simultaneously. Moreover, questions should address actions taken as well as who took the action rather than only the state of adaptable building characteristics. When respondents perceive control over an adaptable building characteristic, we considered the state of that characteristic as resulting from the state they chose or action they took. This simplifies reality slightly as, for example, patients can perceive control over the lighting, but another patient or the nurses could have turned it on. Second, some additional questions will enable refining the data analysis. Questions should be added that allow distinguishing respondents who have no wish for adaptation, who adapt sensations and environmental information and who adapt their position. Furthermore, the need for help to adapt indoor conditions, sensations and environmental information, and position can be questioned (see also Verheyen et al., 2011). More insight should also be gained into the why of actions that are taken simultaneously and that affect IEQ factors in opposite ways, for example why respondents turn the heating on and leave the door open. We expect that such contradicting actions have to do with the choice to achieve the highest overall comfort in the room. For example, the heating can be turned on for warmth and the door can be opened to hear sounds from the corridor. Insights into such contradicting actions can improve the grouping of respondents per adaptation strategy.

The measurements of IEQ parameters can improve as well. First, the measurements can be expanded (e.g. locating sensors in all respondents' rooms and measuring more IEQ parameters such as the air velocity). Second, IEQ parameters related to patients' physiological adaptation can be measured. Verheyen et al. (2011) refer to the impaired physiological adaptation of patients in a neurology ward as a reason for discrepancies. Inspiration to include physiological adaptation in research can for instance be found in Goodhew et al. (2020). Third, grid measurements of IEQ parameters can be conducted in patient rooms. This will allow taking into account the relationship between the adaptation of position and values of IEQ parameters.

The data analysis could have given more attention to relationships between patient and room characteristics and the adaptation strategy applied. As Table 3.2 shows, the sample contains a balanced spread of room and patient characteristics. Despite this balanced spread, there may be more respondents with certain characteristics in one group when they are grouped per adaptation strategy and fewer of them in another group. In our view, this has few implications for the study outcome. After all, the experience of indoor conditions will always be influenced by the adaptation strategy applied, and not only by a personal or room characteristic in itself. For example, the comparison of the adaptation strategies, as described in Chapter 5, indicates that thermal

conditions are adapted more in single compared to double rooms. The group of patients who adapt thermal conditions may therefore contain more patients in single rooms than in double rooms. The observed more positive experience of thermal conditions when they are adapted cannot be explained only by the room type in this case, but is influenced by the adaptation strategy they apply more frequently in each of the room types.

4.3. Future research

Future research should attend to the limitations described above. Moreover, further research on the same topic as this chapter as well as other topics is required. First, slight tendencies were identified in how different adaptation strategies influence the experience of indoor conditions differently. The existence of these tendencies should be further investigated in future research. To this end, a larger dataset is needed. Not only more participants, but also more hospitals should be included in the dataset. In addition, a dataset with more variation in experience is recommended. The presence of more dissatisfied participants and more moments for which indoor conditions do not comply with threshold values seems especially valuable. Such a dataset may improve the understanding of how distinguishing different adaptation strategies informs about patients being dissatisfied when IEQ parameters reach threshold values and patients being satisfied when this is not the case. Based on our limited dataset and the little variation in the data, our analysis suggests that discrepancies between predicted and experienced (dis)comfort may reduce when engineers work with relaxed threshold values while architects try to increase perceived control via indoor environmental design.

Second, in case that future research supports the identified tendencies, insight is needed into the extent to which threshold values can be relaxed before triggering imposed adaptation or before indoor conditions become unhealthy. When threshold values for the indoor air temperature are relaxed for example, patients who cannot leave their bed and hesitate to ask for help or patients who did not bring appropriate clothing might have it cold in winter or warm in summer. This can both trigger imposed adaptation and be unhealthy.

Third, more insight is needed into how stimulating perceived control impacts on energy use. Note that this impact differs between IEQ factors. Providing perceived control over thermal conditions allows relaxing threshold values (de Dear & Brager, 1998). At the same time, stimulating perceived control can result in different behaviours. The energy use can be considerably higher when energy consuming instead of energy efficient behaviour is provoked (e.g. Andersen et al., 2007). Whether the energy gains from the relaxation of thermal threshold values outweigh the energy increases due to less energy efficient behavior can be doubted. Increasing perceived control over the lighting can require the possibility to dim it. Dimmed lighting is more energy efficient than

undimmed light. Providing perceived control over sounds for acoustic comfort requires stricter requirements for the acoustic design. It should be quiet when desired. This will influence the materials used, and thus the embodied energy.

Fourth, stimulating perceived control makes it more difficult for engineers to predict what the indoor conditions will actually be. Several authors develop occupant behaviour models to predict indoor conditions, as well as the energy demand, more accurately (e.g. Verbruggen et al., 2021b). The added value of including in the models not only the adaptation of indoor conditions but also the interaction with other adaptation strategies should be investigated.

Fifth, the variability in settings and people should be extended (e.g. other hospital buildings and user groups (e.g. visitors, staff), patients with various conditions, other cultural backgrounds and other building usages). It should be investigated whether the role adaptation plays in comfort is similar as in our study. The adaptation strategies at play can differ as well and are expected to be more complicated when different people share the same indoor conditions, for example through contradicting preferences. Moreover, more attention should be given to how characteristics of people and the setting relate to which adaptation strategy is applied. This would address the critique on the current IEQ approach of designing for the 'average' occupant (Bluyssen, 2020), by accounting for differences not only in comfort requirements but also in ways of adapting.

Sixth, the indoor environment offers adaptive opportunities, i.e. contextual factors that offer possibilities to adapt behaviourally, such as adaptable building characteristics (Kim & De Dear, 2012a). Relationships between adaptation and spatial and adaptable building characteristics have already been investigated in other contexts (e.g. Marín-Restrepo et al., 2020a, 2020b; Schweiker & Wagner, 2016) and in hospitals (Chapter 2). More insight should also be gained into the relationship between adaptation and building physical characteristics. IEQ parameters that are related to these characteristics should therefore (additionally) be taken into account. Examples include, for acoustic comfort, the airborne, impact and façade sound insulation, service equipment noise and the reverberation time (Rasmussen, 2017); for thermal comfort, the insulation level, air-tightness and the thermal mass (Badescu et al., 2010; Feist et al., 2005; Li & Xu, 2006; Mlakar & Štrancar, 2011); and, for visual comfort, indices which assess glare (e.g. discomfort glare probability) and the amount (e.g. the daylight factor), distribution (e.g. illuminance uniformity) and quality of light (e.g. colour rendering index) (Carlucci et al., 2015).

Seventh, as will be argued in Chapter 4, patients continuously search for the highest possible overall comfort in the room via adaptation. Chapter 2 showed that sometimes adapting indoor conditions to improve an IEQ factor results in choosing to worsen and adapt to another IEQ factor. Therefore adaptation seems to link with another point of attention in current MCP research: interactions between IEQ factors in people's experience (e.g. Bluyssen, 2020; Frontczak & Wargocki, 2011; Heinzerling et al., 2013; Ncube & Riffat, 2012). How adaptation

strategies influence the experience of indoor conditions differently might thus also be a reason why interactions between IEQ factors relate to discrepancies between predicted and experienced (dis)comfort. This link requires further research.

4.4. Implications

In case the main observations of this chapter are supported by future research, these observations have some implications for design practice, care practice and research. First, designers can increase comfort by stimulating perceived control via adaptable building characteristics and the spatial layout. In Chapter 2 it was described that patients like the possibility to dim the lighting, or perceive more control in double rooms where they reside face-to-face instead of next to each other.

Second, care professionals can increase patients' comfort by supporting those for whom adaptation is more difficult. Within the overall research we observed for example that some patients are unable to leave their bed and thus cannot adapt the window curtains or adjustable shading devices themselves. Moreover, one could consider assigning patients to rooms in the ward not only based on their condition, but also on variations in indoor conditions. Such variations imply that other adaptation strategies need to be adopted to increase comfort.

Third, researchers can contribute to reducing discrepancies by attending to how adaptation influences how indoor conditions are experienced and how this differs between adaptation strategies. This will enable them to improve methods to predict (dis)comfort.

5. Conclusion

In studies that investigate patients' comfort in hospitals through on-site measurements and questionnaires, perceived control and adaptation are advanced as a reason for discrepancies between experienced and predicted (dis)comfort. Our case study in two hospital wards explored how distinguishing between hospitalized patients' adaptation strategies informs about reasons for these discrepancies.

We investigated whether tendencies could be identified in how the adaptation strategy adopted, experiences of indoor conditions, and measured values of IEQ parameters relate to each other. Although the observed tendencies are not always significant, nor observed for all IEQ factors, some tendencies can be noted. First, a tendency could be observed in how the adaptation strategy adopted relates to how indoor conditions are experienced. In general, sensations seem to be more neutral or as preferred when respondents adapt indoor conditions or have no wish to do so compared to when they adapt by choice or

imposed, and satisfaction is higher when sensation votes are more neutral or in the direction of their preference. Secondly, two opposite tendencies were noted in how the adaptation strategy adopted relates to measured values of IEQ parameters. On the one hand, adaptations of indoor conditions result sometimes in high or low values of IEQ parameters. On the other hand, actions seem to be taken in order to bring high or low values of IEQ parameters to a more 'moderate' state; and adaptation strategies that involve psychological adaptation seem to be applied to deal with situations in which IEQ parameters have a rather high or low value. The presence of such contradicting tendencies makes it difficult to predict which adaptation strategy has been applied based on measured values. Thirdly, across adaptation strategies no tendency could be identified based on our data in how measured values of IEQ parameters relate to how indoor conditions are experienced.

Since no tendency could be identified in how measured values of IEQ parameters relate to the experience of indoor conditions when adaptation strategies are compared, the strategies seem to influence in a psychological way how indoor conditions are experienced. This psychological influence appears to differ between adaptation strategies. These differences are not taken into account by existing methods that predict (dis)comfort based on measurable values of IEQ parameters alone, based on a combination of IEQ parameters in Fanger's thermal comfort model, or accounted for when adaptation is treated as a 'black box'. The lack of attention for these differences may explain discrepancies between predicted and experienced (dis)comfort.

Future research should verify the results based on a larger dataset, and ideally more variation in respondents' experience. If future research confirms the results, the results have implications for research and practice. In order to predict (dis)comfort more accurately, researchers should search ways to include in comfort predictions that people experience indoor conditions more positively when adapting behaviourally or when having no wish to adapt indoor conditions compared to when adapting psychologically. Taking into account the psychological influence of adaptation on how indoor conditions are experienced is thus more complex than distinguishing between situations with more or less perceived control. Designers can contribute to patients' comfort by providing adaptive opportunities, and care professionals can do so by supporting patients' adaptation.

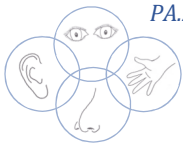
Chapter 4: **Discrepancies Between Predicted and Experienced Indoor Environmental (Dis)comfort: the Role of Hospitalized Patients' Multi-sensory Experience**

Based on: Understanding and Estimating Patients' Indoor Environmental Quality Assessment: A Pilot Case Study in a Hospital Ward. In: Proceedings of IAQ2020. Presented at the Indoor Environmental Quality Performance Approaches.
Co-authored with Dirk Saelens and Ann Heylighen

Abstract

Hospitals' indoor conditions impact on patients' comfort. The indoor environmental quality (IEQ) is often investigated with a focus on one of the main IEQ factors – thermal, visual, and acoustic comfort and indoor air quality. However, discrepancies are observed between predicted and experienced (dis)comfort, possibly because people's experience is multi-sensory. To estimate people's experience better, IEQ models express factors' relative importance in the multi-sensory IEQ assessment through regression coefficients. Yet, questions arise about the trustworthiness of these models. This chapter aims to improve insights into how discrepancies between predicted and experienced (dis)comfort can be reduced by investigating how IEQ factors and parameters combine and interact in patients' experience and multi-sensory IEQ assessment. At a hospital's traumatology ward, 84 patients completed a questionnaire. Twelve of them and four others participated in semi-structured interviews about their experience of the indoor environment, while sensors measured IEQ parameters in their room (temperature, relative humidity, illuminance, CO_2 and sound level). Based on sensor measurements and/or questionnaire results, respondents' sensation and satisfaction votes with indoor conditions are estimated in different ways. Semi-structured interviews enable explaining satisfaction votes, give insight into how IEQ parameters interact and their importance in respondents' multi-sensory IEQ assessment. Combining qualitative and quantitative data informs about possible improvements of multi-sensory IEQ models, which may allow predicting IEQ more accurately.

PA.2



1. Introduction

The indoor environment impacts on comfort. To ensure indoor environmental comfort, researchers aim to predict the quality of indoor conditions based on values of IEQ parameters and sometimes other parameters such as buildings' type of ventilation in the adaptive thermal comfort model (e.g. Bureau for Standardisation, 2003; Bureau for Standardisation, 2005; Berglund et al., 1999; Parkinson et al., 2020). IEQ parameters are measurable quantities of indoor conditions like the sound, light, temperature, humidity, or CO_2 level. IEQ factors are constructs such as thermal comfort that can be assessed by people or estimated based on one or more IEQ parameters. Thermal comfort, visual comfort, acoustic comfort and the indoor air quality are considered the main IEQ factors (Sakhare & Ralegaonkar, 2014). Most often IEQ factors are predicted by setting up dose–response relations for each of them separately (Bluyssen, 2010).

To guarantee that a minimum number of people feel comfortable. threshold values have been developed based on the predictions. These threshold values most often focus on one of the IEQ factors as well, and count for corresponding IEQ parameters. For thermal comfort, different threshold values exist. Fanger's predicted mean vote (PMV) and predicted percentage dissatisfied (PPD) base themselves on the heat balance between people's body and the environment (Fanger, 1970). Sensation and satisfaction votes are predicted based on the combination of the indoor air temperature, mean radiant temperature, air velocity, relative humidity, the clothing insulation and metabolic rate. The adaptive thermal comfort model includes adaptation in the prediction of the thermoneutral temperature based on the outdoor temperature (e.g. Parkinson et al., 2020). For visual comfort the following factors were considered in the development of threshold values: psycho-physiological aspects such as visual comfort and well-being, requirements for visual tasks, visual ergonomics, practical experience, safety and economy (Bureau for Standardisation, 2003). In the development of sound level threshold values, adverse health effects (i.e. any temporary or long-term impairment of physical, psychological or social functioning that is associated with noise exposure) for each specific environment were identified (Berglund et al., 1999). Threshold values for the sound level have been set for each health effect, and the lowest sound level that produces an adverse health effect is taken as the threshold value. For the indoor air quality, CO_2 levels are often assumed as being representative for it (Bureau for Standardisation, 2010; Bureau for Standardisation, 2005). Various methods for ensuring indoor air quality exist, such as the maximum CO_2 levels above the outdoor level (for further discussion see Bureau for Standardisation, 2005).

Attention can indeed facilitate processing relevant stimuli and suppress processing irrelevant ones (Zimbardo & Gerrig, 2002). However, IEQ is increasingly understood to be experienced in a multi-sensory way (Bluyssen, 2010). The lack of attention for how IEQ parameters and factors combine and

interact in people's experience is given as a reason for discrepancies between predicted and experienced indoor environmental (dis)comfort. Such discrepancies show themselves for example in studies in hospitals. Liu et al. (2018) observe, for example, that one of the hospitals studied was assessed more satisfactory than the other one, while the compliance rate of IEQ parameters with threshold values was not necessarily better. Over-crowdedness at the latter hospital was believed to be the major reason for the lower satisfaction votes with the indoor air quality, acoustics and building services.

As a result of such observations, attention grew for IEQ factors' contribution to and relative importance in people's multi-sensory IEQ assessment. Integrated measurement protocols are advanced by NBN EN ISO 28802 (2012) and ASHRAE Performance Measurement Protocols (PMP) (2010). Moreover, ways are sought to predict people's overall comfort experience through a multi-sensory IEQ model (e.g. Frontczak & Wargocki, 2011; Ncube & Riffat, 2012; Heinzerling et al., 2013; Sakhare & Ralegaonkar, 2014; Fransson et al., 2007). Multiple regression analysis of questionnaire data, for instance, enables calculating regression coefficients that represent each IEQ factor's relative importance in the multi-sensory IEQ assessment (Heinzerling et al., 2013).

Questions arise about the trustworthiness of these models as well. Fransson et al.'s (2007) regression analysis, for example, indicates that for patients and staff maximal explained variance was achieved with such models when a combination of the satisfaction votes with IEQ factors and measured values of IEQ parameters were used as independent variables. Fransson et al.'s (2007) finding illustrates that indoor conditions and people are a complex system (Bluyssen, 2014; Bluyssen, 2020). Interactions between IEQ factors occur in people's experience. People are also not always aware of which IEQ factors influence their experience and may have difficulty to isolate one IEQ factor from another. These interactions are not yet fully understood (Bluyssen, 2010; Bluyssen, 2020). Moreover, the wrong factors might be focused on. It is also unclear how factors' satisfaction vote is affected by preferences regarding conditions that are perceived in the same way (Humphreys, 2005; Bluyssen, 2010; Frontczak & Wargocki, 2011). Moreover, a subjective weighing process is supposed to be ongoing. A positive IEQ factor can compensate for a negative one, but both do not contribute equally to the multi-sensory IEQ assessment (Humphreys, 2005). In addition, factors' relative importance within the multi-sensory IEQ assessment is likely to change continuously, possibly influenced by the multi-sensory IEQ assessment (Frontczak & Wargocki, 2011) and the level to which they (dis)satisfy (Humphreys, 2005; Bluyssen, 2010).

The research described above has the objective to set up models for comfort predictions (MCP). To improve the understanding of how IEQ factors combine and interact in experience, we see potential in integrating the strengths of MCP research with those of research that has the objective to understand in

depth different roles of the built environment in experiences (RBE). MCP research allows predicting (dis)comfort with a focus on individual IEQ factors, and sometimes their combination. These factors relate to individual sensations. However, the predictions most often do not include interactions between IEQ factors. RBE research allows gaining an in-depth understanding of how people give meaning to objects (e.g. a plate of food) and events (e.g. nurses preparing food in a nearby room in a hospital ward) as well as to their sensations. Objects and events often influence different sensations simultaneously. A sensation is often influenced by different objects and events, and different sensations are experienced simultaneously.

In the view of the above observations, this chapter aims to improve insights into how discrepancies between predicted and experienced (dis)comfort can be reduced by answering the research question: how do IEQ factors and parameters combine and interact in patients' experience and multi-sensory IEQ assessment? To answer the research question, critical realism is adopted as worldview. This worldview enables combining the strengths of MCP research with those of RBE research.

The remainder of this chapter is structured as follows. Section 2 describes the methodology. Section 3 describes the results. This results section consist of four parts. First, the extent to which individual IEQ parameters and factors enable estimating reported sensation and satisfaction votes with the corresponding IEQ parameter or factor is described. Second, interactions that occur between the assessment of IEQ parameters and factors, and measured values of other IEQ parameters are focused upon. Third attention is given to how IEQ parameters and IEQ factors combine in patients' experience and multi-sensory IEQ assessment. Fourth, how the importance of IEQ parameters and factors varies when the outdoor temperature or the location of the room in the ward differs is addressed. How these insights inform about how discrepancies between predicted and experienced (dis)comfort can be reduced is discussed in Section 4. The conclusion is described in Section 5.

2. Methodology

2.1. Overview

To gain a comprehensive understanding of how IEQ factors and parameters combine and interact in patients' experience and multi-sensory IEQ assessment, a mixed methods case study was applied. A *case study* allows investigating hospitalised patients' experience of their patient room in an intensive, detailed, in-depth way (Yin, 2003; Ritchie & Lewis, 2003). Combining *quantitative and qualitative data* offers more insights than the applied methods offer in isolation (Creswell & Plano Clark, 2018). Choosing a *convergent parallel design*, quantitative (sensor measurements, questionnaires) and qualitative data (semi-

structured interviews, probes) were gathered concurrently. The data were connected as some methods (interviews, sensor measurements) were used with a subsample of respondents involved in other methods (questionnaire). The quantitative and qualitative data were first analysed separately. Subsequently the 'following a thread technique' was applied to obtain integration (Moran-Ellis et al., 2006). The quantitative and qualitative strand were given equal status, and further integrated during data interpretation and reporting.

2.2. The case

We conducted the case study at a hospital's traumatology ward in a Belgian hospital. The building originates from 1984, the ward was refurbished in 2010. The indoor conditions were regulated by a mechanical ventilation system (70 m^3/h in all rooms, supply temperature at outdoor air temperature during data collection), windows operable by people, indoor shading devices, outdoor shading devices (except in rooms with a northeast oriented window), individual fans, and radiators (not in use during the study), and lighting without dimmers. No cooling system was present. The windows of single and double rooms were orientated to the northeast (room 1-3), northwest (9-16), east (20-24), southeast (25-32), southwest (4-8), and west (17-19). Staff rooms were located centrally in the ward. Figure 4.1 includes a plan of the hospital ward. The fieldwork was conducted in two periods: May 14 to 30, 2019 and July 9 to August 1, 2019.

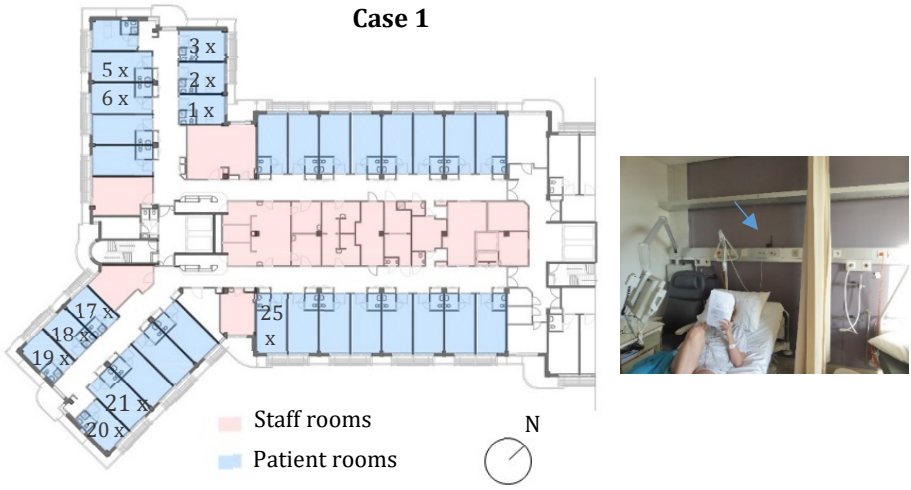


Figure 4.1 Plan of the hospital ward with north arrow (left) and a patient with the questionnaire and a VersaSense Wireless Device in the background (right). Room numbers are indicated on the plan. The 'x' on floor plan indicates rooms where HOBO's and VersaSense sensors were located during interviewees' hospital stay. (Plan: based on the plan of the hospital's infrastructure planning department. Permission was obtained to publish the plan.)

2.3. Data collection

A self-reported paper-based questionnaire gauged patients' assessments, causes of (dis)comfort, and perceived control. Since we consider positive experiences as belonging to comfort, different levels of dissatisfaction as well as satisfaction were questioned with regard to the assessments. The questionnaire was inspired by the one of the Center for the Built Environment. This questionnaire is advised by American Society of Heating, Refrigerating and Air-Conditioning Engineers's (ASHRAE) Performance Measurement Protocols (PMP) for Commercial Buildings (ASHRAE, 2010; Hyojin, 2012; Peretti & Schiavon, 2011), but was adapted to a hospital context based on insights from evidence-based design research in hospitals (e.g. Ulrich et al., 2008; Huisman et al., 2012). Table 4.1 provides a detailed overview of the questionnaire components focused on in this chapter. For these components, questions asked about patients' satisfaction with the overall comfort in the room – representing their multi-sensory IEQ assessment -, and about their sensation and satisfaction with individual IEQ factors and parameters. The full questionnaires can be found in the Appendix (Appendix A). During the fieldwork, simple random sampling was adopted. The researcher asked one or two days a week to random patients to participate. Eighty-four patients, agreeing to participate, provided informed consent and completed the questionnaire. Table 4.2 provides an overview of the respondents.

Twelve of these 84 plus four other patients participated in two in-depth semi-structured interviews. These patients were selected via convenience sampling. Nurses suggested patients based on their ability to participate. The final group of interviewees consists of those asked and willing to participate. Table 4.2 provides an overview of the interviewees. The interviews addressed how patients experienced their hospital stay, especially IEQ related. Experiences in general, but also specific positive and negative experiences were questioned. Table 4.3 provides a detailed overview of the interviews' topic guide.

In between the two interviews interviewees could fill in the questionnaire and a probe. The probe – a form of self-documentation that invites to express for example experiences, feelings, attitudes, and actions they would not think of during an interview (Gaver et al., 2004; Boehner et al., 2007) – consisted of a timeline or booklet for taking notes. On the timeline they could indicate their experiences using handed stickers, or write or draw about them themselves. The probe was filled in by eight interviewees. Figure 4.2 illustrates a filled-in probe.

In between the two interviews, sensors measured the indoor air temperature, relative humidity, CO_2 level, sound level and illuminance level in interviewees' room and the corridor. In July a Thermal Microclimate Data Logger additionally measured in the corridor and empty patient rooms the air and wet bulb globe temperature, and relative humidity. Outdoor temperatures and solar radiation measured at 3 km from the hospital were used. Table 4.4 gives more information about the sensor measurements.

Table 4.1 Overview of the questionnaire components this chapter focuses on, incl. type of questions, questions asked, response scale, and percentages of missing values per question when relevant.

Component	Type of questions	Case 1: questions asked	Response scale[1]	Case 1: % missing values
Room characteristics		Room number, single or double room, window or corridor side	Open questions and multiple choice	1 %/0 % /0 % (question filled in by first author)
IEQ factors				
Overall comfort in the room	Satisfaction	How satisfied are you with the comfort of the room?	Likert scale: 1-7 (very dissatisfied - very satisfied)	10 %
Thermal comfort	Satisfaction	How satisfied are you with the temperature in your room?	Likert scale: 1-7 (very dissatisfied - very satisfied)	7 %
	Sensation	Which of the following aspects leads to less satisfaction with the temperature in your room?	Multiple choice (often too hot, sometimes too hot, sometimes too cold, often too cold)	NA
Indoor air quality	Satisfaction	How satisfied are you with the indoor air quality in your room (e.g. stuffy/stale air, cleanliness, humidity, odours)?	Likert scale: 1-7 (very dissatisfied - very satisfied)	7 %
Visual comfort	Satisfaction	How satisfied are you with the amount of light in your room?	Likert scale: 1-7 (very dissatisfied - very satisfied)	8 %
Acoustic comfort	Satisfaction	How satisfied are you with the amount of sound in your room?	Likert scale: 1-7 (very dissatisfied - very satisfied)	10 %
		How satisfied are you with the amount of tranquility in your room?	Likert scale: 1-7 (very dissatisfied - very satisfied)	10 %
		How satisfied are you with the amount of sound privacy in your room (i.e. the ability to have conversations without others overhearing it and vice versa)?	Likert scale: 1-7 (very dissatisfied - very satisfied)	12 %

[1] Likert scales from 1-7 were used since people tend to indicate positive values more quickly than negative values. During data analysis, the values were transformed to the commonly used values ranging from -3 to +3.

Table 4.2 Overview of the participants of the interviews, probe and questionnaire, their personal and room characteristics, and dates of participation. (Not applicable (NA)).

Case & type of data	Semi-structered interviews	Probes	Questionnaire
Dates of participation	May: 14, 17, 21, 24, 27, 30; July: 9, 11, 12, 15, 16, 19, 20, 22, 26, 30; August: 1	May: 14, 17, 21, 24, 27, 30; July: 9, 11, 12, 15, 16, 19, 20, 22, 26, 30; August: 1	May: 14, 21, 24, 27, 30; July: 9, 10, 11, 12, 15, 19, 22, 25, 26, 29
Number of participants	16	8	84
Number of participants participating in two interviews/answering all questions of the questionnaire (excl. multiple choice questions)	16	NA	58 %
Birth sex: % woman	31 %	40 %	35 %
Age [years]: mean, sd	57.93; 14.48	57.6; 9.6	53.6; 17.23
Nationality: % Belgian	88 %	88 %	100 %
Length of stay [days]: mean, sd	7.31; 6.54		5.36; 4.92
Self-rated well-being: % >= neutral	NA	NA	NA
Number of previous hospitalisations: mean, sd	5.75; 3.28	6.5; 3.8	5.36; 4.92
Type of room: % single room	50 %	50 %	25 %
Window side/corridor side (only double rooms): % window side	44 %	63 %	45 %
Window orientation	NE: 19 %; E: 13 %; SE: 31 %; NW: 0 %; W: 25 %; SW: 13 %	NE: 25 %; E: 13 %; SE: 38 %; NW: 0 %; W: 13 %; SW: 13 %	NE: 16 %; E: 21 %; SE: 34 %; NW: 29 %; W: 8 %; SW: 26 %
Zone of ward	quiet: 50 %; neutral: 25 %; noisy: 25 %	quiet: 50 %; neutral: 12 %; noisy: 38 %	quiet: 37 %; neutral: 33 %; noisy: 30 %
Outdoor conditions: % heat wave (case 1)/cold days (case 2)	19 %	25 %	20 %

Table 4.3 Topic guide of the semi-structured interviews.

Topic guide interviews		
Interview 1	**Introductory questions**	Introduction of themselves
	Transition questions	Positive experiences of the room
		Negative experiences of the room
		Meaning given to the room
	Main questions	Overall comfort
		experiences
		preferences
		IEQ factor which has the main importance
		assessment
		Thermal comfort
		experiences (incl. variations over time and space)
		sources that impact it
		actions to improve it
		preferences
		assessment
		Acoustic comfort (subtopics idem thermal comfort)
		Visual comfort (subtopics idem thermal comfort)
		IAQ (subtopics idem thermal comfort)
		Other factors that the participant experiences as important
		Comparison of the room's IEQ with that in other contexts: why would it be experienced similarly or different?
		Most important characteristics of the IEQ in a patient room
		If a new hospital were built: which characteristics of the room or IEQ would the patient certainly keep or change?
	Concluding questions	What is the most important topic addressed during the interview according to the participant?
		Which factor of the indoor environment does the participant find the most important?
		Additional comments from the participant
Interview 2	**Introductory questions**	How did the participant experience the past few days in the hospital?
	Transition questions	Experiences of the IEQ during the previous days
	Main questions	Discussion of the most important moments during the previous days, and (implicitly) how the indoor environment influenced these moments
		Discussion of the probe if the participant filled it in
		Discussion of the measurements during the previous days, and actions taken which impact on the measured values
		Additionally: discussion of separate IEQ factors
	Concluding questions	Idem interview 1

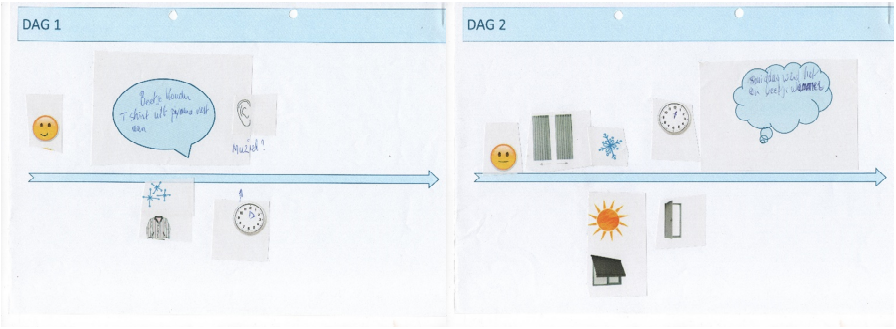


Figure 4.2 Filled-in probe of participant 6. [Translation: title left='Day 1'; title right='Day 2'; text box left='Little bit cold. T-shirt taken off, long sleeved pajamas put on'; text middle='Music?'; text box right= 'It got a little warmer at noon'.]

2.4. Data analysis

The quantitative and qualitative data were first analysed separately. Quantitative analysis of sensor measurements and questionnaires, using the software RStudio (2021), consisted of descriptive (means, medians, boxplots, and standard deviations) and inferential statistics (linear and multiple regression analysis). Note that several questions were asked regarding acoustic comfort (Table 4.1). The mean of the votes was taken into account in the analyses. Interviews were audio-recorded, transcribed and, together with the data of the probes, questionnaires and sensor measurements, analysed qualitatively, roughly following the steps of the coding preparation process of the Qualitative Analysis Guide of Leuven (QUAGOL) (Dierckx de Casterlé et al., 2012) and using NVivo software. This allowed to gain insight into the interviewees' experience.

Subsequently the 'following a thread technique' enabled integration during data analysis (Moran-Ellis et al., 2006). On the one hand, insights into patients' experience informed about which interactions between IEQ parameters and factors could be explored quantitatively, and for which situations the regression coefficient of IEQ parameters in patients' satisfaction vote with the overall comfort in the room could be determined. On the other hand, explanations for findings based on the quantitative data were searched in the interviews.

For reporting, the weaving approach was applied. This involves writing both qualitative and quantitative findings together on a theme-by-theme basis (Fetters et al., 2013).

Table 4.4 Overview of the sensor measurements.

Sensor	IEQ parameter(s) [measurement unit]	Accuracy or sensitivity	Sampling rate [min.]	Calibration year	Location	Position in room
HOBO prov2	air temperature [°C]	± 0.21 °C	10	2019	Interviewees' room and 4 locations in the corridor	1.50 m from floor level, behind patient
	relative humidity [%]	±2.5 % from 10 % to 90 %				
VersaSense Edge Gateway	NA	NA	NA	NA	staff room	NA
VersaSense Wireless Devices	ambient illuminance level [lx]	± 0.01 lx	1	2021	Interviewees' room and 4 locations in the corridor	1.50 m from floor level, behind patient (light sensor pointed to the ceiling)
	sound level [%, with 0 % = 40 dB and 100 % = 80 dB]	noise detection level: approx. equivalent to a finger-click at 1 meter	1	2021	Interviewees' room and 4 locations in the corridor	1.50 m from floor level, behind patient
EXTECH SD800 CO_2/ Temperature/ Humidity logger	CO_2 level [ppm]	±40 ppm (<1000 ppm)	10	2021	Interviewees' room and 3 locations in the corridor	1.50 m from floor level, behind patient
	air temperature [°C]	±0.8 °C				
	relative humidity [%]	±4% RH				
Weather station	outdoor temperature [°C]	Case 1: ±(0.226 - 0.0028 × temperature); Case 2: ± 0.2	Case 1: 10; Case 2: 15	2019	3 km from hospital	NA

3. Results

3.1. Individual IEQ parameters and IEQ factors

As explained in the introduction, people's reported satisfaction with (or acceptance of) an IEQ parameter or factor is typically predicted based on measured values of IEQ parameters, or the combination of these values and measured, estimated or assumed values for other parameters (e.g. the clothing insulation and metabolic rate) (e.g. Fanger, 1970; Fanger, 1988; Maekawa et al., 2011; Carlucci et al., 2015). In our study, such predictions estimated reported satisfaction with the corresponding IEQ factor to a certain extent but not completely.

Participants' assessment of indoor conditions varies over time and space: satisfaction votes with the thermal comfort decrease as the outdoor temperature increases (mean day (8h-20h) temperature: May: 16.5 °C; July before and after heat wave: 21 °C; July during heat wave: 32 °C) and in rooms with a southeast or southwest window orientation compared to those with northeast or northwest one. Based on sound measurements in corridors and the experience of interviewees who resided in rooms at different locations of the ward, three zones with respect to acoustic comfort can be distinguished: noisy, neutral and quiet zones. More noisy zones are located closer to staff rooms. Satisfaction votes with the acoustic comfort decrease as the noise level of the zone increases and for double compared to single rooms.

Indoor air temperatures measured with sensors in patients' room correlate to some extent with their satisfaction votes with the thermal comfort. Figure 4.3A visualizes the relationship between interviewees' (dis)satisfaction vote with the thermal comfort and the mean value of the indoor air temperatures measured in their room in between the two interviews. Dots have the same colour when the mean values are similar. Figure 4.3A suggests that votes tend to lower as indoor air temperatures increase. Yet, for rooms with similar indoor air temperatures, it is less clear why differences in patients' satisfaction votes with the thermal comfort occur. Figure 4.3D presents the relationship between interviewees' (dis)satisfaction vote with the acoustic comfort and the mean value and the background noise level of the sound levels measured in their room in between the two interviews. The dots are coloured differently when the corresponding room is a single or double room, and is located in a noisy, neutral or quiet zone of the ward. Based on Figure 4.3D it is unclear how measured sound levels relate to patients' satisfaction vote with the acoustic comfort.[2,3]

[2] The sound levels measured in room 18 and 28 have been shifted 3.2 units to the right to align their background noise levels with background noise levels measured in other rooms. The measured difference is expected to be mainly caused by inaccuracies in the sensor measurements.

[3] Based on the measured sound levels in patient rooms the first quartile showed to be representative as background noise level.

Patients' assessment of IEQ factors can also be predicted based on (the combination of) measurable parameters. For thermal comfort, Fanger's thermal comfort model is used.[4] Figure 4.3B presents the relationship between the PPD- and PMV-values. PPD-values, presented on Figure 4.3B, are compared with the reported (dis)satisfaction votes with the thermal comfort, presented in Figure 4.3A. This comparison shows that when PPD-values increase, participants' reported satisfaction vote with the thermal comfort is in general lower. Yet, PPD-values indicate only which percentage of people is predicted to be dissatisfied. Participants' reported experience and assessment of IEQ factors are more nuanced than being 'satisfied or not'. Room 20's interviewee, for example, explains that it can be warm during the night, but he is fine with it because opening the window helps. Room 1's interviewee refers to that the warmth can be cozy. Furthermore, Figure 4.3C presents the relationship between (dis)satisfaction votes with the thermal comfort and sensation votes. The reported sensation votes are compared with the PMV-values presented in Figure 4.3B. This comparison indicates that reported sensation votes, expressing how often temperature is too hot or cold, correspond roughly with estimated PMV-values for thermal comfort. It is especially remarkable that patients asses the temperature in the room as often too hot when indoor air temperatures are between 22 °C and 24 °C. These assessments disturb the relationship between reported sensation votes and (dis)satisfaction votes that can be observed on Figure 4.3C.

When an IEQ parameter reaches unacceptable levels according to the Flemish Indoor Environment Decree (Agentschap Zorg en Gezondheid, 2018; Lazarov & Stranger, 2017), insight into patients' experience and adaptation provides possible explanations for variance in their satisfaction vote. As can be observed in Figure 4.3A, during a heat wave, measured indoor temperatures exceeded acceptable levels. In room 2, an interviewee expresses dissatisfaction, and considers an air conditioner absolutely necessary. At the same time he is doing little to keep the heat out. He therefore has to adapt psychologically. In room 3, an interviewee would like to have air conditioning, but thinks it is not allowed because it is unhealthy. Besides being more accepting of the situation, she adapts indoor conditions in several ways to improve the thermal comfort: an air cooler is brought from home, the fan is used continuously, the indoor shading device and curtains are closed. An outdoor shading device is preferred, but absent at this room. In room 17(2), an interviewee had expected a heat wave,

[4] PMV- and PPD-values are calculated using measured air temperatures and relative humidity in participant's room. Air speeds are estimated: v=0.25 m/s when participants indicated in the questionnaire to use a desk fan sometimes, v=0.08 m/s otherwise. The mean radiant temperature is taken equal to the air temperature. 0.8 met, a metabolic rate for lying people, is chosen (International Organization for Standardization (ISO) 7730, 2005), and a clothing insulation of 1.76 clo based on studies in sleeping and hospital environments (Lin & Deng, 2008a; Lin & Deng, 2008b, Verheyen et al., 2011) and assuming a conventional matrass, a blanket covering 59,1 % of the body and half-slip sleepwear.

which made the temperature more tolerable. In the questionnaire he expresses tolerance for uncomfortable circumstances as a hospital has to be first and foremost functional. Moreover, he adapts indoor conditions in a similar way as the interviewee in room 3: outdoor and indoor shading device, curtains and window are closed. Interviewees' higher tolerance and acceptance as well as their adaptations of indoor conditions in room 3 and 17(2) may partly explain their lower dissatisfaction, as shown on Figure 4.3A, compared to the interviewee in room 2. Yet, inacceptable conditions for an IEQ parameter, unexplained variation between satisfaction votes and measured values cannot be understood based on differences in psychological influences on the satisfaction votes alone.

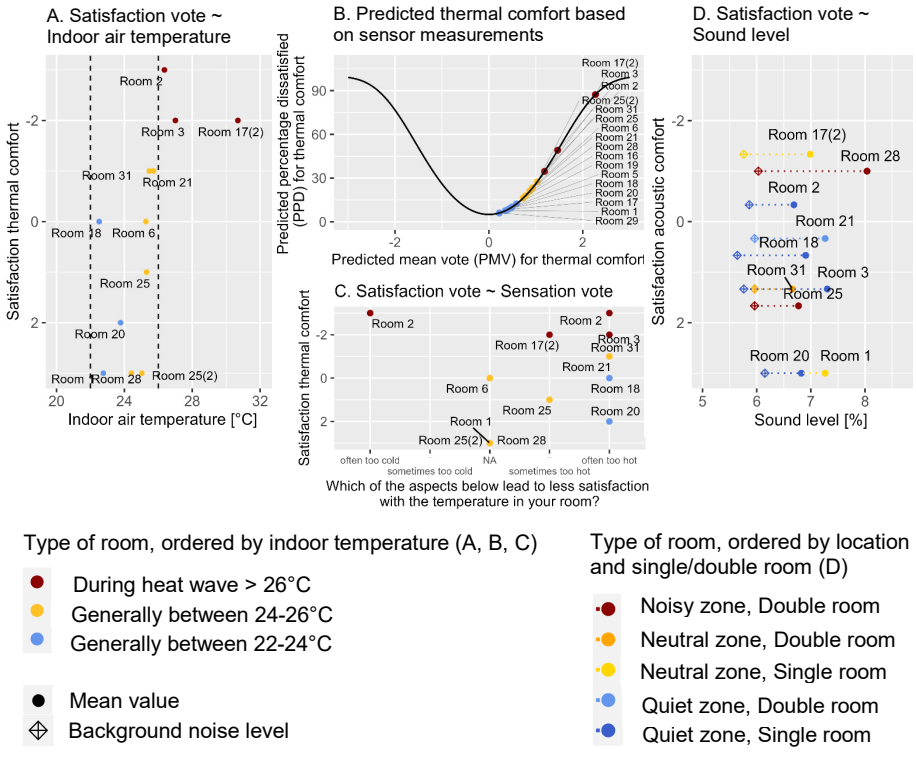


Figure 4.3 Relationship between (dis)satisfaction with an IEQ parameter and its sensor measurements (for the indoor temperature (A), sound level (D)), between estimated PPDs and PMVs for thermal comfort (B), and between (dis)satisfaction with an IEQ parameter and reported sensation votes for the indoor temperature (C). The dotted lines in the graph on the left indicate the acceptable temperature interval according to the Flemish Indoor Environment Decree (Agentschap Zorg en Gezondheid, 2018, Lazarov and Stranger, 2017).

3.2. Interactions between IEQ parameters and between IEQ factors

First, variance in satisfaction with an IEQ factor that cannot be explained by differences in measured values of corresponding IEQ parameters or psychological influences, seems to relate to differences in other IEQ parameters' measured values. Figure 4.4A visualizes, as Figure 4.3D, the relationship between interviewees' (dis)satisfaction vote with the acoustic comfort and the mean value and background noise level of the sound levels measured in their room in between the two interviews. This time the dots are coloured according to the location of the room in the ward and the indoor air temperature. In Figure 4.4A, red dots, representing high indoor air temperatures, correspond in general with lower satisfaction votes with the acoustic comfort; blue dots, representing the lowest, moderate indoor air temperatures, correspond in general with higher satisfaction votes. Therefore, there is a slight indication that indoor air temperatures in interviewees' room help to explain differences in their satisfaction votes with the acoustic comfort.

Similar trends can be noted for respondents' satisfaction votes with the acoustic comfort. As explained in section 3.1, outdoor temperatures increase from May, to July before the heat wave, to July during the heat wave. Applying Mann-Whitney U tests to the questionnaire's data indicates significant differences in satisfaction votes with the acoustic comfort between May and both July before (α=0.05, p=0.02) and during the heat wave (p=0.04). Visually, similar trends can be observed for respondents residing in quiet zones of the ward. The barplots of Figure 4.4B present the number of respondents that give a certain satisfaction vote with the acoustic comfort. A distinction is made between quiet and noisy zones of the ward, and between May, July before the heat wave, and July during the heat wave. In quiet zones, satisfaction votes with the acoustic comfort seem to decrease when outdoor temperatures increase. In noisy zones, this trend cannot be observed. During the heat wave there is even a participant who is very satisfied with the acoustic comfort.

Second, variance in satisfaction with an IEQ factor that cannot be explained by differences in measured values of corresponding IEQ parameters or psychological influences, seems to relate not only to differences in other IEQ parameters' measured values, but also to how interviewees evaluate other IEQ factors. Within interviewees' experience IEQ factors can be considered constructs. Terms as 'warm' or 'cold', corresponding with 'thermal comfort', refer to an aspect of interviewees' experience. Other constructs overlap between factors. This shows in how interviewees adapt and adapt to indoor conditions. Reference is made to 'fresh air' and outdoor sounds coming in when a window is open. Some interviewees prefer this to closing the window, relying on mechanical ventilation, and hearing less outdoor sounds. The indoor air quality, thermal comfort and acoustic comfort are evaluated simultaneously in this

example, and this simultaneous evaluation differs from how the factors would be evaluated independently.

Although these results highlight the need for multi-sensory IEQ models, they raise the question whether IEQ factors are needed as intermediating constructs between the multi-sensory IEQ assessment and IEQ parameters. Table 4.5 visualizes reasons for this question. The red colour refers to dissatisfactory predictions or experiences; a green colour to satisfactory predictions or experiences. Firstly, factors calculated based on sensor measurements are often expressed as PPD's, considering each factor as independent from others. While this simplification allows focusing on one of the occurring variations in assessments, in reality factors interact within each individual's experience (Table 4.5: second and third column). Secondly, the extent to which the condition of IEQ parameters impact on one factor is affected by interactions with other factors. For example, when the window is open, the extent to which the indoor air temperature and air velocity impact on the thermal comfort assessment changes due to the simultaneous assessment of the indoor air quality (Table 4.5: second row). The impact of the clothing level on the thermal comfort assessment changes less in interviewees' experience (Table 4.5: third row). The perceived control over their clothing is more important than whether they adapt it or not (Table 4.5: compare third column, second and third row). Yet, combining IEQ factors into a multi-sensory IEQ model considers each factor as a fixed relation of IEQ parameters. Thirdly, focusing on IEQ parameters in multi-sensory models can avoid problems occurring when there is a different PPD for a factor and similar reported preferences or a similar PPD but other reported preferences (Table 4.5: lines between the rows and the corresponding text). The former happens when some patients prefer not to adapt their clothing when the window is open, and the latter when they adapt their clothing but prefer an open window over a closed one.

Third, the assessment of IEQ factors seems to interact because information about the environment that is picked up by different senses is integrated into coherent representations of objects and/or events in the enviroment. For example, an interviewee who feels nauseous finds it difficult to hear and smell nurses preparing food. In this example, both the acoustic comfort and the indoor air quality are negatively assessed because food is being prepared.

3.3. Combinations of IEQ parameters and combinations of IEQ factors

As different IEQ parameters and factors interact in participants' experience, it is also worth looking at how they have a combined effect on the satisfaction with the overall comfort in the room and patients' experience. In our study, the satisfaction with the overall comfort in the room can be predicted accurately not

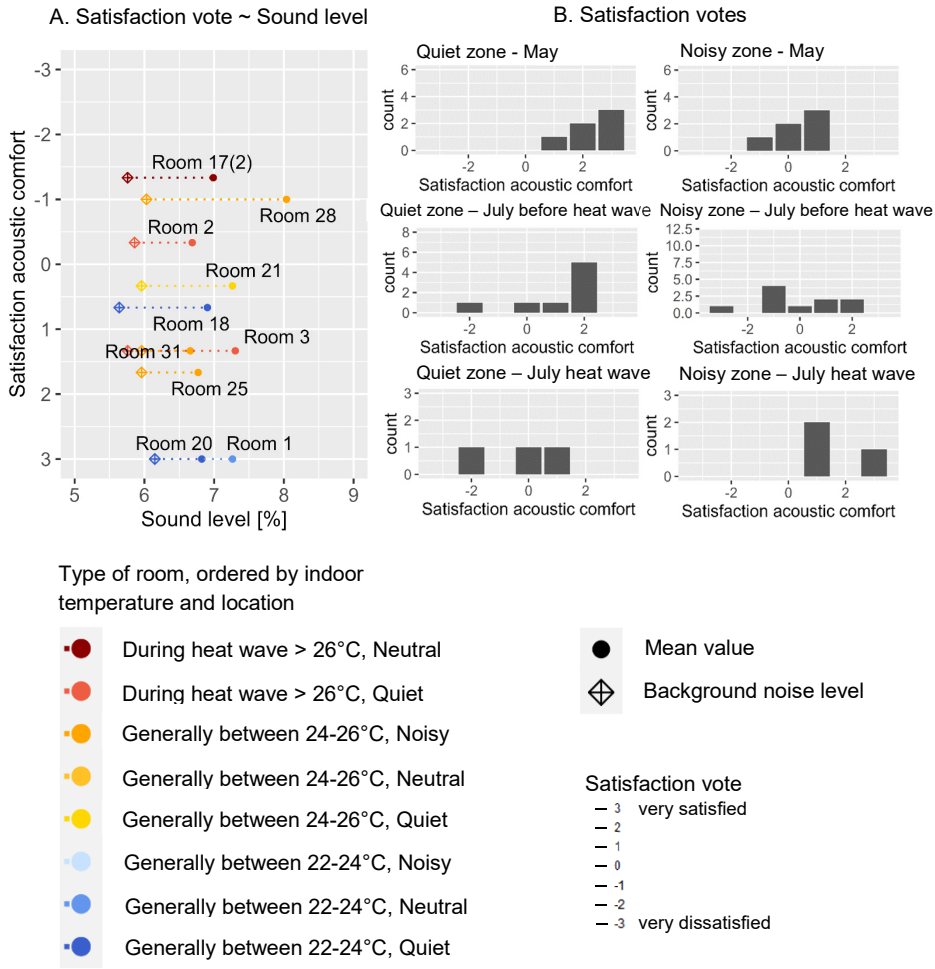
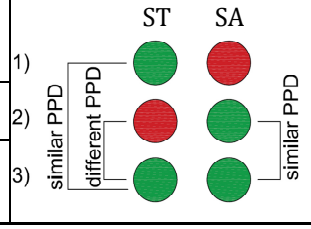
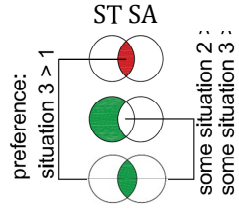


Figure 4.4 Interaction between (dis)satisfaction with the sound level in the room and the indoor and outdoor air temperature.

Table 4.5 Interactions IEQ factors. [ST: satisfaction with the thermal comfort; SA: satisfaction with the IAQ].

Situation	Separate prediction	Simultaneous experience
1) Closed window – poor IAQ		
2) Open window - no clothing adaptation		
3) Open window – clothing adaptation		

by the combination of measured values of IEQ parameters, but by the combination of satisfaction votes with IEQ factors.

How the combination of measured values of IEQ parameters relate to satisfaction with the overall comfort in the room is not clear. Figure 4.5A presents interviewees' satisfaction vote with the overall comfort in the room in relation to measured values of the indoor air temperature, sound level, illuminance level, CO_2 level, and relative humidity expressed in percentages, as well as a the mean of these percentages. For each IEQ parameter, measured values are expressed in percentages by subtracting the 5th percentile value of all values measured for that parameter from the mean of the values measured in an interviewee's room and the 95th percentile value of all values measured for that parameter, and by dividing the two obtained values. Note that minimum threshold values are defined for some parameters and maximum ones for others. Despite this difference, the mean of the obtained percentages was calculated as well per interviewee. This gives an idea of the combined effect of IEQ parameters' measured values on interviewees' satisfaction vote with the overall comfort in the room. Based on Figure 4.5A, no relationship between interviewees' satisfaction vote with the overall comfort in the room and measured values of IEQ parameters could be identified.

In interviewees' experience, mainly qualities of indoor conditions (i.e. their meaning and atmosphere) play a role. For example, interviewees like to hear sounds from the corridor during the day as it keeps them from feeling lonely, but one interviewee finds it inappropriate to hear people playing as there are patients being ill. In both cases sound levels do not differ. IEQ parameters' values play a role as part of the qualities. For example, interviewees who resided in different rooms prefer the lower background noise levels and the more restful atmosphere in the more quiet zones of the ward.

Satisfaction votes represent assessments of indoor environmental qualities. Despite not being observed for measured values, IEQ factors' combined effect on patients' assessment of the overall comfort in the room can be noted in the questionnaire results. Figure 4.5B presents the distribution of patients' satisfaction vote with the overall comfort in the room for four situations: in July before and during the heat wave, and each time in quiet and noisy zones of the ward. It indicates that satisfaction votes with the overall comfort in the room are the highest in July before the heat wave in quiet zones, and decrease in noisy zones and during the heat wave in both zones. Respondents' satisfaction vote with the overall comfort in the room seems therefore simultaneously affected by whether the room is located in a quiet or noisy zone of the ward and the outdoor temperature.

The relationship between satisfaction votes with IEQ factors and the satisfaction vote with the overall comfort in the room can be expressed with a

formula. Assuming a linear relationship, simple linear regression results in (R^2=0.48).

Satisfaction with the overall comfort = 0.81 + 0.19(ST + SV + SS + SA)*

The abbreviations refer to satisfaction with the thermal comfort (ST), visual comfort (SV), acoustic comfort (SS), and indoor air quality (SA).

Not all IEQ factors are equally important in respondents' assessment of the overall comfort in the room, and they balance the positive ones against the negative. Multiple regression analysis allows to estimate the relative contribution of different IEQ factors' satisfaction vote to the model's explained variance in satisfaction with the overall comfort in the room. This results in (R^2 = 0.49)

*Satisfaction with the overall comfort = 2.01 + 0.22*ST + 0.21*SA + 0.06*SV + 0.23*SS*

As described in Section 3.2, assessments seem to be affected not only by the combined effect of IEQ factors, but also by their interactions. Incorporating interactions in the multiple regression analysis gives the highest coefficient of determination and results in (R^2 = 0.57)

*Satisfaction with the overall comfort = 38.02 – 11.05*ST – 6.08*SA – 8.48*SV – 6.95*SS + 2.01*ST/SA + 2.36*ST/SV + 2.03*ST/SS + 1.45*SA/SV + 1.43*SA/SS + 1.73*SV/SS – 0.41* ST/SA/SV – 0.40*ST/SA/SS – 0.32*SA/SV/SS – 0.43*ST/SV/SS + 0.08*ST/SA/SV/SS*

The above results do not only suggest that satisfaction votes with the overall comfort in the room and satisfaction votes with IEQ factors are related. They also suggest that IEQ parameters affect respondents' experience in a combined way, and their experience affects their satisfaction vote with the overall comfort in the room and individual IEQ factors. This suggestion is supported by the rather strong, positive monotonic association – measured with Spearman's correlations – found between satisfaction votes with the overall comfort in the room and satisfaction votes with IEQ factors, and between satisfaction votes with different IEQ factors. The values of the Spearman's correlations are given in Table 4.6. The correlation between satisfaction votes with the overall comfort in the room and the sum of the satisfaction votes with the thermal, visual, and acoustic comfort as well as indoor air quality is also strong (Spearman's correlation: 0.76). It can be argued that such correlations are observed because patients' experience, which is in itself multisensory, impacts the satisfaction votes with the overall comfort in the room and the IEQ factors simultaneously and in the same way.

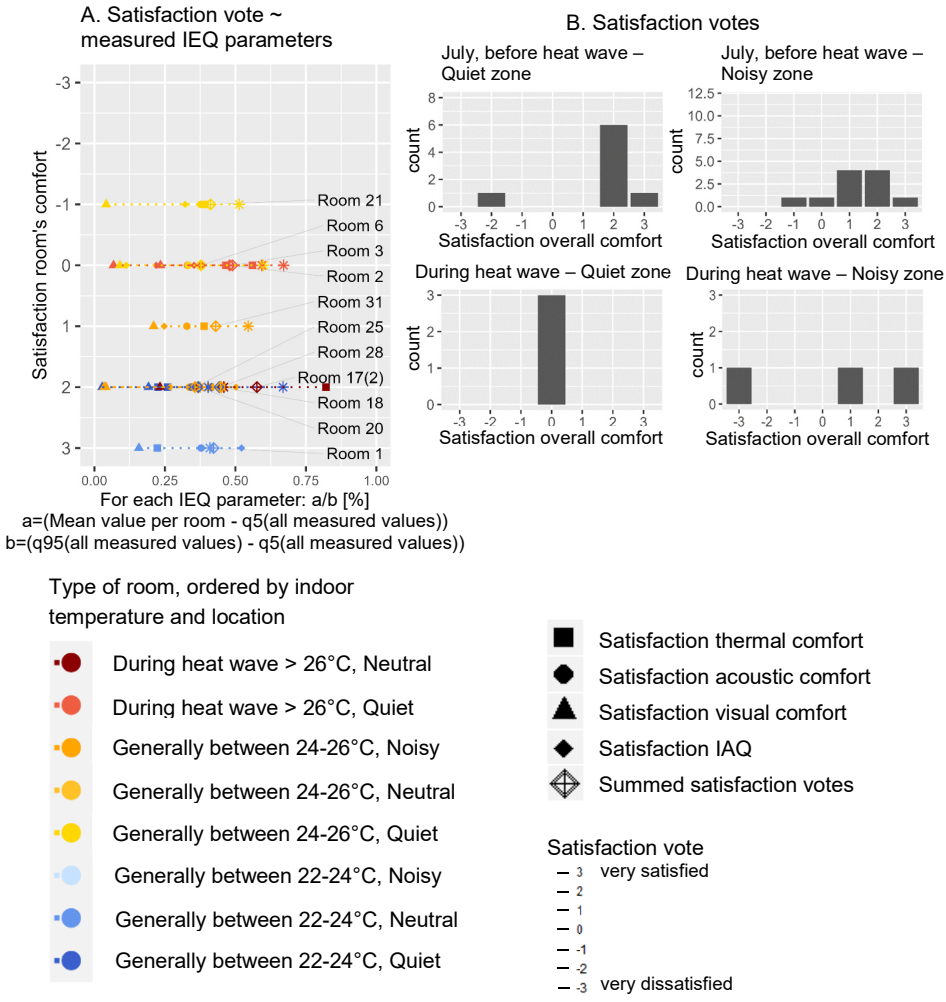


Figure 4.5 Relationship between satisfaction with the overall comfort in the room and (A) IEQ parameters' measured values, and (B) the combination of the outdoor temperature and location in the ward.

Table 4.6 Spearman's correlation.

Satisfaction with:	Overall comfort	Thermal comfort	Visual comfort	Acoustic comfort
Thermal comfort	0.56	-	-	-
Visual comfort	0.56	0.42	-	-
Acoustic comfort	0.64	0.46	0.57	-
Indoor air quality	0.58	0.56	0.66	0.5

3.4. Variable importance of IEQ factors

The relationships presented based on multiple regression assume that regression coefficients do not change across situations, and thus that IEQ factors' assessment and their interactions always contribute to the assessment of the overall comfort in the room to the same extent. Judging from interviewees' experience and measured values, however, regression coefficients seem to vary with differences in corresponding and other IEQ parameters. For example, during the heat wave interviewees paid more attention to thermal comfort than in periods with more moderate temperatures. Next to this, measurements show that interviewees experienced similar indoor air temperatures in room 28 and 20 (Figure 4.3A). Sound measurements in the corridors and interviewees who resided in rooms at different locations of the ward indicate that room 28 is located in a noisy and room 20 in a quiet zone. Room 28's interviewee expresses to be mainly dissatisfied with the acoustic comfort in the room and satisfied with the thermal comfort. Improving the acoustic comfort is more important for her than improving the thermal comfort. Room 20's interviewee mentions to be satisfied with the acoustic comfort and the thermal comfort. For him thermal comfort is most important.

That an IEQ factor's importance varies with its satisfaction votes is supported by the different regression coefficients found via multiple regression analyses in different situations. A relationship is set up for questionnaires (a) completed in May and during the heat wave, and (b) in rooms located in quiet and noisy zones. Table 4.7 presents the regression coefficients.[5] The thermal comfort's higher absolute value of the regression coefficient during the heat wave suggests that improving satisfaction with the thermal comfort would have more impact on the satisfaction with the overall comfort in the room in this period than in May. Satisfaction votes with the thermal comfort are at the same time lower during the heat wave than in May (Figure 4.3A). Similarly, improvements in satisfaction votes with the acoustic comfort seem to have more impact in noisy than in quiet zones. Satisfaction votes with the acoustic comfort are at the same time lower in noisy than in quiet zones (Figure 4.4B).

These results indicate as well that regression coefficients vary with changes in the corresponding IEQ factor's satisfaction votes, but in the opposite direction. For example, improving the satisfaction vote with the acoustic comfort of room 28's interviewee may improve her satisfaction vote with the overall comfort in the room. However, the relative importance of the satisfaction vote with the acoustic comfort within the assessment of the overall comfort in the room may decrease as the sounds in the room will resemble more the sounds in rooms

[5] Interactions are not taken into account in this analysis because of the limited amount of data in each situation. To enable a qualitative understanding of how the importance of each IEQ factor changes in different situations, forward/backward selection were not applied.

Table 4.7 Varying regression coefficients depending on IEQ parameter's condition.

Corresponding IEQ factor	Regression coefficients May	Regression coefficients July during heat wave	Regression coefficients quiet zones of the ward	Regression coefficients noisy zones of the ward
Intercept	3.55	3.51	0.38	0.88
Satisfaction thermal comfort	**-0.01**	**0.76**	0.06	0.34
Satisfaction indoor air quality	0.17	-0.23	-0.04	0.4
Satisfaction visual comfort	0.09	-0.46	0.88	-0.02
Satisfaction acoustic comfort	0.22	0.58	**0.06**	**0.17**
R^2	0.55	0.65	0.94	0.5

located in quiet zones of the ward. As can be observed in Table 4.7, the regression coefficient of satisfaction with the acoustic comfort is lower in quiet compared to noisy zones. Moreover, regression coefficients of other IEQ factors may vary simultaneously with changes in the satisfaction vote and regression coefficient of a factor. After all, the regression coefficients of other IEQ factors differ when, for example, those found for quiet and noisy zones are compared.

In addition, a similarity is noted between how regression coefficients vary with differences in the corresponding IEQ factor's satisfaction votes between situations, and how the importance of IEQ factors varies in interviewees' experience through adaptation. Interviewees search, continuously and influenced by their perceived control, the highest possible indoor environmental comfort in their room. Some interviewees adapt indoor conditions when perceiving control to do so. For example, during the heat wave room 17(2)'s interviewee finds it most important to keep the heat outside. The window, shading devices and curtains are closed and the door to the corridor is opened to have some air circulation. The thermal comfort gets the highest importance, and satisfaction with the thermal comfort is low (Figure 4.3A). However, due to the adaptations of indoor conditions, the importance given to the thermal comfort seems to decrease and satisfaction with it to increase. That these adaptations have a positive influence on satisfaction provided after all an explanation in Section 3.1 for why the satisfaction of room 3's and 17(2)'s interviewee are higher than that of room 2's interviewee (Figure 4.3A). Furthermore, some patients adapt themselves psychologically. They seem to adjust the importance given to IEQ factors. For example, room 25's interviewee refers to an increase in the amount of sounds when the visiting hour starts and is used to sleep in the dark, but 'it is a hospital' so he adapts himself to the situation. His satisfaction vote with the acoustic comfort and visual comfort stay high (e.g. Figure 4.3B). In this example, the importance given to the acoustic and

visual comfort seems to be reduced and the satisfaction increased psychologically.

4. Discussion

In MCP research relationships between measured values of IEQ parameters and people's assessment of them, their assessment of IEQ factors and, to a limited extent, their multi-sensory IEQ assessment are sought (e.g. Fanger, 1970; Fransson et al., 2007; Ncube & Riffat, 2012). Although interviewees of our case study refer to individual IEQ factors (e.g. thermal comfort), their experience is in essence multi-sensory. Not attending to their multi-sensory experience in (dis)comfort predictions may result in discrepancies between predicted and experienced (dis)comfort. In this chapter, a constructionist epistemology was supported alongside a realist ontology by adopting critical realism as worldview. In this way it was explored how IEQ factors and parameters combine and interact in patients' experience and multi-sensory IEQ assessment. Contributions of this perspective are explained below.

Adopting a constructionist epistemology seems valuable in order to improve the understanding of interactions between IEQ factors and parameters in experience. First, interactions seem to occur because the sensations associated with different IEQ factors are experienced simultaneously. Both IEQ factors and parameters are constructs. It is possible to define other constructs than, for example, the typical IEQ factors (i.e. thermal, acoustic, and visual comfort, and the IAQ). These can for instance be constructs in which two IEQ factors are combined, such as a construct for 'fresh air'. Second, information about an object or event in the environment can be perceived simultaneously via different senses and is in this way associated with different sensations and thus IEQ factors. Both insights provide a possible explanation for why the overall assessment of the comfort in the room correlates with the assessment of an individual IEQ factor and why that of different IEQ factors correlate with each other. They put in question whether IEQ factors are needed as intermediating constructs between the multi-sensory IEQ assessment and IEQ parameters. The latter also puts into question whether the overall comfort of the room can be predicted on the basis of IEQ parameters alone.

Improving MCP research's current multi-sensory IEQ models may be a first step to reduce discrepancies between predicted and experienced (dis)comfort. First, the multi-sensory IEQ models may avoid that due to interactions between the assessment of IEQ factors and values of unrelated IEQ parameters, the wrong threshold values are tightened in order to reduce discomfort. For example, to reduce dissatisfaction with the acoustic comfort during the heat wave in our study, it would make little sense to (only) tighten threshold values for the sound

level. The indoor temperatures seem to influence the satisfaction votes. Multi-sensory IEQ models will help to attend to the correct IEQ factor.

Second, multi-sensory IEQ models may help supporting patients' comfort. Tightening (the wrong) threshold values can result in more neutral, boredom indoor conditions. Allowing that indoor conditions vary can make their experience interesting, and thus increase comfort. Adhering to less tightened threshold values is even expected to decrease the operational energy at the same time. By focusing on multi-sensory IEQ models, some threshold values may be relaxed. In case an IEQ factor is highly comfortable all of the time, it can influence patients' experience positively. The experience can on its turn influence the assessment of other IEQ factors positively. Threshold values for the other IEQ factors can then be relaxed. The extent to which these threshold values can be relaxed will depend on their importance within the multi-sensory IEQ assessment. Note that this importance is expected to change when the IEQ factor becomes less comfortable. Optimal balances between the positive influence of some IEQ factors and negative influences of others therefore need to be searched. To make this practically possible, two approaches can be proposed. Either some IEQ factors should have a positive influence all the time in order that broadened but constant threshold values for the other IEQ factors can be used. Either it will be needed to conduct dynamic simulations of indoor environmental comfort. In these simulations, all IEQ factors' or parameters' compliance rate must be taken into account simultaneously.

Improving the understanding of how IEQ parameters combine and interact in patients' experience and multi-sensory IEQ assessment benefits from combining sensor measurements and questionnaires with interviews and, probably, observations. Sensors inform about the values of IEQ parameters that are to be assessed. Questionnaires inform about conscious assessments, IEQ parameters' importance in the multi-sensory IEQ assessment and non-conscious interactions between the assessment of IEQ factors mutually and the overall comfort in the room. Moreover, via questionnaires indoor conditions' qualities are assessed. These can be statistically linked to values of IEQ parameters. In-depth insights into patients' experience inform about their prereflective, prepredicative, and non-conscious experience of indoor conditions and their conscious reflection on it. These in-depth insights can be gained via interviews as in this study, but probably also through observations, The insights can be qualitatively linked to measured IEQ parameters and assessments. In this way, quantitative observations can be better understood.

This chapter has some limitations. The research period was short, the number of interviewees and respondents were limited, only in interviewees' room indoor conditions were measured, and relatively inexpensive sensors were used. Future research should therefore verify the results presented in this chapter. Moreover, due to the limited dataset, the impact of characteristics that relate to the patients and their setting on the relationship between measured

values and satisfaction votes could only be inspected to a limited extent. For example, it was checked whether outdoor conditions and building characteristics, such as the location of the room in the ward, could explain differences in satisfaction with an IEQ factor. However, also differences in characteristics related to the patients and other characteristics related to their setting may lead to differences in satisfaction votes. For example, patients' hearing ability can influence their satisfaction with acoustic comfort. Furthermore, patients' satisfaction with the overall comfort in the room and individual IEQ factors may be influenced by their health. That parameters other than IEQ parameters influence indoor environmental comfort provides a possible explanation for some results. Satisfaction with an IEQ factor could be estimated only roughly with values of corresponding IEQ parameters, PPD-values for thermal comfort and how often sensations differ from neutral. Moreover, satisfaction with the overall comfort in the room could not be estimated accurately by the combination of measured values of IEQ parameters, but by the combination of satisfaction votes with IEQ parameters. In future research, these limitations should be attended to.

5. Conclusion

Based on a mixed methods case study at a hospital's traumatology ward it was explored how IEQ factors and parameters combine and interact in patients' experience and multi-sensory IEQ assessment. The results, despite being based on a limited dataset, provide suggestions about how discrepancies between predicted and experienced (dis)comfort may be reduced.

Satisfaction with an IEQ factor could be estimated only roughly with values of corresponding IEQ parameters, PPD-values for thermal comfort and how often sensations differ from neutral. IEQ parameters seem to affect patients' experience jointly, and patients' experience seems to affect how they assess the overall comfort in the room and individual IEQ factors. Interactions are observed between patients' satisfaction vote with an IEQ factor and differences in other IEQ parameters' measured values or in other factors' satisfaction vote. An IEQ factor's importance within the assessment of the overall comfort in the room seems to vary as well with corresponding values of IEQ parameters. Moreover, it seems to vary with its satisfaction votes as well as with the satisfaction votes with other IEQ factors. In relation to this, a similarity could be noted between how IEQ factors' importance varies with differences in its satisfaction votes and how interviewees improve their experience through adaptation. An IEQ factor that is uncomfortable can have a high importance within the overall comfort assessment. To increase the overall comfort assessment, corresponding IEQ parameters can be adapted. The satisfaction with the IEQ factor increases and the importance of the IEQ factor within the overall comfort assessment may

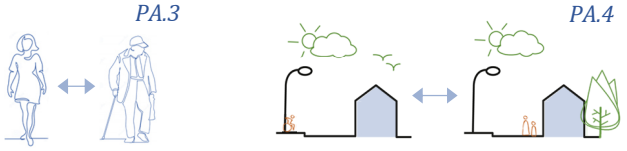
decrease. An alternative to increase the overall comfort is to decrease the importance of the uncomfortable IEQ factor through psychological adaptation.

The results suggest that in order to predict patients' indoor environmental comfort more accurately, more attention for multi-sensory IEQ models is needed. It is expected to avoid tightening threshold values of the wrong IEQ factor. During the design process, such models may also enable relaxing threshold values of IEQ factors for which the assessment is influenced positively by other IEQ factors' assessment. There are two possible approaches to account for such relaxations: some IEQ factors should have a positive influence all the time in order that relaxed but constant threshold values for the other IEQ factors can be applied; or it will be needed to conduct dynamic simulations of indoor environmental comfort. To develop multi-sensory IEQ models, qualitative data about patients' experience should be combined with quantitative data about measurable IEQ parameters and patients' IEQ assessment. In-depth insights improve the understanding of situations in which the indoor environment is experienced and assessed differently. Quantitative data are needed to set up the models.

Chapter 5: **When and Why Do Differences in Comfort and in Adaptation Occur among Hospitalized Patients? A Convergent Mixed Methods Case Study**

Abstract

Patient rooms' indoor conditions impact on hospitalized patients' comfort. Comfort is predicted based on threshold values for indoor environmental quality (IEQ) parameters, but discrepancies with experienced (dis)comfort occur. Current prediction methods focus on the comfort of an 'average' person. However, comfort requirements and adaptation may differ among patients. In this view, we investigated when and why thermal and visual comfort and adaptation differ among hospitalized patients. To answer this research question, a convergent mixed methods case study was conducted at two hospital wards of a Belgian hospital. Qualitative data included interviews with 19 patients and information about the patients residing at the two wards during the fieldwork; and quantitative data included sensor measurements of IEQ parameters (i.e. illuminance and indoor air temperature), a questionnaire among 238 patients, and simulations of the free-running temperature and the total short-wave solar radiation through the windows. Situations for which a characteristic related to the patients or their setting differ were compared. Three types of scenarios could be distinguished: situations for which (1) experienced comfort and adaptation are similar, (2) adaptation differs and experienced comfort is similar, or (3) experienced comfort differs and indoor conditions are similar. Understanding for which characteristics adaptation differs while comfort is similar, can inform architects and engineers about how design can influence the use of the heating and lighting; for which characteristics experienced comfort differs about points of attention if one wants to design comfortable indoor conditions for as many patients as possible.



1. Introduction

People's comfort is affected by the indoor environment. To ensure comfort, it is investigated what high-quality indoor environments are. Based on research with the objective to set up models for comfort predictions (MCP), threshold values for IEQ parameters are set up. IEQ parameters are measurable quantities of the indoor conditions like the sound, light, temperature, relative humidity, or CO_2 level. These thresholds are based on relationships between values for IEQ parameters and people's assessment of IEQ factors. IEQ factors are constructs such as thermal comfort that can be assessed by people or estimated based on one or more IEQ parameters. The threshold values apply for different types of rooms such as patient rooms (e.g. Bureau for Standardisation, 2003; Bureau for Standardisation, 2005; Berglund et al., 1999).

Discrepancies are however observed between predicted and experienced (dis)comfort. It is hypothesized that current threshold values do not include well enough how comfort is affected by adaptation and diversity. Adaptation refers to people's reaction to restore their comfort when a change occurs that causes discomfort (Nicol & Humphreys, 2002). Diversity refers to the many different people, for example patients, who reside in the indoor environment. Some of these people can have different comfort requirements or adapt differently, for example when characteristics related to the person or the setting differ. A better understanding is needed of when and why differences in characteristics related to people or their setting correspond with differences in experienced comfort and adaptation.

To reduce discrepancies, some MCP research has already been conducted to investigate whether comfort requirements differ when characteristics related to people or their setting differ. For example, the role that birth sex and age play in thermal comfort is unclear when studies are compared (Schweiker et al., 2018; Wang et al., 2018; Kaikaew et al., 2018). With respect to age, a study with young adults and elderly, for example, indicated that the elderly preferred a higher temperature in comparison with the young adults (Schellen et al., 2010). A study with older people in residential buildings observed that the range of operative temperature for 80% thermal acceptability is narrower for elderly (Hwang & Chen, 2010). A study with parents and professional caregivers of people on the autism spectrum has indicated that visual comfort requirements differ between young and old (Caniato et al., 2022). A differences is noted in prevalence of natural light and in sensitivity to light colour tones.

Research with the objective to set up models for predictions of adaptations of indoor conditions (MAP) has been conducted as well. It investigates, among other topics, diversity in the way in which people adapt indoor conditions. Note that this research is mainly interested in the impact of adaptation on energy use. Adaptations of indoor conditions are predicted based on characteristics related to people and their setting. For example, based on literature, Stazi et al. (2017)

found that in studies in offices and dwellings, the time of arrival and departure and the (work plane) illuminance influence the use of the lighting. With regard to the use of the thermostat in dwellings, Stazi et al. (2017) mainly found that the indoor and outdoor temperature, habits, routines, the time of the day, and the usability of the thermostat play a role. They identified that when the outdoor temperature decreases, more heating systems are on but no range of operation is reported in literature. Lin et al. (2016) observed, for example, that in urban residential buildings in China the majority of heating is consumed between 16 PM and 22 PM (55 % for the living room and 46 % for the bedroom). Xu et al. (2009) and Peffer et al. (2011) found that the usability of the thermostat influences the extent to which it is adjusted and that user misconceptions may encourage incorrect usage.

To improve the understanding of when and why comfort requirements or adaptation differ among people and settings, we see potential in integrating the strengths of MCP and MAP research with those of research with the objective to understand in depth different roles of the built environment in experiences (RBE). MCP research allows predicting (dis)comfort; MAP research adaptations of indoor conditions. However, these predictions do not sufficiently include differences in comfort and the corresponding adaptation between people and between settings. RBE researchers view reality as multiple. They actively look for multiple perspectives from participants. An example of such research in the context of indoor environmental comfort and adaptation is the study by Annemans et al. (2018a) at a middle-scale hospital with patients with kidney failure. They describe that Louise, one of the participants, is bothered by the sound of televisions of fellow patients after 10 p.m. However, she prefers to leave the door of her room open to get some fresh air. Jane, on the other hand, is not bothered by fellow patients. The integration of MCP, MAP and RBE research may allow improving the understanding of mechanisms that explain differences in indoor environmental comfort and the corresponding adaptation when characteristics related to people and their setting differ.

To investigate this topic, a focus on hospitalized patients in their patient room is valuable. Attention for differences between patients resonates with the paradigm shift from a biomedical perspective towards a person-centred perspective that took place in health care (Lines et al., 2015; Annemans et al., 2018b). With regard to the built environment, it raises the question how a person-centred hospital building can be designed (Lawson, 2010; Annemans et al., 2018b). Furthermore, this focus allows comparing ways in which patients adapt. The comparison can build on the adaptation strategies identified among hospitalized patients based on two mixed methods case studies, as described in Chapter 2. When patients who have a wish for adaptation perceive control, they: (1) adapt indoor conditions, (2) adapt sensations or the experienced environmental information (i.e. change sensations without changing indoor conditions, e.g. by adapting clothing), (3) adapt position (i.e. move to more

comfortable indoor conditions), or (4) adapt by choice to indoor conditions (i.e. alter the meaning and attention given to indoor conditions despite the perceived possibility to adapt them). When they do not perceive such control, they (5) adapt imposed to indoor conditions (i.e. have to alter the meaning and attention given to indoor conditions as perceived control to bring them in line with preferences is lacking).

In view of these observations, this chapter addresses the following research question: when and why do thermal and visual comfort and adaptation differ among hospitalized patients? The research question was answered based on a mixed methods case study. Note that a focus on thermal and visual comfort and adaptation was chosen because of characteristics of the case study (see Methodology, Section 2.1). The strengths of MCP, MAP, and RBE research are integrated by adopting critical realism as worldview.

The remainder of the chapter is structured as follows. Section 2 describes the methodology. Section 3 describes the results. In Section 4 the main contributions, implications of the findings, as well as limitations and directions for further research are discussed. Conclusions are formulated in Section 5.

2. Methodology

2.1. Overview

To explore when experienced comfort and adaptation differ among hospitalized patients, a mixed methods case study with a convergent design was conducted. As case, two surgical wards of a Belgian hospital were chosen.

An overview of the methodology is given in Figure 5.1. Qualitative data (i.e. interviews and information about the patients residing at the two wards during the case study) and quantitative data (i.e. sensor measurements, and a questionnaire) were collected. The free-running temperature and the total short-wave solar radiation through the external windows were simulated as well. These simulated values were compared with measured indoor air temperatures and illuminance levels. This enabled identifying moments when the heating and lighting were on.

In the data analysis, characteristics of patients and their setting that influence comfort and adaptation were identified based on the interviews. Subsequently, the different types of data were analysed separately, followed by an integrated analysis via joint displays.

Note that a focus on thermal and visual comfort and adaptation was chosen because of characteristics of the case study. More as well as more reliable sensor measurements were conducted with regard to these IEQ factors than with regard to acoustic comfort. Moreover, next to closing and opening the room's door, patients had no control over the indoor air quality (IAQ). As a result, little diversity in the applied adaptation strategies can occur among patients.

Below a more detailed description is given of the case, data collection and data analysis. Figure 5.1 is then explained in more detail as well.

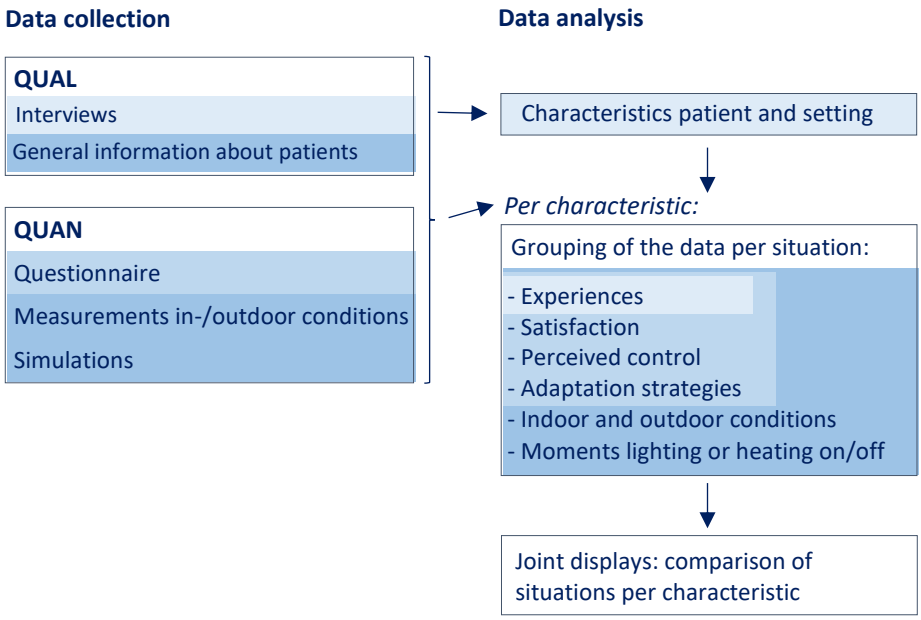


Figure 5.1 Visualization of the methodology.

2.2. The case

The research was conducted in a hospital building which came into use in 2018. Together with hospital management and staff we chose two surgical wards in this hospital as case since surgical patients stay for several days and were expected to be able to participate. Figure 5.2 shows a plan of the wards. Patient rooms are partly conditioned through mechanical ventilation (100 m^3/h per patient in the room, supply temperature at 21°C and top-cooling in summer), operable windows that are locked, and fixed external louvres for shading. The geometry of the fixed external louvres for shading is presented in Figure 5.2. Patients can adapt indoor conditions in various ways: radiators with a thermostat knob; window curtains; the room's door; a curtain between the patient beds in double rooms; and Light-emitting diode (LED) lighting consisting of a main lighting above the patient bed and a small light behind the patient bed in both single and double rooms, an additional ambient light in single rooms and an additional main light in double rooms. All lighting can be operated with a switch and, for the one above the patient bed, a dimmer. The rooms of the wards have four window orientations: northeast, northwest, southeast and southwest. They have three types of views out: a view on a patio, a view on the

neighbourhood and some trees – further referred to as 'an average view out' - or a wide view out. Double rooms have a face-to-face design, i.e. patients are positioned face-to-face in the room. This is illustrated on Figure 5.2.

The research was conducted in autumn and winter. The focus in this chapter is on patients' adaptations of indoor conditions via the heating and lighting. Especially in colder and darker periods of the year, these adaptations were expected to occur.

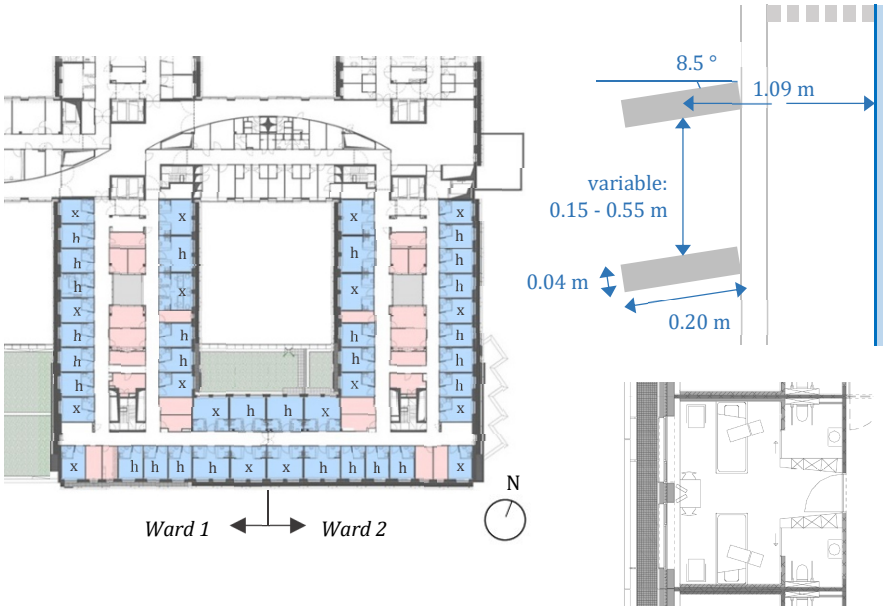


Figure 5.2 Floor plan of the wards, the geometry of the fixed external louvres for shading, and a double room. The 'x' on the left floor plan indicates rooms where HOBO's and VersaSense sensors were located; 'h' indicates those with only HOBO's. (Plans: based on the plan of VK Architects & Engineers).

2.3. Data collection

Different types of data were collected, as presented on the left in Figure 5.1. A darker shade is used when the sample size of the data type is larger. Qualitative data were collected at the wards through interviews (Figure 5.1: light blue). Moreover, information was obtained about the patients residing at the two wards during the case study (Figure 5.1: dark blue). Quantitative data were collected through a questionnaire (Figure 5.1: medium blue), and measurements of indoor and outdoor conditions (Figure 5.1: dark blue). Moreover, the free-running temperature and the total short-wave solar radiation through the external windows were simulated through a building energy performance simulation in TRNSYS17 (2019) (Figure 5.1: dark blue). These simulated values

were compared with measured indoor air temperatures and illuminance levels. This comparison enabled estimating the moments when respectively the heating and lighting were on in patient rooms. A more detailed description of the data collection methods can be found in the subsections that follow.

Patients participating in the interviews and questionnaires provided informed consent. Other patients residing in the wards were informed about the research via posters, and could ask the nurses, me, or the supervisor for more information. The fieldwork was approved by the Social and Society Ethics Committee of KU Leuven (G-2018 08 1304).

2.3.1. Data collected at the hospital wards

Measurements of the illuminance level and indoor air temperature informed about indoor conditions; of the outdoor air temperature, outdoor relative humidity, and outdoor global radiation about outdoor conditions. Those of outdoor conditions were made available to us. Table 2.4 in Chapter 2 provides more information about the sensor measurements.

The questionnaire included questions about respondents' assessment of IEQ factors, perceived control, and states of adaptable building characteristics. Since we consider positive experiences as part of comfort, different levels of dissatisfaction and satisfaction were questioned for the assessments. Table 2.1 in Chapter 2 (columns: 'Case 2: questions asked', 'Response scale', and 'Case 2: % missing values') includes questions of the questionnaire this study focussed upon. The full questionnaires can be found in the Appendix (Appendix B). Two hundred and thirty eight patients filled in the questionnaire. These patients will be referred to by the word 'respondents'. Table 2.2 in Chapter 2 (column: Case 2, questionnaire) provides more information about the respondents.

The interviews dealt with interviewees' experience of their patient room, perceived control, and adaptation, with a focus on indoor environmental comfort. Experiences in general, but also specific positive and negative experiences were questioned. Table 2.3 in Chapter 2 gives an overview of the topic guide of the semi-structured interviews. Nineteen patients participated. These patients will be referred to by the word 'interviewees'. Some of them participated in the questionnaire as well. Table 2.2 in Chapter 2 (column: Case 2, interviews) provides more information about the interviewees.

Interviews were conducted and questionnaires were distributed from September 29 to October 30, 2020 and from December 8, 2020 to January 8, 2021. Measurements took place form September 29, 2020 until January 8, 2021. The end date of the data collection was determined by the weather. At the beginning of January there were still a few cold days. Warmer weather was forecast for the following weeks. Regarding days with warmer weather, saturation in data collection was reached for the interviews. What was expressed in previous data was repeated in the new data (Saunders et al., 2018).

2.3.2. General information about patients and the building with its systems

The hospital's management provided information about the room occupancy in the two wards during the fieldwork. This information included patients' moment of arrival in the hospital and departure from it, room in which they resided, birth sex and age. This information was needed to connect indoor conditions and adaptations of it via the heating and lighting to characteristics that relate to the patient and their setting. The architects provided plans of the wards and a report about a dynamic simulation conducted to design the building's external louver system in a way that thermal and visual comfort in the patient rooms could be ensured. The technical services of the hospital provided information about the supply temperature and airflow rate of the hygienic ventilation in the patient rooms. This information of the architects and technical services was needed to conduct the simulations, as will be explained in the next section.

2.3.3. Estimating when the lighting and heating were on or off, and the set points

The moments when the lighting and heating were on, and the thermostat set point when the heating was on, could not be estimated directly from measured illuminance levels and indoor air temperatures. To identify these moments, a distinction had to be made between daylight and light from the lighting; as well as between the free-running temperature and increases in the indoor air temperature due to heating. To do so, the following steps have been taken. (1) A TRNSYS building model was set up. (2) The heat capacity of the zone and the internal gains were varied in order to align the thermal behaviour of the building model with the one of the real building. The values for which the free-running temperature was closest to the measured free-running temperatures were chosen. (3) For each of the patients focused upon, the illuminance levels, indoor air temperatures, total short-wave solar radiation through the windows and the free-running temperature during their hospital stay were extracted from the continuously measured and simulated values. (4) For each of these patients, the moments when the lighting and heating were on, and the thermostat set points were estimated by comparing the simulated values with measured ones during their hospital stay. Below these steps are explained in more detail.

(1) In the TRNSYS building model, each patient room was a separate thermal zone. Room characteristics, building physical properties of the construction elements, characteristics of the technical services, internal gains and the heat capacity of the air were estimated based on the information from the architects. Shading from parts of the hospital building on the windows of the case was taken into account via the angular heights of these obstructions. The shading factor of the louver shading device was taken from a study that developed a ray-tracing method to describe the global solar transmittance of louver shading devices (Saelens et al., 2013). Shading factors are reported by Saelens et

al. (2013) for south orientations. These were used despite differences in the geometry of the shading device applied in their and in our study and in window orientations. We assumed that the difference between the real and simulated situation would be smaller when using the shading factors reported by Saelens et al. (2013) than when the louver shading would have been modelled as an overhang. Table 5.1 provides an overview of the input values of the building model, and a more detailed description of how these values were estimated.

(2) The heat capacity of the zone and the internal gains were identified via a sensitivity analysis. For different values of both, the free-running temperature was simulated and compared with measured free-running indoor air temperatures. For the simulations, the outdoor air temperature, outdoor relative humidity and outdoor global radiation measured at the hospital were used as input. Two, five and eight times the heat capacity of the air were considered for the heat capacity of the zone; 20 % higher and lower values than those assumed in the architects' simulations for the internal gains. The building model's thermal behaviour aligned most with the one of the real building when five times the heat capacity of the air and the architects' values for the internal gains were used. These values are given in Table 5.1.

(3) For respectively 319 and 424 patients, illuminance levels and indoor air temperatures measured during their hospital stay were extracted from the continuous measurements. The same was done for the simulated free-running temperatures and the total short-wave solar radiations through the windows. Patients' moment of arrival in their room and departure from it was taken from the hospital's management's information. Table 5.2 provides an overview of the personal and room characteristics of the patients for which data were extracted. This group of patients contains respondents in case indoor air temperatures or illuminance levels were measured in their room.

(4) The moments when the lighting or heating were on, and the thermostat set points, were identified by comparing simulated with measured values, and on a 10-minute time base. Especially horizontal patterns in the illuminance levels indicated when the lighting was on. Figure 5.3 illustrates this. The interviews and illuminance levels informed that patterns in the use of the main lighting and bedside lamp differ. Therefore, a distinction was made between moments when a bedside lamp was on (>5lx and <=20lx) and moments when the main lighting was on (>20lx). What follows focusses on the main lighting.

When identifying when the heating was on, the accuracy of the sensors (+-0.21°C) and, based on research of Royapoor & Roskilly

(2015), possible deviations in the simulated temperatures (+-0.5 °C)[1] were taken into account. The heating was assumed to be on if the measured indoor air temperature was more than 0.71 °C higher than the simulated free-running temperature. Figure 5.3 illustrates this. The decreases and increases in the indoor air temperature allowed to estimate the set point when the heating was on. This is also illustrated on Figure 5.3. The set points were estimated with an interval of 0.5 °C.

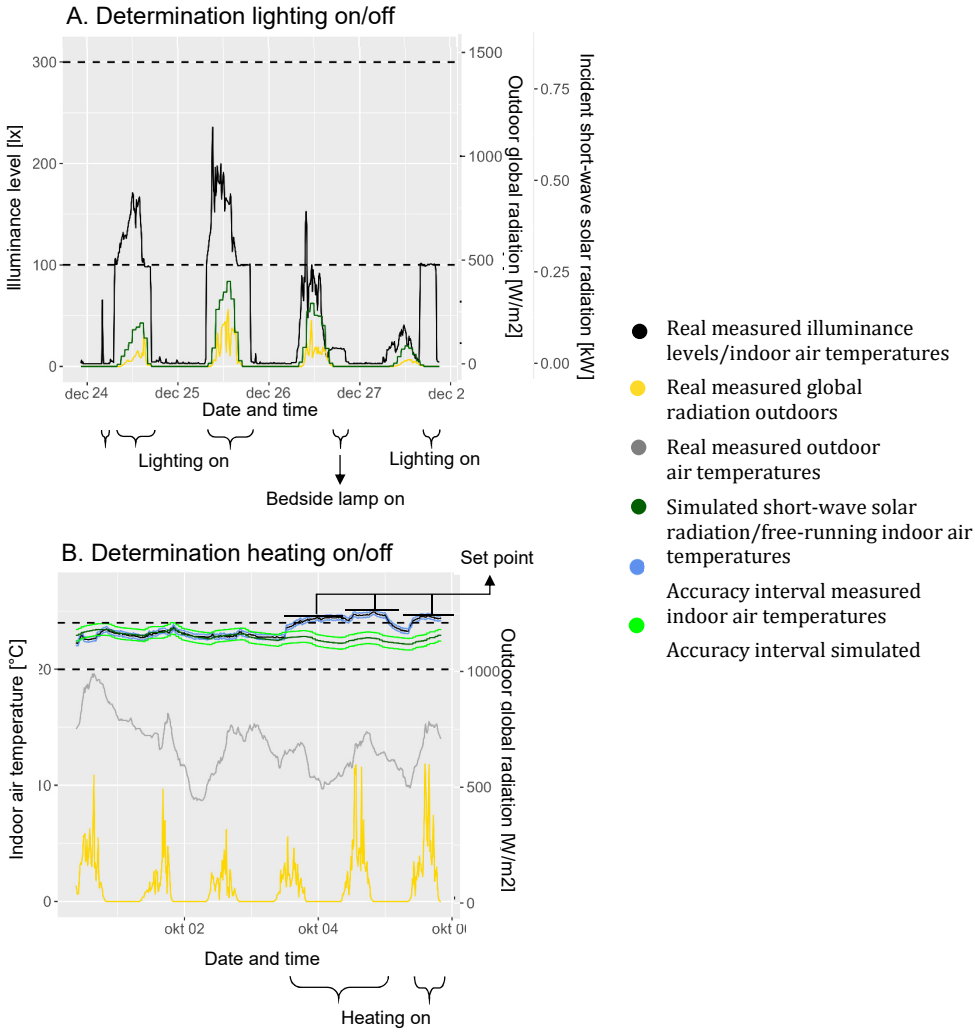


Figure 5.3 Determining when the lighting (A) and heating (B) were on.

[1] Note that a deviation of 0.5 °C holds when simulated results of the energy use for heating fall within the ranges for the mean bias error and the coefficient of variation of the root mean square error as specified in American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Guideline 14 (ASHRAE, 2002). Since no data are available on the actual heating demand of the investigated wards, we were unable to verify this.

Table 5.1 Overview of the values used as input for the simulation, and how these values were estimated.

Type of input	Characteristics	Source
Room characteristics		
Single room	Area=+-17.26 m^2	Plans VK Architects and Engineers
	Volume=+-110 m^3	Plans VK Architects and Engineers
Double room	Area=+-26 m^2	Plans VK Architects and Engineers
	Volume=+-170.5 m^3	Plans VK Architects and Engineers
Building physical properties		
External wall	U=0.25 W/(m^2K)	Based on the comfort analysis of VK Architects and Engineers
Windows	Area=5 m^2	Plans VK Architects and Engineers
	$U_{glazing}$=0.86 W/(m^2K)	Based on the comfort analysis of VK Architects and Engineers
	glazing: g=0.591	Based on the comfort analysis of VK Architects and Engineers
	glazed fraction=0.83	Formula of ISO 52016-1:2017, values based on pictures of the patient rooms
	shading factor sun shading: - September: 0.77 - October: 0.74 - November: 0.69 - December: 0.66 - January: 0.68	Based on Saelens et al. (2013). From their study we used the monthly averages of the shading factor calculated for louvers with an inclination of 30° compared against the horizontal position and when the variation in the transmission of solar radiation due to the changing solar position as well as internal reflections and indirect gains due to heating of the different layers of the louver and glazing are taken into account.
Internal walls	wall corridor: U=0.567 W/(m^2K)	Based on the comfort analysis of VK Architects and Engineers
	wall other room: U = 0.425 W/(m^2K)	Based on the comfort analysis of VK Architects and Engineers
Ceiling	U = 0.246 W/(m^2K)	Based on the comfort analysis of VK Architects and Engineers
Floor	U = 0.422 W/(m^2K)	Based on the comfort analysis of VK Architects and Engineers
Infiltration rate	0.05 h^{-1}	Assumed value
Technical services		
Mechanical ventilation	100 m^3/h per patient, supply temperature = 21 °C	Based on information of the technical services of the hospital

Internal gains		
Patient	90 W per person, 100 % of the time	Comfort analysis VK Architects and Engineers and a sensitivity analysis comparing the real and estimated indoor air temperatures when the gains are lowered or increased with 20 %.
Lighting	7.5 W/m^2, according to the lighting behaviour identified when applicable for that room and moment, between 18 h and 22 h elsewise	Comfort analysis VK Architects and Engineer (assumption lighting on between 18h and 22h) and a sensitivity analysis comparing the real and estimated indoor air temperatures when the gains are lowered or increased with 20 %.
Television	100 W per patient, in 100 % of the rooms between 10 h and 22 h, 0 % elsewise	Comfort analysis VK Architects and Engineers and a sensitivity analysis comparing the real and estimated indoor air temperatures when the gains are lowered or increased with 20 %.
Fridge	33 W per patient, 100 % of the time	Comfort analysis VK Architects and Engineers and a sensitivity analysis comparing the real and estimated indoor air temperatures when the gains are lowered or increased with 20 %.
Characteristics of the zone		
Heat capacity of the zone	5 times the heat capacity of the air volume of the room	Based on two sensitivity analyses: (1) one comparing the real and estimated free running indoor air temperatures; (2) one focusing on the decay curve of the real and estimated indoor air temperatures when the set point is increased or decreased

Table 5.2 Overview of the period of the measurements and the personal (birth sex, age, and length of stay) and room characteristics (type of room and window orientation) of the patients for which the use of the lighting and heating was estimated.

	Use of the lighting	**Use of the heating**
Period of measurements	September 29, 2020 - January 8, 2021	September 29, 2020 - January 8, 2021
Birth sex: % woman	55%	58%
Age [years]: mean, sd	60; 17	59; 17
Length of stay [days]: mean, sd	6.9; 6.3	7.1; 6.7
Type of room: % single room	42%	47%
Window orientation	NE: 33%; SE: 25%; SW: 29%; NW: 13%	NE: 31 %; SE: 26 %; SW: 30 %; NW: 12 %

2.4. Data analysis

Data analysis consisted of three steps, which are visualized on the right of Figure 5.1. First, different characteristics of patients (i.e. birth sex, age, body mass index, length of stay, number of days already in the hospital, and self-rated well-being) and their setting (i.e. outdoor air temperature, outdoor relative humidity, outdoor global radiation, length between sunrise and sunset, moment of the day, type of room, window orientation and view out) were taken into account. Second, for each of the characteristics, different situations were distinguished (e.g. young versus old patients with regard to characteristics related to the patients, or cold versus moderate outdoor temperature with regard to characteristics of the setting). The data was grouped per situation for each identified characteristic (e.g. moderate versus low average outdoor temperature). The data was analysed separately and in an integrated way via joint displays. Third, for each of the characteristics, a comparison was made between the distinguished situations via the joint displays and an integrated analysis. The approach is visualized in Figure 5.4. It was explored whether or not the adaptation strategies adopted, indoor conditions, assessments or experiences are similar or different between the compared situations. Types of scenarios could then be identified. These scenarios combine characteristics for which experienced comfort and adaptation vary in the same way across their compared situations (e.g. similar visual comfort and adaptation when the average outdoor temperature differs

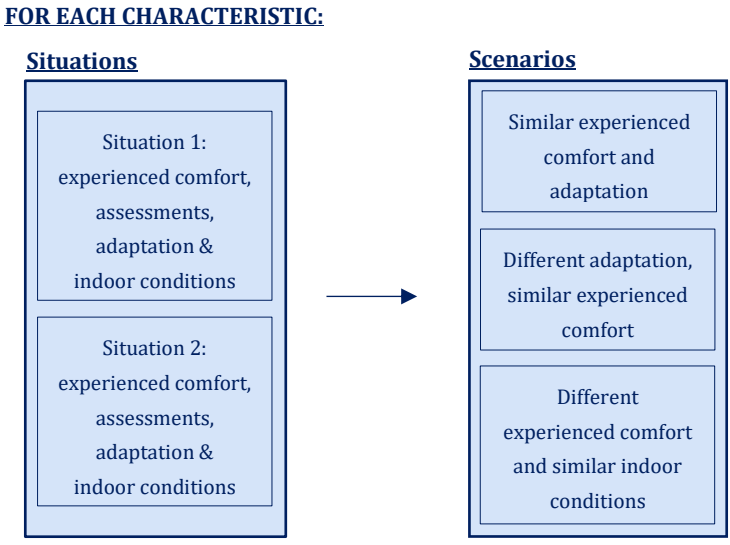


Figure 5.4 Visualization of the integrated analysis.

2.4.1. Identifying characteristics related to the patients or their setting

Characteristics related to the patients or their setting that could influence visual and thermal comfort or adaptation were searched for. Characteristics were identified based on the interviews and supplemented with those that influence adaptations of indoor conditions according to literature (Stazi et al., 2017; Polinder et al., 2013).

To identify characteristics based on the interviews, transcripts of audio-recordings of the interviews were analysed qualitatively, roughly guided by the Qualitative Analysis Guide of Leuven (QUAGOL) (Dierckx de Casterlé et al., 2012). QUAGOL was followed until a conceptual understanding of the interview data as a whole was obtained. The concepts in this chapter are the characteristics. Only the characteristics that could be related to sensor measurements and questionnaire findings were retained. For example, habits at home influenced the use of lighting. However, habits at home were not questioned in the questionnaire, so it could not be included in the analysis that followed.

Based on this qualitative analysis and literature, a distinction was made between environmental (average outdoor temperature, average outdoor relative humidity, average outdoor global radiation, and length between sunrise and sunset), time-related (moment of the day), socio-material (type of room, and the combination of the window orientation and view out), bodily (age, body mass index, and birth sex), and psychological characteristics (length of stay, number of days already in the hospital, and self-rated well-being). The identified characteristics are presented on the top right of Figure 5.1.

2.4.2. Comparison of situations for each identified characteristic

For each of the characteristics, identified as potentially influencing comfort and adaptation, different situations were distinguished. In case the characteristic is a categorical variable, the data were grouped into situations according to the characteristic's categories. In case the characteristic is a numerical variable, the data were grouped into two situations. The values used to distinguish the situations are presented in Table 5.3.

For each characteristic we compared between the distinguished situations (1) the measured indoor air temperatures as well as the illuminance levels; (2) the extent to which the groups of respondents perceived control over the thermostat, heating, light switch, light dimmer and window curtains; (3) the extent to which the groups of respondents applied each of the adaptation strategies; (4) the extent to which the heating and the lighting were on within each of the groups; (5) satisfaction with the thermal and visual comfort; and (6) experiences of the thermal and visual conditions. The grouping of the data and these comparisons are described in more detail below.

(1) Indoor air temperatures and illuminance levels, extracted from the continuous measurements for the different patients, were analysed in

two ways per situation. The first way consists of two steps. First, to give each 10-minute interval of the day an equal weight, the mean was calculated per 10-minute interval of each day. Second, the distribution of measured values (mean, 1st quartile, 3rd quartile, 5th percentile, and 95th percentile) was calculated across the days per 10-minute interval. Next to this analysis, the percentage of 10-minute intervals for which the indoor air temperature and illuminance level achieved threshold values was calculated. The results obtained through both analyses were compared between the situations considered.

(2) A Chi-squared test was performed to compare between situations the extent to which the groups of respondents perceived control over the thermostat, light switch, light dimmer, and window curtains when filling in the questionnaire. The significance level (α) was taken equal to 0.1.

(3) For hospitalized patients five adaptation strategies have been distinguished in Chapter 3: the adaptation of indoor conditions, no wish to adapt indoor conditions, the adaptation of position, adaptation by choice and imposed adaptation. Based on respondents' questionnaire responses, the adaptation strategy that they applied when filling in the questionnaire could be identified. How the strategy is identified, is described in Chapter 3. A Chi-squared test was performed to compare between situations the extent to which the groups of respondents applied each of the adaptation strategies. The significance level (α) was taken equal to 0.1.

(4) The data about the thermostat set points were analysed in three steps. First, the data when the heating was on were extracted from the total dataset. Second, the mean of the set points was calculated across the days to obtain a value per 10-minute interval of the day. Third, the mean of the values obtained in the previous step was calculated. This mean was compared between the situations. To analyse the percentage of moments that the heating and lighting were on, the latter two steps were taken as well. However, in the data file started from, a 10-minute interval with the heating, respectively lighting, being on had been indicated with a '1', a 10-minute interval when it was off with a '0'.

(5) Descriptive and inferential statistics were applied to analyse satisfaction votes. The distribution of respondents' vote was compared visually between situations and statistically by applying Mann–Whitney U tests, Kruskal Wallis tests, and Wilcoxon Signed Rank tests. The results informed about satisfaction at an aggregated level.

(6) The interviews were grouped per situation. It was then analysed qualitatively whether differences in the experiences could be observed between situations. This analysis informed about what the social construct 'comfort' means. Quotes reported in this chapter were translated from Dutch to English.

Table 5.3 Values used to split the patients into groups. (Not applicable (NA)).

Characteristics	Compared situations	Splitting values	Reason behind splitting value
Environmental characteristics			
Outdoor air temperature	Cold	< 9.6 °C	Median of the average of the outdoor temperatures measured during the calendar days that patients of the largest dataset reside in the hospital.
	Less cold	>= 9.6 °C	
Outdoor relative humidity	Humid	>= 87 %	Median of the average of the outdoor relative humidity measured during the calendar days that patients of the largest dataset reside in the hospital.
	Less humid	< 87 %	
Outdoor global radiation	Sunny	>= 95 W/m^2	Median of the average outdoor global radiation measured between 8h30 and 16h30 during the calendar days that patients of the largest dataset reside in the hospital. The period between 8h30 and 16h30 is chosen as this is the shortest period between sunrise and sunset during the case study.
	Less sunny	< 95 W/m^2	
Length between sunrise and sunset	Long length	< 8 h 50 min	Median of the length between sunrise and sunset during the calendar days that patients of the largest dataset reside in the hospital.
	Short length	>= 8 h 50 min	
Time-related characteristics			
Moment of the day	Morning	> 7 h 30 & <= 12 h	Typical division of a day in the hospital
	Afternoon	> 12 h & <= 18 h 30	
	Evening	> 18 h 30 & <= 21 h 30	
	Night[1]	> 21 h 30 & <= 7 h 30	
Contextual and social characteristics			
Type of room	Single room	NA	
	Double room		
Window orientation and view out	Patio - northeast orientation	NA	
	Patio - northwest orientation		

[2] Only analysed for the measurements and moments that the heating and lighting are on or off.

	Patio - southwest orientation		
	Average view - northeast orientation		
	Wide view - southeast orientation		
Bodily characteristics			
Birth sex	Man	NA	
	Woman		
Age	Young	< 55 years	Median age of patients during the fieldwork, based on the largest dataset
	Old	>= 55 years	
Body mass index[2]	Normal BMI	< 25	Underweight (only 3 participants) and normal weight of questionnaire participants are distinguished from overweight or obese
	High BMI	>= 25	
Psychological characteristics			
Length of stay	Short length of stay	<= 4 days	Median length of stay of patients during the fieldwork, based on the largest dataset
	Long length of stay	> 4 days	
Number of days already in the hospital	Few days already in the hospital	< 4 days	Median amount of days in the hospital of patients during the fieldwork, based on the largest dataset
	Many days already in the hospital	>= 4 days	
Self-rated well-being[2]	Low self-rated well-being	< neutral	Negative and neutral self-rated well-being are distinguished from positive self-rated well-being
	High self-rated well-being	>= neutral	

[3] Only analysed for the respondents.

2.4.3. Integrated analysis

As described above, for each characteristic, its situations were compared based on the individual qualitative and quantitative data. In the integrated analysis, these individual analyses were brought together via joint displays (e.g. Table 5.5 and Figure 5.5). One joint display was set up per characteristic. This enabled analysing whether experienced comfort and adaptation are similar or different between the situations considered. Attention was given as well to whether the results of the different types of qualitative and quantitative data were congruent, complementary or discrepant. Conducting this analysis for each of the identified characteristics enabled grouping the observations in types of scenarios.

3. Results

3.1. Overview

As explained in the 'Methodology', different characteristics that could influence comfort and adaptation were identified. For each of these characteristics, different situations were compared. Based on this comparison, three types of scenarios were identified: sometimes adaptation and experienced comfort are similar, sometimes adaptation differs and experienced comfort is similar, and sometimes experienced comfort differs while indoor conditions are similar. Table 5.4 provides an overview of the characteristics that belong to each of these three scenarios. The upper part of the table focuses on thermal comfort, the lower part on visual comfort. In what follows, the three types of scenarios are discussed in more detail and examples of the scenarios are given. In the choice of the examples, priority was given to socio-material, bodily, and psychological characteristics because environmental characteristics have already been described more extensively in the state-of-the-art (e.g. Stazi et al., 2017). Time-related characteristics were not chosen because few patients completed the questionnaire three times. Subsequently the characteristics were chosen for which the scenario was most apparent (e.g. lowest p-values when questionnaire results were compared between the situations).

3.2. Similar experienced comfort and adaptation

In some situations, experienced comfort and adaptation are similar. Indoor conditions can be similar or different.

Thermal comfort and adaptation are similar in situations with a higher and lower average outdoor relative humidity, longer and shorter lengths between sunrise and sunset, different moments of the day, higher and lower body mass indexes, shorter and longer lengths of stay, and more or less days since patients' hospitalization. These situations cover about half of the analysed characteristics.

Table 5.4 Overview of the characteristics belonging to each of the three scenarios for thermal (top) and visual comfort and adaptation (bottom).

THERMAL COMFORT AND ADAPTATION					
Scenarios	**Characteristics**				
	Environmental	**Time-related**	**Socio-material**	**Bodily**	**Psychological**
Similar experienced comfort and adaptation	average outdoor relative humidity	moment of the day		body mass index[3]	length of stay
	length between sunrise and sunset				number of days since hospitalization
Different adaptation, similar experienced comfort	average outdoor temperature		single or double room	age	
	average outdoor global radiation during the day		window orientation and view out		
Different experienced comfort				birth sex	self-rated well-being[3]
VISUAL COMFORT AND ADAPTATION					
Scenarios	**Characteristics**				
	Environmental	**Time-related**	**Socio-material**	**Bodily**	**Psychological**
Similar experienced comfort and adaptation	average outdoor temperature	moment of the day	window orientation and view out	birth sex	
	average outdoor global radiation during the day			body mass index[3]	
	average outdoor relative humidity[4]			age[4]	
	length between sunrise and sunset				
Different adaptation, similar experienced comfort			single or double room		length of stay
					number of days since hospitalization
Different experienced comfort					self-rated well-being[3]

[4] The comparison between patients with a low or high body mass index did not include a comparison of the percentage of moments that the heating or lighting were on as no information about patients' body mass index was available for the dataset extracted from the continuous measurements.

[5] Perceived control (over one or more of the considered adaptable building characteristics) differs significantly, but not the adaptation strategies adopted.

Visual comfort and adaptation are similar in situations with higher and lower average outdoor temperatures, higher and lower average outdoor global radiation levels during the day, a higher and lower average outdoor relative humidity, longer and shorter lengths between sunrise and sunset, different moments of the day, different combinations of the window orientation and view out, different birth sexes, higher or lower body mass indexes, or older and younger patients. These situations cover about 69% of the analysed characteristics.

In what follows, two characteristics are discussed in more detail: birth sex and the combination of the view out and window orientation, each time with respect to visual comfort and adaptation. These characteristics are underlined in Table 5.4. Both differ as indoor conditions are similar in the compared situations for the first, different for the second.

3.2.1. Visual comfort and adaptation – birth sex

The relationship between birth sex and visual comfort and adaptation was investigated. Table 5.5 presents interview quotes, perceived control, adaptation strategies, percentage of moments for which the lighting is on, satisfaction votes, and measurements' compliance rate with threshold values for men and women. Figure 5.5 shows the percentage of moments that the lighting is on, and the distribution of illuminance levels in their rooms. Men adopt similar adaptation strategies as women to achieve similar visual conditions and satisfaction. Men and women can therefore be regarded as similar patients with respect to visual comfort and adaptation.

More specifically, based on the interviews, no difference could be noted between men and women in their experience of visual conditions, perceived control over it, or adaptation strategies applied with respect to it (Table 5.5: interview quotes). The questionnaire results complement the interviews. These indicate that there is no significant difference in the control male and female respondents perceive over the light switch, light dimmer and window curtains (Table 5.5: perceived control). Adaptation strategies applied do not differ significantly either (Table 5.5: adaptation strategies). The measurements are congruent with these observations. These indicate that the probability that the lighting is on is similar for men and women (Figure 5.5: percentage of moments with lighting on; Table 5.5: Adaptation of indoor conditions). The illuminance levels measured in their rooms are similar as well (Figure 5.5: illuminance levels; Table 5.5: threshold values). Congruent with illuminance levels' compliance rate with threshold values, no significant difference in satisfaction with visual comfort could be identified between men and women based on the questionnaire (Table 5.5: satisfaction).

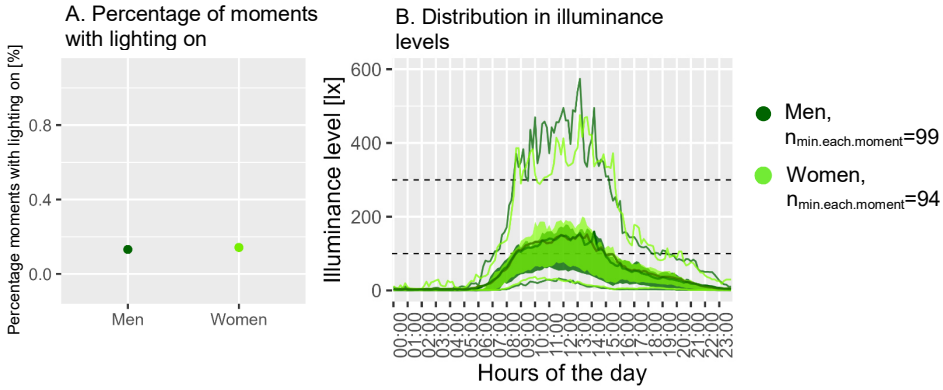


Figure 5.5 Percentage of moments that the lighting is on (A), and the distribution of illuminance levels (B) in rooms of men and women.

Table 5.5 Interview quotes, perceived control, adaptation strategies, satisfaction votes and characteristics of the measured values of men and women (number of interviewees (n_i), number of respondents (n_s), not significant (n.s.)).

TYPE OF SITUATION:	**Men (n_i=5, n_s=97)**	**Women (n_i=14, n_s=138)**	
EXPERIENCE	**Interview quotes**		
	"There's a lot of light, so that's pleasant. Because I know those older rooms. Then there are usually two beds next to each other; and now you're lying opposite to each other." (participant 4)	"You're both at the window. You have sunlight. I think that's important. [...] You can also adapt [the lighting] yourself eh. You can make it lighter and such." (participant 1)	
	"The lighting, that's good eh. You can adapt that. Harder. Lower." (participant 10)		
ADAPTATION	**Perceived control [n]**		**p-value**
Light switch			n.s.
Light dimmer			n.s.
Window curtains			n.s.
	Adaptation strategy [n]		**p-value**
Comparison strategies			n.s.
	Adaptation of indoor conditions		
Percentage of moments with lighting on	13 %	14 %	
ASSESSMENT	**Satisfaction votes [Q1/median/Q3 votes]**		**p-value**
Visual comfort	2 2 3	2 2 3	n.s.
MEASUREMENTS	**Threshold values [% of time]**		
Illuminance level (8 h-18 h)	>=100 lx: 31 %	>=100 lx: 34 %	

3.2.2. Visual comfort and adaptation – view out and window orientation

The relationship between different combinations of the view out and window orientation, and visual comfort and adaptation was investigated. Table 5.6 presents interview quotes, perceived control, adaptation strategies, percentage of moments when the lighting is on, satisfaction votes, and measurements' compliance rate with threshold values in rooms with a view on a patio and a northeast (NE), northwest (NW) or southwest (SW) window orientation, an average view out and a northeast window orientation, and a wide view out and a southeast (SE) window orientation. Figure 5.6 shows the percentage of moments that the lighting is on, and the distribution of illuminance levels in these rooms. Despite differences in the measurements' compliance rate with threshold values, the situations can be considered as similar. This comparison shows an extreme example of situations for which experienced comfort and adaptation are similar.

More specifically, based on the questionnaire, no significant difference is observed in the control that respondents perceive over the light switch, light dimmer and window curtains (Table 5.6: perceived control). No significant difference is found either between the adaptation strategies applied (Table 5.6: adaptation strategies). The probability that the lighting is on, which is estimated based on sensor measurements, is in general similar between the compared situations (Figure 5.6: percentage of moments with lighting on; Table 5.6: adaptation of indoor conditions). The higher probability of the lighting being on in rooms with an average view out and a northeast window orientation can be explained by the lower illuminance levels in these rooms compared with those with a wide view out and a southeast window orientation (Figure 5.6: illuminance levels). Although the percentage of time that the lighting is on is higher in rooms with an average view out, the illuminance levels are still lower than in rooms with a wide view out. The most remarkable is that the illuminance level is also low in rooms with a view on a patio, but the probability that the lighting is on is nevertheless the lowest in these rooms. A reason why the lighting is not used more can be found in the interviews. Interviewees who have a view on a patio feel uncomfortable when the lighting is on in the evening and the window curtain open (Table 5.6: interview quotes). Patients staying in a room on the other side of the patio can then look into their room. However, some interviewees indicate as well that in those situations the lighting is turned on and the window curtain closed. Despite differences in the compliance rate of illuminance levels with threshold values, there is no significant difference in satisfaction with visual comfort (Table 5.6: satisfaction).

Table 5.6 Interview quotes, perceived control, adaptation strategies, satisfaction votes and characteristics of the measured values of interviewees and respondents with different views out and window orientations.

TYPE OF SITUATION:	**Northeast, patio (n_i=1, n_s=40)**	**Northwest, patio (n_i=3, n_s=28)**	**Southwest, patio (n_i=6, n_s=72)**	**Northeast, average view out (n_i=3, n_s=37)**	**Southeast, wide view out (n_i=6, n_s=50)**	
EXPERIENCE	**Interview quotes**					
			"Only at night you close the curtains. Because if there's some light burning there. You can look into the room at the other side. You see those people and they see you. At this moment you can't see it that way because it's not dark. But at night and in the morning and the nurse comes and it's dark and they turn on the lights, and there too. Then you can really see that. It seems like if they are standing next to you." (participant 1)		"I took two pictures of the view. Yes in the light and the dark. [...] I say yes, room with a view." (participant 3)	
ADAPTATION	**Perceived control [n]**					**p-value**
Light switch						n.s.
Light dimmer						n.s.
Window curtains						n.s.
	Adaptation strategy [n]					**p-value**
Comparison strategies						n.s.

	Adaptation of indoor conditions					
Percentage of moments with lighting on	13 %	12 %	12 %	20 %	14 %	
ASSESSMENT	**Satisfaction votes [Q1/median/Q3 votes]**					**p-value**
Visual comfort	1 2 3	2 2 3	1 2 3	2 2 3	2 2 3	n.s.
SENSOR MEASUREMENTS	**Threshold values [% of time]**					
Illuminance level (8 h-18 h)	>=100 lx: 19 %	>=100 lx: 34 %	>=100 lx: 27 %	>=100 lx: 37 %	>=100 lx: 43 %	

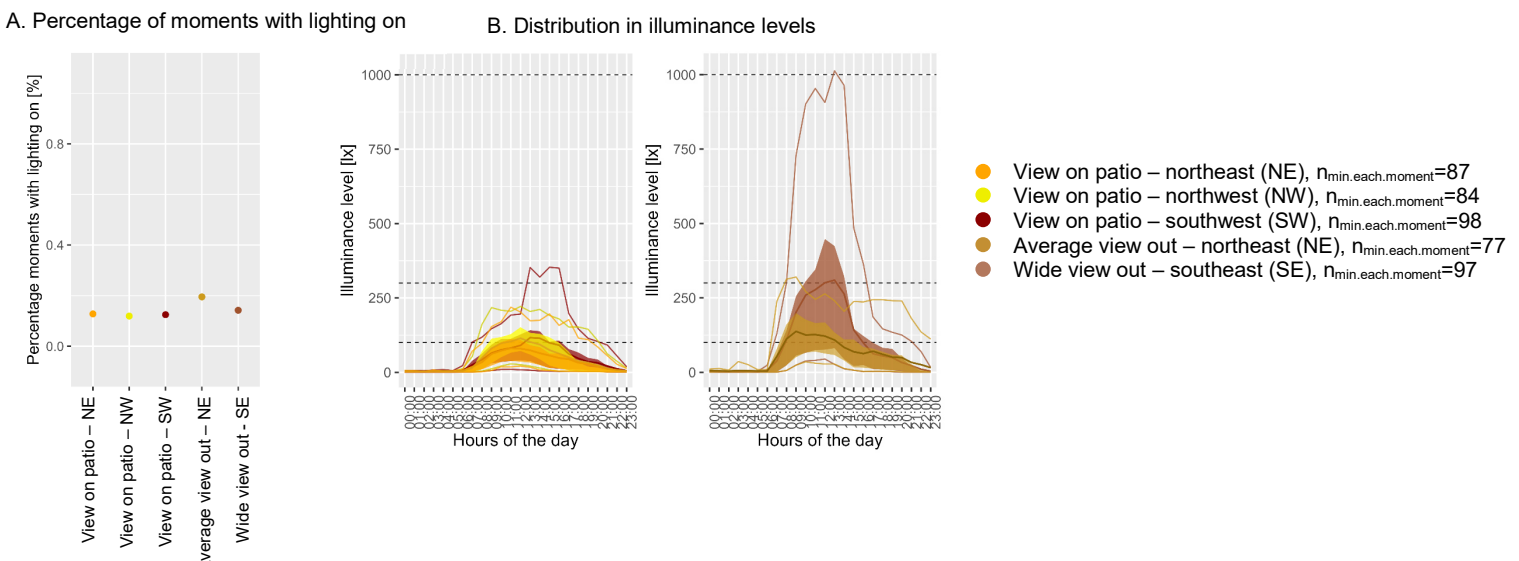


Figure 5.6 Percentage of moments that the lighting is on (A), and the distribution of illuminance levels (B) in rooms with different views out and window orientations.

3.3. Different adaptation and similar experienced comfort

Some patients adopt different adaptation strategies to obtain a similar experienced comfort. In our study, indoor conditions are similar when this scenario is identified.

Different adaptation with a similar experienced comfort is shown for thermal comfort and adaptation in situations with higher and lower average outdoor temperatures, higher and lower average global radiation levels during the day, single and double rooms, different combinations of the window orientation and view out, and younger and older patients. These situations cover 38% of the analysed characteristics.

Different adaptation with a similar experienced comfort is shown for visual comfort and adaptation in situations with single and double rooms, shorter and longer lengths of stay, and more or less days since patients' hospitalization. These situations cover 23% of the analysed characteristics.

In what follows, two characteristics are discussed in more detail: differences between single and double rooms, and the combination of the view out and window orientation, each time with respect to thermal comfort and adaptation. These characteristics are underlined in Table 5.4. Both differ as in the compared situations the heating is used in another way for the first, and to another extent for the second.

3.3.1. Thermal comfort and adaptation – single or double room

The relationship between the type of room and thermal comfort and adaptation was investigated. Table 5.7 presents interview quotes, perceived control, adaptation strategies, percentage of moments with the heating on, satisfaction votes, and measurements' compliance rate with threshold values for single and double rooms. Figure 5.7 shows the percentage of moments that the heating is on, the mean set point when the heating is on, and the distribution of indoor air temperatures in these rooms. In single rooms, patients apply different adaptation strategies than in double rooms to obtain similar thermal conditions and a similar satisfaction.

More specifically, interviewees express that the face-to-face design of double rooms promotes their perceived control over indoor conditions in comparison with designs for which patients reside next to each other. Nevertheless, interviewees of single rooms perceive more control over indoor conditions and refer more to adaptations of them, for example via the heating (Table 5.7: interview quotes). The questionnaire findings are congruent with this observation. They indicate that patients perceive significantly more control over the thermostat in single rooms (Table 5.7: perceived control). Moreover, most adaptation strategies that involve an action are applied significantly more in these rooms (Table 5.7: adaptation strategies). Discrepant with the above observations is the higher probability that the heating is on in double rooms

according to estimations based on the sensor measurements (Figure 5.7: percentage of moments with the heating on). In combination with the previous observations, this suggests that the heating is more likely to be left on for long periods in double rooms. In that case too, there are no adaptations of indoor conditions. Furthermore, higher set points are chosen in single rooms (Figure 5.7: mean set point). The lower probability of the heating being on, and the higher mean set point provide a possible explanation for why aggregated values of the indoor air temperature are similar in both type of rooms (Figure 5.7: indoor air temperatures). Despite the difference in perceived control and adaptation strategies applied, the questionnaire results indicate that there is no significant difference in satisfaction with thermal comfort (Table 5.7: satisfaction).

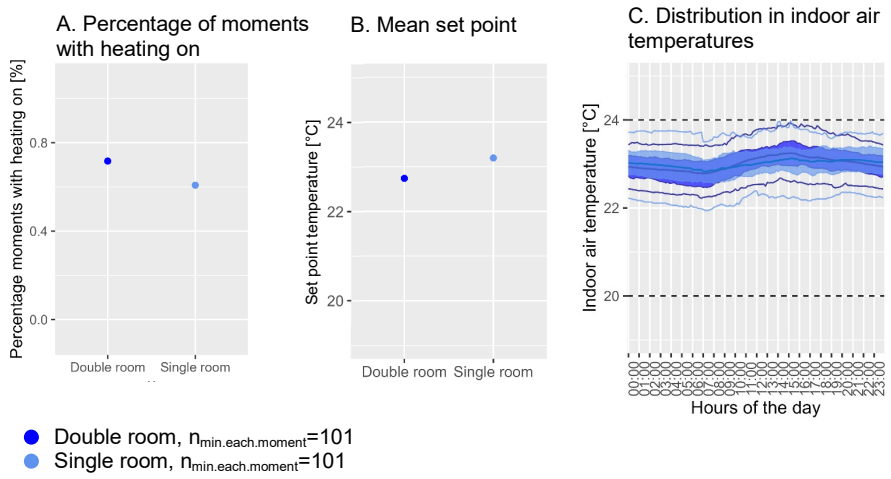


Figure 5.7 Percentage of moments that the heating is on (A), the mean set point when the heating is on (B), and the distribution of indoor air temperatures (C) in single and double rooms.

Table 5.7 Interview quotes, perceived control, adaptation strategies, satisfaction votes and characteristics of the measured values of interviewees and respondents in single and double rooms. If respondents perceive significantly more control or apply a particular adaptation strategy significantly more in one type of room in comparison with the other type, their number is shown in bold and underlined.

TYPE OF SITUATION:	**Single room (n_i=9, n_s=134)**	**Double room (n_i=10, n_s=93)**	
EXPERIENCE	**Interview quotes**		
	"You can adapt [the temperature] yourself. When I got in here it was a little chilly, so I turned it up a little bit myself, so. You can do that when you have a single room. When you're with two, you always have to take each other into account. So. No, everything good." (participant 15)	"Yesterday [the door] was open because it was too hot here. But nobody has been smart enough to turn off the heating eh." (participant 19)	
ADAPTATION	**Perceived control [n]**		**p-value**
Thermostat			0.03
Perceived control [n]	**<u>33</u>**	10	
No perceived control [n]	87	**<u>67</u>**	
Heating			n.s.
	Adaptation strategy [n]		**p-value**
Adaptation of indoor conditions			0.001
Action to increase	**<u>41</u>**	13	
Action to decrease	7	**<u>14</u>**	
No wish to adapt indoor conditions	23	**<u>20</u>**	
Adaptation by choice to indoor conditions			
prefer more	16	**<u>11</u>**	
prefer less	0	**<u>2</u>**	
Imposed adaptation to indoor conditions, with action			
prefer more	**<u>11</u>**	0	
prefer less	**<u>1</u>**	0	

Imposed adaptation to indoor conditions, without action			
prefer more	6	**7**	
prefer less	**1**	0	
	Adaptation of indoor conditions		
Percentage of moments with heating on	61 %	72 %	
Chosen set point	23.2 °C	22.7 °C	
ASSESSMENT	**Satisfaction votes [Q1/median/Q3 votes]**		**p-value**
Thermal comfort	1 2 3	1 2 3	n.s.
SENSOR MEASUREMENTS	**Threshold values [% of time]**		
Indoor air temperature	20 °C <= T < 24 °C: 82 %	20 °C <= T < 24 °C: 84 %	

3.3.2. Thermal comfort and adaptation – view out and window orientation

The relationship between the combination of the view out and window orientation, and thermal comfort and adaptation was investigated. Table 5.8 presents interview quotes, perceived control, adaptation strategies, percentage of moments with the heating on, satisfaction votes, and measurements' compliance rate with threshold values in the rooms with a different view out and window orientation. Figure 5.8 shows the percentage of moments that the heating is on, the mean set point when the heating is on, and the distribution of indoor air temperatures in these rooms. Participants residing in rooms with a view on a patio and a northeast or southwest window orientation use the heating more than in rooms with another view out, while thermal conditions and satisfaction are similar.

More specifically, based on the questionnaire, no significant difference is observed in the control that respondents perceive over the heating and the thermostat (Table 5.8: perceived control). Complementary to this observation, the adaptation strategies applied differ significantly (Table 5.8: adaptation strategies). Respondents with a view on a patio and a northeast or southwest window orientation, as well as those with an average view out and a northeast orientation adapt indoor conditions more through an action which increases the warmth. Respondents are more likely to prefer less warmth in rooms with a wide view out and a southeast window orientation. Congruent with these findings, the probability of the heating being on, estimated based on sensor measurements, is the highest in rooms with a view on a patio and a northeast or a southwest window orientation, high as well in rooms with an average view out and a northeast orientation, and the lowest in rooms with a wide view out and a southeast window orientation (Figure 5.8: percentage with heating on; Table 5.8: adaptation of indoor conditions). When the heating is on, its set point is similar

(Figure 5.8: mean set point; Table 5.8: adaptation of indoor conditions). Partly congruent with the comparison of adaptation strategies and differences in the probability that the heating is on, the highest 95th percentile values of the indoor air temperatures are measured in rooms with a view on a patio (Figure 5.8: indoor air temperatures). In addition, indoor air temperatures in rooms with a wide view out show a clearer day/night profile than those in rooms with a different view out. In line with the rather moderate behaviour in rooms with an average view out and a northeast orientation, indoor air temperatures' compliance rate with threshold values is the highest in these rooms (Figure 5.8: indoor air temperatures; Table 5.8: threshold values). There is no significant difference in satisfaction with the thermal comfort (Table 5.8: satisfaction). Congruent with this observation, no difference is noted in interviewees' experiences of thermal conditions.

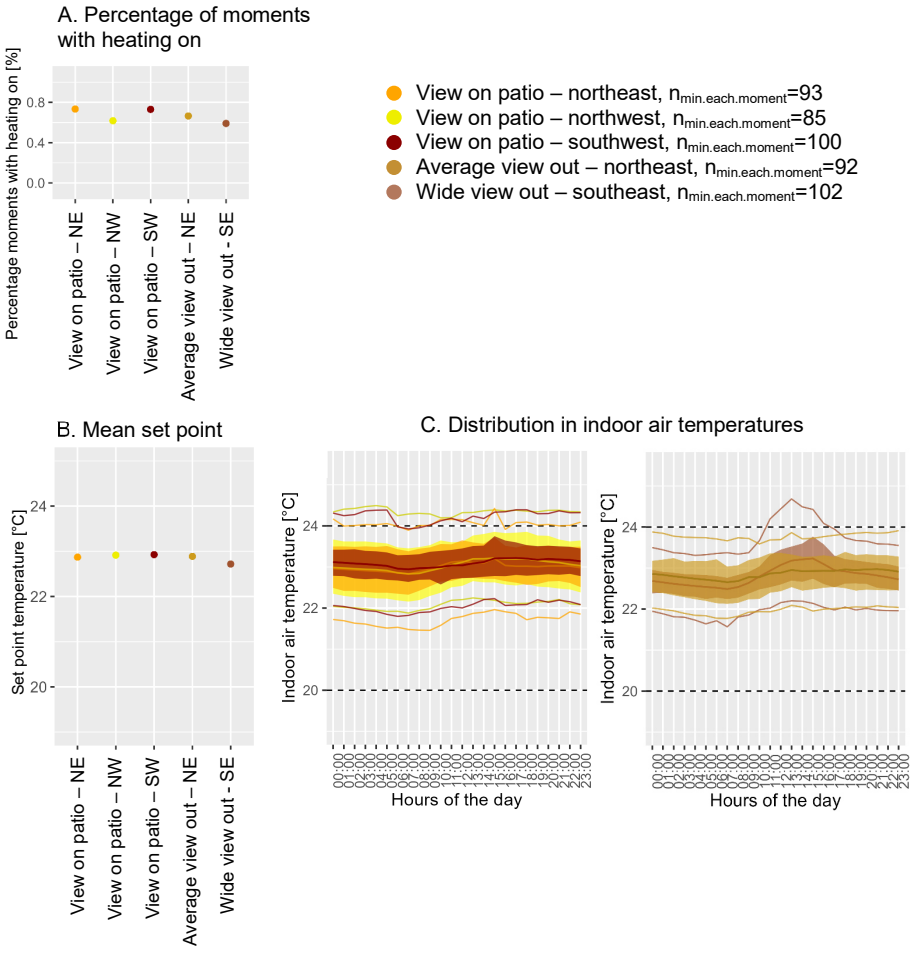


Figure 5.8 Percentage of moments that the heating is on (A), the mean set point when the heating is on (B), and the distribution of indoor air temperatures (C) in rooms with different views out and window orientations.

Table 5.8 Interview quotes, perceived control, adaptation strategies, satisfaction votes and characteristics of the measured values of interviewees and respondents in rooms with different views out and window orientations. If respondents perceive significantly more control or apply a particular adaptation strategy significantly more when their room has a certain view out and window orientation in comparison with other types, their number is shown in bold and underlined.

TYPE OF SITUATION:	**Northeast, patio (n_i=1, n_s=40)**	**Northwest, patio (n_i=3, n_s=28)**	**Southwest, patio (n_i=6, n_s=72)**	**Northeast, average view out (n_i=3, n_s=37)**	**Southeast, wide view out (n_i=6, n_s=50)**	
EXPERIENCE	**Interview quotes**					
ADAPTATION	**Perceived control [n]**					**p-value**
Thermostat						n.s.
Heating						n.s.
	Adaptation strategy [n]					**p-value**
Adaptation of indoor conditions						0.04
Action to increase	**14**	2	**15**	**10**	9	
Action to decrease	**5**	**4**	3	3	**7**	
No wish to adapt indoor conditions	3	**5**	12	**7**	**15**	
Adaptation by choice to indoor conditions						
prefer more	2	**3**	**4**	2	2	
prefer less	0	0	0	0	**1**	

Imposed adaptation to indoor conditions, with action						
prefer more	0	0	**10**	**2**	0	
prefer less	**5**	**5**	5	4	**7**	
Imposed adaptation to indoor conditions, without action						
prefer more	0	**1**	0	0	**1**	
prefer less	0	0	**1**	0	0	
	Adaptation of indoor conditions					
Percentage of moments with heating on	73 %	62 %	73 %	67 %	59 %	
Chosen set point	22.9 °C	22.9 °C	22.9 °C	22.9 °C	22.7 °C	
ASSESSMENT	**Satisfaction votes [Q1/median/Q3 votes]**					**p-value**
Thermal comfort	1 2 3	1 2 3	1 2 3	2 2 3	1 2 2	n.s.
SENSOR MEASUREMENTS	**Threshold values [% of time]**					
Thermal comfort						
Indoor air temperature	20 °C <= T < 24 °C: 76 %	20 °C <= T <24 °C: 85 %	20 °C <= T < 24 °C: 77 %	20 °C<= T < 24 °C: 93 %	20 °C <= T < 24 °C: 90 %	

3.4. Different experienced comfort and similar indoor conditions

In some of the compared situations, experienced comfort differs while indoor conditions are similar. Differences in experienced thermal comfort show themselves in situations with men and women, and a higher and lower self-rated well-being. These situations cover 15% of the analysed characteristics.

Differences in experienced visual comfort show themselves in situations with a higher and lower self-rated well-being. These situations cover 8% of the analysed characteristics.

In what follows, one characteristic is discussed in more detail: differences in birth sex, and this with respect to thermal comfort and adaptation. This example is underlined in Table 5.4.

3.4.1. Thermal comfort and adaptation – birth sex

The relationship between birth sex and thermal comfort and adaptation was investigated. Table 5.9 presents interview quotes, perceived control, adaptation strategies, percentage of moments when the heating is on, satisfaction votes, and measurements' compliance rate with threshold values for men and women. Figure 5.9 shows the percentage of moments that the heating is on, the mean set point when the heating is on, and the distribution of indoor air temperatures for them. Men adopt similar adaptation strategies as women to achieve similar thermal conditions. Yet their satisfaction differs. The experienced thermal comfort of men and women therefore differs.

More specifically, according to the questionnaire, there is no significant difference in the control that men and women perceive over the heating or thermostat (Table 5.9: perceived control). No significant difference is found either in the adaptation strategies applied (Table 5.9: adaptation strategies). Estimations of the use of the heating based on sensor measurements are partly discrepant with these observations. The probability that the heating is on is higher for men than for women (Figure 5.9: percentage with heating on). A possible explanation for this difference are the significantly lower outdoor temperatures during the hospital stay of men in comparison with women ($p=0.03$, mean outdoor temperature during the calendar day: 8,7°C for men; 9,2°C for women). Since adaptation strategies do not differ significantly, it can be assumed that the heating was more often continuously on in men's room. When the heating is on, the mean set point is similar for men and women (Figure 5.9: mean set point). Indoor air temperatures in their rooms are similar as well (Figure 5.9: indoor air temperatures). Despite the similar indoor air temperatures, men are significantly more satisfied with their thermal comfort (Table 5.9: satisfaction). The interviews suggest that women are more sensitive for variations in thermal conditions (Table 5.9: interview quotes).

Table 5.9 Interview quotes, perceived control, adaptation strategies, satisfaction votes and characteristics of the measured values of men and women.

TYPE OF SITUATION:	**Men (n_i=5, n_s=97)**	**Women (n_i=14, n_s=138)**	
EXPERIENCE	**Interview quotes**		
	"[The temperature] was also pleasant. It's almost always, I don't know how much now, it will be about 21 degrees." (participant 4)	"Yes, I do [notice variations in the temperature]. Because yesterday when I washed myself. Then it was fine. And in the afternoon when I had eaten. Then I stood up. Eating while standing up. And then I grabbed my jacket because I got it chilly. I had been lying here like this before. So yes, you notice that. It could also be me." (participant 3)	
ADAPTATION	**Perceived control [n]**		**p-value**
Thermostat			n.s.
Heating			n.s.
	Adaptation strategy [n]		**p-value**
Comparison strategies			n.s.
	Adaptation of indoor conditions		
Percentage of moments with heating on	73 %	64 %	
Chosen set point	22.9 °C	23.0 °C	
ASSESSMENT	**Satisfaction votes [q5/Q1/median/Q3 votes/q95]**		**p-value**
Thermal comfort	0 1 2 3 3	-1 1 2 3 3	0.07
SENSOR MEASUREMENTS	**Threshold values [% of time]**		
Indoor air temperature	20 °C <= T < 24 °C: 82 %	20 °C <= T < 24 °C: 83 %	

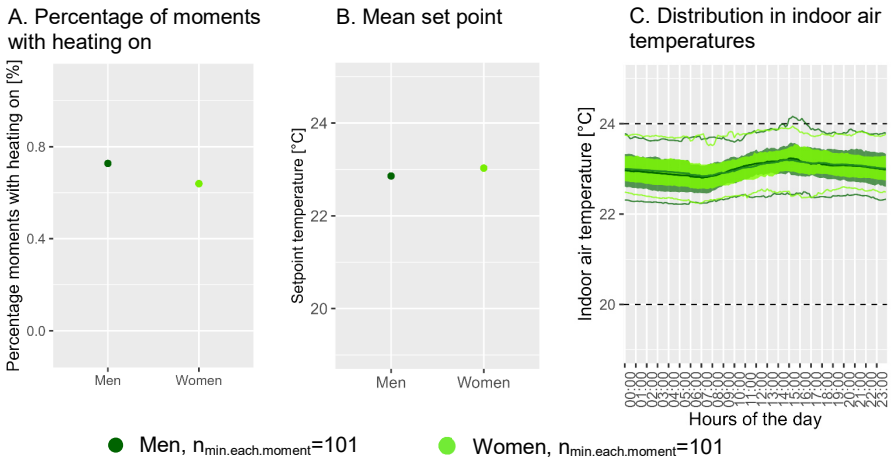


Figure 5.9 Percentage of moments that the heating is on (A), the mean set point when the heating is on (B), and the distribution of indoor air temperatures (C) for men and women.

4. Discussion

4.1. Main contribution

The main contribution of this chapter lies in the research approach. The integrated analysis allows a simultaneous analysis of indoor environmental comfort and adaptation, taking into account differences between people and differences between settings. This approach contributes to the ones typically applied in MCP and MAP research. First, current IEQ models of MCP research have been criticized for focusing on the comfort of an 'average' person (Bluyssen, 2020). The approach of this chapter enables understanding when and why comfort requirements differ. Second, the approach provides MAP research an intermediate step between purely theoretical descriptions of adaptation (e.g. see Yan & Hong, 2018) and purely quantitative models of it (e.g. see Carlucci et al., 2020 for an overview). As acknowledged by the International Energy Agency (IEA) via the Energy in Buildings and Communities' (EBC) Annex 66, such an intermediate step is needed (Yan & Hong, 2018). The research approach enables informing about how the quantitative models can be refined. It informs about the characteristics related to patients and their setting for which adaptations of indoor conditions differ in the case studied.

On a substantive level, an understanding of mechanisms underlying comfort and adaptation, and differences therein was provided. The different situations described provide insight into when and why thermal and visual comfort and adaptation are similar or different in compared situations. It also

provides an understanding of different scenarios that occurred in this case study and which characteristics of patients and their setting belong to them. The specific substantive results, such as the percentage of time that the lighting is on in rooms around a patio, are presumably very specific to this case as they are based on a limited dataset.

4.2. Limitations and future research

The research has limitations:

- The results are based on a limited dataset.
- As no data were gathered about the actual heating demand of the case, the prediction accuracy of the building energy model could not be verified formally. For a limited number of patients, the simulated free-running temperature and the measured indoor air temperature follow a similar pattern, but the former is lower than the latter. At the same time, no sudden rise in the measured indoor air temperatures due to the heating being turned on or the indoor air temperature dropping below the thermostat set point could be identified. In these cases the simulation can have underestimated the free-running temperature. Possibly, the use of the heating is therefore overestimated in this study.
- The identification of when the lighting or heating were on should be improved. It was not always clear at which moment the lighting was turned off if there was a lot of daylight, and short peaks in the illuminance levels can be caused both by daylight as the lighting. The impact of the latter on the results is limited because it concerns short periods. In future research, the luminance of lighting and the incident solar radiation should be measured too. The thermostat set point could not be estimated accurately if the set point was changed before the indoor air temperature reached it. The most plausible set point was chosen in that case. Furthermore, it is uncertain whether the heating is on or off when the free-running temperature is equal to the actual indoor air temperature. In such cases it was assumed that the heating was off. Calorimeters can be used in future research, or, if possible, the position of the thermostat knob can be monitored.
- To attend to differences between patients and between their settings, the data were split into groups. The median of quantitative characteristics was used. Future research should investigate whether different results are obtained if the groups are split differently, or apply a bottom-up cluster analysis (e.g. hierarchical cluster analysis) instead of the applied top-down approach. Inspiration for applying a bottom-up cluster analysis can for example be found in Eijkelenboom and Bluyssen (2020), Kim and Bluyssen (2020), and Ortiz and Bluyssen (2022).

- Indoor conditions vary to a limited extent in the case studied. In such a properly working building, comfort issues are difficult to investigate. Next to this, if indoor conditions differ more in other buildings, other scenarios can show themselves. Differences in experienced comfort can be noted when indoor conditions differ and experienced comfort is similar between compared situations. Different situations occur when both indoor conditions as comfort differs. Differences in experienced comfort and adaptation can occur when adaptation strategies are adopted to obtain similar indoor conditions but a differing experienced comfort.
- The questionnaire can be improved. The questionnaire's construct validity and reliability should be verified. Rephrasing questions about adaptation will enable improving the grouping of respondents per adaptation strategy. The representativeness of the sample should be improved and the sample size increased in order to improve the generalizability of the findings for surgical wards. An increased sample size would enable controlling for different variables simultaneously as well. A more detailed description of these limitations can be found in Chapters 2 and 3.

Future research should attend to the limitations described above. In addition, several topics require further research. First, suggestions can be formulated for similar research:

- Differences between patients and between settings in preferences and needs for thermal and visual comfort were explored. It was explored by looking at the relationship between indoor conditions and satisfaction. Differences in satisfaction with similar indoor conditions indicate, for example, different comfort requirements. However, it may also be possible to investigate differences in preferences between patients and between settings directly and independent from the patient room in which they reside. Eijkelenboom and Bluyssen (2020) observed that outpatient staff members do not relate their preferences with respect to the IEQ and social aspects to the actual building where they are working.
- Due to the explorative nature of the study, the focus was on two surgical wards. The same research should be conducted across the different wards of a hospital. Meeting differences in comfort requirements and attending to differences in adaptation is more evident when differences between wards are identified instead of between patients of the same ward(s).
- Next to different wards, more attention should be given to some patient characteristics that are expected to impact on patients' experience, but which were not included in this study. Patients' disease

or vulnerability (Eijkelenboom & Bluyssen, 2022), previous experiences and exposures (Bluyssen, 2014), recent negative and positive events such as the outcome of surgery (Annemans, 2015), whether the hospital stay was planned in advance or not (Annemans, 2015), patients' familiarity with the hospital (Annemans, 2015), patients' moods (Annemans, 2015), clothing (Heerwagen, 1998), activity (Heerwagen, 1998), demographics (Bluyssen, 2014), physiological characteristics (Bluyssen, 2014), and social aspects (Bluyssen, 2014) may influence their experience next to the analysed characteristics. Moreover, more attention should be given to whether differences in birth sex, gender or both are of interest. For example, both physique and clothing influence thermal comfort (Fanger, 1970).

- The foregoing focused on characteristics for which it is indicated in the literature that they can influence patients' experience. In addition, more attention is needed in future research for characteristics that are observed to influence comfort requirements in other contexts. Which characteristics relate to different comfort requirements is unclear in literature. The summarizing table (Table 5.4) presented in this chapter may help to bring together the findings of different studies. After all, several review studies indicate, for example, that the role that birth sex and age play in thermal comfort is unclear (Schweiker et al., 2018; Wang et al., 2018). Such ambiguities are also apparent when our observations are compared with other studies. Contrary to findings in a study with healthy adults (Schellen et al., 2010), a study with parents and professional caregivers taking care of people on the autism spectrum (Caniato et al., 2022) and a study with older people in residential buildings (Hwang & Chen, 2010), no difference was observed in our study between the experienced thermal and visual comfort of younger and older patients. That differences in birth sex influence thermal comfort aligns with the observation for healthy people between 16 and 35 years old of Kaikaew et al. (2018), who focus on physiological shivering. Furthermore, more insight is needed into the mechanisms underlying differences in experienced comfort when indoor conditions are similar, for example for male and female surgical patients. More insight into these mechanisms may help to identify the characteristics that relate to differences in experienced comfort when indoor conditions are similar, and understand why identified characteristics differ between studies.
- Which characteristics relate to differences in the way in which indoor conditions are adapted is not well understood yet either. The summarizing table (Table 5.4) presented in this chapter may also help to bring together the findings of different studies in this regard. Note that several characteristics related to adaptations of indoor conditions,

reported in MAP research, were not taken into account in this study (e.g. Stazi et al., 2017). On the other hand, other characteristics, such as the length between sunrise and sunset, were identified. More specifically, based on literature, Stazi et al. (2017) reported that in studies in offices and dwellings, the time of arrival and departure, but also the (work plane) illuminance, influence the use of the lighting. A possible explanation for why the illuminance level was not identified as a meaningful characteristic in this study but in the one of Stazi et al. (2017) is the difference in activities in patient rooms compared against offices or dwellings. The time of arrival and departure was not taken into account in this study. With regard to the use of the thermostat in dwellings, Stazi et al. (2017) mainly found that the indoor and outdoor temperature, habits, routines, time of the day, and the usability of the thermostat play a role. In addition to the outside temperature, we observed that the type of room and the combination of the window orientation and the view out play a role in patients' use of the heating.

Second, some suggestions for other topics can be suggested:

- To support designers to take results from this chapter into account in practice, personas should be set up that include indication of which characteristics related to patients and their setting correspond with differences in adaptation and a similar experienced comfort or differences in experienced comfort when indoor conditions are similar. Personas are vivid profiles of people, usually founded on research (Cooper, 2004; Blythe & Wright, 2006; Van der Linden, 2018). They are a scenario-based design technique. These techniques allow designers to gain a nuanced and diversified insight into the experience of future occupants.
- It should be investigated how insights from this chapter can contribute to improved predictions of indoor environmental comfort. Ways can be searched to include in current IEQ models situations for which surgical patients' experienced comfort differs while indoor conditions are similar. More in general, similar as Fanger did in the development of his thermal comfort model (1970), further research is needed to determine which characteristics of people and their setting are best included in the models. To this end, a better understanding is needed of which characteristics relate to differences in experienced comfort when indoor conditions are similar. In addition, a trade-off must be made between the goodness of fit and the simplicity of the models when fewer characteristics are included.
- It should also be investigated how insights from this chapter can contribute to improved predictions of adaptations of indoor conditions. The added value of including characteristics for which adaptations of

indoor conditions differ among patients as independent variables and predictors in statistical or black-box models should be investigated. Insights into when and why visual and thermal adaptation differ also indicate the difficulty of modelling adaptations of indoor conditions. On the one hand, it indicates the importance of drawing up such models. For example, if designers reduce the extent to which people in rooms around patios can look into other patient rooms, the use of the lighting in those rooms may increase. The in this study reported percentages of time that the lighting is on cannot be used anymore in that case. Such interactions between adaptations of indoor conditions and characteristics related to the patients and their setting can be taken into account by models. On the other hand, in case that models are applied to take these interactions into account, the models must be trained based on data about the many situations that can occur. This is also not self-evident. Tahmasebi et al. (2019) already observed for light switch-on actions that the predictions of models based on data from different cases are less accurate for an individual case than models trained on data from the individual case. Further research is needed in this regard.

4.3. Implications

If confirmed by future research, the substantive results may be valuable for practice. First, the examples given provide an understanding of when and why thermal and visual comfort and adaptation differ among hospitalized patients. This understanding can support designers when designing comfortable patient rooms for as many patients as possible with attention for how their design influences adaptation. For example, the results indicate that the comfort requirements of male and female surgical patients, and of surgical patients with a high and low self-rated well-being differ. Since it is not yet completely clear why comfort requirements differ among them, possibilities to adapt indoor conditions can be provided. Moreover, as described in the results, interviewees who have a view on a patio feel uncomfortable when the lighting is on in the evening and the window curtain open. Patients staying in a room on the other side of the patio can then look into their room. Insight into such situations can influence future design choices. Empathy among designers for such situations is needed to transfer the results of this research to the setting of a new design.

Second, the results indicate how nurses can support patients' comfort. Insight into the situations for which experienced comfort differs while indoor conditions are similar can help them anticipate the comfort requirements of different patients in different rooms. This anticipation may also provide some support when aiming to apply person-centred care.

5. Conclusion

Based on a mixed methods case study at two surgical wards of a Belgian hospital, it was explored when and why differences between patients and between their setting relate to differences in patients' comfort with thermal and visual indoor conditions and adaptation of and to them. By integrating quantitative and qualitative data via joint displays, a better understanding of comfort, adaptation, their interaction and the role of diversity in this could be obtained than is possible with the current methods of RBE, MCP and MAP research on themselves.

Characteristics of patients and their setting that could influence comfort and adaptation were identified based on interviews and literature. For each of the characteristics (e.g. birth sex), possible situations (e.g. men and women) were compared via joint displays. Based on the joint displays, three types of scenarios could be distinguished: situations in which experienced comfort and adaptation are similar, in which adaptation differs and comfort is similar, and in which experienced comfort differs while indoor conditions are similar. In the first scenario, patients' experience and assessment as well as the adaptation strategies adopted are similar. The second scenario refers to situations for which patients' experience, assessment and indoor conditions are similar, but the adaptation strategies adopted differ. The third scenario refers to situations for which assessments and experiences differ while indoor conditions are similar.

Similar experienced comfort and adaptation is shown for thermal comfort when the average outdoor relative humidity, the length between sunrise and sunset, the moment of the day, patients' body mass index, their length of stay, or the number of days that they are already in the hospital differ. For visual comfort, experienced comfort and adaptation are similar in most of the compared situations. Situations are similar when the average outdoor temperature, average outdoor global radiation level during the day, the average outdoor relative humidity, the length between sunrise and sunset, the moment of the day, the combination of the window orientation and view out, patients' birth sex, their body mass index, or their age differ.

Different adaptation with a similar comfort is shown for thermal comfort when the average outdoor temperature, the average outdoor global radiation level, the type of room (i.e. single or double room), the combination of the window orientation and view out, or patients' age differ. For visual comfort, different adaptation with a similar comfort is shown when the type of room, patients' length of stay, or the number of days that they are already in the hospital differ.

The experienced thermal comfort differs while indoor air temperatures are similar when patients' birth sex or self-rated well-being differs. For visual comfort, the experienced comfort differs while illuminance levels are similar when the self-rated well-being differs.

The integrated analysis that was applied to identify the scenarios as well as the characteristics that belong to each of them is considered a valuable approach for future research. It enables a simultaneous analysis of indoor environmental comfort and adaptation, while taking into account differences between people and differences between settings. The substantive observations should be verified in future research as they are based on a limited dataset and a dataset that contains little variation in patient experience. Once the results are more substantiated, they are expected to be valuable for practice. The results provide an empathic understanding into patients' perspective. Architects and engineers who aim to design indoor conditions that are comfortable for as many patients as possible or low energy patient rooms will benefit from such an understanding. This understanding may enable attending to differences in comfort requirements in design. It informs as well about how design choices influence adaptation, and therefore possibly patient room's energy use. Furthermore, nurses who aim to apply person-centred care should be aware of characteristics related to patients or the setting for which comfort requirements differ, as well as why comfort requirements differ.

Chapter 6: **Hospitalized Patients' Thermostat Adaptations: Which Occupant Behaviour Model to Choose?**

Abstract

Building occupants' adaptations of indoor conditions are not yet sufficiently integrated in design processes, resulting in inaccurate performance predictions and sub-optimal design decisions. Support is needed in the selection of a fit-for-purpose model. This chapter takes some first steps to explore which models of thermostat adaptations in patient rooms can be set up, and which of these may be appropriate to apply during energy-sensitive design, to obtain robust designs, or to pay attention to simultaneity of energy use. The research question addressed is: 'what are strengths and weaknesses of different deterministic and probabilistic models of thermostat adaptations in patient rooms?' Adaptations of thermal conditions via the thermostat in patient rooms of two wards of a Belgian hospital were estimated by comparing measured indoor air temperatures with simulated free-running temperatures. Eleven data-driven models were constructed. Note that these were constructed based on a limited amount of data. The models were compared for different criteria: the accuracy with which they predict (1) the percentage of time that the heating is on (1a) relative between possible situations, as well as (1b) absolute, (2) the heating demand, and (3) patterns in the thermostat adaptations over the course of the day. Which model performs best seems to depend on the application purpose. For energy-sensitive design and for obtaining robust designs, the first two criteria are important. A black-box model that categorizes patients into four clusters and probabilistically models thermostat adaptations performs best for these criteria in this study. It addresses differences in patients' thermostat adaptations between days, interactions between characteristics related to patients and their setting that may affect thermostat adaptations, and the stochasticity of these adaptations with sufficient precision. The last criterion is of importance when attending to the simultaneity of energy use. Similar black-box models, but which group patients into two clusters perform best in this study in this regard.



1. Introduction

Thermal conditions in patient rooms are controlled via building systems such as the thermostat. Thermostat adaptations affect thermal comfort and patient rooms' energy use (Azar et al., 2014; Azar et al., 2020). The control of the thermostat can happen automatically or it can be the occupants' responsibility. Its automation may lead to the lowest energy use. However, if patients can adapt the thermostat themselves, this may improve their comfort (Chapter 3). In the latter case, the energy use of patient rooms depends on the actions of patients. This chapter focuses on thermostat adaptations made by patients themselves. The thermostat adaptations include actions to switch the heating on or off completely (e.g. when a patient leaves the room), or to increase or decrease the set point via the thermostat knob (e.g. when a patient arrives and does not like the previous setting).

Due to the impact of thermostat adaptations on comfort and energy use, it is important to take them into account during design. Not or inappropriately accounting for such adaptation may lead to inaccurate performance predictions and sub-optimal design decisions (Gilani et al., 2016; Haldi et al., 2017).

During design, adaptations of indoor conditions by patients, for example via the thermostat, can be taken into account by integrating occupant behaviour models into dynamic building simulations. This integration is important. Energy use resulting from space heating is not only related to thermostat adaptations themselves, but also to the outdoor conditions and buildings' thermal response (Carlucci et al., 2020). Therefore it is not sufficient to understand in which situations thermostat adaptations cause the heating to be on more often or the set point higher. In addition, the adaptations should be accurately modelled. Estimated thermostat set points and operation schedules have a significant impact on the predicted energy use and thermal comfort (Carlucci et al., 2020).

Although occupant behaviour models of thermostat adaptations are underdeveloped compared to other occupant behaviour models (Carlucci et al., 2020), thermostat adaptations are modelled in various ways. An overview of existing models can be found in Carlucci et al. (2020). The models differ in their complicatedness. The complicatedness of a model is related to three distinctive features of occupant behaviour that different models take into account in different ways: it is stochastic, divers and complex (Yan et al., 2017). *Stochasticity* refers to the fact that, unlike machines, people do not strictly repeat their behaviour, for example, from day to day. *Diversity* refers to the many different people who reside in an indoor environment and who can adapt indoor conditions in a different way. Differences may arise due to, for example, deviating tolerances and comfort requirements. *Complexity* implies that occupant behaviour has complicated underlying mechanisms.

As acknowledged by the International Energy Agency (IEA) Energy in Buildings and Communities (EBC) Annex 79 (2017), to date, it is not yet

sufficiently common in design practice to take adaptations of indoor conditions into account. To stimulate the integration of occupant behaviour models into design practice, designers need support in selecting a fit-for-purpose model from the various existing models (Gaetani et al., 2020). A fit-for-purpose model is the simplest available model that meets the required accuracy in performance predictions (Yan et al., 2017).

Gaetani et al. (2020) developed a framework that allows selecting a fit-for-purpose model in terms of complicatedness. More complicated models should be used for types of adaptations (e.g. via the thermostat or lighting) that have a relevant impact on energy use.

Their framework can be further improved. First, we assume that existing models have different strengths and weaknesses, which affect their accuracy when used for specific purposes. The models can be used in practice (1) when applying energy-sensitive design, (2) when aiming for robust designs, or (3) to examine how the design influences the simultaneity of energy use. During energy-sensitive design attention is given by designers to the influence of design choices (e.g. number of patient rooms with a certain window orientation) on energy use. Robust designs are building designs for which the energy use is not very sensitive to energy-intensive behaviour (Hoes et al., 2009; Hoes et al., 2011; O'Brien, 2013). The simultaneity of energy use plays a role when designers want to influence peak demand. Understanding which model is most appropriate for specific purposes will support the selection of a fit-for-purpose model.

Second, the framework of Gaetani et al. (2020) is based on the assumption that models with a higher complicatedness lead to more accurate predictions of the adaptations of indoor conditions. However, the accuracy of models also depends on whether they are applied within their validity range (Mahdavi & Tahmasebi, 2017; Yan et al., 2017). We hypothesize that models' validity depends on their sensitivity to how characteristics related to people and their setting influence adaptations of indoor conditions. After all, adaptations of the indoor conditions are predicted based on such characteristics – the so-called 'driving forces' or 'triggers' (Polinder et al., 2013; Stazi et al., 2017). Varying the value of the relevant characteristics (e.g. window orientation) to situations that may occur in new settings (e.g. north-east and south-east), is expected to improve the model's accuracy through validity improvements. To this end, relevant characteristics must be included in the models. To date, most models include only a limited number of environmental characteristics, while others are considered as random noise (e.g. Reinhart, 2004; Rijal et al., 2007; with an exception of Sutter et al., 2006; Haldi & Robinson, 2010; Schweiker et al., 2012; O'Brien et al., 2017; Yan et al., 2015; Ouf et al., 2019). As a consequence of this hypothesis, the models should not only be appropriate for specific purposes in general, but should demonstrate this appropriateness with sensitivity for differences in characteristics related to people and their setting.

In this context, this chapter aims to improve the understanding of which deterministic or probabilistic data-driven models of thermostat adaptations in patient rooms are appropriate to apply (1) during energy-sensitive design, (2) to obtain robust designs, or (3) to attend to the simultaneity of energy use. This chapter focusses on patient rooms. To the authors' knowledge, models for patient rooms do not exist. Only Niu et al. (2022) provided insight into window opening behaviour in a maternity ward to set up models. The research question addressed is: 'what are strengths and weaknesses of different deterministic and probabilistic models of thermostat adaptations in patient rooms?'

The remainder of this chapter is structured as follows. Section 2 describes the methodology. Section 3 describes the findings. Section 4 discusses implications of the findings for practice and research, limitations of the study and suggestions for further research. The conclusions are formulated in Section 5.

2. Methodology

2.1. Overview

To answer the research question, 11 data-driven models of thermostat adaptations in patient rooms with differing complicatedness were set up and compared. The choice of the 11 data-driven models was inspired by models described in literature (e.g. Haldi et al., 2017; Ouf et al., 2019; Zhou et al., 2020; Niu et al., 2022). The models were set up based on data collected at a specific case and building performance simulations. Cases included patient rooms at two surgical wards of a Belgian hospital in autumn and winter. Based on the output of the models, the heating demand of the patient rooms was simulated in TRNSYS17 (2019).

The 11 models were evaluated for the following criteria: the accuracy with which they predict (1) the percentage of time that the heating is on, (2) the heating demand, and (3) patterns in the heating being on or off over the course of the day. To evaluate the first criteria, two sub-criteria were taken into account: the accuracy with which the models predict (1a) relative differences in the percentage of time that the heating is on between situations, and (1b) the absolute value of this percentage. The evaluation gave attention not only to their performance in general, but also to their sensitivity to differences in characteristics related to patients or their setting.

These steps are explained in what follows. They are visualized in Figure 6.1.

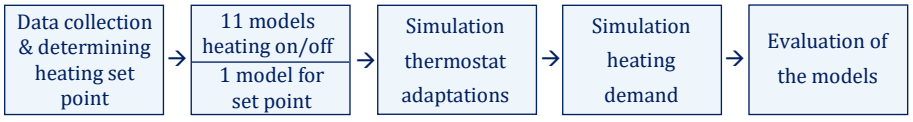


Figure 6.1 Visualization of the methodology.

2.2. The case

Two surgical wards of a hospital in autumn and winter were selected as case. Adaptations of indoor conditions can vary between seasons (Verbruggen et al., 2021a). Data were collected during moths when the use of the heating can be expected: from September 29, 2020 to January 8, 2021.

The hospital building opened in 2018. Together with hospital management and staff two surgical wards in this hospital were selected. Surgical patients stay for several days and were expected to be able to participate in the interviews and questionnaire of the research project this study is part of.

The wards contain single and double patient rooms. A plan of the ward is shown in Figure 6.2. Patients can adapt thermal conditions via a thermostat knob on the radiator. Patients in single rooms and both patients in double rooms have a radiator near their bed (Figure 6.2). Patients can also adapt indoor conditions in various other ways: window curtains; the room's door; a curtain between the patient beds in double rooms; and LED lighting. The LED lighting consists of a main light above the patient bed and a small light behind the patient bed in both single and double rooms, an additional mood light in single rooms and an additional main light in double rooms. All lighting is equipped with a light switch and, for the lighting above the patient bed, a dimmer. Patient rooms are partly conditioned: mechanical ventilation (100 m^3/h per patient in the room, supply temperature at 21°C and top-cooling in summer), operable windows that are locked, and a fixed external louvre system for shading are present. Windows of the patient rooms are oriented to the northeast, southeast, southwest and northwest.

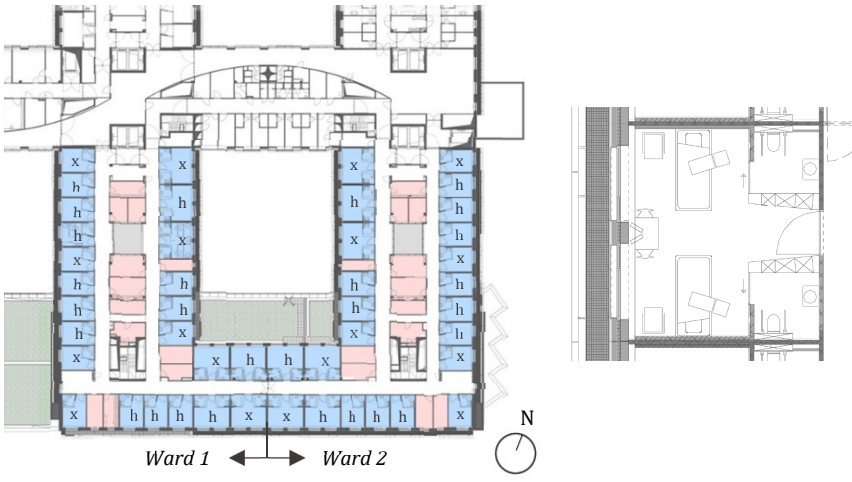


Figure 6.2 Floor plans of the wards where research was conducted with a north arrow, and a double room of these wards. (Plans are based on the design of VK Architects & Engineers. Permission was obtained to publish the plans.)

2.3. Data collection and processing

The collection of data at the wards was approved by the Social and Societal Ethics Committee of the university (G-2018 08 1304). The study had a multiphased case study, mixed methods design. Data collection consisted of interviews, questionnaires, and sensor measurements.

The focus in this chapter is mainly on sensor measurements. The indoor air temperature was measured in all patient rooms. The outdoor air temperature, outdoor relative humidity and the outdoor global radiation were measured at the hospital. Table 6.1 provides more information about these measurements.
In addition, a questionnaire was distributed among patients. The questionnaire asked, among other things, about their satisfaction with the thermal comfort. A Likert scale from 1 (very dissatisfied) to 7 (very satisfied) was given as answer possibility. The full questionnaires can be found in the Appendix (Appendix B). Table 6.2 contains more information about the respondents.

After the fieldwork, the hospital's management provided information about the room occupancy in the two wards during the fieldwork. This information consisted of the time of arrival and departure of patients in the different rooms, their birth sex and their age. The architects provided floor plans of the wards and information about a dynamic simulation that was performed to design the external louver system of the building in a way that ensured thermal and visual comfort in the patient rooms. The technical services of the hospital provided information about the supply temperature and airflow rate of the hygienic ventilation in the patient rooms.

The fieldwork was followed by simulations of the free-running temperature in the patient rooms using TRNSYS17 (2019). The free-running temperature is the indoor temperature when the heating or cooling system are not in use and the air change rate is kept at its nominal value (natural or mechanical ventilation without any air conditioning) (Inard et al., 2011). Based on a comparison between measured indoor air temperatures and simulated free-running temperatures, it was estimated when the heating was on or off in patient rooms during patients' hospital stay, and what the thermostat set point was in case the heating was on. A detailed description of how this estimation was performed can be found in Chapter 5.

2.4. Overview of the modelling of thermostat adaptations

The thermostat adaptations were modelled in different steps, as visualized in Figure 6.1. The models predict an output (i.e. whether the heating is on or off and its set point when being on) based on inputs (i.e. characteristics related to patients and their setting). A well-performing model can accurately predict the output not only for data on which the model was developed, but also for new data. To enable a cross-validation, the dataset was split in two: a training and test

Table 6.1 Overview of the sensor measurements.

Sensor	IEQ parameter(s) [measurement unit]	Accuracy or sensitivity	Sampling rate [min.]	Location	Position in room
HOBO prov2	air temperature [°C]	± 0.21°C	10	all rooms	1.50 m from floor level, behind patient
Weather station	outdoor air temperature [°C]	± 0.2 °C	15	at hospital	NA
	outdoor relative humidity [%]	± 2 %	15	at hospital	NA
	outdoor global radiation [W/m2]	5 %	15	at hospital	NA

Table 6.2 Overview of characteristics of the questionnaire respondents.

Birth sex: % woman	59 %
Age [years]: mean; sd	52.58; 22.76
Nationality: % Belgian	97 %
Days in hospital at moment of the questionnaire [days]: mean; sd	3.83; 3.17
Number of previous hospitalisations: mean; sd	5.25; 4.70
Type of room: % single room	59 %
Window orientation	NW: 12 %; NE: 34 %; SE: 22 %; SW:32 %
Zone of ward	corner: 62 %; central: 38 %

dataset. The training dataset contained the data of 70 % of the patients from the total dataset; the test dataset the remaining 30 %.

Based on the training dataset, thermostat adaptations were modelled in two parts: first it was determined whether the heating was on or off and secondly the thermostat set point was estimated when the heating was on. The plausibility of this split was supported by the significant but weak correlation between the time intervals that the set points were not adapted and the corresponding set points (Spearman correlation coefficient: 0.12; p=0.02). Whether the heating was on or off was modelled in 11 ways. These 11 models include one deterministic and ten probabilistic ones. Deterministic models estimate the

heating state by assuming a deterministic relationship with one or more independent variables or predictors; probabilistic ones by assuming a probabilistic relationship (Carlucci et al., 2020). The choice of the eleven models was inspired by literature (e.g. Haldi et al., 2017; O'Brien et al., 2017; Ouf et al., 2019; Parys et al., 2011; Zhou et al., 2020; Niu et al., 2022; Carlucci et al., 2020). For each of these models, the thermostat set point was modelled in the same way. The models themselves are explained in more detail in subsections that follow (Section 2.6 and 2.7).

Subsequently, thermostat adaptations were simulated for the test dataset with each of the models. For the probabilistic models, the simulated thermostat adaptations differ each time they are simulated. Therefore, a Monte Carlo analysis was performed for these models. The thermostat adaptations were simulated 50 times.

The simulated thermostat adaptations were used as input for the simulation of the heating demand in TRNSYS17 (2019). A detailed description of the building energy performance simulation (BEPS)-model can be found in Chapter 5. Simulating the heating demand provides insight into the need for models of thermostat adaptations. It may be sufficient to only define a comfortable temperature as the set point. In addition, such simulation provides an improved insight into how interactions between characteristics related to patients and their setting influence thermostat adaptations. This insight is necessary to evaluate whether the models should take these interactions into account. The heating demand was simulated per hour, divided by the floor area of the patient room and then summed for all patients in the test dataset. This gives a value in kWh/m^2. The total number of hours that patients, who are part of the test dataset, reside in the hospital during the fieldwork in autumn and winter is 9261 (386 days). Table 6.3 gives an overview of the number of patients and this number of hours in the test dataset (see Section 2.6 for a detailed description of each model). For the probabilistic models, the first five repetitions of the Monte Carlo analysis were taken into account. For these models, the mean of the heating demand simulated by each of the five runs was subsequently calculated.

2.5. Details about the modelling

Before describing each of the models individually, some details about the modelling of whether the heating is on or off will be given. Some of the models use a selection of characteristics related to patients and their setting, a hierarchical agglomerative clustering analysis, or a random forest to simulate the adaptations. These methods require some explanation. They are described in more detail below.

Table 6.3 Number of patients and number of hours of data within the training and test dataset. (Not applicable (NA)).

	Training dataset		Test dataset	
	Number of patients	**Number of hours**	**Number of patients**	**Number of hours**
Comfort-based	424	235215	121	9261
Probability-based	NA	NA	121	9261
Logistic	296	164771	121	9261
Logistic and cox			121	9261
Multiple logistic regression	113	9239	121	9261
Cox proportional hazards regression	18	NA (86 actions)	121	9261
Fitting	210	104976	121	9261
DT - 2 cl – on/off and DT – 2 cl – Markov chain	210	104976	121	9261
RF – 2 cl	210	104976	121	9261
RF – 4 cl	210	104976	121	9261
VSURF – 2 cl	210	104976	121	9261
VSURF – 4 cl	210	104976	121	9261

2.5.1. Selection of characteristics

Some models are able to take into account several characteristics that relate to the patients or their setting simultaneously in order to predict the adaptations. These are statistical and black-box models. For these models, characteristics were selected from the characteristics identified in Chapter 5. Several steps were taken to this end.

First, all characteristics were included in the models. The statistical and black-box models do not determine whether the heating is on or off at every time interval of the simulation. Therefore it was checked first whether the 5th percentile, the mean, or the 95th percentile value of the outdoor conditions were the strongest predictors of the thermostat adaptations. Combinations were made between the outdoor temperature and outdoor relative humidity with the outdoor global radiation or the simulated incident solar radiation. For the black-box models, the values were calculated for the corresponding calendar day. The 5th percentile of the outdoor global radiation and of the simulated incident solar radiation were not taken into account because they were equal to zero for each day. For the statistical models it was also evaluated over which period the values had to be calculated. We considered the past or future hour, three hours, six hours, or twelve hours; the period between the previous and the next half hour,

one and a half hours, three hours or six hours; and the corresponding calendar day.

Next, the best performing combination was identified. For two statistical models, i.e. the 'Logistic' and the 'Logistic and cox model' (Sections 2.6.3 and 2.6.4), the combination with the lowest Akaike information criterion (AIC) was selected. Including the outdoor relative humidity resulted in the exclusion of the outdoor temperature, the outdoor global radiation and the simulated incident solar radiation from the model. Because this did not seem logical, it was chosen not to take the outdoor relative humidity into account for these models. For the black-box models, the receiver operating characteristic (ROC) and the area under the ROC curve (AUC) enabled the selection. The AUC measured the extent to which the cluster of entities of the training dataset were well predicted. The combination with the highest AUC was selected.

Second, a selection was made from all characteristics related to patients and their setting. For two statistical models, i.e. the 'Logistic' and the 'Logistic and cox model' (Sections 2.6.3 and 2.6.4), the combination of characteristics with the lowest AIC was again selected. The VSURF package enabled selecting characteristics when the random forest method was applied (Section 2.5.3). A detailed description of how the VSURF package works can be found in Genuer et al. (2015). Table 6.4 lists the combinations selected for each of the models (see Section 2.6 for a detailed description of each model).

2.5.2. Hierarchical agglomerative clustering analysis

Some of the models make use of clusters of patients. The cluster analysis is based on the work of Aerts (2015). Hierarchical agglomerative clustering analysis was applied. This method orders differences between entities in a dataset hierarchically, enabling the definition of clusters. The result may be graphically presented in a tree diagram. The pattern of the heating being on and off over the 144 10-minute intervals of a full day was considered one entity in the cluster analysis. For each entity, a string of 144 characters contained an ‘a’ when the heating was on during the respective 10-minute interval, otherwise a ‘b’. To group the most similar entities in a cluster, the edit distance with a cost of substitutions, insertions and deletions being respectively 1/1/2, average-linkage and a visualization of the tree were used. To select the costs, the ones described in Aerts (2015) were applied, and a choice was made through visual inspections of the trees. In addition, the cophenetic correlation coefficient, which indicates how closely a tree structure resembles the original distances between entities, was higher when average-linkage was applied compared to single-linkage or complete-linkage. At the same time, the small clusters contained larger numbers of entities without the entities per cluster differing more when average-linkage was applied. The number of clusters was subsequently determined based on a visualization of the tree. In line with the suggestion of Aerts et al. (2013), the tree

Table 6.4 Overview of the characteristics related to patients and their setting that resulted in the best performing models.

	Logistic	**Logistic and cox**		**DT-2cl – on/off and DT-2cl-Markov chain**	**RF-2 cl**	**RF-4 cl**	**VSURF - 2 cl**	**VSURF - 4 cl**	**Fitting**
		Logistic regression	*Cox proportional hazards regression*						
Type of room			x		unknown	unknown			x
Orientation	x			x	unknown	unknown	x	x	x
View out	x			x	unknown	unknown			x
Age	x	x	x	x	unknown	unknown	x	x	x
Birth sex					unknown	unknown			x
Day in hospital	x				unknown	unknown			x
Length of stay	x	x		x	unknown	unknown	x	x	x
Length between sunrise and sunset	x	x	x	x	unknown	unknown	x	x	x
Outdoor temperature		Q95 outdoor temp, previous 6 hours and next 6 hours	Q95 outdoor temperature		unknown (average outdoor temperature)	unknown (q5 outdoor temperature)			Q5 outdoor temperature
Outdoor relative humidity	NA	NA	NA		unknown (q95 outdoor relative humidity)	unknown (q95 outdoor relative humidity)			Average outdoor relative humidity
Radiation	Q5 outdoor global radiation, previous 3 hours and next 3 hours			Average outdoor global radiation	unknown (average outdoor global radiation)	unknown (95 outdoor global radiation)			Average outdoor global radiation

was not cut at one height, but natural divisions were sought. Entities could be clustered into two or four clusters. When choosing two clusters, one cluster mainly contained patients who usually have the heating turned off; one cluster patients who usually have the heating on. When choosing four clusters, one cluster mainly contained patients who usually have the heating turned off; one clusters mainly patients who usually have the heating on; one clusters mainly patients who usually have the heating on from 12 o'clock until 0 o'clock; and one clusters mainly patients who usually have the heating on from 7 o'clock until half past 16.

2.5.3. Hyperparameter tuning of the random forest

Some models make use of random forests to predict to which cluster patients of the test dataset belong. How hyperparameters of the models that make use of random forests (i.e. 'RF-2cl', 'RF-4cl', 'VSURF-2cl' and 'VSURF-4cl model', as will be explained in Section 2.6) were tuned needs further explanation as well. The random forest method worked as follows. Each tree of the random forest was grown on a bootstrap sample of the training dataset. The splitting rule selected out of a group of characteristics that relate to the patients and their setting, the split that minimizes the Gini impurity (Breiman, 2001; Probst et al., 2019; Olson & Wyner, 2018). The group of characteristics to choose from was randomly selected for each split. The size of this group is called the 'mtry'.

Hyperparameters of each of the random forests were tuned to improve their performance: the number of trees, the mtry value and the minimal node size (Probst et al., 2019). Five hundred trees were used. Oshiro et al. (2012) observe that from above 128 trees there is no significant performance gain anymore in using more trees. Using this larger number of trees had nevertheless little impact on the computation time in our analysis. Furthermore, we chose a combination of the mtry value and the minimum node size that resulted in the highest AUC. The AUC measured the extent to which the random forests are able to accurately predict the cluster of each entity – a pattern in heating on or off over the course of a day - of the training dataset.

In addition, the number of entities per cluster is imbalanced when patients are clustered into four. Two clusters contain many more entities than the other two. Therefore we considered oversampling the clusters with few entities, and undersampling those with many entities when setting up the random forests. However, when the predicted probability that the heating is on was compared with its real probability for the training dataset, this considerably decreased the goodness of fit. Therefore the imbalanced dataset was nevertheless used.

2.6. Overview of the models simulating whether the heating is on or off

The 11 data-driven models that simulate whether the heating is on or off differ in their complicatedness, i.e. how they deal with the stochasticity, diversity and complexity of thermostat adaptations. By differentiating the complicatedness, we aim to gain insight into which models are appropriate for the three purposes described in the introduction, while being sensitive for differences in characteristics that relate to patients and their setting. In the subsections that follow, the models are explained in more detail with a focus on these attributes. How the 11 models relate to each other in terms of these attributes is explained first and visualized in Figure 6.3. The colours in Figure 6.3 refer to the 11 models.

First, the models deal with the stochasticity of thermostat adaptations in different ways. The options considered are indicated in the columns of Figure 6.3. We group our models, inspired by Carlucci et al. (2020), as follows: comfort-based, probability-based, statistical and black-box models. Comfort-based models focus on comfortable indoor air temperatures; probability-based models on the probability that the heating is on; statistical models on the relationship between characteristics and the probability that the heating is on; and black-box models on a hidden relationship between characteristics and the probability that the heating is on.

Second, the models deal with the diversity in thermostat adaptations in different ways. The possibilities we considered are, as indicated in the rows of Figure 6.3: aggregated data, combined data, clustered data and data of individual patients. Models using aggregated data do not differentiate between the data gathered in different rooms or for different patients; models which use combined data combine all data as well but make the former distinction; the ones that use clusters differentiate between types of thermostat adaptations; and those focusing on data of individual patients differentiate between the thermostat adaptations of individuals.

Third, how the complexity of thermostat adaptations is taken into account can differ. Several characteristics related to patients and their setting can affect comfort and adaptation. In Chapter 5 the following characteristics were identified: outdoor temperature, outdoor relative humidity, outdoor global radiation, incident solar radiation simulated via TRNSYS17, the length between sunrise and sunset, type of room, window orientation, view out, age, birth sex, length of stay, and number of days already in the hospital. To model the thermostat adaptations, these characteristics can be included to a greater or lesser extent. The options considered are: no distinction between characteristics related to patients and their setting, one characteristic at a time, the selection of characteristics for which the model performs best, or the inclusion of all characteristics. Furthermore, with respect to the outdoor conditions, a detailed analysis has been performed for models separately to determine which

characteristics of the outdoor conditions can best be taken into account (e.g. 5th or 95th percentile value, over three or six hours, and before, after, or before and after each simulated time interval). For the models that make use of a selection of characteristics, the combination of all considered characteristics, including the selected characteristics of the outdoor conditions, for which the model performed best was chosen (Table 6.4). This selection of characteristics is described in more detail in Section 2.5. The number in the coloured rectangle in Figure 6.3 represents each model's complexity.

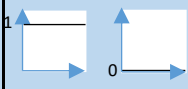
<table>
<tr><td>Stochasticity:
Diversity:</td><td>Comfort-based model
</td><td>Probability-based model
</td><td>Statistical model
</td><td>Black-box model
</td></tr>
<tr><td>Aggregated data</td><td>Comfort-based (C1)</td><td></td><td></td><td></td></tr>
<tr><td>Combined data</td><td></td><td></td><td>Logistic (C3)
Logistic and cox (C3)</td><td></td></tr>
<tr><td>Clusters</td><td></td><td>Probability-based (C2)
DT - 2 cl – on/off (C3)</td><td></td><td>DT - 2 cl – on/off (C3)</td></tr>
<tr><td></td><td></td><td></td><td>DT – 2 cl – Markov chain (C3)
RF – 2 cl (C4)
VSURF – 2 cl (C3)</td><td></td></tr>
<tr><td></td><td></td><td></td><td>RF – 4 cl (C4)
VSURF – 4 cl (C3)</td><td></td></tr>
<tr><td>Individual patients</td><td></td><td></td><td>Fitting (C4)</td><td></td></tr>
</table>

Figure 6.3 Overview of the 11 models that simulate whether the heating is on and off, and their relationship in terms of how they deal with thermostat adaptations' stochasticity (columns), diversity (rows), and complexity (numbers). (C1: no distinction between characteristics; C2: one characteristic at a time; C3: selection of characteristics; or C4: all characteristics).

2.6.1. Comfort-based model

The 'Comfort-based model' is shown in yellow in Figure 6.3. This model was set up because it allows to simulate the heating demand without having to simulate thermostat adaptations in advance. An indoor air temperature that patients experience as comfortable was used as set point at all the time. In our case study, 96 % of the respondents are satisfied with the thermal comfort. Therefore it was assumed that indoor air temperatures are comfortable. The first quartile of indoor air temperatures measured in both the rooms of patients in the training and in de test dataset was used as set point. The first quartile is 22.9 °C. Table 6.3 provides, next to an overview of the number of patients and number of hours in the test dataset, an overview of the number of patients and number of hours in the training dataset upon which this value was based.

- *Stochasticity:* As the name implies, the 'Comfort-based model' is a *comfort-based model*. It does not take stochasticity in thermostat adaptations into account. The set point does not change throughout the simulations.[1]
- *Diversity:* The model does not take diversity in thermostat adaptations into account. It is based on the *aggregated data*. An 'average' person is therefore modelled.
- *Complexity:* The model also does not take into account thermostat adaptations' complexity. *No distinction* is made *between characteristics* related to patients or their setting.

2.6.2. Probability-based model

The 'Probability-based model' is shown in black in Figure 6.3. This model was set up because it allows to directly convert the results of Chapter 5's into models. It describes in percentage the probability that the heating is on. The development of this model is based on a hierarchical agglomerative clustering analysis. Within the study, days when patients' thermostat adaptations were similar were clustered, as was described in more detail in Section 2.5.2. To cluster these days, data from full days that patients from the training data set stayed in the hospital were extracted from the total training data set (Table 6.3). The clustering showed that patients mainly have the heating on or off for a whole day. Therefore, no time-dependent profiles – which is a common approach to include adaptations of indoor conditions in building simulations (Carlucci et al., 2020) - were set up. In contrast, probabilities were used. These express the ratio of the number of days in the cluster in which the heating is usually on over the total number of days. This probability was calculated for the training dataset in general, and for each of the considered situations (e.g. men or women) per

[1] Indoor air temperatures were grouped as well according to characteristics related to patients and their setting. Across these situations, the minimum first quartile value is 22.6 °C, the maximum one 23 °C.

characteristic considered (e.g. birth sex). Because these probabilities were calculated separately for each situation, a separate model had to be developed for each situation. Table 6.5 provides an overview of the probabilities. Consequently, as indicated in Table 6.3, the number of patients in the dataset used to calculate the percentages differs per situation.

- *Stochasticity:* As the name implies, the 'Probability-based model' is a *probability-based model*. It does take into account stochasticity in thermostat adaptations. To determine whether the heating is on or off, a random probability is generated at each time interval. This random probability is each time compared with the probability that the heating is on in the considered situation. In case the random probability is less than the probability that the heating is on, it is simulated that the heating is on; otherwise off.
- *Diversity:* The model is based on *data combined* per situation. Within the considered situation, the model makes no further distinction between patients or settings.
- *Complexity:* Simultaneously *no or only one characteristic* related to patients or their setting is taken into account.

2.6.3. Logistic model

The 'Logistic model' is shown in Figure 6.3 in a dark blue colour. This model was developed because it allows to calculate the probability that the heating is on for different situations with one relationship. Haldi et al. (2017) applied a similar method. In contrast to them, we did not include differences in thermostat adaptations between patients and their setting as a random variable, but as independent variables. This choice was made because it allows the differences in adaptations to be directly related to differences in characteristics. All data in the training dataset could be used to develop this model (Table 6.3).

- *Stochasticity*: This model takes into account stochasticity in thermostat adaptations. It is a *statistical model*. Multiple logistic regression enabled describing the relationship between the probability that the heating is on and characteristics related to the patients and their setting with a formula. Based on this relationship, the probability is calculated at each time interval. To simulate whether the heating is on or off, random probabilities are generated as in the 'Probability-based model'.
- *Diversity:* Like the 'Probability-based model', this model is based on the *combined data*. It distinguishes between patients and their setting by using them as independent variables.
- *Complexity: Characteristics* of patients and their setting were *selected* from the characteristics identified in Chapter 5. Table 6.4 shows the combinations for which the model performed best. Selected

Table 6.5 Percentages, expressing the number of days in the cluster for which the heating is usually on over the total number of days, as well as for the one for which the heating is usually off. These percentages are calculated for the data in general and when the situation differs for characteristics related to patients and their setting.

Characteristic	Situation	Cluster 1: % of days	Cluster 1: hours of the day with heating on	Cluster 2: % of days	Cluster 2: hours of the day with heating on
All data		**64%**	**0h-24h**	**36%**	/
Outdoor temperature (average)	*moderate*	55%	0h-24h	45%	/
	cold	80%	0h-24h	20%	/
Outdoor temperature (5th percentile)	*moderate*	53%	0h-24h	47%	/
	cold	75%	0h-24h	25%	/
Outdoor temperature (95th percentile)	*moderate*	49%	0h-24h	51%	/
	cold	79%	0h-24h	21%	/
Outdoor relative humidity (average)	*low*	65%	0h-24h	35%	/
	high	63%	0h-24h	37%	/
Outdoor relative humidity (5th percentile)	*low*	55%	0h-24h	45%	/
	high	72%	0h-24h	28%	/
Outdoor relative humidity (95th percentile)	*low*	62%	0h-24h	38%	/
	high	65%	0h-24h	35%	/
Outdoor global radiation (average)	*low*	66%	0h-24h	34%	/
	high	29%	0h-24h	71%	/
Outdoor global radiation (95th percentile)	*low*	71%	0h-24h	29%	/
	high	56%	0h-24h	44%	/
Length between sunrise and sunset	*shorter*	83%	0h-24h	17%	/
	longer	56%	0h-24h	44%	/
Type of room	*single*	57%	0h-24h	43%	/
	double	70%	0h-24h	30%	/
View out	*wide view out*	68%	0h-24h	32%	/
	normal view out	50%	0h-24h	50%	/
	view on patio	60%	0h-24h	40%	/
Window orientation	*north-east*	58%	0h-24h	42%	/
	north-west	46%	0h-24h	54%	/
	south-east	60%	0h-24h	40%	/
	south-west	79%	0h-24h	21%	/
Birth sex	*man*	70%	0h-24h	30%	/
	woman	60%	0h-24h	40%	/
Age	*younger*	51%	0h-24h	49%	/
	older	71%	0h-24h	29%	/
Length of stay	*short*	68%	0h-24h	32%	/
	long	62%	0h-24h	38%	/
Day in the hospital	*recent after arrival*	66%	0h-24h	34%	/
	longer after arrival	61%	0h-24h	39%	/

characteristics are: orientation, view out, age, the number of days already hospitalized, the length of stay, the length between sunrise and sunset, and the 5th percentile of outdoor global radiation during the previous and following three hours at each simulated time interval.

2.6.4. Logistic and cox model

The 'Logistic and cox model' is represented in Figure 6.3 with a light blue colour. It combines the former model with survival times. In literature, time of survival based methods are not often used for the modelling of adaptations of indoor conditions (Yan et al., 2017). In this study, however, it seemed interesting to test this combination of methods because the heating in patient rooms is generally on or off for a long time. Survival times avoid the need to simulate the heating state at each time interval. In this model, if the heating is turned off in the previous time step, the probability of the heating being turned on at the considered time step is calculated based on characteristics related to patients and their setting. When the heating is on, also the probability that it will remain on for various possible lengths of time is calculated based on these characteristics. The relationships between the probabilities and characteristics are based on part of the training dataset. For the first relationship, the data when the heating is off and the first moment the heating is turned on was extracted from the training dataset (Table 6.3). For the second relationship, only the data on times that the heating was on was extracted from the training dataset (Table 6.3).

- *Stochasticity*: As the 'Logistic model', this model takes stochasticity into account, and is a *statistical model*. It was constructed by combining multiple logistic regression and cox proportional hazards regression. The heating state is again simulated by generating random probabilities.
- *Diversity:* As the 'Probability-based model' and 'Logistic model', the model is based on the *combined data*. It distinguishes between patients and their setting by using them as its independent variables.
- *Complexity: Characteristics* of patients and their setting have been *selected* from the ones identified in Chapter 5. Selected characteristics for the multiple logistic regression model are: age, length of stay, length between sunrise and sunset, and the 95th percentile of the outdoor temperature measured during the preceding six and subsequent six hours at each simulated time interval (Table 6.4). Selected variables for the cox proportional hazards regression model are: type of room, age, the length between sunrise and sunset, and the 95th value of the outdoor temperature measured on that calendar day (Table 6.4).

2.6.5. Fitting model

The 'Fitting model' is shown in Figure 6.3 in orange. This model was developed because it makes it possible to consider each patient as an individual. Possibly more attention needs to be paid to differences in thermostat adaptations between individuals than between all moments or days. The model is based on the method developed by O'Brien et al. (2017). For each patient, the mean probability of the heating being on or off during their hospital stay was calculated per 10-minute interval of the day. To calculate these mean probabilities, only data on days that patients from the training dataset stay a full-day in the hospital were extracted from the training dataset (Table 6.3). A curve was then fitted to these average probabilities in an automatic way. Based on a visual inspection of the average probabilities, a step function with a maximum of three breakpoints was chosen. These points refer to times of day when the average probability changes, and to four values for the mean probability. A correlation matrix was set up that includes the correlations between the values of the three breakpoints, the four mean probabilities and characteristics related to patients and their setting. By generating correlated random samples, the thermostat adaptations of other patients can be simulated.

- *Stochasticity*: This model is a *statistical model* as the 'Logistic' and 'Logistic and cox model'. The heating state at the four periods of the day is again simulated by generating random probabilities.
- *Diversity:* The model treats *each patient* of the training dataset *individually*.
- *Complexity: All characteristics* identified in Chapter 5 were included in the correlation matrix. After all, irrelevant characteristics do not change the correlations between the relevant characteristics. The selection of representative values for the outdoor conditions was based on this selection for the 'RF-2cl' and 'RF-4cl model' (Sections 2.6.8 and 2.6.9). The best performing combinations for the 'RF-2cl model' were held alongside those for the 'RF-4cl model'. The combination that scored the best when both classifications were combined was chosen. The selected representative values are: the 5th percentile of the outdoor temperature, the average outdoor relative humidity and the average outdoor global radiation, measured during the corresponding calendar day.

2.6.6. DT–2cl–on/off model

The 'DT-2cl-on/off model' is shown in Figure 6.3 in a dark red colour. This model was created because it allows to focus on the main trends in patients' thermostat adaptations. It uses the same hierarchical agglomerative clustering analysis as the 'Probability-based model'. Therefore it is only based on data of days that patients from the training dataset stay a full-day in the hospital (Table 6.3).

However, inspired by Ouf et al. (2019), this model applies a decision tree to divide patients into two clusters based on their characteristics and their setting. Decision trees solve classification problems through a tree structure (Chaitra & Kumar, 2018). The method splits a dataset into smaller and smaller subsets through a root node, decision nodes and leaf nodes. Within the clusters, the thermostat adaptations are modelled in a simplified manner. It was assumed for one cluster that the heating is always on; for the other cluster that the heating is always off.

- *Stochasticity*: The model is grouped as a *black-box model*. The model takes stochasticity in adaptation into account. Random probabilities are generated, and compared to the cumulative probability of patients, with certain characteristics and characteristics of their setting, being classified in each of the clusters.
- *Diversity*: The model distinguishes between two *clusters* of patients.
- *Complexity: Characteristics* were *selected* for which the model performs best. The tree was pruned in order to avoid overfitting. Pruning involves removing redundant parts of the tree. A tree size was chosen for which the cross-validated error is minimized. Characteristics included in the tree are: orientation, view out, age, length of stay, the length between sunrise and sunset, and the average outdoor global radiation measured during that calendar day (Table 6.4).

2.6.7. DT–2cl–Markov chain model

The 'DT-2cl-Markov chain model' is shown in Figure 6.3 in a light red colour. The model is similar to the 'DT-2cl-on/off model'. However, it was developed to model more accurately the thermostat adaptations within each of the clusters. Within the two clusters, the thermostat adaptations were modelled by combining a discrete-time Markov model and the Kaplan-Meier method. Markov chains are regularly used (e.g. Zhou et al., 2020; Parys et al., 2011). A discrete-time Markov model was chosen because patients rarely leave their room, especially during the COVID-19 pandemic. Unlike in a discrete-event Markov model, thermostat adaptations were in this way not linked to events such as entering or leaving the room. However, the discrete-time Markov models were combined with a survival based method. This choice was again made to avoid having to simulate the heating state at each time interval. The heating start state was determined based on the probability that the heating is on between 0 h – 8 h in the training dataset. Transition probabilities were calculated for three phases of the day: 0 h – 8 h; 8 h – 16 h; and 16 h – 24 h, and for the following transitions: the heating is turned off, the set point is increased, the set point is decreased, or the heating is switched on. The Kaplan-Meier method was used to calculate the probability that the heating will remain on or off for different survival times. An observation of the survival times indicated that these times

for the heating remaining on were greatly overestimated within the cluster of patients who usually have their heating off. This is due to the limited number of patients on the basis of which these times were calculated. This survival time was therefore manually set at 10 minutes. All probabilities were expressed as cumulative probabilities. As the 'DT-2cl-on/off model', the model is based only on data of days that patients from the training dataset stay a full-day in the hospital (Table 6.3).

- *Stochasticity*: This model is grouped as a *black-box model*. The model takes into account stochasticity in adaptation, not only to simulate patients' cluster but also to simulate the thermostat adaptations. Random probabilities are generated and compared with the cumulative probabilities to simulate the cluster to which a patient belongs; and to simulate within that cluster the start state of the thermostat, the transitions in its state, and the duration of each state.
- *Diversity:* As in the 'DT–2cl–on/off model', the model distinguishes between two *clusters* of patients.
- *Complexity: Characteristics* were *selected* for which the model performs best. The same decision tree as that of the 'DT-2cl-on/off model' was used. Once patients were assigned to a cluster, no more distinction between them was made to simulate their thermostat adaptations.

2.6.8. RF–2cl model

The 'RF-2cl model' is shown in Figure 6.3 in a dark green colour. This model was set up to allow for a more accurate classification of patients into clusters in comparison with the decision tree method. It works in the same way as the 'DT–2cl–Markov chain model' and is based on the same data (Table 6.3). However, instead of one decision tree, a random forest was applied. Random forests have recently been used to model occupant behaviour (e.g. Zhou et al., 2020, Niu et al., 2022). A random forest for classification uses a collection of un-pruned decision trees to classify patients into a cluster based on characteristics related to them and their setting.

- *Stochasticity*: This model is a *black-box model*. The model takes into account stochasticity in thermostat adaptations as in the 'DT–2cl–Markov chain model'.
- *Diversity*: As in the 'DT–2cl–on/off' and 'DT-2cl-Markov chain model', the model distinguishes between two *clusters* of patients.
- *Complexity:* The random forest method does not allow to gain insight into which of the characteristics are included. After patients were assigned to a cluster, no differentiation between them was made to simulate their thermostat adaptations.

2.6.9. RF–4cl model

The 'RF-4cl model' is shown in Figure 6.3 in a light green colour. The model is similar to the 'RF-2cl model' and is based on the same data (Table 6.3), but divides patients into four clusters instead of two. By distinguishing between more types of patients' thermostat adaptations, the predictions may be more accurate.

- *Stochasticity*: This model is a *black-box model*. The model takes into account stochasticity in thermostat adaptations as in the 'DT–2cl–Markov chain' and 'RF-2cl model'.
- *Diversity*: The model distinguishes between four *clusters* of patients.
- *Complexity:* As described for the 'RF-2cl model', the random forest method does not allow knowing which of the characteristics are included. After patients were assigned to a cluster, no differentiation between them was made to simulate their thermostat adaptations.

2.6.10. VSURF-2cl model

The 'VSURF-2cl model' is shown in Figure 6.3 in a purple colour. The model is comparable to the 'RF-2cl model' and is based on the same data (Table 6.3). However, this model includes a reduced number of characteristics. This reduced number facilitates the application of the model in practice. Less information about future occupants and the building is needed to simulate the thermostat adaptations. At the same time, the model enables to take advantage of the possible precision of a random forest. The VSURF package made it possible to select which characteristics are sufficient to predict to which cluster a patient belongs via the random forest method.

- *Stochasticity:* This model is a *black-box model*. The model takes into account stochasticity in thermostat adaptations as in the 'DT–2cl–Markov chain', 'RF-2cl', and 'RF-4cl model'.
- *Diversity:* As in the 'DT–2cl–on/off', 'DT-2cl-Markov chain', and 'RF-2cl model', the model distinguishes between two *clusters* of patients.
- *Complexity:* The *characteristics selected* by the VSURF package are orientation, age, length of stay, and the length between sunrise and sunset (Table 6.4).

2.6.11. VSURF-4cl model

The 'VSURF-4cl model' is shown in Figure 6.3 with a pink colour. The model is similar to the 'VSURF-2cl model' and is based on the same data (Table 6.3), but divides patients into four instead of two clusters. This model was developed because distinguishing between more types of patients' thermostat adaptations may improve the accuracy of the predictions, while a reduced number of characteristics facilitates the application of the model in practice.

- *Stochasticity:* This model is a *black-box model*. The model takes into account stochasticity in thermostat adaptation as in the 'DT–2cl–Markov chain', 'RF-2cl', 'RF-4cl', and 'VSURF-2cl model'.
- *Diversity:* As in the 'RF-4cl model', the model distinguishes between four *clusters* of patients.
- *Complexity:* The model *selects characteristics* as in the 'VSURF-2cl model'. The same characteristics as for the 'VSURF-2cl model' were selected: orientation, age, length of stay, and the length between sunrise and sunset (Table 6.4).

2.7. Overview of the model simulating the thermostat set point

The thermostat set point was modelled using a random forest method. This modelling is inspired by the work of Deurinck (2015). When the heating is turned on, the random forest method determines based on characteristics related to patients and their setting the probabilities of choosing a set point between 20 °C and 26 °C; if the heating is turned higher, the probabilities of a sethigher between 1 °C and 5 °C; and if the heating is lowered the probabilities of a setback between 1 °C and 4 °C, and this for each of them at 1 °C intervals. The probabilities of each of the set points, sethighers and setbacks were expressed as cumulative probabilities. Random probabilities were generated, and compared with the cumulative probabilities. The first set point, sethigher or setback for which the cumulative probability was greater than the random probability was selected.

The 'DT-2cl-Markov chain', 'RF-2cl', 'RF-4cl', 'VSURF-2cl', and 'VSURF-4cl model' work with start states. In case the heating was on during the first time interval of the simulation, its set point was determined based on the distribution of set points between 0 h and 8 h in the training dataset. The cumulative probability of the occurrence of each of the set points was calculated, and compared to a random probability as explained above. For the remaining patients of the test dataset, the heating state at the time the previous simulated patient leaves the hospital is the start state in their room.

2.8. Analysis of the simulated thermostat adaptations

The eleven models enabled simulating the thermostat adaptations of the patients in the test dataset. The total number of hours that the 121 patients of the test dataset reside in the hospital during the fieldwork in autumn and winter is 9261 (386 days) (Table 6.3). For each of the models, the simulated thermostat adaptations were compared with the estimated ones. Subsequently, the findings of the eleven models were compared. The following criteria were considered: the accuracy with which the models predict (1) the percentage of time that the heating is on, (2) the heating demand, and (3) patterns in heating on or off over the 10-minute intervals of the day. To evaluate the first criteria, two sub-criteria were considered: (1a) the accuracy with which the models predict relative

differences in the probability that the heating is on, and (1b) the accuracy with which they predict the absolute value of the probability. The analyses were performed for the data in general, and for different situations (e.g. north-east or south-east window orientation) of each of the considered characteristics (e.g. window orientation). Table 6.6 provides an overview of the situations that are distinguished per characteristic identified in Chapter 5.

(1) (a) First, it was evaluated to what extent each model can predict relative differences between situations in the probability that the heating is on accurately for different characteristics. To this end, a distinction was made between moments that the heating was on and moments that the heating was off. A data file contained a one when it was estimated that the heating was on at a given moment, otherwise a zero. The same process was performed for the simulated thermostat adaptations. The estimated data and the simulated data were then per model and per characteristic grouped per situation. For each situation, the mean percentage of time that the heating was on was calculated for each 10-minute interval of the day, and subsequently the mean of these values. Thereafter, the mean percentages of different situations were grouped per characteristic and model. It was then checked whether the mean percentages simulated for each of the situations show a similar pattern as those estimated for the test dataset. To this end, it was checked whether the same sequences of situations would be obtained if they were ranked according to the magnitude of their percentage. Second, it was checked whether the difference between the simulated percentage of the situation with the highest and lowest one is not more than twice as large as this difference in the estimated percentages. If these conditions were met, it was assumed that relative differences in the percentages between situations were predicted well for the considered characteristic and model. If a model predicted the differences well for eight or more of the 17 considered characteristics, the model was labelled as good; otherwise as moderate.

(b) A chi-square goodness of fit test was applied to determine whether there is no significant difference between the estimated and simulated absolute value of the probability that the heating is on. We preferred comparing percentages to using a confusion matrix. The latter method gives much importance to whether the simulated state of the thermostat corresponds with the real state of it at each time interval. Moreover, this comparison focusses on the specific patient of the test dataset for which the simulation is conducted. In our analysis, it is important that the models are sensitive to differences in thermostat adaptations when characteristics related to the patients and their setting in general differ. For the chi-square goodness of fit test, the significance level alpha (α) was taken to be 0.001. For large sample sizes, as is the case for the

dataset resulting from the Monte Carlo analysis, the power of the chi-square goodness of fit test becomes great (Cohen, 1988). To reduce the power, the p-value of the Chi-square test was calculated 100 times for a selection of 500 moments from the simulated dataset, and these p-values were averaged. If the p-value of the 46 situations is larger than 0.001 in nine or more of them, the model was rated as good, moderate if this was only the case in seven or eight situations, and poor when true for less than seven situations.

(2) In order to analyse the predicted heating demand, figures were set up that show the heating demand and the probability that the heating is on for each of the models (e.g. Figure 6.4).

(3) Through figures it was analysed whether estimated patterns in the heating being on or off in rooms of patients of the test dataset were comparable to the ones predicted by the models (e.g. Figure 6.5).

3. Results

3.1. Overview of the models' performance

As described in the Methodology section, the performance of the different models was compared. Table 6.7 provides an overview of the results. The header of the columns indicates which criteria are assessed and for which purpose this criteria is important. The rows refer to each of the models described in Section 2.6. Cells are coloured green if the model performs well according to the thresholds mentioned in Section 2.8, blue if it performs moderately, red if it performs poorly, and grey if the model cannot be judged against those criteria. As can be seen from this table, none of our models performs well for all criteria considered. This suggests that models will have to be selected based on the criteria that are relevant to the application purpose. What follows describes in more detail how the different models perform for the individual criteria evaluated.

3.2. Percentage of time that the heating is on

3.2.1. Relative differences in the percentage between situations

Models can be used for energy-sensitive design. For this application it is important that models are sensitive to relative differences between situations in the percentage of time that the heating is on. The number of characteristics for which relative differences between the percentages follow a similar pattern as between estimated ones, was compared between the models. Whether the absolute value of the percentage itself is correctly predicted or not is not considered in this subsection.

Table 6.6 Values used to split the patients into groups.

Characteristics	Compared situations	Splitting values	Reason behind splitting value
Environmental triggers			
Outdoor air temperature (average)	Cold	< 9,6 °C	Median of the average of the outdoor temperatures measured during the calendar days that patients of the total dataset reside in the hospital
	Moderate	>= 9,6 °C	
Outdoor air temperature (5th percentile)	Cold	< 7,9 °C	Median of the 5th percentile of the outdoor temperatures measured during the calendar days that patients of the total dataset reside in the hospital
	Moderate	>= 7,9 °C	
Outdoor air temperature (95th percentile)	Cold	< 12,8 °C	Median of the 95th percentile of the outdoor temperatures measured during each calendar day that patients of the total dataset reside in the hospital
	Moderate	>= 12,8 °C	
Outdoor relative humidity (average)	Humid	< 87 %	Median of the average of the outdoor relative humidity measured during the calendar days that patients of the total dataset reside in the hospital
	Less humid	>= 87 %	
Outdoor relative humidity (5th percentile)	Humid	< 74,5 %	Median of the 5th percentile of the outdoor relative humidity measured during the calendar days that patients of the total dataset reside in the hospital
	Less humid	>= 74,5 %	
Outdoor relative humidity (95th percentile)	Humid	< 96,12 %	Median of the 95th percentile of the outdoor relative humidity measured during the calendar days that patients of the total dataset reside in the hospital
	Less humid	>= 96,12 %	
Outdoor global radiation (average)	Sunny	>= 95 W/m²	Median of the average outdoor global radiation measured between 8h30 and 16h30 during the calendar days that patients of the total dataset reside in the hospital. The period between 8h30 and 16h30 is chosen as this is the shortest period between sunrise and sunset during the case study.
	Less sunny	< 95 W/m²	
Outdoor global radiation (95th percentile)	Sunny	>= 170,85 W/m²	Median of the 95th percentile of the outdoor global radiation measured between 8h30 and 16h30 during the calendar days that patients of the total dataset reside in the hospital.
	Less sunny	< 170,85 W/m²	
Length of the day (between sunrise and sunset)	Long length of the day	< 8 h 50 min	Median of the length between sunrise and sunset during the calendar days that patients of the total dataset reside in the hospital.
	Short length of the day	>= 8 h 50 min	

Contextual and social triggers			
Type of room	Single room	NA	
	Double room		
View out	Wide view out	NA	
	Standard view out		
	View on patio		
Window orientation	North-east	NA	
	South-east		
	South-west		
	North-west		
Bodily triggers			
Birth sex	Man	NA	
	Woman		
Age	Young	< 55 years	Median age of patients during the case study, based on the largest dataset.
	Old	>= 55 years	
Psychological triggers			
Length of stay	Short length of stay	<= 4 days	Median length of stay of patients during the case study, based on the largest dataset.
	Long length of stay	> 4 days	
Amount of days already in the hospital	Few days already in the hospital	< 4 days	Median number of days that patients are in the hospital during the case study, based on the largest dataset.
	Many days already in the hospital	>= 4 days	

Table 6.7 Overview of the performance of the different models.

Model	**Probability that the heating is on**		**Heating demand**	**Profiles heating on/off over the day**
	Relative differences in the probability	***Differences in the absolute value of the probability***		
	Purpose: energy-sensitive design	***Purpose: energy-sensitive design; robust designs***	***Purpose: energy-sensitive design; robust designs***	***Purpose: simultaneity of energy use***
Comfort-based				
Probability-based				
Logistic				
Logistic and cox				
DT-2cl-on/off				
DT-2cl-Markov chain				
RF-2cl				
RF-4cl				
VSURF-2cl				
VSURF-4cl				
Fitting				

Good Moderate Bad NA

Table 6.8 shows the estimated percentages of time that the heating is on for different situations, and the percentage simulated by different models. Cells corresponding to models and characteristics whose relative differences are predicted well, are coloured in green. Table 6.8 gives a slight indication that the performance of the models varies with their complicatedness. It seems that the way in which they deal with *diversity* should allow to take differences in the thermostat adaptations between days of the same patient into account, with *complexity* how interactions between characteristics impact thermostat adaptations.

First, how the models deal with *diversity* may play a role. The 'Fitting model' predicts the relative differences well for the fewest number of characteristics (Table 6.8). Unlike the other models, this model averages out differences in the thermostat adaptations between days of the same patient.

Second, how the models deal with the *complexity* of thermostat adaptations seems of importance. The 'Probability-based model' predicts relative differences well for several characteristics (Table 6.8). However, the difference is not always correctly predicted because the correlations and associations between characteristics are not taken into account. For example, in the training dataset, there are more single than double rooms with a window orientation to the northeast. For the test dataset, the distribution is reversed. The percentage of time that the heating is on is lower in single rooms (Table 6.8: 'Real data' and 'Probability-based model'). This may explain why the percentage of time that the heating is on is underestimated by the 'Probability-based model' for northeast window orientations (Table 6.8: Probability-based model). The other models do predict a higher percentage in rooms with a northeast window orientation compared to a southeast one, but overestimate the difference.

Furthermore, the performance of the models seems to be dependent on the extent to which the group of patients in the training dataset resembles those in the test dataset. First, the green coloured cells across the models are mainly those for which the 'Probability-based model' and the 'Real data' show similar relative differences (Table 6.8). The 'Probability-based model' provides information about the percentages of time that the heating is on in the test dataset, the 'Real data' about those in the training dataset.

The characteristics for which relative differences are well predicted, are not always included in the models as an independent variable or predictor (Table 6.8). In both the training and the test dataset these characteristics are significantly correlated (α=0.05), with a correlation stronger than 0.3, or associated with one or more characteristic(s) that is or are included. For example, the 'VSURF-4cl model' predicts the relative difference in the percentage of time that the heating is switched on well between days with low and high average outdoor temperatures (Table 6.8). The average outdoor temperature is not a predictor in the model, but there is a significant correlation between the average outdoor temperature and the length between sunrise and sunset.

Table 6.8 Performance of the models to predict relative differences in the probability that the heating is on across different situations for various characteristics. Values in the table present the estimated or predicted probability that the heating is on. Cells are highlighted in green when relative differences are predicted well. Values in bold correspond with a characteristic that functions as independent variable or predictor in the model.

Characteristics	Situations	Real data	Probability-based	Logistic	Logistic and cox	DT-2cl-on/off	DT-2cl-Markov chain	RF-2cl	RF-4cl	VSURF-2cl	VSURF-4cl	Fitting
All data		80	64	60	98	71	64	64	67	59	67	74
Window orientation	**Northeast**	87	58	**71**	79	**77**	**71**	66	67	**57**	**84**	**78**
	Southeast	75	60	**44**	60	**58**	**53**	55	60	**53**	**82**	**69**
	Southwest	77	79	**71**	67	**75**	**68**	68	71	**64**	**85**	**76**
	Northwest	78	46	**42**	60	**66**	**57**	64	69	**60**	**78**	**57**
View out	**Patio**	81	60	**67**	70	**78**	**71**	67	70	61	83	**68**
	Standard view out	75	50	**53**	73	**49**	**43**	58	61	60	82	**72**
	Wide view out	80	68	**44**	60	**58**	**53**	55	60	53	82	**69**
Type of room	**Single room**	75	57	59	**68**	61	56	62	66	62	64	**58**
	Double room	83	70	61	**68**	78	70	65	67	57	70	**77**
Birth sex	**Man**	88	70	58	71	76	70	65	67	57	73	**74**
	Woman	72	60	62	66	66	58	63	67	60	63	**64**
Age	**Young**	74	51	**59**	**98**	**65**	**60**	59	59	**53**	**82**	**69**
	Old	84	71	**61**	**98**	**74**	**67**	67	72	**63**	**83**	**69**
Length of stay	**Short stay**	72	68	**65**	**66**	**70**	**64**	61	67	**58**	**65**	**68**
	Long stay	85	62	**55**	**69**	**71**	**64**	66	67	**59**	**66**	**70**
Number of days in the hospital	**Recently arrived**	78	66	**59**	85	69	62	30	31	24	30	NA
	Several days already in the hospital	82	61	**63**	57	74	66	65	68	60	68	NA
Average outdoor temperature	**Moderate**	74	55	57	71	66	60	61	63	56	60	74
	Cold	88	80	78	58	87	76	73	79	68	81	55
5th percentile outdoor temperature	**Moderate**	71	53	47	71	66	61	62	65	54	57	73
	Cold	87	75	72	62	78	69	66	71	67	79	**62**

95th percentile outdoor temperature	**Moderate**	70	49	44	**97**	58	54	56	58	52	58	**67**
	Cold	86	79	71	**99**	80	71	69	73	64	72	71
Average outdoor relative humidity	**Humid**	78	63	50	68	71	16	64	67	59	60	**70**
	Less humid	89	65	72	68	68	18	63	67	59	68	**67**
5th percentile outdoor relative humidity	**Humid**	81	72	68	69	79	70	67	72	66	76	56
	Less humid	78	55	48	68	64	59	61	62	53	60	79
95th percentile outdoor relative humidity	**Humid**	79	65	62	98	58	53	58	60	59	62	65
	Less humid	80	62	58	98	76	69	66	70	59	68	71
Average outdoor global radiation	**Sunny**	74	29	42	60	**42**	**41**	58	59	54	69	**64**
	Less sunny	83	66	67	69	**76**	**68**	65	68	60	60	**70**
95th percentile outdoor global radiation	**Sunny**	76	56	50	97	52	49	53	56	53	57	64
	Less sunny	83	71	68	99	84	74	71	75	63	73	73
Length between sunrise and sunset	**Short**	83	83	**83**	**85**	**87**	**76**	76	84	**74**	**85**	55
	Long	78	56	**49**	**57**	**63**	**59**	58	59	**52**	**61**	75
Interaction	**Northeast, long length between sunrise and sunset**	88	/	65	77	21	74	64	65	53	82	78
	Northeast, short length between sunrise and sunset	83	/	88	67	29	57	74	74	75	90	77
	Southeast, long length between sunrise and sunset	65	/	32	72	61	37	41	44	39	77	72
	Southeast, short length between sunrise and sunset	92	/	70	24	13	83	81	89	78	91	64

	Southwest, long length between sunrise and sunset	81	/	55	76	34	60	63	63	60	81	64
	Southwest, short length between sunrise and sunset	72	/	92	34	8	80	74	83	70	89	46
	Northwest, long length between sunrise and sunset	69	/	28	59	42	50	61	62	53	74	88
	Northwest, short length between sunrise and sunset	98	/	72	29	7	81	76	90	84	93	33

However, some of these correlations and associations can be questioned. An example is birth sex. In addition to age, birth sex is significantly associated with the orientation, type of room and the view out. Based on these associations, differences between men and women in the percentage of time that the heating is on are well predicted by several models. However, it can be questioned whether these are relevant associations.

Second, some characteristics are included as independent variables or predictors in a given model, but the model does not predict relative differences in the percentage of time that the heating is on well. For example, both the window orientation and the length between sunrise and sunset are included as predictors in the 'VSURF-4cl model'. However, the model does not predict the relative differences well when the window orientation or this length differs. The predictions resemble too strongly the variation in the percentages of the training dataset.

3.2.2. Absolute values of the percentage

When applying models during energy-sensitive design or to obtain robust designs, the percentage of time that the heating is on needs to be predicted accurately. The height of this percentage influences the heating demand.

Table 6.9 shows the p-values of the chi-square goodness of fit test. This test compares the predicted and estimated percentages. Cells are coloured green when the predicted and estimated percentages do not differ significantly (α=0.001). Table 6.9 gives a slight indication that the models do not perform well. Only the 'Fitting-model' predicts the percentage of time that the heating is on well for the entire test dataset. By looking at characteristics individually or in combination it seems that the complicatedness of models plays a role. Models that include thermostat adaptations' *complexity* and *stochasticity* in more detail better predict the absolute percentages.

First, the *complexity* of the models seems to play a role. None of the models predicts the absolute percentage well for all situations of a characteristic (e.g. all window orientations) (Table 6.9). In some cases the percentage is predicted well for one of the situations (Table 6.9: green coloured cells). This is especially evident for characteristics included in the models as an independent variable or predictor (Table 6.9: last row). These are in almost all cases different characteristics than those for which relative differences in percentage are predicted well (Table 6.8: green coloured cells versus Table 6.9: green coloured cells). The models with a higher complexity, and therefore including more characteristics as independent variable or predictor, seem to predict the absolute percentage well for more characteristics. This can be noted for the 'Fitting', the 'VSURF-4cl', the 'Logistic and cox', and the 'Logistic' model (Table

Table 6.9 P-values of the chi-square goodness of fit test. P-values higher than 0.001 are highlighted in green.

Model: **Characteristic and its situations:**	**Probability-based**	**Logistic**	**Logistic and cox**	**DT-2cl-on/off**	**DT-2cl-Markov chain**	**RF-2cl**	**RF-4cl**	**VSURF-2cl**	**VSURF-4cl**	**Fitting**
All data	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.04
Window orientation										
Northeast	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Southeast	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.005
Northwest	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.19
Southwest	0.25	0.38	< 0.001	< 0.001	0.002	< 0.001	0.02	< 0.001	0.29	< 0.001
View out										
View on patio	< 0.001	0.01	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Normal view out	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.003
Wide view out	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Type of room										
Single room	< 0.001	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Double room	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Birth sex										
Man	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Woman	< 0.001	0.003	0.02	< 0.001	< 0.001	0.001	0.05	< 0.001	< 0.001	< 0.001
Age										
Young	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Old	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Length of stay										
Short	0.003	0.02	< 0.001	< 0.001	0.007	< 0.001	0.1	< 0.001	0.05	0.007
Long	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Day in the hospital										
Short	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	NA
Long	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	NA
Average outdoor temperature										
Cold	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.002	< 0.001
Moderate	< 0.001	< 0.001	0.46	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.08
Q5 outdoor temperature										
Cold	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Moderate	< 0.001	< 0.001	0.52	< 0.001	< 0.001	0.003	0.04	< 0.001	< 0.001	0.25
Q95 outdoor temperature										
Cold	< 0.001	< 0.001	< 0.001	0.01	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Moderate	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.18
Average outdoor relative humidity										
Low	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
High	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Q5 outdoor relative humidity										
Low	< 0.001	< 0.001	0.002	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.35
High	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.01	< 0.001
Q95 outdoor relative humidity										
Low	< 0.001	< 0.001	< 0.001	0.2	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

High	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Average outdoor global radiation										
Low	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.08	< 0.001
High	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.16
Q95 outdoor global radiation										
Low	< 0.001	< 0.001	< 0.001	0.49	0.003	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
High	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Length between sunrise and sunset										
Short	0.86	0.5	< 0.001	< 0.001	0.002	0.003	0.39	< 0.001	0.28	< 0.001
Long	< 0.001	< 0.001	0.04	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.002
Combination length between sunrise and sunset and window orientation										
Short and northeast	/	0.03	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.28	< 0.001
Long and northeast	/	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Short and southeast	/	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.18	< 0.001	0.04	< 0.001
Long and southeast	/	< 0.001	0.02	0.12	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.04
Short and northwest	/	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.001	< 0.001
Long and northwest	/	< 0.001	< 0.001	< 0.001	< 0.001	0.02	0.02	< 0.001	< 0.001	< 0.001
Short and southwest	/	< 0.001	< 0.001	< 0.001	0.005	0.39	< 0.001	0.34	< 0.001	< 0.001
Long and south-west	/	< 0.001	0.03	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Number of well predicted situations:	**3**	**7**	**7**	**4**	**5**	**5**	**7**	**1**	**9**	**11**
Percentage characteristics included in model & a situation is well predicted	**NA**	**86 %**	**25 %**	**33 %**	**100 %**	**NA**	**NA**	**100 %**	**57 %**	**100 %**

6.9: last row).[2] For the first two models, this also seems to result in the highest number of correctly predicted absolute percentages in general (Table 6.9 second last row).

Second, to which detail the models include the *stochasticity* of thermostat adaptations plays a role. The 'Probability-based' and 'DT-2cl-on/off' model take these adaptations into account with the least detail. They predict the absolute percentages for few characteristics well (Table 6.9: second last row).

3.3. Heating demand

When applying models for energy-sensitive design or to obtain robust designs, insight into the absolute percentage of time that the heating is on and its relative differences between situations is not sufficient. The heating demand interacts with building characteristics and outdoor conditions.

As described in the 'Methodology' section, the total heating demand of the patient rooms in the test dataset was calculated. For the probabilistic models, only the first five simulations of the thermostat adaptations were taken into account. The results give the indication that models with a higher complicatedness perform better. These are models that more accurately capture the *stochasticity*, *diversity*, and *complexity* of thermostat adaptations. The 'Comfort-based model' performs the worst and clearly overestimates the total heating demand. The *stochasticity*, *diversity*, and *complexity* of thermostat adaptations are not taken into account. The heating demand predicted by this model for the total test dataset is 91.2 kWh/m^2. For the other models, that is on average 35.9 kWh/m^2. The 'DT-2cl-on/off model' is the model with the second highest predicted total heating demand. For this model the predicted heating demand is 43.5 kWh/m^2. The same can be noticed when situations are compared. This is shown in Figure 6.4 for the comparison between single and double rooms. There is a possible explanation for this overestimation. The 'Comfort-based model' ensures a minimum indoor air temperature equal to the 1st quartile of the measured indoor air temperatures. This limits the natural variation in indoor air temperatures. After all, outdoor temperatures are significantly lower at moments when indoor air temperatures are lower than their 1st quartile value ($p<0.001$; mean($T_{outd.air,q0\text{-}Q1}$) = 7.9 °C; mean($T_{outd.air,Q1\text{-}q100}$)= 9.6 °C).

Furthermore, the way the models take into account the *complexity* of thermostat adaptations seems to play a role. The findings indicate that the models should take into account how interactions between characteristics affect thermostat adaptations. This can be observed, for example, from the comparison

[2] The combination of the length between sunrise and sunset and the window orientation was not always included in the analysis. It was excluded when only one of both is included as independent variable or predictor in the model. When characteristics of the outdoor conditions are included as an independent variable or predictor in a model (e.g. average outdoor global radiation), and a similar but not equal characteristic is predicted well (e.g. 95th percentile of the outdoor global radiation), this characteristic was not taken into account in the analysis either.

between single and double rooms (Figure 6.4). The heating demand is higher in double rooms. This is not only the case because the heating in double rooms is on more often, but also because most of the double rooms are located at an internal patio and some have a window orientation to the northeast or northwest (Figure 6.2). Rooms with this view to the outside and window orientation are more likely to have the heating on (Table 6.8). At the same time, characteristics related to the patients seem to affect both the percentage of time that the heating is on and the heating demand. For example, both the percentage of time that the heating is on and the heating demand is higher when it comes to older patients and patients with a longer length of stay.

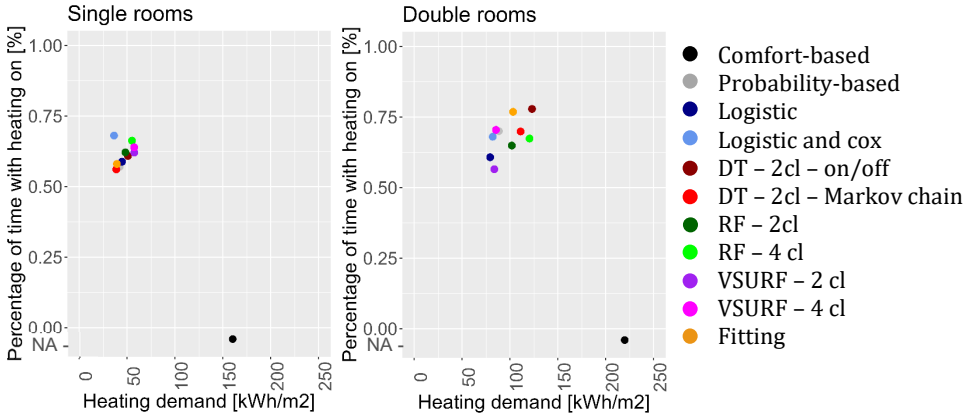


Figure 6.4 Heating demands predicted by the different models for single and double rooms.[3]

3.4. Patterns in the heating being on/off over the day

The simultaneity of heating demands can as well be taken into account during design processes. For this, it is important that models correctly predict the patterns in the heating being on and off over the course of the day. The performance of the models seems to vary with their complicatedness. How they deal with the *diversity* and *stochasticity* of thermostat adaptations seems to play a role.

The findings suggest that models that pay attention to *diversity* and *stochasticity* in thermostat adaptations through the use of clusters and by a probabilistic model of thermostat adaptations within the clusters perform best. These are the 'DT-2cl-Markov chain', the 'RF-2cl' and the 'VSURF-2cl model'. The patterns of the 'RF-2cl model' are shown in Figure 6.5 C, in combination with the real patterns observed in the test dataset in Figure 6.5 A. The patterns in the

[3] Note that the actual heating demands were not measured.

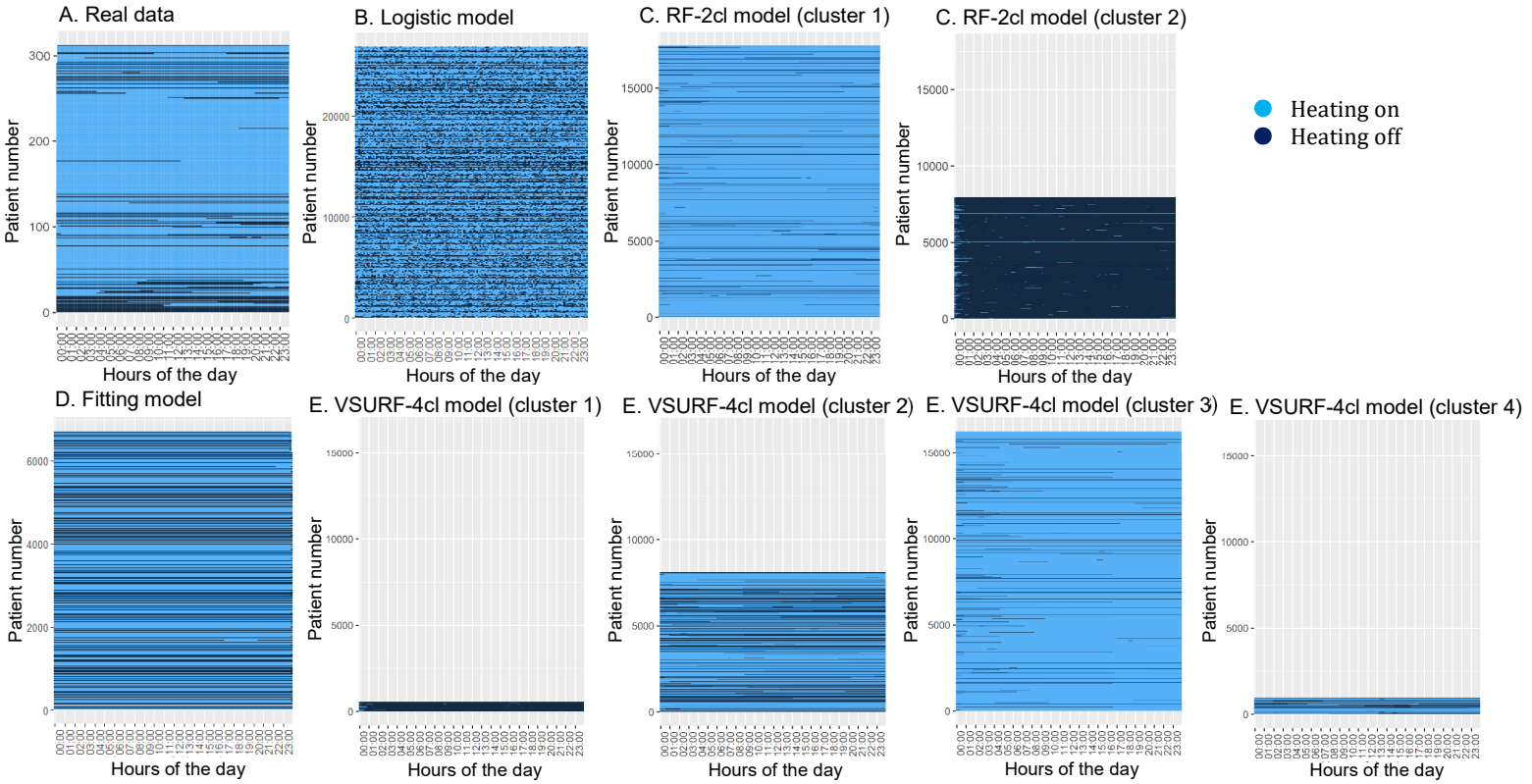


Figure 6.5 Patterns in the heating being on or off over the 10-minute intervals of the day (x-axis) for the different patients of the test dataset (y-axis). The real patterns of the test dataset (A) as well as those predicted by the 'Logistic' (B), 'RF-2cl' (C), 'Fitting' (D) and 'VSURF-4cl model' (E) via the different runs of the Monte Carlo analysis are shown.

heating being off (Figure 6.5: dark blue parts) and being on (Figure 6.5: light blue parts) are similar. The 'Probability-based' and 'Logistic model' predict at each time interval of the day whether the heating is on or off. As shown in Figure 6.5 B for the 'Logistic model', too many and too short actions are therefore simulated. The opposite is true for the 'Logistic and cox model'. The number of actions is very limited in the training dataset (Table 6.3). As a result, the length of the period for which the heating is on is overestimated. Furthermore, the 'DT-2cl-on/off model' assumes that the heating is on or off for a whole day. This is a simplification. The 'Fitting model' distinguishes only four phases of the day to determine the heating state. For our case study, this usually results in days in which the heating is always on or always off (Figure 6.5 D).

Furthermore, the models with two clusters mainly distinguish between patients who usually have the heating on and patients who usually have the heating off. To account for the simultaneity of heating demands, it is also valuable to take a closer look at the thermostat adaptations of patients taking more actions. These patients are distinguished from others in the models that make use of four clusters: the 'RF-4cl' and the 'VSURF-4cl' model. However, due to the limited amount of actions performed by patients, the number of data in the clusters grouping days on which actions are taken is limited. The models that make use of four clusters therefore do not predict accurately the patterns in the heating being on or off in these small clusters (Figure 6.5 E).

At the same time, as the number of patients who take actions is limited in this case study, analysing in detail when the heating is on and off makes little sense for this case. To attend to the simultaneity of the heating demands, the models that simulate relative differences in the percentage of time that the heating is on (Section 3.2.1) and the heating demands (Section 3.3) well can be used.

4. Discussion

4.1. Limitations and future research

The study has some limitations. First, there are limitations in the quality of the data and a larger data set is needed in order to set up models in which all considered parameters are taken into account. The goodness of fit of the models is therefore not only impacted by the performance of the models, but also by the quality of the data. Second, it can be questioned whether it is possible to obtain well performing models for the investigated case. These limitations will be addressed in more detail below.

There are limitations in the quality of the data.

- The actual heating demand was not measured during the case study. As described in more detail in Chapter 5, the prediction accuracy of the building energy model could therefore not be verified formally. It is assumed that the thermal behaviour of the building energy model does

not completely align with the one of the real building. Therefore there is noise in the estimations of the moments when the heating is on and off. However, to determine in future research more accurately when the heating is on and off, and its set point temperature, digital thermostat knobs would be the most appropriate to use.

- The longer a patient stays in the hospital, the more this patient is represented in the datasets. The 'Logistic' and 'Logistic and cox model' are based on the complete data. The cluster analysis considers each full day that a patient is in the hospital as one entity. Section 3.2.1. indicated that it is an added value that these different days are included in the analysis. An explanation for this finding is that outdoor conditions can differ between days, and therefore lead to differences in adaptation. A disadvantage is that individual differences can disrupt the relationship between the percentage of time that the heating is on and characteristics related to the patients and their setting.

The amount of data is limited.

- Initially, the models were drawn up based on all data that could be used to set up the models. This resulted in a more extensive decision tree for the 'DT-2cl-on/off' and the 'DT-2cl-Markov chain model'; to a preference for five instead of four clusters for the 'RF-4cl' and 'VSURF-4cl model'; and the inclusion of other characteristics of the outdoor conditions in the models. This suggests that the training dataset is not rich enough in our study, which may cause difficulties in determining the model parameters.
- Not only the training dataset, but also the total amount of data that could be used to train and test the models is limited. Data on the day of arrival and departure of patients could not be included in the development of models using cluster analysis and the 'Fitting' model. Due to the short hospitalization of several patients, a lot of data could therefore not be used.

The development of the models and how their performance is evaluated could be improved.

- For the 'Fitting model', the selection of representative values of the outdoor conditions can be improved. It would have been a better approach to select the combination that yields the strongest correlations with the other characteristics.
- As described in Chapter 5, characteristics, related to patients and their setting, that impact comfort and adaptation were identified. These characteristics were included in the models. Other characteristics, which are not included, may also play a role (e.g. patients maintained (partially) their habits from home in the hospital).
- An arbitrary choice has been made to determine the relevant differences between the estimated and the predicted percentage of

time that the heating is on. In fact, these threshold values should be determined based on the impact that an increase in the percentage has on the heating demand.

- When comparing the predicted heating demand of the eleven models it is clear that the 'Comfort-based model' overestimates this demand. For the other models, the accuracy could not be verified. The actual heating demand was not measured.

It can be questioned whether it is possible to set up well performing models for the case studied.

- It has been discussed that the training dataset is not that rich. However, this counts as well for the total data set. Patients take few actions with respect to the thermostat. Adding more data from this case might therefore not improve much. Data from another case can be added. However, Section 3.2.1 indicated that the performance of the models depends on the extent to which the group of patients in the training dataset shows similarities with that in the test dataset. Tahmasebi et al. (2019) observed this too for light switch-on actions. Although the models may perform better for the combination of the cases, they probably do less for the individual cases. This finding seems to indicate that well performing models can only be obtained for cases where many adaptations of indoor conditions take place, and that the external validity of these models is limited.

Suggestions for further research can be formulated as well:

- Further research is needed into how the external validity of the models can be improved. For the time being, the method described in chapter 5 can be applied to gain insight into situations in which more or fewer adaptations of indoor conditions occur.
- As indicated in IEA EBC Annex 79 (2017) we suggest to further explore how models of adaptations of indoor conditions can be feasibly integrated into BEPS. As Ouf et al. (2019) indicate, the implementation of the models during BEPS takes time. Ideally the process of using models during design should be simplified. However, if applying them can result in energy savings and an increased patient well-being, these societal gains can justify the use of these models.
- The models discussed in this study focus on thermostat adaptations in patient rooms when these adaptations are not directed in a certain way. These models can be used to search for robust designs and designs that reduce peak demand in general. However, other approaches are also possible. First, future research should pay attention to how adaptations of indoor conditions can be directed towards energy saving behaviour. Liu et al. (2021), for example have developed an interesting approach to identify how occupants can be

encouraged and discouraged from opening or closing windows depending on the impact of the behaviour on energy use. Second, designs can support that energy is used when it is available. The energy system is required to transition from fossil-based dispatchable generation towards renewable energy sources, the so-called 'energy transition' (IEA, 2019; Dupont et al., 2014). Renewable energy sources are less controllable, less predictable and more variable than fossil fuels. That is why demand response becomes important. It refers to (in)direct changes in energy demand by end users or prosumers from their normal consumption or injection pattern in response to certain signals (He et al., 2013, Arteconi et al., 2016). In this context, structural thermal energy storage is a valuable approach (Reynders et al., 2017). It refers to the storage of thermal energy through hot water storages or the building structure's thermal mass. In contrast to the models discussed in this chapter, this requires patients to adapt thermal conditions less themselves. Instead, it requires more adaptation by choice and imposed adaptation. Future research is needed on the flexibility that patients, as well as people in other contexts, show for this reduced control.

Other contexts, such as dwellings and office environments, are valuable for future research. Compared to patients, households will pay more attention to their energy use. At the same time, comfort plays an important role for them too. In the context of offices, it should be investigated how productivity can be increased by enabling adaptation without this being accompanied by higher energy uses.

4.2. Implications for practice

If confirmed by future research, the results have some implications for design practice. Models like the ones shown are expected to support architects in their design choices. They provide insight into how design choices impact adaptation and energy use. Furthermore, the models can increase the accuracy of building simulations. To support this integration in practice, this study provided some preliminary insights into which models may be appropriate to apply for different design purposes.

First, it seems to be an added value when models take into account interactions between characteristics that relate to patients and their setting. The probabilities of the 'Probability-based model' provide an overview of how window orientation, type of room and the view out affect thermostat adaptations. However, the percentage of time that the heating is on, as well as the correlations and associations between characteristics differ between the training and test dataset. Not including interactions between characteristics in the 'Probability-based model' therefore provides a reason why the percentages

of time that the heating is on are wrongly predicted for the test dataset by this model.

On the other hand, the interactions indirectly included in black-box models seem to be valuable for energy-sensitive design and to obtain robust designs. Elasticities may arise from interactions between how room and patient characteristics affect thermostat adaptations. For example, in this study the heating is on more often and the heating demand is higher in rooms with a view on a patio and double rooms, than in rooms with a wide or standard view out as well as in single rooms. Furthermore, the heating is more often on and the heating demand is higher for older patients and patients who have a longer length of stay. During the design process, the models could be used to determine whether the overall heating demand is lower when older patients and patients with a longer length of stay reside in single rooms that do not have a view on a patio, and other patients in rooms that provoke the use of the heating more. In our study, the 'DT-2cl-Markov Chain', the 'RF-2cl', and the 'VSURF-4cl model' perform best for this purpose.

Second, models that more precisely account for the complexity of thermostat adaptations do not necessarily increase the workload for designers. The 'Probability-based model' only includes one characteristic at a time, while other models consider multiple characteristics simultaneously. The first model requires many separate simulations if the impact of different characteristics on the heating demand is to be analysed for different design alternatives. The same would apply if the set points of the 'Comfort-based model' were defined separately for each characteristic. Among the models that more accurately take into account the complexity of thermostat adaptations, only the fitting model requires more work than the others. A correlated random sample must first be generated based on the (expected) correlations between characteristics of the new design and occupants, in this case the patients.

4.3. Implications for research

The results suggest to include relevant characteristics of thermostat adaptations in the models and analyses. The accuracy of the models is important in energy-sensitive design, in the pursuit of robust designs, and when considering the simultaneity of energy use. However, the results indicate a limited internal validity of the eleven models. This is apparent both for relative differences in the percentage of time that the heating is on between situations, as for the absolute value of these percentages. This may be an indication that the correct characteristics were not included in the models. The latter is discussed in the following paragraphs.

The AIC and AUC methods may not select the most relevant characteristics as independent variables or predictors for the statistical and black-box models. Less relevant characteristics may have been selected because of the methods

themselves, or because the dataset is not rich enough. Patients took few actions. Improved models might be obtained by using characteristics that relate to differences in adaptation. The average outdoor air temperature, the type of room, and the combination of the window orientation and the view out were identified as such characteristics in Chapter 5. In this chapter, in three of the nine statistical and black-box models the outdoor air temperature was included, in two the room type, in five the window orientation and in three the view to the outside.

At the same time, not all characteristics included in the analyses of this chapter may be relevant. If models focus on the characteristics identified in Chapter 5, only these should be included in the analyses. The accuracy of the absolute percentage of time that the heating is on and relative differences therein between situations are not important for non-relevant characteristics.

5. Conclusion

This chapter took some first steps to explore which deterministic or probabilistic data-driven models of thermostat adaptations in patient rooms can be set up, and which of these may be appropriate to apply for different design purposes. The models are valuable to use if patients are given the possibility to adapt the thermostat themselves. The design purposes considered are: (1) energy-sensitive design, (2) the search for robust designs, and attention for (3) the simultaneity of energy use during design. The research question addressed was 'what are strengths and weaknesses of different deterministic and probabilistic models of thermostat adaptations in patient rooms?'

The research question has been answered based on a case study. As case study, two surgical wards of a Belgian hospital during autumn and winter were chosen. Different types of data were collected: sensor measurements of indoor air temperatures and outdoor conditions during patients' hospital stay, simulations of the free-running temperature, information provided by the hospital management, and a questionnaire on thermal satisfaction.

By comparing measured indoor air temperatures with simulated free-running temperatures, thermostat adaptations in patient rooms were estimated. This informed the modelling of these adaptations. A total of 11 data-driven models were drawn up and compared. One of them, a deterministic model, was based on comfortable indoor air temperatures. Ten probabilistic models were based on the identified thermostat adaptations. The models were trained on 70 % of the available data and tested on the remaining 30 % of the data.

The findings of the simulations were compared on several criteria: the accuracy with which they predict (1) the percentage of time that the heating is on, (2) the heating demand, and (3) patterns in the heating being on and off over the course of the day. To evaluate the first criteria, two sub-criteria were taken

into account: the extent to which the models predict accurately (1a) relative differences in the percentage of time that the heating is on, and (1b) the absolute percentage. The evaluation did not only attend to the dataset as a whole. The accuracy was also checked for situations (e.g. northeast or southeast window orientation) that occur with respect to characteristics related to patients and their setting (e.g. window orientation). Note that the results of the analyses, given below, should be handled with care. The models were drawn up based on a limited amount of data in relation to the number of parameters that were taken into account. In addition, the models are based on estimates of the moments when the heating is on or off.

Energy-sensitive design can be approached in two ways. Design decisions can be based on an analysis of relative differences in the energy demand between design options, or by considering the absolute energy demand. In the first case, the 'DT-2cl-Markov chain', 'RF-2cl' and 'VSURF-4cl' models seem to perform best. The findings suggest that this is the case because the way they handle with *diversity* allows to include differences in thermostat adaptations between days a patient is in the hospital, with *complexity* interactions between characteristics affecting thermostat adaptations. In the second case, the 'Fitting' and the 'VSURF-4cl' model seem to perform best. This may be the case because they approach the *complexity* and *stochasticity* of thermostat adaptations with sufficient precision. These models therefore also seem to be the most appropriate for checking the robustness of designs.

In order to correctly predict the heating demand, it is important that both relative differences in the percentage of time that the heating is on and the absolute percentage thereof are accurately predicted. In general, the 'VSURF-4cl model' seems the most suitable for this.

To verify the simultaneity of heating demands, models that pay attention to the *stochasticity* and *diversity* of thermostat adaptations by combining the use of clusters with a probabilistic model of thermostat adaptations within the clusters perform best in our study. This are the 'DT-2cl-Markov chain', the 'RF-2cl' and the 'VSURF-2cl' model.

Models with a higher complexity do not necessarily result in a higher workload for designers. Except from the 'Comfort-based model' – which is the least accurate model - all models require a simulation of the thermostat adaptations prior to the simulation of the heating demand. The 'Fitting model' requires a little more effort because a correlated random sample has to be generated first based on the correlations and associations expected to be present for the new building and occupants.

The insights inform researchers about how models of adaptations of indoor conditions can be further improved. Moreover, they provide preliminary insights into which model of patients' thermostat adaptations designers can choose in relation to the intended design purpose.

Chapter 7: **Discussion**

1. Introduction

This chapter discusses the results of the research as a whole. It describes the contributions of the research in Section 2, limitations of the research and suggestions for future research in Section 3, implications for design practice in Section 4, and what can be concluded from this discussion in Section 5. The chapter complements the discussion sections of Chapters 2 to 6, in which these topics were addressed in relation to the research sub-questions.

2. Main contributions

The research contributes to the state-of-the-art at a methodological and substantive level. The contributions, arranged according to these different levels, are the improved understanding of (1) methods to analyse indoor environmental comfort in an integrated way; (2) reasons for discrepancies between predicted and experienced indoor environmental (dis)comfort; (3) the roles of perceived control in patients' experience; and (4) the roles of the indoor environment in patients' well-being. The contributions are described in more detail in what follows.

2.1. Integrated methodology for indoor environmental comfort

The research makes a contribution from a methodological point of view. Its contribution is the depth of integration achieved with the developed methodology for indoor environmental comfort. In mixed methods research on the built environment results based on quantitative data and based on qualitative data are often reported one after the other and compared in the discussion (e.g. Nix et al., 2015; Noguchi et al., 2019; Sclar & Saikawa, 2019; Leung et al., 2019), or results from qualitative data are used to explain results based on quantitative data (Heesch et al., 2012; Guell et al., 2013; Alexander et al., 2014). In this study, we aimed for a deeper integration. We wanted to compare predicted comfort with experienced comfort, and understand in depth why results are congruent, complementary, or discrepant, or why silence

occurred. This in-depth understanding contributed to the understanding of mechanisms underlying indoor environmental comfort and the corresponding adaptation. Inspiration to achieve a deeper integration was sought in literature on mixed methods research (e.g. Morgan, 1998; Bazeley, 2009; Fetters et al., 2013; Wendler, 2001; O'Cathain et al., 2010; Creswell & Plano Clark, 2018; Sandelowski, 2000).

Joint displays were applied to achieve what Fetters and Freshwater (2015) call the '1 + 1 = 3' integration challenge. First, findings from different methods were integrated in tables and figures (Chapters 2 and 5): insights into patients' experience, causes of (dis)comfort, perceived control, adopted adaptation strategies, the percentage of time that the heating is on, thermostat set points, assessments of indoor environmental quality (IEQ) factors and the percentage of time that IEQ parameters remain within their thresholds. At the same time they integrated these findings for different IEQ factors and for different characteristics related to patients or their setting. Through this integration, the joint displays (1) enabled exploring in a similar way several points of attention for an improved understanding of indoor environmental comfort; (2) explicitly informed about discrepancies between predicted and experienced (dis)comfort, i.e. when findings from the interviews or questionnaire were discrepant with what would be expected based on measured values, and why the discrepancies occurred; and (3) allowed for a simultaneous communication of findings on differences in experienced comfort and adaptation. Second, the in graphs and tables observed discrepancies between predicted and experienced (dis)comfort could be explained using insights from the interviews (Chapter 4).

The application of such a deep integration led in turn to contributions to MCP, MAP, and RBE research on a substantive level. First, based on the joint displays, a synergy was created that would not have been achieved with the quantitative and qualitative strands individually. Without insight into patients' experience for example, adaptation strategies would not have been distinguished. Without quantitative data, it would not have been possible to investigate how different adaptation strategies affect the experience of indoor conditions differently.

Second, creating this synergy involves triangulation. In this research triangulation refers to its initial meaning within the social sciences: the claim that comparing findings from two or more different research methods enables the researcher to draw conclusions about the trustworthiness of the individual analyses (Moran-Ellis et al., 2006) and improve them. The confirmability of the qualitative data's interpretations and objectivity of findings based on quantitative data increased by triangulation. For example, before analyzing the data on patients' assessment of the view out in case 1, it was wrongly assumed that interviewees at the corridor side dislike having to look to the window over another patient. It were a few interviewees residing at the window side who express this opinion. Those residing at the corridor side do not complain about

it, are more positive about their experience of looking through the window, and also assess the view out more positively (Chapter 2). Furthermore, without insights into experiences, the questionnaire's multiple choice options, and a qualitative analysis of the measured values of IEQ parameters, it would have been assumed that visual comfort during the heat wave is the same as during other periods of the fieldwork. However, the compliance rate of illuminance levels is similar due to the different ways in which the indoor conditions are adapted: during the heat wave, the blinds are more often closed and the lighting more often on, while there is more daylight during other periods of the fieldwork (Chapter 2). Satisfaction votes are similar through adaptation by choice.

2.2. Reasons for discrepancies between predicted and experienced indoor environmental (dis)comfort

On a substantive level, the research identified four reasons for discrepancies between predicted and experienced (dis)comfort: there is a lack of attention for *interactions (1) between people and indoor conditions* through perceived control and adaptation, and *(2) between the different IEQ factors* in experience, as well as for *differences (3) between people and (4) between settings*. The research improves the understanding of why these reasons relate to discrepancies between experienced and predicted (dis)comfort, and furthermore suggests that the four reasons for discrepancies are not necessarily unrelated.

The understanding of adaptation strategies that individuals apply at a given time was refined (Chapters 2 and 3). When patients adapt behaviourally, there is a tendency towards more neutral or more preferable sensations and a higher satisfaction compared to when they adapt psychologically. This result suggests that adaptation strategies influence the experience of indoor conditions differently in a psychological way. These tendencies are observed not only for thermal comfort, but also for visual and acoustic comfort. The tendencies do not conflict with the hypothesis of existing research on the adaptive thermal comfort model. How people and indoor conditions interact through adaptation is a reason for discrepancies between predicted and experienced (dis)comfort (e.g. de Dear & Brager, 2001; Nicol & Humphreys, 2002). At the same time, these tendencies contribute to this existing research. Existing research focuses on adaptation that occurs due to expectations regarding indoor conditions, but does not distinguish between adaptation strategies (Parkinson et al., 2020; de Dear et al., 2020).

Insight was also obtained into interactions between IEQ factors in patients' experience (Chapter 4). To date, interactions between IEQ factors in experience are not yet fully understood (Bluyssen, 2010; Bluyssen, 2020). First, interactions seem to occur because the sensations associated with different IEQ factors are experienced simultaneously. Both IEQ factors and parameters are constructs. It is possible to define other constructs than, for example, the typical IEQ factors

(i.e. thermal, acoustic, and visual comfort, and the indoor air quality (IAQ)). These can for instance be constructs in which two IEQ factors are combined, such as a construct for 'fresh air'. Second, information about an object or event in the environment can be perceived simultaneously via different senses and is in this way associated with different sensations and thus IEQ factors. Both insights provide a possible explanation for why the overall assessment of the comfort in the room correlates with the assessment of the individual IEQ factors and why that of different IEQ factors correlate with each other. Moreover, to date IEQ factors are often used as intermediate constructs between the multi-sensory IEQ assessment and IEQ parameters (e.g. Frontczak & Wargocki, 2011; Ncube & Riffat, 2012; Heinzerling et al., 2013; Sakhare & Ralegaonkar, 2014; Fransson et al., 2007). The two ways in which interactions were observed put this approach in question. The second way also puts in question whether the overall comfort of the room can be predicted on the basis of IEQ parameters alone. In addition, the results indicate that patients can increase their comfort through adaptation. As indicated by the observed correlations, this increased comfort may influence the satisfaction votes for several IEQ factors. The observed interactions can be regarded as a reason for discrepancies between predicted and experienced (dis)comfort. The improved insights into these interactions contribute to the mainly quantitative descriptions of the relationship between individual IEQ factors and overall comfort assessments in current MCP research (e.g. Frontczak & Wargocki, 2011; Ncube & Riffat, 2012; Heinzerling et al., 2013; Sakhare & Ralegaonkar, 2014; Fransson et al., 2007).

Moreover, the understanding of how experienced comfort and adaptation differ between patients and between settings was improved (Chapter 5). Satisfaction votes do not vary as expected based on measured illuminance levels when patients' self-rated well-being differ; and also not based on measured indoor air temperatures when patients' birth sex or self-rated well-being differ. These insights contribute to MCP research. They inform about which parameters may be included in future IEQ models if the aim is to take more account of differences between people and between settings. Note that despite the observed unexpected variations, differences in birth sex, self-rated well-being and the combination of the view out and window orientation are unlikely to lead to discrepancies between predicted and experienced (dis)comfort in this research. Dissatisfaction occurs little in general. However, they may in indoor environments where indoor conditions are less well regulated. In these indoor environments, the differences may be more pronounced.

The combination of these chapters contributes to the state-of-the-art as well. The combination suggests that the reasons for discrepancies between predicted and experienced (dis)comfort are related. Which adaptation strategy is applied for an IEQ factor can be related to that for another IEQ factor (Chapter 2). For example, when patients use a desk fan to obtain more air circulation in the room, some of them have to adapt by choice to the noise of it. In this example,

the adaptation of indoor conditions leads simultaneously to adaptation by choice. Adaptation strategies are applied to achieve the highest possible overall comfort in the room (Chapter 4). The adaptation strategies applied can differ due to differences in characteristics related to the patient or their setting. What is considered as the highest overall comfort in the room may differ as well between men and women because they show differences in experienced thermal comfort while indoor air temperatures are similar, and between patients with another self-rated well-being because of differences in visual and thermal comfort when indoor conditions are similar (Chapter 5). These results suggest that when in different situations either a different adaptation strategy is applied for a particular IEQ factor or when the overall comfort in the room differs, the factor can be assessed in a different way although measured values do not necessarily differ. At the same time, due to differences in experienced comfort when indoor conditions are similar, IEQ factors can be assessed similarly although measured values differ.

2.3. The roles of perceived control in patients' experience

On a substantive level, the research also improved the understanding of the roles of perceived control in patients' experience. This understanding contributes to MCP and RBE research.

The results question the prevailing assumption in MCP research that perceived control enhances the experience of indoor conditions (e.g. Boerstra et al., 2013; Brackley et al., 2021; Sakellaris et al., 2019, Yun, 2018; Brown & Gorgolewski, 2014; Luo et al., 2014; Xu & Li, 2021). Our results suggest that differences in the adaptation strategies adopted, rather than the presence or absence of perceived control, are related to differences in experiences. Patients who adapt indoor conditions or have no wish to adapt them have the tendency to be more satisfied than those who adapt by choice or feel imposed to do so (Chapter 3). However, patients who adapt by choice, do perceive control over adaptable building characteristics. Nurses indicated during the focus group interviews that the presence of adaptable building characteristics, such as a desk fan, can also be a source of frustration. For example, sometimes one of the patients in a double room would like to use it but the other would rather not. Probably other situations in which adaptation by choice leads to frustrations do exist.

For RBE research in healthcare settings, our research improved the understanding of the roles perceived control can play in patients' experience. Ulrich's theory of supportive design (1991) argues that a sense of control over the socio-material environment reduces patients' stress and supports their well-being. However, in studies by Andrade & Devlin (2015) and by Andrade et al. (2017) perceived control did not predict patients' stress. It is unclear why. That patients have the tendency to be less satisfied when they perceive control but

adapt by choice may provide an explanation (Chapter 3). Moreover, Andrade et al.'s hypothesis, based on Entwistle et al. (2010), that the desire for control increases along with the length of the hospitalisation cannot be generalized according to our results. Patients in our research show, with respect to their visual comfort, fewer adaptation strategies with an action after the first four days of hospitalization (Chapter 5). With regard to thermal comfort, limited differences were observed in the adaptation strategies before and after four days of hospitalization. Nurses indicated during the focus group interviews that patients who have been hospitalized for a longer period become less interested in engaging with the adaptable building characteristics.

2.4. The roles of the indoor environment in patients' well-being

On a substantive level, the research provides an indication of which roles the indoor environment can play in patients' well-being. These roles are not yet clear (Altomonte et al., 2020).

The distinction psychologists make between hedonic and eudaimonic well-being offers a possible explanation for why a tendency towards more neutral or more preferable sensations and higher satisfactions could be observed when patients adapt behaviourally compared to when they adapt psychologically (Chapters 2 and 3). When adapting behaviourally, the adaptation itself may be linked to eudaimonic well-being, the experience of the more preferred indoor conditions resulting from it to hedonic well-being. When adapting psychologically, the adaptation itself may be linked to eudaimonic well-being. When there is no wish for adaptation and indoor conditions are experienced in a positive way, the positive experience may be linked to hedonic well-being. When adapting behaviourally, both hedonic as eudaimonic well-being therefore seem to be supported; in the other cases, only one form of well-being.

The indoor environment can support the different adaptation strategies in different ways. For example, no wish for adaptation can be supported by providing indoor conditions which patients experience in a positive way (assuming that such indoor conditions exist in general). Adaptations of indoor conditions can be supported by providing adaptable building characteristics which align with patients' competences and by patient room designs that support autonomy. Adaptations of position can be supported through the movement friendliness of the room. These results suggest that the indoor environment can play different roles in patients' well-being.

3. Limitations and future research

3.1. Limitations

The research had an explorative character. It enabled improving the understanding of mechanisms underlying indoor environmental comfort. It informed about the roles of the indoor environment in patients' experience, about reasons for discrepancies between predicted and experienced (dis)comfort, and how models of adaptation can be refined. The disadvantage of this explorative character is that it also resulted in several limitations. These require attention when the mechanisms are investigated further in future research. In short the limitations are:

(1) the limited dataset and the limited variation in patients' experience within the dataset;
(2) the absence of a substantive focus in data collection;
(3) shortcomings in the measurement procedure;
(4) shortcomings in the representativeness of the sample;
(5) the lack of attention for discrepancies that may result from patients' unawareness of what influences their comfort;
(6) the limited attention for how other characteristics of the setting than IEQ parameters can impact on indoor environmental comfort and adaptation;
(7) the limited attention for some characteristics that relate to the patients and that are known to impact on patients' experience;
(8) and the lack of attention for discrepancies that may result from differences between patients' health state and the one of healthy adults.

In what follows, the limitations are described in more detail.

3.1.1. Limited dataset and limited variation in patients' experience within the dataset

The results are based on a limited dataset. Moreover, within the dataset, patients' experience varied only to a limited extent.

First, sufficient qualitative data were collected. However, with respect to the quantitative data, more data is needed. More data would allow excluding the questionnaire responses of interviewees in the statistical analyses. Their responses may have been influenced by the interview. Note that having them complete the questionnaire prior to the interview can influence their responses during the interview, which, in our view, poses a greater risk for bias. Furthermore, the effects of multiple confounders could often not be checked during data analysis. Including such confounders would provide more certainty about the internal validity of the results. It would also improve the credibility of the qualitative data's interpretation. After all, this credibility is enhanced via triangulation by findings based on the quantitative data.

Second, within the dataset there was little variation in patients' experience due to the case chosen for case study 2. Indoor conditions only hindered or supported positive experiences to a limited extent. With regard to the qualitative data, attention for indoor conditions was therefore hardly present in patients' description of their experience. With regard to the quantitative data, few patients were for example dissatisfied in case study 2. When indoor air temperatures are within threshold values, 5% of the patients are dissatisfied, which is lower than the predicted 10% (Lazarov and Stranger, 2017); and when illuminance levels are within threshold values, 3%. When they are outside the thresholds respectively 0% and 3% are dissatisfied. When the A-weighted equivalent continuous sound level (LAeq) and the maximum instantaneous A-weighted sound pressure level, measured on fast response (LAmax, fast), in interviewees' room are used 11% are dissatisfied with the acoustic comfort. In none of the rooms, the measured values complied with threshold values.

A focus on buildings with more variable indoor conditions and higher dissatisfactions, or participants between whom there is more variability is suggested for the future. These cases are likely to yield more variability in people's experience. Due to this higher variability, mechanisms underlying comfort and adaptation may become more clear. Despite that the limited presence of negative experiences in case study 2 means that current design approaches enable designing comfortable patient rooms, the improved insights may allow developing more precise models of indoor environmental comfort and adaptation. In comparison with current models, comfort may therefore be predicted more precisely, and the impact of design choices on energy use better evaluated. Moreover, research in buildings with higher dissatisfactions makes it possible to give more feedback to the building owners on how to improve the indoor environmental comfort of their building(s).

3.1.2. Absence of a substantive focus in data collection

There was an absence of a substantive focus in data collection. The research started looking for ways in which RBE research could be integrated with MCP research. The original objective was to improve the understanding of roles of the indoor environment in patients' experiences, and reasons of discrepancies between predicted and experienced (dis)comfort. The four points of attention addressed in this research were not predefined. They evolved from the literature review that was conducted at the start of the research as well as the empirical research (Willems et al., 2020). This resulted in the main limitation of this research. The lack of a substantive focus explains why the data collection methods have many limitations. A detailed description of the limitations of these methods is given in the individual results chapters (Chapter 2-6). General limitations are described below.

The questionnaire lacked some relevant questions. For example, questions can be added that enable distinguishing respondents who have no wish for adaptation, who adapt sensations and environmental information, and who adapt their position (Chapter 3). In addition, the questions about patients' well-being are based on the World Health Organization's (WHO) Quality of Life Questionnaire (WHOQOL-BREF) (De Vries & Van Heck, 1996). Questions could also specifically question hedonic and eudaimonic well-being. Questionnaires for both well-being perspectives have been developed (e.g. Watson et al., 1988; Diener et al., 1985; Ryff & Keyes, 1995; Diener, 2009). Note that these questionnaires do not focus specifically on indoor environmental comfort or the corresponding adaptation. It should also be considered whether birth sex, gender, or both should be questioned. For example, both physiological characteristics and clothing influence thermal comfort (Fanger, 1970). The former is expected to differ mainly because of biological differences between men and women; the latter because of differences in how someone identifies themselves.

Furthermore, the interview questions were too broad because it was unclear which gap would be focussed upon. For example, in future research interviews can focus on adaptation and how it affects patients' comfort and (hedonic and eudaimonic) well-being.

The sensor measurements can be focused more on the mechanism being investigated. To improve, for example, the estimation of the moments when the lighting is on, the luminance of lighting and the incident solar radiation should be measured.

Because of these limitations, sequential mixed methods research designs are recommended for future research. For example, it can first be explored based on interviews or observations which points need attention. Subsequently, a questionnaire and measurement procedure can be set up to investigate this point of attention. Unclear findings can subsequently be discussed during follow-up interviews.

3.1.3. Shortcomings in the measurement procedure

The sensors were positioned next or above patients' bed, at eye level when lying in the bed. However, patients could also sit at the table or on a couch next to the bed. It is expected that the difference in position between the patients and the sensors has a limited impact on the results. It is assumed that the measured IEQ parameters (e.g. indoor air temperature, illuminance level, and sound level) differ only slightly between these different positions in the room.

Furthermore, attention was given to the positioning of the sensors. Light sensors pointed to the ceiling. It was also avoided that the sensors provoke to put something on them, or could be shielded by the curtains. In addition, continuous measurements were performed. In case there was a temporary error

in the measurements, the impact of this error on the averaged values of the measurements is therefore probably limited.

3.1.4. Shortcomings in the representativeness of the sample

As described in Chapter 2, the representativeness of the sample can be improved. Several patients with low cognitive competences or who did not feel well refused or were unable to participate in this research. Selecting those participants for (short) interviews or interviewing them together with an assistant (e.g. a nurse or guardian) can be a direction for the future.

3.1.5. Patients' unawareness of what influences their comfort

During data analysis and interpretation, as described in Section 2.1 of this chapter, discrepancies between patients' experience and predictions by IEQ models were attributed to shortcomings in IEQ models. The results could have been interpreted differently. Based on Steinmetz-Wood et al.'s (2019) discussion of their literature review on mixed methods research on the built environment and health, it can be assumed that MCP research is limited in understanding contextual factors, while RBE research may fail to identify important impactful characteristics of the built environment as they are not always captured by the participants' experiences. In our research, discrepancies between predicted and experienced (dis)comfort can also occur because patients are not always aware of what influences their comfort. For example, some interviewees were unsure whether their thermal comfort was affected by their illness or the indoor conditions in the room; others were not sure if they were thirsty because of the medicines or because the air was dry. The added value of applying sensor measurements is that they are able to single out, quantify and make perceivable individual IEQ parameters (e.g. the indoor air temperature), while humans cannot.

3.1.6. Other characteristics of the setting that can impact indoor environmental comfort and adaptation

More attention could be given to how other characteristics of the setting than IEQ parameters can impact on indoor environmental comfort and adaptation. For example, it was investigated whether characteristics such as the location of the room in the ward, the combination of the window orientation and view out, and the difference between single and double rooms, could explain differences in indoor environmental comfort and the corresponding adaptation (Chapters 4, 5 and 6). In addition to these characteristics, other characteristics of the setting may also play a role. In future research checklist can be used to obtain data about building-related characteristics of cases studied, (e.g. Eijkelenboom & Bluyssen, 2020; Eijkelenboom et al., 2021).

3.1.7. Other characteristics of patients that can impact indoor environmental comfort and adaptation

As described in Chapter 1, several characteristics that relate to people in general or patients in particular can impact their experience according to literature. As indicated shortly in Chapter 5 as well, more attention could be given to some of these characteristics.

In this research, differences in comfort and adaptation when patients' birth sex, age, body mass index, length of stay and self-reported well-being differ were analysed and reported (Chapter 5). Patients' mood was taken into account as one of the parameters that impact self-rated well-being (Chapter 2, Table 2.1). The relationship between differences in activities or clothing insulation and thermal satisfaction were analysed but not reported. The clothing insulation was estimated based on questionnaire responses about respondents' clothing and ISO 7730 (International Organization for Standardization, 2005). No clear association between the clothing insulation and thermal satisfaction, or activity and thermal satisfaction, was found.

As described in Chapter 2, a comparison of the two wards of case study 2 suggests that differences in experiences, assessments, perceived control and adaptation, and indoor conditions between patients who undergo different types of surgery were limited. However, surgical patients with different diseases resided in each of the wards. Future research should therefore attend more to how differences in diseases and in the level of vulnerability among patients impact on comfort and adaptation. The interviews indicated that some patients who do not feel well prefer boredom, unnoticeable indoor environments.

Whether the patients have already had surgery, if applicable; whether the hospital stay was planned in advance; the number of previous hospitalisations in the same or other wards and hospitals; the number of hours the patient stays in the room in a day; patients' nationality; and sensory abilities (e.g. visual impairments) were questioned in the questionnaire (Appendix A & B). How these characteristics influence comfort and adaptation was not analysed. Either there was in general too little data in one of the groups (i.e. nationality and sensory abilities), or the influence of the characteristics on comfort and adaptation was not clear based on the interviews. An exception to this was that patients compared their experience with previous experiences in other hospitals, other hospital wards, and their dwelling. However, no data about the indoor conditions in these other hospitals, other wards, or their dwelling were gathered.

Lastly, except for reasons of (dis)comfort, recent positive and negative events such as the outcome of surgery were not questioned in the questionnaire. Their impact on comfort and adaptation was therefore not analysed. The interviews however indicate that such events can have an influence. One of the interviewees, for example, enjoyed the indoor environment in her patient room

recently after being discharged from intensive care. During the second interview she was more negative about it. That she was tired of being in the hospital seemed to be the main reason for this negativity. Moreover, occupant's physiology and physical state can impact indoor environmental comfort and adaptation. Except from patients' body mass index, these characteristics were not taken into account in this work. Data about these characteristics can be gathered by medical examination, by monitoring bodily responses or fluids, and some by a questionnaire.

The patient characteristics that are known to impact on patients' experience and that were not taken into account are expected to influence which adaptation strategies are adopted by specific patients. However, we do not expect major changes to the framework presented in Chapter 2. This framework presents an overview of adaptation strategies that could be identified.

3.1.8. Differences between patients' health state and the one of healthy adults

One characteristic that relates to the patients and that could be given more attention in particular is patients' health state. As described in Chapter 1, it is expected to influence their indoor environmental comfort and adaptation. However, several threshold values seem to be based on relationships between IEQ parameters and IEQ factors that are developed based on data from healthy adults (e.g. Bureau for Standardisation, 2005; Bureau for Standardisation, 2003). Patients' physiology and physical state can differ from that of a healthy adult. This may be a reason for discrepancies between experienced and predicted (dis)comfort in this research as well. This reason for discrepancies was not taken into account. Note that it was checked whether the dissatisfied votes with the different IEQ factors came from the same respondents. This turned out not to be the case. Respondents who did not feel well therefore did not seem to have assessed all IEQ factors badly.

3.2. Future research

In future research, the mechanisms identified in this work as underlying comfort and adaptation should be verified and their understanding improved by attending to the limitations described above. In addition, other topics require attention. The suggestions are arranged according to the different levels of a research approach. On the substantive level there is a need for an improved understanding of (1) interactions between IEQ factors and parameters in experience; (2) interactions between reasons for discrepancies between predicted and experienced (dis)comfort; and (3) influences of the interactions between different occupants on adaptation. On the theoretical level a suggestion is formulated about (4) a theoretical framework that can be adopted and contributions that can be made to theories. On the level of the research objective a suggestion is formulated about (5) how the mechanisms identified as

underlying indoor environmental comfort and adaptation can improve predictions of this comfort and adaptation. On the level of research valorisation, a suggestion is formulated about (6) the valorisation of insights into mechanisms underlying indoor environmental comfort and adaptation through scenario-based design techniques. These suggestions are described in more detail below. In addition to these topics, attention for cooling and overheating is relevant for future work in the view of climate change. Moreover, future research should take the indoor environmental comfort and adaptation of other hospital users (e.g. nurses and visitors) into account as well.

3.2.1. Interactions between reasons for discrepancies between predicted and experienced (dis)comfort

On a substantive level, future research should try to gain a better understanding of how reasons for discrepancies between predicted and experienced (dis)comfort interact. As described in Section 2.2 of this chapter, the combination of the chapters suggests that reasons for discrepancies between predicted and experienced (dis)comfort are related. To improve IEQ models, these interactions between the discrepancies need to be better understood. One way to do this has been explored, but is not reported in this work because of the too limited amount of data. The regression coefficient of each IEQ factor, which expresses its importance within the assessment of the overall comfort in the room, was calculated by the use of multiple regression analyses. It was calculated separately for different characteristics related to the patients and their setting. The mean of the regression coefficients corresponding to a patient's characteristics and setting was then calculated per IEQ factor. Next, the transparency of each of the data points in Figure 3.3. of Chapter 3 was determined based on this mean value. In this way, the importance of the IEQ factor within the assessment of the overall comfort in the room could be analysed simultaneously with the applied adaptation strategy, satisfaction, preference and sensations votes, as well as measured values. Through such analyses, or other methods, attention should be given to interactions between reasons for discrepancies between predicted and experienced (dis)comfort in future research.

3.2.2. Interactions between IEQ factors and parameters in experience

On a substantive level, future research should further improve the understanding of interactions that occur between IEQ factors and parameters in experience. The 'Discussion' section of Chapter 4 explains why it is valuable to set up multi-sensory IEQ models. Threshold values in particular may be improved. Future research should investigate as well how threshold values, enhanced via multi-sensory IEQ models, can be applied within design practice. Threshold values for individual IEQ factors can be set via multi-sensory IEQ models to reduce the influence of other IEQ factors on the values. These

threshold values can then be used as in current design practices. However, when designers want to widen threshold values of IEQ factors because of the positive influence of other IEQ factors on their assessment, other methods will be needed. Either some IEQ factors should have a positive influence all the time in order that broadened but constant threshold values for the other IEQ factors can be used. Either it will be needed to conduct dynamic simulations of indoor environmental comfort. In these simulations, all IEQ factors' or parameters' compliance rate must be taken into account simultaneously.

Another topic to explore is whether perceived control over some adaptable building characteristics can compensate for the lack of perceived control over others. This compensation would have several advantages. (1) Control can be given over adaptable building characteristics whose use causes the least increase in energy use. (2) When IEQ models indicate that heating or cooling is not needed in new buildings, the absence of perceived control over them can be compensated for by perceived control over others (e.g. shading devices). (3) When building systems require coordination (e.g. no cooling when shading devices are open), this coordination reduces patients' perceived control. This reduction can be compensated for.

Based on this research two conflicting hypotheses can be formulated regarding whether the absence of perceived control over an adaptable building characteristic can be compensated for by the presence of perceived control over others. On the one hand, patients seem to look for the highest possible overall comfort in the room (Chapter 4). A similar overall comfort can be achieved in several ways. This overall comfort indirectly can positively influence the assessment of IEQ factors over which less control is perceived. On the other hand, patients' assessment of indoor conditions seems to be influenced by the adaptation strategies adopted, rather than by the presence or absence of perceived control (Chapter 3). The combination of the wish to adapt an IEQ factor and the lack of perceived control over an adaptable building characteristic that can change that specific IEQ factor, can lead to dissatisfaction. This dissatisfaction can negatively affect the assessment of the overall comfort in the room, and thus the assessment of other IEQ factors. Whether one of these two phenomena affects the assessments more than the other, or whether both phenomena cancel out, requires further research.

3.2.3. Influences of the interactions between different occupants on adaptation

On a substantive level, future research should also attend more to how interactions between different occupants impact adaptation. In this research, the focus is on which adaptation strategies patients adopt and how these strategies differ when characteristics related to them or their setting differ. Patients are mainly considered as individuals. However, as other researchers acknowledge, not only personal characteristics but also the social context affects which and

when adaptation strategies are adopted (e.g. O'Brien & Gunay, 2014). Attention has only been given to a limited extent to the influence of the social context on adaptation in this research. How the other patient in double rooms affects adaptation as well as how some adaptations of indoor conditions by nurses affect patients' experience was taken into account. Furthermore, other researchers stress that the cultural context impacts how indoor conditions are experienced (e.g. Pink et al., 2022). This cultural context may impact on adaptation as well. The influences of the social and cultural context on adaptation require further research and may complement Chapter 5. Insight into the impact of the social and cultural context on adaptation will make it possible to further refine models of adaptations of indoor conditions, such as those described in Chapter 6.

Despite not attended to in the Result chapters, examples can be given based on our data of how the social and cultural context influence adaptation. First, with respect to the social context, some patients adapt indoor conditions when visitors come in. For example, a patient turned on the heating because his wife came from outside and was cold. In contrast to this example, a patient opened the window to have some air circulation when the room got crowded despite the cold visitors experienced because of this. The adaptation of some patients to indoor conditions is influenced by actions taken by nurses as well. Some patients assume that nurses know best which indoor conditions are best for their health and comfort. Other patients want to disturb nurses as little as possible. For example, when patients are placed on a couch, they put on some extra clothing. This way, they do not have to ask for help with adapting the heating. The latter examples in particular are in line with the on literature based observation of O'Brien and Gunay's (2014) that reduced perceived ownership influences adaptation in offices.

Second, the cultural context also seems to play a role. For example, some patients adapt by choice because they believe that it is important to be considerate to others. Several patients adapt because they are not alone in the hospital or in their room. Others believe that nurses should be able to do their job as well as possible, which benefits the health of patients. For example, some accept that lights remain on in the hallways at night. When the door is open, this results in light entering their room. Several patients accept it despite the fact that some of them are used to sleeping in the dark. Consistent with research from multisensory anthropology, the meaning given to indoor conditions and adaptation is therefore influenced by values (Ingold, 2011b; Pink et al., 2022).

3.2.4. Theoretical framework and contributions to theory

On a theoretical level, a theoretical framework on how people experience the indoor environment was established based on literature at the start of the research (see Willems et al., 2020). A narrative review addressed: 'how do MCP and RBE research address people's experience of the indoor environment?' and

'how do both views interrelate?' However, the Results chapters (Chapter 2-6) did not aim to start from the original framework and to explore how to contribute to it on a theoretical level. Nevertheless, based on the original theoretical framework and literature additionally read during the research, three suggestions for future research can be formulated.

First, it seems valuable to investigate how sensations and sense perception relate to each other, and how they interact in order to improve the understanding of how IEQ factors combine and interact in experience. Gibson (1968, pp. 47-58) distinguishes between sensations and sense perception. Sensations are the different modes of conscious qualities of experience which result from stimulus energy from the physical world falling into the senses (Gibson, 1968, p. 47, p. 58). Gibson, and researchers who continued to work on his theory (e.g. Baggs and Chemero, 2021), focus on sense perception. According to them people perceive and respond to permanent properties of the environment although sensations vary constantly (Gibson, 1968, pp. 3–4, p. 45). In their view, the problem of perception is not so much how to associate equivalent sensations resulting from different stimulus energies, but how to discriminate the stimulus energies that specify an object or event from all other stimulus energies (Gibson, 1968, p. 55). An object or event often influences different sensations. Note that the distinction between sensations and sense perception relates to the distinction between the senses and perceptual systems, but both distinctions are not equal. When the senses are distinguished from perceptual systems, the focus is on how information is picked up from the environment instead of which information is picked up.

Future research should investigate how sensations and sense perception relate to each other, and how they interact. After all, both play a role in people's experience (Gibson, 1968, p. 47, p. 58). In this work, both sensations as sense perception were taken into account as a result of the types of research being combined. The focus in RBE research is mainly on experiences, which includes sensations and sense perception (e.g. Annemans et al., 2018a), while the focus in MCP research is mainly on assessments of IEQ factors, which relate to sensations (e.g. Sakhare & Ralegaonkar, 2014). Combining the two types of research illustrated that the occurrence of sense perception may be a reason for interactions between IEQ factors in experience. For example, an interviewee who feels nauseous found it difficult to hear and smell nurses preparing food. In this example, both the acoustic comfort and the indoor air quality are negatively assessed because food is being prepared (Chapter 4). Second, relationships between sensations and sense perception can be interesting to investigate. Our research indicates that sensations and sense perception interact. For example, the measured indoor air temperature is high during the heat wave, participants experience it as warm, the shading devices are lowered in several rooms to keep heat outside, and the understanding that there is a heat wave influences the experience of the sensations (Chapter 2).

Second, future research should investigate how the understanding of affordances can contribute to the understanding of interactions between people and indoor conditions through perceived control and adaptation. Affordances are "*relations between (a) aspects of the sociomaterial environment in flux and (b) abilities available in a 'form of life'*" (Rietveld et al., 2018). Affordances are properties of the environment taken with reference to a person, but not properties of the person's experience exclusive of the environment. As discussed in Chapter 2, this theoretical lens seems interesting because it stresses that there is an interrelation between an occupant and its environment. The nuanced understanding that exists about affordances may lead to a better understanding of the roles of perceived control in experiences in RBE research, and more accurate predictions of comfort and adaptation in MCP and MAP research.

Third, it seems valuable to investigate how measurements of IEQ parameters can contribute to the understanding of affordances. To the best of the authors' knowledge, IEQ parameters are not measured in the current literature on affordances. Measuring these IEQ parameters can fill a gap. After all, Gibson (1968) distinguishes the physical world from affordances. The physical world refers to the physical ontologically objective environment. Baggs and Chemero (2021) split affordances into: (1) the environment as a set of resources for a typical, or ideal, member of a species, which they call the habitat, and (2) the environment as the meaningful, lived surroundings of a given individual, which they call the umwelt (Von Uexküll, 1992; Baggs & Chemero, 2021). The distinction between species habitat and animal-specific umwelt enables understanding the environment in realist terms while acknowledging that individual living organisms are phenomenal beings (Baggs & Chemero, 2021). The umwelt is given in experience, while knowledge of the world beyond the umwelt, of the habitat is theoretical or inferential.

Only with respect to sense perception, the habitat can be inferred from the umwelt. This is not possible with respect to sensations. People are not able to indicate the exact state of indoor conditions. Sensors, on the other hand, are able to single out, quantify and make perceivable one type of IEQ parameter (e.g. the temperature of a room) in the physical world. Measuring IEQ parameters may thus contribute to current theories on affordances. However, measuring the IEQ parameters also has its limitations. Sensors are not able to distinguish between the different objects or events that influence the measured IEQ parameter. Moreover, sensors do not know which sensations, objects or events are attended to by people. Attention can facilitate processing relevant stimuli and suppress processing irrelevant ones (Zimbardo & Gerrig, 2002).

3.2.5. From mechanisms underlying indoor environmental comfort and adaptation to their predictions

On the level of the research objective, future research should investigate how predictions of indoor environmental comfort and adaptation can be improved based on the improved understanding of mechanisms underlying them. This research adopted critical realism as worldview. The focus was on identifying mechanisms underlying indoor environmental comfort and adaptation. Moreover, it was assumed that predictions that can be made about social phenomena are of the crude 'rule of thumb' type. That such predictions are possible is, however, mainly supported by researchers with naïve realism as their worldview. It is expected that, despite the difference in worldview, the identified mechanisms and improved understanding of them may contribute to their models.

The mechanisms explored based on the developed integrated methodology can provide MAP research an intermediate step between purely theoretical descriptions of adaptation (e.g. see Yan & Hong, 2018) and purely quantitative models of it (e.g. see Carlucci et al., 2020 for an overview). As acknowledged by the International Energy Agency (IEA) via the Energy in Buildings and Communities' (EBC) Annex 66, such an intermediate step is needed (Yan & Hong, 2018). Insight into the mechanisms underlying comfort and adaptation can be used to refine models of adaptations of indoor conditions. The models of thermostat adaptations set up in this research indicated that such an approach may be valuable (Chapter 6). On its turn, refined models may support their integrating into design practice, which is a need acknowledged by the IEA via the EBC's Annex 79 (Wagner & O'Brien, 2018). Further research is required in this regard.

In addition, as the focus group interviews indicated, more accurate IEQ models and threshold values can support design practice. They will enable determining more precisely, possibly via dynamic simulations, whether and to which extent building systems such as cooling or heating are needed, and support the design of shading devices. Future research should therefore investigate how the improved understanding of mechanisms underlying comfort and adaptation can improve predictions of indoor environmental comfort. The improved understanding may contribute to new ways to quantify and predict it. It may contribute as well to those that have already been applied. The latter include (1) adjustments of Fanger's Predicted Mean Vote (PMV)/Predicted Percentage of Dissatisfied (PPD)-model or Gagge's standard effective temperature (SET)-model in order to highlight different adaptation strategies (Schweiker & Wagner, 2015); (2) multivariate analysis used to investigate interactions between IEQ factors and parameters in people's experience (e.g. Frontczak & Wargocki, 2011; Ncube & Riffat, 2012; Heinzerling et al., 2013; Sakhare & Ralegaonkar, 2014; Fransson et al., 2007); (3) multivariate analysis

to determine patterns in the relationship between building-related symptoms and building characteristics – a need for an integrated analysis approach not addressed in this research - (e.g. Eijkelenboom et al., 2021); (4) cluster analyses performed to determine clusters of people based on their IEQ experience and their corresponding profiles (e.g. Kim & Bluyssen, 2020; Ortiz & Bluyssen, 2022); and (5) quantitative comparisons between settings such as traditional and non-traditional schools (e.g. Bluyssen et al., 2018). In addition, it should be explored how indoor environmental comfort and adaptation can be predicted simultaneously.

Lastly, it seems valuable to integrate models of adaptations of indoor conditions with models that predict comfort. Without this integration, designs for which the use of building systems is automated and optimized with respect to comfort and energy use will likely come out as the best design alternatives. However, in case study 2 satisfaction has the tendency to be higher when patients can adapt behaviourally, e.g. through the adaptation of indoor conditions (Chapter 3). By integrating the models, a better trade-off can be made between supporting comfort or reducing the use of building systems that consume energy.

3.2.6. Valorising insights into mechanisms underlying indoor environmental comfort and adaptation through scenario-based design techniques

On the level of research valorisation, future research can valorise insights into which adaptation strategies patients adopt and diversity therein through scenario-based design techniques (Chapters 2 and 5). Scenario-based design techniques enable to explicitly and iteratively explore use situations in the design process (Van der Linden et al., 2019). Scenarios are often used in conjuncture with personas. Personas are a technique to create vivid user profiles. These user profiles are usually founded on research. The scenarios offer various stakeholders of the design process a way to integrate information about users, settings, and their interactions into a coherent story. They enable making use issues and people's spatial experience tangible, negotiable, and applicable during design. Moreover they can support creative and reflective thinking by taking into account the diversity and dynamics of use situations and offer a frame of reference to evaluate design decisions (van der Bijl-Brouwer & van der Voort, 2013; Van der Linden et al., 2019). In this way they may support architects in designing human-centred environments (Van der Linden et al., 2019).

4. Implications for design practice

Due to limitations of the research, the results must be verified by future research. If confirmed by future research, the results have implications for design practice. The adaptation model (Chapter 2, Figure 2.4), concrete examples given, and

insights from the Results chapters (Chapter 2-6) may increase designers' empathy for surgical patients' comfort, the adaptation strategies that they apply, and diversity therein. For example, interviewees who have a view on a patio feel uncomfortable when the lighting is on in the evening and the window curtain open (Chapter 5). Patients staying in a room on the other side of the patio can then look into their room. Insight into such situations can influence future design choices. Empathy among designers for such situations is needed to transfer the results of this research to the setting of a new design.

Second, some tentative suggestions can be formulated. Stimulating adaptations of indoor conditions may support patients' comfort (Chapter 3). It also seems to stimulate turning off the heating and lighting when their use is not necessary for comfort (e.g. Chapter 5 – comparison single and double rooms). Note that Zhang and Bluyssen (2021) observed in schools as well that when teachers turn on the lighting more frequently, less electricity is consumed. Aligning adaptable building characteristics to patients' competences and increasing patients' autonomy through the design of the patient room may support them to adapt indoor conditions (Chapter 2). Differences in physical (e.g. ability to leave the bed), cognitive (e.g. understanding the use of adaptable building characteristics) and psychological competences (e.g. self-rated well-being) were found among participants (Chapters 2 and 5). The focus group interviews with nurses also revealed that differences in patients' familiarity with technology and their vulnerability may relate to diversity in comfort and adaptation.

In addition, the results suggest that adaptation by choice or imposed adaptation should be avoided (Chapter 3). To avoid both, an understanding of what role adaptable building characteristics will play in patients' experience within the wider socio-material environment will be needed. For example, in case study 1 satisfaction is lower in double rooms than in single rooms (Chapter 2); indoor conditions are less adapted in double rooms and more adaptation by choice is occurring (Chapters 2 and 5); and dissatisfaction is more common when patients adapt by choice (Chapter 3). The adaptable building characteristics are similar in single and double rooms. It is the socio-material environment of a double room that seems to influence the experienced autonomy, and in this way the applied adaptation strategies, and comfort.

5. Conclusion

This chapter discussed the contributions, limitations and suggestions for future research, and implications for design practice based on the research as a whole. It adds to the discussion sections of the results chapters, in which these topics were addressed with a focus on the research sub-questions.

From this ‘Discussion’ chapter can be concluded that contributions were made on a methodological and substantive level. A method was sought to analyse indoor environmental comfort and the corresponding adaptation in an integrated way. It enabled improving the understanding of reasons for discrepancies between predicted and experienced indoor environmental (dis)comfort, the roles of perceived control in patients’ experience, and the roles of the indoor environment in patients’ well-being.

Future research should look for cases and participants that will provide a rich dataset. Furthermore, sequential mixed methods research designs are advised. Data analysis should focus not only on shortcomings in IEQ models, but also on limitations in patients' awareness of what affects their indoor environmental comfort. Topics that require further research are interactions between reasons for discrepancies between predicted and experienced (dis)comfort, interactions between IEQ factors and parameters in experience, and influences of the interactions between different occupants on adaptation. In addition, suggestions for future research can be formulated based on theories from environmental psychology about how the environment is experienced. Future research should investigate as well how comfort predictions can be improved and alternative ways to quantify indoor environmental comfort found based on the improved understanding of mechanisms underlying comfort and adaptation. The improved understandings should also be included in scenario-based design techniques.

If confirmed by future research, the results have implications for design practice. When designers stimulate adaptations of indoor conditions via design, comfort may increase and turning off the heating and lighting when their use is not necessary for comfort stimulated. Adaptations of indoor conditions may be stimulated by designing adaptable building characteristics that align with various competences of patients, and patient room designs that support autonomy.

Chapter 8: **Conclusion**

1. Introduction

There is a need for an improved understanding of indoor environmental comfort and the corresponding adaptation. In MCP research, discrepancies are observed between predicted and experienced (dis)comfort; in MAP research between predicted and actual adaptations of indoor conditions. In RBE research the roles of the built environment in experiences are not yet fully understood. A better understanding of *interactions (1) between people and indoor conditions* through perceived control and adaptation, and *(2) between the different indoor environmental quality (IEQ) factors* in experience, as well as of *differences (3) between people and (4) between settings* in indoor environmental comfort and adaptation may reduce these gaps. Strengths of the research approaches, substantive focus, and applied methods of RBE, MCP and MAP research seem complementary. In this view, this work aimed to explore whether integrating RBE, MCP, and MAP research enables improving the understanding of the four points of attention described above. The main research question was 'how do hospitalized patients' experiences of their patient room's indoor environment relate to measureable values of IEQ parameters?' This main research question was answered by five research sub-questions.

Two mixed methods case studies and interviews with architects, engineers and nurses were conducted. The mixed methods case studies included data collection at surgical wards of two Belgian hospitals as well as building simulations of the second case, and separate as well as integrated analyses of the data. Together with the interviews with the practitioners, they made it possible to address the research objective and answer the research (sub-)question(s).

This chapter describes the conclusions of the research. First, the research sub-questions are answered, followed by an answer to the main research question.

2. Answers to the research sub-questions

RQ.1: How does patient room design influence patients' comfort through its impact on their adaptation of, and to, indoor conditions via their perceived control?

Chapter 2 focusses on interactions between patients and the indoor environment. It addressed the above research question in the light of the research objective.

Focusing on the interactions enabled characterizing known adaptation strategies in more detail. Strategies with perceived control were identified as adaptation (1) of indoor conditions, (2) of sensations or the environmental information, (3) of position, and (4) by choice to indoor conditions; and without perceived control: (5) imposed adaptation to indoor conditions. Via its adaptable building characteristics and spatial layout, the indoor environment affects which adaptation strategy is or has to be adopted. Both affect patients' autonomy over the experienced indoor conditions, competences to adapt and relatedness with others with whom the indoor conditions are shared.

Both having the ability to influence the experience of indoor conditions through adaptation and the more preferable indoor conditions that can be obtained through adaptation seem to support comfort. Links could therefore be identified between how the adaptation strategies impact comfort and the distinction psychologists make between hedonic and eudaimonic well-being. The behavioural adaptation of the first three adaptation strategies, described above, seems to contribute to both hedonic and eudaimonic well-being. The psychological adaptation of the fourth adaptation strategy seems to contribute to eudaimonic well-being. For the latter strategy, patients seem to experience eudaimonic well-being only if they are able to adapt psychologically themselves. Moreover, the way the indoor environment affects adaptation corresponds with the basic needs for well-being according to the self-determination theory. Further research into the links between comfort and hedonic and eudaimonic well-being are needed.

To support patients' comfort, designers should pay attention to how they can increase patients' autonomy and competences to adapt indoor conditions or position. Our observations suggest that the indoor environment should be designed as a means that patients can use to influence indoor conditions, next to an environment that aims to provide comfortable indoor conditions.

This conclusion is based on two mixed methods case studies on hospital wards. More insight into the interactions between patients and the indoor environment could be gained by the use of joint displays. These joint displays consist of tables and figures. They enabled bringing data from the interviews, questionnaire and measurements, and related to different IEQ factors and situations together.

RQ.2: How does distinguishing between hospitalized patients' adaptation strategies inform about reasons for discrepancies between predicted and experienced indoor environmental (dis)comfort?

Chapter 3 focussed as well on interactions between patients and the indoor environment. It addressed the above research question in the light of the research objective.

Tendencies were noticed in how the adaptation strategies identified in Chapter 2 affect the experience of indoor conditions differently psychologically. Sensations seem to be more neutral or as preferred when respondents adapt indoor conditions or have no wish to do so compared to when they adapt by choice or imposed. When sensation votes are more neutral or vary in the direction of patients' preference, satisfaction is slightly higher. These differences in experiences between the different adaptation strategies could not be explained by differences in measured values.

The different ways in which adaptation strategies seem to affect the experience of indoor conditions psychologically are not explicitly accounted for by existing IEQ models. (Dis)comfort is predicted based on measurable values of IEQ parameters only, based on a combination of IEQ parameters in Fanger's thermal comfort model, or by treating adaptation as a 'black box' in the adaptive thermal comfort model. Discrepancies between predicted and experienced (dis)comfort are expected to reduce if researchers find ways to explicitly include in comfort predictions how different adaptation strategies influence the experience of indoor conditions differently. Including this influence in predictions is more complex than distinguishing between types of indoor environments with more or less perceived control.

This conclusion is based on the quantitative data of case study 2. The relationships between adaptation strategies and assessments of indoor conditions, adaptation strategies and measured values of IEQ parameters, and measured values of IEQ parameters and assessments of indoor conditions were analysed visually and quantified.

RQ.3: How does understanding interactions that occur between IEQ factors and parameters in patients' experience inform about reasons for discrepancies between predicted and experienced (dis)comfort?

Chapter 4 focussed on interactions between IEQ factors in experience. It addressed the above research question in the light of the research objective.

Satisfaction with an IEQ factor could only be roughly predicted with values of IEQ parameters, and likewise how often sensations differ from preferences. Patients' satisfaction with the overall comfort in the room seems to influence

satisfaction with individual IEQ factors. In line with this finding, interactions were observed between their satisfaction with one IEQ factor and their satisfaction with other IEQ factors. It was noticed as well that the relative weight of IEQ factors within patients' satisfaction with the overall comfort in the room varies with their satisfaction with the corresponding and other IEQ factors. To improve satisfaction with the overall comfort in the room, and thus satisfaction with individual IEQ factors, patients seem to seek the highest possible overall comfort via adaptation. This comfort can be seen as an optimal balance between IEQ factors' assessment and factors' weight in the assessment of the overall comfort. Moreover, this balance can change continuously.

Interactions between IEQ factors and parameters in patients' experience are currently not included in (dis)comfort predictions. This can be regarded as a reason for discrepancies between predicted and experienced (dis)comfort. It is hence suggested that more research on multi-sensory IEQ models is valuable in order to reduce discrepancies. These models will also avoid that threshold values of the wrong IEQ parameters or factors are tightened in order to increase comfort. Discomfort with one factor may be due to discomfort with another factor. In addition, such models enable widening constraints for threshold values of IEQ factors and parameters when another IEQ factor influences the experience of these positively.

This conclusion was obtained based on the data of mixed methods case study 1. Relationships between values of IEQ parameters, measured with sensors, and patients' assessments of IEQ factors, questioned via a questionnaire, were analysed visually via graphs and through quantitative analyses. In-depth insights into patients' experience, obtained via interviews, helped explaining findings that were unclear based on the quantitative data only.

RQ.4: When and why do thermal and visual comfort and adaptation differ among hospitalized patients?

Chapter 5 focussed on differences between people and between settings. It addressed the above research question in the light of the research objective.

Differences in patients' comfort and adaptation were investigated when for characteristics related to the patients or their setting, the situation differs. Three types of scenarios could be distinguished: situations in which experienced comfort and adaptation are similar, in which adaptation differs and comfort is similar, and in which patients show differences in experienced comfort while indoor conditions are similar.

In the first type of scenarios, experienced comfort and adaptation are similar between the compared situations. It could be observed for thermal comfort when the average outdoor relative humidity, the length between sunrise and sunset, the time of day, the patient's body mass index, their length of stay, or the number of days they have been in the hospital differ. For visual comfort, in

most of the compared situations experienced comfort and adaptation are similar. For visual comfort, situations are similar in this study when the average outdoor temperature, the average outdoor global radiation level during the day, the average outdoor relative humidity, the length between sunrise and sunset, the time of day, the combination of window orientation and view out, the patient's birth sex, their body mass index or their age differ.

In the second type of scenarios, patients apply different adaptation strategies to achieve a similar experienced comfort. For thermal comfort it manifests itself in this study when the average outdoor temperature, the average outdoor global radiation level, the type of room, the combination of window orientation and view out, or the age of patients differ. For visual comfort, it shows when the room type, patients' length of stay, or number of days they have been in the hospital differs.

In the third type of scenarios, the indoor conditions are similar but experienced comfort differs. Differences in experienced thermal comfort were noted when patients' birth sex or self-reported well-being differ. For visual comfort, experienced comfort differs in this study when self-rated well-being differs.

Nurses who aim to apply person-centred care can take insights into characteristics for which experienced comfort differs while indoor conditions are similar into account. The insights support anticipating patients' adaptation and differences in experienced comfort in different situations. Architects and engineers can use insights into the characteristics that relate to differences in adaptation with a similar comfort or differences in experienced comfort while indoor conditions are similar when aiming to design indoor conditions that are comfortable for as many patients as possible, and to reduce the amount of time that the heating or lighting are on. It should be checked whether the design meets various comfort requirements. Moreover, situations for which patients regularly adapt indoor conditions provide good examples. At the same time, for their opposing situations it should be examined how the adaptations of indoor conditions can be stimulated more through the design. Stimulating these adaptations is necessary for two reasons. Either these adaptations are applied to guarantee comfort. Either, these adaptations are applied to prevent the heating or lighting from remaining on unnecessarily.

This conclusion is based on analyses of the quantitative and qualitative data from mixed methods case study 2. Quantitative and qualitative data were integrated through joint displays.

RQ.5: What are strengths and weaknesses of different deterministic and probabilistic models of thermostat adaptations in patient rooms?

Chapter 6 focussed on differences between people and between settings as well. It is an additional chapter. It addressed the above research question to explore how results of the research can contribute to MAP research.

Eleven data-driven models of thermostat adaptations, including one deterministic and 10 probabilistic ones, were set up. The models differ in their complicatedness, i.e. how they deal with the stochasticity, diversity and complexity of adaptations of indoor conditions. The comparison of the models informed about which of them are the most appropriate to apply for several purposes: (1) energy-sensitive design, (2) the search for robust designs, and (3) to evaluate the simultaneity of energy use. Note that the results of the analyses, given below, should be handled with care. The models were drawn up based on a limited amount of data in relation to the number of parameters that were taken into account. In addition, the models are based on estimates of the moments when the heating is on or off.

For energy-sensitive design options, the assessment can focus on relative differences in the energy demand between design options, or on their absolute energy demand. In the first case, the models that performed best were those which attend to *diversity* in thermostat adaptations by including differences in the adaptations between days of patients' hospitalization, and *complexity* by including interactions between characteristics that impact thermostat adaptations in the model. In the second case, the models that performed best were those that approach thermostat adaptations' *complexity* and *stochasticity* with sufficient precision. In our study, these models are therefore also the most suitable for checking the robustness of designs.

In order to correctly predict the heating demand, it is important that both relative differences in the probability that the heating is on and its absolute probability are accurately predicted. The model of this study that performs best in this respect applies a random forest method to classify patients in four clusters, and combines a discrete-time Markov model with a survival based method to simulate the thermostat adaptations within each of the clusters. Patients are classified based on a selection of characteristics that relate to them and their setting.

To verify the simultaneity of heating demands, models that attend to the *stochasticity* and *diversity* of thermostat adaptations by combining a classification of patients into clusters with the probabilistic model of thermostat adaptations described above perform best in our study.

Furthermore, models with a higher complicatedness do not necessarily result in a higher workload for designers. Most models require a simulation of the thermostat adaptations prior to the simulation of the heating demand. Only

the need to generate a correlated random sample prior to these simulations can be avoided.

The insights inform researchers about how models of adaptations of indoor conditions can be further improved. Moreover, they provide preliminary insights into which model of patients' thermostat adaptations designers can choose in relation to the intended design purpose.

This conclusion is based on quantitative data of case study 2. Especially the measurements of the indoor air temperature and simulations of the free-running temperature in TRNSYS17 (2019) were used. They enabled estimating when the heating was on or off in patient rooms, and the set point temperature chosen.

3. Answer to the main research question

RQ: How do hospitalized patients' experiences of their patient room's indoor environment relate to measureable values of IEQ parameters?

It can be concluded that values of IEQ parameters are to some extent related to patients' experience of their patient room's indoor environment, but do not fully explain that experience. IEQ models help to predict (dis)comfort based on values of IEQ parameters. However, due to shortcomings in current IEQ models, discrepancies occur between experienced (dis)comfort – which is the (dis)comfort as experienced by patients -, and predicted (dis)comfort – which is the (dis)comfort predicted based on parameters such as measured values of IEQ parameters.

A better understanding of the relationship between measured values of IEQ parameters and patients' experience of the indoor environment could be gained by integrating research with the objective to understand in depth different roles of the built environment in experiences (RBE), research with the objective to set up models for comfort predictions (MCP), and research with the objective to set up models for predictions of adaptations of indoor conditions (MAP). Their worldview, theoretical lenses, methodology and methods address other aspects of people's experience. Through their differences, they can complement each other.

The use of joint displays made it possible to bring empirical data from RBE, MCP and MAP research together. Next to these joint displays, graphs enabled relating measured values of IEQ parameters with questionnaire responses. The graphs could be explained based on the interviews. Particularly through the joint displays, attention could be given to *interactions* (1) *between patients and indoor conditions* that occur by the use of adaptable building characteristics, and (2) *between IEQ factors* in patients' experience; and to *differences* in the indoor conditions that are comfortable and in adaptation (3) *between patients*, and (4) *between their settings*.

The integration of RBE, MCP and MAP research informed about why current IEQ models that predict (dis)comfort based on IEQ parameters cannot fully describe patients' experience of indoor conditions, and improved the understanding of the roles of the indoor environment in experience. Patients *interact with indoor conditions*. They apply adaptation strategies to improve their overall indoor environmental comfort in the room. The adaptation strategies seem to impact the experience of indoor conditions in a psychological way. To reduce the gap between experienced and predicted (dis)comfort, it may be valuable to include these psychological influences in comfort predictions. To do so, IEQ models can be integrated with models that predict patients' adaptation.

Furthermore, the adaptation strategies applied *differ between patients and between their setting*. How the experience of indoor conditions is impacted by adaptation may therefore differ when characteristics related to patients and their setting differ. This result emphasizes, among other things, the roles of the material environment in comfort and adaptation. Perceived control will impact which adaptation strategies are applied, and this perceived control depends on the material environment. The adaptable building characteristics and patients' competences to use them play a role in the level of perceived control. Moreover, how the spatial layout influences the experienced autonomy is of importance. To reduce the gap between experienced and predicted (dis)comfort, characteristics related to patients and their setting should therefore be included (more) in IEQ models and models that predict patients' adaptation. In this case it is valuable as well to combine IEQ models with models that predict patients' adaptation.

Next to differences in the adaptation strategies applied, experienced comfort differs *between patients* when indoor conditions are similar. The same values of IEQ parameters can therefore relate to a different experience. The characteristics that relate to differences in experienced comfort may be included in the models to reduce the gap between experienced and predicted (dis)comfort. A trade-off must be made between the simplicity of the models when fewer characteristics are included, and their goodness of fit.

Finally, adaptation strategies can be applied to achieve the highest overall comfort in the room. What is considered as the highest overall comfort may differ depending on which adaptation strategies are perceived as possible and comfort requirements. The highest overall comfort level will therefore differ *between patients* and *between settings*. The level of the overall comfort seems to influence the assessment of individual IEQ factors. In this way *IEQ factors interact in patients' experience*. The gap between experienced and predicted (dis)comfort may be reduced by including in comfort predictions how different adaptation strategies are applied simultaneously with regard to different IEQ factors, and by different patients and in different settings. Adapting one IEQ factor, for example, can involve adapting by choice to another one.

This research mainly focused on the interrelationship between individual patients and the indoor environment. However, indoor environmental comfort

is not only influenced by this interrelationship. The socio-material environment with its adaptive opportunities also plays a role. This requires further research.

The insights into the complex interrelationships between patients and the indoor environment should be valorised. The results were reported in a way that is expected to support this valorisation. Improved IEQ models should be developed; architects and engineers should be informed about the role of adaptation in patients' experience and of indoor conditions and the material environment in it, for example by the use of personas; and more nuanced models of patients' adaptations of indoor conditions should be set up. Interviews with architects, engineers and nurses stressed that the former and the second may support the design of comfortable patient rooms; the latter may enable to ensure this comfort while seeking for energy-efficient patient room designs. In this way, this research may contribute to a reduced gap between predicted and experienced indoor environmental (dis)comfort.

Appendix A: **Questionnaire case 1**

Kamernummer: *Patiënt[1]:*

Hoe ervaren patiënten het ziekenhuis?

1. Gegevens

Leeftijd:……
Nationaliteit: ……
Geslacht: ……..

Aantal keer patiënt in Gasthuisberg (inclusief deze opname):……
Hoeveel dagen heeft u in totaal al doorgebracht in dit gebouw (bij deze en voorgaande opnames)?

☐	1 dag	☐	1 week
☐	2 dagen	☐	2 weken
☐	3 dagen	☐	3 weken
☐	4 dagen	☐	1 maand
☐	5 dagen	☐	2 maanden
☐	6 dagen	☐	Andere:……

Mijn ziekenhuisverblijf was op voorhand gepland: ja/nee
Aantal keer patiënt op deze afdeling: ……
Hoeveel dagen verblijft u momenteel op deze kamer?

☐	1 dag	☐	1 week
☐	2 dagen	☐	2 weken
☐	3 dagen	☐	3 weken
☐	4 dagen	☐	1 maand
☐	5 dagen	☐	2 maanden
☐	6 dagen	☐	Andere:……

Bent u (al) geopereerd? Ja/Nee/Niet van toepassing
Vermoedelijke duur van opname (indien gekend):……
Op een typische dag, hoeveel uur brengt u door in uw kamer?

☐ Minder dan 16 uur ☐ 16 uur – 20 uur ☐ Meer dan 20 uur

[1] Here a number was entered by me.

Aantal keren opgenomen in een ander ziekenhuis: ……

Gezondheidsstatus: goed/slecht
Pijn: Veel/Matig/Af en toe/Geen
Mentale gezondheid: goed/slecht
Koorts: ja/nee
Zichtbeperking: ja/nee
Gehoorbeperking: ja/nee
Snel koud: ja/nee/gemiddeld
Geurbeperking: ja/nee
Smaakbeperking: ja/nee
Mobiele beperking in het dagelijkse leven: ja/nee
Wijze van verplaatsing doorheen het ziekenhuis:

☐ Te voet
☐ Rollator
☐ Rolstoel
☐ Bed
☐ Andere:……

Gewicht (kg):……

Grootte (cm):……

---

2. Ziekenhuis en ziekenhuisafdeling

1. Hoe tevreden bent u met het vinden van uw weg in het ziekenhuis? Omcirkel het cijfer dat uw mate van tevredenheid weergeeft.



Zeer ontevreden — Zeer tevreden

OF, indien u hier ***geen ervaring*** mee heeft, gelieve dit vakje aan te vinken: ☐

1.1. Welk van onderstaande aspecten zorgen voor minder tevredenheid met het vinden van uw weg in het ziekenhuis? (Gelieve alle aspecten aan te duiden die van toepassing zijn met een ✓.)

☐ *De ingang van het gebouw is niet duidelijk aangegeven*
☐ *De locatie van ruimtes is niet logisch*
☐ *Wegwijzers zijn onduidelijk*
☐ *Er zijn onvoldoende informatiepunten*
☐ *De cafetaria is niet makkelijk vindbaar*
☐ *Andere:……*
☐ *Ik weet het niet*

---

2. Hoe tevreden bent u met de wachtruimtes in dit ziekenhuis?



Zeer ontevreden — Zeer tevreden

OF, indien u hier ***geen ervaring*** mee heeft, gelieve dit vakje aan te vinken: ☐

2.1. Welk van onderstaande aspecten zorgen voor minder tevredenheid met de wachtruimtes in dit ziekenhuis? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

- ☐ *Te weinig wachtruimtes*
- ☐ *Te veel wachtruimtes*
- ☐ *Het is te druk in wachtruimtes*
- ☐ *Het is te stil in wachtruimtes*
- ☐ *De opstelling van de meubels is onaangenaam*
- ☐ *Te weinig afleiding (geen tv, lectuur,…)*
- ☐ *Andere:……..*
- ☐ *Ik weet het niet.*

---

3. Hoe tevreden bent u met de hoeveelheid ontspannings- en ontmoetingsruimtes op deze afdeling?



Zeer ontevreden — Zeer tevreden

OF, indien u hier ***geen ervaring*** mee heeft, gelieve dit vakje aan te vinken: ☐

---

3. Indeling ziekenhuiskamer

1. Hoe tevreden bent u met de hoeveelheid ruimte die u heeft in uw kamer?



Zeer ontevreden — Zeer tevreden

1.1. Welk van onderstaande aspecten zorgen voor minder tevredenheid met de hoeveelheid ruimte in uw kamer? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

- ☐ *Te kleine kamer*
- ☐ *Te grote kamer*
- ☐ *Te weinig vrije ruimte in de kamer*
- ☐ *Geen eigen badkamer*
- ☐ *Geen douche of bad in de badkamer*
- ☐ *Te weinig opbergruimte*
- ☐ *Te weinig ruimte voor persoonlijke spullen*
- ☐ *Te weinig ruimte om andere mensen te ontmoeten*
- ☐ *Geen/te weinig ruimte om te werken*
- ☐ *Geen/te weinig buitenruimte*
- ☐ *Andere:.....*

---

2. Hoe tevreden bent u met de privacy in uw kamer?



Zeer ontevreden — Zeer tevreden

2.1. Welk van onderstaande aspecten zorgen voor minder tevredenheid met de privacy in uw kamer? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

- ☐ *De ziekenhuisafdeling is te druk bevolkt*
- ☐ *Er liggen te veel personen in 1 kamer*
- ☐ *Hoge densiteit: te weinig ruimte tussen personen*
- ☐ *Scheidingen tussen personen geven onvoldoende visuele privacy*
- ☐ *Verplegend personeel kan gemakkelijk binnenkijken*
- ☐ *Anderen kunnen gemakkelijk binnenkijken door ramen*
- ☐ *Te veel personen komen in mijn kamer*
- ☐ *Andere:.....*

---

3. Hoe tevreden bent u met de manier waarop u contact kan hebben met anderen?



Zeer ontevreden — Zeer tevreden

3.1. Welk van onderstaande aspecten zorgen voor minder tevredenheid met de manier waarop u contact kan hebben met anderen? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

- ☐ *Mijn kamer is te ver van de verpleegpost.*
- ☐ *Mijn kamer is moeilijk te vinden voor bezoekers.*
- ☐ *Gesprekken worden ontmoedigd omdat deze andere patiënten hinderen.*
- ☐ *Er zijn geen ruimtes om met andere patiënten samen te komen.*
- ☐ *Er worden weinig mogelijkheden gecreëerd om met anderen in contact te komen.*
- ☐ *Er zijn geen ruimtes om met bezoek op een aangename manier te praten.*
- ☐ *Bezoek kan niet op een aangename manier ontvangen worden in het ziekenhuis (bv. eetgelegenheden, drankgelegenheden, voldoende parking,…)*
- ☐ *Bezoek kan niet blijven slapen.*
- ☐ *Het is niet mogelijk om met vrienden en familie contact te hebben via internet.*
- ☐ *Andere:……..*

---

4. In het algemeen, ondersteunt of hindert de indeling van de kamer uw mogelijkheid om te genezen?



Hindert erg — Ondersteunt erg

---

5. Gelieve hieronder andere aspecten die u als belangrijk ervaart in verband met de indeling van de kamer te beschrijven.

……
……
……
……

---

4. Inrichting kamer

1. Hoe tevreden bent u met het comfort van de inrichting in uw kamer?



Zeer ontevreden — Zeer tevreden

---

2. Hoe tevreden bent u met het comfort van het meubilair?



Zeer ontevreden — Zeer tevreden

---

3. Hoe tevreden bent u met de kleuren en texturen van vloeren, meubels en afwerkingsmaterialen?



Zeer ontevreden — Zeer tevreden

---

4. Hoe tevreden bent u met de aankleding van de ruimte (planten, sfeerverlichting, televisie, kunstwerken,…)?



Zeer ontevreden — Zeer tevreden

---

5. Hoe tevreden bent u met de mogelijkheden tot personalisatie van uw kamer?



Zeer ontevreden — Zeer tevreden

---

6. Ondersteunt of hindert de manier waarop uw kamer is ingericht uw mogelijkheid om te genezen?



Hindert erg — Ondersteunt erg

---

7. Gelieve hieronder andere aspecten die u als belangrijk ervaart in verband met de inrichting van de kamer te beschrijven.

……
……
……
……

---

5. Thermisch comfort

1. Welke van onderstaande aspecten past u persoonlijk aan of kan u zelf controleren in uw kamer? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

- ☐ Zonwering of zonnescherm
- ☐ Ramen open/gesloten
- ☐ Thermostaat
- ☐ Draagbare verwarming
- ☐ Permanente verwarming
- ☐ Airco in de kamer
- ☐ Draagbare ventilator
- ☐ Plafondventilator
- ☐ Aanpasbare ventilatieopening in wand of plafond
- ☐ Aanpasbare ventilatieopening in de vloer
- ☐ Deur naar binnenruimte open/gesloten
- ☐ Deur naar buitenruimte open/gesloten
- ☐ Geen van bovenstaande
- ☐ Andere:.....

---

2. Hoe tevreden bent u met de temperatuur in uw kamer?



Zeer ontevreden

Zeer tevreden

2.1. Welk van onderstaande aspecten zorgen voor minder tevredenheid met de temperatuur in uw kamer?

- ☐ *Vaak te warm*
- ☐ *Soms te warm*
- ☐ *Vaak te koud*
- ☐ *Soms te koud*

2.2. Wanneer is dit meestal een probleem? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

- ☐ *'s Morgens (voor 11u)*
- ☐ *'s Middags (11u – 14u)*
- ☐ *Namiddag (14u – 17u)*
- ☐ *Avond (na 17u)*
- ☐ *Geen specifiek tijdstip*
- ☐ *Andere:.....*

2.3. Hoe zou u de oorzaak van het discomfort beschrijven? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

- ☐ *Luchtvochtigheid te hoog (klam)*
- ☐ *Luchtvochtigheid te laag (droog)*
- ☐ *Luchtverplaatsing te hoog*
- ☐ *Luchtverplaatsing te laag*
- ☐ *Invallende zon*
- ☐ *Warmte van toestellen in de kamer*
- ☐ *Tocht komende van ramen*
- ☐ *Tocht komende van ventilatieopeningen*
- ☐ *Mijn kamer is warmer/kouder dan andere ruimtes*
- ☐ *De thermostaat is niet toegankelijk*
- ☐ *De thermostaat wordt gecontroleerd door andere mensen*
- ☐ *De kleding die ik moet dragen is niet flexibel*
- ☐ *Warme/koude oppervlakken in de omgeving (vloer, plafond, wanden of ramen)*
- ☐ *Verwarming/koelsysteem dat niet voldoende snel reageert op de thermostaat*
- ☐ *Andere:……*

2.4. Gelieve hieronder andere aspecten die u als belangrijk ervaart in verband met de temperatuur in uw kamer te beschrijven.

……
……
……
……

---

3. In het algemeen, ondersteunt of hindert uw thermisch comfort uw mogelijkheid om te genezen?



Hindert erg — Ondersteunt erg

---

6. Luchtkwaliteit

1. Hoe tevreden bent u met de luchtkwaliteit in uw kamer (bv. muffe lucht, zuiverheid, luchtvochtigheid, geuren)?



Zeer ontevreden — Zeer tevreden

1.1. Gelieve een score te geven aan ieder van de onderstaande problemen:

De lucht is muf:

Groot probleem | -6 | -5 | -4 | -3 | -2 | -1 | 0 | Geen probleem

***OF**, indien dit **geen probleem** vormt, gelieve dit aan te vinken:* ☐

De lucht is niet proper

Groot probleem | -6 | -5 | -4 | -3 | -2 | -1 | 0 | Geen probleem

***OF**, indien dit **geen probleem** vormt, gelieve dit aan te vinken:* ☐

De lucht is te droog

Groot probleem | -6 | -5 | -4 | -3 | -2 | -1 | 0 | Geen probleem

***OF**, indien dit **geen probleem** vormt, gelieve dit aan te vinken:* ☐

De lucht is te vochtig

Groot probleem | -6 | -5 | -4 | -3 | -2 | -1 | 0 | Geen probleem

***OF**, indien dit **geen probleem** vormt, gelieve dit aan te vinken:* ☐

De lucht ruikt slecht (geuren)

Groot probleem | -6 | -5 | -4 | -3 | -2 | -1 | 0 | Geen probleem

***OF**, indien dit **geen probleem** vormt, gelieve dit aan te vinken:* ☐

1.2. Welk van onderstaande aspecten dragen bij tot geurproblemen? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

- ☐ *Tapijt of meubels*
- ☐ *Parfum*
- ☐ *Bronnen van de buitenomgeving (uitstoot van auto's, smog)*
- ☐ *Eten*
- ☐ *Geur van urine of stoelgang*
- ☐ *Andere mensen*
- ☐ *Geur van de afvoer*
- ☐ *Schoonmaakproducten*
- ☐ *Ontsmettende alcohol gel*
- ☐ *Andere:……*

1.3. Gelieve hieronder andere aspecten die u als belangrijk ervaart in verband met de luchtkwaliteit in uw kamer te beschrijven.

.....
.....
.....
.....

---

2. In het algemeen, ondersteunt of hindert de luchtkwaliteit uw mogelijkheid om te genezen?



Hindert erg — Ondersteunt erg

---

7. Visueel comfort

1. Welk van onderstaande controlemogelijkheden heeft u over de verlichting in uw kamer? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

- ☐ Lichtschakelaar
- ☐ Lichtdimmer
- ☐ Bedlamp
- ☐ Zonwering of zonnescherm
- ☐ Geen van bovenstaande
- ☐ Andere:.....

---

2. Hoe tevreden bent u met de hoeveelheid licht in uw kamer?



Zeer ontevreden — Zeer tevreden

---

3. Hoe tevreden bent u met het visueel comfort van het licht in uw kamer (nl. verblindend licht, reflecties, en contrast)?



Zeer ontevreden — Zeer tevreden

---

4. Hoe tevreden bent u met de hoeveelheid ramen in uw kamer?



Zeer ontevreden — Zeer tevreden

5. Hoe tevreden bent u met het uitzicht door de ramen in uw kamer?



Zeer ontevreden

Zeer tevreden

***In verband met de bovenstaande vragen over uw visueel comfort**, welk van onderstaande aspecten zorgen voor minder tevredenheid? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)*

- ☐ *Te donker*
- ☐ *Te licht*
- ☐ *Onvoldoende daglicht*
- ☐ *Te veel daglicht*
- ☐ *Onvoldoende elektrische verlichting*
- ☐ *Te veel elektrische verlichting*
- ☐ *De elektrische verlichting is te intens*
- ☐ *Flikkeringen van de elektrische verlichting*
- ☐ *De elektrische verlichting heeft een ongewenste kleur*
- ☐ *De elektrische verlichting creëert een ongewenste sfeer*
- ☐ *Onvoldoende licht om te kunnen lezen of schrijven*
- ☐ *Reflecties op schermen (bv. tv-scherm, computerscherm)*
- ☐ *Ongewenste schaduw*
- ☐ *Andere:……*

Gelieve hieronder andere aspecten die u als belangrijk ervaart in verband met uw visueel comfort in uw kamer te beschrijven.

……
……
……

---

6. In het algemeen, ondersteunt of hindert de lichtkwaliteit uw mogelijkheid om te genezen?



Hindert erg

Ondersteunt erg

---

8. Akoestisch comfort

1. Hoe tevreden bent u met de hoeveelheid geluid in uw kamer?



Zeer ontevreden — Zeer tevreden

---

2. Hoe tevreden bent u met de hoeveelheid rust in uw kamer?



Zeer ontevreden — Zeer tevreden

---

3. Hoe tevreden bent u met de geluidsprivacy in uw kamer (nl. de mogelijkheid om conversaties te hebben zonder dat anderen ongewenst meeluisteren en vica versa)?



Zeer ontevreden — Zeer tevreden

Welk van onderstaande aspecten dragen bij tot uw tevredenheid over uw akoestisch comfort in uw kamer? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

- ☐ *Muziek*
- ☐ *Natuurgeluiden*
- ☐ *Controle over televisieprogramma's*
- ☐ *Interacties met mensen in mijn kamer*
- ☐ *Mensen pratend in naburige ruimtes*
- ☐ *De stilte*
- ☐ *Andere:……*

Welk van onderstaande aspecten dragen bij tot minder tevredenheid? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

- ☐ *Alarmen*
- ☐ *Monitors*
- ☐ *Rinkelende bellen*
- ☐ *Geluid van toestellen*
- ☐ *Geluid van verlichting*
- ☐ *Karren*
- ☐ *Geluid van verkeer (buiten)*
- ☐ *Geluid van TV's*
- ☐ *Mechanisch geluid (verwarming, airco en ventilatiesysteem)*
- ☐ *Muziek*
- ☐ *Buitensporige echo's van stemmen of andere geluiden*

☐ *Rumoer en wenen, snurken, roepen van andere patiënten*

☐ *Mensen pratend in naburige ruimtes*

☐ *Mensen die meeluisteren wanneer u met het personeel praat over delicate en persoonlijke onderwerpen*

☐ *Mensen die meeluisteren met mijn privé conversaties*

☐ *De stilte*

☐ *Andere:……*

Gelieve hieronder andere aspecten die u als belangrijk ervaart in verband met de akoestiek in uw kamer te beschrijven.

……
……
……
……

---

4. In het algemeen, ondersteunt of hindert de akoestische kwaliteit uw mogelijkheid om te genezen?



Hindert erg — Ondersteunt erg

---

9. Veiligheid van patiënten

1. Hoe tevreden bent u over de zorg voor veiligheid van de patiënt in uw kamer?



Zeer ontevreden — Zeer tevreden

1.1. Welk van onderstaande aspecten zorgen voor minder tevredenheid met de zorg voor veiligheid van pati? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

☐ *Gladde vloerbekleding*

☐ *Ongeschikte handvaten*

☐ *Ongeschikte tilliften voor patiënten*

☐ *Onvoldoende visuele controle van verplegend personeel op patiënten*

☐ *Onvoldoende licht voor verplegend personeel bij de verzorging van patiënten*

☐ *Verplegend personeel wordt gestoord tijdens de verzorging van patiënten*

☐ *Andere:……*

---

10. Netheid en onderhoud

1. Hoe tevreden bent u met de algemene netheid van het gebouw?



Zeer ontevreden — Zeer tevreden

---

2. Hoe tevreden bent u met de hygiëne in uw kamer?



Zeer ontevreden — Zeer tevreden

2.1. Welk van onderstaande aspecten zorgen voor minder tevredenheid met de hygiëne in uw kamer? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

- ☐ *Te weinig ontsmettingsmogelijkheden voor handen*
- ☐ *De locatie van wasbakken*
- ☐ *Moeilijk poetsbare materialen*
- ☐ *Luchtkwaliteit en ventilatie zijn onvoldoende*
- ☐ *Andere:……*

---

3. Hoe tevreden bent u met de poetsdienst die voorzien is voor uw kamer?



Zeer ontevreden — Zeer tevreden

3.1.Hoe vaak heeft u significante problemen met de poetsdienst in uw kamer?

- ☐ *Altijd*
- ☐ *Vaak*
- ☐ *Soms*
- ☐ *Zelden*
- ☐ *Nooit*
- ☐ *Ik weet het niet/Geen mening*

3.2. Welke van onderstaande aspecten zorgen voor minder tevredenheid? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

- ☐ *Stof op oppervlakken dichtbij u*
- ☐ *Stof op andere oppervlakken die u mogelijk zal aanraken*
- ☐ *Stof op oppervlakken die moeilijk bereikbaar zijn*
- ☐ *Vlekken en afval*
- ☐ *Vuile vloeren*
- ☐ *Vuilbakken die niet éénmaal per dag leeggemaakt worden*
- ☐ *Vuilbakken geraken te vol doorheen de dag*
- ☐ *Vuilbakken zijn significante bronnen van geur*
- ☐ *Andere:……*

3.3. Gelieve hieronder andere aspecten die u als belangrijk ervaart in verband met het poetsen en onderhoud te beschrijven.

.....
.....

4. Hoe tevreden bent u in het algemeen met het onderhoud van het gebouw?



Zeer ontevreden — Zeer tevreden

5. Ondersteunt of hindert de netheid en het onderhoud van dit gebouw uw mogelijkheid om te genezen?



Hindert erg — Ondersteunt erg

11. Gebouwkenmerken

1. Gelieve voor elk van de gebouwkenmerken die hieronder opgesomd staan aan te geven hoe tevreden u bent met de effectiviteit van dat kenmerk:

Thermostaat:



Zeer ontevreden — Zeer tevreden

☐ Ik heb er geen ervaring mee.

Opmerkingen:.....
.....

Lichtschakelaars:



Zeer ontevreden — Zeer tevreden

☐ Ik heb er geen ervaring mee.

Opmerkingen:.....
.....

Zonwering:



Zeer ontevreden

Zeer tevreden

☐ Ik heb er geen ervaring mee.

Opmerkingen:.....
.....

---

2. Hoe goed voelt u zich geïnformeerd over bovenstaande kenmerken van dit gebouw?



Niet goed geïnformeerd

Zeer goed geïnformeerd

---

3. Gelieve hieronder andere aspecten die u als belangrijk ervaart in verband met het ontwerp van het gebouw en bovenvermelde gebouwkenmerken te beschrijven.

.....
.....
.....
.....

---

12. Algemene opmerkingen

1. Alle aspecten in beschouwing nemend, hoe tevreden bent u met uw kamer?



Zeer ontevreden

Zeer tevreden

---

2. Gelieve te schatten in welke mate uw genezingsproces verbeterd of verslechterd wordt door de toestand van het binnenklimaat in dit gebouw (bv. thermische situatie, verlichting, akoestische situatie, netheid):



Verslechterd

Verbeterd

---

3. Hoe tevreden bent u met het gebouw in het algemeen?



Zeer ontevreden

Zeer tevreden

4. Welke andere bijkomende opmerkingen of aanbevelingen heeft u over uw kamer of het gebouw in het algemeen?

……
……
……

Hartelijk dank om deel te nemen aan deze enquête!

Appendix B: **Questionnaire case 2**

Enquête: hoe ervaren patiënten het ziekenhuis?

A. Gegevens

Graag onderstaande gegevens bij iedere enquête volledig invullen

Kamernummer:……
Het raam is aan mijn (omcirkel het correcte antwoord): linkerzijde/rechterzijde
Geslacht:……
Geboortedatum:……
Nationaliteit: ……
Datum vandaag:……
Uur op dit moment:……
Datum opname in ziekenhuis:……
(Vermoedelijke) datum van verlaten ziekenhuis:……

B. Bijkomende gegevens

De gegevens in deze grijze zone dient u enkel in te vullen bij de eerste enquête waaraan u deelneemt.

Op een typische dag, hoeveel uur brengt u door in uw kamer?

☐ Minder dan 16 uur ☐ 16 uur – 20 uur ☐ Meer dan 20 uur

Mijn operatie is al geweest: ja/nee/geen operatie nodig
Mijn ziekenhuisverblijf was op voorhand gepland: ja/nee
Aantal keren al gehospitaliseerd in het AZ Sint-Maarten (inclusief deze keer):……
Aantal keren gehospitaliseerd op deze afdeling van het AZ Sint-Maarten:……
Aantal keren gehospitaliseerd in een ander ziekenhuis:……

Zichtbeperking: ja/nee
Gehoorbeperking: ja/nee
Snel koud: ja/nee/gemiddeld
Snel warm: ja/nee/gemiddeld
Geurbeperking: ja/nee

Smaakbeperking: ja/nee
Mobiele beperking in het (normale) dagelijkse leven: ja/nee
Gewicht (kg):…… ……
Grootte (cm):……

1. Gezondheid

1. Hoe vindt u uw lichamelijke gezondheid **op dit moment**? Omcirkel het cijfer dat weergeeft hoe gezond u u voelt.



Zeer ongezond — Zeer gezond

2. Hoe energiek voelt u zich **op dit moment**?



Helemaal niet — Zeer veel

3. Hoeveel pijn heeft u **op dit moment**?



Veel pijn — Geen pijn

4. Hoe tevreden bent u **op dit moment** met de hoeveelheid slaap en rust die u gehad heeft?



Zeer ontevreden — Zeer tevreden

5. Hoe vindt u uw mentale gezondheid **op dit moment**?



Zeer slecht — Zeer goed

6. In welke mate heeft u negatieve gevoelens zoals somberheid, wanhoop, angst of depressie **op dit moment**?



Zeer veel — Helemaal niet

7. In welke mate heeft u positieve gevoelens **op dit moment**?



Helemaal niet — Zeer veel

8. Heeft u koorts **op dit moment**? ja/nee

2. Algemeen comfort

1. Hoe tevreden bent u met het comfort van uw kamer **op dit moment**?



Zeer ontevreden — Zeer tevreden

2. Hoe tevreden bent u met de kwaliteit van de binnenomgeving (thermisch comfort, visueel comfort, akoestisch comfort en de luchtkwaliteit) van uw kamer **op dit moment**?



Zeer ontevreden — Zeer tevreden

3. Thermisch comfort

1. Welke van onderstaande gebouwkenmerken kan u zelf aanpassen in de kamer? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

- ☐ Zonwering of zonnescherm
- ☐ Ramen open/gesloten
- ☐ Thermostaat
- ☐ Draagbare verwarming
- ☐ Permanente verwarming
- ☐ Airco in de kamer
- ☐ Draagbare ventilator
- ☐ Aanpasbare ventilatieopening in wand, plafond of vloer
- ☐ Deur naar binnenruimte open/gesloten
- ☐ Geen van bovenstaande
- ☐ Andere:.....

2. Wat is de toestand van onderstaande gebouwkenmerken **op dit moment**?

- Permanente verwarming: aan/uit/niet van toepassing
- Airco: aan/uit/niet van toepassing
- Draagbare ventilator: aan/uit/niet van toepassing
- Deur naar de gang: open/gesloten/niet van toepassing
- Thermostaat zelf bediend/niet zelf bediend
- Andere:.....

3. Omcirkel op onderstaande schaal het cijfer dat weergeeft hoe u zich **op dit moment** voelt.



Heel koud — Heel warm

4. Hoe benauwd voelt u zich **op dit moment**?



Zeer benauwd — Niet benauwd

5. Hoe tevreden bent u **op dit moment** van de thermische omgeving?



Zeer ontevreden — Zeer tevreden

6. **Op dit moment**, vindt u uw thermische omgeving acceptabel?

☐ Acceptabel ☐ Niet acceptabel

7. Hoe zou u de oorzaak van thermisch comfort **op dit moment** beschrijven? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

☐ Invallende zon
☐ Warmte van toestellen in de kamer
☐ Tocht komende van ramen
☐ Tocht komende van ventilatieopeningen
☐ Mijn kamer is warmer/kouder dan andere ruimtes
☐ De thermostaat is toegankelijk
☐ De temperatuur kan ik zelf controleren
☐ De kleding die ik draag/de lakens en dekens die ik gebruik zijn flexibel
☐ Warme/koude oppervlakken in de omgeving (vloer, plafond, wanden of ramen)
☐ Verwarming/koelsysteem dat voldoende snel reageert
☐ Andere:……

8. Hoe zou u de oorzaak van thermisch discomfort **op dit moment** beschrijven? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

- ☐ Invallende zon
- ☐ Warmte van toestellen in de kamer
- ☐ Tocht komende van ramen
- ☐ Tocht komende van ventilatieopeningen
- ☐ Mijn kamer is warmer/kouder dan andere ruimtes
- ☐ De thermostaat is niet toegankelijk
- ☐ De thermostaat wordt gecontroleerd door andere mensen
- ☐ De kleding die ik moet dragen is niet flexibel
- ☐ Warme/koude oppervlakken in de omgeving (vloer, plafond, wanden of ramen)
- ☐ Verwarming/koelsysteem dat niet voldoende snel reageert op de thermostaat
- ☐ Andere:……

9. **Op dit moment**, hoe zou u de thermische omgeving verkiezen:

Veel kouder | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Veel warmer

10. **Op dit moment**, hoe tochtig vindt u uw omgeving:

1	2	3	4	5	6	7
Zeer tochtig						Zeer weinig tocht

11. **Op dit moment**, verkiest u:

- ☐ Meer luchtverplaatsing
- ☐ Geen verandering
- ☐ Minder luchtverplaatsing

12. Gelieve hieronder aan te duiden welke kledij u **op dit moment** draagt.

- ☐ Korte broek, T-shirt met korte mouwen
- ☐ Korte broek, T-shirt met lange mouwen
- ☐ Lange broek, T-shirt met korte mouwen
- ☐ Lange broek, T-shirt met lange mouwen
- ☐ Lange broek, trui
- ☐ Nachtkleed tot aan de knie, korte mouwen
- ☐ Nachtkleed tot aan de knie, lange mouwen
- ☐ Nachtkleed tot aan de enkels, korte mouwen
- ☐ Nachtkleed tot aan de enkels, lange mouwen
- ☐ Rok tot aan de knie, T-shirt met korte mouwen
- ☐ Rok tot aan de knie, T-shirt met lange mouwen
- ☐ Rok tot aan de enkels, T-shirt met korte mouwen
- ☐ Rok tot aan de enkels, T-shirt met lange mouwen
- ☐ Andere:……

13. Gelieve hieronder aan te duiden waarmee uw lichaam bijkomend bedekt is **op dit moment**.

- ☐ Laken, enkel op voeten
- ☐ Laken, half lichaam bedekt
- ☐ Laken, volledig lichaam bedekt
- ☐ Deken, enkel op voeten
- ☐ Deken, half lichaam bedekt
- ☐ Deken, volledig lichaam bedekt
- ☐ Niets

14. Gelieve hieronder aan te duiden wat u **op dit moment** doet als activiteit.

- ☐ Liggen
- ☐ Zitten
- ☐ Lezen of schrijven
- ☐ Typen
- ☐ Tv kijken
- ☐ Andere:……

4. Luchtkwaliteit

1. Hoe tevreden bent u met de luchtkwaliteit in uw kamer (bv. muffe lucht, zuiverheid, luchtvochtigheid, geuren) **op dit moment**?



Zeer ontevreden — Zeer tevreden

2. **Op dit moment**, vindt u de luchtkwaliteit acceptabel?

- ☐ Acceptabel
- ☐ Niet acceptabel

3. Gelieve een score te geven aan ieder van de onderstaande problemen:

De lucht is muf **op dit moment**:

Groot probleem								Geen probleem
	-6	-5	-4	-3	-2	-1	0	

De lucht is niet proper **op dit moment**

Groot probleem								Geen probleem
	-6	-5	-4	-3	-2	-1	0	

De lucht is te droog **op dit moment**

Groot probleem								Geen probleem
	-6	-5	-4	-3	-2	-1	0	

De lucht is te vochtig **op dit moment**

Groot probleem								Geen probleem
	-6	-5	-4	-3	-2	-1	0	

De lucht ruikt slecht (geuren) **op dit moment**

Groot probleem								Geen probleem
	-6	-5	-4	-3	-2	-1	0	

4. Welk van onderstaande aspecten dragen bij tot tevredenheid met de luchtkwaliteit **op dit moment**? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

- ☐ Parfum
- ☐ Bronnen van de buitenomgeving
- ☐ Eten
- ☐ Andere mensen
- ☐ Schoonmaakproducten
- ☐ Ontsmettende alcohol gel
- ☐ Andere:……

5. Welk van onderstaande aspecten dragen bij tot geurproblemen **op dit moment**? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

- ☐ Tapijt of meubels
- ☐ Parfum
- ☐ Bronnen van de buitenomgeving (uitstoot van auto's, smog)
- ☐ Eten
- ☐ Geur van urine of stoelgang
- ☐ Andere mensen
- ☐ Geur van de afvoer
- ☐ Schoonmaakproducten
- ☐ Ontsmettende alcohol gel
- ☐ Andere:……

6. **Op dit moment**, hoe zou u de luchtkwaliteit verkiezen:

Veel droger | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Veel vochtiger

5. Visueel comfort

1. Welk van onderstaande controlemogelijkheden heeft u over de verlichting in uw kamer? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

- ☐ Lichtschakelaar
- ☐ Lichtdimmer
- ☐ Gordijn aan het raam
- ☐ Gordijn rond het bed
- ☐ Zonwering of zonnescherm
- ☐ Geen van bovenstaande
- ☐ Andere:……

2. Wat is de toestand van onderstaande aspecten **op dit moment**?

- Hoofdverlichting in de kamer: aan/uit
- Bedlamp: aan/uit
- Zonwering of zonnescherm: open/gesloten
- Gordijn aan het raam: open/gesloten
- Gordijn rond het bed: open/gesloten/niet van toepassing
- Andere:……

3. Hoe tevreden bent u **op dit moment** van uw visuele omgeving (nl. hoeveelheid licht, verblindend licht, reflecties, en contrast)?



Zeer ontevreden — Zeer tevreden

4. **Op dit moment**, vindt u uw visuele omgeving acceptabel?

☐ Acceptabel ☐ Niet acceptabel

5. **Op dit moment**, hoe licht vindt u uw omgeving:

Zeer donker 1 2 3 4 5 6 7 Zeer licht

6. **Op dit moment**, hoe zou u uw visuele omgeving verkiezen?

Veel donkerder 1 2 3 4 5 6 7 Veel lichter

7. Welk van onderstaande aspecten zorgen voor tevredenheid met uw visuele omgeving **op dit moment**? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

- ☐ Invallende zon
- ☐ Voldoende daglicht
- ☐ De sfeer van het daglicht
- ☐ Voldoende elektrische verlichting
- ☐ De intensiteit van de elektrische verlichting is aangenaam
- ☐ Afwezigheid van flikkeringen van de elektrische verlichting
- ☐ De elektrische verlichting heeft een aangename kleur
- ☐ De elektrische verlichting creëert een gewenste sfeer
- ☐ Voldoende licht om te kunnen lezen of schrijven
- ☐ Afwezigheid van reflecties op schermen (bv. tv-scherm, computerscherm)
- ☐ Aangename schaduw
- ☐ Aantrekkelijk uitzicht door de ramen
- ☐ Voldoende ramen
- ☐ Andere:……

8. Welk van onderstaande aspecten zorgen voor minder tevredenheid met uw visuele omgeving **op dit moment**? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

- ☐ Invallende zon
- ☐ Onvoldoende daglicht
- ☐ Te veel daglicht
- ☐ Ongewenste sfeer van het daglicht
- ☐ Onvoldoende elektrische verlichting
- ☐ Te veel elektrische verlichting
- ☐ De elektrische verlichting is te intens
- ☐ Flikkeringen van de elektrische verlichting
- ☐ De elektrische verlichting heeft een ongewenste kleur
- ☐ De elektrische verlichting creëert een ongewenste sfeer
- ☐ Onvoldoende licht om te kunnen lezen of schrijven
- ☐ Reflecties op schermen (bv. tv-scherm, computerscherm)
- ☐ Ongewenste schaduw
- ☐ Onaantrekkelijk uitzicht door de ramen
- ☐ Onvoldoende ramen
- ☐ Andere:……

9. Hoe tevreden bent u met het uitzicht door de ramen in uw kamer **op dit moment**?



Zeer ontevreden — Zeer tevreden

6. Geluidscomfort

1. Hoe vervelend vindt u het geluid in uw kamer **op dit moment**?



Zeer hinderend — Zeer aangenaam

2. **Op dit moment**, hoe vindt u het niveau van het geluid van uw omgeving:



3. **Op dit moment**, hoe zou u het geluid verkiezen?



Veel stiller — Geen verandering — Veel luider

4. Hoe tevreden bent u **op dit moment** van het geluid in uw kamer?



Zeer ontevreden — Zeer tevreden

5. **Op dit moment**, vindt u het geluid acceptabel?

☐ Acceptabel ☐ Niet acceptabel

6. Hoe tevreden bent u met de hoeveelheid rust in uw kamer **op dit moment**?



Zeer ontevreden — Zeer tevreden

7. Welk van onderstaande aspecten dragen bij tot uw tevredenheid over uw akoestisch comfort in uw kamer **op dit moment**? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

☐ Muziek
☐ Geluid van TV's
☐ Natuurgeluiden
☐ Geluid van verkeer (buiten)
☐ Controle over televisieprogramma's
☐ Interacties met bezoekers in mijn kamer
☐ Interacties met de dokter en verpleegkundigen in mijn kamer
☐ Interacties met andere patiënten in mijn kamer
☐ Mensen pratend in naburige ruimtes
☐ De stilte
☐ Alarmen
☐ Monitors
☐ Rinkelende bellen
☐ Geluid van toestellen
☐ Geluid van verlichting
☐ Karren
☐ Mechanisch geluid (verwarming, airco en ventilatiesysteem)
☐ Geluiden en wenen, snurken, roepen van andere patiënten
☐ Andere:……

8. Welk van onderstaande aspecten dragen bij tot minder tevredenheid **op dit moment**? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

- ☐ Alarmen
- ☐ Monitors
- ☐ Rinkelende bellen
- ☐ Geluid van toestellen
- ☐ Geluid van verlichting
- ☐ Karren
- ☐ Geluid van verkeer (buiten)
- ☐ Natuurgeluiden
- ☐ Geluid van TV's
- ☐ Mechanisch geluid (verwarming, airco en ventilatiesysteem)
- ☐ Muziek
- ☐ Buitensporige echo's van stemmen of andere geluiden
- ☐ Rumoer en wenen, snurken, roepen van andere patiënten
- ☐ Mensen pratend in naburige ruimtes
- ☐ Mensen die meeluisteren wanneer u met het personeel praat over delicate en persoonlijke onderwerpen
- ☐ Mensen die meeluisteren met mijn privé conversaties
- ☐ De stilte
- ☐ Interacties met bezoekers in mijn kamer
- ☐ Interacties met de dokter en verpleegkundigen in mijn kamer
- ☐ Interacties met andere patiënten in mijn kamer
- ☐ Andere:……

7. Indeling ziekenhuiskamer

1. Hoe tevreden bent u met de privacy in uw kamer **op dit moment**?



Zeer ontevreden Zeer tevreden

2. Welk van onderstaande aspecten zorgen voor tevredenheid met de privacy in uw kamer **op dit moment**? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

- ☐ De ziekenhuisafdeling is niet te druk bevolkt
- ☐ Het aantal personen per kamer is aangenaam
- ☐ Er is voldoende ruimte tussen personen
- ☐ Scheidingen tussen personen geven voldoende visuele privacy
- ☐ Verplegend personeel kan niet gemakkelijk binnenkijken
- ☐ Anderen kunnen niet gemakkelijk binnenkijken door ramen
- ☐ Er komen niet veel personen in mijn kamer
- ☐ Andere:……

3. Welk van onderstaande aspecten zorgen voor minder tevredenheid met de privacy in uw kamer **op dit moment**? (Gelieve alle aspecten aan te duiden die van toepassing zijn.)

- ☐ De ziekenhuisafdeling is te druk bevolkt
- ☐ Er liggen te veel personen in 1 kamer
- ☐ Hoge densiteit: te weinig ruimte tussen personen
- ☐ Scheidingen tussen personen geven onvoldoende visuele privacy
- ☐ Verplegend personeel kan gemakkelijk binnenkijken
- ☐ Anderen kunnen gemakkelijk binnenkijken door ramen
- ☐ Te veel personen komen in mijn kamer
- ☐ Andere:.....

4. Hoe tevreden bent u met de manier waarop u contact kan hebben met anderen **op dit moment**?



Zeer ontevreden

Zeer tevreden

8. Algemeen comfort

1. Welke bijkomende opmerkingen of aanbevelingen heeft u over het comfort van uw kamer?

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.....

Hartelijk dank om deel te nemen aan deze enquête!

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Curriculum

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Scientific experience

KU Leuven, Leuven

2018-2022 Doctoral researcher (100%)
PhD FWO fellowship fundamental research
(grant number: 11A7521N)
KU Leuven, Department of Architecture,
Research[x]Design
Supervisors: prof. dr. ir. arch. Ann Heylighen and prof. dr. ir. arch. Dirk Saelens

Professional positions

Architecture firm 'De Gregorio & Partners'

2017-2018 Internship as architect (100%)
Employers: Alfredo De Gregorio, Serge Bosmans, Patrick Smits

Education

KU Leuven, Leuven

2015-2017 Master of Science and Engineering: Architecture
Option: Building Construction Design
Master thesis: 'Een nieuw(e) (t)huis voor erkende en subsidiair beschermde vluchtelingen in Vlaanderen'
Supervisors: prof. dr. ir. arch. Ann Heylighen and arch. Henk de Smet
(magna cum laude, 82,50 %)

2012-2015 Bachelor of Science and Engineering: Architecture
(magna cum laude, 78,78 %)

List of Publications

Journal articles (peer reviewed)

Willems, S., Saelens, D., & Heylighen, A. (2022). Discrepancies between predicted and actual indoor environmental (dis)comfort: the role of hospitalized patients' adaptation strategies. *Building Research and Information*. https://doi.org/10.1080/09613218.2022.2038060

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Journal articles (not peer reviewed)

Coomans, K., Annemans, M., Jellema, P., Nguyen Lan, P., Pérez Liebergesell, N., Van der Linden, V., Vermeersch, P., Willems, S., Heylighen, A. (2021). Ruimte voor samenzijn vanop afstand. *Viewz, Visie en Expertise in Welzijn en Zorg*, (Viewz 2021/2), 34-37.

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