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An investigation into the effect of (the usage of) personal control over the indoor climate on office workers' satisfaction with the indoor climate and building performance, with the aim to find a balance between the two

MASTER THESIS

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Summary

The indoor climate is considered a common key concern within the FREM-field since this is one of the most important indoor environmental quality factors. Since it has a significant influence on end-user satisfaction with the indoor environment, which in its turn influences job satisfaction and (perceived) productivity of office workers. While this is the factor end-users state to be most dissatisfied about. It is commonly believed that allowing end-users to have personal control over the indoor climate (e.g. allowing them to open windows or adjust temperature, ventilation, window blinds or artificial lighting) enhances end-user satisfaction with the indoor climate. However, giving the end-users this control may also potentially harm building performance. Hence, a balance needs to be established between these two. New technological developments may help to find this balance. Therefore, within this research, the effect of (the usage of) personal control on office workers' satisfaction and building performance was investigated. With the objective to formulate recommendations for the field on how to find a balance between allowing end-users personal control over the indoor climate with the aim to reduce office workers' dissatisfaction with the indoor climate and preserve building performance. To carry out this research the following research questions were formulated:

MQ 1: What is the effect the usage of personal control over the indoor climate on office workers' satisfaction with the indoor climate?

MQ 2: What is the effect of personal control over the indoor climate on building performance?

The conducted research is a two-stage study with a mixed methods approach to answer the two main questions. To answer MQ 1, a single holistic case study is done in which a questionnaire and a building management system is used to collect data. To answer MQ 2, four semi-structured in-depth expert interviews were conducted.

After thorough analysis, the following results were exposed. The respondents on average were between neutral and satisfied about the measured indoor climate factors. They were on average neutral about the available personal control options while most respondents declared to be dissatisfied about the personal control over the temperature. Furthermore, a weak but significant relationship was found between the usage of personal control over temperature and air quality, on office workers' satisfaction with these factors. This relationship indicated, against the statements made in literature, that the higher the frequency of usage of the personal control options, the lower the satisfaction score for the related factor. This outcome is expected to be caused by the unsuitable expectations end-users have over the personal control options and therefore stay dissatisfied after making adjustments. Moreover, the interview results revealed that personal control over the indoor climate has an effect on all the measured building performance factors, although, the consequences depend on the type of climate management system and how the system is used. Technology can help to find the balance that is searched for in this study by interfering when adjustments are made that harm the building performance, though this may increase dissatisfaction, and can help create awareness and understanding of the indoor climate and consequences of the usage of personal control.

The following recommendations have been formulated to establish a balance between allowing end-users personal control over the indoor climate with the aim to reduce office workers’ dissatisfaction with the indoor climate and preserve building performance. Firstly, create awareness and managing expectations may drive beneficial behaviour for the building performance and reduce unsuitable expectations and thereby enhance end-user satisfaction. Secondly, when selecting a climate management system and its set-points, it is important to make sure these support the organisational objectives. Lastly, reduce the size of zones to which adjustments can be made. Smaller zones are more beneficial for the energy performance of the building, the stability of the objective climate and could help to reduce consensus issues, since the effect is only for a limited area. Repeating this study after following up on the given recommendations can asses if usage of personal control over the indoor climate in these scenarios does enhance end-users satisfaction over the indoor climate, in contrast to the results discovered within this research.

Foreword

Within this report, the process and the results of this research, aiming to formulate recommendations for the field on how to find a balance between allowing end-users personal control over the indoor climate with the aim to reduce office workers' dissatisfaction with the indoor climate and preserve building performance, are described. This report comes with several appendices which are provided in a separate document. Below the table of content, an overview of the available appendices is presented. I would like to thank Ms. van Sprang, my thesis supervisor for the support, guidance and reassurance given throughout the process of writing this thesis. Furthermore, I would like to acknowledge Provincie Noord-Holland for allowing me to conduct a case study within their organisation and all the interviewed experts for their valuable contribution to my research. Moreover, I would like to acknowledge my appreciation for my colleagues, especially my supervisor Mr. Zorge, that have been involved and supported me in this process. Lastly, I would like to express my gratefulness towards those in my social surroundings for their unlimited support during this the past months. Everything written in this report is solely my own work unless stated otherwise.

Sarai van der Heide,
Haarlem, August 2018

Table of content

Table of content

List of tables

List of figures

1. Introduction

As agreed by multiple academic models, activities in the field of Facility and Real Estate Management (FREM) have an influence on end-user satisfaction and perceived productivity, thereby adding value to the core business of an organisation (Jensen, Sarasoja, Van der Voordt & Coenen, 2013). The workplace, the environment where employees of an organisation execute their job, has a significant influence on the perceived productivity and level of job satisfaction of employees (CBRE, 2017; Fassoulis & Alexopoulos, 2015; Haynes, 2007; Vimalanathan & Ramesh Babu, 2014). Additionally, the workplace and job satisfaction can contribute to attracting and retaining talent, which is valuable due to the current war for talent. (CABE, 2005; Earle, 2003; Wright & Bonett, 2007). Therefore, providing a workplace that optimally supports the end-user is of high importance.

Within the workplace, a set of multiple factors determine the indoor environmental quality (IEQ). Physical factors (e.g. furniture, colours & textures, indoor climate, cleanliness and building maintenance) and behavioural factors (e.g. interaction and distraction). These factors can influence the end-user's satisfaction according to their workplace and thereby influence their job satisfaction and perceived productivity (Fassoulis & Alexopoulos, 2015; Frontczak et al., 2012; Kim & de Dear, 2012). With the WODI-toolkit, a measurement instrument developed by The Dutch Center for People and Buildings, Maarleveld et al. (2009) have identified a list of the most important IEQ factors according to employees based on numerous post-occupancy evaluations. Indoor climate has been identified as the second most important IEQ factor of the work environment for employee satisfaction and perceived productivity, right after concentration. Within this study indoor climate is defined as thermal quality, daylight, artificial light and air quality.

The importance of indoor climate is confirmed by multiple studies, it is one of the IEQ factors that significantly influences (perceived) productivity and job satisfaction (CABE, 2005; Fassoulis & Alexopoulos, 2015; Frontczak & Wargocki, 2011; Maarleveld, Volker & van der Voordt, 2009; Vimalanathan & Ramesh Babu, 2014). However, the indoor climate tends to be the factor office workers, in general, are most dissatisfied with (Boge, Salaj, Bakken, Granli & Mandrup, 2017; Facto, 2015). End-users seem to be more critical on indoor climate circumstances within an office environment than in a residential environment (Kurvers, Raue, Alders & Leijten, 2011). Numerous studies agree that dissatisfaction with the indoor climateis a common issue within the workplace with important consequences (Boge, et al., 2017; Jensen & van der Voordt, 2017; Maarleveld et al., 2009). Roelofsen (2002) even states it to be a major problem within the FREM field. One of the causes for the dissatisfaction about the indoor climate is the high degree of disunity in preferences of the end-users according to the indoor climate conditions (te Kulve, Boerstra, Toftum, Loomans & Hensen, 2013). Therefore, no single set of indoor climate conditions will suit all occupants (Buckman, Mayfield & Beck, 2014).

Numerous scholars agree that satisfaction with the indoor climatecan increase productivity (Boerstra & Leijten, 2003; Boerstra, 2016; Fassoulis & Alexopoulos, 2015; (Smith & Pitt, 2011). Batenburg and van der Voordt (2008) state based on the studies of Clements-Croome (2000), Leijten (2002) and Stoelinga (2007) that a good indoor climate can increase the perceived productivity of the office worker by 10-15%. While bad indoor climate conditions, resulting in sick building syndrome symptoms and poor indoor thermal- and air quality can reduce the perceived productivity and health of the office worker (Smith & Pitt, 2011). The increase or decrease in productivity can have large financial consequences for organisations. Therefore, office workers dissatisfaction with the indoor climate is one of the major concerns for indoor environment management.

Giving end-users control over the indoor environment (e.g. allowing them to open windows or adjust temperature, ventilation, window blinds or artificial lighting) is a commonly accepted measure to enhance end-user satisfaction with the indoor climate (Hellwig, 2015). This may be a solution for the dissatisfaction since people tend to react to discomfort by trying to make adjustments (Kurvers et al., 2011). Many scholars believe that personal control has a positive effect on end-users satisfaction and thereby productivity (Boerstra & Leijten, 2003; Boerstra, 2016; Boerstra, Loomans & Hensen, 2014; Brager & De Dear, 1998; Buckman et al., 2014; Hellwig, 2015; Van Hoof, 2008; Lee & Brand, 2005; Lee & Brand, 2010; Smith & Pitt, 2011). However, personal control can also potentially harm building performance, which includes longevity, energy performance and objective comfort (Buckman et al., 2014). Some of these scholars mention offering personal control over the indoor climate does not always lead to optimal comfort conditions (Smith & Pitt, 2011; Van Hoof, 2008). Lee and Brand (2005) state that providing effective personal control to those who have little understanding of the indoor climate can be counterproductive. Klein et al. (2012) adds to this that offering the personal control to end-users influences the energy usage of a building. Which is highly relevant in a time that sustainability is one of the megatrends and with the development in the Netherlands that obligates all office buildings to handle energy efficiently from 2023 onwards (PwC, 2018; Rijksoverheid, 2018). Buckman et al. (2014) stress that there is a need to find a balance between allowing end-users to have a certain level of personal control while constructing a stable, reliable, comfortable and energy efficient indoor environment, to preserve building performance.

One of the current megatrends is technology and the acceleration of its development (Ipsos Global Trends, 2017). These novel technological developments may offer a solution to find this balance. Many of the current options for personal control over the indoor climate are enabled by technology. Due to the technology of real-time thermostats, environmental systems can control the indoor climate for local environments and adaptions can be made to meet personal preferences (Van Hoof, 2008). Zeiler et al. (2007) and Klimovich, Nicolle, Anagnostopoulos, de Groote and Staniaszek (2017) claim that due to new technology energy consumption can de be reduced and end-user comfort demands can be met. The current and near future technology could offer new possibilities to facilitate (the perception of) personal control over the indoor climate and may possibly be, in part, a solution for the common key issue of office workers' dissatisfaction according to the indoor climate. New technological developments may help to find the balance between allowing end-users to have a certain level of personal control and preserving or even enhancing building performance.

To summarize, the indoor climate is considered a common key concern within the FREM-field. The indoor climate is one of the most important factors for end-user satisfaction with the indoor environment, which in its turn influences job satisfaction and (perceived) productivity of office workers. One of the causes for the dissatisfaction with the indoor climate is the high degree of disunity of preferences according to the indoor climate conditions. Providing personal control over the indoor climate could be a solution to accommodate for the disunity and thereby reduce office workers' dissatisfaction according to the indoor climate. However, allowing end-users to have personal control may potentially harm building performance. Therefore, a balance needs to be established. New technological developments may help to find this balance between allowing end-users to have a certain level of personal control and preserving or even enhancing building performance. Furthermore, Boerstra (2016) states there to be a lack of knowledge about the effects of personal control over the indoor climate among building scientists and decision makers as leaders, architects and consultants. Therefore, this research will investigate the effect of (the usage of) personal control on office workers' satisfaction and building performance. The indoor climate factors that will be taken into account are; thermal quality, air quality, daylight and artificial light. To carry out this research the following research questions have been formulated:

MQ 1: What is the effect the usage of personal control over the indoor climate on office workers' satisfaction with the indoor climate?

MQ 2: What is the effect of personal control over the indoor climate on building performance?

This research focusses on office workers' satisfaction with the indoor climate in their workplace and the building performance of office buildings. Therefore, for simplicity the term end-user addresses office workers. Likewise, when speaking of end-user satisfaction in this paper this means end-user satisfaction according to the indoor climate.

2. Literature review

Within this chapter, the theoretical background of this study will be discussed. First of all the concept of the workplace and the indoor environment is discussed since this is the environment where all the components of this research take place. Hereafter, the focus goes to the indoor climate and its sub-factors to conclude with the elaboration of personal control over the indoor climate and its effect on office workers and building performance. Including the current and innovative technological solutions to manage these two. Based on the literature that is discussed in this chapter the indoor environmental quality and building performance have been operationalised and are available in appendix 1 and 2.

2.1 Workplace

Studies in the psychological field sciences interpret the workplace as a wider concept including social connections with colleagues and supervisors (Cohrs, Abele & Dette, 2006; Poggi, 2010). Within the FREM field, the workplace is considered to be a more focused concept as discussed in this paragraph. Davis, Leach and Clegg (2011) and Vischer (2008) do consider the workplace as a building or premises including equipment as climate control systems, office furnishing, etc. of an organisation that affects its users and the level of effectiveness in their job performance. However, Fassoulis and Alexopoulos (2015) do not agree with this and consider this description to be incomplete. They state that due to changes in the nature of employment resulting from demographic, organisational and technological developments the workplace is no longer limited to a specific building or place. Because of the demographic developments, the composition of the workforce is changing, businesses tend to deviate from the traditional organisational structure and technological developments as internet and wireless devices enabled new opportunities such as remote working. Because of all these developments the extent of the definition of the workplace has broadened. Employees do not have to perform their job within the actual building or premises any more, as Davis et al (2011) and Vischer (2008) considered the workplace, though they still need to be supported. As a result of this revolution in the workplace, different services and facilities are required (Dery, Sebastian & van der Meulen, 2017; Fassoulis & Alexopoulos, 2015). However, within this study, the workplace is limited to the office environment.

2.1.1 Office workers

Vimalanathan and Ramesh Babu (2014) define the office as the place where professional responsibilities and administrative work is carried out. Where before manual workers were the majority, nowadays office workers are the single largest group in the workforce in developed countries (Ramírez & Nembhard, 2004). The end-users of the workplace that are considered within this research can be labelled as office workers. Serrat (2017) defines office workers as “Someone who is employed because of his or her knowledge of a subject matter, rather than ability to perform manual labour. They perform best when empowered to make the most of their deepest skills” (p. 285). Both Batenburg and van der Voordt (2008) and Ramírez and Nembhard (2004) state that the actual productivity of office workers, in some studies also referred to as “white-collar” workers, is very difficult to measure. Therefore, perceived productivity is commonly used as a measure when assessing the productivity of this type of worker. As Serrat (2017) stated office workers generate and supply ideas instead of delivering goods or services and perform best when they are enabled to fully exploit their skill. Many scholars have studied the conditions within the workplace that can support the office worker in doing their job. Kim and de Dear (2012) state that there is a lack of scientific evidence for causally linking IEQ issues to office worker productivity, though there is a strong prevalent belief that such causality does exist. Roelofsen (2002) states that improving the working conditions will have a reduction in complaints, absenteeism and an increase in productivity as a result. Roelofsen (2002) based this statement on a study among 170 knowledge workers among six buildings. After improving the indoor environment, a productivity increase of 10% was observed; based on the office worker's evaluation of their own productivity, which is by researchers considered a suitable measurement method for productivity (Roelofsen, 2002). The indoor environment within the workplace is one of the key factors that support the office worker. Within this study (perceived) productivity is not directly measured. However, as will be later discussed, literature indicates the indoor climate and personal control to have an indirect effect on (perceived) productivity of office workers.

2.2 Indoor environment

The indoor environment includes all physical, chemical and biological factors within a building that are of influence on the health and wellbeing of the end-users (Boerstra, van Dijken, Marinus, Hulsman & Snepvangers, 2013b). Since people, in general, spend 80% of their time indoors, the indoor environment has a large influence on them (Arditi, Mangano, De Marco & Komurlu, 2013; Bluyssen, 2015; Boerstra et al., 2013b). Moreover, the indoor environment is an essential factor for job satisfaction and perceived performance for office workers (Fassoulis & Alexopoulos, 2015; Poggi, 2010; Raziq & Maulabakhsh, 2015). A research conducted by Gensler (2005), a global architecture, design, planning and constructing firm, among 200 randomly sampled middle and senior managers indicated that almost four out of five of their respondents stated the quality of their working environment as being very important to their sense of job satisfaction. Haynes (2007) has developed a validated theoretical framework displayed in Figure 1. Within this framework, he distinguishes the physical and behavioural environment within the workplace and claims both have an influence on the perceived productivity of the office worker. The division Haynes made (2007) is similar to the division made by Raziq and Maulabakhsh (2015) who distinguishes the physical and social working environment. The physical environment includes the office layout and indoor climate, while the social or behavioural environment includes interaction and distraction (Haynes, 2007; Raziq & Maulabakhsh, 2015). Although, Haynes (2007) concluded that the behavioural environment has the greatest impact on office workers' perceived productivity, within this research the focus lies on the physical environment with the indoor climate in particular.

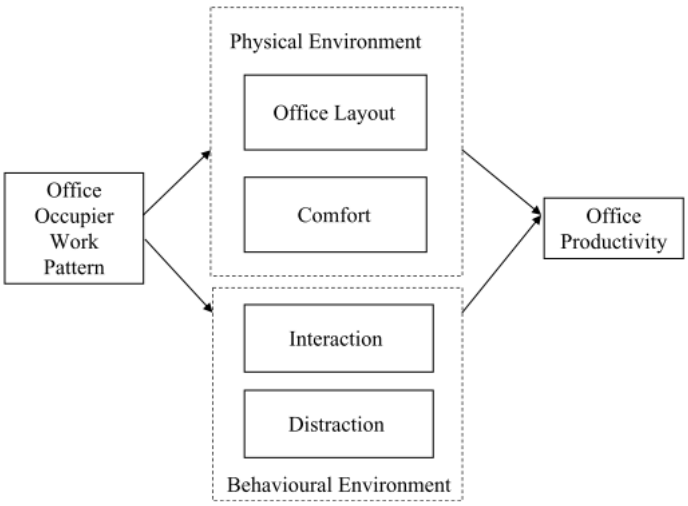


Figure 1. Validated theoretical framework of office productivity (Haynes, 2007)

2.2.1 Indoor environmental quality factors

The indoor environmental quality (IEQ) factors influence how the end-users perceive the workplace. Within the study of Fassoulis and Alexopoulos (2015) a list of IEQ factors of the present-day workplace has been identified, displayed in table 1. These factors can influence the indoor environment of the end-users of the workplace. Additionally, they state that these factors therefore have an effect on perceived productivity and job satisfaction. Similar to these factors, the study of Maarleveld, Volker and van der Voordt (2009) have identified a list of most important IEQ factors according to employees. Within this study, which measures employee satisfaction in new offices, the WODI-toolkit is used. This is a measurement instrument developed by The Dutch Center for People and Buildings, with the aim to assess whether organisation expectations are achieved and to provide valid and reliable data. This data can be used for future evidence-based decision making according to the organisation's accommodation. The IEQ factors that have been identified as most important among the respondents of this study in order of importance are presented in table 1 (Maarleveld et al., 2009). Frontczak et al., (2012), Kim and de Dear (2012) and Peretti, Schiavon, Goins, Arens and De Carli (2010) study a set of highly similar indoor environmental quality factors. However, they use another questionnaire developed by Center for the Built Environment (CBE). The questionnaire developed by CBE is highly similar to the WODI-toolkit and has the purpose of assessing the performance of the design of the workplace (CBE, 2018). The indoor environmental quality factors mentioned that influence the working conditions in the studied literature are summarized in table 1.

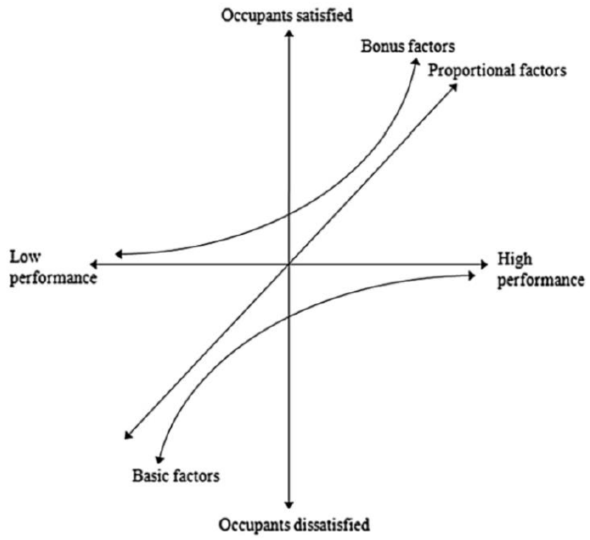
(Fassoulis & Alexopoulos, 2015) Case study, 160 office workers, 238 respondents.	**(Frontczak et al., 2012; Kim & de Dear, 2012)** Database analysis, 351 office buildings, 43.021 respondents.	**(Maarleveld, Volker & van der Voordt, 2009)** Database analysis, 17 office buildings, 2000+ respondents.
Indoor environmental quality	Temperature	Indoor climate
Suitable lighting	Air quality	lightening and acoustics
Controlled noise levels	Amount of light	Concentration
Ergonomic furniture	Visual comfort	Functionality and comfort of the workplace
Location of the building	Noise level	Accessibility of the workplace
The exterior environment	Sound privacy	Architecture and appearance
Aesthetics of the workplace	Amount of space	Interior design, appearance and ambiance
Premises and equipment	Visual privacy	IT and supporting services
Possibilities to personalise	Ease of interaction	User influence
	Comfort of furnishing	Openness and transparency
	Adjustability of furniture	Privacy
	Colours & textures	Communication
	Building cleanliness	Facility management
	Workspace cleanliness	Location of work sites
	Building maintenance	Number, diversity and functionality of workplaces
		Spatial configuration
		Facilities for remote working

Table 1. Indoor environmental quality factors

Frontczak and Wargocki (2011) concluded that thermal quality is considered to be the most important factor to achieve overall satisfaction with the IEQ. Additionally, Fassoulis and Alexopoulos (2015) determined that satisfaction with indoor climate was the most important predictor variable, of all the studied IEQ, for office worker's perceived productivity and job satisfaction. Vimalanathan and Ramesh Babu (2014) add to this that temperature and lighting have the biggest effect on performance within an office environment. While CABE (2005) states, that the most important factors are air quality, followed by temperature, overall comfort, noise, and lighting. The study of Maarleveld et al. (2009) presented the IEQ factors in the order of importance. This study also indicated that most dissatisfaction among the questioned employees was about the indoor climate. In 2015, the indoor climate remained the topic of most dissatisfaction (Boge et al., 2017). This is also measured with the WODI-toolkit, though now based on the results of 118 case studies with 20.320 respondents from 45 different organisations (Facto, 2015). The indoor climate is identified as the second most important aspect of the indoor environment and scores the lowest, which makes this a key issue within the FREM field.

2.2.2 Adapted Kano's satisfaction model

Kim and de Dear (2012) have studied the perceived building performance on specific indoor environmental quality factors and end-users overall satisfaction with the indoor environment based on an adapted version of Kano's satisfaction model (Kano, Seraku, Takahashi & Tsuji, 1984). Their adapted version of Kano's satisfaction model is presented in figure 2. Their version of the model distinguishes three groups of IEQ factors based on how the perceived quality of a particular IEQ factors increases, decreases or does not affect the overall satisfaction with the indoor environment. Basic factors can be considered as a precondition. Factors in this category do not necessarily enhance the level of overall satisfaction but can cause dissatisfaction when the quality is considered poor. Bonus factors are considered to exceed the minimum requirements and therefore poor performance on these factors does not necessarily cause dissatisfaction. When the quality is considered good this can have a strong positive effect on the overall satisfaction of the workplace. For proportional factors the overall satisfaction of the workplace rises proportionally with the level of satisfaction according to the particular measured factor. The results of the study are presented in table 2. No Bonus factors were identified, though it is hinted that personal control over the indoor environment could belong to this category. However, this factor was not investigated since it is not part of the CBE survey (Kim & de Dear, 2012). The indoor climate factors are mentioned by many studies to be an important predictor of office worker's satisfaction with the indoor environment and thereby perceived productivity and job satisfaction.



Basic Factors	Proportional Factors	Bonus Factors
Temperature	Air quality	-
Noise levels	Amount of light	
Amount of space	Visual comfort	
Visual privacy	Sound privacy	
Adjustability of furniture	Ease of interaction	
Colours and textures	Comfort of furnishing	
Workspace cleanliness	Building cleanliness	
	Building maintenance	

Figure 2. Adapted Kano's satisfaction model (Kim & de Dear, 2012)   *Table 2. Factor division (Kim & de Dear, 2012)*

2.3 Indoor climate

The indoor climate is influenced by multiple factors displayed in table 3. These indoor climate factors are influenced by many other factors, for example the indoor temperature is influenced by the outdoor conditions and the use of materials. When a building has a glass façade on a very sunny day the temperature may rise quickly. It is up to the building installations to assure the stability of the indoor climate factors against the interference of the internal and external influences. Moreover, the air quality is influenced by occupant activities, since occupants produce heat, CO^2, odours and dust. Achieving a high-quality indoor climate requires collaboration between architects, builders, installation technicians and the facility management staff (Boerstra et al., 2013b). Haynes (2008) distinguishes indoor environmental comfort into hard and soft comfort factors. According to his theory, soft comfort factors are the indoor design, cleanliness of the environment and the physical security of the occupier. The hard comfort consists of the indoor climate factors.

The objective quality of the indoor climate has an effect on the well-being of the office worker (Boerstra et al., 2013b; Newsham et al., 2009). Moreover, a bad indoor climate can lead to various long and short-term health problems. Long-term problems may be caused by extreme hot or cold situations. These circumstances are more applicable to industrial settings and are highly unexpected within an office environment. Due to the large amount of time spent indoors the indoor climate quality is therefore of high importance (Boerstra et al., 2013b). Moreover, research has revealed that besides psychological and physiological factors, personal factors (e.g. gender, age, culture, recent thermal exposures, thermal expectations), the season, the colour of the wall and the level of personal control can influence one's experience of the indoor climate (Boerstra et al., 2013b; Frontczak et al., 2012; Nasrollahi, Knight & Jones, 2008; Schellen, Van Marken Lichtenbelt, Loomans, Toftum & De Wit, 2010). Research has shown there are large differences among how individuals experience the same indoor climate. In general, older office workers prefer a higher temperature than younger office workers do. Likewise, women tend to complain more quickly about cold feet and hands (Boerstra et al., 2013b). Brager and De Dear (1998) add to this that how indoor climate conditions are experienced also depends on the expectations of the individual.

The decline in productivity because of health complaints due to the indoor environment is called the sick building syndrome (Shaikh, Nor, Nallagownden, Elamvazuthi & Ibrahim, 2014). There is not one explicit cause to appoint for the complaints related to the sick building syndrome. The cause is a combination of multiple factors. As for instance, insufficient maintenance or hygiene, an incorrect design of the climate control system and the lack of personal control. The problems started when building regulations became stricter, which reduced the indoor airflow. Symptoms of the non-specific health complaints that relate to the indoor environment usually disappear quickly after leaving the building (Boerstra et al., 2013b).

(Batenburg & van der Voordt, 2008; Maarleveld, Volker & van der Voordt, 2009)	(Fassoulis & Alexopoulos, 2015)
Temperature	Temperature
Ventilation	Air quality
Air quality	Natural and artificial lighting
Individual temperature control	Controlled noise levels
Access of daylight	Ventilation
Individual daylight control	Humidity
Artificial light	Ability to change to personal needs
Personal control of the artificial light	
Reflection on your monitor	
Noise level of climate control	
Acoustics	

(Frontczak et al., 2012; Kim & de Dear, 2012)	(Haynes, 2007)	(Boerstra et al., 2013b)
Temperature	Ventilation	Thermal indoor climate
Air quality	Heating	Indoor air quality
Amount of light	Natural lighting	Sound and acoustics
Visual comfort	Artificial lighting	Light and view
Noise level		Personal control
Sound privacy		

Table 2. Indoor climate factors

The factors that are considered to belong to the indoor climate vary strongly between studies. Within this research, the focus lies on thermal quality, air quality, daylight, artificial light and personal control since these are the factors that are most often studied in comparable studies (Boerstra et al., 2013b; Fassoulis & Alexopoulos, 2015; Frontczak et al., 2012; Kim & de Dear, 2012; Maarleveld et al., 2009). Moreover, Peretti and Schiavon's (2011) gave an overview of IEQ surveys. Their research shows that thermal quality, air quality, visual comfort and personal control over the indoor climate are the most common studied factors in IEQ studies.

2.3.1 Thermal quality

Boerstra et al. (2013b) defines an adequate thermal quality as the situation when people do not feel the need for a higher or lower temperature. Therefore, thermal quality is expressed in the degree to which one is satisfied with the temperature within the workplace. Here a distinction is made between general thermal quality and local thermal quality. The local thermal quality can differ from the general thermal quality when for instance the room temperature is comfortable, though certain body parts are hot or cold. For instance, due to draught or when standing in front of a fireplace. Local thermal quality can be influenced by radiation asymmetry, temperature gradient and floor temperature (Bluyssen, 2015; Boerstra et al., 2013b).

The thermal quality within the office is an important factor in how office workers experience the indoor climate and therefore for their satisfaction with the indoor climate. When the indoor thermal quality is insufficient, complaints about heat or cold are a common consequence. The most common complaints are; the temperature is too high, the temperature is too low, the temperature is too inconsistent, draught, cold radiation and hot or cold feet because of the floor. Non-specific short-term health complaints that can be related to the effect of indoor temperature are; a headache, fatigue, dizziness and deterioration of motor skills. Furthermore, a prolonged uncomfortable experience in a hot or cold environment may extend the tendency of office workers to complain, also about other aspects according to the indoor climate (Boerstra et al., 2013b). Furthermore, the multiple studies have shown that the indoor temperature influences the perceived productivity of office workers. (Seppänen & Fisk, 2006; Wyon, 2004) According to Boerstra et al. (2013b) perceived productivity is decreased by 10% in a too hot or cold working environment, compared to an environment with an adequate temperature.

There are multiple theories about which factors determine the level of thermal quality. The use of thermophysiological models is a commonly used theory that assumes the thermal quality to be adequate when there is thermal balance and the heat production in the body is equal to the heat release to the environment. Besides the use of thermophysiological models, psychophysiological are also used. In these models, psychological factors are also taken into account. There have been studies in which building occupants complained about too high temperatures, while based on thermophysiological factors the thermal quality was neutral. NEN-EN-ISO 7730, a Dutch quality standard according to the indoor climate uses the comfort model of Fanger (1970) to determine the percentage of dissatisfied office workers with the thermal quality. This model calculates the Predicted Mean Vote (PMV) which reflects how the thermal quality is assessed by the average user. Taking into account the following set of thermophysiological factors; metabolism, clothing isolation, air temperature, relative air humidity and air velocity. If the PMV is calculated the Predicted Percentage of Dissatisfied can be calculated (PPD) which indicates what percentage of the office workers in theory is dissatisfied (Boerstra et al., 2013b).

Due to critique on the model of Franger (1970), Humphreys and Nicol (1998) introduced an adaptive model to predict indoor thermal comfort. In contrast to Franger's model, their model takes into account factors related to the building, outside climate and cultures. Especially, the outdoor temperature is a key factor within this model to calculate the adaptive thermal comfort (Nasrollahi et al., 2008). Kim and de Dear (2012) identified thermal quality to be a basic factor. Thus, when considered poor, thermal quality can cause dissatisfaction.

The parameters that influence the indoor thermal quality are; temperature, relative humidity, air velocity, turbulence, activity and clothing (Bluyssen, 2015; Boerstra et al., 2013b; Nasrollahi et al., 2008; Shafaghat et al., 2016). To control these parameters the following measures can be taken; Heating, cooling, air conditioning & ventilation and building design (e.g. isolation) (Bluyssen, 2015). Within this study, only the indoor and outdoor temperature is taken into account to compare with factual measured data.

2.3.3 Visual comfort

Adequate visual comfort exists when the task to perform is clearly visible, space is not monotonously illuminated, daylight enters, no hindrance exists and daylight, artificial lighting and view are in balance. The aspects daylight, artificial light and view together from the visual comfort within the indoor environment. Within this research, view is left out of scope. Light is essential within the workplace in order to make sure workplaces are well lit, so activities can be performed effectively. The desired illuminance differs greatly per work task and is expressed in Lux. Furthermore, light conditions heavily contribute to the health and wellbeing of offices workers. When lighting in the workplace is inappropriate for the activities that need to be performed this could lead to visual discomfort and health complaints. The presence of lighting in the workplace seems to have an impact on the alertness and productivity of office workers. This depends on the lighting level and colour of the light. However, the exact effects of this are not yet known (CABE, 2005; Boerstra et al., 2013b).

Daylight

Besides illuminating the workplace to enable people to see, daylight also drives other physical processes such as the sleep-wake cycle, body temperature, alertness and moods. Daylight constantly varies in composition, direction and intensity. Artificial lighting cannot optimally simulate this yet. Therefore, as far as possible sufficient daylight, according to a daylight factor, should be available at every single workplace. The luminous transmittance of the glass used in the window determines the amount of light that can get through the window. Since daylight is not always available, due to cloudy days or time of the day, it has to be supplemented by artificial light. Within an environment where a lot of computer work is performed, daylight can also cause hindrance due to great brightness differences or reflections. Therefore, options should be available to avoid hindrance, as outside window blinds to ward off the sun and inside roller blinds for brightness control (Boerstra et al., 2013b; Kunkel, Kontonasiou, Arcipowska, Mariottini & Atanasiu, 2015).

Artificial lighting

Illuminance, colour temperature and colour rendering influence the visual comfort in the indoor environment. Besides, the prevention of glare and ease of use are of high importance. Glare can be caused when illumination of the task is too big compared to the illumination of the direct surroundings. This is depending on the position from where a person observes artificial lighting, the reflection factors of used materials, size of the space and the characteristics of the type of used artificial lighting (Boerstra et al., 2013b).

Kim and de Dear (2012) identified visual comfort as a proportional factor so it is expected that the overall satisfaction of the workplace rises proportionally with the level of satisfaction according to the daylight and artificial lighting.

The parameters that influence the visual comfort relating to daylight and artificial lighting in the indoor environment are; illuminance, colour rendering, colour temperature, luminance transmittance and the daylight factor. To control these parameters and realise a comfortable working environment in terms of light it is essential to carefully align the room layout and artificial and daylight measures to make sure daylight can be optimally used and where needed artificial lighting can supplement (Boerstra et al., 2013b). Within this study, lux value is taken into account for daylight and artificial lighting combined to compare with factual measured data.

2.3.2 Air quality

Adequate indoor air quality exists when the indoor air contains no pollutants in a concentration that affects health or causes hindrance. The quality of the indoor air is determined by the amount of fresh air supply, the quality of the supplied air, the presence of the possibility to vent, the amount of pollutants released by materials, use of equipment and people. All pollutants can be grouped into three main categories that influence the quality of the inside air. Namely, dust and fibres, chemical agents and biological agents. The most significant source of pollutants within the indoor environment are people, due to the production of CO^2, humidity, bio-effluents and behaviour. Besides these, there are the emissions of materials, equipment and processes that influence the indoor air quality. For the emission due to materials a distinction can be for evaporation of newly used materials and the pollution that occurs after long-term use. When selecting materials for the indoor environment conscious decisions need to be made, taking into account the risks related to specific materials. Furthermore, pollutants are released due to the use of equipment, as printers, that influence the air quality. The volume of emissions produced by equipment strongly depends on the type. Though, in general applies, the older and larger the machine, the more emissions it produces. Due to the emissions, the location of equipment has to be chosen carefully. Preferably equipment, especially the larger machines, should be located in unmanned, well-ventilated areas (Boerstra et al., 2013b).

The quality of the indoor air affects office workers health and well-being. Exposure to poor indoor air quality can have serious consequences for the health, varying from comfort complaints to serious health issues such as respiratory tract infections, asthma, allergies, cardiovascular diseases and cancer. Common complaints related to the air quality are odour nuisance and complaints about musty and dry air. Non-specific short-term health complaints that can be related to the effect of the indoor air quality are; dry eyes, stuffy nose, dry throat, headache and fatigue. More serious health issues that may arise in the office on short-term are; infections of the airways, laryngitis, flu, asthma attacks for those who are sensitive to it, infection with the legionella bacteria, development of multiple chemical sensitivities and toxicity due to carbon monoxide. Furthermore, multiple studies have shown that indoor air quality has an effect on office workers perceived productivity and absenteeism (Boerstra et al., 2013b).

To freshen the by the emissions polluted indoor air, ventilation is essential. Commonly used methods for ventilation are; natural supply and discharge, mechanical supply and discharge or a combination of natural and mechanical methods for supply and discharge of the fresh and polluted air. To maintain adequate indoor air quality sufficient ventilation is essential. Although, it must be taken into account that the air used to ventilate has to be of sufficient quality and the climate control installation must be well maintained to avoid becoming a source of indoor air pollution itself (Boerstra et al., 2013b). Kim and de Dear (2012) identified air quality as a proportional factor so it is expected that the overall satisfaction of the workplace rises proportionally with the level of satisfaction with air quality.

The parameters that influence the indoor air quality are; pollutant concentrations and pollutant sources and ventilation. To control these parameters the following measures can be taken; source control, choice of materials, ventilation system, maintenance, air cleaning and activity control (Bluyssen, 2015; Boerstra et al., 2013b). Within this study only the CO^2 concentration is taken into account to compare with factual measured data.

2.3.4 Indoor climate standards

Within this paragraph, the indoor climate standards within the Netherlands will be discussed. Laws and regulations about the indoor climate within the non-industrial sector are known to be relatively limited. All buildings have to comply with the minimum requirements recorded by government-defined construction and working conditions regulations (Bouwbesluit and Arbowet), the requirements that have been established can differ per branch. Besides the minimum requirements, the Arbowet offers an outline that encourages optimization of the indoor climate. The Arbowet states that the employer in general must strive to make the working conditions as good as possible unless this is not feasible due to reasonable circumstances. Next to the legislation, there are various (international) standards, including guidelines according to the indoor environment and climate. The standards that are most relevant for this study are the NEN standards according to the indoor environment and climate conditions; NEN-EN 15251:2007 Binnenmilieu, NEN-EN-ISO 7730:2005 Klimaatomstandigheden and NEN 3087 visuele ergonomie. Tabel 4, displays the standards for the factors that are studied within this research (Boerstra et al., 2013b). These standards are used in the results chapter to compare with the factual in door climate data. In order to see if the responses are in line with what is expected based on the factual indoor climate conditions and the NEN standards that are commonly used with in Dutch offices.

Factor / Class	A	B	C
Thermal quality	**Very Good**	**Good**	**Acceptable**
Winter	21-23°C	20-24 °C	19-25 °C
Summer	23.5-25.5 °C	23-26 °C	22-27 °C
Air quality			
Max. CO^2 in the air	650 ppm*	850 ppm*	1050 ppm*
Min. fresh air supply	60 m3/h a person	45 m3/h a person	36 m3/h a person
Daylight			
Daylight factor	5%	3%	2%
Artificial lighting			
Min. Illuminance	lux 750 + personal control	lux 500 + personal control	lux 500

Table 3. Indoor climate standards (Boerstra et al., 2013b)

** based on an outside air concentration of 400 ppm in urban areas (Boerstra et al., 2013b)*

2.4 Personal control

Brager and De Dear (1998) state that the response to stimuli modifies when a person is exposed to the option of having control over the factors that cause the stimuli. This statement suggests that the availability of personal control options over the indoor climate can change the response of the office worker. According to Paciuk (1990), personal control consists of the combination of available control, exercised control and perceived control. Available control is the availability and effectiveness of options to have control over the indoor climate factors within the indoor environment (e.g. operable windows, thermostats, vans, blinds and adjustable artificial lighting). Exercised control is the relative frequency of the use of the personal control options by the end-users. Perceived control is the amount of control end-users perceive to have over the indoor climate factors (Paciuk, 1990)

2.4.1 Effect on office workers' satisfaction

Several scholars state that the perception of personal control over the environmental conditions can contribute to the level of satisfaction with the IEQ (Boerstra, 2016; Karjalainen & Lappalainen, 2011; Lee & Brand, 2005; Nasrollahi et al., 2008). Van Hoof (2008) even claims that realising thermal comfort for all building occupants is only possible when occupants have effective control over their own thermal environment. Boerstra (2016) states that some personal control over the indoor climate is necessary for the general wellbeing of office workers since not offering any personal control will make them feel powerless. Therefore, end-users who have personal control over the indoor climate tend to be happier and more comfortable in their working environment, more productive and absenteeism is reduced (Boerstra et al., 2014; Boerstra, 2016; Buckman et al., 2014; Hellwig, 2015; te Kulve et al., 2013; Roelofsen, 2002). Although, Smith and Pitt (2011) state that personal control does not always lead to optimal comfort conditions and too much personal control can even frustrate end-users.

Furthermore, scholars state there is a difference in effect between the perceived personal control and exercised personal control. Where study results show that the perception of personal control over the indoor thermal conditions correlates with satisfaction, the actual use of this control seems to be negatively related to satisfaction. A reason for this inconsistent effect could be a limited understanding of the indoor climate among end-users. Giving the control to individuals who have limited understanding of this topic may lead to undesired results (Lee & Brand, 2005). The psychological aspect of individual control can explain the positive correlation between the satisfaction with the indoor thermal conditions and the perception of personal control. The results of the research of Nasrollahiet al. (2008) showed that satisfaction with the thermal quality increases when people believe to be in control, even though in fact they were actually not. Conversely, the research of Boerstra (2016) and Hellwig (2015) found that offering dummy personal control options or options that are not effective tend to result in more complaints.

Moreover, (perceived) personal control over the indoor climate is one of the factors that has the greatest effect on office workers (perceived) productivity (Batenburg & van der Voordt, 2008). According to Boerstra and Leijten (2003) on average productivity can be increased by three percent. Kim and de Dear (2012) did not include the level of personal control within their study, although they expect it to be a bonus factor. Thus, this factor potentially could drive satisfaction with the IEQ.

2.4.2 Effect on building performance

Besides the effect of personal control over the indoor climate on office workers' satisfaction with the indoor climate, offering end-users personal control over the indoor climate also seems to have an effect on the building performance.

Buckman et al. (2014) distinguishes the three drivers behind building performance; longevity, energy & efficiency and comfort & satisfaction. Longevity relates to the ability of a building to remain valuable in the long term what manifests itself in maintenance. Energy & efficiency, relates to the energy usage of the building, which is a hot topic within the field since buildings are responsible for forty percent of the total energy consumption in the world (Kejriwal & Mahajan, 2016; Klimovich et al., 2017; Moreno, Ramos & Skarmeta, 2014; Včelák, Vodička, Maška & Mrňa, 2017). Allowing end-users to have personal control over the indoor climate, influences the energy performance of a building (Klein et al., 2012). Depending on how personal control is implemented and used, allowing personal control over the indoor climate can have advantageous and adverse effects on energy performance (Van Hoof, 2008). Among scholars, there is disunity about the effect of allowing end-users to have personal control over the indoor climate on their comfort and satisfaction. As discussed before, many state personal control to be beneficial for end-user comfort and satisfaction. However, others state that offering effective personal control may lead to undesired results due to a limited understanding. For example, opening windows may cause draught (Fanger, 2001). This means that the usage of personal control options can also harm the objective comfort in the indoor environment.

Buckman et al. (2014) states "There is a need to strike a balance between allowing users to have control of their environment, and creating stable, reliable and comfortable conditions which allow the building systems to manage the energy consumption efficiently" (p. 101). According to Zeiler et al. (2007), this balance can be achieved with the help of technology.

2.4.3 Technology

To maintain the indoor climate at a satisfactory level the indoor climate factors need to be controlled. To control the thermal quality, a distinction is made between measures to preserve the general thermal quality in summer (to prevent overheating) and winter time (ensure sufficient heating). The possible measures to control the indoor climate whilst offering personal control range from simple low-tech methods to more thorough high-tech solutions (Boerstra et al., 2013b).

The Internet of Things (IoT) is a recently growing technology invented by Ashton (2009) in 1999 (Ryu, Kim & Yun, 2015). IoT can be defined as a large network of uniquely identifiable everyday objects that are connected to the internet and deliver data gathered by the sensors they contain (Moreno et al., 2014; Nambi, Sarkar, Prasad & Rahim, 2014; Ryu et al., 2015). Due to these recent developments, progress in sensing and wireless communication data can be collected over extended periods at low cost (Noye, North & Fisk, 2015). Monitoring of this data will provide useful information about the health and wellbeing conditions within the office (Nanni, Benetti & Mazzini, 2017). IoT sensors can gather data to enhance the quality, efficiency, user experience and can locate individual end-users within the workplace.

Thus far, mainly traditional solutions to offer personal control have been discussed. According to the literature, these measures may have undesired results for the building performance. However, Klimovich et al. (2017) states that technology offers tools to facilitate more efficient buildings. Zeiler et al. (2007) statements align with this and adds to that due to new technology, new at the time of the research, energy consumption can be reduced while individual end-users comfort can be enhanced, even when personal control is allowed. Smart systems can use IoT technology to create a comfortable and safe indoor climate specified on end-user preferences (Simmonds & Bhattacherjee, 2015). Due to IoT, the indoor climate can be measured real-time. As a result, if needed adjustments can be made and in some cases dissatisfaction could be avoided (Kejriwal & Mahajan, 2016; Klimovich et al., 2017). In addition, the climate can be controlled based on the actual parameters. Consequently, the climate control system does not have to be active when unnecessary. Therefore, this technology could also save energy usage (Buckman et al., 2014; Klimovich et al., 2017; Moreno et al., 2014). Furthermore, the trend for wearables and the possibility to locate individual end-users within the building enhances the possibility to personalise the indoor climate (Clements-Croome, 2018). Another benefit is that IoT sensors can be used to predict and plan maintenance and thereby reduce downtime (Klimovich et al., 2017).

Moreover, the research of von Frankenberg und Ludwigsdorff et al. (2016) shows that giving end-users access to IEQ data (e.g. thermal, air and light quality and energy consumption data) in a well visualized and understandable format can enhance the end-user awareness and understanding of the IEQ and change their behaviour. This may help to reduce the undesired effects of offering end-users personal control over the indoor climate, as an increase in energy usage. Also, Moreno et al. (2014) emphasises that a user-driven approach is required to make these solutions successful.

2.5 Conceptual framework

The framework presented in Figure 3 is based on the studied literature that visualizes how the studied and discussed topics relate to each other.

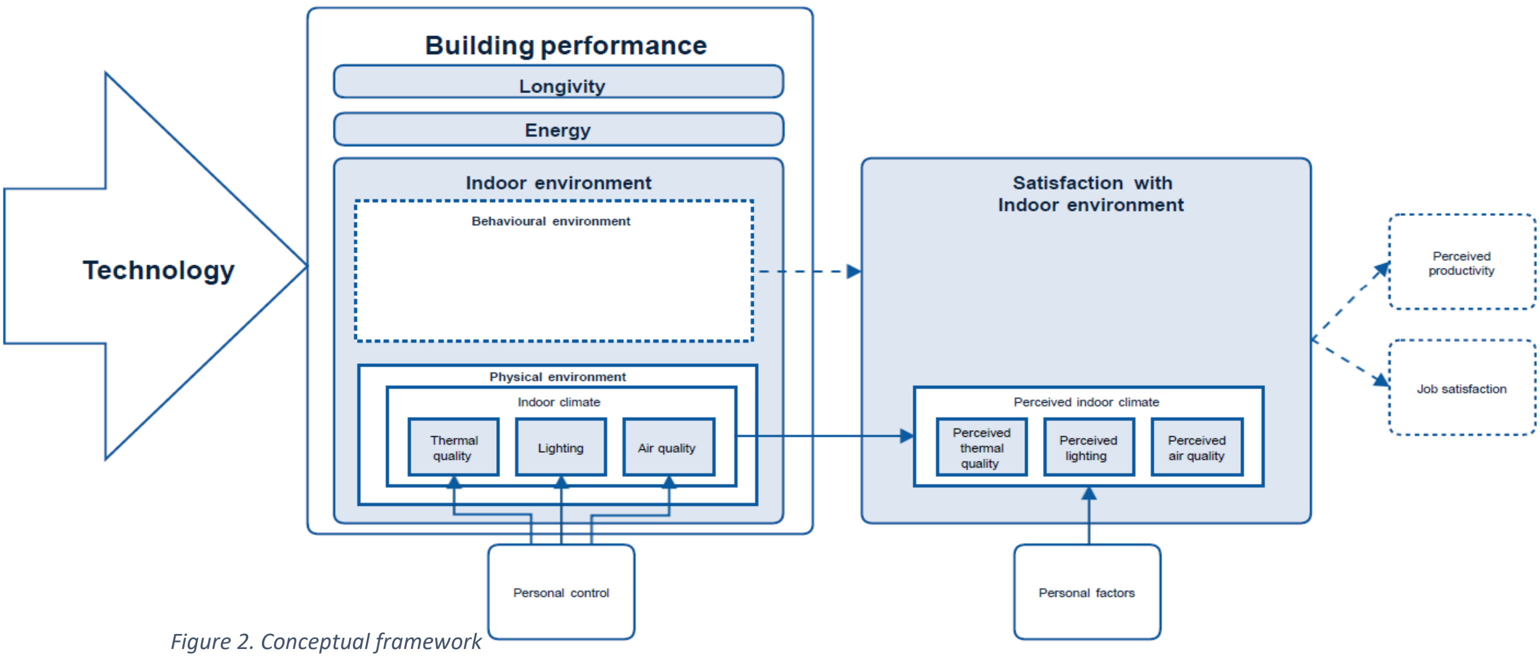


Figure 2. Conceptual framework

3. Questions, objectives and hypotheses

Within this chapter, the objective of this research is discussed and the relating research question, sub-questions and the hypothesis are presented. The hypothesis was formulated for main question one, to convert the research question into a testable format, which suits the deductive nature of this part of the research (Gray, 2014). The hypothesis was based on the positive statements made within the literature by several scholars according to the effect of offering personal control over the indoor climate (Boerstra & Leijten, 2003; Boerstra, 2016; Boerstra, Loomans & Hensen, 2014; Brager & De Dear, 1998; Buckman et al., 2014; Hellwig, 2015; Van Hoof, 2008; Lee & Brand, 2005; Lee & Brand, 2010; Smith & Pitt, 2011).

3.1 Research objective

Office workers dissatisfaction with the indoor climate is considered to be a common key concern within the workplace since this factor is ranked as one of the most important IEQ factors for end-user satisfaction with the workplace among office workers (CABE, 2005; Fassoulis & Alexopoulos, 2015; Frontczak & Wargocki, 2011; Maarleveld, Volker & van der Voordt, 2009; Vimalanathan & Ramesh Babu, 2014). Furthermore, indoor climate is also the IEQ factor that on average office workers are least satisfied with (Boge et al., 2017; Facto, 2015). Moreover, many scholars believe that allowing end-users to have personal control has a positive effect on end-users satisfaction and thereby productivity (Boerstra & Leijten, 2003; Boerstra, 2016; Boerstra et al., 2014; Brager & De Dear, 1998; Buckman et al., 2014; Hellwig, 2015; Van Hoof, 2008; Lee & Brand, 2005; Lee & Brand, 2010; Smith & Pitt, 2011). However, personal control can also potentially harm building performance (Klein et al., 2012; Lee & Brand, 2005; Smith & Pitt, 2011; Van Hoof, 2008). Therefore, a balance needs to be established between allowing end-users to have a certain level of personal control and preserving or even enhancing building performance (Buckman et al., 2014). Due to new technology energy consumption can be reduced and end-user comfort demands can be met (Klimovich et al., 2017; Zeiler et al., 2007). Hence, this study will investigate the effect of (the usage of) personal control on office workers' satisfaction and the building performance to gain insight in how to find a balance between these two and explore if new technologies could help in finding this balance. In order to see if the responses are in line with what is expected based on the factual indoor climate conditions, the office workers' satisfaction scores will be compared to the factual indoor and outdoor climate data and the NEN standards according to the indoor climate. With the objective to formulate recommendations for the field on how to find a balance between allowing end-users personal control over the indoor climate with the aim to reduce office workers' dissatisfaction with the indoor climate and preserve building performance.

3.2 Research questions

The following research questions are formulated based on the studied literature. The research framework presented in appendix 3, visualizes how the sub-questions and main question connect.

Main question 1
What is the effect of the usage of personal control over the indoor climate on office workers' satisfaction with the indoor climate?

Sub-question 1.1
A: What is the effect of the usage of personal control over the thermal quality on office workers' satisfaction with the thermal quality within their workplace?

B: What is the factual indoor and outdoor temperature during the period of the questionnaire?

Sub-question 1.2
A: What is the effect of the usage of personal control over the air quality on office workers' satisfaction with the air quality within their workplace?

B: What is the actual air quality in terms of CO^2 levels within the workplace during the period of the questionnaire?

Sub-question 1.3
A: What is the effect of the usage of personal control over the access of daylight on office workers' satisfaction with the access of daylight within their workplace?

B: What is the factual Lux value during the period of the questionnaire? *

Sub-question 1.4
A: What is the effect of the usage of personal control over artificial light on office workers' satisfaction with the artificial lighting within their workplace?

B: What is the factual Lux value during the period of the questionnaire? *

*Both sub-questions will be measured and discussed as one since both influence the lux value

Main question 2
What is the effect of personal control over the indoor climate on building performance?

Sub-question 2.1
What is the effect of personal control over the indoor climate on maintenance?

Sub-question 2.2
What is the effect of personal control over the indoor climate on energy performance?

Sub-question 2.3
What is the effect of personal control over the indoor climate on the objective comfort?

3.3 Hypothesis
The usage of personal control over the indoor climate enhances office workers' satisfaction with the indoor climate.

4. Research methods, operationalisation and analysis

This chapter discusses in detail how the research was conducted and justifies all the decisions made to realise transparency. First, the research design is discussed, followed by the data collection techniques and instruments. Then, the sampling technique and procedure is deliberated. To conclude with an elaboration on how the gathered data is analysed.

4.1 Research strategy and approach

The conducted research is a two-stage study that used a mixed methods approach to answer the two main questions since both questions required another approach and method of data collection. Main question 1 (MQ 1) required an explanatory study based on an existing theory since for this part of the study the aim was to study the relationship between two variables based on an existing theory (Gray, 2014; Saunders, Lewis, & Thornhill, 2009). The two variables on which the relationship was tested were the usage of personal control over the indoor climate and office workers' satisfaction with the indoor climate. Studies according to IEQ and the indoor climate, within the FREM-field generally use quantitative methods with a survey design to test the relationship between variables (Fassoulis & Alexopoulos, 2015; Frontczak et al., 2012; Kim & de Dear, 2012; Maarleveld et al., 2009; Peretti et al., 2010). A survey is a popular design since this allows researchers to access a large amount of data from a substantial population in an efficient manner (Saunders et al., 2009). To answer MQ 1, a survey design within a single holistic case study was used. A case study is suitable here since a particular phenomenon, the effect of the usage of personal control over the indoor climate on office workers' satisfaction with the indoor climate, was studied within a real-life context (Saunders et al., 2009). The case study that is conducted is a single holistic case study because a typical case was selected to make a comparison with factual indoor climate data possible and office workers' are considered as a whole. Within the case organisation, a questionnaire was used to gather data among the end-users of the building. Additionally, factual data on indoor and outdoor climate factors were gathered during the period of the survey. This data was compared to quality standards on the studied factors to assess if the office workers' satisfaction responses about the indoor climate were in line with the objective comfort conditions according to the NEN standards. The selection of multiple cases would have made the factual data incomparable.

Main question 2 (MQ 2) required an exploratory study since this question studies a phenomenon, the effect of personal control over the indoor climate on building performance, was studied in the new light of the current technological developments (Saunders et al., 2009). The use of expert interviews seems to be rare in the field of IEQ studies. However, due to the explorative nature of this research, the use of this method was the most suitable since this allows to gain in-depth knowledge on the studied topic (Gray, 2014). Furthermore, a typical end-user of a building within this case organisation would not have the required knowledge to answer MQ 2. Other exploratory studies in the field that research current trends, as the working environment as a tool for retaining top talent or smart working environments, do use this method (Earle, 2003; Kim, Nussbaum & Gabbard, 2016; Simmonds & Bhattacherjee, 2015).

4.2 Data collection techniques and instruments

The data to answer MQ 1 was gathered with the use of questionnaire within one specific case organisation. The use of questionnaires is common practice in IEQ studies (Peretti & Schiavon, 2011). A questionnaire is frequently used within the survey strategy (Gray, 2014; Saunders et al., 2009). The questions in the questionnaire are based on the operationalisation of IEQ, available in appendix 1 and the expected relations as displayed in the conceptual framework in paragraph 2.5. Additionally, it is inspired by the questionnaire used by Boerstra et al. (2013a), that takes into account the usage of personal control options in offices and the WODI-toolkit of CfPB as used by Fassoulis and Alexopoulos (2015) and Maarleveld et al. (2009). This questionnaire assesses the employee satisfaction with the workplace in offices. The questionnaire that was used for this research has five questions about personal factors. Twenty-one closed questions were asked about satisfaction with the indoor climate (5) and control options (5), usage of personal control options (5), the frequency of consensus issues due to usage of personal control options (1) and the importance of personal control options (5). These questions covered all studied factors and several personal control options that control these factors. Furthermore, two open questions were asked to give respondents the opportunity to share their opinion in more detail. The questionnaire that is used for this study is available in appendix 4.

To maximize the response rate effort was taken to keep the questionnaire clear and concise. The question asked about the days present in the office was left out of consideration for the data analysis. The used questionnaire can be labelled as a self-administered intranet-mediated questionnaire as a link to an online form was posted on the intranet of the case organisation (Saunders et al., 2009). Additionally, the factual indoor climate data was gathered by the building management system (BMS). Due to the use of multiple methods, triangulation could be executed in the data analysis, which is recommended for case studies (Saunders et al., 2009). The factual data for sub-question 1.3 and 1.4 about daylight and artificial lighting were measured as one factor, lux since both factors influence the lux value. Furthermore, it was intended to compare the fresh air supply to the NEN standards. The NEN standard for fresh air supply depends on the number of users in the room. Due to the open and flexible workplace concept, there is no fixed number of users for a room. During this study, no tools were available to verify the number of users in the room for the measurement period. Therefore, the fresh air supply was not studied.

The data to answer MQ 2 was gathered with the use of semi-structured interviews with experts about an indoor climate and personal control within an office environment and new technological developments in the field, to gather in-depth information (Saunders et al., 2009). For each interview the same topic list that was used, which is available in appendix 5. The topic list that was used was based on the statements made in literature and the operationalisation of building performance, available in appendix 2. Because in all interviews the same topics were discussed, the outcomes are comparable (Saunders et al., 2009).

4.3 Sampling technique

For the first part of this research, it was essential that data was gathered in an office environment with options for office workers to have personal control over the indoor climate. Therefore, this was a vital selection criterion for a case organisation. Furthermore, it was attempted to select a case that was relatively representative of the whole population of office workers. Therefore, a purposive typical case sampling technique was used to select a case organisation for this study, in an attempt to approach representativeness (Gray, 2014). Within the case organisation, all the office workers of the selected building belong to the population within the case organisation.

The selected case organisation for this research was Provincie Noord-Holland, which is a public governmental organisation. Provincie Noord-Holland can be considered a typical case for this study since it has an up to Dutch standards, typical open office environment, a high diversity in office workers (e.g. Numerous employment levels) and meets the selection criteria of allowing office workers to have personal control over the indoor climate. A link to an online form was posted on the organisation's intranet and therefore was available to all the approximately 1200 office workers of the selected building of the case organisation. The questionnaire was open for two weeks and was promoted via multiple channels as email, word of mouth and internal social media channels. A full sample technique was used since all the employees that work for the case organisation and are office workers have access to the intranet and thereby the link to the questionnaire. In total 156 respondents filled in the questionnaire. After extensive inspection, only 141 of the responses were found valid for further analysis. Since the complete population consists of 1200 people, the response rate is 11.75%. Therefore, with a reliability of 95%, the actual error margin is 7,76% (CheckMarket, 2018). This means that the found results in reality may vary by between plus or minus 0 and 7,76%.

For the second part of this research, it was required that the interviewee is an expert on indoor climate and personal control within an office environment and new technological developments in the field. Therefore, the selection criteria for interviewees are expertise on the topics; indoor climate, indoor climate experience, personal control and technological developments around this topic with experience in the office sector. These criteria outline the profile of an indoor climate consultant. A convenience sampling technique was used to find interviewees, due to the low related costs (Gray, 2014). The interviewees were selected via the network of the researcher and by approaching consultants and authorities on the studied topic. One of the interviewees is a leading expert on the topic of personal control over the indoor climate in the Netherlands. In total four in-depth expert interviews of approximately one hour were conducted, after this the point of data saturation was reached. Table 5 displays an overview of the interviewees, their job title and employer. Three of the interviews were face-to-face, one interview was conducted over the phone.

Interviewee	Job title and employer
Jack Ponsteen	Senior consultant building physics – DPA Cauberg-Huygen
Artze Boerstra	Researcher and senior consultant indoor climate – BBA Binnenmilieu BV
Ruud van der Sman	Smart Solutions manager – OVG Real Estate / EDGE Technologies Teacher process engineering – Avans +
Rico Logman	Senior consultant building physics – DWA

Table 4. Overview of the interviewees

4.4 Data analysis

The gathered quantitative data for MQ 1 was analysed in SPSS, which is a software program that analyses quantitative data, often used in the field of social sciences (Gray, 2014). The codebook available in appendix 7, gives an overview of the questions and the coded answering options. A combination of univariate and bivariate analyses, according to the measurement plan available in appendix 8, were performed to come to the results that will be discussed in the following chapters. The measurement plan was based on the expected relation between the usage of personal control and office workers' satisfaction with the indoor climate, as is displayed in the conceptual framework in paragraph 2.5. In addition, factual data on indoor and outdoor climate conditions during the period of the questionnaire in the case building were measured. This data was compared to the NEN standards according the indoor climate and the satisfaction ratings given by the respondents, in order to see if the given responses are in line with what is expected based on the measured objective climate conditions. The answers to the open questions will be analysed using a similar qualitative analysis technique as for MQ 2, which will be discussed next.

The gathered qualitative data for MQ 2 was analysed using a combination between a deductive and inductive analysis approach to avoid missing hidden patterns or the risk of the literature not fitting the data (Eros, 2018). For both the qualitative data gathered with the open questions in the questionnaire and the expert interviews, the belonging operationalisation was used as code tree, which belongs to the deductive analysis approach. To develop this code tree created based on theory, axial coding was performed. First, the interview transcripts were analysed according to the code tree based on theory, here the sections that conveyed a message were labelled with one or multiple key-themes. During this phase, patterns between data and data that were not yet discussed in the studied literature were noticed and added to the code tree as new key-themes of sub-themes, to bring more depth into the code tree (Eros, 2018). After this, the sub-themes were also added to the labels of the coded data. This belongs to the inductive analysis approach (Saunders et al., 2009). Which is essential for the second part of the study since the aim is to find new knowledge. The code tree including axial coding for the expert interviews is available in appendix 9 and the coded interview transcripts are available in appendix 10. The coded open question responses are available in appendix 6, the type of comments given by the respondents were categorised as sub-themes. Afterwards, it was counted how many times each sub-theme was mentioned.

5. Results

Within this chapter, the results of the data gathering of both research questions is discussed, linked to each other and the literature described in chapter 2. First, the results of the case study are discussed followed by the expert interviews.

5.1 Questionnaire results

Within this paragraph, the results of the case study is discussed. First, a case description is presented which outlines details about the case organisation. Followed by an overview of the respondents. Where after, the outcomes of the questionnaire and the factual data is discussed.

5.1.1 Case description

The building that is used for this case study is the headquarters of Provincie Noord-Holland located in an urban area at Houtplein 33 in Haarlem, the Netherlands. Provincie Noord-Holland is a governmental organisation that employs a high variety of people (e.g. numerous employment levels). The main activities of those included in the sample, office workers, is deskwork and consultations with colleagues. The building has a net floor space of 20.000 M^2, a highly insulated façade and triple glazing. The most recent renovation of the building finished in 2013. The building has an open and flexible workplace concept with three workplace types (standard, calm and concentration) and houses roughly 1200 office workers. To control the thermal quality, a thermal energy storage and chilled beam system are used which works based on low-temperature heating and high-temperature cooling and therefore its effects flow slowly. This type of system is selected because it is highly energy efficient. The standard temperature set-point is 22 °C. The ventilation system to sustain the indoor air quality is controlled by the presence of end-users and the measured CO^2 levels within a specific zone, with 600 ppm as a set-point. To control the daylight, manually controlled inside blinds are available and automatically controlled outside blinds responding to the light intensity. The artificial lighting in the building automatically adjusts to the measured illuminance conditions for the specific zone when end-users are present, to get to the anticipated conditions, for which the desired set-point is 500 lux. Furthermore, a variety of personal control options are available, including a control panel to adjust the temperature (+2°C / -2°C), outside window blinds, inside window blinds, artificial lighting and the option to leave t the window ajar. To control the temperature a threshold is built in, 25% of a quadrant control panels need to be adjusted before the system reacts. This was a conscious decision of the organisation to avoid inefficient adjustments that harm their energy performance. Figure 4 displays a floor plan of the second floor, including the division of the quadrants, this floor is comparable to the other floors is in the building.

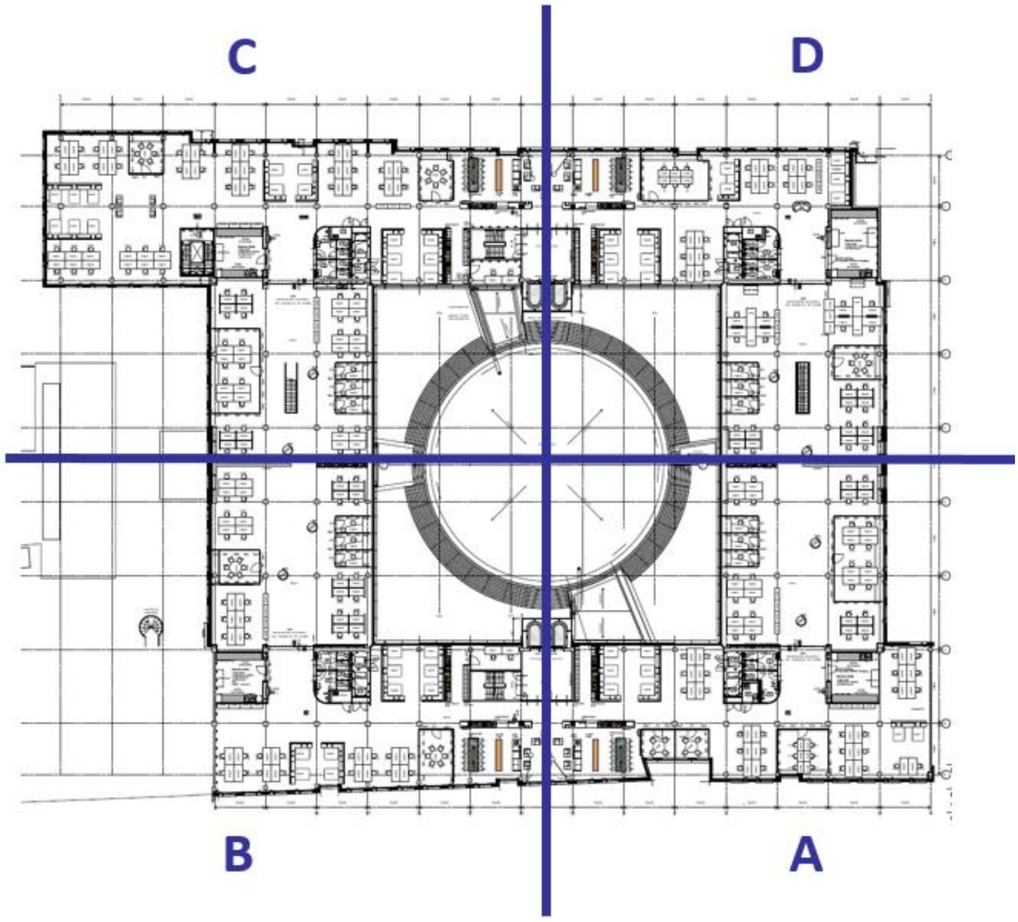


Figure 3. Floor plan 2nd-floor case building

5.1.2 Respondents

The full demographic profile of the respondents is available in appendix 11. The age of the respondents lies between 21 and 66 years, with an average of 46 years. 33% of the respondents were male and 67% were female, while in the case organisation the division is 57% male and 43% female. This indicates a non-response bias. Literature states that gender is one of the personal factors that influence one's experience of the indoor climate (Boerstra et al., 2013b; Frontczak et al., 2012). Considering these elements means that the internal validity is decreased, this has to be considered when interpreting the results. On average respondents are 29 hours per week present in the office, the case building. Among respondents, this varies between 4 and 40 hours per week. The respondents are relatively equally spread over the four quadrants of the building, as to see in table 6. 68% of the respondents are located on the second floor of the building, this also harms the internal validity of the research. However, compared to the factual data, available in appendix 12, the objective indoor climate conditions measured on the 2nd floor are comparable to the other floors.

Workplace location	Percentage of respondents
Quadrant A	31,2%
Quadrant B	25,5%
Quadrant C	22,7%
Quadrant D	20,6%

Table 5. Division of respondents over building quadrants

5.1.3 Univariate analysis and open questions

The complete analyses output for this paragraph is available in appendix 13. In total 93 respondents answered the open questions, the coded open questions are available in appendix 6.

Satisfaction with indoor climate

The respondents in the case organisation on average stated to be in between neutral and satisfied with the indoor climate (3,5) as displayed in table 7. Of all the measured factors on average, the respondents were most satisfied with the daylight in the workplace (3,71), followed by artificial lighting (3,6). The respondents were least satisfied with the temperature in the workplace (3,09). On average this item scored neutral, 41% of the respondents were (very) dissatisfied about this factor. Temperature is also the factor respondents were most divided about. The given scores were also traceable in the responses to the open questions of the questionnaire, which were mainly negative, especially about temperature. However, also several respondents declared to be satisfied with the indoor climate (N=7). Common complaints about the temperature in the workplace were strong varying temperature (N=4), and a too big difference with outside temperature (N=4) and too cold (N=33), which also in literature is mentioned as a common complaint (Boerstra et al., 2013b). Common complaints about the air quality were the air being too dry (N=11), insufficient oxygen (N=5) and smelly air (N=3). Several respondents declare to experience health complaints due to, according to them, poor indoor air quality (N=10). These complaints align with what the literature identifies as the sick building syndrome (Boerstra et al., 2013b; Shaikh et al., 2014). Common mentioned complaints about light within the workplace were that it is too dark inside (N=6) and that there is not enough daylight (N=2).

		General satisfaction with indoor climate	Construct average indoor climate satisfaction	Satisfaction with temperature	Satisfaction with air quality	Satisfaction with daylight	Satisfaction with artificial lighting
N	Valid	141	136	141	136	141	141
	Missing	0	5	0	5	0	0
Mean		3,50	3,46	3,09	3,36	3,71	3,60
Median		4,00	3,50	3,00	4,00	4,00	4,00
Mode		4	3[a]	2	4	4	4
Std. Deviation		1,093	,750	1,186	1,066	1,039	1,006
Variance		1,195	,563	1,407	1,136	1,079	1,013

a. Multiple modes exist. The smallest value is shown

(1=Very dissatisfied, 2= Dissatisfied, 3= Neutral, 4= Satisfied, 5=Very satisfied)

Table 6. Satisfaction with the indoor climate

Satisfaction with personal control options

The respondents in the case organisation were on average neutral about the options for personal control in general, that are available within the workplace (2,96), as displayed in table 8. 34% of the respondents were (very) dissatisfied. Of all measured items, the respondents were most satisfied with the options of personal control over artificial lighting (3,49). In the open questions, several respondents suggested making the artificial lighting adjustable per workplace (N=7). The second most satisfied were the respondent about the personal control for daylight (3,18). Even though the most common complaint about the personal control options was that the outdoor blinds open and close automatically against the will of the respondents (N=20). Least satisfied were the respondents with the options for personal control over the temperature within the workplace (2,77). This aligns with the comment given by numerous respondent that they experience little to no effect after adjusting the temperature (N=18). Additionally, several respondents declared to desire more options (N=8) and a wider range to adjust the indoor climate (N=7). Others also declared to desire to be able to make adjustments for per workplace instead of for a whole zone (N=4).

		Satisfaction with personal control general	Construct average personal control satisfaction	Satisfaction with personal control temperature	Satisfaction with personal control air quality	Satisfaction with personal control daylight	Satisfaction with personal control artificial lighting
N	Valid	136	125	137	129	136	136
	Missing	5	16	4	12	5	5
Mean		2,96	3,08	2,77	2,92	3,18	3,49
Median		3,00	3,00	3,00	3,00	3,00	4,00
Mode		3	3	2	3	4	4
Std. Deviation		1,007	,747	1,138	1,080	1,056	,951
Variance		1,013	,557	1,294	1,166	1,114	,904

(1=Very dissatisfied, 2= Dissatisfied, 3= Neutral, 4= Satisfied, 5=Very satisfied)

Table 7. Satisfaction with the personal control options

Usage of personal control options

For all the measured items, except opening the window and adjusting the inside blinds, most respondents in the case organisation stated to never use the personal control options, as displayed in table 9. However, the respondents are quite equally spread across the other answering options, except daily. Most respondents (58%), stated to never have an issue in finding consensus about the use of personal control options. Of the respondents that reported to do have issues in finding consensus with co-workers on controlling the indoor climate (42%), only 12% reported this to be an (almost) daily struggle. Furthermore, due to several comments, it could be deduced that some respondents did not seem to be aware of (some of) the personal control options (N=8) or do not know how to use them (N=5).

		Usage option to adjust the temperature	Usage option to open the window	Usage of option to adjust the outside blinds	Usage of option to adjust the inside blinds	Usage of option to adjust artificial lighting	Frequency consensus issues usage personal control
N	Valid	137	137	137	137	137	137
	Missing	4	4	4	4	4	4
Median		2,00	3,00	3,00	3,00	2,00	1,00
Mode		1	4	1	4	1	1
Variance		1,677	1,819	1,718	1,439	1,643	1,261

(1= Never, 2= Less than one time a week, 3= One time a week 4= Multiple times a week, 5= Daily)

Table 8. Frequency of usage of personal control options and consensus issues

Importance of personal control options

The respondents in the case organisation on average indicated that having personal control over the indoor climate, in general, tends to be somewhat important to them (3,79), as displayed in table 10. Overall the option to have personal control over daylight has been indicated as the most important (4,09), closely followed by temperature (4,04). While the results also indicated that the personal control option to adjust the temperature is among the options that are used the least. This may be related to the low level of satisfaction with the personal control options to adjust the temperature within the workplace.

		Importance of personal control general	Construct average importance of personal control	Importance of personal control over temperature	Importance of personal control over air quality	Importance of personal control over daylight	Importance of personal control over artificial lighting
N	Valid	136	136	136	136	136	136
	Missing	5	5	5	5	5	5
Mean		3,79	3,92	4,04	3,70	4,09	3,85
Median		4,00	4,00	4,00	4,00	4,00	4,00
Mode		4	4	4	4	4	4
Std. Deviation		,742	,594	,783	,889	,765	,833
Variance		,550	,353	,613	,790	,585	,694

(1= Very unimportant, 2= Unimportant, 3=Neutral, 4= Important, 5= Very important)

Table 9. Importance of personal control options

5.1.4 Bivariate analysis

The complete analyses output for this paragraph is available in appendix 14. The factual indoor and outdoor data is available in appendix 12.

Age

No significant relationship was found between the age of the respondents and satisfaction with any of the measured factors. Except a very weak negative relationship with the importance of personal control over daylight (r=-0,183<0,25 p=0,033<0,05) and a very weak positive relationship with the frequency of adjusting artificial lighting (r=0,21<0,25 p=0,001<0,05). This indicates that the older the respondent the less control over daylight is important to them and tend to adjust the artificial lighting more frequently.

Gender

Within this case, study men seem to be more satisfied with all measured indoor climate factors and personal control options. This aligns with the statements in literature made by (Boerstra et al., 2013b). Tests for influence of gender on satisfaction with the studied indoor climate factors showed a significant (very) weak relationship for satisfaction with the indoor climate in general (eta=0,289<0,5 p=0,000<0,05), temperature (eta=0,257<0,5 p=0,002<0,05), air quality (eta=0,216<0,25 p=0,012<0,05) and daylight (eta=0,210<0,25 p=0,012<0,05). The only factor in this category that for which no significant relationship with gender was found is satisfaction with artificial lighting (p=0,098>0,05). Tests for a relationship between gender and satisfaction with the personal control options only revealed a very week relationship with satisfaction with the personal control over the artificial lighting (eta=0,17<0,25 p=0,048<0,05). This indicates that men are slightly more satisfied with the personal control over the artificial lighting than women are. Based on the results it can be observed that within this case study men in general use personal control options less frequently than women do. However, the only significant relationship that was found is a weak relationship with the usage of the option to adjust the inside blinds (Cramers V=0,266<0,50 p=0,045>0,05) and the frequency of consensus issues according the usage of personal control options (Cramers V=0,291<0,50 p=0,02>0,05). This indicates that women within this organisation use personal control options somewhat more frequently and have more issues to find a consensus about this usage. Within this case study, in general, all the personal control options seem more important to women than to men. Tests for a relationship between these two showed (very) weak relationships between gender and importance of personal control; in general (eta=0,185<0,25 p=0,031<0,05), over the temperature (eta=0,253<0,50 p=0,003<0,05) and over air quality (eta=0,202<0,25 p=0,018<0,05).

Workplace location

When testing the relationship of the workplace location with all the measured items, only weak significant relationships were found. These relationships were established between the workplace location and satisfaction with the temperature in the workplace (eta=0,455<0,50 p=0,002), satisfaction with the personal control in general (eta=0,413<0,50 p=0,021<0,05), the option to adjust the temperature (eta=0,393<0,50 p=0,042<0,05) and the importance of personal control in general (eta=0,421<0,50 p=0,015<0,05). When performing the same tests per building quadrant a very weak significant relationship with satisfaction with the temperature (eta=0,247<0,25 p=0,034<0,05) and daylight (eta=0,236<0,25 p=0,048<0,05) in the workplace was found. Performing these tests to see if there is a relation with the floor at which the respondent showed a very weak significant relationship between the floor level and the satisfaction with the temperature (eta=0,188<0,25 p=0,018<0,05). This indicates that respondents in specific locations have a significantly different level of satisfaction with certain factors than respondents in other locations. Later on in this chapter, it is attempted to explain these differences by comparing the satisfaction scores per location to the factual indoor climate data.

Thermal quality

Respondents who indicated to never use personal control options to adjust the temperature in the workplace seem more satisfied with the temperature in the workplace (3,6) than respondents that indicated to use this personal control option daily (2,3). A weak but significant relationship is found that indicates that respondents who make more use of the personal control option to adjust the temperature, in general, are less satisfied about the temperature within the working environment (eta=0,327<0,5 p=0,005<0,05) and the indoor climate in general (eta=0,377<0,5 p=0,000<0,05). No significant relationship was found within the case study between opening a window and satisfaction with the temperature within the workplace (0,971>0,5).

The average outdoor temperature during the period of the questionnaire was 22,6 °C. While this data was gathered in the spring season, the factual outdoor temperatures measured during this week tend more towards summer conditions (KNMI, 2018). Therefore, the factual data was compared to NEN standard that apply to summer conditions. On average the respondents stated to be neutral (3,09) about the temperature within the workplace, while the average factual indoor temperature scores good according to the NEN standard, class B, with some minimal outliers that score class C, which is still acceptable according to NEN standards. Although the factual data scores sufficient, a substantial share of the respondent declare it to be too cold within the workplace (N=33). This might be caused by the set-point of 22 °C, which is acceptable according to the NEN standard. However, for the summer season, it tends to the lower side of the spectrum. The respondents in quadrant D stated to be least satisfied with the indoor temperature (2.76) while the respondents of quadrant B stated to be most satisfied (3,53). Even though the differences are minimal, this aligns with the factual data measured on quadrant level. The average temperature measured in quadrant D (22,9°C) deviates further from the NEN standard than the temperature measured in quadrant B (23,5°C). When assessing the same factors per floor level, the third floor stated to be least satisfied (2,5). In the factual data, the measured average temperature (23°C) for this floor also deviated the most from the NEN standard. The respondent of floor 5 sated to be most satisfied (4). However, the measured temperature at this floor did not score best compared to the other floors, based on the NEN standard.

Air quality

Opening a window influences the indoor air quality and temperature (Boerstra et al., 2013b). On average the respondents stated to be between neutral and satisfied (3,36) with the air quality within the workplace. Respondents who indicated to never open the window appeared to be most satisfied (3.9 on average, bordering "satisfied"). A weak but significant relationship was found between the frequency of opening the window and satisfaction with the air quality (eta=0,359<0,5 p=0,001<0,05). Respondents who indicated other usage frequencies scored the air quality between 2,5 and 3.3, the lower the frequency of opening the window the higher the satisfaction score. This may indicate the outside air quality to be poor. No significant relationship was found within the case study between opening a window and satisfaction with the temperature (0,971>0,5) and the indoor climate in general (p=0,043>0,05).

The satisfaction score between neutral and satisfied was expected based on the measured CO^2 levels, that on average score at least acceptable (< 1050 ppm), or better according to the NEN standards. When assessing the factual climate data according the air quality on room level large deviations were found between different rooms. On all floors quadrant A scores considerably poorer than the other quadrants. Except for floor 2, where quadrant D hast the poorest score. Some of the measured rooms widely exceed the maximum acceptable amount of CO^2 in the air. These deviations may be an explanation for the respondents who declare to experience sick building symptoms. However, these deviations may also indicate malfunctioning sensors for these particular rooms or the presence of large machines. Since large machines have higher CO^2 emissions (Boerstra et al., 2013b). At this point, the cause cannot be determined with certainty.

Daylight

According to the literature, the use of inside and outside blinds has an effect on the indoor temperature and daylight observed (Boerstra et al., 2013b). Based on the gathered data no significant relationship between the usage of the outside blinds and general indoor climate satisfaction (p=0,539>0,05), satisfaction with temperature (p=0,523>0,05) and daylight (p=0,180>0,05) was found. The same applies to the relationship between the usage of inside blinds and general indoor climate satisfaction (p=0,612>0,05), satisfaction with temperature (p=0,840>0,05) and daylight (p=0,970>0,05).

Artificial light

Based on the gathered data no significant relationships were found between the usage of the personal control option to make adjustments to the artificial lighting and the satisfaction with the indoor climate in general (p=0,612>0,05) and artificial lighting (p=0,405>0,05).

The artificial lighting in the case organisation is activated based on end-user presence. When an end-user is present, artificial light will illuminate the zone up to 500 lux, complementing the daylight that is present within the workplace. End-users can per zone decide to reduce the illumination for their workplace or to activate additional artificial lighting. With additional artificial lighting, illumination up to 1000 lux can be realised. These adjustments for the illumination for workplaces were observable in the factual indoor climate data. Based on the NEN standard this type of condition belongs to class B, good. Therefore, the tending towards satisfied scores for daylight (3,71) and artificial lighting (3,6) are as can be expected according to the NEN standard.

Additional correlations

The previous tests showed an unexpected relationship indicating that the respondents who use specific personal control options more frequently are less satisfied about the factors they control. Therefore, this relationship is also tested with satisfaction as independent variable and the usage of control options as dependent variable. These tests showed some significant (very) weak negative relationships that mean that respondents who are more satisfied about the tested indoor climate factor, in general, less frequently use the option to adjust the tested factor with the available personal control options or have less consensus issues as is displayed in table 11.

	Usage of option to:			
Satisfaction with indoor climate factor:	Adjust temperature	Open window	Adjust artificial lighting	Consensus issues
General	r= -0,299<0,50 p= 0,000<0,05	r= -0,184<0,25 p= 0,000<0,05		r= -0,307<0,50 p= 0,000<0,05
Temperature	r= -0,273<0,50 p= 0,000<0,05			r= -0,275<0,50 p= 0,000<0,05
Air quality	r= -0,146<0,25 p= 0,044<0,05	r= -0,274<0,50 p= 0,000<0,05		r= -0,267<0,50 p= 0,000<0,05
Daylight			r= -0,157<0,25 p= 0,029<0,05	r= -0,275<0,50 p= 0,000<0,05
Artificial lighting			r= -0,283<0,50 p= 0,000<0,05	r= -0,313<0,50 p= 0,000<0,05

Table 10. Significant relationships between satisfaction with indoor climate factors and the usage of control options.

Furthermore, the relationship between satisfaction with the available options for personal control and the usage of the personal control options is tested. As displayed in table 12 only (very) weak relationships have been established. These negative relationships indicate that the more satisfied a respondent is about the personal control options the less they use them.

	Usage of option to:	
Satisfaction with option for personal control:	Control the temperature	Open the window
General	r= -0,258<0,50 p= 0,000<0,05	r= -0,258<0,25 p= 0,000<0,05
Temperature	r= -0,189<0,25 p= 0,008<0,05	
Air quality		r= -0,191<0,25 p= 0,009<0,05

Table 11. Significant relationship between satisfaction with personal control option and the usage of the personal control options

As discussed in chapter 2, Kim and de Dear (2012) studied how the perceived quality of a particular IEQ factors affects the overall satisfaction with the indoor environment. Within their study temperature was identified as basic factor, air quality and light (daylight and artificial lighting combined) as proportional factor and while personal control was not tested, it was expected to be a bonus factor. As displayed in table 13, significant relationships between general satisfaction with the indoor climate and the studied indoor climate factors were found. All relationships found were positive and varied from weak to very strong. A very strong significant relationship between general satisfaction with the indoor climate and satisfaction with personal control is established. However, personal control in this case study seems to be a basic factor since end-users who use personal control with a higher frequency seem to be less satisfied with the indoor climate in general. Which may be caused by end-users not noticing any effect of the adjustments they have made, as is declared by respondents via the questionnaire (N=18).

	Satisfaction with:				
	Temperature	Air quality	Daylight	Artificial lighting	Personal control
General satisfaction with the indoor climate	r= 0,749<0,75 p= 0,000<0,05	r= 0,661<0,75 p= 0,000<0,05	r= 0,293<0,50 p= 0,000<0,05	r= 0,300<0,50 p= 0,000<0,05	r= 0,755<1 p= 0,000<0,05

Table 12. Significant relationship between general satisfaction with the indoor climate and satisfaction with other factors

5.2 Expert interview results

Within this paragraph, the results of the expert interviews are discussed. First, the topic personal control is discussed followed by the consequences on the building performance aspects. Where after the solutions for balance and potential barriers. The respondents, Artze Boerstra (AB), Jack Ponsteen (JP), Rico Logman (RL), and Ruud van der Sman (RS), are indicated by name or initials.

Even though, within this research, no (positive) effect of the usage of personal control over the indoor climate on office workers' satisfaction could be determined. All interviewees did agree on the positive effect of offering personal control over the indoor climate on end-user satisfaction with the indoor climate. According to Boerstra offering personal control reduces complaints about the indoor temperature, enhances perceived productivity and reduces absenteeism due to indoor climate conditions which aligns with the statement made in literature (Batenburg & van der Voordt, 2008; Boerstra et al., 2014; Boerstra, 2016; Buckman et al., 2014; Hellwig, 2015; te Kulve et al., 2013; Roelofsen, 2002). The statement made in literature by Brager and De Dear (1998) that one's response to stimuli modifies when one has control over the stimuli may explain the stated effect of personal control on satisfaction with the indoor climate. Personal control was also mentioned to be a weapon in the war for talent (AB, RS). This aligns with the statements made in literature that the workplace is an important tool in the war for talent (CABE, 2005; Earle, 2003; Wright & Bonett, 2007). Within open plan offices, implementing personal control is more difficult (RL). In this situation, where multiple end-users are placed within one zone they need to find consensus on the usage of personal control (AB, JP, RL). End-users tend to like to be in control over their own environment. When the effect from making adjustments to the indoor climate takes longer than fifteen minutes to appear, end-users may get the idea that the adjustment made was ineffective. This may cause end-users to stop using personal control options and cause an increase in complaints (AB). Conversely, Logman stated that even dummy personal control options enhance end-user satisfaction with the indoor climate. In literature, there is also disunity about this topic, where Nasrollahiet al. (2008) advocates dummy personal control Boerstra (2016) and Hellwig (2015) state that it is ineffective and leads to more complaints. The respondents within the case study of this research addressed to experience little to no effect after adjusting the temperature (N=18). Which can be expected since the current system is a slow system, a threshold is applied and the range is limited to two degrees. This may be an explanation for the moderate satisfaction with the personal control option to adjust the temperature (2,77) and the relationship that indicates that respondents who make more use of the personal control option to adjust the temperature, in general, are less satisfied about the temperature within the working environment. This aligns with as stated in literature by Van Hoof (2008), that thermal comfort can only be achieved when personal control is effective.

5.2.1 Consequences for maintenance

The initial response of the experts on the question "What is the effect of personal control over the indoor climate on maintenance?" was that implementing more technique increases the risk of malfunction and requires more maintenance because more components are involved that could break down and have to be maintained (JP, RS). Thus, in general the longevity of an indoor climate system is reduced by offering personal control (RL). These statements align with the study of Buckman et al. (2014). However, the longevity of the system also depends on the type of system that is implemented (JP). For instance, in comparison to smart solutions, older and simpler systems with less components may require less maintenance (RL). To realise options for personal control in the workplace sometimes components are required that have a shorter longevity. For instance, as van der Sman gave as example, when adjusting the ventilation or temperature with a smart-controlled air supply, a control valve with an engine may be required. The engine will have a shorter lifespan than for instance a traditional radiator.

Conversely, Ponsteen stated that due to developing techniques more intelligent indoor climate systems are introduced that with the use of sensors can predict when maintenance is required and thereby can reduce the risk of malfunction. This statement aligns with the statement made in literature by Klimovich et al., (2017). Currently, this is the main driver for organisations to invest in systems that use smart technology (JP). Additionally, new technology can contribute to reduce the deterioration of the indoor climate management system due to adjustments made by end-users, as cooling and heating in the same place or leaving on the light when there is no one present (RL). Technology can interfere when adjustments are made that harm the longevity of the system, by overruling these adjustments (JP). Moreover, with the development of technological solutions, the longevity tends to increase (RL). For example, personal control can also be made via an app. Due to this development control panels are not required anymore, so less maintenance is required (RL, RS).

Logman stated that even though the lifespan of systems may be reduced by offering personal control, this is no argument not to allow end-users to have personal control over the indoor climate. The longevity of the more simple systems may be better, but according to van der Sman, this does not outweigh the advantages of the smart systems.

More technique is not necessarily less longevity but there is more risk that things go wrong - Rico logman

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5.2.2 Consequences for energy performance

From the responses of the interviewees, it can be concluded that allowing end-users to have personal control over the indoor climate affects the energy performance of a building, aligning with the statements made by Buckman et al. (2014), Klein et al. (2012) and Van Hoof (2008). However, this can go both ways. Depending on how it is implemented and used, personal control over the indoor climate can reduce or enhance energy performance (AB, RS). Adjusting the temperature to a set-point that requires more activity from the indoor climate management system harms the energy performance of the building (RS). Furthermore, misunderstandings about how to use personal control options may lead to misuse or large fluctuations in the indoor climate that have to be restored, which also harms the energy performance (AB, JP, RL). Moreover, when end-users make contradicting adjustments in adjacent zones, the effect of the activated systems can be nullified with no enhanced comfort as result while this requires extra energy (RL). Ponsteen stated that offering personal control in general harms the energy performance of the organisation. However, he added to this that when not striving for a strict set-point and using personal control to activate the system, this can reduce energy consumption. Because, when offering personal control the basis set-points which are strived for, can have a broader range and still meet user-satisfaction with the indoor climate. In this situation, energy consumption is enhanced only when the indoor climate gets outside the range of the basis set-points or when end-users actively make adjustments. Besides, the effect of personal control on energy performance depends on the insulation used in the building, the type of cooling and heating systems that are installed and the size of the zones for which adjustments are made (RS).

Loosening the basis set-points for the indoor climate management system is required in order to have a positive effect on the energy performance of the building (AB, JP). According to Boerstra this can reduce energy consumption by 25%. The implementation of smaller zones for personal control is beneficial for the energy performance of a building since less activity is required form the system to adjust a smaller zone (AB). van der Sman stated, that the smallest zone that currently can be created is 3.60 meters by 5.40 meters, a space for approximately four workstations. Boerstra even spoke about personal control on individual workstation level and called this microklimatisation. According to Boerstra, energy consumption can be reduced by 20-30% with the use of microklimatisation because the basis set-points for the indoor climate factors can have a broader range. When speaking of potential future possibilities, Boerstra even spoke about making adjustments closer to the skin, since this requires even less energy for the same effect on end-user level. Furthermore, automation was mentioned as a solution to make sure energy performance and the objective comfort are not harmed (RL). All interviewees mentioned that the use of sensors could reduce energy consumption. Since sensors can detect the presence of end-users or objective climate levels and adjust the activity of the indoor climate management system accordingly. This aligns with the statements made in literature (Buckman et al., 2014; Klimovich et al., 2017; Moreno et al., 2014). Moreover, systems that use smart technology interfere when ineffective adjustments are made by end-users (JP, RL). Additionally, Ponsteen stated that end-users need to be aware of energy efficient objectives the organisation they work for may have, to accept the consequences. van der Sman spoke about a feature “the green button” that changes the set-point to the most energy efficient setting. This feature in an app could make end-users aware of their influence on the energy performance of a building. He stated the usage of the “green button” in practice to be minimal since the users who use this feature are most of the time already satisfied with the standard set-points, even though so far he only experienced beneficial effects of implementing smart indoor climate management solutions on the energy performance of a building.

> *If someone puts the thermostat 2 °C warmer, while it is already warm inside the system can say we will not do that. Technically this is no problem … Only you do not want users to feel like “it does not matter what I do.” – Jack Ponsteen*

5.2.3 Consequences for objective comfort

All interviewees have specified that preferences among end-users for indoor climate conditions differ per individual. Therefore, every individual experiences the indoor climate conditions differently, as also stated by literature (Boerstra et al., 2013b; Frontczak et al., 2012; Nasrollahi et al., 2008; Schellen et al., 2010). While the indoor climate factors that form the indoor climate also influence the end-users productivity and health (Boerstra et al., 2013b). For example, people tend to be more productive when the indoor climate is considered a little cold and when CO^2 concentrations are according to standard or better (AB, RS). Offering personal control can affect the objective indoor climate conditions and subjective comfort, which depends on personal factors and preferences. For instance, opening a window can change the indoor temperature and humidity (JP). Both Ponsteen and Logman stated that when end-users do not understand how the system works they can harm the objective comfort and energy performance. These statement aligns with the studies of Smith and Pitt (2011), Van Hoof (2008) and Lee and Brand (2005) who state that offering personal control does not always lead to optimal comfort conditions and that when end-users have little understanding of the indoor climate, offering personal control can even work counterproductive. However, according to Ponsteen, the subjective experience is more important than the objective comfort and that an according-to-standards poor indoor climate, can still lead to end-user satisfaction. Therefore, he indicates reduced objective comfort conditions, due to adjustments made by end-users to not be a problem. He adds to this that end-users need to be aware about the consequences of using personal control on the objective comfort conditions and the effect these have on end-user productivity and health.

The respondents in the case study did declared to desire a broader range to adjust the indoor climate (N=7). However, one of the solutions to keep the objective comfort conditions stable is limiting the range within end-users can make adjustments (AB). Ponsteen and Logman stated that workshops can be a tool to inform end-users about the consequences of using personal control options for the objective comfort in the workplace. For instance the negative consequences of a wider range. Also including end-users in the design phase of a building and be open about decisions that are made could help to enhance understanding and decrease dissatisfaction with the indoor climate (JP). In addition, an interface in an app could guide users to make the right adjustments to feel comfortable but not to harm their own productivity and energy performance of the building (AB). Automation can also be a solution to protect the objective comfort. Technology can interfere when adjustments are made that deviate too much from the average (JP). Moreover, as for energy performance, creating smaller zones can also be a solution to protect the objective comfort from deviating too much from the average. Because the adjustments can be made for smaller zones, this means that the other zones do not have to be affected by the adjustments and the effect on the objective comfort is minimal (RS). Additionally, both Boerstra and Ponsteen indicated that having free choice for a workstation is also a form of personal control. With this form of personal control, end-users can choose a location where the objective indoor climate conditions are according to the end-users preferences in order to achieve satisfaction. This is also a beneficial solution for the energy performance of the building since this does not require extra activity of the indoor climate management system. With the use of a smart system, an app can give advice on where in the building the objective comfort conditions match with the preferences of an individual (JP). Additionally, van der Sman stated that machine learning might help to further optimize the indoor climate (RS).

Through machine learning, we try to optimize the indoor climate even further. – Ruud van der Sman

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5.2.4 Solutions for balance and potential barriers

Automation is mentioned multiple times to be a solution to protect the building performance (RL). An example of this is overruling harming or inefficient adjustments made by end-users (JP). However, this is also addressed to be a risk for the end-users satisfaction since their adjustments being overruled could give them a feeling of having no control (RL). Furthermore, overruling adjustments made by end-users will go against the expectations of the end-users while expectations influence how an end-user experiences the indoor climate (Brager & De Dear, 1998). Boerstra even stated that automation makes end-users comfort dependent on the building manager, which may harm their satisfaction. According to Boerstra, end-users should always be able to overrule the automated set-point. The interviewees seem to disagree on which aspect is most important, the end-user satisfaction or the building performance. A more end-user friendly method, however possibly less effective to protect the building performance, is informing end-users. This can be achieved with the suggested tools as information sessions and an interface within an app (AB, JP, RL). Awareness and understanding of indoor climate and consequences of the adjustment that can be made are beneficial for all studied building performance aspects (AB, JP, RL). Whilst within the case study respondents declared not to be aware of the personal control options (N=8) and did not know how to use them (N=5).

Furthermore, a solution that is mentioned to find a balance between end-user satisfaction and both energy performance and objective comfort is to implement small zones on which personal control options are effective. Ponsteen stated that systems that are equipped to make these adjustments very locally are costly, especially for existing buildings. According to Boerstra, in most cases, these investments are worth it since it reduces energy consumption and may enhance end-user productivity, although this is still a grey area. Within the case study, some respondents also declared to prefer to make adjustments to the indoor climate per workplace instead of for a whole zone within an open plan office (N=4).

Moreover, the use of app's and intelligent systems were mentioned multiple times as a technological solution that can potentially help to find a balance between end-user satisfaction and building performance. According to Boerstra, end-users know very well when they are comfortable. Nevertheless, an interface in an app could help to guide users to make the right adjustments to feel comfortable but not to harm their own productivity and the energy performance of the building. He added to this that intelligent systems could remember and learn about end-user preferences and can adjust the indoor climate accordingly. However, this introduces another challenge, namely the acceptance of technology by the end-users. This might be a barrier since not all end-users are willing to use technology and it may not suit the image of every organisation (AB, RS). Another barrier related to the use of an app, that learn about end-user preferences is privacy (JP). Ponsteen stated that end-users need to see the advantages of the features the app has to offer, in order to overcome the privacy barrier.

A good climate installation is like a dog not like a cat. A cat does what he wants … a dog can be trained and after a while knows what you want. – Artze Boerstra

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6. Conclusion and recommendations

This chapter will draw up the conclusions that were made based on the findings and results that have been discovered while conduction this research.

6.1 Conclusions

The objective of this research was to investigate the effect of (the usage of) personal control on office workers' satisfaction and building performance to gain insight in how to find a balance between these two and explore if new technologies could help in finding this balance. Since literature indicated that office workers dissatisfaction with the indoor climate is considered to be a common key concern within the workplace and many scholars believe that allowing end-users to have personal control over the indoor climate has a positive effect on end-users satisfaction with the indoor climate and thereby their productivity. However, scholars also indicate that personal control can harm building performance. Therefore, the goal of the research is to formulate recommendations for the field on how to find a balance between allowing end-users personal control over the indoor climate with the aim to reduce office workers' dissatisfaction with the indoor climate and preserve building performance.

MAIN QUESTION 1

What is the effect of the usage of personal control over the indoor climate on office workers' satisfaction with the indoor climate?

HYPOTHESIS

The usage of personal control over the indoor climate enhances office workers' satisfaction with the indoor climate.

Within the previous chapter, the results of the research have been discussed to answer main question one and test the belonging hypothesis presented above. These results showed that the indoor climate of the case building, in general, scored at least acceptable for all measured factors according to the NEN standards. Therefore, an overall positive satisfaction rate could be expected and was found. Within the sample in the case study, no significant relationship was found between the usage of personal control over daylight and artificial light, on office workers' satisfaction with these factors within the workplace. A weak but significant relationship was found between the usage of personal control over temperature and air quality on office workers' satisfaction with these factors within the workplace. However, instead of enhancing the office workers' satisfaction the results indicated that the higher the frequency of usage of the personal control options, the lower the satisfaction score for the related factor. These findings go against the statements made in the studied literature and within the expert interviews which advocate that allowing end-users to have personal control over the indoor climate enhances their satisfaction with the indoor climate. Therefore, based on the results found for this case study the hypothesis is rejected.

This unexpected outcome may be explained by the discovery that more satisfied end-users in general use the option to adjust the tested factor with the use of personal control options less frequently. The same applies to satisfaction with the available personal control options, the more satisfied a respondent is about the personal control options the less they use them. This results in predominantly dissatisfied end-users using the personal control options. Furthermore, the results showed that respondents are at best neutral about the available personal control options and the existing range. Several respondents declared to not notice any effect of the adjustments they have made and in general, consequently they stay dissatisfied with the indoor climate factors. This is not unexpected because of the type of indoor climate management system that is used, due to the limited range, the build in threshold and the slow effect, within the case building. However, the respondents seem to be unaware of this state to expect another effect. This misunderstanding about the effect of using personal control options can also be seen as unawareness. Literature indicates that giving the control to individuals who have limited understanding of this topic may lead to undesired effects such as dissatisfaction. Moreover, within the expert interviews, it was indicated that when end-users feel like the adjustments they make are ineffective this may also increase dissatisfaction. The previously described factors appear to be the situation within this case study. Therefore, this relationship does not seem to be causal. Since the factors may have influenced how the relationship is reflected. In another situation where using personal control options would be more effective and noticeable by the end-users, the results may be different. However, more effective and noticeable personal control options may reduce the energy performance and thereby the building performance, which is a critical point in a time where sustainability is one of the megatrends in the FREM field.

MAIN QUESTION 2

What is the effect of personal control over the indoor climate on building performance?

Even though within this research no (positive) effect of the usage of personal control over the indoor climate could be determined the experts all stated that offering personal control has positive effects, such as reducing complaints and absenteeism, enhancing end-user satisfaction and perceived productivity plus being an important tool in the war for talent. The interview results revealed that personal control over the indoor climate has an effect on all the measured building performance factors. However, the consequences depend on the type of climate management system and how the system is used.

Based on the results, supported by the literature, it was concluded that in general offering personal control over the indoor climate requires more elements within the climate management system, which required more maintenance. Although, according to the experts this is no reason not to offer personal control. Furthermore, it was established that personal control has an effect on the energy performance of a building. Offering personal control enhances or reduces the energy consumption of the building dependent on the chosen set-points, the range that is allowed and the size of the zones to which adjustments can be made. The more flexible the set-points, the smaller the zones and the closer to the skin the less energy is consumed. Moreover, these aspects also influence the effect of personal control on the objective comfort. It was concluded that end-users can make adjustments that can harm the objective climate. Reducing the zone size and range to make adjustments maintains stability in the objective climate. Nevertheless, according to an expert, the subjective experience is more important than the objective comfort being according-to-standard. Additionally, awareness and understanding among end-users have a large influence on building performance, due to a lack of knowledge inefficient adjustments can be made which harm the building performance.

The results revealed that technology can help to find a balance between offering personal control while preserving building performance by interfering when adjustments are made that harm the building performance. However, this form of automation may also harm end-user satisfaction since their adjustments being overruled could give them a feeling of having no control. Technology can also be used to create awareness and understanding of the indoor climate and consequences of the adjustment that can be made among the end-users, for instance via an interface within an app. However, this may bring up barriers in the form of unwillingness to use technology, high costs and privacy issues.

As stated by Lee and Brand (2005) offering effective personal control over the indoor climate to end-users who have little understanding of indoor climate may lead to undesired results. Based on this research undesired results, such as decreased satisfaction, expected to be caused by unsuitable expectations due to unawareness, and potentially harmful consequences on building performance due to unawareness were identified. Therefore, creating awareness among the end-users and managing their expectations by informing them can be a solution to find the balance between allowing end-users personal control over the indoor climate with the aim to reduce office workers' dissatisfaction with the indoor climate and preserve building performance.

6.2 Recommendations

Since the aim of this study is to formulate recommendations for the field on how to find a balance between allowing end-users personal control over the indoor climate with the aim to reduce office workers' dissatisfaction with the indoor climate and preserve building performance, several elements of these recommendations have been discussed already throughout the previous chapters.

Creating awareness and managing expectations are brought up as potential solutions to establish the desired balance. Therefore, it is advised to take an effort to increase awareness among building end-users about the indoor climate and the available personal control options. Giving end-users insight into this may drive beneficial behaviour for the building performance (von Frankenberg und Ludwigsdorff et al., 2016). Likewise, informing end-users about the effect that can be expected from the available personal control options by managing their expectations may reduce unsuitable expectations and thereby enhance end-user satisfaction. This can, for instance, be achieved via an interface in an app or information workshops. Furthermore, when choosing a climate management system and its set-points one needs to be critical whether these support the organisational objectives. Since, for instance a highly sustainable system may work slower, which can influence end-users satisfaction. Even though technology can help to establish a balance between these aspects, concessions have to be made between costs, building performance or the end-users experience. Also, organisations should carefully consider whether the use of high-tech solutions suits their organisation. Additionally, it is advised to minimize the zones to which adjustments can be made, where the budget and functionality allows for it. This is best achieved when using personal control via an app, instead of physical control panels. Smaller zones are beneficial for the energy performance of the building, the stability of the objective climate and could help to reduce consensus issues since the effect is only for a limited area.

As established in the conclusions the usage of personal control over the indoor climate within this case study does not add to the satisfaction with the indoor climate of the end-users. As mentioned before more effective and noticeable personal control options may reveal different results. Furthermore, recommendations are given to find a balance between allowing end-users personal control over the indoor climate with the aim to reduce office workers' dissatisfaction with the indoor climate and preserve building performance. Repeating this study after following up on the given recommendations may also result in different outcomes. Therefore, it may be interesting to investigate these alternative scenarios in future research. To asses if usage of personal control over the indoor climate in these scenarios does enhance end-users satisfaction over the indoor climate, as stated in literature and by the interviewed experts. Moreover, within this study the effect of personal control on office workers' (perceived) productivity was discussed. However, this was mentioned to be still a grey area. However, the effect on office workers productivity is highly interesting. Within this research, no evidence was found to confirm or reject this. Likewise, the disunity about the effect of dummy personal control that exists within literature and among the interviewed experts could not be resolved, while this could give valuable insights for the field. More research on these topics, via for instance another case study or an experiment may help to close these knowledge gaps, in order to find solutions to enhance the overall indoor climate experience of office workers or contribute to this.

7. Discussion

Within this chapter the validity, reliability and limitations of this study are critically assessed and discussed.

7.1 Validity

7.1.1 Construct validity

Several measures were taken in an attempt to secure the accuracy and thereby validity of the findings (Gray, 2014; Saunders et al., 2009). In an attempt to ensure the construct validity within this research all the factors that were measured and addressed in the interviews are operationalised based on the studied literature in chapter 1 and 2 (Saunders et al., 2009). The operationalisation for both parts of the study are available in appendix 1 and 2. The research design and the questionnaire that was used are inspired by highly similar published academic studies according to IEQ within the field (Fassoulis & Alexopoulos, 2015; Frontczak et al., 2012; Kim & de Dear, 2012; Maarleveld et al., 2009). Additionally, to reduce the risk of confusion terms used within the questionnaire were explained in the introduction text and both the questionnaire and the interviews were in Dutch, the mother tongue of the respondents and the researcher. Furthermore, an interview questionnaire pilot was done to test the instruments, after which some changes to the topic list were made and some sentences were rephrased, to avoid misunderstandings (van Sprang, 2018).

7.1.2 Internal validity

Since the first part of this research was not conducted within a lab setting, not all factors were controllable. An experiment could also be a suitable design for this research. However, then the research would miss a link with practice, while this link is more present in a case study. With the use of proper statistical tests, it was attempted to enhance the accuracy of the conclusions that were made based on the results in order to ensure the internal validity (Gray, 2014; van Sprang, 2018). Despite the effort that is taken complete internal validity cannot be assured. However, the outcomes of the study and the recommendations for the field, are still valuable. Due to triangulation, between questionnaire data, factual indoor climate data, expert interviews data and literature, it was revealed that the found relationship between usage of personal control options and office workers' satisfaction with the indoor climate is expected to be caused by the end-users having unsuitable expectations of the available personal control options. The formulated recommendations were anticipated on this finding. Furthermore, due to triangulation, it could be established that the questionnaire results aligned with what could be expected based on the factual indoor and outdoor climate compared to the NEN-standard. Moreover, to avoid socially desirable answers, the respondents of the questionnaire were guaranteed that answering the questionnaire was completely anonymous. Moreover, the Cronbach's alpha method was used to calculate the reliability of the constructs which influences the internal consistency (Verwijmeren, 2018). The construct of satisfaction with the indoor climate (0,67) and satisfaction with the personal control options (0,66) were both of questionable quality (between 0,6-0,7). However, it was decided to keep all items since deleting one of the items would only reduce the Cronbach's alpha. The construct of the importance of personal control scored acceptably on the reliability test (0.7 = 0,7). For this construct, Cronbach's alpha could have been increased by removing the item importance of personal control over the temperature. The decision was made not to do this since the improvement was minimal (+ 0,006) and construct scored acceptably. The construct average of all items combined was compared to the scores respondents gave to the questions that directly asked the respondent for their opinion about the indoor climate, the control options and the importance of personal control. The differences between these averages appeared to be minimal. This is an indication for the reliability of the construct. The complete output of the Cronbach's alpha tests is available in appendix 15. For the second stage of the research, convenience sampling is used for the expert interviews, this harms the internal and external validity of the results of the research (Saunders et al., 2009). This sampling technique has a low level of credibility, however, is useful for a study in an exploratory stage such as this one (Gray, 2014). To assure the internal validity of the interview results a test interview was conducted to assess whether the topic list measured what it should.

7.1.3 External validity

In an attempt to ensure the external validity of the results of the first part of this research purposive, typical case sampling was used to select a case organisation. Since this is a non-probability technique, this means that the results are not generalizable to a larger population on statistical grounds and therefore are not definitive (Saunders et al., 2009). However, due to the thick case description available in paragraph 5.1 other organisations can decide if they consider themselves comparable to the case organisation and whether the results and the derived recommendations are valuable to them. Therefore, the choice for the typical case sampling technique contributes to the external validity of the results. Since a typical case has a higher chance to be comparable to other organisations and thereby the population than for instance a critical case (Gray, 2014). Provincie Noord-Holland can be considered a typical case for this study since it has an open office environment which is common in the field. The high variety among the office workers within the case organisation is advantageous for the representativeness of the case and therefore increased the external validity. To reduce a possible non-response bias, reminders to complete the questionnaire were spread by multiple channels after the first week (Brinkman, 2011). The second part of the study is not part of the case study. The experts that have been interviewed have in-depth knowledge about indoor climate in the multiple types of office environments which enhances the external validity. Furthermore, interviews were conducted up to the point of data saturation, several findings were mentioned multiple times by different interviewees. This showed that the results are not a fortuity.

7.2 Reliability

To minimize threats to reliability several measures were taken. To ensure transparency in procedure, all decisions made for the research design, analyses procedure, case- and sample selection are described in detail within chapter 4. The data collection for the first part of this study is gathered in May, with summer-like weather conditions. Data collection with different weather conditions may have resulted in different outcomes. Furthermore, the selection of a typical case also enhances the reliability of the results since what occurs in a typical case is more likely to occur in other cases than when selecting, for instance, a critical case. For sampling within the case, a full sample was used, which is a highly transparent procedure. To ensure the measurement procedure all respondents were approached with the same introductory text accompanying the questionnaire. Furthermore, it was clearly mentioned that the questionnaire was about the experiences in the last month. However, it may be the case that the responses are influenced by the general experience of the indoor climate throughout the year. This reduced the chance of participant error to some extent. To reduce the chance of participant bias to some extent, the anonymity of the respondents was guaranteed. To secure the reliability of the quantitative data, before analysing the data set was crosschecked for errors. Furthermore, some of the data was modified before analysing to make analysis possible (Gray, 2014). For the respondents that selected the answer option "I do not know", the answer was transformed into missing data to realise a scale measurement level. The answer options for the questions about the importance and usage of personal control options have been mirrored, to make the scale go from most negative or least use to most positive and most use, as it is for all the other answering options. The fact that this was not the case in the actual survey may have led to participant error. The BMS reports supplied temperature (°C) data on quadrant and room level. The CO^2 levels (ppm) and illuminance (Lux) were only available on room level. For the reports, two rooms per quadrant per floor were selected to secure the representativeness of the data. Unfortunately, some parts of the report showed up empty and therefore the data was not based on the number of measurement points as was planned for. Still, every quadrant of every floor was represented in the data. The factual indoor and outdoor data was filtered to make sure only data measured during opening hours of the case building (Monday to Friday 06:00 – 20:00) is taken into account, since only during opening hours the indoor and outdoor climate conditions can influence the end-user experience. To enhance transparency for the qualitative data collection the interviews are recorded and transcribed verbatim, the transcripts are available in appendix 10. Furthermore, the interviewees were knowledgeable about the topic and the point of data saturation was reached, all this contributed to the reliability of the results (Morse, Barret, Mayan, Olson, & Spiers, 2002). To reduce the participant bias the option was offered to the interviewees to remain anonymous. However, none of the interviewees chose this option. Although during the interview, some confidential information was shared, as requested by the interviewee these were not included in the transcript. It was the aim to conduct all interviews face-to-face. Unfortunately, due to practical matters, this was not possible for one of the interviews, as there was no direct personal contact and visual cues and non-verbal communication could not be observed. This may have reduced the reliability of the results (Saunders et al., 2009).

7.3 Limitations

All research projects have their limitations (Saunders et al., 2009). Due to time constraints, this research was focused on just three of the factors of the indoor climate. Therefore, the results will be limited and conclusions can be drawn only based on these three factors. Furthermore, it was planned to compare all the measured factors to factual indoor climate data. However, for daylight and artificial lighting, this was not done in as much detail as was planned for since the tools to measure the related factors were not available. Despite the effort taken to maximize the reliability and validity of the research, the actual reliability; internal- and external, stay limited. Furthermore, due to the set time frame of this study and to keep the information manageable it will not be possible to review all the relevant literature. Therefore, decisions were made on which literature to include in the research and which not. An effort was taken to include recent and relevant literature out of many different angles and opinions. However, it was inevitable that potentially some beliefs on the topics discussed were left out due to the immense availability of literature. The same applies to the number of interviews interviewed, although the point of data saturation is reached. Conducting more interviews could have enriched the gathered data. However, due to time constraints, this was not feasible. Moreover, the chosen methods have their limitations. Although probability sampling would have been better for the external validity of this study, non-probability sampling was used to select a case organisation and interviewees, since probability sampling is unfeasible within this study, due to practical and time constraints. The validity of the results is limited to the case organisation. However, due to the provision of a detailed description of the case organisation, as discussed before, other similar organisations can still benefit from the results. In addition, the time and place and way of conducting the interview may have led to participant error (van Sprang, 2018). To limit the participant error to some extent the interviewees did propose a time, place and way to conduct the interview. Also, the objective and the role of the researcher may have been influenced by the educational background and previous experiences. These factors should be taken into account when interpreting the results.

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