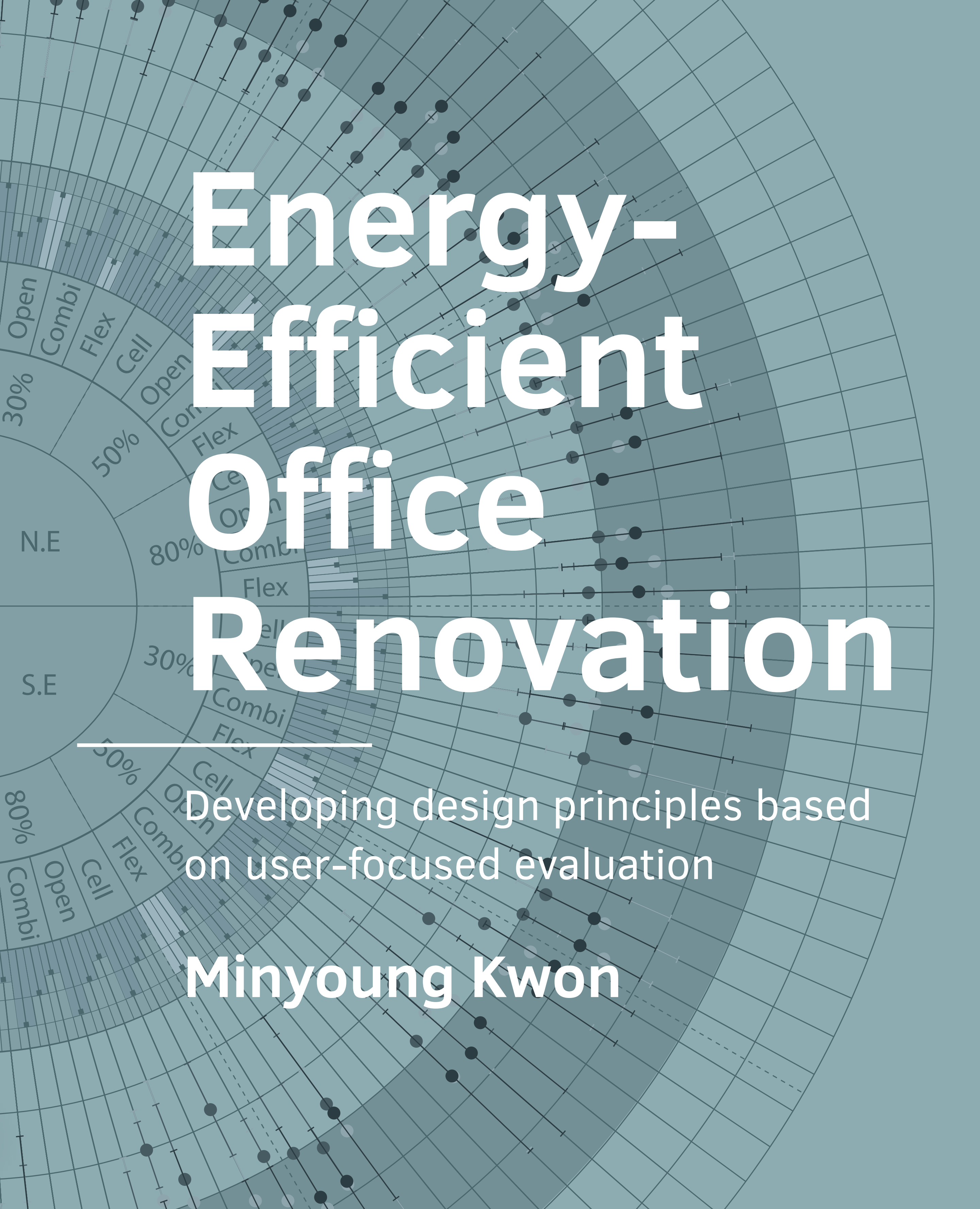
Energy-Efficient Office Renovation

Developing design principles based on user-focused evaluation

Minyoung Kwon



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Energy-Efficient Office Renovation

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by

Minyoung KWON
Architect and Master of Science in Architecture and the Built Environment,
Delft University of Technology, the Netherlands
born in Gwangju, South Korea

This dissertation has been approved by the promotors.

Composition of the doctoral committee:

Rector Magnificus,	chairperson
Prof. dr. ir. A.A.J.F. van den Dobbelsteen	Delft University of Technology, promotor
Prof. dr.-Ing. U. Knaack	Delft University of Technology, promotor
Dr. H.T. Remøy	Delft University of Technology, copromotor

Independent members:

Prof. dr. R. de Dear	University of Sydney
Dr. ir. H.A.J.A. Appel-Meulenbroek	Eindhoven University of Technology
Prof. dr. D. Keyson	Delft University of Technology
Prof. dr.ir. H.J. Visscher	Delft University of Technology
Prof. ir. P. G. Lusuere	Delft University of Technology, reserve member:

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Preface

The topic of this research is developed based on my motivation toward architecture design and society. I had a dream to become an architect. Fortunately, my dream came true, but there is still something I want to explore. I thought about what brings me the feeling that I need to explore. Observing human behaviour and considering people in building design have always fascinated me since I studied architecture. My design approach often started from the point that how people like to use certain spaces.

My question in the built environment was that are people happy to stay in a good energy-labelled building. If we consider the users in the renovation design phase, how can the approach be different from how we are doing now. We are aware of the necessity of upgrading existing buildings and developing energy-efficient buildings to reduce energy demand and to provide a healthier indoor climate to users. There are many technics and studies to achieve these goals. I started this research from a technical aspect in the building environment. However, my fascination and curiosity about the impact of building users on building design drove me to end up studying the topic of the user-focused office renovation.

Dealing with this issue, this thesis is written in consideration of people who work in an office. Moreover, this is targeted at the architects or facility managers who are interested in user-focused office design, energy efficiency, or office renovation. This research deals with four sub-topics related to office renovation: energy consumption, indoor climate and users' thermal comfort, personal control, and user satisfaction. I expect the design principles resulted from this research will be valuable to the development of office renovation.

I made an effort to grasp the impact of design factors on user satisfaction and to go beyond the bounds of surveys and the data analyses. The impact of design factors is illustrated to make it easy to understand and to be easily integrated into the renovation process. I have enjoyed studying the topic and writing this book. I hope you, holding this book now, also enjoy to read and explore the knowledge regarding the importance of user satisfaction in the sustainable built environment.

Minyoung Kwon, Delft, January 2020.

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Summary

This research aims to develop user-focused design principles for energy-efficient office renovations. The goal of this is to improve the quality and comfort of workspaces without compromising on energy-saving goals. Due to increasing sustainability requirements, new ways of working and changing office user preferences, there is a growing need for office renovations that not only deal with the energy performance and the replacement of building facilities, but also the occupants' health and well-being. The renovation of office buildings can substantially reduce energy demand and improve building performance. For this reason, most studies regarding office renovations have focused on achieving better energy performance and indoor environmental quality. Also, several studies have investigated employee satisfaction in the work environment. However, the users are only considered after the buildings have been built and taken into use (e.g., post-occupancy evaluation), but not in the early stage of the design phase. Although there are building regulations and norms regarding indoor comfort, no clear design principles or guidelines considering users have been developed for office renovations. Therefore, it is necessary to explore how office users can be included in the early design stage of office renovations to improve their comfort and satisfaction. This led to the following main research question to be answered in this thesis:

How can design principles for energy efficient office renovation be developed, based on the evaluation of user satisfaction?

To answer to this question, field studies were conducted in 5 office buildings in the Netherlands. The cases consist of four renovated offices and one non-renovated office, originally built in 1960s to 70s. Before conducting empirical studies, a literature was conducted that is implemented in the theoretical framework. Ten parameters for satisfaction, such as thermal comfort, air quality, light, noise, personal control, privacy, concentration, communication, social contact, and territoriality, were defined and were classified based on the findings from 124 items of studies focussing on physical and psychological satisfaction in the work environment. Each chapter and several sub-research questions address these parameters. Based on the findings, a classification of user satisfaction parameters is proposed, including a discussion about an hierarchy of ten parameters. This hierarchy is structured based on theoretical definitions of parameters and its physical, functional, and psychological influences.

For the empirical studies, a multidisciplinary methodology was applied to prioritise the important aspects of office renovations. The various methods for data collection and analyses included examining energy use and the quality of indoor climate after renovation, and investigating the impact of design factors on user satisfaction with thermal, visual, and psychological comfort. The design factors in this research are influential design factors on user satisfaction. These are office layout, orientation, window-to-wall ratio, and desk location. The empirical studies are structured in four parts.

Energy consumption

As a preliminary study, architects and facility managers were interviewed to identify the building characteristics of renovated offices and energy consumption. Henceforth, the five case studies were conducted. A cross-case-analysis was used to compare the building characteristics of the five case studies. The energy consumption of renovated and non-renovated offices were compared by different energy matrix. In addition, the limitations that hinder the achievement of better energy performance, were described.

Indoor climate and users' thermal comfort

Indoor temperature and humidity were measured by using data loggers to identify the condition of the indoor climate for users' thermal comfort after renovation. A questionnaire, including thermal sensation, preference, and satisfaction, was distributed among the building users. The monitored climate data of the thermal conditions were evaluated based on the Dutch building norms and users' responses.

Personal control

This part aims to identify the relationship between the degree of personal control over indoor environmental conditions (e.g., temperature, ventilation, light) and user satisfaction with thermal and visual comfort. This study investigated the impact of personal control on user satisfaction through user surveys and statistical analyses. The results present that higher controllability leads to more satisfaction in terms of thermal and visual comfort. It also reveals the psychological impact of personal control on user satisfaction by showing differences in perceived satisfaction according to 'no control' and 'do not have'. These findings provide support to workplace management and the design of personal environmental control systems.

User satisfaction with thermal, visual, and psychological comfort

Together with the indoor climate conditions of workspaces, 579 office users from the five cases were studied. The responses of the users were collected and analysed through statistical analyses. This study phase demonstrates the results of the impact of influential office design factors on user satisfaction with thermal, visual, and psychological comfort. It also contributes to predicting which design variables may bring better user satisfaction.

After the empirical studies, the conceptual study was conducted through energy simulation to evaluate the impact of the combination of design factors on the energy demand. Twenty-four office model variants were created based on the combination of design factors, which are consisted of 3 or 4 variables. The energy demand is predicted according to the office model variants. As a next step, the design principles were developed by incorporating the previous findings and various perspectives of energy-efficient office renovation. An overview of the predicted user satisfaction and energy demand is graphically provided in this research.

Based hereupon, a flow chart is created for applying the principles to the renovation process. First, the most influential design factors on thermal, visual, and psychological satisfaction are suggested in the design principles. Next, the values of predicted user satisfaction and energy demand can be evaluated by following the flow chart, to find the optimal renovation plan. In this step renovation alternatives are suggested in terms of office variants to create a balance between user satisfaction and energy efficiency. Last, if design limitations occur, the degree of personal control should be included to increase user satisfaction. The comprehensive design principles can help architects, designers, and facility managers to make design decisions in an early stage of office renovations.

To summarise, this research demonstrates the relationship between design factors, indoor climate and user satisfaction, without neglecting the fundamental goal of office renovation: reducing the energy demand, upgrading facilities, and improving building performance. It also contributes to developing design principles for office renovations with integrated user perspectives, that improve users' satisfaction and comfort, as well as energy efficiency. Although users' individual control over the indoor environment has a significant impact on satisfaction, it needs to be explored further. In addition, it is important to mention that other variables such as building elements and various façade configurations need to be included in further research. In conclusion, design principles considering both energy efficiency and user satisfaction will not only contribute to an increase in the value of a building, but also serve as a stepping stone for user-focused office designs or user-related aspects of the built environment.

Samenvatting

Dit onderzoek streeft naar de ontwikkeling van gebruikersgeoriënteerde ontwerpprincipes, gericht op energie-efficiënte kantoorrenovaties. Het doel hiervan is de kwaliteit en het comfort van werkplekken te verhogen, zonder energiebesparing te compromitteren. Door een toenemende hoeveelheid duurzaamheidsmaatregelen, nieuwe werkvormen en veranderende gebruikswensen is het noodzakelijk dat kantoorrenovaties zich niet alleen richten op de verbetering van energieprestaties en vervanging van gebouwinstallaties, maar ook op de gezondheid en het welzijn van de gebruiker.

Door een kantoorgebouw te renoveren kan het energiegebruik substantieel gereduceerd worden en kunnen de gebouwprestaties verbeteren. Om deze reden richten de meest studies van kantoorrenovaties zich op de energieprestatie en kwaliteit van het binnenmilieu. Diverse studies hebben de tevredenheid van de werknemer op de werkvloer onderzocht; echter, de gebruikers worden alleen in beschouwing genomen na ingebruikname van het gebouw ('post-occupancy evaluation', POE). Hierdoor wordt de gebruiker zelden meegenomen voorafgaand aan en gedurende het ontwerpproces.

Ondanks bouwvoorschriften, wet- en regelgeving en normering voor binnencomfort bestaan er geen duidelijke ontwerpprincipes of -richtlijnen voor kantoorrenovaties die de gebruiker in beschouwing nemen. Ten behoeve van het verbeteren van het comfort en welzijn is het noodzakelijk om onderzoek te doen naar betrekking van de gebruiker in de vroege ontwerpfases. Deze observatie leidde tot de volgende hoofdonderzoeksvraag, beantwoord in de dissertatie:

Hoe kunnen ontwerpprincipes voor het energie-efficiënt renoveren van kantoorgebouwen worden ontwikkeld, die zijn gebaseerd op evaluaties van gebruikerstevredenheid?

Ter beantwoording van deze vraag is een veldstudie gedaan in vijf Nederlandse kantoorgebouwen. Deze vijf kantoorgebouwen zijn gerealiseerd in de jaren 60 en 70, waarvan vier gerenoveerd. Voorgaand aan het empirische onderzoek is een literatuurstudie gedaan binnen een theoretisch kader van tien parameters met betrekking tot welzijn: thermisch comfort, luchtkwaliteit, verlichting, individuele controle, geluid, privacy, concentratie, communicatie, sociaal contact en territorialiteit. Deze parameters zijn verwerkt en geclassificeerd op basis van bevindingen uit 124 studies gericht op fysieke en psychologische tevredenheid in de werkomgeving.

Elk hoofdstuk en verscheidene sub-onderzoeksvragen adresseren de parameters. Op basis van de bevindingen was een classificatie van gebruikerstevredenheidsparameters voorgesteld, en aangevuld met een discussie over de hiërarchie van de tien parameters. De hiërarchie is bepaald op basis van de theoretische definitie en de fysieke, functionele en psychologische invloed van elke parameter.

Voor het empirische onderzoek zijn de aspecten van kantoorrenovatie, middels een multidisciplinaire methodologie, op prioriteit geordend. De methodes voor het verzamelen van data en analyses waren: onderzoek naar het energiegebruik en binnenklimaat na een renovatie en onderzoek naar de invloed van ontwerpfactoren op de gebruikerstevredenheid, tezamen met visueel en psychologisch comfort. De invloedrijke ontwerpfactoren in dit onderzoek zijn gericht op gebruikerstevredenheid: kantoorinrichting, oriëntatie, raam/muurverhouding en werkpleksituering. De empirische studies zijn georganiseerd in vier onderdelen.

Energiegebruik

Als voorafgaand onderzoek zijn architecten en facilitair managers geïnterviewd, ter identificatie van de kenmerken en het energiegebruik van gerenoveerde kantoorgebouwen. Hierna zijn vijf casestudies uitgevoerd. De gebouweigenschappen van elke casestudie zijn met elkaar vergeleken middels een cross-case-analyse. In dit onderdeel zijn het energiegebruik van de gerenoveerde en niet-gerenoveerde kantoren met elkaar vergeleken. Aanvullend zijn beperkingen beschreven die verbetering van de energieprestatie belemmeren.

Binnenklimaat en thermisch comfort van de gebruikers

Ter bepaling van de kwaliteit van het binnenklimaat en thermisch comfort van de gebruikers is het binnenklimaat en de relatieve luchtvochtigheid gemeten middels dataloggers. Een enquête met vragen over thermisch comfort, voorkeur en tevredenheid was verspreid onder de gebruikers van deze gebouwen. De gemonitorde data van het klimaat en thermisch comfort zijn geëvalueerd op basis van de Nederlandse NEN-normen en terugkoppeling van de gebruikers.

Individuele controle

Dit onderdeel richt zich op het identificeren van verbanden tussen de graad van individuele controle op het binnenklimaat (bijvoorbeeld tempratuur, ventilatie en licht) en gebruikerstevredenheid aangaande thermisch en visueel comfort. Deze studie onderzocht de impact van individuele controle op gebruikerstevredenheid middels enquêtes en statistische analyses. Het resultaat toont aan dat een hogere beheersbaarheid tot een hogere tevredenheid leidt ten aanzien van thermisch en visueel comfort. Het resultaat onthult ook de psychologische impact van individuele controle op de gebruikerstevredenheid, door verschillen in waargenomen tevredenheid volgens het criterium ‘geen controle’ versus ‘niet hebben van’. De uitkomsten creëren draagvlak voor werkplekbeheer en voor het ontwerp van individuele omgevingscontrolesystemen.

Gebruikerstevredenheid met thermisch, visueel en psychologisch comfort

Tezamen met de fysieke condities van werkplekken zijn de bevindingen van 579 kantoormedewerkers van de vijf kantoorgebouwen onderzocht. De reacties van de gebruikers zijn verzameld en geanalyseerd door middel van statistische analyse. Deze studiefase toont de invloed aan van kantoorontwerpfactoren op gebruikerstevredenheid, samen met thermisch, visueel en psychologisch comfort. Deze bevindingen dragen bij aan het kunnen voorspellen van welke ontwerpvariabelen tot een hogere gebruikerstevredenheid leiden.

Om de invloed van combinaties van ontwerpfactoren (bestaande uit drie of vier variabelen) op de energievraag te evalueren, is na het empirisch onderzoek een conceptuele energiesimulatie van 24 kantoormodelvarianten uitgevoerd. De energiebehoefte is voorspeld overeenkomstig de kantoormodellen. Aansluitend zijn ontwerpprincipes ontwikkeld middels het integreren van voorgaande bevindingen en de verschillende kenmerken van energie-efficiënte kantoorrenovaties. Een overzicht van de voorspelde gebruikerstevredenheid en energiebehoefte is weergegeven in een grafiek.

Hierop is een stroomdiagram opgesteld die de toepassing van ontwerpprincipes in het renovatieproces weergeeft. Als eerste zijn invloedrijke ontwerpfactoren, thermische, visuele en psychologische tevredenheid voorgesteld in de ontwerpprincipes. Door het volgen van het stroomschema kunnen de waardes van voorspelde gebruikerstevredenheid en energievraag worden geëvalueerd, om zo tot een optimaal renovatie plan te komen. In deze stap worden renovatiealternatieven voorgesteld in de vorm van kantoorvarianten, om balans te creëren tussen welzijn en energie-efficiëntie. Als zich een ontwerpbeperking voordoet, dient

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als laatste een graad van individuele controle te worden meegenomen om de gebruikerstevredenheid te verhogen. In de beginfases van een kantoorrenovatie kunnen de omvangrijke ontwerpprincipes architecten, ontwerpers en facilitair managers ondersteunen om de juiste ontwerpbeslissingen te nemen.

Samengevat toont dit onderzoek de relatie aan tussen ontwerpfactoren, binnenklimaat en gebruikerstevredenheid, zonder ondermijning van het fundamentele doel van een kantoorrenovatie, namelijk vermindering van de energievraag, bijwerken van de faciliteiten en verbetering van de gebouwprestaties. Het onderzoek draagt ook bij aan de ontwikkeling van ontwerpprincipes voor kantoorrenovaties met integratie van gebruikersperspectieven, die de gebruikerstevredenheid, het comfort en de energie-efficiëntie bevorderen. Er wordt aanbevolen nader onderzoek te doen naar de impact van de individuele controle op het binnenklimaat, aangezien dit een significante impact heeft op de gebruikerstevredenheid. Bovendien is het van belang om te vermelden dat variabelen zoals gebouwelementen en diverse gevelconfiguraties dienen te worden meegenomen in verdergaand onderzoek.

Ter conclusie: ontwerpprincipes die zowel de energieprestatie alsook gebruikstevredenheid beschouwen, dragen niet alleen bij aan waardeverhoging van het gebouw, maar dienen ook als opstap naar gebruikersgericht kantoorontwerp of naar gebruikersgerelateerde studies in de gebouwde omgeving.

요약

본 연구는 에너지 효율성을 높이는 오피스 건물 리노베이션을 위한 사용자 중심의 디자인 원칙을 발전시키는데에 목표를 두고있다. 에너지 절약 목표를 낮추지 않으면서도 업무공간의 기능과 편안함을 향상시키기 위함이 이 연구의 주 목적이다. 지속가능성에 대한 요구의 증가, 새로운 업무방식과 사용자들의 기호의 변화함에 따라, 단순히 에너지 성능이나 건물 설비시설들 교체만 다루는 것 뿐 아니라 사용자들의 건강과 웰빙까지 고려하는 오피스 건물의 리노베이션에 대한 필요성이 증가하고 있다. 오피스 리노베이션은 상당한 에너지 요구의 절감을 가져올 뿐 아니라 건물 성능도 향상 시킬 수 있다. 이러한 이유들로 대부분의 리노베이션 관련 연구들이 에너지 성능의 향상과 실내 환경 개선에만 집중을 해왔다. 비록 몇몇의 연구들이 업무환경에서의 사용자 만족에 대해서 연구해 왔지만, 대부분 건물 디자인의 초기 단계가 아닌 실내환경의 거주 후 평가에 관한 연구들이다. 실내 환경 쾌적성을 위한 건물 법규와 규범들이 있긴 하지만, 사용자들을 고려한 명확한 설계 원칙이나 디자인 가이드라인이 없는 실정이다. 따라서 어떻게 하면 사용자들의 편안함과 만족도를 높이고, 사용자들을 오피스 리노베이션을 위한 건물 디자인의 초기단계에서 부터 포함시킬 수 있는지에 대한 많은 연구가 필요하다. 이 논문에서 다루어질 주 연구 문제는 다음과 같다.

에너지 효율을 높이는 오피스 리노베이션에 있어서 사용자 만족 평가를 기반으로 한 설계원칙을 어떻게 발전시킬 수 있는가?

이 연구 문제에 답하기 위해, 네덜란드에 있는 5개의 오피스 건물들에 대한 현지 조사가 이루어졌다. 네개의 리노베이션 오피스들과 한 개의 리노베이션을 하지 않은오피스 건물이 선정 되었으며, 이는 모두 1960년대에서 70년대 지어진 건물들이다. 실증적 연구가 이루어지기 전에, 이론적 틀을 잡기 위한 문헌연구를 실행했다. 업무환경에서의 물리적, 심리적 만족도에 관한 124 개의 문헌연구를 통해 사용자 만족도와 관련있는 10개의 변수들을 결정, 분류하였다. 10개의 변수들은 열쾌적성, 실내공기의 질, 빛, 소음, 실내 환경에 대한 개별제어, 프라이버시, 집중도, 의사소통, 동료들 간의 사회적 접촉, 영역성을 포함하고 있다. 논문의 각각의 쳅터는 10가지의 변수들에 관하여 설명하고 있으며, 문헌조사 결과를 바탕으로 변수들의 중요도를 설명, 체계에 따라 분류되었다. 중요도는 이론적 정의와 각각의 변수들의 물리적, 기능적, 그리고 심리적 영향을 바탕으로 조직화 되었다.

실증적 연구 자료의 분석과 오피스 리노베이션에 있어서 중요한 관점들에 우선순위를 정하기 위해, 다학제적 방법론이 적용되었다.건물의 에너지 사용도, 리노베이션 후 실내환경의 질, 디자인 요소들이 열쾌적, 시각적, 심리적 편안함에 미치는 영향에 관한 데이타 수집이 이루어졌고, 다양한 분석방법을 통해 결과를 도출하고자 하였다. 여기서 말하는 디자인 요소는 앞서 말한 세 가지의 사용자 만족도에 영향을 미치는 디자인적 요소들로서, 오피스 레이아웃,

업무 공간의 지리적 방향, 창문의 비율, 창문으로부터의 작업 데스크의 위치를 포함한다. 실증적 연구는 다음과 같은 네 가지 부 주제로 이루어진다.

에너지 소비

선행 연구로써, 앞서 말한 4개의 리노베이션 오피스 프로젝트에 참여한 건축가들과 5개의 오피스 시설 관리자들과의 인터뷰를 통해 리노베이션 된 오피스 건물들의 기본 정보, 건물 특징, 에너지 사용량에 대한 정보를 수집하였다. 이후 교차 사례분석을 통해 각각의 특징들을 비교 분석하였으며, 리노베이션 한 건물들과 안 한 건물의 에너지 소비량을 비교하기 위해 여러가지 다양한 에너지 단위들이 적용되었다. 추가적으로, 에너지 성능을 높이는데 방해요소를 일으킨 한계점들에 대한 고찰이 이루어졌다.

실내환경과 사용자의 열 쾌적성

실내 온도와 습도 측정이 가능한 데이터 로고들을 각각의 오피스에 설치하여 리노베이션이 이루진 오피스와 그렇지 않은 오피스간의 실내 환경 및 사용자들의 열 쾌적성에 관해 비교, 분석하였다. 동시에, 사용자 설문을 통해 온열 감각, 열 환경 선호도, 만족도에 관한 데이터를 수집하였다. 실내 환경 및 열 쾌적성에 대한 기준은 네덜란드 건물 규준과 사용자들의 응답을 바탕으로 평가되었다.

사용자들의 개별 제어방식

이 챕터는 사용자들의 실내 환경 (온도, 환기, 빛)에 대한 개별 제어방식의 정도과 건물 사용자들의 열 쾌적성 및 시각적 편안함 사이의 관련성을 알아보는데 목적이 있다. 따라서 이 연구는 설문조사와 통계학적 분석을 통해 개별 제어방식이 사용자 만족도에 미치는 영향을 조사하였다. 그 결과, 일반적으로 개별 제어 정도가 높을 수록 열적, 시각적 편안함에 있어 높은 만족도를 보였다. 또한, 개별 제어장치가 있지만, 사용할 수 없었을 때와 개별 제어 장치가 실내에 배치되지 않았을 때에서 오는 인지적 만족감에 차이를 보이면서, 개별 제어력 정도가 만족도에 미치는 심리적 영향에 대해서도 증명되었다. 이러한 결과들은 업무 공간 관리와 개별 환경 제어 시스템 디자인에 기여할 것으로 예측된다.

실내 온열, 시각적, 심리적 편안함에 대한 사용자 만족도

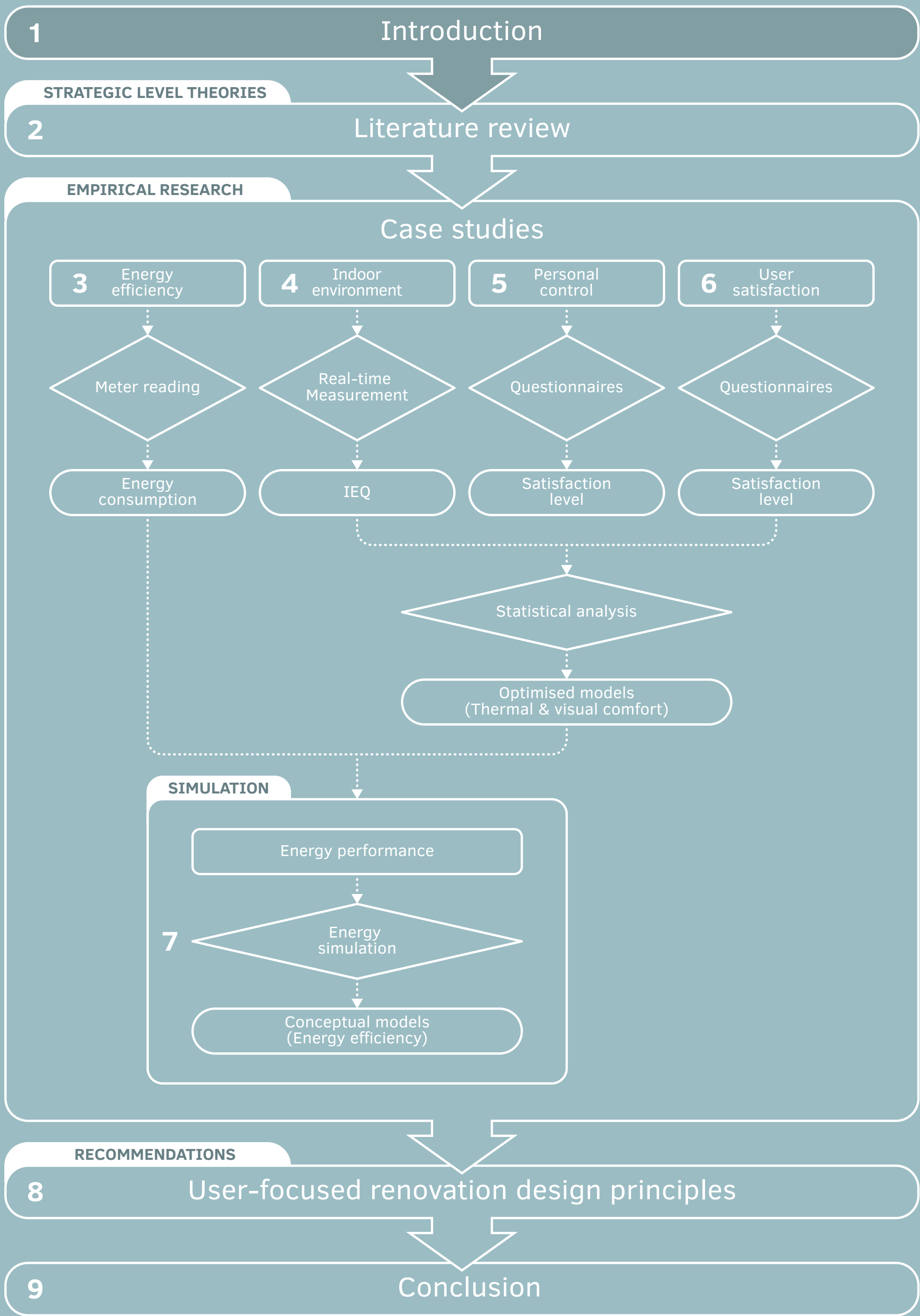
업무 공간의 실내 기후 환경에 대한 조사와 함께, 5개의 사례 건물들에서 일하는 579명의 업무 공간 사용자들이 연구 대상이 되었다. 설문조사를 통해 사용자 응답들을 수집하고, 통계적 분석을 통해 결과를 도출하였다. 이 연구 단계는 오피스 건물의 디자인 적 요소들이 실내 온열, 시각적, 심리적 편안함에 대한 사용자 만족도에 미치는 영향을 추론하고, 입증하였다. 또한, 그 결과들은 어떠한 디자인 요소가 더 나은 사용자 만족도를 가지고 오는지를 예측하였다.

실증적 연구 후, 에너지 시뮬레이션을 통한 개념적 연구가 수행 되었다. 이는 각각 다른 변수들을 가지는 디자인 요소들의 조합이 에너지 수요에 미치는 영향 정도를 평가하기 위함이다. 3개

혹은 4개의 변수들을 가지는 디자인 요소들의 조합을 통해 24개의 다른 모델들이 생성되었으며, 각각의 모델에 따른 에너지 수요가 예측되었다. 다음 단계로써, 이전 챕터에서 도출된 결과들과 에너지 효율을 위한 오피스 리노베이션을 보는 다양한 관점을 바탕으로 디자인 원칙들을 발전시켰다. 사용자 만족도와 에너지 수요를 예측할 수 있는 개괄적 도표가 제시되었다.

결과적으로, 디자인 원칙들을 리노베이션 계획중에 반영하기 위한 순서도가 만들어졌다. 첫째로, 온열, 시각, 심리적 만족도에 가장 영향력있는 디자인 요소들이 제시되었다. 다음 단계로, 순서도를 따라감으로써 예측되는 사용자 만족도의 가치와 에너지 수요에 대한 평가를 할 수 있고, 이는 최적화한 디자인 방안을 찾을 수 있게 도와준다. 이 단계에서, 만족도와 에너지 효율적 가치에 균형을 잡기 위한 몇개의 오피스 리노베이션 대안들을 얻을 수 있다. 마지막으로 디자인적 한계, 즉, 앞서 제시한 대안들이 기존 건물의 상황에 대응하기 어려울 경우, 실내환경의 개별 제어 정도를 계획에 반영함으로서 더 나은 사용자 만족도를 제공하는게 타협할 수 있다. 또한, 종합적인 디자인 원칙들은 건축가들, 디자이너들, 오피스 시설 관리자들에게 리노베이션 초기 단계에서 디자인적 결정을 하는데 도움을 줄 수 있다.

요약하자면, 본 연구는 오피스 디자인 요소들과 실내 환경, 사용자 만족도 사이의 관계들에 대해 증명하고, 단순히 사용자 만족도에만 집중된 연구가 아닌 오피스 리노베이션의 기본적 목표들인 에너지 수요 절감, 시설 개선, 건축 성능 향상을 간과하거나 도외시하지 않는 방향으로 설계되었다. 건물 사용자들에 집중된 통합적 관점에서 오피스 리노베이션을 위한 디자인 원칙들을 발전시키는데 기여하고, 이러한 통합적 관점들은 에너지 효율 뿐만 아니라 사용자 만족도와 편안함을 향상 시킬 수 있도록 한다. 본 연구에서 개별 환경 제어가 만족도에 중대한 영향을 미치는 것이 증명되었다. 하지만, 이 관점은 더 자세한 추가적 연구가 필요하며, 본 연구에 포함한 디자인 요소외에 건물을 구성하는 건축적 요소들, 건물 파사드의 다양한 형태에 관해서도 더 연구해 볼 필요가 있다. 결론적으로, 에너지 효율과 사용자 만족도를 고려한 디자인 원칙들은 단순히 건물의 가치를 높이는데 이바지 할 뿐만 아니라 사용자에 집중한 오피스 계획 혹은 건설 환경에서의 사용자 관련 연구들의 발전을 위한 발판이 될 것이다.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1 Introduction

1.1 Background

The annual energy consumption of non-residential buildings in EU has increased during the last 20 years by 74%, which is 40% greater than in the domestic sector (Jung et al., 2018). FIG. 1.1 shows that the non-residential sector accounts for 18% of the total energy consumption, next to the residential sector with a 21% share. FIG. 1.2 shows that the office is the major energy using building type, with a share of 24% among non-residential buildings (CBECS, 2013). In other words, offices are responsible for the major part of energy consumption within non-residential buildings.

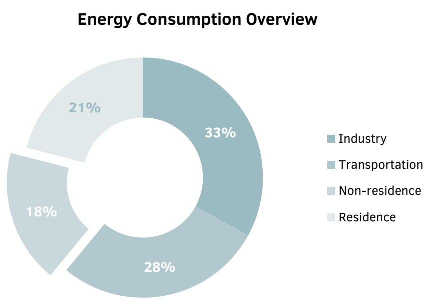

FIG. 1.1 Energy consumption overview (CBECS 2013)

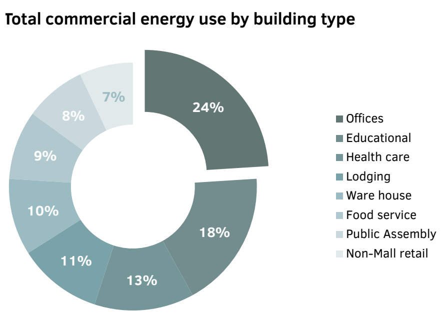

FIG. 1.2 Total energy use by non-domestic buildings (BPIE 2011)

In the European Union, around 85% of the 160 million buildings are showing thermally uneconomic conditions and bad energy performance (SwedishScienceNet, 2010). Consequently, global organisations and governments have paid attention to energy reduction through building renovations. The International Energy Agency (IEA), for example, reports that building renovation can contribute to a 50-70%

reduction in the overall energy demand of buildings (2016). Energy Performance Building Directives (EPBD) suggested several actions focusing on renovation and retrofitting to reduce existing buildings' energy needs (Mazzarella, 2015).

Energy-efficient building renovation in the built environment has received wide attention, particularly during the last decade. The EU has ambitious goals for energy reduction. According to the European commission and Energy Performance of Buildings Directive (EPBD, 2010; EuropeanCommission, 2016), compared to 2005, by 2050 the primary energy demand should be reduced by 32-41%. Many studies have stated that building renovations are important to achieve this goal (Bournas et al., 2016; BPIE, 2013; Kamenders et al., 2014; Marszal et al., 2011; Risholt et al., 2013). The building façade is one of the major considerations in building renovations. There are two reasons why facade technology is important for renovation. Firstly, the façade can significantly reduce the use of energy in the building. According to Mavromatidis et al. (2013), 50% of the total building energy is lost through the façade. This implies that improving the performance of the building envelope is important to save energy dissipated through facade. Secondly, the building envelope is an essential building element which can generate energy (e.g., applying photovoltaic technology).

Retrofitting is often defined as 'providing something with a component or feature not fitted during manufacture or adding something that it did not have when first constructed' (Eames et al., 2014). The European Parliament Directive (2002) reported that it is to modify the systems or the structure of something. Renovations are often used for the aesthetic improvement of buildings, but it also includes upgrades, repairs to certain elements of the building, removing, and adding new elements or systems for energy efficiency (Mazzarella, 2015). Thus, renovation covers a wide range of building upgrades.

From a sustainability perspective, maintaining an existing building can be preferable to demolishing an aging building and replacing it. However, it cannot solve the fundamental problems such as low quality of building components and mechanical systems since the building does not perform as it would be with new building requirements. Therefore, it is necessary to focus on renovating existing buildings in order to take a step forward for a sustainable built environment and to counteract the increasing operational costs of buildings. Hence, renovating existing buildings offers a great opportunity for cutting back energy consumption.

1.2 Problem statement

Energy-efficient office renovation is obviously required for the reasons mentioned in the previous section, and there is a great growth of energy renovation projects in practice. However, does a high energy performance office provide a comfortable working environment to its users? One of the reasons of office existence is to provide comfortable and healthy indoor environments (Ornetzeder et al., 2016). According to Klepeis et al. (2001), people spend over 80% of their time in enclosed spaces. Moreover, good indoor environments can lead to an increase of occupants' productivity (Al-Horr et al., 2016). For these reasons, planning healthy and comfortable work environment can be as important as reducing energy use. The question is, how can we design healthy and comfortable work environments, with which the users are satisfied? The starting point to answer this question is to include building users' requirements and satisfaction in workspaces in energy renovation schemes. A concern is that conventional renovation principles are mainly physical- and technical-oriented, whereas it does not focus on enhancing user satisfaction in the work environment. Moreover, as long as the renovated building does not offer sufficient quality or satisfaction, there will be less demand for renovated office buildings. When energy efficiency is considered as the only advantage of office renovation, it is difficult to convince developers, building owners, and investors that renovation is useful. From a managerial perspective, achieving better employee's satisfaction should be a focal point to strengthen the market values of renovated offices, thereby achieving a higher demand from the market, preventing environmental degradation or vacancy of existing buildings. Therefore, office renovation also has to provide a high-level of comfortable work environment for the users' well-being and satisfaction beside maximising energy reduction goals. Therefore, there is a significant need to investigate how to define the users' satisfaction to contribute to better office renovations.

The relationship between indoor climate and users' physical health has been explored in extensive research (Al Horr et al., 2016; Bluyssen et al., 2016; Leder et al., 2016; Mandin et al., 2017). Followed by these studies, the framework of international green building rating systems such as Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM) include a category of social sustainability as a means of providing a healthy and comfortable environment to users for both new and renovated buildings (Sarkis et al., 2012; Zuo & Zhao, 2014). Although international green building rating systems address the significance of including user perspectives, there is a lack of guidelines and information that focus on user satisfaction in building renovation. Especially, the relationship between design factors and user satisfaction has rarely been investigated due to several reasons; user satisfaction is a subjective topic; design factors are closely related to energy efficiency and aesthetic aspects rather than user satisfaction. Therefore, the main problem is that in spite of the development of various renovation techniques, there is still a lack of renovation design principles considering user preferences and user satisfaction due to the indirect relationship with energy use.

In any renovation project, the initiative is the most significant phase to ensure proper decisions and to optimise overall renovation values and results, that should be considered in the early renovation design stage. Jensen and Maslesa (2015) stated that the main barriers include lack of standard principles and a lacking overview of potential values in the initiative phase. To summarise all these aspects, it is required to develop an overview of potential values and standard design principles that not only focus on energy efficiency but also on the building users for office renovations.

1.3 Research objectives and questions

1.3.1 Research objectives

The main objective of this research is to develop user-focused design principles for energy efficient office renovation that address the impact of office design factors on user satisfaction with thermal, visual, and psychological comfort through case studies in the Netherlands, and by evaluating user satisfaction in renovated office buildings.

1.3.2 Research questions

The main research question that will be answered is:

How can design principles for energy efficient office renovation be developed, based on the evaluation of user satisfaction?

In order to answer the main question, the following sub-questions need to be explored. Each question corresponds to a different chapter in the dissertation.

A What are the main parameters that are currently applied to evaluate user satisfaction in office buildings? (Chapter 2)
B How does energy performance differ between renovated offices and non-renovated offices on the basis of the façade renovation? (Chapter 3)
C What are the effects of indoor climate on physical and psychological satisfaction in the workspaces of the case studies? (Chapter 4)
D What is the impact of person control on user satisfaction with thermal and visual comfort? (Chapter 5)
E How do the office design factors affect user satisfaction with physical and psychological comfort? (Chapter6)
F To what extent do the office design factors contribute to the energy demand in different energy categories? Which combination of design variables constitute the optimal scenarios for energy-savings? (Chapter 7)
G How can user-focused design principles that optimise user satisfaction and energy performance be formulated? (Chapter 8)

1.4 Scope of research

The climate is very different worldwide. This research focused on case studies in the Netherlands, which is located in Cfb (Marine West Coast Climate) based on Köppen Climate Classification, to minimise complicated parameter requirements. However, the results suggest generic renovation principles that can be applied to any office model in similar climate zones.

A second consideration of this research is that offices have diverse characteristics according to different location, layout, size and materials. The renovation boundary in this thesis is restricted to the technical strategies for the building envelope and office functionality. Reasons for this are, first, that the building envelope has a major effect on improvement of the energy performance, and the mechanical service system, such as the heating, ventilation, and air conditioning (HVAC) system, is regarded as the most important renovation target. Second, the users' interest is only focused on the result of the building renovation instead of which technologies are used to improve the energy performance.

1.5 Research methodology

User-focused building evaluation is an important method to check the performance of a building in use (Heo et al., 2012). In order to examine the users' opinions, a mixed methods research design is applied to this research with three main study processes, which consist of literature review, real-time case studies including a user survey, and energy simulation. Before the start of the case studies, it is required to know the current state of the evaluation parameters for user satisfaction from literature reviews. Literature review contributes to sorting out the main parameters applied to user satisfaction evaluation in office buildings. The selected parameters are classified by the theoretical hierarchy of the user satisfaction framework in office design.

1.5.1 Research approach

FIG. 1.3 shows four stages of user-focused evaluation of offices that are conducted in this research. A quantitative and qualitative research approaches are chosen to convert observation in real-time contexts into generalisable principles. First phase focuses on collecting data from the field study consisting of three parts. The quantitative research includes two observation methods: real-time monitoring of the indoor climate and distributing questionnaires to users. In phase 2, statistical and comparative analyses are conducted to verify the reliability of the collected data. In phase 3, the collected data are used as input to formulate generalised design principles. In phase 4, energy simulation by design builder software is applied to assess the generalised principles and to validate adequacy for energy efficient renovation.

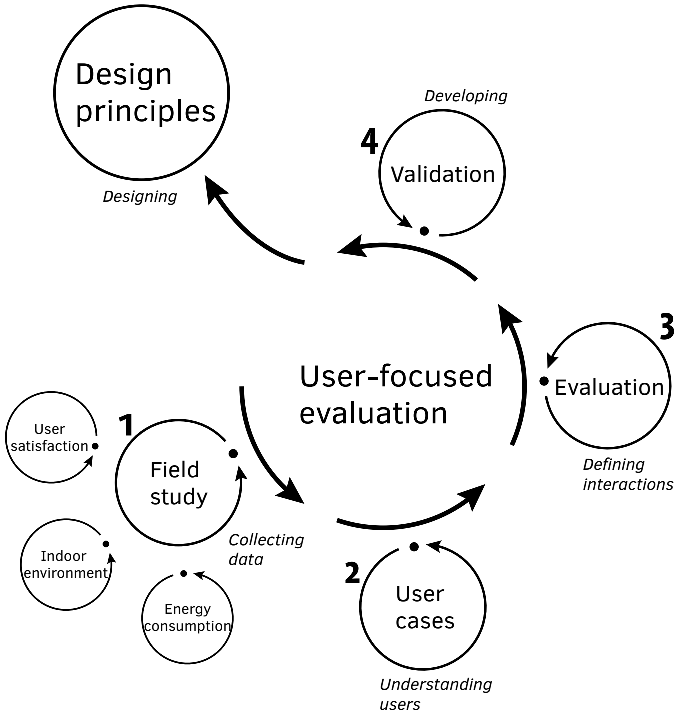

FIG. 1.3 User-focused evaluation research approach

1.5.2 Research methods

This research applies three data collection methods regarding the three main research topics (energy, indoor environment, and user satisfaction). In addition, the two analyses methods are conducted to validate the results (statistics and energy simulation).

A Literature study

Literature reviews are used to investigate the most important factors for user satisfaction on workplaces, and exploring the gap between real workplace and theories from the findings of former studies. The theoretical framework contributes to create the hierarchy of satisfaction factors.

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B Case study

B1 **Interviews**

Facility managers and architects are invited to collect the building information. In addition, the information of the annual energy consumption of case studies is collected by meter-reading.

B2 **Measurement of indoor climate**

Real-time monitoring of indoor climate was conducted with HOBO devices, which can measure indoor air temperature, relative humidity, and illuminance, in five case studies in the Netherlands.

B3 **User survey**

Questionnaires are distributed to the building users to collect the degree of user satisfaction with, and perception of workplaces.

C Energy simulation

Energy simulation is conducted by using the software Design Builder. The results assume the energy demand based on the different combination of office design factors.

1.6 Research framework and outline of the thesis

This thesis presents empirical and simulation-based results. A research framework is developed to answer the research questions. It consists of eight chapters, as shown in FIG. 1.4. This research is approached by focusing on three aspects: energy efficiency, indoor environmental quality (IEQ), and user satisfaction.

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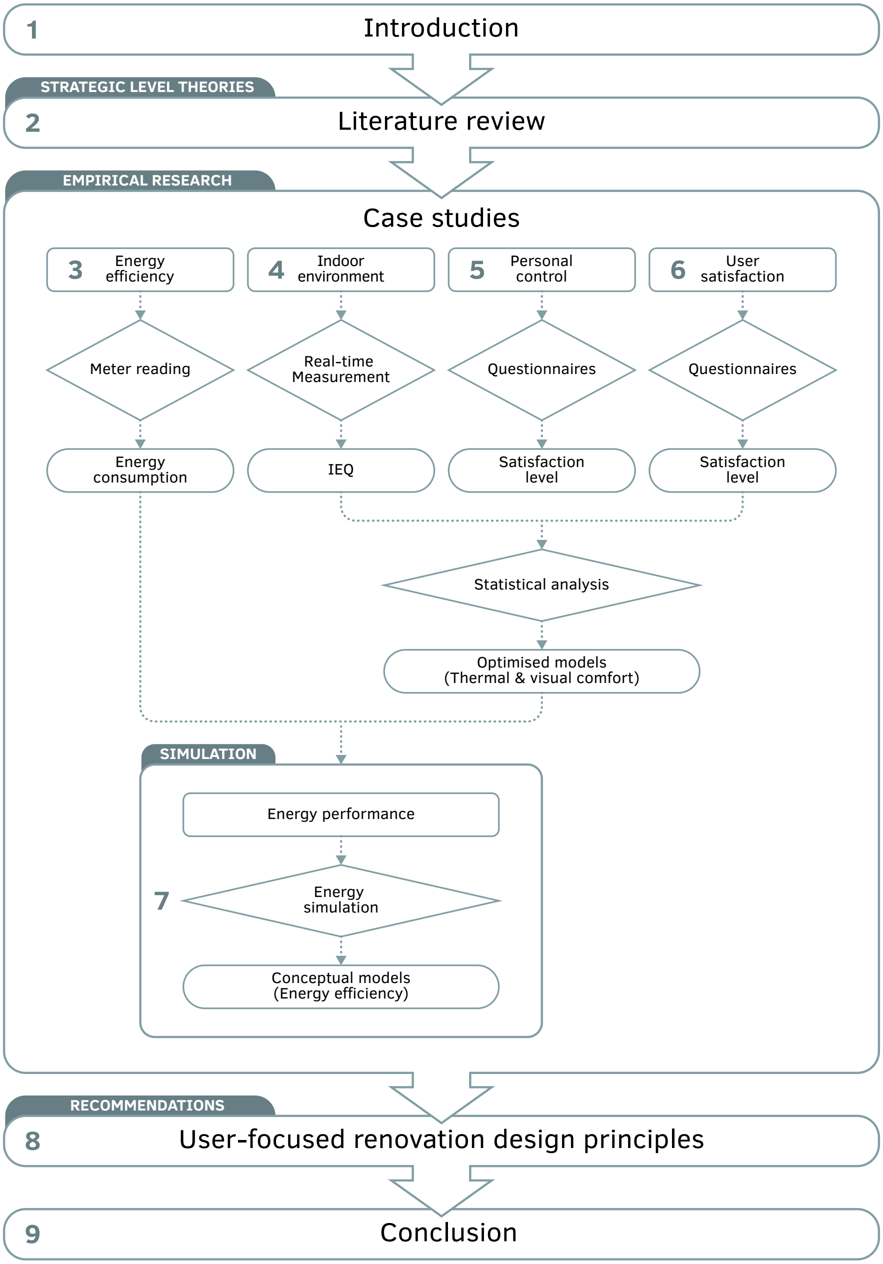

FIG. 1.4 Research structures and methods

Chapter 2 provides the main parameters currently applied for the evaluation of user satisfaction, including the definitions based on literature reviews. Ten key indicators for users' satisfaction in workspaces are discussed and structured based on the priority of users' needs.

In order to identify the impact of building characteristic of renovated offices on energy performance, Chapter 3 compares the performance of renovated and non-renovated offices in terms of energy efficiency and the characteristics of renovated office buildings.

The results of empirical studies conducted in the Netherlands is presented in Chapter 4. It compares the effect of indoor climate on user satisfaction in each case study, and investigates the seasonal adaptive thermal comfort and users' thermal perception.

Chapter 5 explores the relationship between the office design factors and user satisfaction with physical and psychological comfort. Multi-statistical analyses were conducted to investigate influential office design factors on user and its contribution weight on satisfaction. The findings show predicted satisfaction models and which design factors may bring better satisfaction to users.

The predicted models in Chapter 5 are simulating the energy performance to verify energy consumption in Chapter 6. This chapter assesses the impact of design factors on energy performance using possible combination models and energy efficiency and presents optimal energy reduction models.

The integrated design principles were formulated based on the findings of the previous chapters. Chapter 7 describes the optimal models based on both energy efficiency and user satisfaction. Furthermore, the optimal model proposes optimised user satisfaction and energy performance.

Chapter 8 concludes the user-focused design principles with recommendations, and practical implications to improve the quality of work environment in the future.

1.7 Research relevance

1.7.1 Scientific relevance

This aims to bridge the gap between energy efficient renovation principles and realised office conditions by reflecting on non-technical considerations such as users' thermal, visual and psychological satisfaction in a scientific way. Understanding users' satisfaction and requirements is a fundamental research step to develop a user-focused office renovation.

This research is, therefore, highly related to the topic of indoor comfort and user satisfaction with thermal and visual comfort. On the one hand, most of scientific studies among the topics deal with the influence of design parameters on a certain satisfaction parameter such as visual or thermal comfort. On the other hand, the user-centred approach focuses on human behaviour and its pattern in a workspace. However, the condition of the workspace is created by many design factors. Moreover, the interplay among different design factors can influence differently on user satisfaction. Therefore, this research considers the different design factors as a whole and its importance on user satisfaction.

The user-focused design principles in this research provide estimated satisfaction values for possible combinations of design factors. The design principles for office renovation suggest how the principles can be applied in practice and shows the contribution weight of the design factors on different types of user satisfaction. The predicted satisfaction models were tested by simulating their energy performance. The models can contribute to an estimate of the energy demand of each typology and the level of satisfaction.

In addition, the mixed-methods applied in chapter 4 can contribute to the user-related studies for building evaluation. The recommended design principles can contribute to energy efficiency and user satisfaction as a result. It is expected that the results of this research will be a starting point for considering new work environment and user-focused choices. Furthermore, it will contribute to applying user consideration into any energy-efficient office renovations.

1.7.2 Social relevance

This research investigates the impact of design factors on user satisfaction and introduces user-focused design principles for office renovation. Energy-efficient office renovation with a consideration of building users is often a challenging task to developers and other professionals since the satisfaction is subjective and difficult to measure. For this reason, renovation was not often supported by users' perspectives. In this research, office design factors are analysed from new perspectives focusing on the user perspective. The results are expected to have an impact on sustainable office design and better work environment, thereby increasing employees' satisfaction and productivity, and reducing the rate of absenteeism. When an energy renovated office serves as a favourable work space, the market demand for this type of office can be expected to increase. Therefore, besides better physical indoor quality and energy savings, this research will contribute to better workspace quality considering thermal, visual and psychological satisfaction for users. Furthermore, user-focused energy efficient renovation will open a new chapter for an advanced-sustainable built environment in society and will guide architects, facility managers, and owners towards extra advantages; higher productivity, higher market value, and so on.

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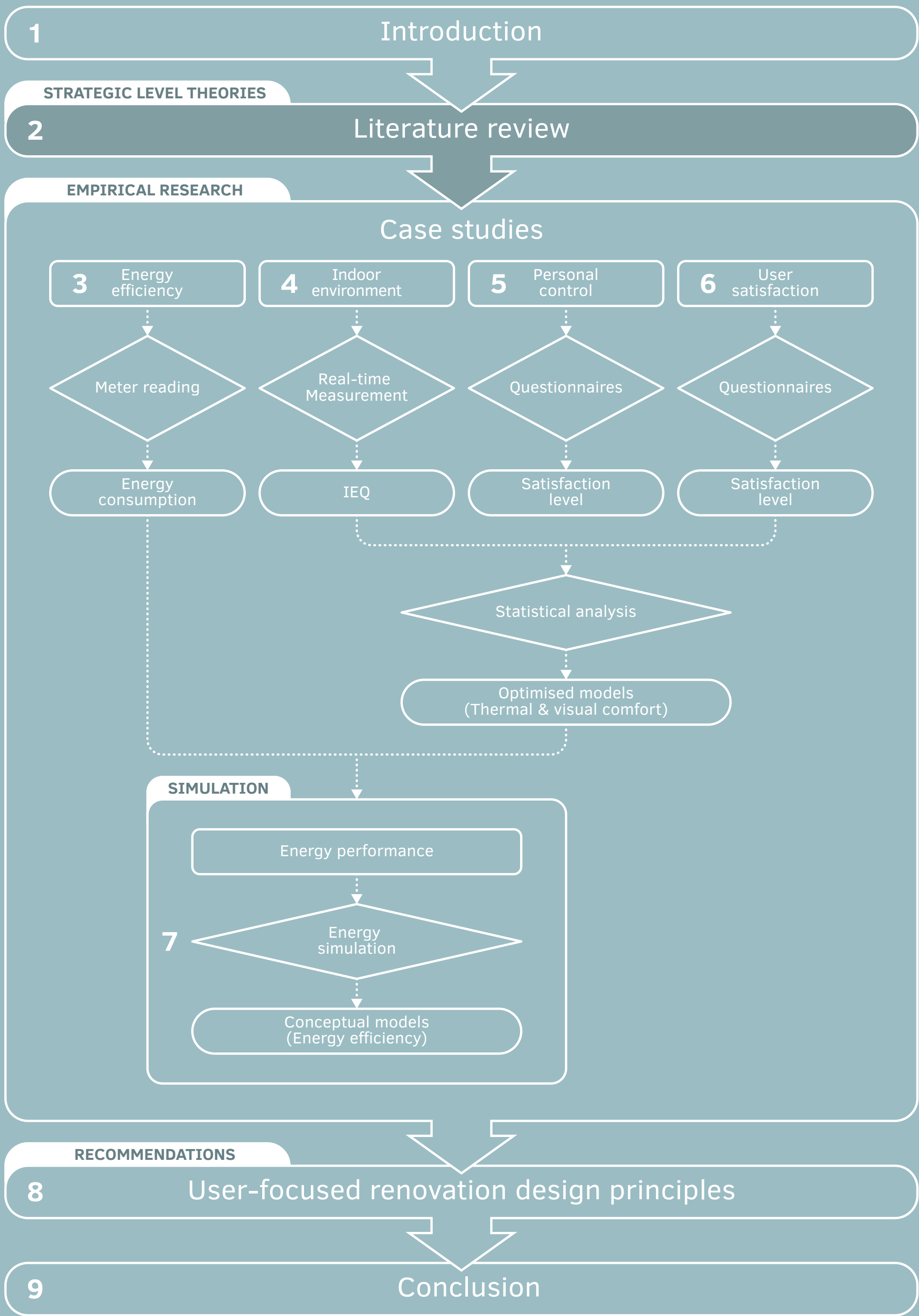
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2 Theoretical framework for user-focused evaluation in office design

As was stated in the introduction, a user-focused renovation approach can enhance user satisfaction in offices and the functional quality of the offices while meeting energy performance goals. The first step for this renovation approach is to identify users' needs and the physical and psychological factors affecting user satisfaction, as input to office renovation projects. The main aim is to identify the factors that are affecting the physical and psychological satisfaction of users, based on what previous research has found in that field. Therefore, this chapter highlights the main parameters currently applied to the evaluation of user satisfaction, including the definitions based on the literature review.

The research approach for the literature review is discussed in section 2.2. Searching was limited to the main key terms of office, work environment, and user satisfaction and comfort. Section 2.3 explores the relationship between office renovation and user satisfaction. The terms user satisfaction and the user's expectations in workplaces are defined in section 2.4. In section 2.5, the important factors were searched through empirical-based international literature mainly. Based hereupon, section 2.6 discusses the challenge of evaluating user satisfaction. In section 2.7, the findings present ten main parameters to increase user satisfaction in office renovation. The parameters were categorised into three levels based on needs theories to organise the hierarchy of priorities.

2.1 Introduction

Awareness of healthy living has led to a concept of office design aimed to provide a comfortable work environment and to make high-quality workplaces. According to the European "Energy performance of Buildings Directive", new energy efficient buildings should secure occupants' comfort and high satisfaction in both physiological and psychological ways to increase productivity (Wagner et al., 2007). It means that new building concepts should be developed to meet the occupants' comfort standard.

Some studies stated that green building offices lead to greater productivity, lower absence, and happier employees (Abbaszadeh et al., 2006; Armitage et al., 2011; Liang et al., 2014). In contrast, others argued that there is no significant relationship between green buildings and the occupants' satisfaction with Indoor Environmental Quality (IEQ) or that the influence is quite small compared to conventional offices (Paul & Taylor, 2008; Thatcher & Milner, 2012). Leaman and Bordass (2007) and Gou et al. (2013) also concluded that the indoor environment of green buildings was not always performing highly, but that users tended to be more tolerant and forgivable in green buildings. Other research of Liang et al. (2014) explained that occupants were more tolerant with IEQ when concerning energy consumption. These studies proved that green buildings, such as LEED or Green Star certified buildings do not always support high level of user comfort and satisfaction.

Therefore, the question that this chapter considers is: does a high energy performance office provide end-users with a comfortable working environment? At present, building designs or renovation processes mainly focus on practical aspects such as energy performance, aesthetical aspects, cost optimisation, and fundamental indoor quality by complying with the building regulations. However, office renovation also has to provide a high-level comfortable work environment for the occupants' well-being and satisfaction beside maximising energy reduction goals. Furthermore, a user-focused design approach or guideline for office renovation is lacking.

User satisfaction has been emphasised by several researchers as a significant factor for successful sustainable buildings (Leifer, 1998; Ornetzeder et al., 2016; Rothe et al., 2011; Wilkinson et al., 2011). Van Der Voordt (2004) stated that satisfaction can be related to the work itself, the social environment, the physical environment and interactions among them. Haynes (2008) narrowed down the occupants' satisfaction to the physical environmental scale. According to him, user satisfaction can be measured by how comfortable occupants feel in their environment. The author also found that employees' productivity became low when they are physically uncomfortable.

Several researchers have revealed the relationship between healthy buildings and employees' productivity (Abbaszadeh et al., 2006; Heerwagen, 2000; Singh et al., 2010), and the significance of IEQ impact on user satisfaction in green buildings (Altomonte et al., 2017; Krarti, 2018). According to ASHRAE (2001), poor indoor condition can cause low productivity and discomfort. Houtman et al. (2008) addressed that indoor conditions may be also connected to the mental health of building users.

The aim of this chapter is to identify the influential factors that have to be considered to increase user satisfaction in workplace. The outcome proposes ten physical and psychological parameters for user satisfaction. It also suggests the hierarchical priority structure based on needs theory: basic, proportional, and bonus factors. Integrating a user satisfaction approach for workplaces in energy renovation projects is a challenge in both building engineering and building management fields. Thereby the advanced user satisfaction approach is at the cutting edge of research in the built environment. The main research questions that will be answered in chapter 2 are: what are the initial factors to maximise user satisfaction, how can the order of priority of influential factors be determined, and how are the influential factors related to energy-efficiency?

2.2 Methodology

This chapter presents an international literature review on user satisfaction of workplaces with the aim to apply the findings to energy-efficient office renovations. The key search terms for the literature study focused on work environment including 'office renovation', 'user satisfaction', 'comfort, 'wellbeing', 'work environment', 'workspace' and 'workplace', 'energy efficiency', and 'green building'. The search was carried out by using the online journal article databases: Scopus, ScienceDirect and Google Scholar. TABLE 2.1 shows keywords used for searching journal and book databases. In order to select only office related user satisfaction, some keywords were used to sort out unrelated field information such as hospital, school, house, housing, systems, software, network, infrastructure and city grid.

TABLE 2.1 Keywords used for journal article searches

Search keywords	
AND	(work environment or office or workplace or workspace) (user satisfaction or comfort or wellbeing) (office renovation or energy efficiency or green building)
AND NOT	(hospital) (school building or educational building) (housing or house) (systems or software or network or infrastructure) (city grid or urban structure)

From Scopus, only 12 documents were found. 3 journal articles dealt with these topics from 1989 to 1999, and 9 articles were found from 2000 onwards. Seventy-seven articles were found from 2001 onwards via ScienceDirect. Google scholar was used to limit missing information as a result of excluding some keywords. The results from the literature search showed that the topic first gained interest after 2000, and so the literature review was limited to the period 2000-2018.

The scope of chapter includes the most influential factors in workplace environment and office renovation that were determined in studies during the previous two decades. 124 papers were referenced as main input to analyse the relationship between the two fields. The finding intersections approach (Ridley, 2008) was used for the literature review in this chapter (see FIG. 2.1). This approach helps to define the gap and overlapping issues between office renovation and user satisfaction, showing how each field has been developed separately, and where intersection is found.

The literature selected was classified into five categories (see TABLE 2.2). Literature was prioritised based on these categorised keywords. Literature was reviewed on energy-efficient building renovation and user satisfaction as main areas. FIG. 2.1 presents the intersection from the literature approach and keywords identifying overlapping and separated subject fields. However, user satisfaction and wellbeing has been a major consideration.

TABLE 2.2 Summary of keywords from selected journal articles

Keywords	Number of literatures
Energy efficient building renovation/sustainable office	39
Organisational management of workplace	36
User satisfaction, well-being and psychological comfort	58
Indoor climate and physical comfort	25
Office environment and comfort	31

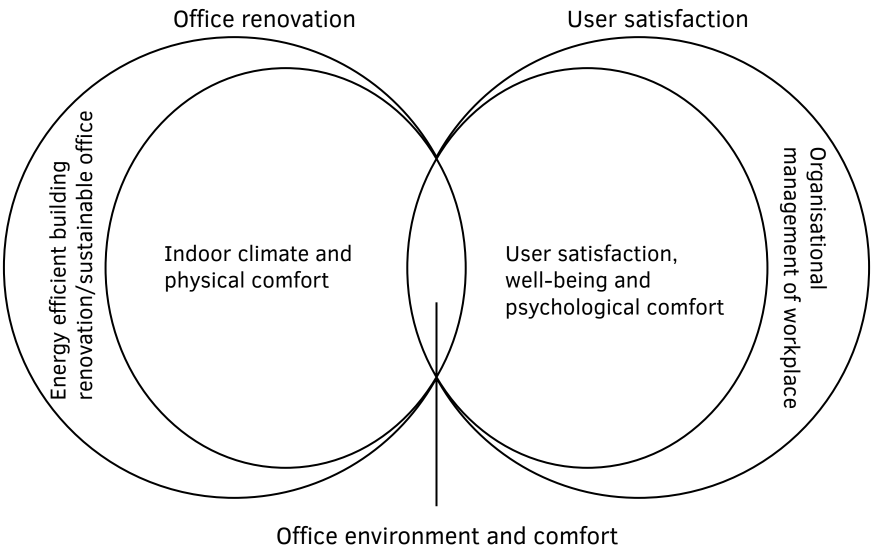

FIG. 2.1 Literature review approach

2.3 Energy-efficient office renovation and user satisfaction

Building renovation technologies mainly deal with energy efficiency and high-quality indoor environments. However, human comfort is often overlooked in sustainable building design principles (Shahzad et al., 2016). Retrofitted buildings are often regarded as comfortable and healthy buildings because of improved indoor environmental quality (Krarti, 2018; Leaman & Bordass, 2007). Lower environmental impact or green buildings scored better on indoor environment and (Leaman & Bordass, 2007). Nonetheless, building energy research shows a conflicting issue between energy saving and optimisation of indoor comfort (Lu et al., 2017; Shaikh et al., 2014). It is a big challenge to include office users in a renovation design process due to many uncertainties, such as service change and various human behaviour, which can directly affect the selection of renovation technologies (Allouhi et al., 2015; Ma et al., 2012). Besides, there are many factors with significant impact on the sustainability of a building, for instance the building envelope, building elements and building services (Bruel et al., 2013; Iwaro & Mwasha, 2013; Jensen et al., 2013). Similar studies also found barriers regarding the relationship between economic issues and building property value (Allouhi et al., 2015; Chegut et al., 2014; Kok & Jennen, 2011; Kok & Jennen, 2012; Newell et al., 2011). Most of the studies mentioned above stressed the importance of standard renovation methods that can provide guidelines for user-focused building renovation.

From a functional point of view, the main concept of the office design is becoming more focused on the occupant's satisfaction and preferences. At the same time, the concept of office design has changed due to the various working patterns with the advancement of ICT. Studies have proved that a high quality of the physical environment is directly connected to employee satisfaction (Veitch et al., 2007; Wells, 2000) and productivity (Al-Horr et al., 2016; Maarleveld et al., 2009; Tucker & Smith, 2008; Wilkinson et al., 2011) Other studies have investigated the relationship between sustainable office buildings and workspace environment (Arge, 2005; Dobbelsteen, 2004; Wilkinson et al., 2011), and the well-being and health of occupants and office design (De Croon et al., 2005; Leder et al., 2016; G. Newsham et al., 2009).

In those findings, the physical working environment (e.g., the organisational plan and indoor environmental quality) and user comfort are interlinked to satisfaction, and these perspectives need to be considered for office renovation. Thus, three concepts for the sustainable office plan can be defined: high functionality for occupants, renovation strategies for energy efficiency and user satisfaction.

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2.4 An overview of the occupant satisfaction of workplaces

2.4.1 Definition of the occupants' satisfaction of workplaces

Occupant satisfaction is quite intangible. Huber et al. (2014) alerted that a general overview of user satisfaction and influencing factors in building design research is lacking. Moreover, it is difficult to define the term of user satisfaction, since there is no standardised measurement method for user satisfaction. Van der Voordt (2003), however, defined that employee satisfaction is improved by meeting the employees' preferences and needs in their working environment, and the increase of the employees' satisfaction level is caused by their physical and psychological comfort degree. Shaikh et al. (2014) stated that comfort is the condition of mind influenced by psychological effects and is coherent with satisfaction of the environment. Their definitions show that the occupants' preferences are important elements for them to be satisfied and perform well. Rothe et al. (2012) also agreed that when the workplace condition meets the occupants' preferences, they show higher user satisfaction. Other research of Rothe et al. (2011) summarised the concepts of user needs, preferences and requirement based on literature (see FIG. 2.2). Basic psychological needs, such as comfort, safety, sense of belonging, and security are required for people to perform well and maximise their potentials.

The majority of scholars have explored the relationship between environmental influences and occupants' well-being by focusing on the range from physical-related well-being, such as indoor environmental quality (IEQ) (Humphreys, 2005; Levin, 2003; Mofidi & Akbari, 2016; G. Newsham et al., 2009; Wargocki et al., 2012), to psychological-related well-being. These factors are controlled by organisational management, the employees' way of working as described by work pattern, flexibility of workspaces, and social interaction (Ekstrand & Hansen, 2016; Harris, 2016; Haynes, 2007; Ruostela et al., 2015). The influence of the office layout, ceiling height and openness (Danielsson & Bodin, 2008; Vartanian et al., 2015) also have been studied as a part of psychological elements.

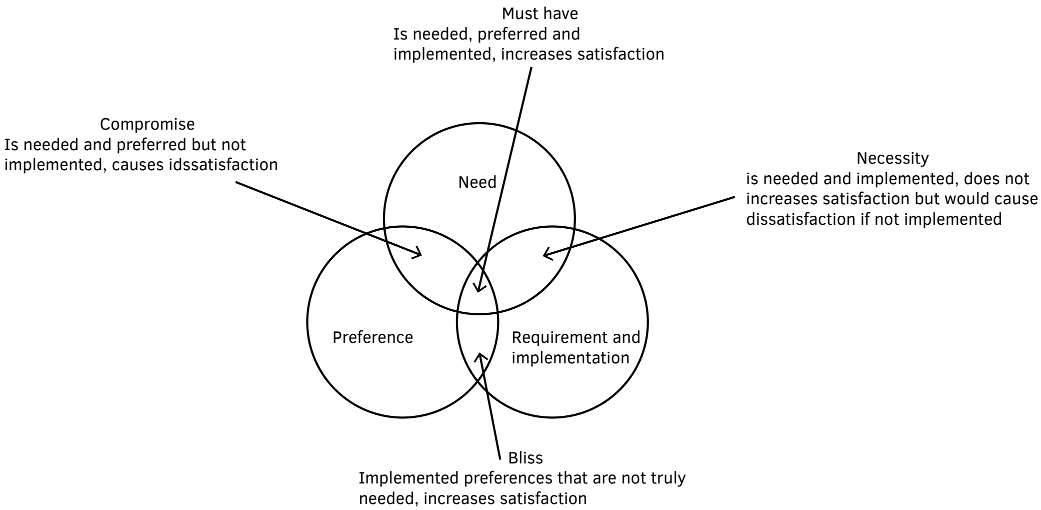

FIG. 2.2 The relationship between the concepts need, preference, and requirement and implementation (Rothe et al. (2010))

2.4.2 Occupant preferences and expectations of workplaces

Understanding occupants' preferences and requirements in working environment is a key driver to increase their satisfaction level. IEQ is the main element which has an effect on the degree of user satisfaction (Bluyssen, 2013; Frontczak et al., 2012). A preliminary study of Wilkinson et al. (2011) analysed parameters influencing user satisfaction in office buildings from various perspectives. The author revealed that there was a big gap between user satisfaction and expectations in individual control of environmental quality. Moreover, IEQ factors such as temperature, ventilation, heating, cooling and lighting were the most problematic issues, because the indoor condition does not qualify occupants' expectations.

From the employee's perspective, the interesting issues of office renovation are well-being and a healthy work environment (Leather et al., 2003). Employees want to work in a hygienic, comfortable and user controllable workplace where they can feel at home (Naccarella et al., 2018). Another study about the user value of office buildings distinguished the meaning of well-being into psychological well-being and physical well-being. Van der Voordt and Wegen (2005) defined the concept of functional quality of buildings with nine aspects: accessibility, parking facilities, efficiency, flexibility, safety, spatial orientation, privacy, territoriality and social contact, health and physical well-being, and sustainability.

TABLE 2.3 shows the most frequently mentioned factors with a significant impact on user satisfaction, according to the selected literature from the last twenty years. The literature was selected based on keywords: occupants (user) satisfaction, comfort/well-being, indoor climate and comfort, energy efficient building renovation. Nevertheless, a built environmental factor being mentioned in the literature does not necessarily establish a casual link. Many studies of Haynes (2007), Van Der Voordt (2004), Rothe et al. (2011), Appel-Meulenbroek et al. (2011), Wilkinson et al. (2011), Techau et al. (2016), and Ornetzeder et al. (2016) cover a wide range of user requirements contributing to satisfaction, ranging from physiological and psychological to social aspects. Rothe et al. (2011), and Al-Horr et al. (2016) included additional factors such as building location and amenities as factors that attribute user preferences. Kim and De Dear (2013) conducted survey based on various parameters that are not only physical and psychological conditions but also ergonomics and office equipment (see TABLE 2.3). The main conclusion was that spatial configuration has a significant influence on physical and psychological satisfaction.

Harris (2016), Oseland (2009), and Danielsson and Bodin (2008) focused on psychological aspects of user requirements such as interaction with colleagues, privacy, and outside scenery. Interestingly, the researchers connected these preferences to office types and organisation. Choi and Moon (2017) revealed that environmental satisfaction is influenced by the location of the workstations. Baird et al. (2012); Choi and Moon (2017); Liu et al. (2018), and Levin (2003) studied the relationship between user satisfaction and indoor environmental parameters. Levin (2003) emphasised that user control over indoor environment is essential to increase the level of user satisfaction. Pathak et al. (2014) observed in an empirical study that thermal, lighting and spatial arrangements are the most important parameters for users' comfort, satisfaction and efficiency.

Based on TABLE 2.3, the top ten factors for measuring user satisfaction level according to the literature were selected: thermal comfort, air quality, noise, light, user control, privacy, spatial comfort, concentration, communication/collaboration, and social contact. Indoor climate and thermal comfort are significantly related to each other. Many studies deal with the topic. On the other hand, organisational management of workplace strongly influences psychological comfort of employees.

TABLE 2.3 Criteria influencing user satisfaction in office buildings

References	User preferences/requirement factors																		
	Thermal comfort	Air quality	Noise control	Light/ Daylight	User control	Spatial comfort	Privacy	Ability to do work	Concentration	Communication / collaboration	Social contact	Work location	Ambience	Aesthetic	Dimension work desk	Ergonomics	Building location/amenities	View/scenery	Well-equipped facility
Altomonte et al. (2019)	+	+		+	+	+						+						+	
Liu et al. (2018)	+	+	+	+	+		+			+									
Choi and Moon (2017)	+	+	+	+		+	+											+	
Al-Horr et al. (2016)	+	+	+	+		+	+					+		+			+		
Harris (2016)									+	+		+	+						
Techau et al. (2016)		+	+	+	+								+					+	
Ornetzeder et al. (2016)	+	+	+	+		+	+	+			+	+							+
Pathak et al. (2014)	+			+		+						+							
Kim and De Dear (2013)	+	+	+	+		+	+			+		+			+	+			+
Baird et al. (2012)	+	+	+	+	+														
Appel-Meulenbroek et al. (2011)	+				+	+	+				+	+	+	+	+	+			+
Wilkinson et al. (2011)	+	+	+	+	+							+							+
Rothe et al. (2011)	+	+	+	+		+	+	+	+	+		+	+				+		+
Niemi and Lindholm (2010)	+	+	+	+						+		+							
Oseland (2009)							+		+	+	+	+						+	
Danielsson and Bodin (2008)					+		+		+	+	+	+							
Haynes (2007)	+		+	+			+		+	+	+	+		+					
Van Der Voordt (2004)	+		+	+			+		+	+	+	+	+					+	+
Levin (2003)	+	+		+	+														
Total	15	12	12	15	8	8	11	2	6	9	6	14	5	3	2	2	2	5	6

2.5 Measuring user satisfaction and measurement factors

2.5.1 User satisfaction measurement

Although measuring user satisfaction is complicated, it is imperative to develop a measurement method that can be applied to building design. A higher user satisfaction can strengthen renovation design solutions and the building’s total value (Shafaghat et al., 2016). Post occupancy evaluation (POE) has widely been used to evaluate building performance (Göçer et al., 2015). This method is also applicable for user’s wellbeing and satisfaction with renovation projects (Al-Horr et al., 2016). Existing measurement tools mainly focus on the indoor office environment.

TABLE 2.4 shows literature on user satisfaction parameters as well as on analytical measurement tools. It also highlights that POE is a common method to collect feedbacks on a building's performance in use. POE uses three different tools, questionnaires and interviews, bills and metrics, and physical measurements by using sensors. Green buildings are considered healthy indoor environments when 80% of the end-users are satisfied with the environmental settings (ASHRAEStandard, 2010). However, in a recent study, Loftness et al. (2018) designed a new framework for evaluating building performance and POE, based on spatial, thermal, air, acoustic, visual and building integrity.

TABLE 2.4 Summary of studies investigating parameters affecting user satisfaction

Study	Title	Results	Tools
Loftness et al. (2018)	Critical Frameworks for Building Evaluation: User Satisfaction, Environmental Measurements and the Technical Attributes of Building Systems (POE + M)	POE+M helps occupants and managers to understand the impacts of work environments on health and productivity; to analyse building systems for IEQ.	Post Occupants Evaluation and Measurements (POE + M), National Environmental Assessment Toolkit (NEAT)
Candido et al. (2016)	BOSSA: A multidimensional post-occupancy evaluation tool	Evaluation tool for nine indoor environmental quality dimensions and occupants' satisfaction	Building Occupants Survey System Australia (BOSSA)
Wargocki et al. (2012)	Satisfaction and self-estimated performance in relation to indoor environmental parameters and building features	Occupants in green buildings are on average more satisfied with their air quality and thermal comfort. Green offices prefer the spatial layout of open or partitioned floor plans to enclosed private offices.	LEED-rated/green buildings for indoor environmental quality (IEQ)
Bluyssen et al. (2011)	Comfort of workers in office buildings: The European HOPE project	Perceived comfort is more than the indoor air quality, noise, lighting and thermal comfort responses. it also includes emotional state	Sir Karl Popper's theory model, Principal component analysis (PCA)
Schakib-Ekbatan et al. (2010)	Occupant satisfaction as an indicator for the socio-cultural dimension of sustainable office buildings development of an overall building index	User satisfaction for comfort parameters at workplaces was affected by temperature, lighting conditions, air quality, acoustics, spatial condition and office layout	Principal component analysis (PCA), Post occupancy evaluation (POE)
Veitch et al. (2007)	A model of satisfaction with open-plan office conditions: COPE field findings	18-item environmental satisfaction measure formed a three-factor structure reflecting satisfaction with: privacy/acoustics, lighting, and ventilation/temperature	Satisfaction with environmental features (SEF) measure
Humphreys (2005)	Quantifying occupant comfort: are combined indices of the indoor environment practicable?	Balanced occupants' satisfaction and overall assessments about indoor environment.	ASHRAE scale
Leifer (1998)	Evaluating user satisfaction: case studies in Australasia	User survey instrument based on nine parameters five grade scales regarding to user satisfaction	User satisfaction evaluation tool developed by Works Canada

2.5.2 Classification of parameters affecting user satisfaction

Many studies mixed physical quality and psychological or cognitive user satisfaction by using a cause and effect analytical approach. The approach basically analyses measurable human behaviour and satisfaction based on physical conditions (Vischer, 2008). However, perceived satisfaction is more than physical conditions (Bluyssen et al., 2011). Therefore, it is important to develop a theoretical framework to determine the order of priority or the degree of importance among factors influencing user satisfaction.

From an architectural point of view, Vischer (2008a) illustrated a form for assessing user experience including three comfort levels: physical comfort, functional comfort and psychological comfort, and how well the office provides effective and comfortable workplaces to users. Feige et al. (2013) redefined the dimension of comfort factors with three levels: Physical comfort relates to biological responses to indoor quality, climate, noise and ergonomics; functional comfort refers to the suitability for work tasks; psychological comfort indicates space-related needs such as social and spatial variables. Kim and de Dear (2012) classified the dimensions of comfort into three categories: basic factors can cause dissatisfaction when they are not fulfilled; proportional factors can change the satisfaction level proportionally; and bonus factors that although showing poor performance do not result in dissatisfaction. The classification of Kim and de Dear (2012) is similar to the Kano model (Kano, 1984).

2.5.3 Physical factors

Physical factors were selected based on the relationship with biological responses to indoor climate and quality. Those factors are basic needs that may cause severe dissatisfaction and illness.

Thermal comfort

Thermal comfort is subjective and depends on dynamic factors consisting of four variables: air temperature, relative humidity, relative air velocity, and radiation (Hong et al., 2015). Although providing a place where every occupant can be fully satisfied is practically impossible, it is important to define the thermal comfort range of occupants. Thermal comfort in an office can be measured by the number of discomfort complaints from occupants (Al-Horr et al., 2016). A laboratory study examining the effect of operative temperature on relative work performance. According to Roelofsen (2002) and Witterseh et al. (2004), comfortable temperature brings optimal work performance. Lan et al. (2012) shows that in summer the indoor temperature for optimum performance can be increased from 23.9 to 25.4°C. In winter, the indoor air temperature for optimum performance can be decreased from 21.9 to 19.7°C. Another laboratory study of Tham and Willem (2010) tested thermal comfort levels and time exposure of occupants in three different room conditions. The result is that the thermal comfort is the highest at 23°C, and that decreasing the temperature in winter and increasing it in summer for energy efficiency had a negative impact on occupants' comfort. Two studies of Ornetzeder et al. (2016) and Tham and Willem (2010) stated that the preferred indoor air temperature for occupants' comfort is regardless of energy efficiency considerations.

Air quality

A work place with good air quality has an impact on the health condition and satisfaction rate of occupants. Indoor air quality (IAQ) defines the air quality related to pollutants, contaminants, and ventilation. IAQ studies have found these issues by conducting a survey about irritation, headaches, fatigue and illness, which are related to Sick Building Syndrome (SBS) symptoms (Seppänen et al., 2006; Wargocki et al., 2000). IAQ is one of factors has influcence on SBS, particularily caused by chemical and biological contaminants, inadequate ventilation, and physical air humidity (Berglund et al., 1999; Joshi, 2008). Stolwijk (1991) defined the sick-building syndrome as 'the occurrence of an excessive number of subjective complaints by the occupants of a building. These complaints include headache, irritation of the eyes, nose, and throat, lethargy, inability to concentrate, objectionable odours, and less frequently, nausea, dizziness, chest tightness, etc.'

Ventilation systems play a key role for air quality. Newsham et al. (2013) found that LEED rated buildings provided higher satisfaction levels with the air quality than non-LEED rated buildings. However, Ornetzeder et al. (2016) reported that occupants' satisfaction with the air quality was relatively low during winter due to dry air and low humidity. Schiavon and Altomonte (2014) stated that LEED buildings did not necessarily affect occupants' satisfaction with the indoor environment. In line with earlier research, occupants in non-BREEAM certified offices tended to be more satisfied with the air quality than occupants in BREE certified offices (Altomonte et al., 2017). Particularly, modern office buildings that have an automatic air handling unit without openable windows could cause occupant dissatisfaction.

Noise control

Noise has a high relevance in office building design. The effect of noise can lead to distraction and interruptions in work processes of occupants. Noise in the office normally comes from colleagues, and it often occurs in the open-plan office (Ornetzeder et al., 2016). Banbury and Berry (2005) stated that office noise would cause dissatisfaction with the work environment. The most disturbing noise is irrelevant speech in the background (Hongisto, 2005), especially 'intelligible speech' (Venetjoki et al., 2006). Altomonte et al. (2019) revealed a strong relationship between noise, sound privacy and occupant satisfaction Noise performance not only has an impact on privacy but also productivity. For instance, open-plan offices have advantages in terms of good interaction and communication with colleagues (Heerwagen et al., 2004). Kim and De Dear (2013) stated that enhanced interactions in open-plan offices do not compensate for distraction from noise. However, they found sound-privacy is a relatively unimportant factor in overall workspace satisfaction. The British Standards Institution recommends a range of background noise level that is acceptable for open-plan offices of 45 to 50 dB and for cellular offices of 35 to 40 dB (Field, 2008; Standard, 2014). In European standards, the level for the cellular office is 30 to 40 dB and for the open-plan office 35 to 45 dB.

Light and daylight

Light conditions have an impact on visual comfort and are another factor with an influence on user satisfaction. Many studies have shown the correlation between daylight and user satisfaction. Groth (2007) found that lighting quality is important to attain user satisfaction. Kim and De Dear (2013) found that occupants in open-plan office were provided with more light than those in cellular offices. An et al. (2016) stated that more sun exposure was related to less depression and higher user satisfaction. The majority of office users prefers natural light over artificial light, for physical and psychological reasons (Galasiu & Veitch, 2006). Dissatisfaction with light quality was mainly caused by glare, and when the glazed percentage was under 40%, people felt comfortable in their workplaces (Menzies & Wherrett, 2005). A research of Villa and Labayrade (2016) aiming for energy-efficient luminous environment identified an optimal solution to be suitable for different user requirements. In shared office spaces, the solution is to supply an individual task lamp that does not have a high-power demand (11W each, LED lighting). Most problems of visual comfort were caused by too much sunlight (glare) coming from the south façade (Ornetzeder et al., 2016). The window and shade system, in this point of view, are important factors for an outdoor view and to serve natural light.

The preferred window size varies for different office conditions; a survey (Galasiu & Veitch, 2006) stated that the optimal window size on average needs to be in the range of 1.8 to 2.4 m in height to provide a wide lateral view.

2.5.4 Functional comfort factors

Functional factors are related to the suitability for work activities. When those factors have the right value, users can be satisfied with work environment and perform the work task efficiently.

User control

User control is considered as one of the important factors in relation to the cognitive aspect, since when the indoor environment is individually controlled, the user satisfaction is likely to increase (Lee & Brand, 2005; Liu et al., 2018; Loftness et al., 2018; Proctor, 2014). A research found that when office workers could control their own indoor environment, their health was improved (Raw et al., 1990). Brager et al. (2004) revealed that occupants with a higher degree of personal control experienced most thermal satisfaction, and emphasised the importance of personal thermal control.

From an economic perspective, user control can cause a waste of energy due to inefficient thermal control (Shahzad et al., 2016). In general, if people adjust to a cooler temperature during summer than the average temperature, and to a warmer temperature during winter, this will cause a greater energy use. According to Zhang et al. (2010), reducing the degree of personal control in workplace could save energy, but had no severe impact on user comfort. In addition, determining the optimal points of IEQ levels for various occupant types and the optimal operational strategy will be key to achieve both goals.

Privacy

Privacy has a close relationship with office layout. The privacy of office workers is better protected in an individual space than in an open-plan office. Privacy is distinguished by physical and cognitive aspects; sound privacy, visual privacy and perceived privacy, experienced by uncontrolled social contact and interruptions (Kim & De Dear, 2013). Especially, the open-plan office has poor privacy conditions.

On the other hand, combi and flex offices lead to higher satisfaction for privacy and concentration, since those offices still can provide back-up spaces (De Been & Beijer, 2014). However, the occurrence of privacy problems in an open-plan office depends on the density of workstations, office layout, people moving around, noise level, next to several other factors. High density might lead to decreased satisfaction due to the lack of privacy and unexpected social contact (Maher & von Hippel, 2005). On the contrary, a larger workstation with low density increases the satisfaction rate with acoustics and privacy (Leder et al., 2016) because of a greater distance between colleagues. When privacy increased, the environmental satisfaction tended to increase (Duval et al., 2002).

Concentration

Concentration implies being able to focus on work (Vos & Van der Voordt, 2002). Studies dealing with concentration issues mainly compare the occupants experience between open-plan and cellular office, and investigate distracting factors. Concentration is disturbed by different elements: air quality, intelligible speech, and glare. In the work environment, concentration is a significant factor for a worker who has more single-oriented work task. Kaarlela-Tuomaala et al. (2009) revealed that the most distracting factor in open-plan offices was intelligible speech followed by too high or too low temperature. In private offices, temperature was the most distracting factor followed by draught, and intelligible speech was third.

Communication/collaboration

Improvement of the communication level is connected to productivity, and leads to effective collaboration (Heerwagen et al., 2004), because better information exchange between colleagues and having more contact creates more understanding of each other (Van der Voordt, 2003). Open-plan offices are believed to enhance communication and interactions between colleagues (Brand & Smith, 2005). On the contrary, open plan offices have a potential sound disruption and lack of privacy (Kim & De Dear, 2013; Schiavon & Altomonte, 2014). One empirical study of De Been and Beijer (2014) explained that people were more satisfied with communication in combi offices than cellular and flex offices. Rothe et al. (2011) stated that opportunity to concentrate and opportunity to communicate were the most important attributes, and privacy was found less important for productivity.

2.5.5 Psychological comfort factor

Psychological factors are related to spatial needs such as social and spatial comfort. These factors contribute to better work results and high level of satisfaction, although absence of these factors does not mean that people are not able to work.

Social contact

Establishing social contact is another factor to satisfy user demands. The definition of social contact here means interacting with other people during breaks or to have a chat occasionally. This parameter is highly linked to office layout and workplace operation, but is not necessarily required for user satisfaction. Samani (2015) used the concept of social and spatial density defined by Duval et al. (2002). According to Samani (2015), increased density provided chances for building friendship, communication, and environmental work satisfaction. Shier and Graham (2011) found that the overall wellbeing was affected by the relationship with colleagues.

Spatial comfort

Spatial comfort is another key factor that determines to which extent workers are satisfied and motivated in their workplace (Chandrasekar, 2011). Spatial comfort here defines that employees feel at home at their workplace. For example, they can ensure their privacy, or they can have a sense of belonging in their working group through the spatial design of the office. Although this is a quite subjective factor, it is worthwhile to mention for office design: several studies have revealed that office workers who feel comfortable with their work environment tend to show better work results and have relatively higher self-esteem (Leder et al., 2016; Lee & Brand, 2005; Salama & Courtney, 2013). The awareness of spatial comfort is also associated with the organisation of the office such as spatial configuration and density of workplaces. Kim et al. (2016) stated that flexi-desk users tended to be dissatisfied due to the issues about lack of territory and ability to personalise their work desks. Ikonne and Yacob (2014) found that spatial comfort significantly contributes to high level of satisfaction. A survey revealed that almost 90% of the respondents found that better workplace layout and functional support result in higher overall workers' performance (El-Zeiny, 2012). Vischer (2008) states that a sense of territoriality and belonging is one of the typologies of the environmental psychology of workspace. Through other studies, it is identified that spatial comfort is only defined by workplace design and layout.

2.6 Discussion

This chapter presented the influential factors for user satisfaction and the importance of user satisfaction in office renovation processes. The definition of user satisfaction in this research is different from job satisfaction of employees. Job satisfaction often includes emotional aspects of having a good working relationship with a boss or a leader or colleagues. Job satisfaction, however, is not part of the physical design approach in office renovations.

The physical and psychological factors that can increase user satisfaction, were classified and analysed. The purpose of this section is to explore influential factors related to user satisfaction in broad range. The literature is not always empirical based studies. Therefore, the factors in this section are not necessarily evidence-based casual factors. The main challenge was how to compare the factors and evaluation of user satisfaction from different sources. Measuring human comfort and satisfaction is subjective, so the results might depend on the specific user's opinion. One possible method to deal with this, is to employ a questionnaire. However, qualitative data gathered by empirical research would need to be further processed to reveal correlations between satisfaction and office design.

The theories of human comfort help to understand the priority of user needs and requirements, and to decide the extent of including user demands in office renovations to enhance user satisfaction. The categorisations of factors influencing user satisfaction that were introduced by other researchers are quite similar to each other. However, they also can be interpreted in various ways. This literature review provides a classification which may help to examine user satisfaction based on the prioritisations of comfort.

2.7 Conclusion

This chapter reviewed factors affecting user satisfaction in work environments. Findings in chapter 2 highlight ten influential factors (e.g., thermal comfort, air quality, lighting, noise, user control, privacy, concentration, communication, social contact, and spatial comfort). In FIG. 2.3, the ten factors are integrated into the three-step requirement structure: physical comfort, functional comfort and psychological comfort. Physical factors listed in the previous chapter do not only contribute to user satisfaction, but are also associated with energy use. Therefore, these 10 factors should be included in a framework for achieving user satisfaction. Using this framework, designers or owners may decide to which extent they want to achieve user satisfaction and balance between energy saving and satisfaction.

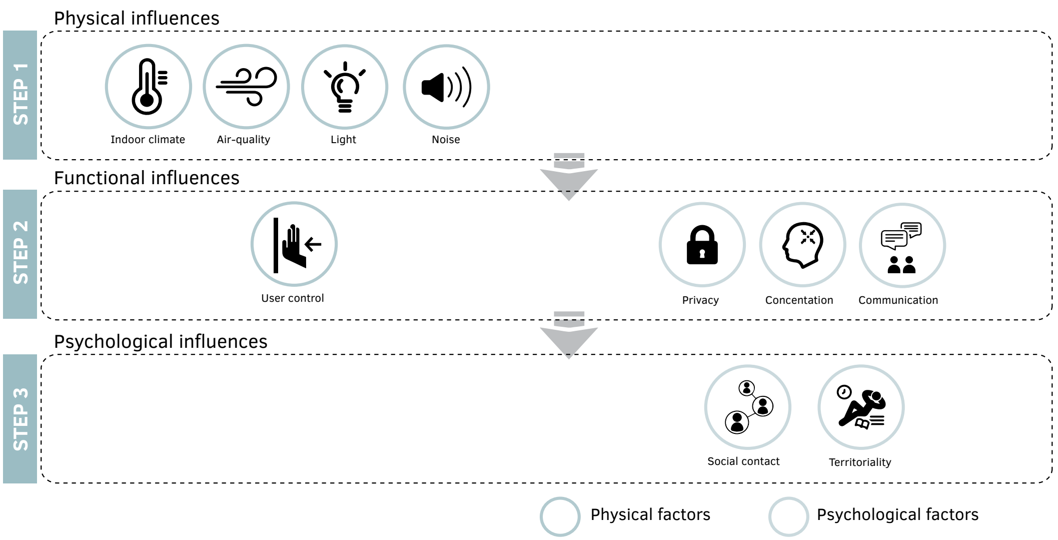

FIG. 2.3 Classification of physical and psychological factors based on the dimensions of comfort

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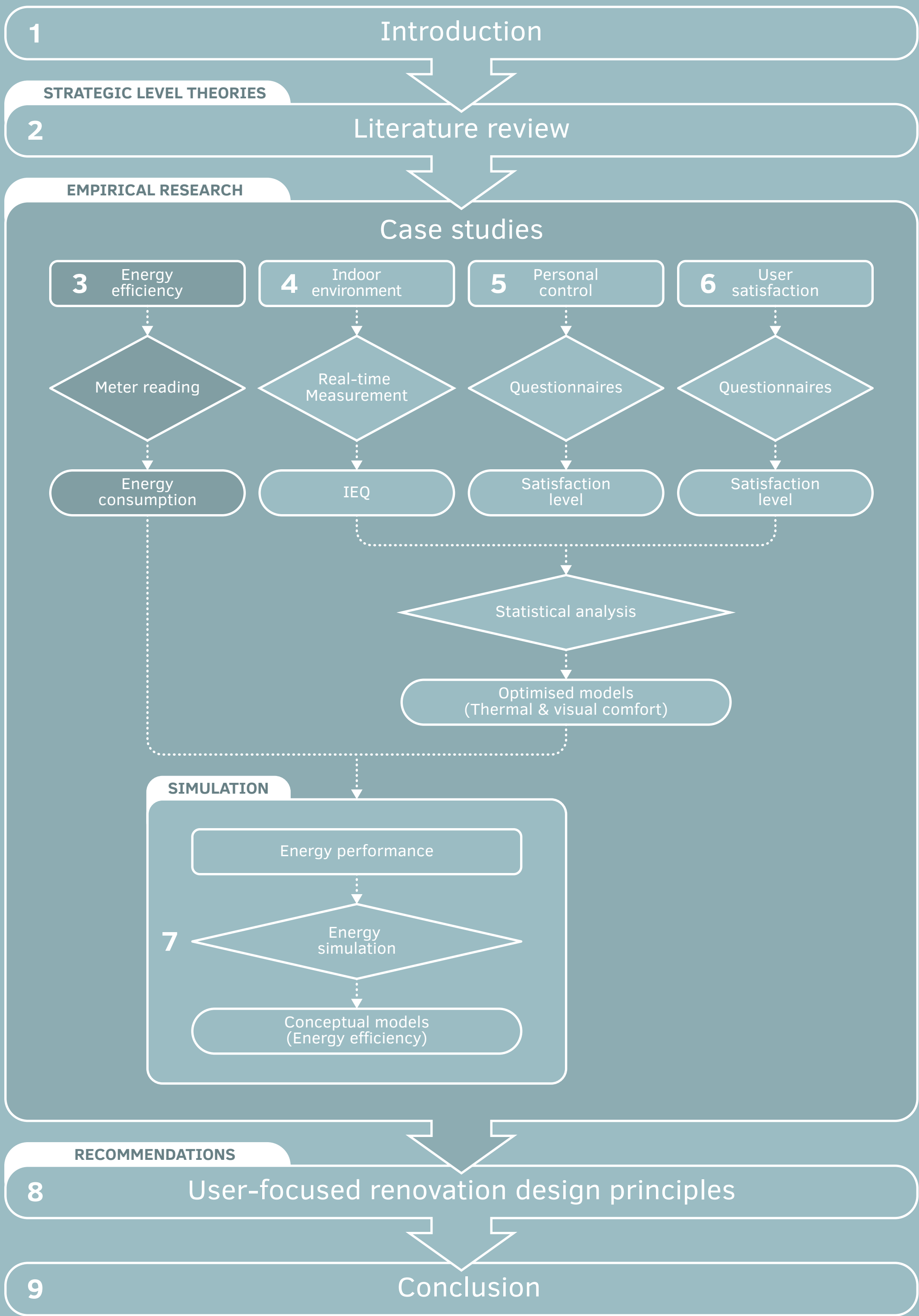
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3 Building characteristics and energy use of energy-efficient renovated offices

Chapter 2 presented the physical and psychological satisfaction parameters for user-focused evaluation. In most renovation projects, the façade is a major consideration next to the HVAC system to optimise the performance of the building. Many studies reveal that façade renovation has a large impact on the energy efficiency. The aim of this chapter is to identify the characteristics of renovated offices, such as façade types, HVAC system, and sun shading, and compare the energy performance based on user typologies in renovated and non-renovated office buildings.

Section 3.2 describes an overview of façade renovation strategies based on literature. The renovation strategies are classified into four strategies: passive add-in, replacement, climate skin, and active add-in. Section 3.3 presents the criteria to select case studies. Section 3.4 describes the characteristics of four renovated case studies and one non-renovated case located in the Netherlands. The building information was collected through interviews with architects, a review of project documents, and a field survey. Cross-analysis was used to compare the renovation plan, physical conditions. Energy consumption of each office building was compared by different energy metrics in section 3.5. Section 3.6 discusses the limitation of the renovation projects and suggestions for the future study. The finding from cross-evaluation of case studies are described in section 3.7.

3.1 Introduction

Energy-efficient building renovation has received wide attention, particularly during the last decade. The EU has ambitious goals for energy reduction. According to the European commission and Energy Performance of Buildings Directive (EPBD, 2010; EuropeanCommission, 2016), compared to 2005, by 2050 the primary energy demand should be reduced by 32-41%. Many studies have stated that the building renovation is an important key to achieve this goal (Bournas et al., 2016; BPIE, 2013; Kamenders et al., 2014; Marszal et al., 2011; Risholt et al., 2013).

The building façade is one of the major considerations in the building renovation. There are two reasons why facade technology is important for the renovation. Firstly, the façade can significantly reduce the amount of energy use. According to Feng and Hewage (2014), 26% of the total building energy is lost through the façade in a cold climate zone. Susorova et al. (2013) stated that unwanted heat gain and loss occur through facades (This implies that improving the performance of the building envelop is important to save dissipated energy. Second, the façade contributes to create indoor environment quality, and influences energy consumption and thermal comfort (Echenagucia et al., 2015; Huang et al., 2013). Recent studies elaborated the paradigm shift of facade technologies from a single function to a multi-functional façade that responds and adapts to outdoor climate conditions (Ahmed et al., 2015). Capeluto and Ochoa (2017) stated that:

'an intelligent building envelope will be understood as the outer layer of a building, designed through a specific process for adaptability to the challenges posed by interior and exterior conditions using minimum energy'.

This paradigm shift is mainly caused by the increasing awareness of the indoor comfort and the need of reducing energy consumption (Knaack et al., 2014). Comparing different scales of renovation strategies is required to establish a general overview that contributes to the pre-design phase of the renovation process. Cross-analysis is used to compare the building characteristics of different offices, such as façade structure, HVAC system, window-to-wall ratio (WWR), façade configuration, and so on. Another issue in the cross-analysis is the energy units. Conventional annual energy consumption is given by kWh/m2/year. However, using this measure makes it difficult to compare energy use of offices due to the different occupied hours and the number of occupants. Therefore, the different metrics such as kWh/occupied hour, kWh/person, and Wh/m2h are proposed to normalise the energy consumption unit by considering various sizes of buildings, occupant time, and system running hours.

TOC

3.2 Literature review

3.2.1 Façade renovation strategies for optimal energy efficiency

The building envelope plays a key role in building renovation, because it determines the comfort level, day-lighting, natural ventilation and the amount of energy used for heating and cooling. Approximately 50-80% of the energy used is consumed for heating and cooling in offices (Birchall et al., 2014; Pérez-Lombard et al., 2008). Advanced façade renovation can save heating and cooling energy use by up to 50-60 % (IEA, 2013). System-based façades, such as where mechanical services are integrated into the building envelope, the so-called integrated façade (Knaack et al., 2014), could provide advantages to reduce the energy demand (Favoino et al., 2014). The key role of the building envelope for energy efficiency is not simply to focus on increasing the thermal insulation, which was done until recent times (Ruparathna et al., 2016), but also to pay attention to the system scale, such as façade systems integrating a ventilation system (Ciampi et al., 2003; Coydon et al., 2016; Ibañez-Puy et al., 2017; Stec & Paassen, 2005), adaptive façade (Perino & Serra, 2015; Ruparathna et al., 2016), solar radiation, solar control systems etc. (Silva et al., 2016; Valladares-Rendón et al., 2017).

Owing to the countless façade technologies and availabilities, it is necessary to identify the general concept of renovation strategies and their effect on the indoor climate and energy efficiency. Different strategies are defined according to the extent of façade intervention (see TABLE 3.1), which has influence on the appearance of the building. Agliardi et al. (2018) classified the possible façade addition for deep energy renovation. However, this classification does not contain a simple façade replacement. Façade renovation strategies of Konstantinou (2014) classified various types of principles for façade intervention, covering most basic strategies. Ebbert (2012) categorised three different strategies, focusing on climate design and integration of façade and building service. Rey (2004) included architectural attitude in a renovation project such as the appearance of a building. In this study, the renovation strategies are classified by integrating the change of building appearance and basic principles that cover most basic renovation strategies of façade. The strategies are ordered in a way of renovation from passive to active.

TABLE 3.1 Identification of facade renovation strategies based on literature

Reference	Strategies	Description
Agliardi et al. (2018)	Completing	The Addition is 'filling' and 'completing' the existing empty spaces, urban voids and left out sections that make the volume 'incomplete'.
	Adding	The Addition consists in aside or front apposition of extra new elements, like extensions of the existing one.
	Topping	The topping-Addition consists of an extension of the existing building by an increase in height through the construction of extra floors, new volumes or new prefabricated elements on top of the existing one.
	Translating	The Addition here happens with no uniform character, with the aim of transforming and re-defining the entire envelope and layout of the existing building.
	Extending	The Addition is a side extension on the blind wall side as continuation of the existing building.
Konstantinou (2014)	Replace	Old façade elements are removed and replaced with new ones
	Add-in	Upgrade from inside
	Wrap-it	Wrapping the building in a second layer
	Add-on	New structure is added on the existing building
	Cover-it	Cover parts or entire internal and external courtyards and atria
Ebbert (2012)	Necessary restoration solution	Existing windows and climate-units are replaced and extra insulation added
	Optimising energy saving	Installation of a climate skin
	Integral planning of façade layer	New façade takes advantage of the existing service
Rey (2004)	Stabilization strategy (STA)	A set of incremental interventions that do not fundamentally modify either the substance or the appearance of the building
	Substitution strategy (SUB)	A complete change of certain elements and simultaneously a transformation of the substance and the appearance of the building
	Double-skin facade strategy (DSF)	Partially stabilising the existing façade and adding a new glass skin, and maintaining a large part of the original building.

FIG. 3.1 provides an overview of renovation strategies for building envelopes, classified, interpreted and informed based on TABLE 3.1. These strategies aim to improve energy and building performance.

The main criteria for the selection of four strategies are based on the following conditions:

- Presenting different degrees of renovation strategies
- Establishing a general overview of façade renovation
- Considering architectural and technical issues of façade renovation

The 'Add-in' strategy is a passive way of renovation by supplementing thermal capacity to the wall and windows without substantial change of the building appearance. A new layer is added to the inside wall. Adding or increasing extra insulation layers is mainly included in this strategy. ‘Replace’ is the way to improve the façade quality and energy performance of a building by replacing existing façade elements with thermally efficient glazing, or replacing the whole façade. ‘Climate skin’ is a means to remove the complete existing façade, and then installing a new skin. The new façade concept is based on the building’s climate design, and the appearance of the building is partially or totally transformed. The last scheme is ‘Active add-in’ with integration of different climate functions such as ventilation, heating, cooling and controlling the level of lighting. The Climate Adaptive Skin (CAS) concept is an example of integration of building services into the façade system (Hasselaar et al., 2010).

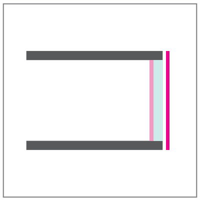
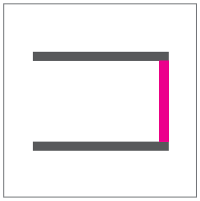
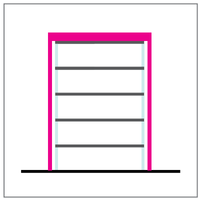
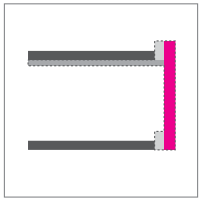
Passive add-in	Replacement	Climate skin	Active add-in
			
Adding layers to the inside wall or the outside to upgrade energy performance without change of the substance and the appearance of the building.	Replacing or removing existing façade elements, and the appearance of the building is partially or totally transformed.	Installing a new façade or adding a new layer to the existing building envelope. The new skin concept is based on climate design and the appearance of the building is partially or totally transformed.	Single skin system with integration of different façade systems to upgrade energy performance of the building.

FIG. 3.1 Classification of renovation strategies for the building envelope

3.3 Case study selection

The scope of this chapter is to study the range of renovation strategies that have been established over the last decade, and learning from case studies. Three methods are chosen to obtain information about the physical building condition: literature study, interviews, and case studies. A multiple case study is applied to compare representative renovation cases. In general, a single case study is suitable for in-depth research (Greene & David, 1984), whereas a multiple case study can be conducted to generalise the results through a cross-comparative analysis.

Four façade renovation strategies based on literature reviews are selected for in-depth study according to a different extent of façade renovation (see TABLE 3.1). The four strategies are: passive add-in, replace, climate skin, and active add-in. Based on these preconditions, four renovated office buildings located in the Netherlands are selected for the case studies, meeting the following criteria:

- originally built in the 1960s to 1980s
- occupied at least over one year after renovation
- highly energy-efficient labelled offices
- can provide over one-year energy-use data
- façade renovation is the main part of the renovation

TABLE 3.2 Classification of building information used in case studies

Building description	Building services	Room and interior
Year of original construction	Lighting (to optimise the use of daylight)	Office type
Year of renovation	Heating/cooling	Ceiling height
Building storeys	Cooling production plant	Occupancy density
Roof structure	Heating/cooling distribution network	Lighting
Type of glazing	Room temperature control	Type of window frames
Sun shades	Temperature set point	Main light control
Building shape	Ventilation	Sun-shading devices
Building occupancy time	Type of mechanical ventilation	Openable windows
Building size	Control system for mechanical ventilation	Location of air supply devices
	Air handling units (AHUs)	Heating/cooling system
	Type of heat recovery	Ceiling type
	Position of ventilation system	

The selected offices have to generate comparable data because each office has a different shape, size and condition. Thus, a standard checklist was designed to generalise the results and to establish research boundaries. TABLE 3.2 shows the building checklists referenced from ‘The healthy indoor environment’ (Bluyssen, 2013) to compare case studies. The checklist provides the fundamental questions to collect essential information. It has three categories: building description; building services regarding HVAC; and room and interior. Only relevant energy subjects were adapted in this study.

At the same time, interviews were conducted to collect technique-related information such as information on physical properties, adapted renovation techniques, and design approaches, between April and May 2017. Interviewees are architects who involved in the renovation projects and facility managers of the case buildings.

3.4 Building information of case studies

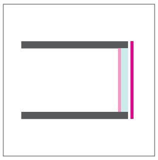
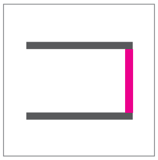
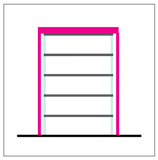
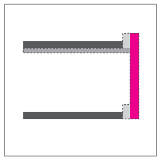
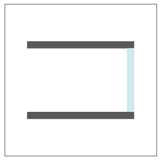
	Case A	Case B	Case C	Case D	Case E
	Passive add-in	Replacement	Climate skin	Active add-in	No renovation
Case					
Façade renovation					
WWR	£ 30%	£ 80%	£ 50%	£ 50%	£ 30%
Location	The Hague	Amersfoort	The Hague	The Hague	Delft
Built year	1973	1971	1975	1960s	1960s
Adaptation	2010 – 2011	2012	2008	2012	
Available size	Available size: 6,000 m^2/ 3989 m^2 (use space), 5 storeys	Available size: 19,200 m^2, 2 storeys	Available size: 66,000 m^2, 7 storeys	18,000 m^2, 16 storeys	18,504 m^2, 7 storeys
Energy label improvement	F to A (EPC)	G to A (EPC)	Energy label A, BREEAM Very good	BREEAM Excellent	No measurement

FIG. 3.2 The information of case studies (photos by the author)

3.4.1 Passive add-in

Case A was an outdated and abandoned office building built in the 1980s, in The Hague, the Netherlands. The office building had been vacant for two years before renovation. However, since renovation, all spaces have been rented out. The main change is the addition of a glass layer in front of the existing façade and adding new insulation layers from the inside. The existing façade is kept so that the project could been done in a short renovation period, within three months. Worthy to note is the HVAC system: The building uses an air-to-air heat exchanger installed on the roof. The heat exchanger serves cooling, heating and ventilation through the ceiling. The office spaces do not need extra radiators during winter. Employees can control the temperature in their office room individually. The system allowed to increase the floor-to-ceiling height from 2.4 m to 2.55 m by replacing the old massive ducts. This makes it possible to provide sufficient daylight for work spaces. Before, the 21.6 m deep floor plan and low ceiling height created relatively dark spaces in the middle part of the floors. By cutting off the concrete floor and creating staircases in the middle, the space provides more spaciousness and more light.

Façade renovation

The main façade is oriented to the NW and SE. The original façade had a window-to-wall ratio (WWR) of 45%. The façade consisted of prefabricated concrete panels attached to floors. It was a load-bearing façade structure without insulation. A remarkable point in this façade renovation is that two different concepts for the north and south façade are applied to the building. The building originally had no insulation layer in the wall and had single-glazed windows with wood frames. During the renovation, a new insulation layer of 100 mm thickness was added to the inside of the walls, and the single glazing was replaced with HR++ glazing, with a U-value of 1.1 and C-value of 2.5. The south façade got manual sunscreens so that users can control them individually. The south façade configuration was not changed and kept its original appearance. The north façade has a more important role for the building image since it faces the main access of the building. In this case, the new glass façade has a more architectural than functional value. Nevertheless, the glass layer allows people to open windows without being hindered by wind.

Energy efficiency

Case A achieved energy label A, coming from F, mainly due to the new insulation layer to the façade and to replacement of the HVAC system. After renovation, the building consumed 353,244 kWh in 2014 and 335,071 kWh in 2015. On average, a workspace uses 57 kWh/m^2 of electricity and 2 m^3 (19.54 kWh) of gas. The heat exchanger serves heating, cooling and ventilation in one system, so that workspaces do not require extra radiators or air condition. The warm and cool air is distributed through the ceiling connected to ducts. People can adjust their room temperature individually, but they cannot set an extreme warm or cold indoor temperature. The office spaces use automatic sensors for the lighting. These also contribute to reducing the electric energy consumption.

3.4.2 Replacement

Case B is a successful office building renovation in the Netherlands, achieving a high energy label rating. The first renovation was conducted in 2006 and mainly focused on the building façade, which was outdated and falling apart. There were basic requirements for the beginning of the office renovation. The main aim of the renovation was to achieve energy savings, improve fire safety, replacing the old façade, achieve an equal comfort level at least, and all of this should be achieved for a limited budget.

Façade renovation

In terms of design, façade replacement was the main part of this office renovation. The existing façade with wood frames was replaced by a fully glazed façade with HR++ glass. It provides more daylight and solar-controlled sun-blinds preventing over-heating. Although the building has no natural ventilation, the building envelope was improved by adding 9 cm of roof insulation and finishing it with light-coloured roofing material. The light coloured roof results in a cooler building during summer and it reduces the use of air-conditioning.

Energy efficiency

According to the energy consumption data measured by meter reading, after renovation the office saved 31% of electricity compared to before renovation, and a reduction of 56.4% was achieved for the use of gas. On average, per square meter, workspaces use 88.25 kWh of electricity and 3.26 m^3 (31.85 kWh) of gas. The electricity energy is fully supplied by wind energy. The office uses pre-occupancy cooling during night and the central air handling units (AHU) provide heating and cooling through a water cooled chiller + cooling tower. In addition to this system, the building heats the occupied spaces by a solar collector.

3.4.3 Climate skin

Case C was one of the examples of brutalist buildings in the Netherlands, with a huge and fortress-like concrete façade. The image of the building was closed and unfriendly. Moreover, office users also struggled with the working environment. Therefore, the purpose of renovation was focused on comfort in the working environment, energy efficiency and creating a friendlier and open image to citizens. Wrapping the concrete structure with a new glass façade was one of the main measures applied to this office building. The original structure could be preserved by wrapping the original façade, reducing renovation costs. As a result, the new transparent façade created a lively and modern building image. The building originally had two internal courtyards. However, one of them was converted to a winter garden by covering it with a glass roof. The garden provides a playful space to people.

Façade renovation

Although the main contribution to energy saving in this renovation was by the use of an aquifer thermal energy system (ATES), a double-skin façade (glazing: heat resistant, U-value 1.2 W/m^2K) also created substantial energy savings with the integration of a thermal buffer and climate ceiling. A single glass was put in front the second glass skin, and a thermal layer was created in front of the existing façade. The original façade structure supports the second layer so that the original structure is completely maintained. The double-skin façade helps to prevent cold draughts by a buffer zone between the original façade and concrete balcony element. The buffer zone also contributes to improved acoustics. 80% of the total window area is openable and the WWR is 57%, which allows more natural daylight. External sun-shading blinds were installed for all facades, and they are automatically let down but can be individually controlled.

Energy efficiency

Annual energy consumption data were available from after renovation. For comparing energy consumption, the average number of the last four years, from 2013 to 2016, was used. On average, the building now uses 67.58 kWh of electricity and 3.9 m^3 (38.10 kWh) of gas per square meter. In total, over 2200 people work in the office, and the building serves around 2000 desks to work at. The building occupancy rate is around 65 to 70% which means that around 1430 to 1540 of the total number of employees appear during working days. After renovation the energy performance coefficient (EPC) of the building was 0.89 which is considerably lower than the required 1.40.

3.4.4 Active add-in

Case D, originally built in the 1960s, was renovated and extended in 2012. It is located in the new central business district in The Hague. It has 18,000 m^2 of office space on 16 storeys, providing around 1230 working desks. The existing structure had many columns. After calculation, several columns could be removed and the building could be wrapped with a new glass façade. As a result, the office with less columns could provide more open view and natural daylight. The ceiling height was increased to 2.7 m by replacing the HVAC system in the ceiling.

Façade renovation

The building has a shallow-depth floor with a length of 66 m and a width of 15 m. The skeleton façade structure had small columns every 1.5 m. By removing the façade columns every 3.0 m, one third of void area in the original façade could be extended to two thirds of void. Now the columns are situated every 3 m. The WWR of the new façade is 51%, with an R-value of 3.5 m^2K/W. The south-east façade has a double sun shading system, interior and exterior, to prevent over-heating of workspace. The façade is one of the façade cases with the integration of ventilation systems behind of the structure.

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Energy efficiency

The office was rated Excellent by BREEAM-NL. Energy consumption data was collected by meter measuring in the whole building for the period of January to March 2017. The building uses 304,458 kWh during power peak and 161,028 kWh during off-peak. Approximately 155,162 kWh of electricity is used per month. The annual energy consumption is around 103.44 kWh/m^2 for the Gross Floor Area (GFA).

3.4.5 Non-renovated office

Case E represents the most common office type built between 1960s and 1970s in Delft, the Netherlands. The building has under 30% WWR with single glazing. This building in general is poorly insulated. Each office room has a radiator that is individually controlled and does not have a cooling system. During summer, the cellular office can be cooled down by opening windows, and internal blind can be controlled by occupants.

3.5 Energy consumption compared by different units

The annual total energy consumption represents the energy delivered from the outside, and it was collected by meter-reading from each office building. The energy use includes annual electricity and gas use for heating, cooling, ventilation and equipment. TABLE 3.3 shows the energy consumption of case studies with various metrics.

The total energy consumption from meter-reading divided by the floor area on a yearly base is equal kWh/m2/year. kWh/year divided by running hours results in kWh/hour. However, the international unit kWh/m2/year can be differently interpreted regarding to the occupancy rate. The metric, kWh/person is calculated by annual energy consumption per year divided by occupancy number in daily base per year. The metric, Wh/m2h is the calculated annual energy consumption per square meter divided by the total occupied hours in a year (Dooley, 2011).

TABLE 3.3 Normalising energy consumption with various metrics to compare offices in different conditions

Energy consumption						
	kWh/m²/year	System running hours/ year	kWh/hour	Occupancy number/day	kWh/person/ day	Wh/ m²h
Case A	79.47	2544	135.28	94	14.65	0.39
Case B	125.25	2915	602.81	468	15.02	0.12
Case C	111.20	3180	2307.92	1485	19.77	0.04
Case D	108.38	4240	460.12	829	9.41	0.06
Case E	361.00	4770	1400.38	1100	24.29	0.15

When we compare the conventional energy consumption of each office, Case B (replace) uses the largest amount of energy, and Case A (passive add-in) the least. However, the four different offices have a different number of employees, and different system running hours. Therefore, other metrics are used to compare them from diverse perspectives. As we consider how much energy each person consumes, a person in Case D (active add-in) uses the least amount of energy, 9.41 kWh/day. In contrast, a person in Case C (climate skin) consumes 19.77 kWh/day of energy. As occupied hours considered, Case C and Case D consume around 1/6 to 1/8 times less energy than the most energy used office (Case A). Inconsistent results were shown due to the different number of occupants.

3.6 Discussion

3.6.1 Learning from case studies

This study shows three major barriers that hinder achieving better energy performance. The major barriers found in the cases are: implementation defects, structural limitations and an over-designed plan. First of all, case A has structural limitations. Windows were changed from single glazing to HR++ double glazing, and new insulation was added from the inside of the building. The limitation of this case is the load-bearing façade structure. Interestingly, a new glass layer was added to the north façade only for the aesthetic aspect, instead of energy efficiency or functionality. However, after renovation, the new glass layer contributes not only to refreshing the building image but also to blocking off harsh winds, so that people can open windows for natural ventilation. Although there was a structural limitation, case A shows the highest energy saving after renovation.

Case B was renovated with an over-focused design plan. This building adapted the replace strategy. The HVAC system and the whole façade were replaced to an efficient HVAC system and air-tight new windows, which can significantly reduce the energy demand. Nevertheless, the office encounters over-heating problems due to the increased window area. As a result, sun-blinds were installed inefficiently on every elevation of façade. By increasing the glazed area, occupants have a better view outside and this also expresses a modernised building image (according to current standards). On the other hand, glazed buildings are likely to overheat during summer and become cold in winter. In other words, a large amount of window area is an conflicting point between energy efficiency and architectural demand.

Case C has an implementation defect. The double-skin façade concept is helpful to reduce the primary energy demand by pre-heating fresh air during heating seasons and by extracting air through the cavity during cooling seasons. Basically, the outer layer of the double-skin façade functions to pre-heat fresh air from the outside and ventilate exhaust air to the top. The cavity between the outer and inner layer can be opened and closed. However, case C does not have openable panels for the cavity. The building shows a relatively high energy consumption compared to the other case studies. The new façade does not contribute to energy reduction because the strategy was not correctly implemented to the building.

Case D shows a similar design approach which is ‘replace’, but this renovation has better results than case B, with the second highest energy saving. Furthermore, the WWR is also quite high, like that of case B. We can assume two reasons why case D shows better results. First, the ventilation-integrated façade contributes to energy savings. Second, although the building has openable windows, people are not allowed to open windows. As a result, an unpredictable indoor condition is avoided, and the indoor climate is only controlled by a central-heating and cooling system.

3.6.2 Limitations

The limitation of a case study in this chapter is the difficulty of identifying causality. Ideally, comparing energy and building performances before and after renovation would have been a stronger research design to investigate the impact of renovation on the performances. However, due to the limited timeframe, it was difficult to use a before-and-after design.

Energy performance is influenced by types of operation pattern, user control, indoor comfort, HVAC system, energy supply, night ventilation and so on. Indoor comfort is, particularly, an important factor in energy performance since it affects the system running hours and the climate control to provide comfortable indoor environment to occupants. This chapter mainly explores the characteristics of renovated office buildings and whether the renovated office buildings are functioning well in terms of energy efficiency. Although the office buildings are improved to achieve better energy labels, the actual use and condition of the offices do not qualify to the planned condition. Therefore, it is important to investigate the building characteristics and design factors and their impacts on the work environment. In addition, the occupant is a major factor in energy consumption. For the future research, it will be important to identify general occupant types before we understand occupant behaviour and energy use patterns.

3.7 Conclusion

This chapter analysed four renovated office buildings to understand the building characteristics of renovated offices and presented a comparative evaluation of the energy consumption by means of various metrics. The results were mainly evaluated on the basis of real-time observation during field studies. Appendix B compares the characteristics of renovated office buildings, such as façade structure and configuration, WWR, sun-shadings, glazing types, HVAC system, heat recovery, openable windows, system running hours, and temperature set-point. Overall, the glazing area of the façade increased, together with an improved insulation capacity of the façade after renovation. External or internal blinds were installed to prevent glare and over-heating. Renovated offices often have a heat recovery system with improved HVAC systems. Due to safety reasons, occupants are not allowed to open windows in high-rise offices.

The main findings from this study include the following. (1) The strategy of façade renovations is mainly decided by the existing condition of the façade structure and budget. (2) Various metrics should be applied to compare the energy use of different buildings. kWh/person and Wh/m^2h can be appropriate to use, to compare

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energy consumption of buildings. (3) During the design stage, architects need to fully consider the quality of the indoor climate to prevent inefficient energy use. For example, if a building has a large glazing area, this causes over-heating or heat loss problems, which leads to more energy use for indoor comfort, and the building eventually needs extra layers to reduce the heat loss or over-heating. Thus, the design phase should give better attention to the balance between energy use and indoor climate. (4) During the construction phase, engineers need a full understanding of the design strategy. The principle of climate design should be implemented to the building correctly without missing any component or being compromised by the budget. (5) During the operation phase, occupants are required to understand the right way of operating the climate system for the indoor comfort. The right way of climate control can contribute to effective energy use.

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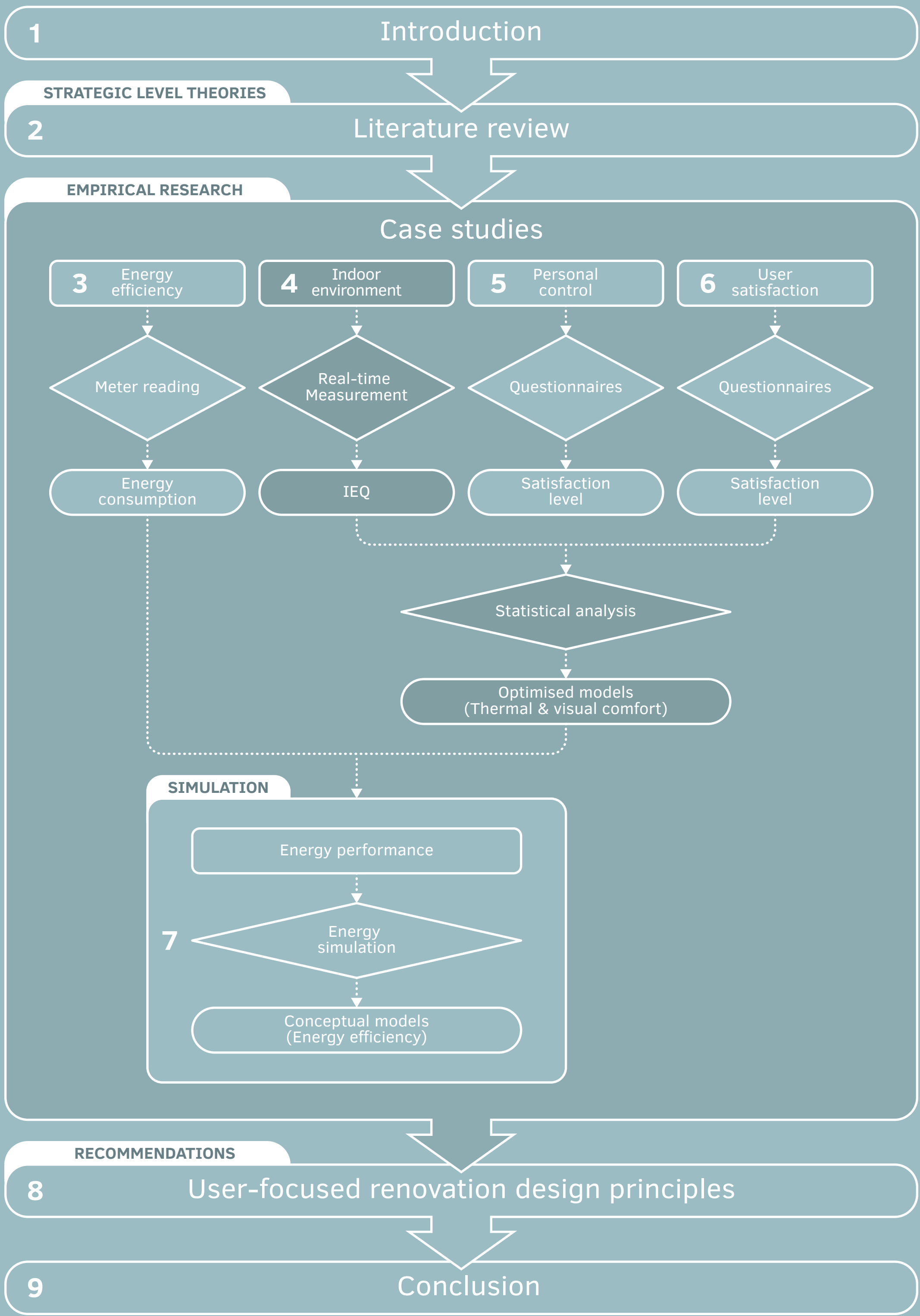
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4 Evaluation of user's thermal perception and satisfaction towards indoor environmental quality

Chapter 3 compared the building characteristics of renovated offices such as façade types and the HVAC system and energy consumption with different units. These physical building characteristics do not only contribute to energy performance but also to the indoor environment. For user satisfaction studies, a comfortable indoor environment is one of the primary conditions of the working environment. Therefore, it is important to identify the impact of indoor climate on user satisfaction in different office buildings (technical attributes of renovated office buildings). The purpose of this chapter is to identify the impact of indoor climate on user satisfaction, comparing how much they are satisfied with the indoor climate to temperature and relative humidity and how much the users can adapt the certain temperature.

Section 4.2 presents the data collection for 2 weeks in three seasons: summer, winter, and the intermediate season. Monitored indoor climate such as temperature, and relative humidity is compared in section 4.3. Section 4.4 compares the occupants' thermal sensation, preference and satisfaction with physical measurements are compared in section 4.3. Lastly, the predicted optimal thermal conditions, and limitations are discussed in section 4.5.

4.1 Introduction

A comfortable indoor environment is one of the primary conditions of buildings. How people perceive the indoor environment in buildings is a growing area of research. Thermal environmental quality is one of the fundamental needs for building users. Brager and Baker (2009) stated that occupants' satisfaction is highly influenced by thermal conditions. User-related studies of the indoor environment show interactive relations (Vischer, 2008), since uncomfortable work environments may lead to low productivity, and affect physical and mental health (Sant'Anna et al., 2018).

Thermal comfort defined by Hensen (1991) is "a state in which there are no driving impulses to correct the environment by the behaviour". The occupants' comfort is often explored to assess the building condition after renovation to improve environmental quality beyond energy efficiency. In addition, many studies have attempted to compare occupants' satisfaction of green-certificated offices and conventional offices. Nevertheless, the majority of building assessment research, dealing with building renovations, tends to focus on energy saving.

Some studies revealed that building energy can be saved by decreasing set-point temperature in cold climates (Hoyt et al., 2015; Verhaart et al., 2015), and by narrowing the range of temperature and humidity (Luo et al., 2018). Theoretically, buildings controlled with a HVAC system should keep at least 80% of the users feeling comfortable (ASHRAE 55:2017). However, when considering energy saving, thermal comfort is often compromised. It causes a substantial percentage of occupants feeling cold or hot (Arens et al., 2010). According to Huizenga et al. (2006), only 11% of 215 office buildings accommodated 80% of the occupants within the comfort range. In other words, a comparison of occupant perception to real-time indoor climate data may show different recommendations for the Global guidelines for comfort temperature.

Thermal comfort analysis helps designers plan a proper environmental zone (Brager & Baker, 2009). Current phenomenological studies in the built environment have focused on user experience by comparing past thermal perception of indoor thermal quality and current thermal preferences of building users (De Dear & Brager, 1998; Vischer, 2008), to give an insight into building users' expectations for the indoor climate. Investigating users' thermal perception, preferences, and satisfaction can be used to suggest solutions for a comfortable work environment that meets occupants' needs (Rijal et al., 2017). Therefore, it is important to explore how the perception of occupants in renovated offices differs from occupants in non-renovated buildings.

In addition, it is also important to see how well-controlled thermal conditions are in energy-efficient renovated offices by comparing these with the outdoor temperature. The research question that will be answered in this chapter is what are the predicted optimal thermal condition for user satisfaction in workspaces?

The aim of this chapter is to investigate the user perception of indoor temperature in renovated versus non-renovated office buildings based on a real-time field study. This research will be helpful for developing user-focused thermal design of office buildings and will provide a better understanding of the actual occupant perception in renovated offices. First, occupant's experience with the thermal indoor climate over a year's time is discussed and subsequently their preference. Next, this study assesses the thermal satisfaction of users. This work compares occupants' perception and indoor thermal quality.

4.2 Methodology

4.2.1 Monitoring indoor climate

The data were collected by monitoring the actual indoor climate for two weeks in three seasons: July, October in 2017, and January in 2018. HOBO loggers were placed 0.9 m above floor level in different orientations of workplaces, in the middle of the room, avoiding unexpected heat such as direct sunlight and heat from computers or monitors. Measurement time was started and ended at the same date and time in all offices. The indoor climate data measured include temperature, relative humidity, and illuminance. Outdoor temperatures were obtained from the nearest local meteorological stations. TABLE 4.1 shows the location of devices placed in five case studies. One logger was placed in each orientation in a building.

TABLE 4.1 Locations of HOBO devices in five case studies

Renovation strategies	Orientations			
	N.E.	N.W.	S.E.	S.W.
Passive add-in		*	*	
Replacement	*	*	*	*
Climate skin	*	*	*	*
Active add-in	*			*
Non-renovated case	*			*

4.2.2 Survey of user perception and satisfaction

The purpose of the questionanires was to understand the occupants' thermal experiences in seasonal base. Appendix A1[1] shows a modified questionnaire based on Bluyssen (2013); D'Oca et al. (2016); Nicol et al. (2012). Based hereupon, 38 questions were generated consisting of three chapters: general information, indoor environmental quality, and functional quality and user perception. This chapter focuses on users' thermal perception, preferences, and satisfaction with indoor thermal comfort. The Online-based thermal comfort surveys were conducted in five offices. The survey included three questions as follows:

- Q1. How do you experience the indoor temperature of your workspace? (for mid-season, summer and winter)
- Q2. How would you prefer the indoor temperature to be?
- Q3. How satisfied are you with the thermal conditions?

7-point for thermal sensation and 3-point scale method for thermal preference were adopted to determine the answers of occupants' thermal sensation and preferences. Each option of these questions was allocated a score, as shown in TABLE 4.2.

1 Questionnaires got permission to distribute to employees from each office. Purpose of user survey is clearly explained to participant. '*This survey is based on an anonymous system, it means that it is unable to track identifying information.*' was added in the survey form.

TABLE 4.2 Questionnaires used in the thermal perception and preference surveys

Number	Thermal sensation (TSV)	Thermal preference (TPV)	Thermal satisfaction
1	Cold	Cooler	Extremely dissatisfied
2	Cool	No change	Dissatisfied
3	Slightly cool	Warmer	Neither dissatisfied nor satisfied
4	Neutral		Satisfied
5	Slightly warm		Extremely satisfied
6	Warm		
7	Hot		

The scales of the thermal sensation vote (TSV) and thermal preference vote (TPV) were based on ASHRAE Standard-55 (ASHRAE, 2013) and on the McIntyre scale (Cena & Clark, 1981) respectively. For the satisfaction survey, respondents were asked to rate their satisfaction on a five-point Likert scale: 1 = extremely dissatisfied, 2 = somewhat dissatisfied, 3 = neither dissatisfied nor satisfied, 4 = somewhat satisfied, and 5 = extremely satisfied regarding environmental variables such as temperature, air quality, humidity and overall comfort.

4.2.3 Data analyses

IEQ data were stored and analysed in SPSS 24.0 (Statistical Packages for the Social Sciences) which can examine the datasets, including descriptive statistics showing minimum, maximum, mean value and standard deviation (SD). The characteristics of indoor climate of each office were summarized. After that, the data were compared to outdoor climate information to check how well each office has managed indoor climate quality. The analysis of occupant responses was conducted by statistical analyses. With calculations of the mean value, frequency distribution was included. Additionally, a Welch ANOVA test was used to test differences between mean values (office cases and thermal perception) with the significant level of 0.05. Games-Howell was used for a post-hoc test to investigate different groups of variables.

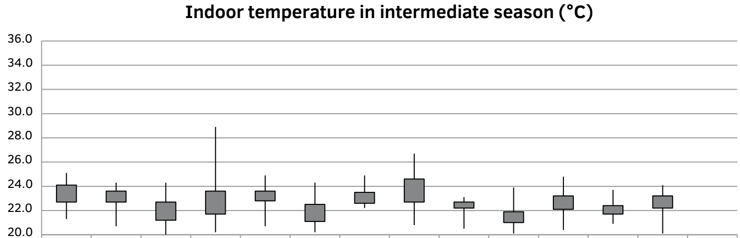
4.3 Comparison of indoor climate between renovated and non-renovated offices

4.3.1 Indoor air temperature

Indoor air temperature is generally used to find adequate air temperature. Indoor air temperature here indicates the average temperature of the air surrounding an occupant (ASHRAEStandard, 2010). FIG. 4.1, 4.2, and 4.3 compare the indoor temperature of different orientations in the 5 case studies. The measured temperature data were collected only for working hours from 7.00 am to 8.00 pm in three seasons, in order to compare indoor environmental quality of different orientations in a building and the same orientations of different office buildings. Dutch norm NEN 15251 recommends maintaining the indoor temperature between 23-26 °C as comfort zone in summer, and between 20-24 °C in winter (highlighted in FIG. 4.1- 4.6).

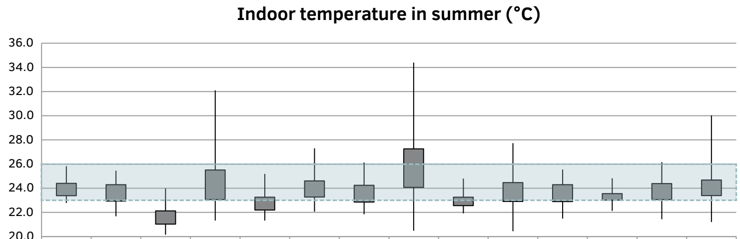
Overall, both renovated and non-renovated offices provide comfortable indoor temperature. In summer, the air temperature in case B and C sometimes cooler than comfort level. On the other hand, the non-renovated office reached the extremely high air temperature maximum of 34.4°C in summer. In winter, the non-renovated office reached a minimum of 14.4°C, and renovated offices also reached a temperature under 20°C. This tendency was observed on Monday since HVAC systems do not run during weekends. Although most renovated offices achieved the comfortable indoor temperature range in winter, case A was, in general, much warmer than the other renovated ones.

When the different orientations were compared in an office building, the workspaces oriented to the north side tended to be slightly cooler than the south side in intermediate season and winter. On the contrary, the workspaces oriented to the north side tended to be slightly warmer than the south side in winter. This can be explained because sun-shades were actively used for south-oriented workspaces in summer, and not every office had applied sun-shades on the northern façade.



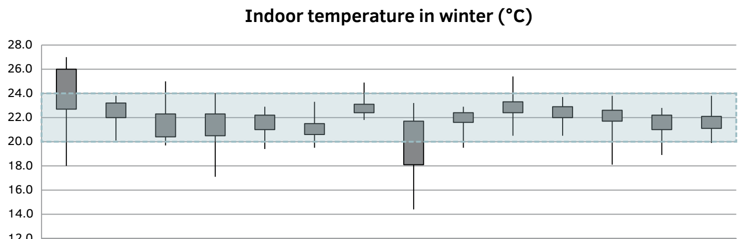
	S.E, Case A	S.E, Case B	S.E, Case C	S.W, Case E	S.W, Case B	S.W, Case C	S.W, Case D	N.E, Case E	N.E, Case B	N.E, Case C	N.E, Case D	N.W, Case A	N.W, Case B	N.W, Case C
75%	24.1	23.6	22.7	23.6	23.6	22.5	23.5	24.6	22.7	21.9	23.2	22.4	23.2	0
Max.	25.1	24.3	24.3	28.90	24.9	24.3	24.9	26.7	23.10	23.9	24.8	23.7	24.1	0
Min.	21.3	20.7	20	20.2	20.7	20.2	22.2	20.8	20.5	20.1	20.4	20.9	20.1	0
25%	22.7	22.7	21.2	21.7	22.80	21.1	22.6	22.7	22.2	21	22.10	21.7	22.2	0

FIG. 4.1 Indoor air temperature monitored in intermediate seasons



	S.E, Case A	S.E, Case B	S.E, Case C	S.W, Case E	S.W, Case B	S.W, Case C	S.W, Case D	N.E, Case E	N.E, Case B	N.E, Case C	N.E, Case D	N.W, Case A	N.W, Case B	N.W, Case C
75%	24.4	24.3	22.1	25.5	23.3	24.6	24.2	27.3	23.3	24.5	24.3	23.6	24.4	24.7
Max.	25.8	25.5	24.0	32.1	25.2	27.3	26.1	34.4	24.8	27.7	25.6	24.8	26.2	30.0
Min.	22.8	21.7	20.2	21.3	21.3	22.1	21.8	20.5	21.9	20.4	21.5	22.1	21.4	21.2
25%	23.4	22.9	21.0	23.1	22.2	23.3	22.9	24.1	22.6	22.9	22.9	23.0	23.1	23.4

FIG. 4.2 Indoor air temperature monitored in summer

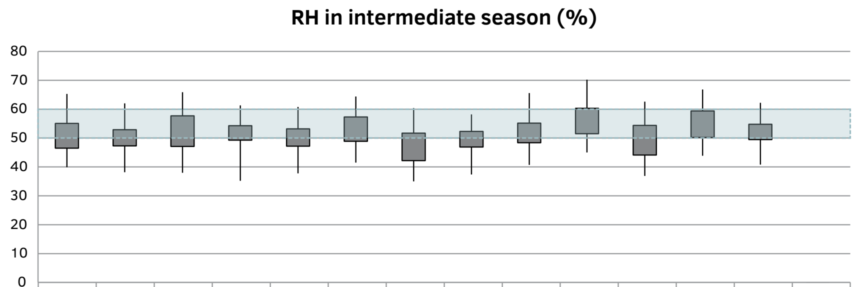


	S.E, Case A	S.E, Case B	S.E, Case C	S.W, Case E	S.W, Case B	S.W, Case C	S.W, Case D	N.E, Case E	N.E, Case B	N.E, Case C	N.E, Case D	N.W, Case A	N.W, Case B	N.W, Case C
75%	26.0	23.2	22.3	22.3	22.2	21.5	23.1	21.7	22.4	23.3	22.9	22.6	22.2	22.1
Max.	27.0	23.8	25.0	24.0	22.9	23.3	24.9	23.2	22.9	25.4	23.7	23.8	22.8	23.8
Min.	18.0	20.1	19.7	17.1	19.4	19.5	21.8	14.4	19.5	20.5	20.5	18.1	18.9	19.9
25%	22.7	22.0	20.4	20.5	21.0	20.6	22.4	18.1	21.6	22.4	22.0	21.7	21.0	21.1

FIG. 4.3 Indoor air temperature monitored in winter

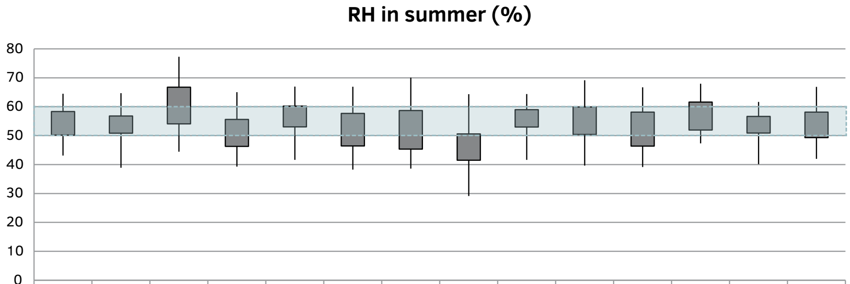
4.3.2 Relative humidity

The Dutch norm 15251 recommends 60% relative humidity (RH) for an office building. According to Shikdar and Al-Kindi (2007), the range between 50% and 60% RH is recommended for human comfort exposed in occupied offices. FIG. 4.4, 4.5, and 4.6 show the range of monitored RH (%) values in different seasons. Overall, north-oriented workspaces tended to be better within the comfort RH range than south-oriented ones in intermediate season and summer, with 1-5% higher RH value in northern workspaces than southern ones. The RH values of south-oriented workspaces were also slightly lower in winter than north-oriented workspaces. Moreover, case C and D reached the minimum RH of 21%. The majority of RH values in the five buildings were within the range of a comfortable zone in intermediate season except for case D (40-60% RH). In summer, case C oriented S.E. showed relatively higher RH value of over 65% and around 21°C air temperature. The RH value in case E oriented N.E. was 44% RH with 26.7°C temperature, which was significantly lower than in the other cases. In winter, the RH values in the five offices were very much lower than the recommended RH range. Following the recommended RH range of Vellei et al. (2017), case C oriented to the south-west can be considered as a comfortable workspace, but only for a short period a day.



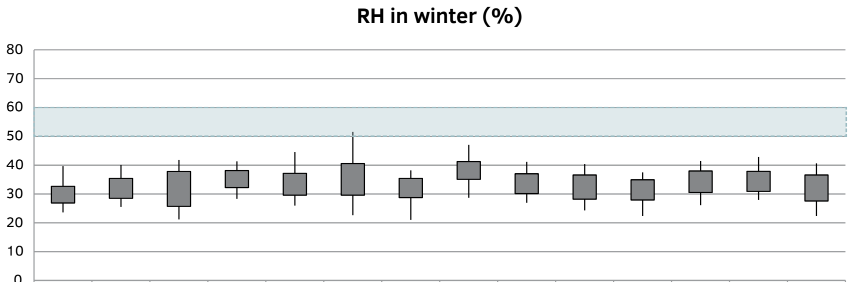
	S.E, Case A	S.E, Case B	S.E, Case C	S.W, Case E	S.W, Case B	S.W, Case C	S.W, Case D	N.E, Case E	N.E, Case B	N.E, Case C	N.E, Case D	N.W, Case A	N.W, Case B	N.W, Case C
75%	55.1	52.9	57.7	54.3	53.2	57.3	51.7	52.3	55.2	60.3	54.4	59.4	54.8	0
Max.	65.3	62	65.9	61.3	60.8	64.4	60.4	58.2	65.6	70.2	62.6	66.8	62.2	0
Min.	39.9	38.2	38.0	35.2	37.8	41.5	35.0	37.4	40.7	45.0	36.9	43.9	40.8	0
25%	46.5	47.3	47.1	49.3	47.2	48.9	42.2	46.9	48.4	51.5	44.1	50.2	49.5	0

FIG. 4.4 Relative humidity in intermediate season



	S.E, Case A	S.E, Case B	S.E, Case C	S.W, Case E	S.W, Case B	S.W, Case C	S.W, Case D	N.E, Case E	N.E, Case B	N.E, Case C	N.E, Case D	N.W, Case A	N.W, Case B	N.W, Case C
75%	58.3	56.8	66.8	55.6	60.2	57.7	58.7	50.6	59.0	59.9	58.2	61.6	56.6	58.1
Max.	64.5	64.7	77.3	65.0	67.0	66.9	70.0	64.4	64.4	69.1	66.7	68.0	61.6	66.9
Min.	43.1	38.9	44.4	39.3	41.6	38.3	38.6	29.1	41.7	39.6	39.2	47.3	40.1	42.0
25%	50.2	50.8	54.1	46.3	53.0	46.4	45.4	41.5	53.0	50.4	46.4	51.9	50.9	49.3

FIG. 4.5 Relative humidity in summer



	S.E, Case A	S.E, Case B	S.E, Case C	S.W, Case E	S.W, Case B	S.W, Case C	S.W, Case D	N.E, Case E	N.E, Case B	N.E, Case C	N.E, Case D	N.W, Case A	N.W, Case B	N.W, Case C
75%	32.7	35.4	37.8	38.1	37.2	40.5	35.4	41.2	37.0	36.6	34.9	38.0	37.9	36.6
Max.	39.6	40.1	41.8	41.3	44.5	51.6	38.2	47.1	41.2	40.3	37.5	41.4	42.9	40.6
Min.	23.6	25.5	21.2	28.3	26.0	22.6	21.0	28.7	27.0	24.3	22.3	26.1	27.9	22.3
25%	26.9	28.5	25.7	32.2	29.6	29.6	28.7	35.1	30.1	28.2	27.9	30.5	30.9	27.6

FIG. 4.6 Relative humidity in winter

4.4 Comparison of thermal perception between renovated and non-renovated offices

4.4.1 Thermal sensation and preference votes

The total number of responses were 606 (95.1%) out of a total of 637 approached office users. The group of respondents comprised 308 (50.8%) males and 298 (49.2%) females. The assumption of homogeneity of variance was violated, therefore Welch's ANOVA was used to control that there are differences of thermal perception among the cases. The Games Howell post-hoc test, which is used for the unequal variance, compares independent groups and shows which groups are different. TABLE 4.3 shows the mean differences in thermal sensation between groups according to different seasons.

The mean TSV of case A, B, and C was similar over a season. On the other hand, the lowest mean value was shown in case D regardless of seasons, which means most people felt relatively cool or cold compared to the other offices. On the contrary, occupants in case E (the non-renovated case) felt warmer in mid-season and hotter in summer than users in the other offices. In terms of seasonal comparison, mid-season and winter showed similar mean TSV values.

TABLE 4.3 Mean values of thermal sensation vote and significant differences between the means in different seasons

Office	TSV-intermediate			TSV-summer			TSV-winter		
	Mean	*p*-value	Post-hoc	Mean	*p*-value	Post-hoc	Mean	*p*-value	Post-hoc
Case A	3.87	*P* < 0.001	E>B A,B,C,E >D	4.18	*P* < 0.001	A,B,C,D <E	3.87	*P* < 0.001	A,B,C>D E>D
Case B	3.81			4.04			3.38		
Case C	3.88			4.24			3.46		
Case D	2.68			3.59			2.56		
Case E	4.27			6.08			3.48		

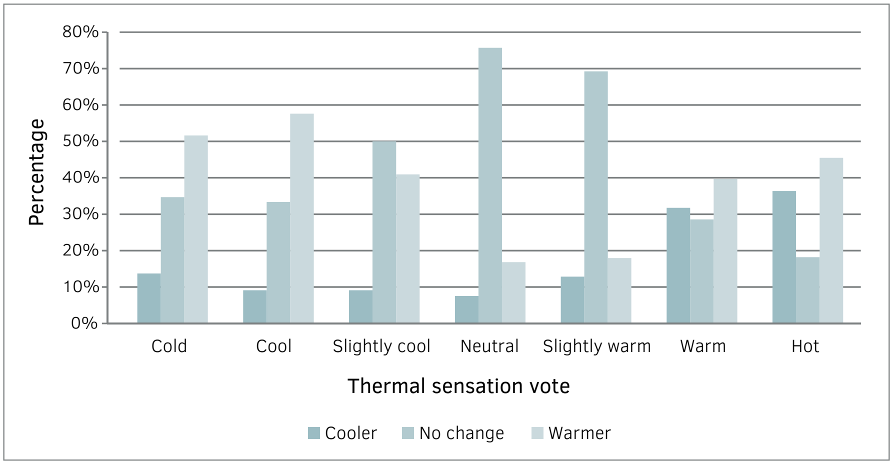


FIG. 4.7 Cross analysis of TSV and TPV in intermediate season

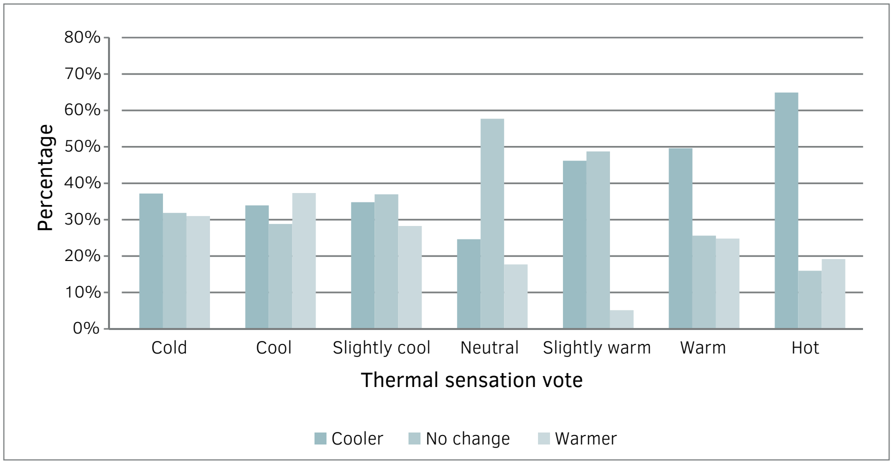


FIG. 4.8 Cross analysis of TSV and TPV in summer

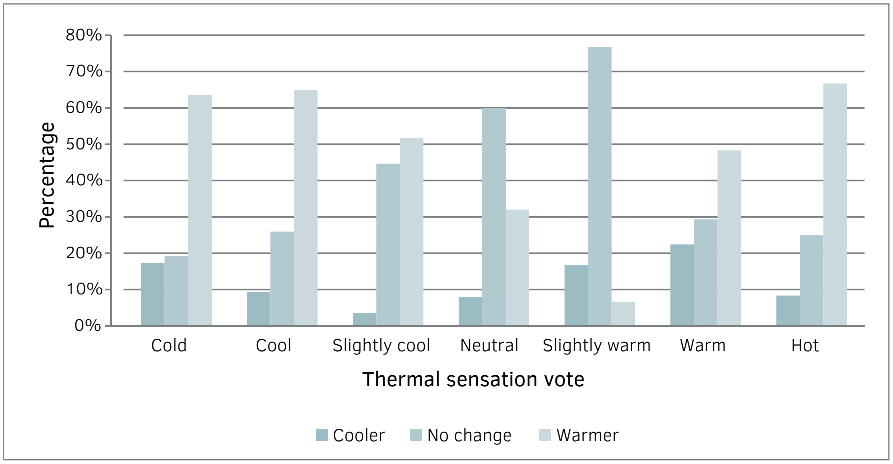


FIG. 4.9 Cross analysis of TSV and TPV in winter

FIG. 4.7, 4.8, and 4.9 the cross analysis of TSV and TPV. As a result of Spearman analysis, there was a significant correlation between thermal sensation and thermal preference (*p<0.001)*. The occupants who responded that they perceive the indoor temperature being slightly cool, neutral, or slightly warm desired no temperature change through different seasons. Therefore, slightly cool, neutral, and slightly warm can be regarded as acceptable thermal conditions.

Unexpected results were observed for the group of occupants who responded that they perceive the temperature to be cold and cool in summer and warm or hot in winter. Although people felt cold or cool in summer in their workspace, over 30% of them desired the indoor environment to be cooler than the air temperature (see FIG. 4.8). In contrast, people felt warm and hot in winter, around 50%-60% of them desired to be warmer than the air temperature (see FIG. 4.9).

4.4.2 User satisfaction with indoor air temperature

TABLE 4.4 shows the differences of thermal satisfaction between groups. There was a significant different mean value between the group of A, B, C, and E and D in intermediate season and winter. In summer, the mean values of the group D and E were different from the group of A, B, and C. Occupants were generally satisfied with the indoor temperature across the periods with approximately 3.5 of mean value. Case D had a substantially low mean value over all seasons, but the mean value of other renovated offices was, in general, slightly higher than for the non-renovated office.

TABLE 4.4 Mean values of thermal satisfaction vote and significant differences between the means in different seasons

Office	Satisfaction-intermediate			Satisfaction-summer			Satisfaction-winter		
	Mean	*p*-value	Post-hoc	Mean	*p*-value	Post-hoc	Mean	*p*-value	Post-hoc
Case A	3.36	$P <$ 0.001	A,B,C,E >D	3.10	$P <$ 0.001	A,B,C >D,E	3.23	$P <$ 0.001	A,B,C,E >D
Case B	3.55			3.43			3.26		
Case C	3.46			3.37			3.37		
Case D	1.96			1.92			1.91		
Case E	3.18			1.92			3.08		

A thermal comfort zone was considered 3 to 5 on the 7 Likert scale. At least 80% of the occupants should vote the range of 3 to 5 for an acceptable thermal environment (ASHRAE, 2013). In only two case studies, over 80% occupants were satisfied with the indoor temperature in the intermediate season (see TABLE 4.5). In average, the percentage of thermally satisfied occupants was between 60% and 80%. On the other hand, only 20% occupants in case D were satisfied with the indoor temperature. In addition, the case E, which is non-renovated office, had an uncomfortable temperature issue only in summer.

TABLE 4.5 Percentage of thermal satisfaction

Office	Intermediate				
	Extremely dissatisfied (%)	Dissatisfied (%)	Neither dissatisfied nor satisfied (%)	Satisfied (%)	Extremely satisfied (%)
Case A	2.6	28.2	15.4	38.5	15.4
Case B	4.7	12.1	15.4	59.1	8.7
Case C	2.4	14.6	24.4	51.2	7.3
Case D	36.9	41.5	10.8	10.5	0.3
Case E	11.4	17.7	21.5	40.5	8.9
Summer					
Case A	12.8	25.6	10.3	41.0	10.3
Case B	6.0	16.1	16.1	52.3	9.4
Case C	2.4	22.0	14.6	58.5	2.4
Case D	41.5	37.9	8.5	11.8	0.3
Case E	40.5	40.5	6.3	11.4	1.3
Winter					
Case A	5.1	23.1	23.1	41.0	7.7
Case B	10.1	16.1	19.5	47.0	7.4
Case C	4.9	19.5	14.6	56.1	4.9
Case D	41.2	36.9	11.8	10.1	0
Case E	11.4	21.5	19.0	44.3	3.8

4.4.3 User satisfaction with relative humidity

In TABLE 4.6, there was a statistically significant difference in the mean value between the group of A, B ,C ,and E and D. In general, case D showed the most dissatified responses in terms of RH similar to the results of user satisfaction with air temperature. On the other hand, occupants from case A were most satisified with RH.

Over 80% of the occupants from each office building was satisfied and adapted to the RH in their workspace (see TABLE 4.7). Around 53% occupants in case D reponded that they were satisifed with the RH or that the condition was acceptable. The occupants' RH satisfaction was more generous compared to the occupants' thermal satisfaction. In case A, none of occupants reponded that they are extremely dissatisfied with relative humidity over seasons.

TABLE 4.6 Significant differences in the mean values of RH satisfaction vote in different seasons

Office	Satisfaction-intermediate			Satisfaction-summer			Satisfaction-winter		
	Mean	*p*-value	Post-hoc	Mean	*p*-value	Post-hoc	Mean	*p*-value	Post-hoc
Case A	3.62	*P* < 0.001	A,B,C,E >D	3.62	*P* < 0.001	A,B,C,E >D	3.59	*P* < 0.001	A,B,C,E >D
Case B	3.5			3.5			3.51		
Case C	3.17			3.27			3.17		
Case D	2.51			2.51			2.52		
Case E	3.34			3.23			3.32		

TABLE 4.7 Percentage of RH satisfaction

Office	Intermediate				
	Extremely dissatisfied (%)	Dissatisfied (%)	Neither dissatisfied nor satisfied (%)	Satisfied (%)	Extremely satisfied (%)
Case A	.	5.1	43.6	35.9	15.4
Case B	6.7	6.0	26.8	51.7	8.7
Case C	4.9	9.8	53.7	26.8	4.9
Case D	20.3	26.8	35.3	16.7	1.0
Case E	2.5	10.1	46.8	31.6	8.9
Summer					
Case A	.	2.6	48.7	33.3	15.4
Case B	6.0	6.7	26.8	51.7	8.7
Case C	.	9.8	58.5	26.8	4.9
Case D	20.6	26.1	35.9	16.3	1.0
Case E	3.8	15.2	41.8	32.9	6.3
Winter					
Case A	.	2.6	51.3	30.8	15.4
Case B	7.4	4.7	26.2	53.0	8.7
Case C	7.3	7.3	48.8	34.1	2.4
Case D	20.6	26.1	35.3	17.0	1.0
Case E	3.8	8.9	45.6	35.4	6.3

4.5 Discussion

The main challenge of this research was comparing occupants' perception and the actual indoor conditions. Since the indoor conditions differ over the days, occupants had to respond to questionnaires based on their average perception for each season. The prediction of optimal comfort temperatures is based on the thermal perception and satisfaction of the users.

ASHRAE 55 and NEN 15251 recommend summer comfort zone of 23-26 °C and winter comfort zone of 20-24 °C. However, the temperature that occupants felt satisfied with, had slightly different range compared to the guidelines. There is no clear satisfied temperature range for the intermediate season. In this research, the thermally satisfied zone for the season was observed in the range of between 22.4 °C and 23.4°C. Less than 10% of the occupants were dissatisfied with the temperature in this range of temperature. In summer, occupants tended to be satisfied in the range of 23-24 °C. In contrast, people were dissatisfied when the indoor temperature became below 23 °C or over 24.6 °C. In winter, people could adjust better to cooler temperature than warmer, preferably the range of 21.2-22.0 °C. However, when the temperature was below 20 °C or over 23 °C, the occupants were dissatisfied with the temperature. An important finding is the temperature range of comfort zone is wider than that of thermally satisfied zone.

This outcome is in the same line with a laboratory study by Tham and Willem (2010). Their study revealed that 23 °C indoor temperature provides the highest thermal comfort to occupants. The comfort temperature decreases slightly in winter and increases in summer. As the average temperature was similar within the same building but with different orientations, the significant dissatisfaction was observed in the temperature of around 1.5-2 °C lower or 1 °C higher than comfort temperature.

Humphreys et al. (1975) revealed that occupant's are satisfied with much wider range of indoor temperature in actual buildings than predicted by the predicted mean vote (PMV)/ predicted percentage of the dissatisfied (PPD) model. However, this research shows that the scope of comfortable temperature was narrower than the guideline.

4.5.1 Prediciton of optimal comfort RH based on thermal perception

The range of optimal RH value for satisfaction was observed based on occupants' thermal perception. In general, the occupants were more sensitive about indoor temperature than about relative humidity. Less than 15% of the occupants were dissatisfied with the RH condition except for case D. In detail, occupants were highly satisfied with an RH of 51-55% in intermediate season. Occupants exposed to below 50% RH were dissatisfied with the RH. The range between 54% and 58% RH showed the highest satisfaction in summer, and around 70% of the occupants were dissatisfied when the RH was over 58%. The lowest RH values were observed during winter. Although the RH value was significantly lower than the guideline, the occupants were satisfied with an RH in the range from 30% to 35%. People were dissatisfied when it became below 30%.

The RH value is highly related to indoor temperature, and it is a significant thermal comfort paramter. Vellei et al. (2017) framed three clusters of RH conditions:

- High: RH ≥ 59%,
- Medium: 37% < RH < 59%,
- Low: RH ≤ 37%

The optimal range to minimise risks to human health was suggested to be between 40% and 60% RH. According to Tsai et al. (2012), the comfortable RH in the office ranged between 49% and 51% during working hours with the office temperature ranging from 25.5°C to 26.0°C. The optimal RH value by Tsai et al. (2012) was more narrow than that of Vellei et al. (2017). This chapter also shows relatively narrow optimal RH values between 50-58% instead of 40-60%. The outcome of this research is close to the guideline. However, winter is an exceptional case. People could adjust until around 30% RH, but not below that value.

4.5.2 Limitations

Some critical issues can be stated in this section. First, adaptive comfort temperature is normally compared by the indoor operative temperature considering mean radiant temperature and air temperature. The adaptive comfort model also includes outdoor temperature. Due to the technical limitation, only air temperature was measured and compared in the five case studies. Thus, the measurements are insufficient for a full heat-balance comfort analysis such as PMV/PPD which is the index that appears in the standards and design guildelines such as ISSO 74 adaptive comfort model and ASHRAE 55.

Second, an indoor temperature following the guideline did not always result in higher user satisfaction. For example, the office with active façade renovation (case D) has a compliant comfortable indoor environment according to the NEN 15251 norm. The occupants were, however, considerably dissatisfied with the indoor climate. It can be assumed that there may be other factors that affect the occupants' thermal satisfaction. For instance, people who sit close to a window can have different thermal perception. They may feel colder in winter and warmer in summer than other people who do not sit near windows. Therefore, there may be more reasons why people feel dissatisfied with the indoor climate next to temperature and RH.

Third, the current global standards for adaptive comfort mainly focus on naturally ventilated buildings. The case studies selected in this study are mixed-mode buildings, neither air-conditioned nor fully naturally ventilated. The methodology used in this chapter compared measured thermal condition to global guidelines. Later, the occupants' thermal sensation was compared to their thermal preference to investigate whether their perception is matched to their preference. As the last process, the measured thermal data were compared to the results of users' satisfaction and perception to identify preferred thermal conditions. This methodology can be useful to investigate user satisfaction alike studies in mechanically cooled buildings.

4.6 Conclusion

For a year, thermal perception surveys were held with occupants in energy-efficient renovated offices in the Netherlands. The aim of this research was to identify the comfortable indoor climate to enhance user satisfaction. This study investigated the relationship between indoor climate and users' perception, preferences, and satisfaction for a year. There was not a significant difference in satisfaction with temperature between the non- renovated case and the renovated office cases in intermediate season and winter, but in summer there is a difference. The field measurement revealed that the global guideline for indoor comfort did not necessarily provide greater satisfaction of occupants.

The main conclusions from this chapter are:

- The temperature range of comfort zone (3-4 °C gap between min. and max.) is wider than the range of thermally satisfied zone (around 1°C gap between min. and max.).
- When people preferred not to change the temperature, they were satisfied with the thermal comfort. However, 'neutral' of thermal sensation did not mean people were highly satisfied with thermal comfort.
- The ideal temperature for occupant satisfaction was observed 22.4-23.4°C in intermediate season, and 23.0-24.0°C in summer, and 21.2-22°C in winter.
- In winter, occupants were dissatisfied with the indoor temperature of below 20°C or over 23°C.
- Occupants easily adapted to cooler temepratures than warmer ones in winter.
- The global guideline for thermal comfort has a wider range compared to actually prefered thermal condition in workspaces.

This chapter provided an integrated analytical approach to identify the optimal thermal indoor conditions that users can be satisfied. The analysis was conducted by comparing user satisfaction and . The results can help redefining the indoor thermal condition to ensure user satisfaction through occupant surveys.

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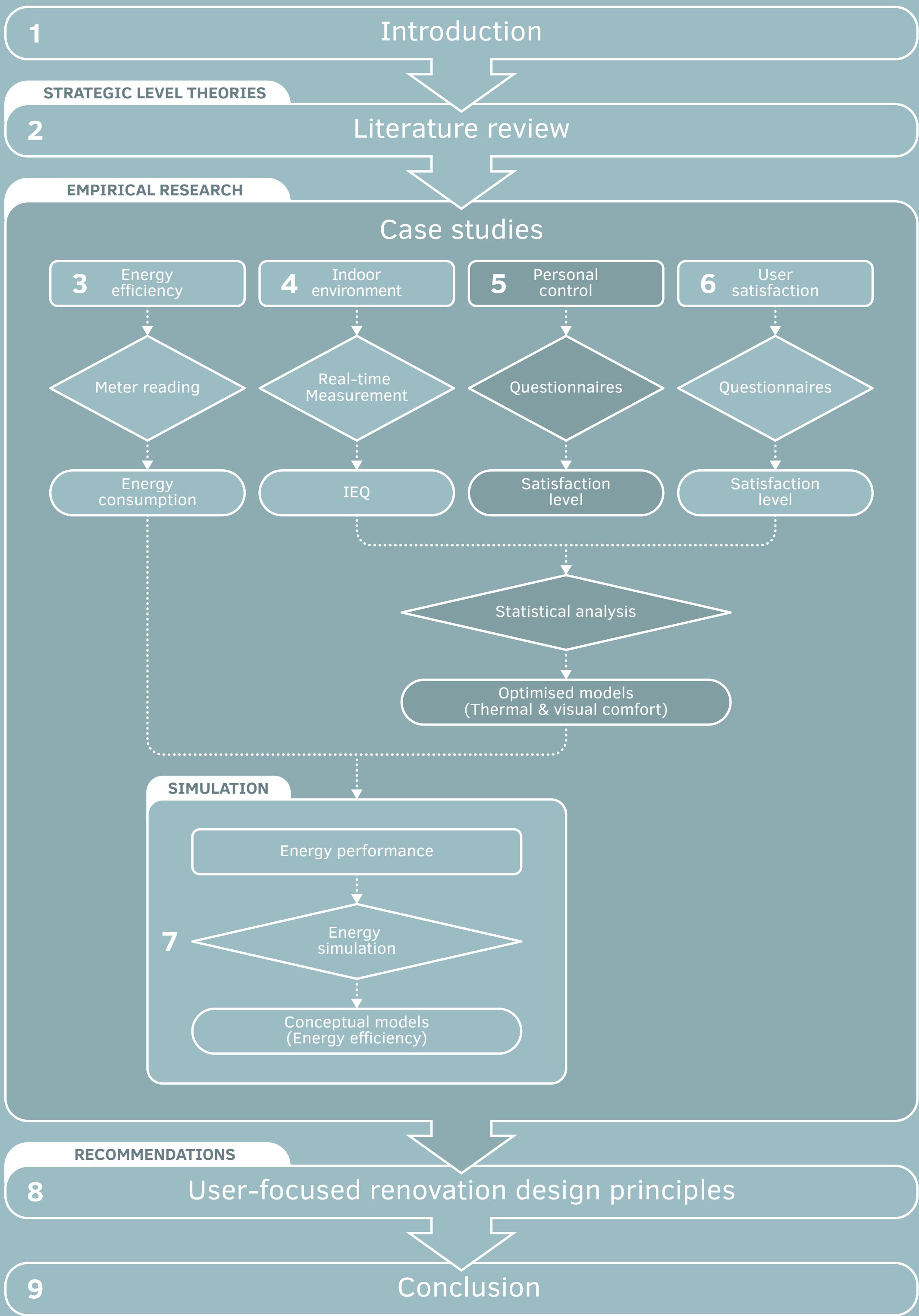
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5 Impact of personal control on user satisfaction

Chapter 4 provided the impact of indoor climate on user satisfaction. Many studies reported that personal control over indoor environmental conditions is one of the influential factors for user satisfaction and environmental comfort due to its physical and psychological impacts. However, it is not clear to what extent users should be allowed to have control over the indoor environment. This chapter aims to identify the relationship between the extent to which users can personally control the conditions of their indoor environment and how satisfied they are with their thermal and visual comfort.

Section 5.2 presents the data collection and assessment methods of occupants' perceived satisfaction. The relationship between personal control and satisfaction is explained in section 5.3. Section 5.4 presents the dependency of user satisfaction with thermal comfort based on the degree of personal control over indoor environmental conditions, and section 5.5 explains the impact of the degree of person control on the user satisfaction with visual comfort. Section 5.6 discusses limitations of research of personal control, psychological impact of personal control, and how to design the personal control to optimise user satisfaction.

5.1 Introduction

User satisfaction, in terms of indoor comfort, is a subjective topic. According to Fanger (1970), there is no thermal environment that makes everybody satisfied. In that sense, user control is an important issue for an individual's thermal comfort. There are many studies dealing with automated control of building systems and control strategies for shading devices (Da Silva et al., 2012; Nielsen et al., 2011; Shen & Tzempelikos, 2012) and lighting with occupancy sensors (Aghemo et al., 2014), in order to manage the energy consumption in an efficient way. Moore et al. (2002) found that some people overused the personal lighting control although they do not feel uncomfortable, and people had negative opinions due to partial failure of the system (Bordass et al., 1993). Occupant interactions indeed influence energy performance and consumption (Da Silva et al., 2012). However, systems fully automated for energy efficiency may incur a risk of serious occupant dissatisfaction. Aghemo, Blaso, and Pellegrino (2014) stated that although automatic control has potential energy savings, user control is important to correct the defects of the automatic system and accommodate individual differences.

The importance of user control at work has been dealt with in various studies. The studies identified that greater direct individual control leads to higher thermal comfort (Brager et al., 2004; Fountain et al., 1996; Karjalainen & Koistinen, 2007; Melikov, 2004), higher satisfaction (Brager & Baker, 2009; Huizenga et al., 2006; S. Y. Lee & Brand, 2005), energy savings (De Bakker et al., 2017; Nagy et al., 2015; Wagner et al., 2007), and self-assessed productivity in work environments (Leaman & Bordass, 2001). From a psychological point of view, personal control is an important factor to increase user satisfaction and the employee's productivity (Lee & Guerin, 2009; Samani, 2015; Vine et al., 1998). In short, individual control affects not only an employee's satisfaction and thermal comfort but also productivity and energy saving.

User control is often referred to in different ways, such as individual, personal or occupant control. The terms of user control are not clearly defined yet in the built environment. There is a difference between exercised control and perceived control. Exercised control means actual control over environment (Walsh & Brief, 2007). As a form of perceived control, *Personal control* is defined by Greenberger and Strasser (1986) as 'an individual's beliefs at a given point in time, in his or her ability to effect a change, in a desired direction on the environment.' However, the definition is generic, and it needs to be defined for the built environment. Huang and Robertson (2004) used *environmental control* over a workstation as ergonomics-related control, influencing an employee's satisfaction and stress. Karjalainen (2009) stated that *occupant control* is the actions occupants take to be comfortable in thermal conditions by controlling the thermostats. Luo and Cao (2016) used *person environmental control* as 'regarding space conditioning systems on occupants' thermal comfort perception'. In fact, the terms of *personal* or *occupant control* over the indoor environment go along the line of occupant's comfort. Based on previous definitions, this research uses the term personal control as user actions towards environmental comfort.

Although many researchers have studied the positive impacts of personal control, there are different opinions about personal control and related problems (Bordass et al., 1993; Karjalainen, 2009; Karjalainen & Koistinen, 2007; Moore et al., 2002). One research found that there was no big difference in user satisfaction between an office equipped with thermostats and an office having more limitations to users for thermal control, since users did not notice whether personal temperature control works or not (Karjalainen & Koistinen, 2007). In addition, employees have few chances to control thermostats for an individual's thermal comfort (Karjalainen, 2009). Karjalainen's study revealed the main reasons of user problems to be that people often did not use individual controls, because the control system was not recognisable or people were not sure whether the control system was operable. Luo and Cao (2016) examined whether the thermal comfort improvement was solely influenced by psychological factors or together with physical factors through a chamber experiment. They demonstrated that people were more satisfied with thermal comfort perception only due to psychological reasons of person control. Nevertheless, the result from a chamber experiment may be different from an actual-site experiment. Therefore, the actual use of person control and its impact on user satisfaction in workplaces needs more attention and exploration. The research question answered in chapter 5 is what is the impact of person control on user satisfaction with thermal and visual comfort?

The purpose of this chapter is to provide an overview of the actual use of person control over the environmental condition systems in offices; to understand the dependency of a user's environmental satisfaction regarding the degree of personal control; and to contribute to designing better user control that enhances user satisfaction at work. This chapter, therefore, focused on the occupants' rating of environmental satisfaction parameters, divided into two contexts: thermal and visual comfort. In addition, it also investigated whether there were significant relations between the degree of personal control and the user satisfaction in different seasons.

5.2 Methodology

5.2.1 Data collection

Data were collected in two ways: e-mails containing an online survey link (Qualtrics online survey software), and physical distribution of hard copies. The data were collected in the year 2017. The offices selected are cellular[2], open[1], combi[2], and flex-offices[3], equipped with a range of user control systems. Four buildings are energy-retrofitted offices and one is a conventional office. Facility managers from each office participated in individual interviews to collect information about building physics. Interview questions were modified based on the book of 'The healthy indoor environment: how to assess occupants' wellbeing in buildings' (Bluyssen, 2013).

5.2.2 Building information

FIG. 5.1 displays further details about building information: building structure, WWR, sunshades, glazing type, renewable energy sources, HVAC terminal units, temperature set-points, heat recovery, types of HVAC system, openable windows, HVAC system running hours, and types of thermal control. The four renovated offices have ceiling-mounted heating and cooling, and independent thermostats at each workplace. The non-renovated office case does not offer thermostats nor a ventilation system, only openable window. In the renovated offices, each office has centrally programmed set-points for heating and cooling (each office has slightly different set-points). Occupants can control the temperature within a limit of ±2^{o}C or ±3^{o}C with a thermostat.

The background air velocities, checked on a real-time base, were <0.1m/s, which did not significantly affect users' thermal perception (Luo et al., 2016). The indoor temperature in retrofitted offices was generally controlled by a local thermostat or by fully automated control by zone sensors. The non-renovated office was equipped with complete manual control.

2 Vos et al. (2000)

3 Danielsson and Bodin (2008)

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		Case A	Case B	Case C	Case D	Case E
Structures	Load bearing structure + Thermal layer position Skeleton structure + Thermal layer position					
WWR	≤ 20% ≤ 30 % ≤ 50 % ≤ 80 % ≤ 90 %	≤ 30 %	≤ 80 %	≤ 50 %	≤ 50 %	≤ 30 %
Sun shading		External blinds (south only)	Internal blinds (all sides)	External blinds (all sides)	External screens (south only)	Internal blinds
Glazing type		HR ++	HR ++	HR ++	HR ++	Single glazing
Renewable energy		.	Wind energy from own electricity grid, Sun collecter heater	Acquifer system	.	.
Climate ceiling		O	O	O	O	X
Temp. Set point		21 ± 2 °C	21 ± 3°C	20 ± 3°C	20 ± 3°C	X
Heat recovery		O	O	O	X	X
HVAC	Types of HVAC	Heat pump (heating and cooling)	Water cooled chiller + cooling tower	LTES and Heat pump	Water cooled chiller + cooling tower	Hot-water based radiator
Openable windows		O	X	O	O BUT not allow to open	O
System running hours	per week	35 - 45 h	55 h	60 h	80 h	.
Thermal control	Room temperature control	Local thermostat	Zone sensor	Local thermostat, Facade and zone sensor	Local thermostat	Manual control

FIG. 5.1 Physical building information

5.2.3 Respondents demography

Participants of the survey were from five offices in the Netherlands, with a total of 579 (90.9%) completed respondents out of a total of 637 office users approached. TABLE 5.1 shows the completion rate of participants in the questionnaire. The group of respondents comprised 324 (50.9%) of males and 313 (49.1%) of females, both aged 18 to 69. The main age group consisted of 194 (30.5%) 30 to 39 years old employees, followed by 161 (25.3%) 40 to 49-year employees. 425 (66.7%) of the respondents were full-time employees (working at least 36 hours per week), and 212 (33.3%) were part-time employees.

TABLE 5.1 Number of participants in the questionnaire and completion rate

Occupants responses	Case A	Case B	Case C	Case D	Case E	Total
Started survey	46	161	102	306	103	718
Completed survey	39	142	41	279	78	579
Percentage	84.8%	88.2%	40.2%	91.1%	75.7%	80.6%

The gender balance between male and female was almost 50%, and the age of 30-49 accounted for half of the total responses. The respondents' group was composed of 66.7% of full-time employees and 33.3% part-time (see FIG. 5.2).

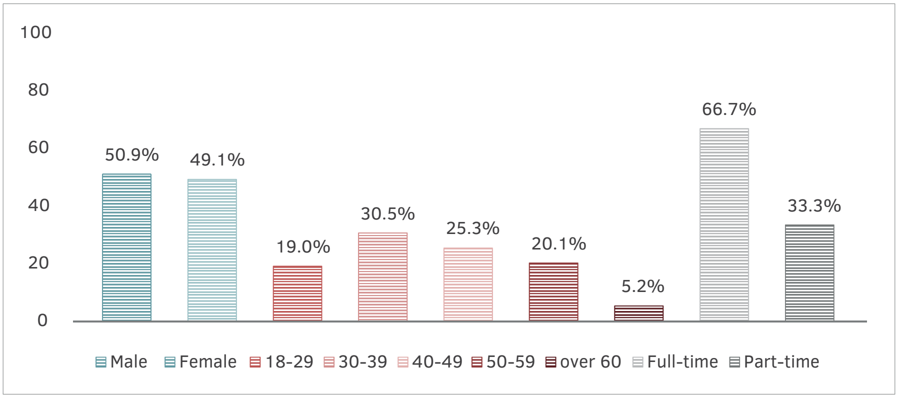

FIG. 5.2 Demographic information of respondents

5.2.4 Questionnaires

The questionnaires are about satisfaction with the indoor environmental quality (IEQ) and the degree of personal control for individuals' thermal and visual comfort during summer, winter, and mid-season. Appendix A displays original questionnaires and scales used for online survey. The first question asked was "To what extent can you control the following aspects of your workplaces?" (i.e., heating, cooling, operable windows, sunshades, and lighting). Only the variables that affect indoor climate were selected. User control was scaled as follows: 1 = complete, 2 = partial, 3 = no control, 4 = do not have. Prior field study showed that people sometimes were not allowed to open windows for safety reasons. For this reason, the "No control" choice was available for each question. The degree of user control is defined based on literature by De Dear and Brager (2002) and Boerstra (2016):

- Complete control: no central control system and full control by users, and they have wide range of temperature control.
- Partial control: having set-points, occupants are allowed to control their own environment within the limited thermal range.
- No control: fully centrally controlled conditions, the control system is installed, but people are not allowed to use it.
- Do not have: no user control system is installed.

The second question was “Can you indicate how satisfied you have been with your work environment during summer?” This question was repeated for each season. Thermal comfort variables were temperature, air quality, humidity, and overall satisfaction; visual comfort variables are lighting, daylight, and outside view. A 5-point Likert scale was used to evaluate their perception. Each option was given a score: 1 = extremely dissatisfied, 2 = somewhat dissatisfied, 3 = neither dissatisfied nor satisfied, 4 = somewhat satisfied, and 5 = extremely satisfied.

5.2.5 Data analysis

All statistical analysis was carried out using SPSS (version 24.0). User satisfaction variables were structured within two variable groups, thermal comfort and visual comfort variables, by factor analysis with Oblimin rotation (oblique rotation), that assumes that the factors are correlated. Spearman’s Chi-Square test was applied to analyse the relation between user control and user satisfaction with indoor environment, and frequency distributions of two or more variables. An adjusted residual value was used to compare the level of user satisfaction and personal controllability. There were two assumptions to conduct the Chi-Square test. First, both independent and dependent variables should be categorical data (i.e., nominal and ordinal level). Second, two variables should consist of more than 3 or 4 independent groups respectively. A 5-point Likert scale for user satisfaction was rescaled to 3 scores: 1 = dissatisfied, 2 = neither dissatisfied nor satisfied, 3 = satisfied. The rescaled score provided a simplified interpretation in the cross-tabulation analysis. Two models were built to investigate the relations between comfort satisfaction and personal control parameters. The first model examined the relation between thermal comfort variables and personal control of heating, cooling and ventilation. The second model examined the relation between visual comfort variables and personal control of sun shades and lighting.

In this case, the null hypothesis (H0) was that there is no relation between user control and user satisfaction. The alternative hypothesis (H1) was that there is an relation between user control and user satisfaction. The level of significance was defined as $p<0.05$, confidence levels were set at 95%. Since Chi-Square does not provide the strength of relation, effect sizes and a residual analysis were used to investigate a statistically significant omnibus Chi-Square test result. Effect sizes were tested by Cramer's V. Cramer's V, indicating a number between 0 and 1, was used to examine how strongly two categorical variables are associated. It is calculated using the following formula:

$$\phi_c = \sqrt{\frac{\chi^2}{N(k-1)}}$$

- Φc denotes Cramer's V;
- χ^2 is the Pearson Chi-Square statistic;
- N is the sample size involved in the test and
- k is the lesser number of categories of either variable.

Since Cramer's V does not identify the pattern of relationship, an adjusted residual table was added. The adjusted residual indicates the difference between the observed counts and expected counts divided by an estimate of standard error, which means the larger the residual, the greater the contribution to the Chi-Square test result (Sharpe, 2015). The positive adjusted residuals mean that (depending on satisfaction variables in this research) there are more satisfied or dissatisfied occupants than expected, adjusted for the sample size. The negative adjusted residuals mean that there are less satisfied occupants than expected.

5.3 Relationship between user control and satisfaction

User satisfaction is influenced by many factors. In order to explore the impact of each environmental factor, satisfaction variables were integrated into a thermal comfort variable and a visual comfort variable. To apply Pearson's Chi-Square, independent and dependent variables should be independent, and no more than

20% of the cells have expected counts less than 5 (Daniel et al., 1996). The results of each test showed the expected counts less than 5 were 1 cell (8.3%) or 0 cell (0.0%). Thus, the dataset was qualified to continue with this examination. TABLE 5.2 presents the relation between user controllability and satisfaction in the work environment, showing the *p* – value of each variable. The most significant satisfaction factor was temperature, in terms of heating, ($p = 0.003$), cooling ($p = 0.049$), and operable windows ($p < 0.001$) in mid-season. However, the relationship between cooling control and user satisfaction regarding indoor temperature had a relatively weak statistical significance. In particular, controllability of operable windows was the most important user control variable for satisfaction with thermal comfort in this season, for temperature ($p < 0.001$), for air quality ($p < 0.001$), for humidity ($p = 0.001$), and for overall satisfaction ($p < 0.001$).

Summer measures showed a trend similar to mid-season. Overall, the most significant user control system was operable windows in terms of satisfaction with temperature ($p = 0.017$), air quality ($p < 0.001$), humidity ($p = 0.005$), and comfort ($p < 0.001$). The relation between heating ($p = 0.008$) and cooling control ($p < 0.001$), and temperature satisfaction was statistically significant. Unlike mid-season, user control for cooling was strongly related to overall satisfaction as well as temperature satisfaction.

In winter, the relation between heating and cooling, and temperature satisfaction was observed at ($p < 0.001$) and ($p < 0.001$) respectively. According to the Chi-Square value, heating control had a stronger impact on temperature than cooling control. Those variables also affected overall satisfaction for heating, and for cooling. The relation of operable windows with four satisfaction parameters (e.g., temperature, air quality, humidity, and overall comfort) were highly significant over the thermal satisfaction variables.

To conclude, heating control was strongly related to overall satisfaction in mid-season and winter. Ventilation and cooling control affected overall satisfaction in summer. Conversely, there was no significant relation between heating control with air quality and humidity, and cooling with the same two variables.

TABLE 5.2 Results of relation analysis between user control and thermal comfort satisfaction using Pearson's Chi-Square test (statistical significance $p < 0.05$)

Seasons	User control	User satisfaction	P - value	Effect size
Mid-season	Heating	Temperature	**0.003**	0.131
		Air quality	0.166	
		Humidity	0.224	
		Overall	0.058	
	Cooling	Temperature	**0.049**	0.105
		Air quality	0.145	
		Humidity	0.466	
		Overall	0.091	
	Ventilation/Operable windows	Temperature	**p < 0.001**	0.168
		Air quality	**p < 0.001**	0.167
		Humidity	**0.001**	0.136
		Overall	**p < 0.001**	0.185
Summer	Heating	Temperature	**0.008**	0.122
		Air quality	0.253	
		Humidity	0.338	
		Overall	0.570	
	Cooling	Temperature	**p < 0.001**	0.155
		Air quality	0.086	
		Humidity	0.278	
		Overall	**0.037**	0.107
	Ventilation/Operable windows	Temperature	**0.017**	0.116
		Air quality	**p < 0.001**	0.145
		Humidity	**0.005**	0.127
		Overall	**p < 0.001**	0.165
Winter	Heating	Temperature	**p < 0.001**	0.174
		Air quality	0.145	
		Humidity	0.302	
		Overall	**0.041**	
	Cooling	Temperature	**p < 0.001**	0.155
		Air quality	0.331	
		Humidity	0.576	
		Overall	**0.034**	0.109
	Ventilation/Operable windows	Temperature	**p < 0.001**	0.172
		Air quality	**p < 0.001**	0.148
		Humidity	**p < 0.001**	0.152
		Overall	**p < 0.001**	0.193

Note: p-values in bold highlighted are statistically significant (p < 0.05),
Effect size by Cramer's V indicates 0.04: small, 0.13: medium, 0.22: large.

TABLE 5.3 shows the relation between personal controllability and visual comfort satisfaction. There was a significant correlation between sunshades and satisfaction with 'artificial light' ($p < 0.001$), 'daylight' ($p < 0.001$), and 'outside view' ($p < 0.05$), over all seasons. Controllability of sunshades was an important factor for the overall visual comfort. In addition, there was a significant correlation between lighting control and daylight satisfaction at $p < 0.05$ during whole seasons. The number of Cramer's V revealed that two categorical variables, in general, had weak (<0.06) or medium effects (<0.17); only the relation between sunshades and daylight showed a large effect size.

TABLE 5.3 Results of relation analysis between user control and visual comfort satisfaction using Pearson's Chi-Square test (statistical significance $p < 0.05$)

Seasons	User control	User satisfaction	P - value	Effect size
Mid-season	Sun shades	Artificial light	**p < 0.001**	0.144
		Day light	**p < 0.001**	0.220
		Outside view	**0.023**	0.113
	Lighting	Artificial light	0.492	
		Day light	**p < 0.001**	0.148
		Outside view	0.165	
Summer	Sun shades	Artificial light	**p < 0.001**	0.147
		Day light	**p < 0.001**	0.172
		Outside view	**0.006**	0.125
	Lighting	Artificial light	0.199	
		Day light	**0.024**	0.112
		Outside view	0.116	
Winter	Sun shades	Artificial light	**0.001**	0.143
		Day light	**p < 0.001**	0.223
		Outside view	**0.037**	0.108
	Lighting	Artificial light	0.225	
		Day light	**0.007**	0.124
		Outside view	0.184	

Note: p-values in bold highlighted are statistically significant (p < 0.05),
Effect size by Cramer's V indicates 0.04: small, 0.13: medium, 0.22: large

5.4 The dependency of user satisfaction with thermal comfort based on the degree of personal control

TABLE 5.4 and 5.5 summarise the trend of user satisfaction with thermal and visual comfort in relation to the degree of person control. The data includes only statistically significant results ($p<0.05$). The null hypothesis, claiming no statistically significant relation between independent and dependent variables was rejected. The adjusted residual of the satisfied variable was only compared to observe contribution of each cell, and important numbers were highlighted.

TABLE 5.4 shows that, in most variables, 'complete control' ranked as highest adjusted residual level (minimum 1.9, maximum 3.4), while 'no control' ranked lowest (minimum -4.8, maximum -2.7). For air quality, 'I do not have' for ventilation control was highly related to satisfaction in all seasons. In mid-season, occupants tended to be more satisfied with temperature perception and overall comfort according to the following degree of heating control and ventilation: 'complete' > 'partial' > 'do not have' > 'no control'. However, having complete cooling control did not mean people were more satisfied with temperature perception. The heating system affected satisfaction more than cooling. For satisfaction with air quality regarding ventilation control, the majority of occupants were satisfied with the condition of 'do not have' followed by 'complete'. This result showed people were satisfied either when they had total ventilation control or they do not have personal control at all.

In summer, the results showed the same order of preferred heating and cooling control as mid-season ('complete' > 'partial' > 'do not have' > 'no control'). Although there was a statistically significant relationship between heating control and temperature satisfaction, occupants did not care about the heating control as shown in TABLE 5.4. For user satisfaction, cooling control was important on temperature and overall comfort. Occupants had different preferences about the degree of ventilation controllability compared to personal heating and cooling. Occupants were more satisfied with the indoor climate according to controllability in the following order: 'do not have' > 'complete' > 'partial' > 'no control'.

During winter, cooling control was not an important factor. For temperature and overall satisfaction, complete heating control was the largest adjusted residual level, while no control had the smallest one. The results of ventilation control showed that people were likely to be more satisfied with the following degree of control (‘complete’ > ‘partial’ > ‘do not have’ > ‘no control’) in temperature satisfaction. In terms of air quality, occupants were satisfied with the degree of ‘do not have’ > ‘complete’ > ‘partial’ > ‘no control’. On the other hand, people who could completely control the ventilation were relatively more satisfied than those who did not have control.

TABLE 5.4 Assessment of user satisfaction with thermal comfort based on personal controllability

Adjusted residual						
	Satisfaction variables	Personal control	Complete control	Partial control	No control	I do not have
Mid-season	Temperature	Heating	**2.5**	0.8	-3.4	1.9
	Temperature	Cooling	0.5	**1.4**	-2.7	1.2
	Temperature	Ventilation	**2.0**	0.9	-3.9	0.5
	Air quality		1.2	-0.9	-4.3	**2.8**
	Humidity		**1.7**	-0.8	-3.3	1.6
	Overall comfort		**3.4**	-0.6	-4.8	1.2
Summer	Temperature	Heating	0.4	0.4	-2.6	2.7
	Temperature	Cooling	**2.1**	1.7	-3.5	1.2
	Overall comfort		1.2	**2.1**	-2.5	0.0
	Temperature	Ventilation	0.3	0.1	-2.5	**1.5**
	Air quality		1.3	-1.8	-3.4	**2.8**
	Humidity		1.5	-1.0	-2.8	**1.6**
	Overall comfort		0.7	-1.1	-3.8	**3.0**
Winter	Temperature	Heating	**3.0**	0.2	-3.1	2.0
	Overall comfort		**2.0**	1.1	-2.7	0.8
	Temperature	Cooling	1.4	1.4	-3.2	**1.5**
	Overall comfort		1.0	**2.6**	-3.1	0.2
	Temperature	Ventilation	**2.8**	0.8	-3.1	-0.6
	Air quality		0.8	-1.0	-3.0	**2.2**
	Humidity		**1.9**	-1.0	-3.0	1.4
	Overall comfort		**2.8**	-0.9	-4.0	1.2

Note: adjusted residual numbers in bold highlighted mean the largest contribution to satisfaction.

5.5 The dependency of user satisfaction with visual comfort based on the degree of personal control

TABLE 5.5 illustrates the trend of user satisfaction with visual comfort according to the degree of person control regarding sunshades and lighting. Overall, occupants working without personal control of sun-shading and lighting were least satisfied with light quality and outside view. 'Complete control' of sun-shading and lighting had the greatest contribution to satisfaction with visual comfort, while 'I do not have' often ranked lowest. Although people who were not allowed to use personal control were relatively more satisfied with visual comfort than those of 'do not have', people were still irritated by the fact that they could not personally control sun-shading and lighting.

TABLE 5.5 Assessment of user satisfaction with visual comfort based on personal controllability

Adjusted residual						
	Satisfaction variables	Person control	Complete control	Partial control	No control	I do not have
Mid-season	Artificial light	Sun shades	1.7	1.1	-1.8	-1.4
	Daylight		5.4	0.9	-3.3	-3.7
	View to outside		1.1	0.9	-1.2	-1.0
	Daylight	Lighting	2.6	1.6	1.1	-3.6
Summer	Artificial light	Sun shades	1.3	1.2	-1.6	-1.4
	Daylight		4.1	1.3	-3.6	-2.4
	View to outside		1.1	0.7	-1.1	-0.9
	Daylight	Lighting	2.1	2.5	0.2	-3.1
Winter	Artificial light	Sun shades	2.2	0.8	-1.7	-1.7
	Daylight		4.3	0.9	-2.4	-3.5
	View to outside		0.7	1.3	-0.7	-1.8
	Daylight	Lighting	2.1	0.8	0.9	-2.6

Note: adjusted residual numbers in bold highlighted mean the largest contribution to satisfaction.

Interestingly, mid-season and summer had similar patterns. In terms of lighting and daylight, people were likely to be satisfied following this order: ‘complete’ > ‘partial’ > ‘do not have’ > ‘no control’. People who did not have personal control were less satisfied than those who had a control system but could not use the system. Results suggest people were less dissatisfied about lighting and daylight when they could not use the sunshade control system than when they did not have sunshade control at all. It can be explained that even though the indoor environment without personal sunshade control was not appropriate for the satisfaction, people accepted and adjusted to the fact that their workplace does not provide personal control. However, respondents tended to be satisfied with outside view according to the degree of sunshades control: ‘complete’ > ‘partial’ > ‘no control’ > ‘do not have’. It is assumed that although people could not use the control system, they were aware of the existence of the control system, therefore less dissatisfied than the people who did not have control over sun-shading. People were sensitive with outside view when the workplace was not equipped with control over sun-shading.

In winter, the tendencies for user satisfaction in lighting, daylight and outside view were different from the results of mid-season and summer. Still, complete control made occupants more satisfied with lighting and outside view. Having sunshades in mid-season and winter was quite important regardless of whether they were able to control it.

In addition, there were different tendencies towards daylight satisfaction and personal lighting control. In general, occupants who could ‘completely’ and ‘partially’ control lighting were more satisfied than ‘no control’ and ‘do not have’. In mid-season and winter, the trend of satisfaction with daylight quality followed the order of ‘complete’ > ‘partial’ > ‘no control’ > ‘do not have’. However, the results of the summer season showed that occupants who could partially control the lighting were most satisfied (2.5 of residual level) with daylight quality in workplaces.

In short, occupants sometimes easily accepted a working environment without having personal control; however, for certain factors, such as thermal comfort, people were more dissatisfied when they could not adjust the thermal conditions than when they did not have thermostats.

5.6 Discussion

5.6.1 Personal control studies

This chapter identified user satisfaction with thermal and visual comfort according to personal controls through a user survey and statistical analysis. As most studies reported, personal control strongly influences user satisfaction with thermal and visual comfort. Many studies focus on the correlation between window opening behaviour and various parameters e.g., the location of working desks (D'Oca & Hong, 2014) and indoor and outdoor environment (Haldi & Robinson, 2008; Herkel et al., 2008; Raja et al., 2001; Zhang & Barrett, 2012) in naturally ventilated office buildings. Raja et al. (2001) reported that opening windows and controlling sunshades are the most frequently used behaviour to adjust thermal conditions, and that occupant discomfort is significantly correlated with ventilation. Similarly, the most significant relation was found to be satisfaction with thermal comfort according to the degree of ventilation. Personal control of sun-shading was the largest contribution to satisfaction with visual comfort, and it can be relevant to thermal comfort.

Boerstra et al. (2013) reported that a significant correlation was observed between perceived control[4] and comfort, but there was no correlation between available control and perceived control. Conversely, in their occupants study conducted in 12 mixed mode office buildings, Brager and Baker (2009) stated a 'high degree of direct personal control' contributed to more than 80% of the occupant's satisfaction level. Similar to the study by Brager and Baker (2009), this research has revealed that a higher degree of personal control leads to more satisfaction with IEQ. Although this research could not compare the same occupant satisfaction level before they had control and afterwards, we could analyse the impact of personal control in depth by collecting data from various target groups. The predominant outcome is that 'complete personal control' showed the highest satisfaction for thermal and visual comfort in most of the cases. In contrast, the most dissatisfied occupants appeared in 'no control' or 'do not have' groups, depending on which environmental satisfaction variable was analysed.

4 Wallston et al. (1987)

5.6.2 Psychological adaption

In general, occupants tended to be least satisfied with thermal comfort when they had no control over the heating and cooling system. Unexpectedly, people often accepted the fact of having no personal thermal controls, which make them dissatisfied with thermal comfort in general. For example, when the workplace was not equipped with personal control, building occupants were rather less dissatisfied than the occupants who could not adjust the personal control. In this sense, they were more intolerant as they acknowledge the personal thermal controls, but they were not allowed to use them or they did not know whether the personal control affects temperature changes or not. This finding may be linked to a statement by Luo et al. (2016) that the impact of user control on satisfaction is only related to psychological aspects. It is difficult to say user control only has psychological impact. However, results from this chapter indicated that the relation between control and satisfaction cannot only rely on psychological impacts of personal control alone, but on both physical and psychological impacts. Therefore, it is clear that occupants should have control over the office environment.

5.6.3 Designing the degree of person control

The most essential discussion is which degree of personal control should be designed and planned to increase the satisfaction of individuals and to make them agree with a compromise on the circumstances. Existing post-occupancy evaluation (POE) studies of office buildings have shown that occupants who work in high-performance[5] buildings are more accepting and generous, even though the thermal environment is out of the comfort range (Pei et al., 2015). As a number of studies proposed thermal comfort ranges based on their observation (Daum et al., 2011; Guillemin & Morel, 2002; Murakami et al., 2007), personal control mechanisms need to be combined with user comfort ranges.

For example, when people did not have personal ventilation in summer, they were most satisfied. The main reason for this may be related to HVAC and thermal control systems. Retrofitted offices were especially equipped with high-performance HVAC

5 A definition by the United States Energy Independence and Security Act 2007, *"a high performance building is a building that integrates and optimizes on a life cycle basis all major high-performance attributes, including energy conservation, environment, safety, security, durability, accessibility, cost-benefit, productivity, sustainability, functionality, and operational considerations". Lewis et al. (2010)*

systems controlled by zone sensors, combined with local thermostats, so that users did not realise the necessity of a personal ventilation control. Another assumption is that occupants rarely opened windows in summer to avoid high-temperature air to come in. Although Herkel et al. (2008) revealed that higher outdoor temperature is more opening windows in a naturally ventilated office, the trend of personal control may change in the case of an actively ventilated office. Brager and Baker (2009) stated that mixed manual and automatic window system can have advantages to avoid unpleasant outdoor conditions, such as heavy wind or rain. Therefore, the HVAC system could affect the user satisfaction results in summer.

5.6.4 Limitations

Despite the importance of personal control, having complete personal control over the indoor environment is challenging. A limitation of this study was that the indoor temperature was not monitored before and after occupants' control of heating, cooling, ventilation, and sun-shading. Therefore, it is difficult to compare the impact of personal control on the indoor environment. Second, it is difficult to explain the reason why 'partial control' sometimes was the strongest factor contributing to building user satisfaction. The findings from the study presented may contribute to a guide for planning personal control in workplaces to achieve great user satisfaction and high occupant comfort. However, this study only focused on user satisfaction without considering differences of energy use so it was impossible to suggest the ideal degree of personal control in relation with both user satisfaction and energy efficiency.

5.7 Conclusion

This chapter examined the environmental user satisfaction based on the degree of personal control in office buildings. This chapter provides insights into the degree of user control that increases building user satisfaction. What this research found in addition to other literature is:

- Person control for ventilating indoor air such as opening/closing windows and turning on ventilation is the most significant factor for thermal comfort.
- Personal control of sun-shading was the largest contribution to satisfaction with visual comfort.
- The relation between personal control and satisfaction relys on both users' physical and psychological impacts.

The findings suggest a theoretical framework to deal with personal control and occupants' environmental satisfaction.

- Environmental user satisfaction can be increased by providing more freedom and personal control of thermal and visual comfort in workplaces.
- Occupants' control should be designed to be relevant to the prevailing season.
- To improve user satisfaction, based on the findings of this research, thermal-related personal control should follow the order of 'complete' > 'partial' > 'do not have' > 'no control'. In summer, switching off the local thermostat and changing to fully automated control will have less effect on satisfaction.
- For satisfaction with visual comfort, occupants should have direct personal control of any visual comfort related factors such as sun-shading and lighting.
- Users tend to easier accept the fact that they do not have personal control than that they cannot use an available control system for environmental comfort. However, they tend to be more dissatisfied when they do not have personal control of visual comfort than when they cannot use the devices.
- In an office with a well-performing automated system, the impact of personal control on satisfaction is low.

Next to these points, facility managers should consider the following aspects: (1) implementing the proper degree of personal control by building occupants, such as providing complete or partial control over thermal and visual comfort; (2) identifying the impact of personal control on energy and its contribution to employee satisfaction; and (3) managing a balance between energy consumption and the degree of personal control.

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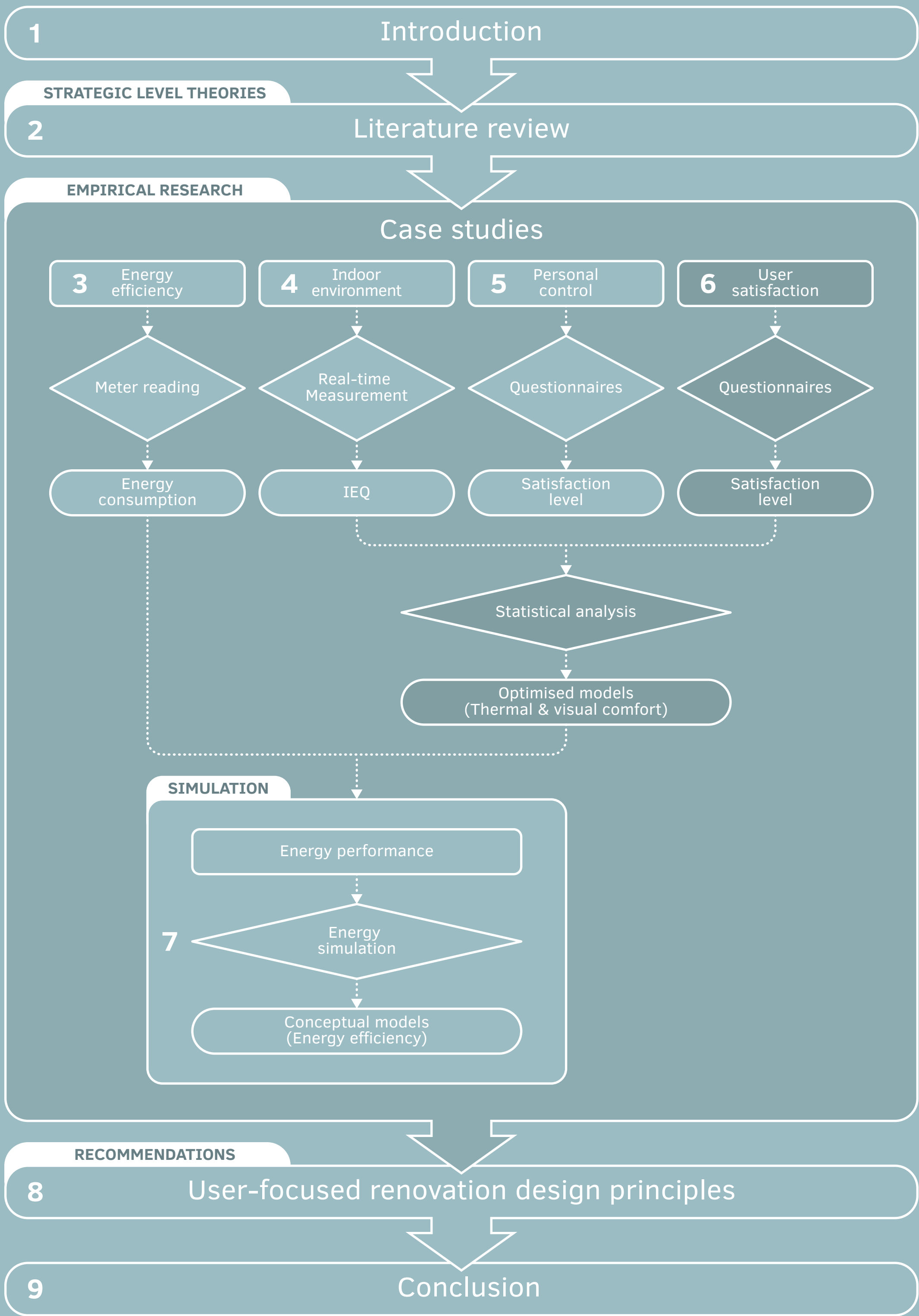
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6 Impact of design factors on user satisfaction

Personal control was one of the influential parameters for user satisfaction presented in chapter 5. Personal control is not related to architectural office design, and in this thesis it is not associated with privacy and communication with colleagues. Thermal and visual comfort is analysed exhaustively in this chapter. Psychological comfort is an extra parameter for user satisfaction studies since the design factors such as office layout could be correlated to privacy, communication and so on. As a next step, chapter 6 investigates influential office design factors on user satisfaction related to thermal, visual, and psychological comfort and predicting which design factors may bring better satisfaction to users.

Section 6.2 presents design factors affecting user satisfaction based on literature review. Five office cases in the Netherlands with 579 office occupants were studied using questionnaires, and interviews with facility managers and architects (section 6.3). Different statistical analysis tests were conducted to summarise satisfaction factors (section 6.4). The relative importance of design factors is described in section 6.5, and a regression analysis was used to predict profound outcomes in section 6.6.

6.1 Introduction

User satisfaction in offices has been studied across disciplines such as social science, real estate, and building environment from different perspectives. The term 'user satisfaction' in the built environment has not been clearly defined. According to Cambridge dictionary, *satisfaction* is a pleasant emotion, when the expectations, or needs, are fulfilled or there is nothing to complain about. Frontczak et al. (2012) reviewed 10 studies related to occupants' satisfaction and stated occupants' satisfaction is highly related to indoor environmental quality or to the workspace. Particularly, indoor environmental quality (IEQ) is one of the key issues for users' satisfaction. This is because occupants' satisfaction with environmental quality affect users' health and comfort perception (Sant'Anna et al., 2018). For these reasons, users' perception and satisfaction of the space they use should be underscored in the built environment (Sant'Anna et al., 2018). In addition, Samani (2015) revealed that users' dissatisfaction normally comes from more than one ambient condition of the workplace. It also may come from composite physical workplace conditions such as location of their working desk, orientation of façade, cellular or open-plan layout, etc.

Despite of the importance of users' satisfaction in building performance, there are many problems in the built environment due to exclusion of the users' perspective. During the conceptual design phase of a building, many decisions are made based on the energy performance, indoor quality, and economic conditions, while the design phase has not adopted end-users' requirement and satisfaction because there is no standard principle and a lack of actual information about their requirements/needs (Heydarian et al., 2017). Huber et al. (2014) classified the number of publications dealing with criteria influencing user satisfaction according to types of buildings. For office buildings, air quality, temperature and lighting were the most frequently studied parameters followed by HVAC usability, and outside views through windows (Attia, 2018; Choi & Moon, 2017; Oseland, 2009; Van der Voordt, 2004). However, the empirical studies examined the impact of IEQ on user satisfaction, but not how building design factors affect user satisfaction with indoor environment. When the users are considered in the early design phase, the design approach may be different than in conventional design approaches in which users are not considered. Rupp et al. (2015) stated that contextual factors such as architectural features, space layout, behavioural aspect, demographic characteristics can also affect occupant's thermal perception.

Another issue in user satisfaction studies is the psychological aspect. Environmental psychology has been studied by empirical research from the ergonomics field, which normally gives immediate responses towards the working environment. In Europe, the environmental psychology of office users has analysed the individual and organisational level (Sundstrom & Sundstrom, 1986). A recent trend in the research field favours physical comfort of office users, which is also called satisfaction with working conditions assessed by post occupancy evaluation. However, early studies by Altman (1975) developed the connection of physical environment and users through social-psychological analyses, including privacy and territoriality. Many studies have highlighted the importance of user satisfaction for promoting work performance and productivity (De Been & Beijer, 2014; Tanabe et al., 2015). Van der Voordt (2004) and Tanabe et al. (2015) stated that higher employee satisfaction in workplaces leads to increased productivity, whereas lack of privacy and territorialism can cause decrease of the satisfaction and productivity. Thus, it is essential to understand employees' perception, and how workplaces are used for better support the office users.

The field of environmental psychology explores the association between human and physical conditions (Oseland, 2009). According to Oseland (2009), people seek enclosed place for concentration on work. At the same time, they also seek social spaces for casual interaction with colleagues. The measurements of environmental satisfaction has been studied by some projects, for instance, The OFFICAIR project (Sakellaris et al., 2016), and the COPE project (Veitch et al., 2007). In spite of numerous studies regarding environmental satisfaction, (Frontczak & Wargocki, 2011) stated that the relationship between indoor environment and end-users' comfort is not fully identified. In addition, the relationship between various design factors (e.g., orientation, WWR, and distance of desk location from window) and psychological satisfaction in offices is rarely known, and very few studies investigated this relationship.

A review by Rolfö et al. (2018) found that psychological workspace comfort such as privacy and territoriality (De Croon et al., 2005), and communication (Brennan et al., 2002) affect occupants' satisfaction and performance as well as physical office conditions (Brill & Weidemann, 2001). Some studies explored the impact of physical environmental factors on job satisfaction and productivity. For instance, Banbury and Berry (2005) compared the effect of noise on users' concentration between cellular and open-plan offices. Similarly, Kaarlela-Tuomaala et al. (2009) studied the different acoustic environment and the degree of users' concentration between those two office layouts. De Been and Beijer (2014) revealed that office type is a significant predictor for employees' productivity, concentration, communication etc. The studies regarding office layout often compare only cellular and open plan types. However, De

Been and Beijer (2014) included combi and flex office types in their study. Kwon et al. (2019) found that prominent psychological variables are privacy, concentration, communication, social contact, and spatial comfort (territoriality).

Therefore, the primary purpose of this chapter is to examine the effect of building design factors on user satisfaction with thermal, visual, and psychological comfort through the field study and provide insight by reporting on the satisfaction differences according to different design factors in offices. This chapter aims to answer the research question: What is the relationship between the office design factors and user satisfaction with thermal, visual, and psychological comfort? And can the relationship be predictable to develop user-focused design principles? Answering these questions, this chapter examines the relationship between different design factors and user satisfaction, and investigates the significant design factors that highly contribute to increasing employees' satisfaction. Finally, predicted satisfaction models are suggested to improve environmental satisfaction in workspaces, and it also offers an overview of influential factors for the workspace design based on the thermal, visual, and psychological satisfaction.

6.2 Design factors for office design: literature review

6.2.1 Keywords selection

Prior to proceeding with the methodology, the main design factors affecting occupant satisfaction and energy performance of the office building are described in this section. The key search terms of the literature search were applied as follow: (office design elements or office design factors or office design) AND (energy efficiency) AND (user satisfaction or occupant satisfaction) AND NOT (school) AND NOT (house) AND NOT (hospital). 17 papers were selected based on the purpose of this research, which is to predict the correlation of physical design factors for office buildings with the level of IEQ and psychological satisfactions.

6.2.2 Design factors influence on user satisfaction

TABLE 6.1 A summary of influential design factors for user satisfaction based on literature reviews

Authors	Design factors	Findings
Danielsson and Bodin (2008)	Office design	Individual's perception related to health and job satisfaction are different according to office types.
Seddigh et al. (2015)		Office layout influences occupants' health and performance.
Zerella et al. (2017)		Layout features are highly associated with employee perception of work satisfaction.
Lee (2010)		Office layout affects worker perception regarding environmental quality issues (LEED-certified buildings)
Schiavon and Altomonte (2014)		Open space layout in LEED buildings showed successful improvement of occupant satisfaction with IEQ, including office type, spatial layout, distance from window, occupants' demographics, occupancy hours.
Baird et al. (2012)		Office layout is a major factor affecting overall occupant comfort.
Shahzad et al. (2017)		Cellular office equipped with personal thermal control showed 35% higher satisfaction and 20% higher comfort level compared to open plan offices.
Rao (2012)		Open space layout will cause reduction of acoustic quality.
Mofidi and Akbari (2018)	Desk location, and dimension	Position-based comfort depends on the dimension of the office, orientation, desk location and placement of openings.
Kong et al. (2018)	Environmental variations	Distance from windows, orientations and window heights significantly affect user satisfaction with daylight and visual comfort.
Dodo et al. (2013)	Façade design and orientation	Orientation, and area of windows determine daylight quality and thermal condition.
Hua et al. (2014)	Façade design	Glazing and shading designs need to be considered for thermal and daylight performance
Tzempelikos et al. (2007)		The impact of WWR and glazing type on thermal comfort was studied for optimal choice of a façade.
Lee et al. (2013)		The study tested building performance based on the relationship between WWR and orientation.
Jin and Overend (2014)		The impact of façade-intrinsic and extrinsic design factors (e.g., WWR, thermal properties, and orientation HVAC system) are evaluated in chamber-based research.
Hua et al. (2014)	Orientation	Orientation is an important factor for thermal and visual comfort and energy efficiency of workspaces.
Konis (2013)		Visual discomfort observed frequently in S.E perimeter zone due to direct sun-light.
Rao (2012)		Building orientation determines solar radiation.

TABLE 6.1 shows a summary of design factors that have been investigated in other studies. Although there are many studies related to occupants' satisfaction with energy efficiency in office buildings, and the impact of façade components and office layout on IEQ, only a few studies deal with the relationship between user satisfaction or comfort and design factors. The office design factors can be divided into two categories with sub-parameters: spatial office design such as layout and position of work places, and façade design such as orientation, window-to-wall ratio (WWR). The effective façade design gives influence on IEQ and user satisfaction as well as orientations. Hua et al. (2014) revealed that the level of occupant's satisfaction with IEQ was different according to orientations. However, office types such as individual office and shared office was not statistically significant.

Based on previous studies, design factors can be classified as four factors: office layout, desk location, orientation, and WWR.

Office layout

In early studies, office layouts were classified by different dimensions. Vos et al. (2000), an idea of an office layout was classified by location, the internal configuration of space and the use of space. Dobbelsteen (2004) defined workplace layout in terms of spatial concepts which have an influence on the interaction of people, the type of climate control, spatial flexibility and spatial efficiency. Danielsson and Bodin (2008) defined office types by different architectural and functional features.

The cellular layout provides individual workspace along the façade accommodating 1-3 workplaces in one cell (Vos et al., 2000). The single cell provides a work environment for high concentration and people can adjust their own preferred indoor climate. The open-plan office type emphasises flexibility of space, sharing workspace with more than 13 persons (Vos et al., 2000). For this type, people complained about the quality of the indoor climate, for instance regarding unpleasantly high or low temperatures, lighting and noise levels etc. The combi-office is an office type that integrates the single-cell type and open-plan type, combined with more types of spaces (Danielsson & Bodin, 2008; Dobbelsteen, 2004). This type is a group work-based plan, and adapted advantages of cellular and open-plan offices (Dobbelsteen, 2004). Employees can work independently, and at the same time, the office provides open space where people can relax and communicate. Flex-office means that no individual workstation includes backup spaces. It is dimensioned for <70% of the workforce to be present simultaneously (Danielsson & Bodin, 2008).

Desk location

Desk location here indicates work desk's distances from windows, having a direct effect on satisfaction with IEQ (Frontczak et al., 2012; Kim et al., 2013). With the importance of this factor, Mofidi and Akbari (2019) developed a position-based evaluation method for user comfort and energy management. Recent studies of Kong et al. (2018) tested occupant's satisfaction with their visual comfort based on the distance from windows. They noted that a location 2.3 m from the windows can protect the building users from the direct sunlight. Awada and Srour (2018) and Altomonte et al. (2019) classified the parameter based on the location of desks within 4.6 m and further than 4.6 m from the nearest window. A study of Christoffersen and Johnsen (2000) measured the satisfaction rate according to the position of desks in window, mid, and wall zones, with less than 7 m depth. They monitored light quality at 2 m from the window. By considering these early studies, desk location comprised three groups in this research: 0-2 m, 2-4m and over 4 m.

Orientation

Seating orientations contribute to the visual comfort in offices (Galasiu & Veitch, 2006; Konis, 2013). In the same way, Hua et al. (2014) stressed that orientation is highly correlated to the visual comfort, especially extreme illuminance was observed in both southwest and northeast orientation. The studies also reported that certain orientations caused high levels of thermal dissatisfaction. However, it is difficult to say that orientation was the main reason that causes occupant's discomfort since other factors such as glazing area, artificial lighting, and blinds may also affect occupants' visual comfort.

Window-to-wall ratio (WWR)

Many studies stated the importance of the glazing area for thermal comfort and daylight (Dodo et al., 2013; Hua et al., 2014; Lee et al., 2013; Tzempelikos et al., 2007). WWR has an impact on building performance in terms of indoor quality due to the influence on natural daylight, heat gain/loss and optical properties, and windows and outside views are psychologically important to employees (Smith & Pitt, 2011; Yildirim et al., 2007). The WWR is calculated by dividing the glazed/window areas by the gross exterior wall area for a particular facade. In other words, it is the ratio between the transparent area versus and the opaque area of the facade. Goia et al. (2013) claimed that the range of 35-45% of WWR is the optimal rate in terms of energy minimisation. This result can be applied to Atlantic and Central Europe only.

Further research of Goia (2016) proposed WWR ranges and orientations for different climate conditions in Europe. Köppen Classification for The Netherlands is Cfb (Marine West Coast Climate). According to Goia (2016), WWR for Cfb classification is 37-45% for south, 40-45% for north, 37-43% for west, and 37-43% for east orientation. Modern offices often have a fully glazed façade. In order to cover the various range of WWR of office buildings, the WWR was classified by three types: 30%, 50%, and 80%.

6.3 Methodology

This chapter examines the impact of design factors on user satisfaction. User surveys and statistical analyses were used to answer the sub-research question. The samples of occupants are the same as those who participated in the previous user survey. Therefore, the number of participants is the same as the previous dataset. To collect accurate information about the physical conditions of their workplace, each user should answer the questions about the workspace conditions they use. Additionally, a map showing the placement of their office building was provided to collect the correct answer about where their workspace is oriented.

6.3.1 Questionnaires

Post-occupancy evaluation (POE) was used to assess building related occupants' feedbacks since the POE tool is useful to investigate how the building performance or environment affect occupants (Vischer, 2002). The questionnaires included design factors such as desk location, orientation, window-to-wall ratio (WWR), and office layout (see TABLE 6.2). Psychological user satisfaction was measured by the following questions: 'How satisfied are you with the following conditions?' regarding privacy during work at your workstation, opportunity to concentrate on your work, opportunities to communicate for work, social contact with colleagues in the office, and feeling of territoriality. In order to investigate the degree of user satisfaction with psychological comfort in the work environment, the following question was asked: 'How satisfied are you with the following conditions?', applying five psychological satisfaction variables, and 'what are the most important issues for better work environment?'. These variables measure the degree of satisfaction using a five-points Likert scale ranging from 1=extremely dissatisfied, 2=dissatisfied, 3=neither dissatisfied nor satisfied, 4=satisfied, 5=extremely satisfied.

TABLE 6.2 Questions about physical condition of workplaces

Categories	Question	Answer
Design factors		
Desk location	Where is your desk located?	1 = 0-2m away from windows 2 = 2-4m away from windows 3 = Over 4m away from window
Orientation	Which direction does your window face?	1 = South-east 2 = South-west 3 = North-east 4 = North-west
WWR	What types of windows does your workplace have? (Choose what comes closest to your situation)	1 = 30% 2 = 50% 3 = 80%
Office layout	What type of office layout do you work at?	1 = Cellular 2 = Open plan 3 = Combi-office 4 = Flexible office
Psychological satisfaction parameters		
Better work environment	What is the most important issue for better work environment?	1 = Privacy 2 = Concentration 3 = Communication 4 = Social contact 5 = Territoriality
Satisfaction	How satisfied are you with the following conditions? (Privacy, concentration, communication, social contact, and territoriality)	1 = Extremely dissatisfied, 2 = Dissatisfied, 3 = Neither dissatisfied nor satisfied, 4 = Satisfied 5 = Extremely satisfied

6.3.2 Statistical data analysis

The survey recorded the degree of satisfaction on an ordinal scale. A mean satisfaction score and percentile were used to understand how satisfied users were with psychological variables in their work environment. First, Cronbach's Alpha was tested to determine if the Likert scale was reliable. Second, the normality was checked by one-sample Kolmogorov-Smirnov test, before conducting the Kruskal – Wallis H test (KWH) which determines that the satisfaction variances are correlated with nominal dependent variables. This test assesses the difference among independent sample groups in non-normally distributed data (Vargha & Delaney, 1998). As following up test of the KWH test, a non-parametric post hoc test was conducted by pairwise comparison to examine which groups show differences.

The number of dependent variables (satisfaction parameters) had to be reduced to fewer dimensions by grouping similar patterns of responses. The process can simplify the data and prevent multi-collinearity error. Factor analysis was conducted to establish the underlying data structure with Oblimin rotation (oblique solution), to find out if the factors were correlated (Jackson, 2005). Two factors (e.g., thermal-related satisfaction and visual-related satisfaction) were identified to explain over 70% of the variance in the data structure by the factors that were extracted. Aggregate variables were created based on the factor analysis and henceforth these were recoded into binominal variables to create a redundant and more powerful model. However, the collected dataset showed non-normal distributions.

Categorical regression (CATREG) (McCullagh, 1980), also called regression with optimal scaling (Angelis et al., 2001), circumvents this problem by converting nominal and ordinal variables into interval scales (Meulman, 1998), and also circumvents the issue of unequal sample sizes between the cases since the analysis uses a weighted average according to (IBMKnowledgeCenter). This analysis identify a direct probability model and the predictors (independent variables) of satisfaction (dependent variables) and relative contributions with the variance explained by R^2 (Ibem et al., 2015).

Subsequently, binary logistic regression analysis was used to predict the models for occupants' satisfaction with the given thermal, visual and psychological variables. This analysis has been applied in previous studies (Au-Yong et al., 2014; De Kluizenaar et al., 2016). The independent variables (predictors) were design factors, and the dependent variables were the satisfaction with psychological parameters. In order to conduct the binary logistic regression, the degrees of satisfaction were recoded with the value of 'not satisfied' = 0, 'satisfied' = 1. Goodness of fit of the models was evaluated by the Hosmer-Lemeshow test, which was over the 5% level, revealing that the satisfaction could be explained by the models. Desk location, orientation, layout and WWR were entered as explanatory (categorical) variables. The last dummy was the reference category as each category compared against each other.

In order to check whether or not the model is fit to the data, the Hosmer-Lemeshow (Chi-square) (Hosmer et al., 1997) test was conducted. The H0 hypothesis is that the model is a good enough fit with the data ($p<0.05$) that allows to estimate values of the outcome variables (Field, 2015). H1 is that the model is not a good enough fit to the data. The associations are shown as Odds Ratios (OR) with 95% of confidence interval (CI 95%). In general, an OR indicates the likelihood of increasing the value of dependent variables. However, the independent variables are nominal scale and the dependent ones are ordinal scale, thus, ORs are used to compare the relative relationship between the design factors and the satisfaction.

6.4 Overview of measured satisfaction degrees

The Cronbach's Alpha of satisfaction parameters was 0.817, which means a high level of reliability. FIG. 6.1 and 6.2 show a summary of the percentile scores in each physical and psychological satisfaction category. The figure also compared the percentile scores between renovated and non-renovated offices. Overall, the mean values of each satisfaction variable were less than 4 in both physical and psychological categories. The range of satisfaction with thermal and visual comfort was wider in renovated offices than that of non-renovated offices. People in non-renovated offices showed neither satisfied nor dissatisfied on average. On the other hand, there were some people responded that they were dissatisfied with thermal and visual comfort throughout a year.

In terms of psychological categories, the highest mean value was recorded for the 'social contact with colleagues' (mean: 3.80), and the lowest one was 'opportunity to concentrate on work task' (mean: 2.78). Although the occupants in the non-renovated office were slightly more satisfied than those in renovated offices, there was no big difference between the two conditions. Interestingly, people who work in non-renovated offices answered higher satisfaction for privacy and concentration than those in renovated offices. People in renovated offices were more satisfied with social contact with colleagues than those in non-renovated offices. The reason for this is assumed that modern offices often have an open-plan layout, and 1960-70's offices are with a cellular office plan.

	Season	Parameters	Number of participants	Mean (SD)
Renovated cases	Mid-season	Thermal comfort	500	3.10 (0.99)
		Visual comfort	500	2.84 (0.73)
	Summer	Thermal comfort	500	3.10 (1.00)
		Visual comfort	500	2.80 (0.73)
	Winter	Thermal comfort	500	3.06 (0.99)
		Visual comfort	500	2.82 (0.73)
non-renovated cases	Mid-season	Thermal comfort	79	3.50 (0.86)
		Visual comfort	79	3.01 (0.63)
	Summer	Thermal comfort	79	2.98 (0.91)
		Visual comfort	79	2.94 (0.59)
	Winter	Thermal comfort	79	3.44 (0.82)
		Visual comfort	79	2.92 (0.67)

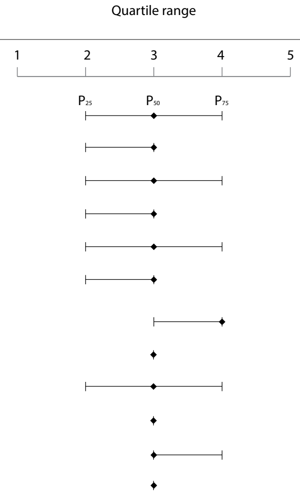


FIG. 6.1 Quartile ranges by physical categories from 1 (extremely dissatisfied) to 5 (extremely satisfied)

	Categories	Number of participants	Mean (SD)
Overall	Privacy	579	2.92 (1.10)
	Concentration	579	2.78 (1.16)
	Communication	579	3.42 (1.02)
	Social contact	579	3.80 (0.91)
	Territoriality	579	3.09 (0.98)
Renovated offices	Privacy	500	2.86 (1.06)
	Concentration	500	2.72 (1.12)
	Communication	500	3.42 (1.00)
	Social contact	500	3.81 (0.89)
	Territoriality	500	3.05 (0.97)
Non-renovated offices	Privacy	79	3.25 (1.26)
	Concentration	79	3.15 (1.32)
	Communication	79	3.41 (1.14)
	Social contact	79	3.77 (1.06)
	Territoriality	79	3.33 (1.03)

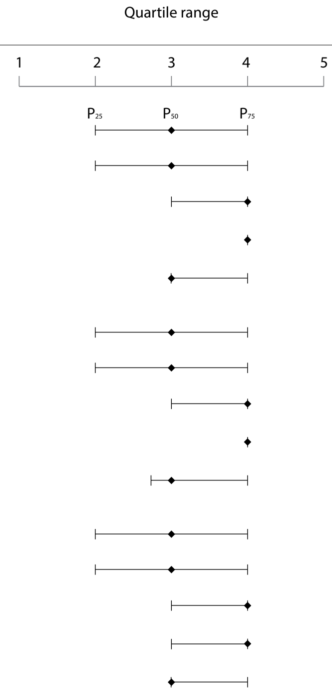


FIG. 6.2 Quartile ranges by psychological categories from 1 (extremely dissatisfied) to 5 (extremely satisfied)

FIG. 6.3 shows the percentage of responses on each satisfaction variable. In detail, 36% of the occupants were dissatisfied with ‘privacy’ and 43% with ‘concentration’. On the other hand, around 60% of the occupants were satisfied with the opportunity of ‘communication’, and three quarter of the occupants were satisfied with ‘social contact’. In terms of ‘territoriality’, most people tended to be neither satisfied nor dissatisfied, and they were rarely dissatisfied. Remarkably, around 18% of the occupants were extremely satisfied with ‘social contact’, and only less than 10% of occupants were extremely satisfied with the rest of the variables, whereas occupants were extremely dissatisfied with privacy and concentration with 11% and 16%, respectively.

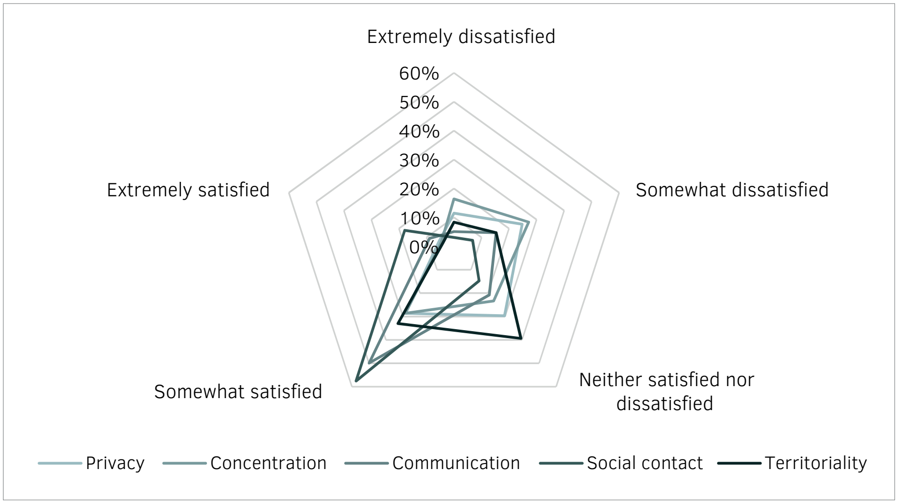


FIG. 6.3 Percentages of measured satisfaction degrees

6.5 Data extraction of user satisfaction variables

The first step in the analysis was to check how the indoor satisfaction variables clustered together and to learn about the underlying structure. Indoor satisfaction variables were analysed with Oblimin rotation of factor analysis. When p-value < 0.05, the test results were considered as statistically significant. Two factors were established: thermal and visual comfort (see TABLE 6.3). The first factor consists of items describing thermal affective dimensions such as temperature, air quality, humidity and overall comfort. Factor 1 was labelled thermal comfort-related satisfaction. The first factor explained 57.0% of variance. The second factor was labelled visual comfort-related satisfaction that consists of view to outside, daylight, and artificial lighting. Together these factors explained over 71.4% of variance. A KMO (Kaiser-Meyer-Olkin measure) and Bartlett's test were conducted to check if these factors met sample adequacy. 0.865 of KMO value exceeded the accepted value of 0.5, and Bartlett's test of Sphericity was significant ($X^2(21) = 2128.70$, $p< 0.001$. This indicates that the samples' adequacy can be accepted and validated the significance of this study. Noise was eliminated from satisfaction factors due to low factor loading (under 0.5), and it represented a different construct. Substantively, two tendencies were identified which are independent of one another.

TABLE 6.3 Results of factor analysis based on structure matrix with Oblimin rotation

	Loadings			
	Factor 1: Thermal comfort-related satisfaction	Factor 2: Visual comfort-related satisfaction	Communalities	Cumulative (%)
Temperature	0.880		0.634	56.979
Air quality	0.874		0.599	
Humidity	0.855		0.722	
Overall comfort	0.793		0.775	
View to outside		0.850	0.738	71.397
Daylight		0.835	0.731	
Artificial lighting		0.700	0.797	
Noise		Eliminated		

6.6 Exploring design factors related to user satisfaction

The categorical regression analysis was performed using the enter method, to identify the relative contribution of influential design factors on user satisfaction and to predict the factors in all seasons. The enter method prevents the elimination of the variables that are significant but have a weak contribution. These regression models, based on two factor models, were designed for each season. The results describe which design factors had substantial contribution to user satisfaction with thermal and visual comfort, and how user satisfaction depends on desk location, orientation, layout and WWR.

TABLE 6.4 shows the relative contribution of influential design factors on thermal and visual satisfaction. R^2 indicates how well the model fits the data.

$$R^2 = \frac{\text{Variance explained by the model}}{\text{Total variance}}$$

The range of R^2 was between 9.0% and 15.0%, which were relatively low R-squared values. However, the regression models showed that independent variables were statistically significant. Therefore, objective variables (desk location, orientation, layout, and WWR) were found to be significant predictors for user satisfaction in the work environments. All objective variables had a positive relationship with satisfaction parameters. β value refers to the standardised coefficient. In detail, the largest coefficient of thermal satisfaction occurred in 'desk location', $\beta = 0.269$, $p < 0.001$, for mid-season, $\beta = 0.230$, $p < 0.001$ for summer, and $\beta = 0.212$, $p < 0.001$ for winter. The largest coefficient of visual satisfaction occurred in 'desk location', $\beta = 0.180$, $p < 0.001$ for mid-season, $\beta = 0.189$, $p < 0.001$ for summer, and $\beta = 0.206$, $p < 0.001$ for winter, followed by 'layout'.

TABLE 6.4 Results of categorical regression analysis (N=579)

	Dependent	Independent	β	Importance	*P*-value	R^2	*P*-value
Mid-season	Thermal satisfaction	Desk location	**0.269**	**0.586**	**p < 0.001**	0.128	*p* < 0.001
		Orientation	0.106	0.131	**p < 0.001**		
		Layout	0.185	0.263	**p < 0.001**		
		WWR	0.046	0.020	0.184		
	Visual satisfaction	Desk location	**0.180**	**0.408**	**p < 0.001**	0.088	*p* < 0.001
		Orientation	0.125	0.214	**p < 0.001**		
		Layout	0.168	0.309	**p < 0.001**		
		WWR	0.069	0.068	**0.026**		
Summer	Thermal satisfaction	Desk location	**0.230**	**0.406**	**p < 0.001**	0.149	*p* < 0.001
		Orientation	0.191	0.306	**p < 0.001**		
		Layout	0.183	0.218	**p < 0.001**		
		WWR	0.094	0.069	**0.007**		
	Visual satisfaction	Desk location	**0.189**	**0.420**	**p < 0.001**	0.093	*p* < 0.001
		Orientation	0.141	0.238	**p < 0.001**		
		Layout	0.162	0.304	**p < 0.001**		
		WWR	0.058	0.038	0.086		
Winter	Thermal satisfaction	Desk location	0.212	**0.386**	**p < 0.001**	0.124	*p* < 0.001
		Orientation	0.126	0.184	**p < 0.001**		
		Layout	**0.213**	0.332	**p < 0.001**		
		WWR	0.110	0.097	**0.001**		
	Visual satisfaction	Desk location	**0.206**	**0.511**	**p < 0.001**	0.092	*p* < 0.001
		Orientation	0.094	0.126	**0.002**		
		Layout	0.167	0.305	**p < 0.001**		
		WWR	0.058	0.059	0.071		

Note: p-values in bold highlighted are statistically significant (p < 0.05),
β coefficients in bold highlighted mean the largest satisfaction coefficient.

To interpret the contributions of four predictors, it is important to inspect Pratt's measure of relative importance. The largest importance corresponded to 'desk location', 'layout', and 'orientation' accounting for over 90% of the importance. Despite of the relatively small standardised coefficient of 'orientation', the large importance of 0.306 occurred in the satisfaction with thermal comfort in summer. In summary, 'desk location', 'layout', and 'orientation' predictors highly contributed to environmental user satisfaction in workplaces.

TABLE 6.5 shows the relative contribution of design factors to predict psychological satisfaction. The range of R^2 was between 5.6% and 14.2%, which shows how well the model fits the data. Overall, WWR was not a statistically significant design factor for the satisfaction with psychological comfort, except for the satisfaction with 'concentration' and ‘territoriality’. ‘Desk location’, ‘orientation’ and ‘layout’ were the significant predictors for psychological user satisfaction in the work environment. The largest coefficient of ‘privacy’, ‘concentration’, and ‘territoriality’ occurred in ‘layout’, β = 0.326, p <0.001, β = 0.248, p <0.001, and β = 0.243, p <0.001, respectively. ‘Orientation’ was the greatest contribution factor for the satisfaction with communication of β = 0.172, p <0.001, and social contact of β = 0.154, p <0.001. Therefore, the factor contributing most to the user satisfaction was ‘layout’ followed by ‘orientation’.

TABLE 6.5 Relative contribution of design factors (results from categorical regression analysis)

Dependent	Independent	β	Importance	*P*-value	R^2	*P*-value
Privacy	Desk location	0.112	0.068	**0.004**	0.142	*p* < 0.001
	Orientation	0.145	0.188	**p < 0.001**		
	Layout	**0.326**	**0.744**	**p < 0.001**		
	WWR	0.018	-0.001	0.779		
Concentration	Desk location	0.092	0.077	**0.009**	0.115	*p* < 0.001
	Orientation	0.207	0.423	**p < 0.001**		
	Layout	**0.248**	**0.489**	**p < 0.001**		
	WWR	0.081	0.012	**0.045**		
Communication	Desk location	0.101	0.160	**0.006**	0.068	*p* < 0.001
	Orientation	**0.172**	**0.507**	**p < 0.001**		
	Layout	0.153	0.335	**p < 0.001**		
	WWR	0.032	-0.002	0.600		
Social contact	Desk location	0.138	0.383	**0.001**	0.056	0.001
	Orientation	**0.154**	**0.457**	**p < 0.001**		
	Layout	0.061	0.036	0.104		
	WWR	0.090	0.124	**0.012**		
Territoriality	Desk location	0.044	-0.004	0.537	0.077	*p* < 0.001
	Orientation	0.112	0.202	**0.001**		
	Layout	**0.243**	**0.774**	**p < 0.001**		
	WWR	0.037	0.027	0.404		

Note: p-values in bold highlighted are statistically significant (p < 0.05),
β coefficients and importance in bold highlighted mean the largest satisfaction coefficient.

FIG. 6.4 illustrates which of the independent design variables have a greater impact on user satisfaction with thermal and visual comfort in different seasons. Taken together, ‘desk location’ and ‘layout’ showed greater impact on thermal and visual comfort regardless of seasons. On the other hand, ‘WWR’ was the least important predictor for satisfaction with thermal comfort, and the variable did not significantly attribute to visual comfort in summer and winter but mid-season. Although ‘orientation’ was a significant predictor, the beta weight was relatively smaller than that of ‘desk location’ and ‘layout’.

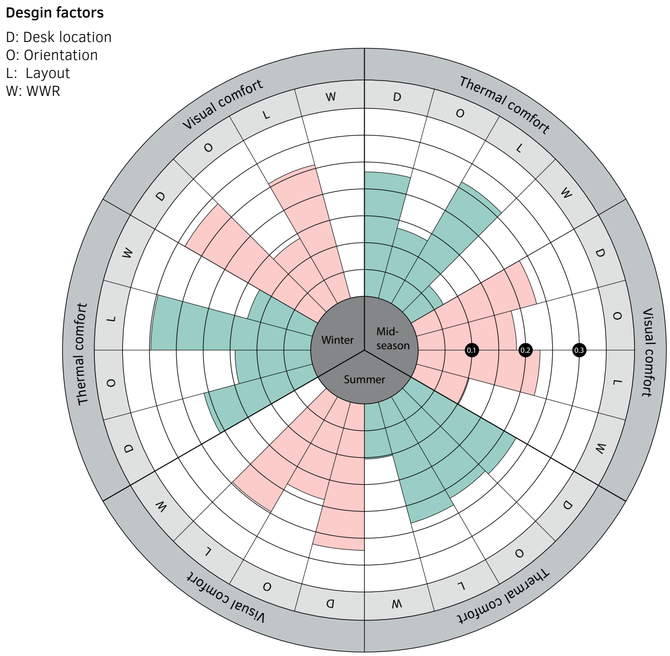


FIG. 6.4 Influential weight of design factors on user satisfaction with thermal and visual comfort

FIG. 6.5 illustrates the influential weight of design factors based on TABLE 6.5. According to FIG. 6.5, ‘layout’ must be considered as the most important design factor for ‘privacy’, ‘concentration’, and ‘territoriality’, and relatively low contribution for ‘communication’. In contrast, the factor was not statistically significant for ‘social contact’. ‘Orientation’ was the second significant design factor of all satisfaction variables. In contrast, WWR was only presented as a statistically significant factor to concentration and social contract.

TOC

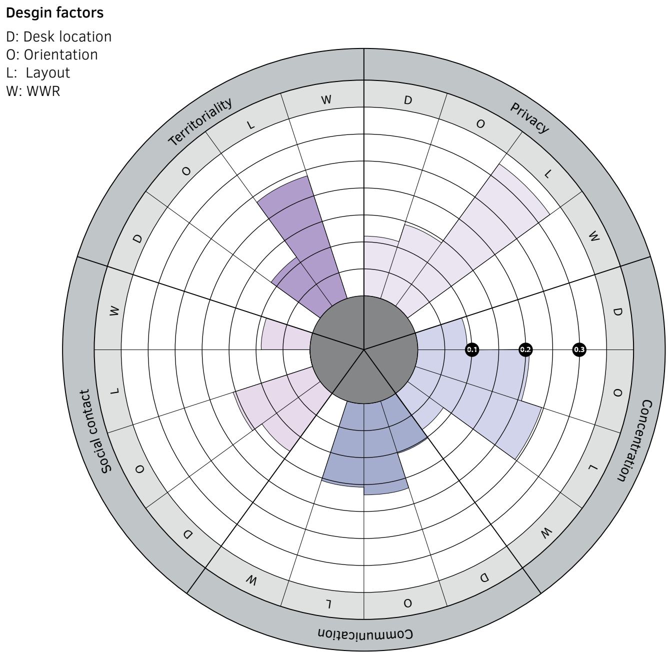


FIG. 6.5 Influential weight of design factors on psychological satisfaction factors

FIG. 6.6 displays nominal transformation plots for design factors. It shows the relationship between the quantifications and the independent categories selected by optimal scaling level. It was created based on categorical regression. It shows the tendency of user satisfaction for design factors. The X axis represents the order of the codes used in each parameter, and the Y axis represents the quantification values of transformed dependent variables.

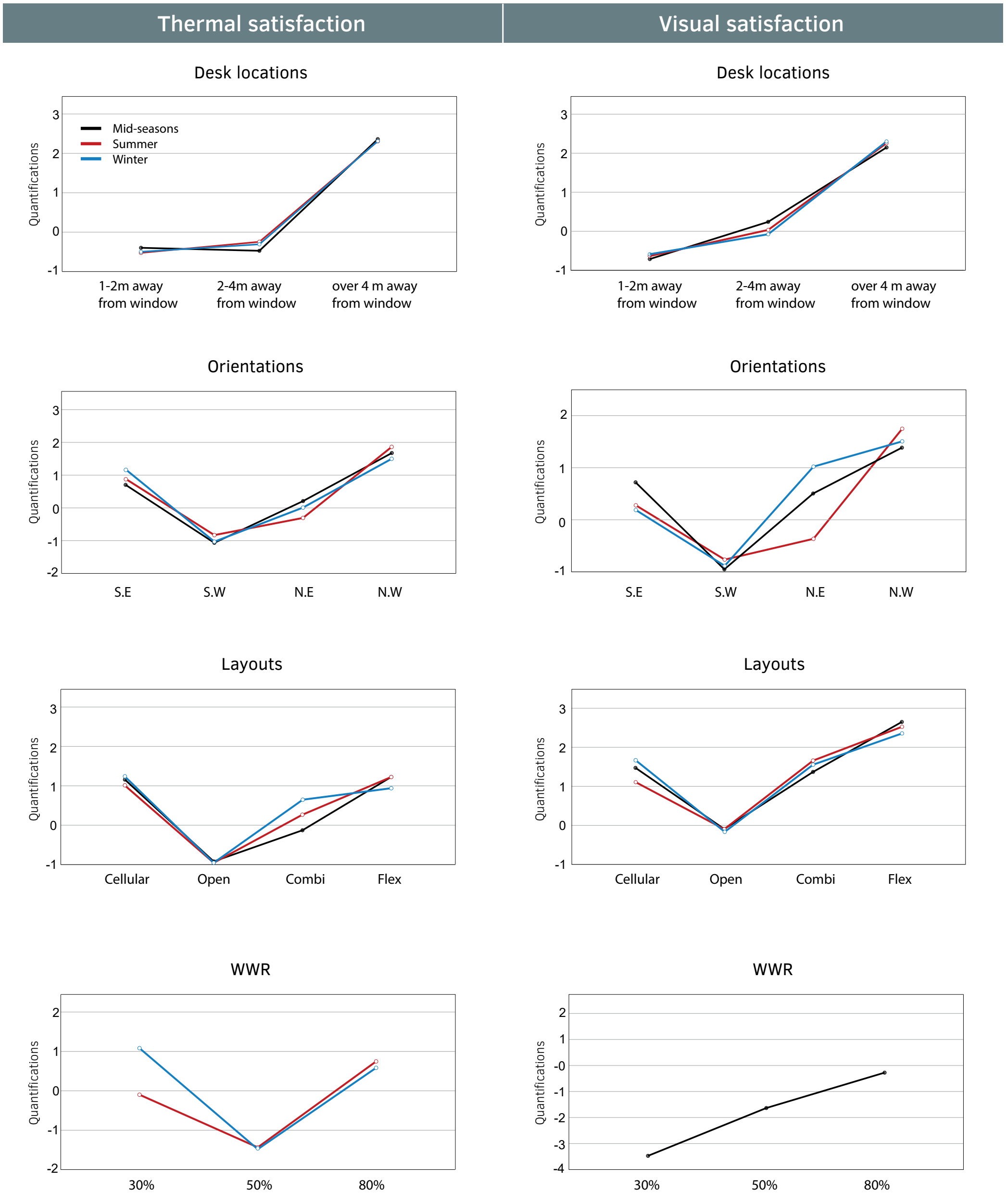
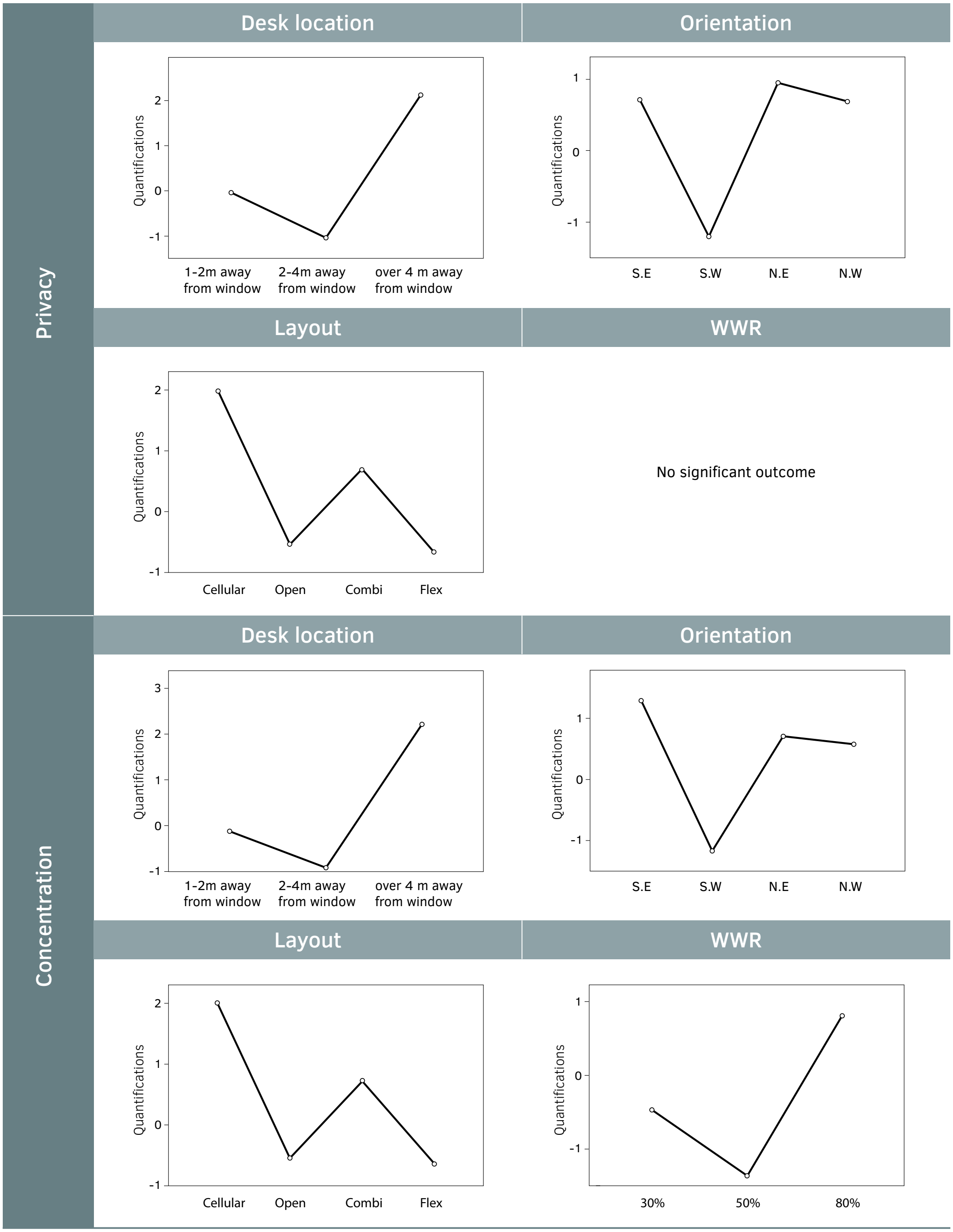
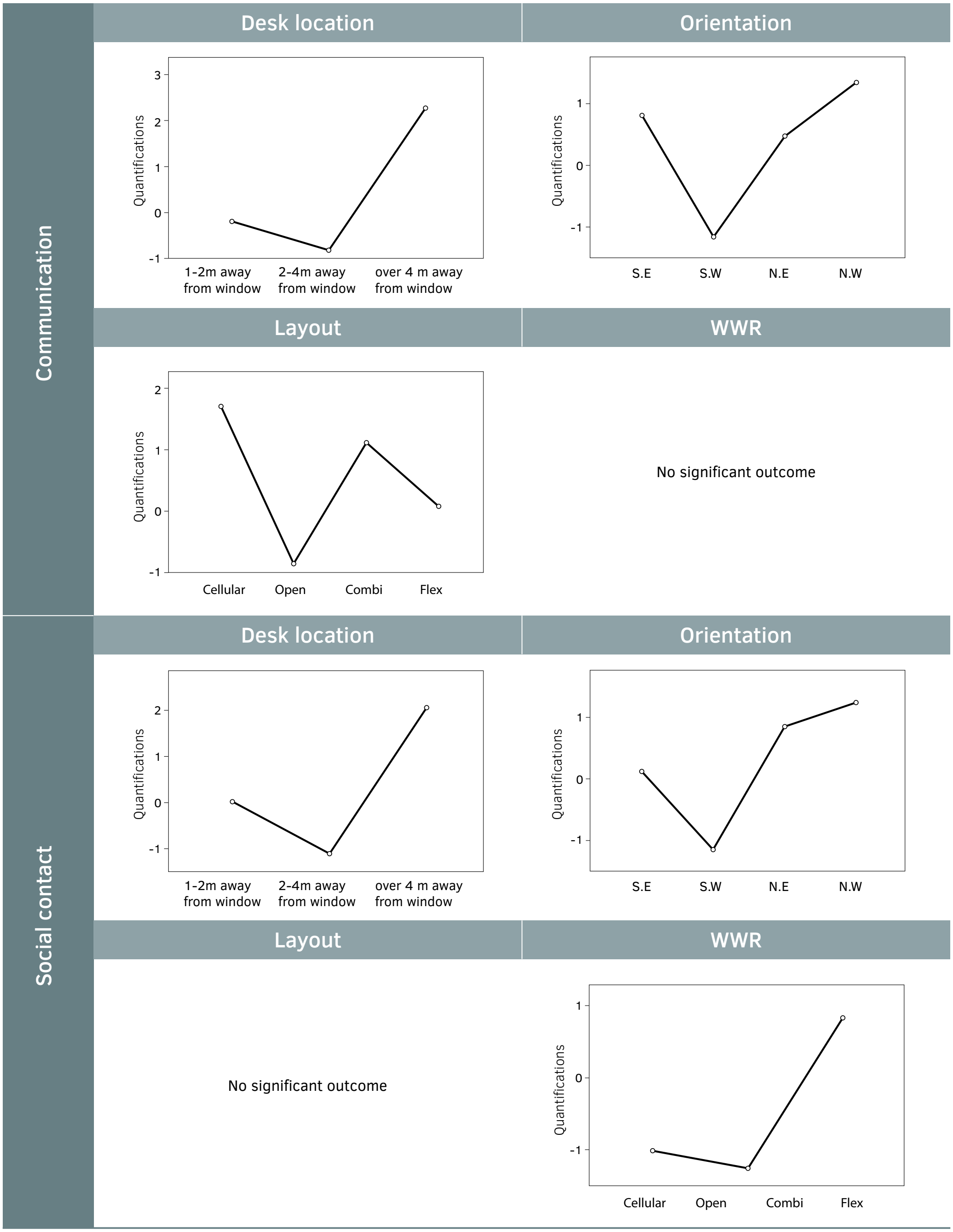


FIG. 6.6 The relationship between design factors and user satisfaction with thermal and visual comfort based on categorical regression

The original values of dependent variables are categorical; therefore, the values were transformed to numerical quantification through the optimal scaling. The procedure of transformation allows categorical variables to be analysed to find the best-fitting model (Shrestha, 2009). The transformed quantifications are the values assigned to each category to make non-linear relation and reflects characteristics of the original categories (Meulman & Heiser, 1999). Therefore, each quantification value itself is not important. For example, ‘over 4m distance from windows’ showed the largest quantification, therefore, increasing the predicted satisfaction level. First, for the desk location placed far away from windows, people were more satisfied with the thermal and visual satisfaction. Second, cellular office as one of four layouts showed the highest satisfaction for thermal comfort in mid-season and winter among four layouts. In summer, however, the flexible office showed a higher thermal satisfaction than the cellular type. On the other hand, open-plan office was the worst layout for thermal comfort for all seasons. For visual satisfaction, the pattern was quite similar, but combi and flexible offices tended to be preferred and resulted in higher visual satisfaction. Next, the orientation that the occupants were most satisfied with was north-west, and least satisfied was south-west for both thermal and visual satisfaction. The results of thermal satisfaction in mid-season, and visual satisfaction with comfort in summer and winter according to WWR were not statistically significant. Therefore, the graphs were eliminated.

FIG. 6.7 presents the tendency of user satisfaction with psychological comfort according to the nominal design factors. The β values in TABLE 6.5 were positive, and therefore the higher Y axis values indicate the higher predicted satisfaction level. The design factors which were not significant for a certain satisfaction variable were eliminated. In detail, the desk location over 4m away from windows was predicted to increase user satisfaction with psychological comfort variables, except for territoriality. However, the contribution weight of ‘desk location’ was not as high as other design factors. The most notable outcome in the categorical regression analysis was ‘office layout’. The probability of higher satisfaction with privacy, concentration, and territoriality was shown in the order of cellular > combi > open > flex-office, whereas the probability of higher satisfaction with communication was presented as following the order of cellular > combi > flex > open-plan office.


Privacy
Desk location
Quantifications
2
1
0
-1
1-2m away from window
2-4m away from window
over 4 m away from window
Orientation
Quantifications
1
0
-1
S.E
S.W
N.E
N.W
Layout
Quantifications
2
1
0
-1
Cellular
Open
Combi
Flex
WWR
No significant outcome
Concentration
Desk location
Quantifications
3
2
1
0
-1
1-2m away from window
2-4m away from window
over 4 m away from window
Orientation
Quantifications
1
0
-1
S.E
S.W
N.E
N.W
Layout
Quantifications
2
1
0
-1
Cellular
Open
Combi
Flex
WWR
Quantifications
1
0
-1
30%
50%
80%


Communication
Desk location
Quantifications
3
2
1
0
-1
1-2m away from window
2-4m away from window
over 4 m away from window
Orientation
Quantifications
1
0
-1
S.E
S.W
N.E
N.W
Layout
Quantifications
2
1
0
-1
Cellular
Open
Combi
Flex
WWR
No significant outcome
Social contact
Desk location
Quantifications
2
1
0
-1
1-2m away from window
2-4m away from window
over 4 m away from window
Orientation
Quantifications
1
0
-1
S.E
S.W
N.E
N.W
Layout
No significant outcome
WWR
Quantifications
1
0
-1
Cellular
Open
Combi
Flex

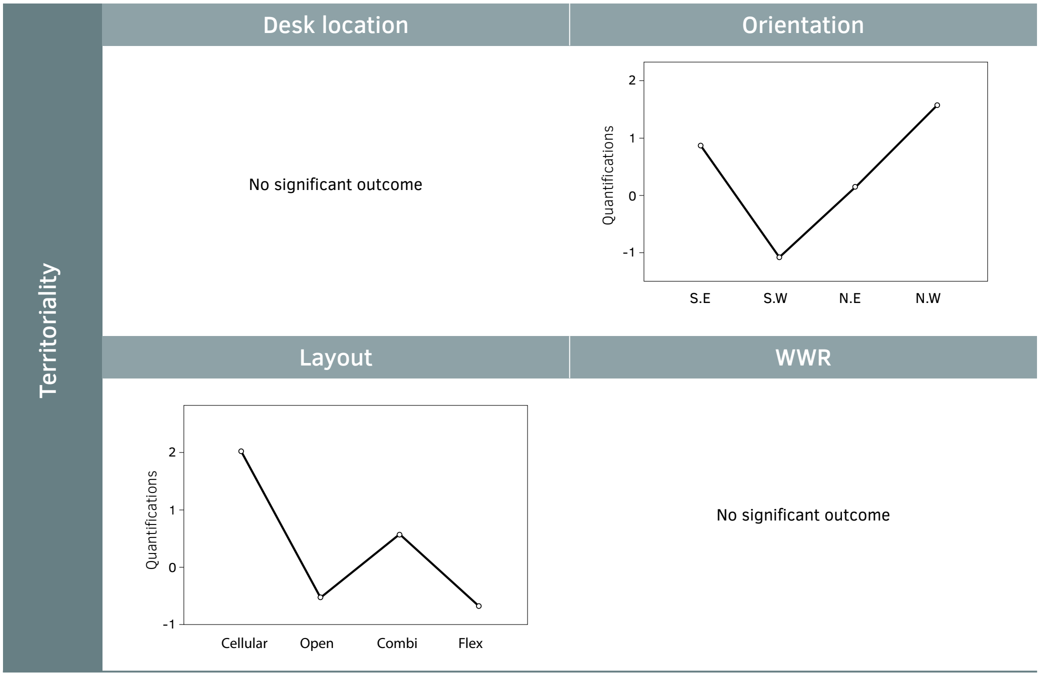


FIG. 6.7 The relationship between design factors and user satisfaction with psychological comfort based on categorical regression

6.7 Predicted environmental and psychological user satisfaction models

Based on a categorical regression test, variables of 'desk location', 'layout', and 'orientation' were further examined by the binary logistic regression using office design factors as the dependent variable and thermal and visual satisfaction as the independent variable. Nagelkerke R^2 (Nagelkerke, 1991) shows that the model explains roughly 20-25% of the variation in the outcome. Hosmer-Lemeshow test indicates goodness of fit for logistic regression. The *p*-value was higher than 0.05 so that the model fits the data.

TABLE 6.6 presents the results of the logistic regression reporting a regression coefficient (B), an odds ratio (β), and *p*-value. In the model, one less than the number of categories were created as dummy variables. Therefore, desk location over 4m away from window, N.W, and flex-office layout were omitted, and calculated as the base variables. The results represent that there was a statistical significance between desk location and environmental satisfaction. In detail, occupants who sit over 4m away from the windows were 3.85-5.71 times more satisfied with the thermal comfort than those who sit closer to the windows, and 2.65-7.25 times more satisfied with the visual comfort. The impact of orientation on satisfaction was only significant for thermal satisfaction in summer, and visual satisfaction in mid-season and summer. South-west and north-west façade had strong impact on thermal and visual comfort, mainly in summer. Occupants of workplaces facing to the north-west orientation were 3.53-4.50 times more satisfied (followed by those who sit on the north-east) than were people facing south-west. As the results of categorical regression analysis shows, office layout was an important predictor for environmental satisfaction for all seasons. The prediction impact between open plan and flex-office was significant, $p < 0.05$. The occupants in flex-office tended to be 3.55-4.07, and 3.90-4.85 times more satisfied with thermal and visual comfort respectively than those in open-plan offices.

TABLE 6.6 Results of binary logistic regression of design factors and IEQ user satisfaction: Hosmer-Lemeshow test, Odd-ratios are reported with confidence intervals parentheses and P-value (N = 579)

Satisfaction with thermal comfort						
Variable	Moderate season		Summer		Winter	
	OR(CI 95%)	*P*- value	OR(CI 95%)	*P*- value	OR(CI 95%)	*P*- value
Desk location		**$p < 0.001$**		**$p < 0.001$**		**0.001**
0-2m	**0.20 (0.08-0.44)**	**$p < 0.001$**	**0.18 (0.08-0.40)**	**$p < 0.001$**	**0.23 (0.10-0.50)**	**$p < 0.001$**
2-4m	**0.22 (0.09-0.49)**	**$p < 0.001$**	**0.20 (0.09-0.47)**	**$p < 0.001$**	**0.26 (0.11-0.60)**	**0.002**
Orientation		0.069		**$p < 0.001$**		0.070
S.E	0.63 (0.24-1.63)	0.343	0.53 (0.20-1.37)	0.191	0.69 (0.27-1.75)	0.433
S.W	0.38 (0.18-0.80)	0.011	**0.22 (0.10-0.47)**	**$p < 0.001$**	0.38 (0.18-0.81)	0.012
N.E	0.50 (0.23-1.08)	0.080	**0.28 (0.12-0.58)**	**0.001**	0.52 (0.24-1.13)	0.099
Layout		**0.000**		**$p < 0.001$**		**$p < 0.001$**
Open	1.09 (0.47-2.57)	0.836	0.79 (0.36-1.73)	0.552	1.14 (0.48-2.70)	0.760
Combi	**0.28 (0.15-0.53)**	**$p < 0.001$**	**0.28 (0.15-0.52)**	**$p < 0.001$**	**0.25 (0.13-0.48)**	**$p < 0.001$**
Flex	0.44 (0.18-1.09)	0.077	0.55 (0.22-1.38)	0.202	0.63 (0.25-1.61)	0.338
WWR	-	-	-	-	-	-
30%	-	-	-	-	-	-
50%	-	-	-	-	-	-
	R^2	0.210	R^2	0.255	R^2	0.224
	HL test	0.535	HL test	0.700	HL test	0.423
	Classification (%)	66.5	Classification (%)	68.0	Classification (%)	67.3
Satisfaction with visual comfort						
Variable	Moderate season		Summer		Winter	
	OR(CI 95%)	*P*- value	OR(CI 95%)	*P*- value	OR(CI 95%)	*P*- value
Desk location		**0.002**		**$p < 0.001$**		**$p < 0.001$**
0-2m	**0.19 (0.07-0.49)**	**0.001**	**0.14 (0.05-0.38)**	**$p < 0.001$**	0.14 (0.05-0.37)	**$p < 0.001$**
2-4m	**0.38 (0.15-0.98)**	**0.045**	**0.30 (0.11-0.79)**	**0.015**	0.20 (0.07-0.53)	**0.001**
Orientation		**0.038**		**0.034**		0.165
S.E	0.45 (0.15-1.30)	0.141	0.57 (0.20-1.66)	0.304	0.55 (0.18-1.66)	0.292
S.W	**0.28 (0.11-0.68)**	**0.005**	**0.28 (0.11-0.71)**	**0.007**	0.34 (0.13-0.91)	0.031
N.E	0.52 (0.21-1.32)	0.170	0.65 (0.25-1.68)	0.370	0.61 (0.23-1.63)	0.322
Layout		**0.005**		**0.002**		**0.002**
Open	0.59 (0.22-1.60)	0.300	**0.34 (0.12-0.96)**	**0.042**	0.38 (0.13-1.08)	0.069
Combi	**0.26 (0.12-0.56)**	**0.001**	**0.21 (0.09-0.46)**	**$p < 0.001$**	0.23 (0.10-0.50)	**$p < 0.001$**
Flex	0.53 (0.19-1.54)	0.245	0.35 (0.12-1.06)	0.064	0.69 (0.23-2.14)	0.526
WWR	-	-	-	-	-	-
30%	-	-	-	-	-	-
50%	-	-	-	-	-	-
	R^2	0.229	R^2	0.248	R^2	0.245
	HL test	0.743	HL test	0.515	HL test	0.917
	Classification (%)	68.7	Classification (%)	75.0	Classification (%)	71.5

Note: B coefficients and odd ratio (β) in bold highlighted are statistically significant ($p < 0.05$)

A binary logistic regression was used to predict the impact of design factors on psychological user satisfaction, The data were recoded to dependent variables (satisfied, not satisfied), and each design parameter was analysed as dummy variables. This analysis validated the categorical regression result, and used the enter method to include the predictors that significantly contributed to the regression model.

In TABLE 6.7, the significance of regression models was tested by the Omnibus test ($p < 0.05$). The model explained 4-12% (Nagelkerke R^2) of the variance in satisfaction and correctly classified over 60% of the cases. The data were fit for the logistic regression analysis, showing over 0.05 of p-value tested by the Hosmer-Lemeshow analysis. The significant relationships contributing to satisfaction were found for 'layout', 'desk location', and 'orientation'. On the contrary to the result of CATREG, the variable 'orientation' was not statistically significant for psychological satisfaction, except for 'concentration'. In detail, occupants in cellular offices were 3.4 times (OR 0.29, 95% CI: 0.17-0.49) more likely to be satisfied with privacy, 2.7 times (OR 0.37, 95% CI: 0.21-0.63) more with concentration, and 1.8 times (OR 0.55, 95% CI: 0.33-0.90) more with territoriality than those who work in open-plan offices. The cellular office users also tended to be 3.7 times (OR 0.27, 95% CI: 0.15-0.5) more satisfied with privacy, 3.0 times (OR 0.33, 95% CI: 0.17-0.61) more with concentration, and 2.2 times (OR 0.45, 95% CI: 0.25-0.81) more with territoriality than those who work in flex-offices. 'Desk location' was an important predictor for psychological satisfaction variables except for 'concentration'. Remarkably, occupants sitting over '4m away from windows' were 2-2.5 times more satisfied than those sitting '2-4m away from windows', and 2-2.2 times more than the group of occupants sitting '0-2 m away from window'. Although 'orientation' was the second significant factor for the satisfaction in the results of the categorical analysis, this design factor was only significantly predicting the satisfaction with concentration. People in the workstations oriented to N.W tended to be more satisfied with concentration than those working in S.W. oriented workstations, and no statistical significance was found for WWR.

TABLE 6.7 Results of binary logistic regression of design factors and psychological user satisfaction: Hosmer-Lemeshow test, Odd-ratios are reported with confidence intervals parentheses and P-value (N = 579)

Variable	Privacy		Concentration		Communication		Social contact		Territoriality	
	OR(CI 95%)	*P*- value	OR(CI 95%)	*P*- value	OR(CI 95%)	*P*- value	OR(CI 95%)	*P*- value	OR(CI 95%)	*P*- value
Desk location		**0.010**		0.066		**0.027**		0.141		**0.006**
0-2m	0.49 (0.28-0.85)	**0.011**	0.72 (0.41-1.26)	0.250	0.47 (0.26-0.82)	**0.009**	0.56 (0.27-1.15)	0.119	0.44 (0.26-0.75)	**0.003**
2-4m	0.40 (0.22-0.73)	**0.003**	0.49 (0.27-0.91)	**0.024**	0.48 (0.26-0.87)	**0.017**	0.47 (0.22-0.99)	**0.048**	0.43 (0.24-0.76)	**0.004**
Orienta-tion		**0.001**		**p < 0.001**		**0.034**		0.213		**0.007**
S.E	1.77 (0.92-3.43)	0.087	1.59 (0.82-3.05)	0.164	0.97 (0.50-1.85)	0.929	1.48 (0.65-3.40)	0.346	1.80 (0.95-3.41)	0.068
S.W	0.75 (0.42-1.31)	0.317	0.52 (0.30-0.91)	**0.024**	0.63 (0.37-1.06)	0.088	0.71 (0.39-1.30)	0.273	0.70 (0.41-1.2)	0.205
N.E	1.75 (0.99-3.10)	0.053	1.32 (0.76-2.31)	0.320	1.16 (0.66-2.02)	0.593	0.86 (0.45-1.62)	0.646	1.15 (0.66-2.00)	0.604
Layout		**p < 0.001**		**0.001**		0.463	-	-		**0.018**
Open	0.29 (0.17-0.49)	**p < 0.001**	0.37 (0.21-0.63)	**p < 0.001**	0.70 (0.42-1.16)	0.169	-	-	0.55 (0.33-0.90)	**0.019**
Combi	0.52 (0.25-1.08)	0.080	0.46 (0.22-0.99)	**0.047**	0.96 (0.46-1.97)	0.913	-	-	0.97 (0.48-1.98)	0.951
Flex	0.27 (0.15-0.50)	**p < 0.001**	0.33 (0.17-0.61)	**p < 0.001**	0.86 (0.48-1.54)	0.626	-	-	0.45 (0.25-0.81)	**0.008**
WWR	-	-		0.314	-	-		0.295	-	-
30%	-	-	0.89 (0.44-1.79)	0.748	-	-	0.67 (0.34-1.33)	0.257	-	-
50%	-	-	0.70 (0.44-1.10)	0.130	-	-	0.73 (0.47-1.14)	0.174	-	-
	R^2	0.129	R^2	0.120	R^2	0.050	R^2	0.040	R^2	0.081
	HL test	0.529	HL test	0.364	HL test	0.435	HL test	0.337	HL test	0.414
	Classifica-tion (%)	69.8	Classifica-tion (%)	68.0	Classifica-tion (%)	60.6	Classifica-tion (%)	75.4	Classifica-tion (%)	65.9

Note: B coefficients and odd ratios (95% CI) in bold highlighted are statistically significant ($p < 0.05$),
The results of Omnibus test are statistically significant ($p < 0.05$),
HL test refers Hosmer-Lemeshow test

FIG. 6.8 shows the most significant parameters of user's psychological satisfaction based on occupants' vote. In the questionnaire, 47.5% occupants responded 'having individual spaces for concentration' which was to be the most important aspect for their work environment followed by 'privacy'. On the contrary, 'social contact' was the least important aspect with 9.7% responses.

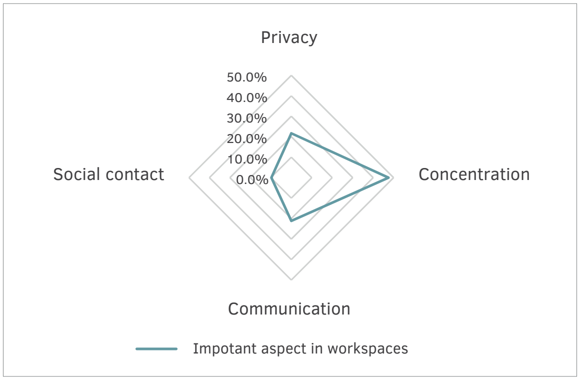


FIG. 6.8 Important psychological aspects in workspaces

6.8 Discussion

6.8.1 Design factors as predictors of occupant satisfaction

This chapter attempted to identify which design factors among desk location, layout, orientation, and WWR play a major role for the occupants' satisfaction with thermal, visual, and psychological comfort through user-based surveys and statistical analyses. As shown in TABLE 6.4 and 6.5, the occupants' satisfaction with thermal and visual comfort were statistically different according to the 'desk location', 'office layout', and 'orientation'. In contrast, WWR was not a statistically significant factor for thermal and visual satisfaction. The results from 579 office occupants showed that 'desk location' was the most influential factor to optimise IEQ satisfaction.

Desk location

Awada and Srour (2018) reported that employees who are close to a window tend to be more satisfied with IEQ conditions than those who are far away from a window. In contrast to their study, the results in this chapter showed that occupants who sit far away from windows tend to be more satisfied with environmental comfort compared to occupants who sit close to windows. Interestingly, there was no difference on the responses of satisfaction with thermal and visual comfort in different seasons. According to descriptive analysis, around 37% responded neither dissatisfied nor satisfied with thermal satisfaction, and over 60% for visual satisfaction in different seasons, followed by dissatisfied. In other words, people were almost equally responded their satisfaction in questionnaires. The outcomes in this chapter showed that workstations located close to windows have a bigger chance to be exposed to overheating indoor spaces due to the direct sun (Montazami et al., 2017) and unwanted illumination (Šeduikyte & Paukštys, 2008). Kamaruzzaman et al. (2015b) also revealed that thermal and glare level can be problems according to how close people sit to the window. Other reasons could be unoperable windows, positions of air inlets and outlets, and placement of radiators. However, these were not examined.

Orientation

Despite of the importance of design factors, few studies included ‘orientation’ as a design factor or a building feature in thermal comfort studies, since some studies stated that ‘orientation’ is not correlated to thermal comfort (Hua et al., 2014; Schakib-Ekbatan et al., 2015). On the other hand, Sadeghi et al. (2018) emphasised considering the influence of different façade orientations on visual preference. This research included ‘orientation’ as one of the design factors, and showed that the factor was comparatively less relevant to the satisfaction. However, the result in this chapter, showed that it was a considerably important factor for the satisfaction with thermal comfort in summer. Similarly, Konis (2013) suggested that ‘orientation’ has an impact on visual comfort, and people on the N.W zone were dissatisfied due to the direct sun and glare. Hua et al. (2014) stated that satisfaction with temperature is low regardless of orientations in both summer and winter. It means that orientation has no influence on the satisfaction with temperature. Instead, orientation contributed to the level of visual comfort with glazed façades. It is assumed that the existence of façade elements such as window blinds and management of the system could cause the different results.

Office layout

The findings in this chapter are consistent with an earlier study by Bluyssen et al. (2011), addressing that office layout has a primary impact on the comfort satisfaction in summer and winter. A study by Altomonte et al. (2019) revealed a strong correlation between spatial layout and workplace satisfaction and addressed that spatial design factors have a substantial impact on user satisfaction. The results related to layout are in line with the findings of Altomonte et al. (2016) and Shahzad et al. (2016), which revealed that IEQ satisfaction and thermal comfort are higher in cellular offices than open offices. It assumed that people have the high availability of thermal and lighting control in cellular offices than open offices.

6.8.2 Psychological satisfaction studies

As the categorical regression results have shown, office layout is absolutely important for user satisfaction. This research included four different layout groups, and the results were in line with the precedent research findings. In this research, open office was predicted to give higher satisfaction with territoriality than flex office, while flex office was predicted to give higher satisfaction in terms of communication than open plan office. This outcome supports the findings of Rolfö et al. (2018) and Gorgievski et al. (2010).

Rolfö et al. (2018) compared user satisfaction between open-plan offices and activity-based work places with flexi-desks, and observed different satisfaction rate according to the office types. Open-plan offices decreases user satisfaction in terms of privacy (De Croon et al., 2005; Kim & De Dear, 2013), and communication (Brennan et al., 2002). On the other hand, cellular offices showed good overall psychological satisfaction results. Aries et al. (2010) also reported that the best satisfaction results were found in cellular offices.

Combi and flex-office types were included additionally in this research. The probability of higher satisfaction was observed in combi-offices as well as cellular offices, as opposed to open and flex offices. It is assumed that combi-office has personal workstations, which can be shared with others, and meeting spaces for group/team work. Although the probability of user satisfaction in combi offices was not higher than for cellular offices, it was relatively higher than for open and flex-offices. De Been and Beijer (2014) revealed that occupants in combi-offices were more satisfied with communication than those in flex-offices. They argued that creating more chance to meet colleagues through the layout design does not lead to better communication. De Been and Beijer (2014) also reported that occupants in combi and flex offices were less satisfied with privacy and concentration than occupants in cellular and shared offices. In the result of the categorical regression analysis, users in combi-offices were more satisfied with communication than users in open and flex offices, which can partly support the results of De Been and Beijer (2014). Even though open-plan offices have been known as causing lower concentration, and more interruptions (Samani et al., 2017), occupants from open offices tended to be more satisfied with privacy, concentration, and territoriality than those working in flex offices. It is assumed that open offices allow occupants to have their own desks so that they were guaranteed territoriality. According to the regression analysis, 'office layout' did not significantly predict user satisfaction with communication. Nonetheless, the office users were found to be the most satisfied with the cellular office layout, followed by combi offices, the open plan office and lastly, flex offices.

'Orientation' was the second largest contribution factor to psychological satisfaction in. Nonetheless, there are few studies dealing with the association between façade/ workstation orientation and psychological satisfaction. Instead, there are many studies about orientation and visual comfort (Araji, 2008). Aries et al. (2010) tried to identify the impact of façade orientation on physical psychological discomfort, but orientation was ignored and combined in one group for their further research. One of the questionnaires in their research, was to examine the view quality. Users were supposed to answer whether they had good or bad outside view. They found that view quality influences employees' visual or psychological comfort, which was also confirmed by Tuaycharoen and Tregenza (2007). Even though the impact of orientation on psychological satisfaction has not been investigated yet, it can be explained that view/orientation may affect psychological satisfaction. Fabi et al. (2011) reported that users located towards the south façade would interact more with windows by opening and closing windows, and blinds. However, it does not mean that people were highly satisfied with the interaction. In this chapter, orientation greatly contributed to users' concentration on work. having a N.E orientation tended to be more satisfied than those working at the S.W. People working at the S.W showed least satisfaction with other psychological variables. Together with the findings of Fabi et al. (2011), the phenomenon can be explained by an assumption that as having more interaction with the façade causes low concentration of occupants on work.

How far people sit away from the window was not a significant predictor for territoriality, but it was a significant factor for the rest of the satisfaction parameters. Remarkably, 'desk location' gave the biggest effect on satisfaction with social contact. Although this research found that there was a relationship between desk location and psychological satisfaction, hardly any research has studied this association. Aries et al. (2010) used the same scale of parameters for desk location categories: 0-2m, 2-4m, and over 4m. The most frequent subject related to vicinity of the window is illuminance. For this reason, desk location was an important factor for the exposure of occupants to natural daylight or not. Escuyer and Fontoynont (2001) and Wang and Boubekri (2011) revealed that the desk location influences satisfaction with illuminance, and shows negative impact of desks close to windows on concentration. It is obvious that glare from direct sunlight causes occupants' visual discomfort (Inkarojrit, 2005). In line with the previous research, this chapter showed that the glare may not only decrease visual comfort but also disturb concentration on work. Although WWR was analysed to examine the impact of the natural daylight on psychological satisfaction, the 'WWR' was not a significant factor to predict any of the psychological satisfaction factors.

6.8.3 Statistical analysis

Evaluating users' comfort and satisfaction is complicated since it is difficult to interpret the results and to find a representative time and sample (Nicol & Wilson, 2011). Some studies used various statistical analysis to investigate the relationship between building characteristics and occupants' comfort or satisfaction. Factor analysis is often implemented for user studies to investigate variable relationships (Kamaruzzaman et al., 2015a; Veitch et al., 2007). In such a way, the analysis can reduce multi-collinearities and can group variables into statistically correlated groups (Flora et al., 2012; Sant'Anna et al., 2018). By performing the factor analysis, two underlying factors (thermal comfort and visual comfort) were proposed, which had bigger impact and could better explain occupants' responses towards environmental satisfaction. Similarly, a literature review defined occupants' comfort by four categories: thermal, visual, acoustic and indoor air quality (Antoniadou & Papadopoulos, 2017).

Later, we performed categorical and binary logistic regressions (Harrell, 2015). Frontczak et al. (2012) addressed that logistic regression can help to find the relative importance among IEQ parameters and building characteristics. Wong et al. (2008) examined IEQ parameters based on thermal comfort, air quality, acoustic comfort and illumination through a logistic regression model. However, the analysis can be used to predict the influence of design factors on user satisfaction. In this research, the CATREG was used before the logistic regression since the analysis can be implemented for a non-linear transformation of multiple (non-binary) dependent and independent variables to determine the logistic factors affecting dependent variables (Çilan & Can, 2014). The analysis uses optimal scaling method to assign numerical quantification to the categories of each variable (Meulman & Heiser, 1999). it contributes to narrowing the focus variables. Consequently, binary logistic regression used to verify the significance of each predictor with dummy variables and to prevent a multi-collinearity problem in the linear multiple regression model. Therefore, this statistical approach may provide an appropriate process for user-based studies in the indoor environment and draw general conclusions in the different work environment.

6.8.4 Low level of R2 value

The low R-square was observed in the outcomes of the regression analyses. R^2 indicates the percentage of variation in the independent variables, therefore the higher the R-square value is the better the explanation of the model. In general, an R^2 of 0.75 is strong, 0.5 is moderate, and 0.25 is weak (Wong, 2013). For that reason, some researchers interpret that the model is incomplete when the R^2 is lower than 0.25, although the relation is statistically significant. However, the low R^2, indicating the large spread of data explained by independent variables, is often presented in social science since human behaviour or satisfaction is difficult to predict (Frost, 2017).

Glenn and Shelton (1983) stated that eliminating the regression results with low R^2 is not appropriate in social research, instead, it is recommended to compare to other research. Moksony (1990) demonstrated that R^2 is not useful to compare either contribution of the independent variable or the goodness of the model fit; and suggested to use the unstandardized regression coefficient for the explanatory power and the standard error for the goodness of fit.

This chapter presented the percentage of cases correctly classified, which is one of methods to examine the predictive accuracy (Hosmer et al., 2013) and the Hosmer-Lemeshow analysis was used for the goodness of fit. The regression models had statistically significant explanatory power with between 60 and 70% of cases correctly classified, and the Hosmer-Lemeshow test showed higher than 0.05 in overall model coefficient. The range of the R^2 was from 5.6% to 14.2% in the categorical analysis, and from 5% to 12.9% in the logistic regression. A study about employees' discomfort by Aries et al. (2010) shows a similar range of R^2 (2% - 22%), and an outlier of 27%.

6.8.5 Limitations

The analysis compares one design parameter to each satisfaction variable. In reality, indoor climate is influenced by a combination of design factors, not one by one. Although certain design options showed a better outcome, it is necessary to consider the combination of a design option with other design options. Therefore, a limitation of this research is that it is difficult to say that the suggested design options will always lead to the best results in terms of occupants' satisfaction. Second, noise was excluded by factor analysis. Thus, noise needs to be studied separately from IEQ study. Last, the results to buildings located in other climates may lead to different conclusions. However, the study's approach can be used for different scenarios dealing with user studies. The findings may contribute to a user-focused office design during the conceptual design phases.

Four renovated offices and one non-renovated office were selected as case studies. This research included all collected samples for the statistical analyses, which could be a limitation of the study. The collected answers may be influenced by whether the office was renovated or not, since renovated offices are expected to have a higher environmental quality compared to non-renovated offices. In order to complement the issue that office renovation might affect the user satisfaction, the mean values of satisfaction were compared in FIG 6.1 and FIG 6.2. The result showed that there was no big difference, and the non-renovated office actually showed higher satisfaction level for some categories. Thus, all samples were included for further analyses. The scale of independent variables was recoded (e.g., satisfied, no satisfied) for the binary logistic regression. This is a common simplification to interpret being satisfied and not being satisfied instead of being dissatisfied.

This research intended to explore the indirect connection between the size of windows and psychological satisfaction. WWR was not a statistically significant predictor for the increase of satisfaction. The limitation of this research is that the research boundary condition was limited to the office design with physical design factors and socio-psychological aspect, which means that variables such as interaction with nature or view quality were not considered. Instead of including cognitive visual impact, it focused on the analysis of the individual and organisational level of satisfaction. Lastly, this research did not investigate the impact of psychological satisfaction on overall work/job satisfaction. However, it is obvious that lack of privacy and personal territory can cause overall dissatisfaction in workplaces (De Been & Beijer, 2014; Lansdale et al., 2011).

6.9 Conclusion

Office buildings have been mainly designed based on practical aspects following design guides. Design factors have not been tested by occupants' satisfaction. This chapter demonstrates influential design factors that can satisfy occupants' thermal, visual, and psychological comfort by focusing on architectural space and façade design. These design factors were evaluated by the user-focused subjective assessment in real office spaces. The subjective assessment by users was a useful method to evaluate design factors and its impact on the working environment. Satisfaction ratings provide the data on occupants' satisfaction and no satisfaction. In addition, the results clearly show that how well physical environments support the needs of the occupants.

The findings provide an insight into the relationship between design factors and user satisfaction in workplaces, and the attributes of design factors on thermal, visual, and psychological satisfaction. It also suggests the relative importance of each design factor, and the probability of increasing user satisfaction according to predictable design factors. This exploration of design factors, therefore, could play a crucial role to improve occupants' satisfaction and may suggest a new approach to office planning.

Following, prediction models were created through the logistic regression analysis. The planners and architects can consider the following suggestions:

- For the user satisfaction-related study, IEQ categories (e.g., temperature, humidity, air quality, lighting, daylight, view to outside, overall comfort) can be classified by thermal and visual comfort. However, acoustic comfort needs to be analysed separately from the IEQ satisfaction model, as acoustic comfort clearly did not load on any of the factors identified in the factor analysis.
- Office layout and desk location contribute most to thermal and visual user satisfaction, and layout, orientation, and desk location contribute to psychological satisfaction in workplaces.
- Despite the weak relevance of 'orientation' for thermal and visual comfort, 'orientation' can be a significant factor for thermal comfort in summer. Moreover, workspaces facing north-west and north-east are recommended to provide higher satisfaction with thermal comfort than other orientations. it is assumed that north-oriented workspace can avoid overheating during summer.

- With similar reasons, having distance from window for working desks can increase the level of satisfaction by preventing a sudden temperature difference and unwanted illuminance.
- In contrast, WWR may not affect occupants' satisfaction with thermal and visual comfort. However, it was one of the important factors having impact on energy savings.
- The same methodology can be applied to the user-related research. However, more complex models in which different design factors interact need to be explored for further research. Moreover, the results of predicted models can be tested in different climate zones.
- High levels of satisfaction corresponded to 'layout', except for variables of 'communication' and 'social contact'.
- Although the WWR was a significant predictor for satisfaction with social contact, the binary logistic regression showed that the factor was not statistically significant for predicting satisfaction.
- The probability of user satisfaction increased following the order of flex < open < combi < cellular office for privacy, concentration, and territoriality.
- The probability of user satisfaction increased following the order of 2-4m < 0-2m < 4m away from windows for privacy and territoriality, and 0-2m < 2-4m < 4m for communication.
- Users sitting at the N.W oriented workplace were more satisfied than those who sit at the S.W oriented workplace.
- The office design for the highest probability of users' satisfaction can be estimated to be a combination of N.W oriented workplaces, working desks located at least 4m away from the windows in a cellular office layout.

From an office organisational perspective, the conclusions in this paper may not directly give directions for the best office design to increase employee satisfaction, since the results focus only on occupants' psychological comfort. To give a complete picture, also criteria contributing to physical comfort should be included. Therefore, to develop a new design approach for office renovations, these results could be enhanced by including more satisfaction parameters. Nevertheless, this exploration of design factors could play a crucial role to improve occupants' satisfaction.

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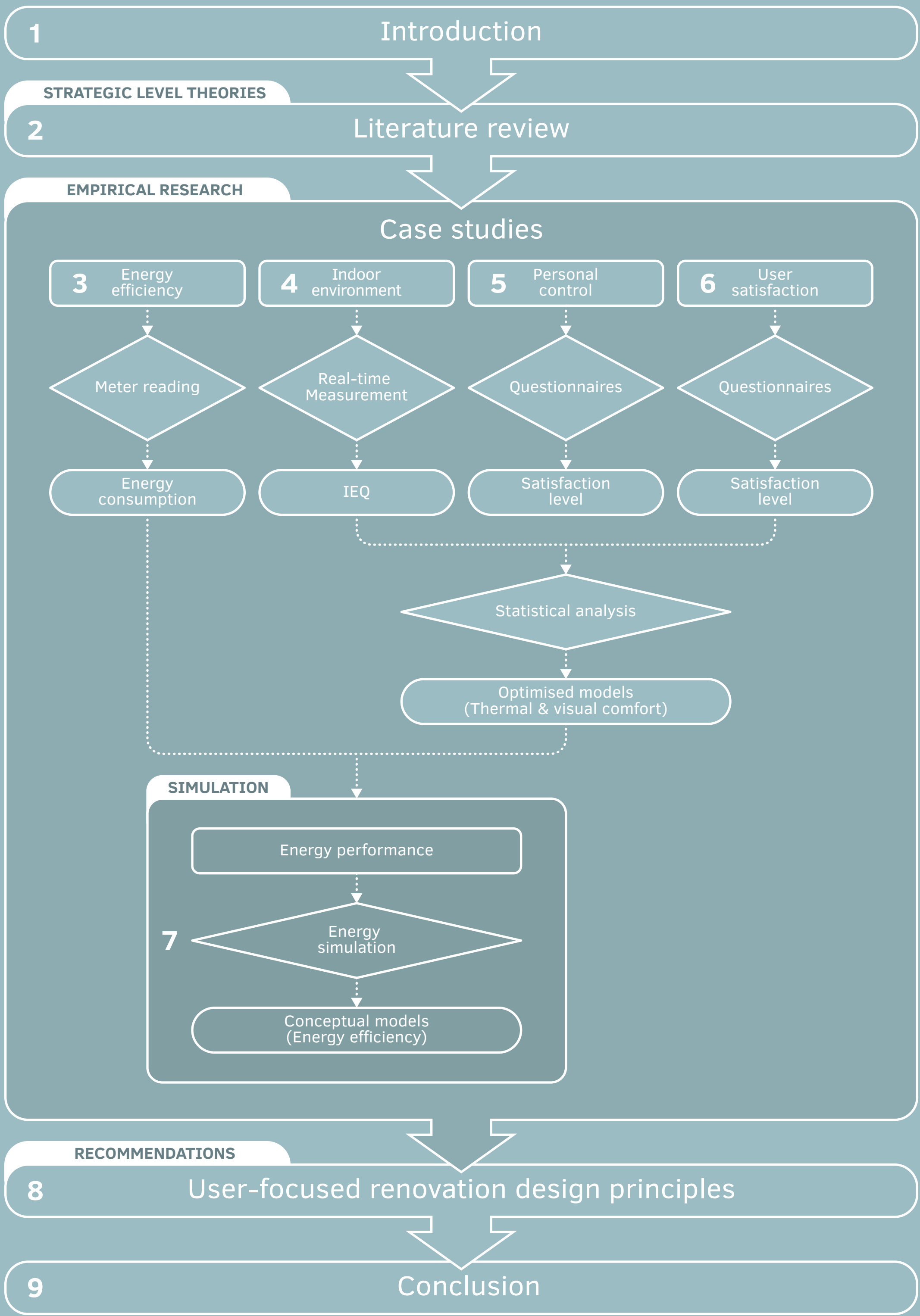
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7 The Impact of Design Parameters on Energy Demand for Office Renovation

Chapter 6 showed that the office layout and desk location were the most influential design factors for the thermal and visual comfort of users, and layout and orientation were most influential for psychological comfort in office buildings. Office design parameters were analysed to optimise user satisfaction in relation to indoor environmental and organisational quality in office buildings by showing predictable models. However, the predicted satisfaction models had not been tested in terms of energy performance. Therefore, this chapter evaluates the energy performance of the predicted models by computational assessment.

Section 7.2 explains the energy simulation scheme, model typologies, and simulation parameters. Section 7.3 presents the comparison of energy simulation results based on three design factors such as office layout, orientation and WWR. The results present the differences of the energy demand according to the alternative office typologies and contribution of design factors. The annual energy demand of 24 models are compared on the basis of different model typologies, and present the most energy-efficient typologies in section 7.4.

7.1 Introduction

In Europe, office buildings account for one quarter of the total non-residential floor area, which consume 280 kWh/m^2 per year (Jung et al., 2018). Renovating office buildings can have energy saving potential in the built environment. Despite the increasing attention to renovating existing offices, few studies have explored the relationship between alternative office designs and energy use. Offices are often designed to meet a functional and organisational requirement for workspaces. Numerous studies have analysed effective spatial layouts in an aspect of work performance (Haynes et al., 2017; Haynes, 2008; Rolfö et al., 2018). Chapter 6 analysed the impact of office design factors on user satisfaction. In the chapter, office layout is the most influential factor for user satisfaction with thermal and visual comfort, followed by orientation. In detail, people from cellular and flex offices tend to be highly satisfied with thermal and visual comfort and for satisfaction the open plan office proved to be the worst layout. In addition, workplaces oriented North-West are recommended for satisfaction, not South-West.

The predicted satisfaction models have not been analysed in terms of energy performance. According to Musau and Steemers (2008), the energy consumption of workspaces can be different according to their spatial planning since partition walls can affect daylight levels and airflows in workspaces, but it is not clear which design factors may cause higher energy demands. Therefore, it is necessary to test the energy performance of different office configurations. Optimal office configurations and envelop design may lead to significant improvements in energy savings.

Energy simulation is an important method that can help to test different models and test them before realisation (Heo et al., 2012). Lin et al. (2016) analysed façade configurations with the position of sunshades to minimise energy use, and Ochoa et al. (2012) investigated the optimal window-to-wall ratio (WWR) from a perspective of energy efficiency. They also considered visual comfort as a result of the façade design. This approach can be beneficial to quantify and validate the energy performance during the conceptual design stage. By using the DesignBuilder simulation tool, this paper examines the energy consumption of different workspace models for office renovations composed by design parameters such as orientation, layout, and WWR. The main research question answered in this study is which design combination of office layout, orientation, and WWR performs well to optimise energy-savings.

7.2 Methodology

7.2.1 Design parameters and model typologies

The shape and size of the office considered are the same for all simulation cases. The simulation models are sited in The Hague in the Netherlands. 24 office models were created, representing a possible combination of design parameters (see TABLE 7.1).

TABLE 7.1 List of 24 energy simulation model variants

Number	Orientation	Office layout	WWR (%)
1	N.W/S.E	Cellular	30
2	N.W/S.E	Cellular	50
3	N.W/S.E	Cellular	80
4	N.W/S.E	Open	30
5	N.W/S.E	Open	50
6	N.W/S.E	Open	80
7	N.W/S.E	Combi	30
8	N.W/S.E	Combi	50
9	N.W/S.E	Combi	80
10	N.W/S.E	Flex	30
11	N.W/S.E	Flex	50
12	N.W/S.E	Flex	80
13	N.E/S.W	Cellular	30
14	N.E/S.W	Cellular	50
15	N.E/S.W	Cellular	80
16	N.E/S.W	Open	30
17	N.E/S.W	Open	50
18	N.E/S.W	Open	80
19	N.E/S.W	Combi	30
20	N.E/S.W	Combi	50
21	N.E/S.W	Combi	80
22	N.E/S.W	Flex	30
23	N.E/S.W	Flex	50
24	N.E/S.W	Flex	80

In the Netherlands, the standard structural grid of an office room is 5.4 m or 7.2 m wide (Remøy, 2010), and for the columns parallel to the façade a grid of 7.2 m is most common (Koornneef, 2012). Therefore, the simulation model in this study is a 14.4 m wide and 12.6 m deep office with a gross floor area of 163 m2 and a ceiling height of 3.3 m. The variations in the simulation model consider office layout, orientation, and WWR. As a fixed parameter, orientation is commonly not a part that can be influenced during a building renovation. Nonetheless, this study considered building orientation to include office buildings positioned in different ways.

FIG. 7.1 shows the types of office layout simulated in this study: cellular (Vos et al., 2000), open (Vos et al., 2000), combi (Danielsson & Bodin, 2008), and flex office (Danielsson & Bodin, 2008). The cellular office is composed of individual workspaces along the façade. The open-plan office accommodates more than 13 persons to share a space. The combi-office is an integrated type of single cells and open-plan office. Lastly, the flex office indicates that there are backup spaces, but individual workstations are not provided.

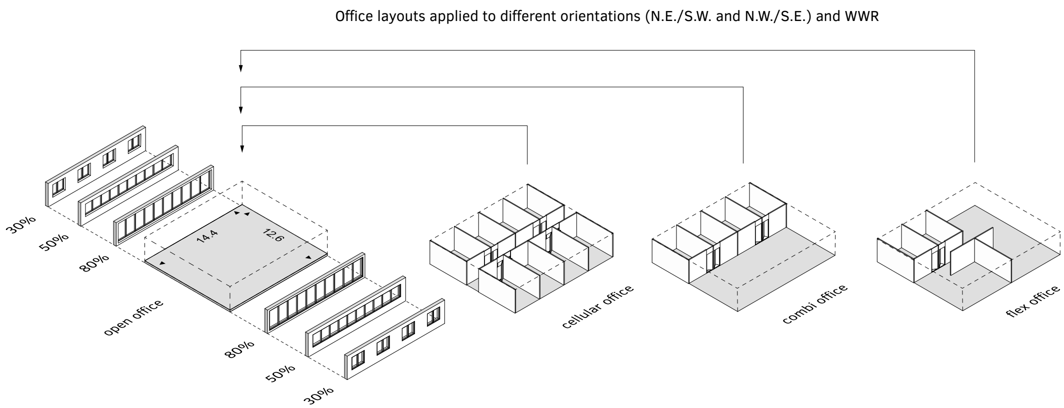

FIG. 7.1 Combination models of office design factors for the workspace energy simulation

The entire office building was not considered in the energy simulation. The support spaces, such as building core, pantry, and large conference or meeting rooms were excluded. The conceptual simulation model indicates workstations. Each layout has windows on two facades with opposite orientations such as North-West versus South-East, or North-East versus South-West. The orientations were chosen from existing office buildings in the Netherlands. Different window-to-wall ratios (30, 50, and 80%) were applied to the models.

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7.2.2 Building parameters

Construction

The thermal transmittance values of construction elements used in energy calibration are summarised in TABLE 7.2. In the Netherlands, U-values (W/m2K) of different elements of office buildings must follow the Dutch building regulation Bouwbesluit2012 (2011). The floor and ceiling are treated as adiabatic.

TABLE 7.2 Thermal transmittance of building elements used as input values for simulations

		External wall	External floors	Internal floors	Flat roof	Windows	Sun-shading
Bouwbesluit2012 (2011) Netherlands	U-value	0.214	0.272	1.45	0.162	1.65	
	R_c value	4.5	6		3.5		
	g-value					0.7	0.2

HVAC system

The most dominant part of the energy consumption in commercial buildings is the heating, ventilation and air-conditioning (HVAC) system (Allouhi et al., 2015), which plays an important role in thermal comfort. Paoletti et al. (2017) stated that for high-energy efficient buildings, over 80% of mechanical ventilation systems include heat recovery, and around 30% of buildings use a heat pump to produce heating, cooling, and domestic hot water (DHW). Electricity is the most common energy source for thermal systems in Europe. Following these conditions, the simulation used variable air volume (VAV), air-cooled chilling, heat recovery (HR), outdoor reset for mixed mode ventilation types as options for the HVAC system. The heat pump was applied with a coefficient of performance (COP) of 2.0 for heating and cooling.

Operating settings for heating, cooling and ventilation

According to the NEN 15251 Guideline, an indoor temperature between 23-26°C is recommended in summer, and 20-24°C in winter. In order to qualify the recommended thermal condition, 22°C was chosen as the set-point temperature for heating, and 16°C as the set-back temperature. The cooling system operates at an indoor cooling set-point of 26°C. During non-occupied time, 28°C was applied as the cooling set-back temperature.

In the models, natural ventilation only operates when the indoor temperature is higher than the outdoor temperature, but not in wintertime. In order to use natural ventilation maximally, the set-point is 2°C lower than the cooling set-point and 2°C higher than the heating set-point, therefore reducing the energy use required for the active cooling system. For this reason, 24°C was chosen as the set-point for natural ventilation. Night ventilation was applied for the summer period, operating between 12.00 am to 6.00 am from June to August.

Lighting settings

The office zones require a illuminance of 500 lux (NEN 15251), and, require 1.8 W/m2, 100 lux of normalised power density based on EN 1246-1:2011. The lighting operating schedule was based on an occupancy schedule (see FIG. 7.2). For the illuminance, a LED type with linear control was used, which is a highly energy-efficient type, since the brightness output operates based on the relative illuminance of the workplace (daylight). A study of Tian and Su (2014) revealed that around 70% decrease in energy consumed by electric lighting was observed by the use of a dimming lighting control. Li and Lam (2001) found that the total energy use was mainly reduced by a dimmed lighting control and occupancy sensors. Lighting control is managed based on daylight illuminance and the occupancy schedule in the workplace. The lighting is off when a certain daylight illuminance is reached, and lighting was on when the daylight illuminance drops below the required illuminance value. The value of maximum allowable discomfort glare was set at 22 for offices (Suk et al., 2017). Internal sun-shading was applied to the workspace to minimise discomfort glare, with a transmission value (g-value) of 0.2.

Pandharipande and Caicedo (2011) reported that 5 m is a reasonable coverage range of lighting sensors in a typical workspace. For the calculation in this study, each room has a sensor, and the corridor has a sensor target of 200 lux for the cellular office layout. The distance between the lighting sensors and the number of sensors placed in an open-plan office was chosen by following the structured grid of a cellular office layout, placing 8 lighting sensors covering 3.6 m distance between the sensors. A shading device positioned outside is active when the solar radiation on the window exceeds the solar set-point of 150 W/m^2 (Raji et al., 2016; Park, 2003).

Occupancy and schedule

In order to reduce the energy consumption of office buildings, the optimal occupancy density is 0.03 persons/m2 (Kang et al., 2018). However, based on the Dutch NEN-1824 (2010) code, 0.1 persons/m2 occupancy density was considered for a cellular workspace and 0.09 persons/m2 for an open workspace including the circulation area. TABLE 7.3 shows the occupancy density and the number of people in each office type, 16 people for the cellular office and 15 people for the open, combi, and flex office layout. FIG. 7.2 shows the occupancy schedule and occupation percentage during weekdays. This data set was collected based on the working hours of case studies through field study. For the energy simulations, the use of a computer was also considered by following this occupancy schedule.

TABLE 7.3 Occupancy density and the number of people in each office layout

	Cellular	Open	Combi	Flex
Conditioned area (m2)	151.40	162.81	157.10	158.42
Occupant density (m2/ Person)	9.76	11.11	10.62	10.86
People	16	15	15	15

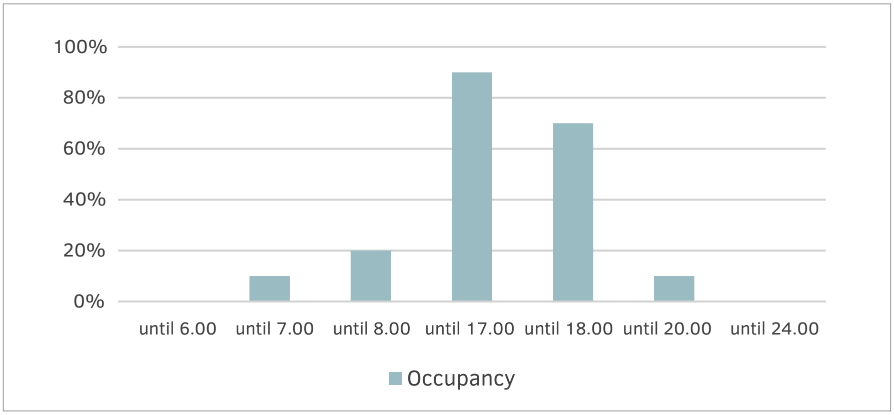


FIG. 7.2 Occupancy schedule

7.2.3 Simulation

Design Builder interface version 5.4, and 8.6 for EnergyPlus was used as the energy performance simulation tool. First, an office space was created as a prototype for each office layout. The values of occupancy schedule and density, HVAC, lighting types, temperature set-points, and U-values of building elements as fixed parameters were defined by literature (Allouhi et al., 2015; Bouwbesluit2012, 2011; CEN, 2007; Li & Lam, 2001) as given above. The values were applied to every model. Twenty-four models with different combinations of design parameters were tested to evaluate operating energy demands. The operating energy here indicates maintaining the indoor environment through heating, cooling, lighting and operating appliances (Cabeza et al., 2014).

7.3 Lighting sensor position

In order to validate the suggested positions of the lighting sensor, five different variants were simulated. FIG. 7.3 shows the results of simulation data based on the different number of lighting sensors and positions. First, an office space was divided into 3 and 2 zones parallel to the glazed façade, and 6 and 4 sensors were placed respectively. The energy demand of the two models was the same. It indicates that placing sensors in two rows is enough to cover the range of space. Next, the model was tested to identify how many sensors need to be placed in a row. Lighting sensors were placed every 1.8 m, 2.4 m, 3.6 m, 4.8 m, and 7.2 m perpendicular to the long facades with windows. The energy demand between lighting sensors placed every 1.8 m and 2.4 m was negligible by only 3% of energy reduction of lighting. Interestingly, there was a large decrease in energy demand between lighting placed at a 2.4 m distance and at 3.6 m. Positioning lighting sensors every 3.6 m could reduce 6% of the lighting energy demand and 5% of the total energy demand. From a structural perspective, 3.6 m matches the structural grid for beam spans in office buildings. Consequently, 4 zones (8 lighting sensors) with 3.6 m of sensor distance was selected for further simulation.

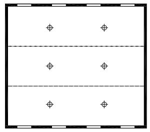
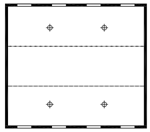
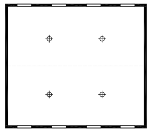
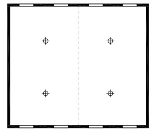
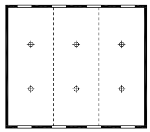
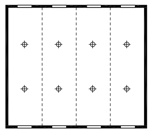
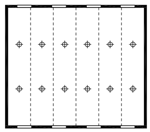
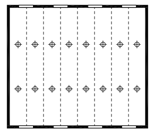
	3 zones, 6 sensors	3 zones, 4sensors	2 zones, 4 sensors	2 zones (7.2m)
				
Total (kWh/m²/year)	41.74	41.74	39.36	39.41
Lighting	14.70	14.70	13.67	15.42
Heating	4.27	4.27	4.99	4.96
Cooling	10.90	10.90	8.82	7.16
Others	11.87	11.87	11.87	11.87
	3 zones (4.8m)	4 zones (3.6m)	6 zones (2.4m)	8 zones (1.8m)
				
	41.94	43.71	45.91	45.96
	16.94	17.88	18.96	19.66
	3.89	3.31	2.75	2.75
	9.23	10.65	12.32	11.67
	11.87	11.87	11.87	11.87

FIG. 7.3 Simulation of the lighting sensor positions for open plan

7.4 Energy performance based on energy criteria

Annual energy simulations were performed for 24 models (i.e., combination of 4 office layouts, 3 WWRs, and 4 window orientations). The simulation calculated the energy used for heating, cooling, lighting, and equipment (e.g., ICT equipment), and the total energy demand per square meter per year of workspace. The hourly weather data of the Rotterdam – The Hague region were obtained from OneBuilding (http://climate.onebuilding.org). FIG. 7.4 shows the division of energy demand based on heating, cooling, lighting and others. In general, lighting was responsible for 31% of the total annual energy demand per square meter, 22% for heating, 19% for cooling, and 28% for ICT equipment.

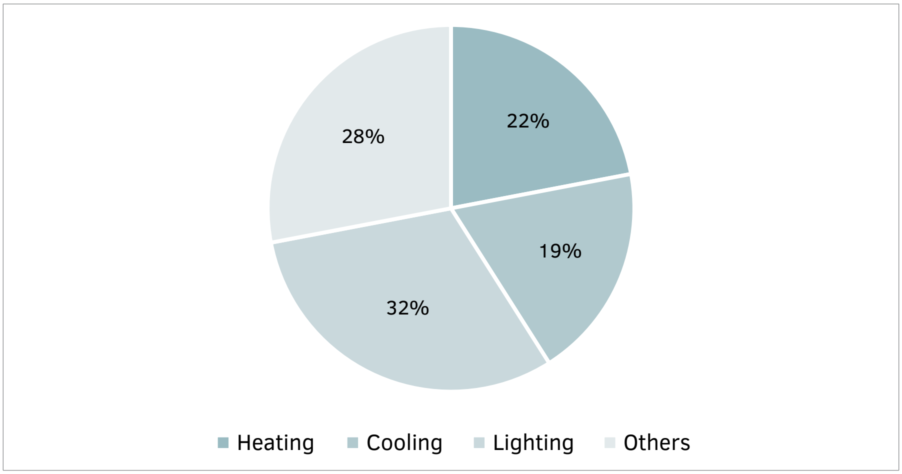


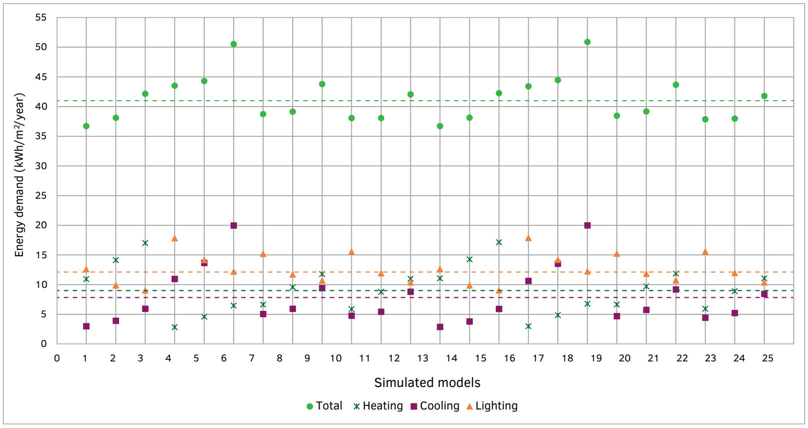
FIG. 7.4 Ratio of energy demands based on heating, cooling, lighting and others for all 24 models

7.5 Results of energy simulation models

TABLE 7.4 shows the annual energy demand in a workspace according to the combination of different office design parameters. The typologies consisted of 24 alternative models that encompassed a combination of different design parameters. FIG. 7.5 further elaborates the annual energy demand per square meter and the distribution of the demand according to each energy demand category in different variants. The dotted lines in FIG. 7.5 indicate the average of the energy demand in each energy category.

TABLE 7.4 Annual energy demand in an office space according to different office typologies

Number	Orientation	Office layout	WWR (%)	Total (kwh/m2/year)	Heating	Cooling	Lighting	Others
1	N.W/S.E	Cellular	30	36.71	10.95	3.00	12.61	10.16
2	N.W/S.E	Cellular	50	38.12	14.14	3.93	9.90	10.16
3	N.W/S.E	Cellular	80	42.16	17.00	5.94	9.05	10.16
4	N.W/S.E	Open	30	43.52	2.85	10.96	17.84	11.87
5	N.W/S.E	Open	50	44.31	4.61	13.67	14.16	11.87
6	N.W/S.E	Open	80	50.53	6.48	19.97	12.20	11.87
7	N.W/S.E	Combi	30	38.75	6.63	5.06	15.18	11.87
8	N.W/S.E	Combi	50	39.15	9.60	5.93	11.74	11.87
9	N.W/S.E	Combi	80	43.78	11.77	9.43	10.71	11.87
10	N.W/S.E	Flex	30	38.07	5.87	4.77	15.55	11.87
11	N.W/S.E	Flex	50	38.06	8.80	5.45	11.93	11.87
12	N.W/S.E	Flex	80	42.06	11.00	8.81	10.38	11.87
13	N.E/S.W	Cellular	30	36.73	11.07	2.88	12.63	10.16
14	N.E/S.W	Cellular	50	38.13	14.26	3.81	9.90	10.16
15	N.E/S.W	Cellular	80	42.26	17.15	5.91	9.04	10.16
16	N.E/S.W	Open	30	43.40	3.01	10.63	17.88	11.87
17	N.E/S.W	Open	50	44.46	4.86	13.52	14.21	11.87
18	N.E/S.W	Open	80	50.88	6.77	19.99	12.24	11.87
19	N.E/S.W	Combi	30	38.48	6.66	4.70	15.24	11.87
20	N.E/S.W	Combi	50	39.19	9.72	5.76	11.84	11.87
21	N.E/S.W	Combi	80	43.67	11.86	9.19	10.75	11.87
22	N.E/S.W	Flex	30	37.87	5.95	4.44	15.60	11.87
23	N.E/S.W	Flex	50	37.98	8.91	5.22	11.98	11.87
24	N.E/S.W	Flex	80	41.79	11.06	8.46	10.39	11.87



Number	Orientation	Office layout	WWR (%)
1	N.W/S.E	Cellular	30
2	N.W/S.E	Cellular	50
3	N.W/S.E	Cellular	80
4	N.W/S.E	Open	30
5	N.W/S.E	Open	50
6	N.W/S.E	Open	80
7	N.W/S.E	Combi	30
8	N.W/S.E	Combi	50
9	N.W/S.E	Combi	80
10	N.W/S.E	Flex	30
11	N.W/S.E	Flex	50
12	N.W/S.E	Flex	80
13	N.E/S.W	Cellular	30
14	N.E/S.W	Cellular	50
15	N.E/S.W	Cellular	80
16	N.E/S.W	Open	30
17	N.E/S.W	Open	50
18	N.E/S.W	Open	80
19	N.E/S.W	Combi	30
20	N.E/S.W	Combi	50
21	N.E/S.W	Combi	80
22	N.E/S.W	Flex	30
23	N.E/S.W	Flex	50
24	N.E/S.W	Flex	80

FIG. 7.5 Comparisons of energy demand between 24 models

Total energy demand

Regardless of orientations, the flex office model with a WWR of 50% consumed less energy in all energy criteria than on average. Open-plan offices and workspaces with a WWR of 80% required the greatest amount of total annual energy use, while cellular offices showed the smallest total energy use. The highest total energy demand model (N.E/S.W, open, 80%) in total required around 38% more energy than the lowest one (N.W/S.E, cellular, 30%). However, the lowest total energy demand models were not optimal energy-efficient ones for all categories. The cellular, combi, and flex office with a WWR of 30% and 50% required a relatively lower total annual energy demand than on average. In contrast, the open-plan office showed the highest energy demand.

Heating energy demand

The open-plan office with a WWR of 30% was the optimal layout that can reduce a large amount of heating energy, followed by the open-plan office with a WWR of 50% and the flex office with 30%. In contrast, cellular office types showed the worst energy efficiency for space heating. The reason can be that a smaller WWR contributes to reduced heat loss, and each room needs to be heated separately to reach a certain temperature; therefore, the cellular office layout consumed more energy.

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Cooling energy demand

The cellular office with a WWR of 30% was the most efficient office type for space cooling. The flex office required less cooling energy than the combi office. In contrast, the open-plan office with a WWR of 80% had the highest cooling energy demand. Mixed-mode ventilation was applied to the simulation models. For that reason, having more cellular rooms could cool down the individual workspaces quicker than a large open-plan area, resulting in a lower cooling energy demand.

Lighting energy demand

Overall, a larger window-to-wall ratio required less energy for lighting than smaller ones. When the WWR increased from 30% to 50%, around lighting energy demand decreased by 20%, and if the WWR increased from 50% to 80%, the lighting energy demand decreased by around 10%. The cellular office with a WWR of 80% had the lowest lighting energy demand. The flex office with a WWR of 80% was the second optimal model for a low lighting energy demand. In contrast, the open-plan office with a WWR of 30% required almost twice more energy for lighting than the optimal model. Flex and combi offices with a WWR of 30% also required more energy for lighting than average.

7.6 Energy demands based on design factors

In spite of the energy distribution ratio shown in Figure 7.4, the energy category majorly responsible for the total energy demand was different according to the design factors. Although the total energy demand was quite similar among cellular, combi, and flex offices, except for the open-plan office, the flex office layout was shown as the most energy-efficient layout for the total energy consumption, as shown in FIG. 7.6.

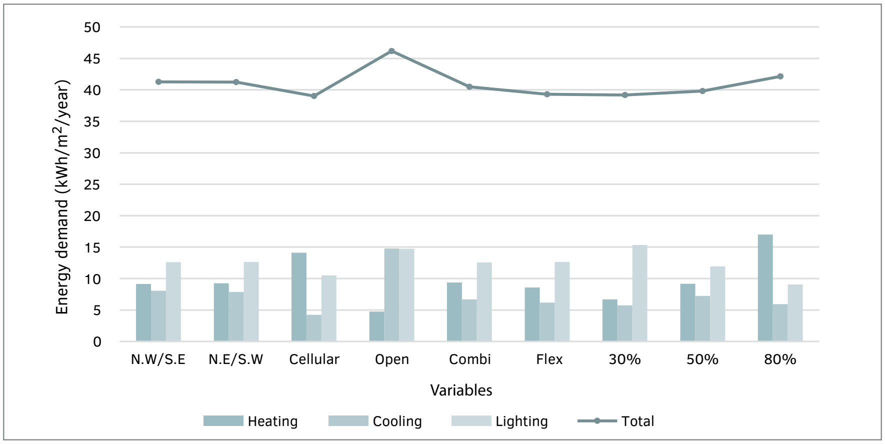

FIG. 7.6 Mean values of annual energy demand based on orientations, office layouts, and WWR

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7.6.1 Office layouts and energy demand

FIG. 7.7 shows the energy demand according to the office layout. There was a significant difference between cellular and open-plan offices. The cellular office required the largest amount of energy for space heating, accounting for 36% of total energy demand, and the smallest for cooling. Moreover, due to a smaller lighting illuminance needed for corridors, the cellular office required relatively less energy for lighting than other types. In contrast, the open-plan office required significantly less energy for cooling, and more for heating and lighting. The heating and cooling demands accounted for a similar percentage in combi and flex office types. Remarkably, the lighting was majorly responsible for the total energy demand, except for the cellular office. A trend shown in FIG. 7.7 is that when the heating demand increases, the cooling and lighting demand decrease.

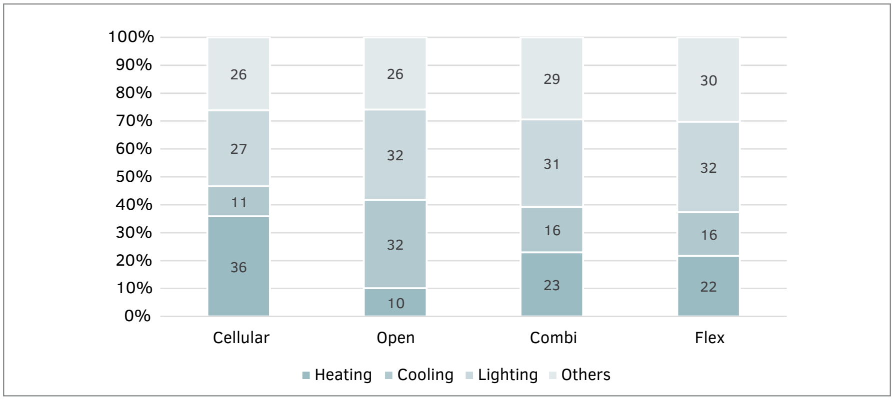

FIG. 7.7 The energy categories based on spatial layouts

7.6.2 Orientations and energy demand

FIG. 7.8 shows the ratio of energy demands based on the orientation. Proportion-wise, there was no difference in energy demand for each category between N.W/S.E-oriented models and N.E/S.W-oriented ones. It is noteworthy to mention that there was no significant difference between the heating and cooling energy demand according to different orientations. It is assumed that the cause of this result is that the energy demand was compensated by solar gains or sun-shading from the opposite orientation. Therefore, the energy demand was barely influenced by the orientation.

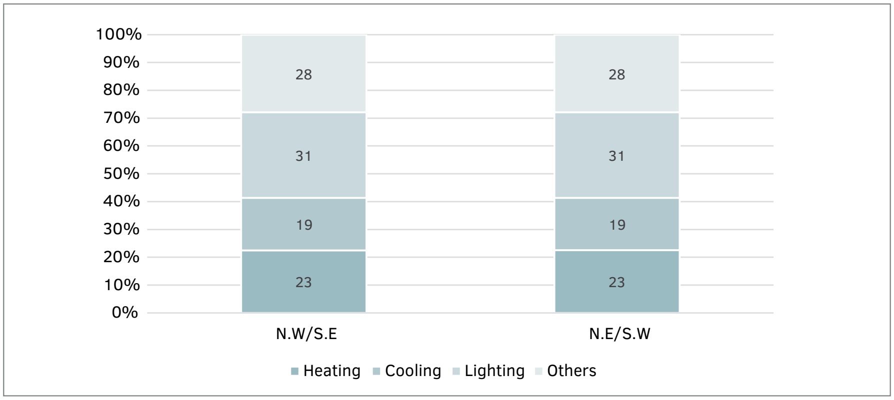

FIG. 7.8 The energy categories based on orientations

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7.6.3 Window-to-wall ratio and energy demand

The energy demand of models classified by the WWR shows a significant difference in total, heating, cooling and lighting energy demand (see FIG. 7.9). Overall, a larger WWR required more heating energy. When the heating energy demand increased, the cooling demand also increased within the same office layout, while lighting energy demand decreased. There is a positive linear relationship between heating and cooling energy demand on the one hand and WWR on the other. The energy demand for lighting showed a negative linear relationship. The heating and cooling energy demand gradually increased when the WWR increased from 30% to 80%. In addition, there was a drastic drop of lighting energy demand in case the WWR increased from 30% to 50%.

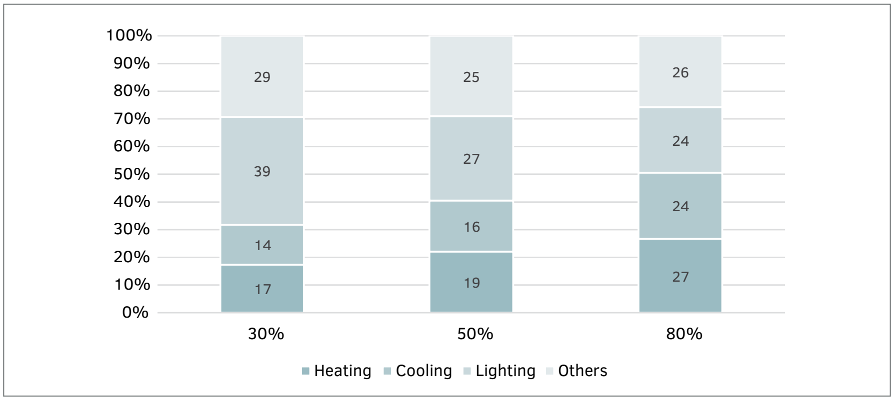

FIG. 7.9 The ratio of energy categories based on window-to-wall ratio

7.7 Discussion

7.7.1 Impact of design factors on energy performance studies

The research presented shows that the spatial layout and glazing area are significant design factors in relation to energy use for space heating, cooling and lighting. Furthermore, it was possible to find the optimal combination of design parameters to minimise energy demands.

A study of Poirazis et al. (2008) indicated that the energy use for space heating in the cellular office is higher than for the open-plan ones. Moreover, the open-plan offices were warmer than the cellular offices, thereby a greater demand for cooling energy. The findings of their study are similar to this paper. This paper showed that the heating energy demand was almost 3 times higher for the cellular office layout than for the open-plan office. In contrast, the cooling demand was much lower for the cellular office layout than for the open-plan office.

In our study, spatial layouts showed to be an important factor in energy performance. Overall, the flex office was the most efficient layout for the total energy demand, with around 17% of energy savings compared to the open-plan office, which had the highest energy demand. Next to the flex office, the cellular one was the second most efficient office layout. The reason for this is that the flex office has less individual rooms that have a higher heating energy demand. Although the total energy demand was not significantly different between the cellular and the combi office, the combi office required less heating energy than the cellular one.

The outcomes from this study support previous studies. Goia (2016) revealed that the range of optimal WWR is narrow: between 30% to 45%, regardless of different climates in Europe. Moreover, the impact of the WWR on energy use is less sensitive in a cold climate than in a warm climate. From his findings, it can be assumed that solar radiation would be the main impact factor related to determining glazing areas according to the orientation. Raji et al. (2016) stated that a smaller glazing area achieves a higher percentage of energy savings for heating and cooling. As the results are shown in this study, a WWR of 30% was the optimal case for energy efficiency, which is in line with the previous study. Approximately 40% and 48% of heating energy savings were simulated for the workspace with a WWR of 30% compared to that of 50% and 80% respectively, and 18% and 35% of cooling energy savings.

However, there is a different opinion regarding the WWR. Having a small glazing area would not be an optimal solution in every case. Due to a lack of daylight, workspaces with a small WWR required more energy for lighting. On the other hand, the higher heating and cooling energy demand required for a workspace with WWR of 80% was mainly due to the solar radiation in summer and due to heat losses through the windows in winter.

Based on the result, the orientation was not a significant factor in the total energy use, as Poirazis et al. (2008) revealed. The study in this paper did not distinguish between workspaces facing different orientations, making it difficult to analyse the impact of different orientations on energy loads. Nevertheless, it is assumed that north-facing workspaces in the northern hemisphere may encounter higher energy consumption for heating and lighting because of a lack of sunlight. One way to reduce the total energy demand can be to have a larger glazing area for north-facing workspaces, reducing the energy demand for lighting. Chen et al. (2018) also suggested that the optimum design for lighting and cooling is oriented to the north by avoiding direct solar radiation.

7.7.2 Impact of occupancy and lighting on energy performance

Occupancy density and lighting may cause a different energy demand in each model. In this study, the occupancy density was the same for open, combi, and flex offices, and the cellular office accommodated one person more than other typologies. Nevertheless, the heating demand of the cellular office was relatively higher than other office layouts. The internal heating production would be different according to the number of people in a workstation. For example, a workstation in the open-plan office is shared among 15 people who produce heat; therefore, the heating loads can decrease.

The reason for the energy demand gap between the cellular and open-plan office can be explained by the different requirements for lighting illuminance in office layouts. For instance, the cellular office layout includes a corridor that requires less lighting illuminance than the workspaces themselves. Therefore, the cellular office had the lowest, and the open-plan office had the highest energy demand for lighting.

7.7.3 Limitation

Simulating only the working space of one floor is a limitation of this study. For example, the energy gain from solar radiation may be different according to the floor height because of the different sun angles reaching the windows, which is also dependent on buildings in the surrounding area. In addition, support spaces, such as circulation areas, pantries, and large meeting rooms were excluded from this energy simulation. When these spaces are considered, the total end-use energy demand will increase. However, this simplified simulation approach is mostly conducted in energy simulation research to decrease the simulation running time and to simplify the models (Jung et al., 2018).

Different types of glazing can also bring a different energy demand. According to Poirazis et al. (2008), there is a different heating and cooling energy use between office spaces supplied with double glazing and triple glazing. Their study showed that, for heating and cooling, the office space with triple glazing and a WWR of 30% used 4-9 kWh/m2 more than the one with double glazing and the same WWR. Moreover, when the WWR increases the double-glazed office space uses more energy for heating and less for cooling than the triple-glazed one. The use of renewable energy, such as solar thermal system and photovoltaics, was not considered in this assessment. However, implementation of renewable energy in buildings will be an important parameter for studies of nearly-zero-energy buildings (Ahmed et al., 2018; Paoletti et al., 2017).

7.8 Conclusion

This chapter investigated the impact of design factors on the energy demand of workspaces by using an energy simulation tool. The objective was fulfilled by simulating 24 alternative workspace models. For existing office renovations, the orientation of the building cannot be changed, and the impact of the orientation on the energy demand is insignificant. Spatial layout and WWR are the important determinants of energy loads. It is possible to characterise the optimal design solutions for a specific building orientation. The energy efficiency of an office area highly depends on the office layout and the glazing area of a façade.

7.8.1 Office layout

The results demonstrated that different combinations of office design parameters influence the primary energy demand. It is worth noting how different design factors contribute to the energy demand. Layout-based results showed that the cellular and flex offices were more energy-efficient layouts compared to open-plan office models. Although the cellular office showed the lowest total energy demand, having more cellular rooms required more energy for heating. In contrast, open-plan offices had a much lower energy demand for heating, but they showed the highest total energy demand due to the high cooling demand. Therefore, it is worthwhile to investigate how cooling loads can be reduced in the open-plan office and heating loads in the cellular office.

7.8.2 Window to wall ratio and orientation

The glazing area of a façade was highly relevant for the energy demand. A larger WWR showed a greater energy demand for heating and cooling and a lower energy demand for lighting. There was a drastic increase of the energy demand for cooling between the workspaces having a WWR of 30% and 50%. The energy demand for lighting decreased around one fifth when the WWR increased from 30% to 50%. The energy demand for lighting decreased by approximately 11% when the WWR increased from 50% to 80%. Although an 80% glazing area could reduce the amount of energy used for lighting, for the total energy demand, a lower WWR is recommended for any combination of office types.

No significant difference was seen in energy demands according to different orientations. Since office buildings often have at least two opposite sides of window facades, the total energy loads may be compensated by the different indoor conditions of opposite orientations. When designing large glazed office buildings, the cooling demand should be studied well to decrease the total energy demand.

7.8.3 Recommendations

A certain combination of design parameters is recommended for the energy savings by office renovation. As a strategic tool, energy demand data may contribute to the conceptual renovation design phase. The most energy saving model in this paper is a cellular office with a WWR of 30%, followed by a flex office with a WWR of 50%

and 30%. Ideally, a WWR of 30% is recommended for combi and open-plan offices. Although having a large glazing area is not preferred for energy efficiency, a WWR of 80% may be applicable to the flex office. This typology would be more efficient than the open-plan office with any glazing area and the cellular office with a WWR of 80%. These outcomes are potentially valuable for architects, façade designers, and facility managers to design renovation plans.

To develop effective office renovation options further, renewable energy systems such as solar collectors and photovoltaic panels should be integrated into simulation models. The aim of this study was limited to energy efficiency, indifferent to the source of the energy used.

Providing offices where people are satisfied with their working environment is essential for successful office renovations in practice. Therefore, occupant satisfaction should be considered with energy-efficient models as well.

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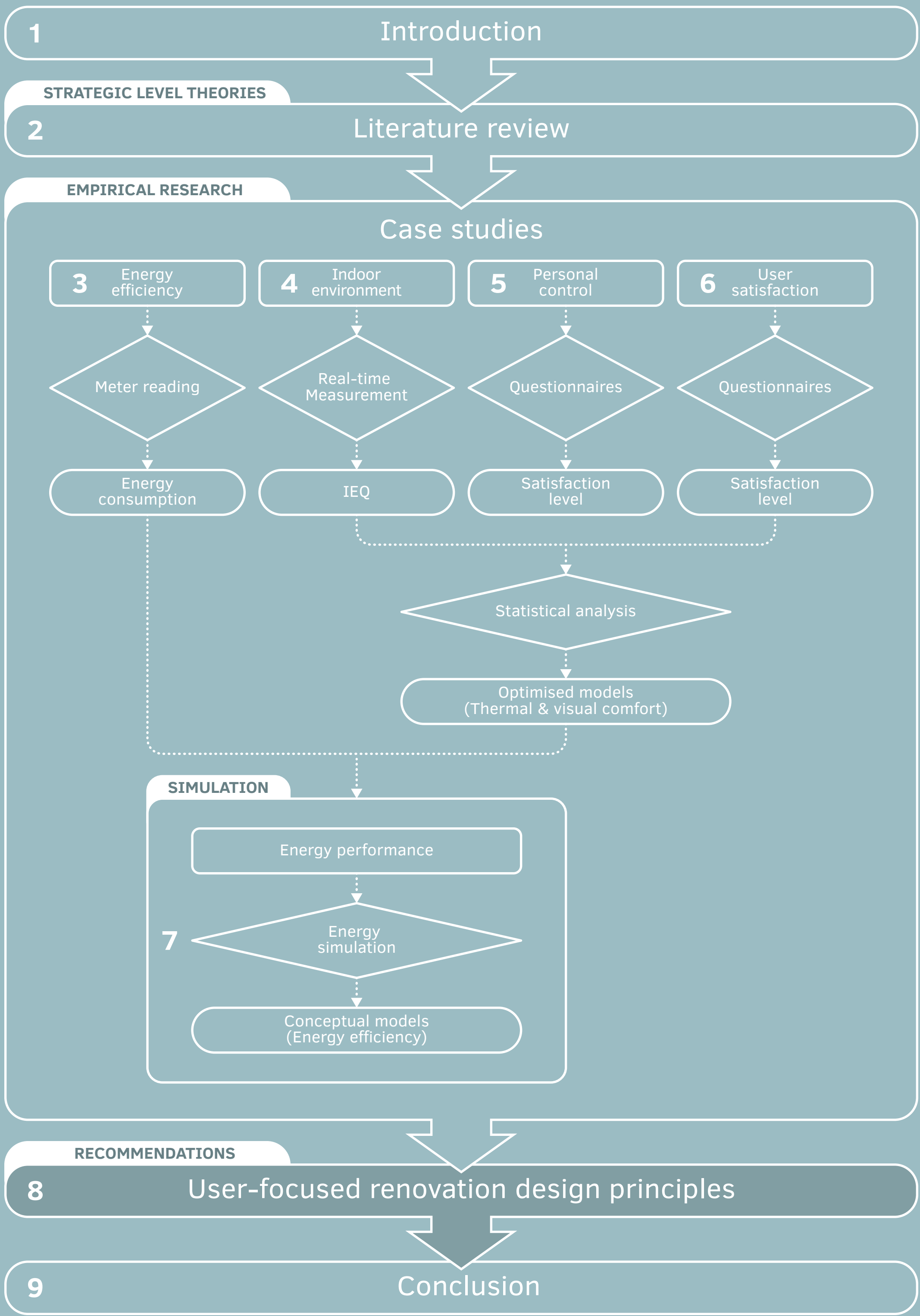
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8 User-focused design principles

Chapter 7 tested the energy demand of possible office typologies. However, the main aim of the thesis is to develop user-focused design principles for energy efficient office renovation. Therefore, it is important to compare the degree of user satisfaction of highly energy-efficient office typologies. Based on the results from chapter 7, chapter 8 introduces design principles that architects, and facility and real estate managers can use to select the combination of parameters with better user satisfaction during a conceptual design stage of office renovation. It contains a database of the different degrees of user satisfaction with thermal, visual, and psychological comfort, according to the combination of design parameters.

Section 8.2 explains the design principles considering user satisfaction and energy efficiency. Section 8.3 provides the overview of predicted satisfaction of 144 office combinations. Recommended office combinations based on energy efficiency are explained in section 8.4. Section 8.5 describes the process of application of the design principles: how can designers interpret and use the principles and predicted models for energy-efficient office renovation?

8.1 Introduction

The goal of user-focused design principles is to increase user satisfaction and comfort, which can lead to the increase of productivity in energy-efficient office renovations. The integration of office design factors with user satisfaction is relatively new. Assessing the building users' actual satisfaction enables the investigation of the relative impact of office design factors. This chapter explains the overview of the outcomes from the previous chapters. The principles focus on five points, such as the users' thermal, visual, and psychological satisfaction, the reduction of energy demand, and the degree of personal control. Next, an overview of predicted user satisfaction models is given, based on the findings regarding user satisfaction from previous chapters. The new design principles for renovation and the graph giving an overview of predicted satisfaction, created in this research project, can support architects, facility and real estate managers in their decisions.

8.2 Design principles for energy-efficient office renovation

This section proposes predicted models for office renovation based on user satisfaction and energy efficiency. In order to make user-focused design principles applicable in practice, the models were simulated in terms of energy efficiency. The principles were built upon user experience rather than building performance. The comprehensive outcome provides a common ground for user-focused energy efficient office renovation by combining different perspectives of satisfaction. Multiple perspectives of satisfaction were considered to predict satisfaction in workspaces. The design factors included in the predicted satisfaction models included: orientation, window-to-wall ratio (WWR), layout, and desk location distance from a window, and thermal, visual, and psychological comfort as satisfaction variables.

FIG. 8.1 illustrates the design principles based on user satisfaction and energy efficiency. During the renovation process, architects, facility and real estate managers need to decide which perspective of user satisfaction is prioritised.

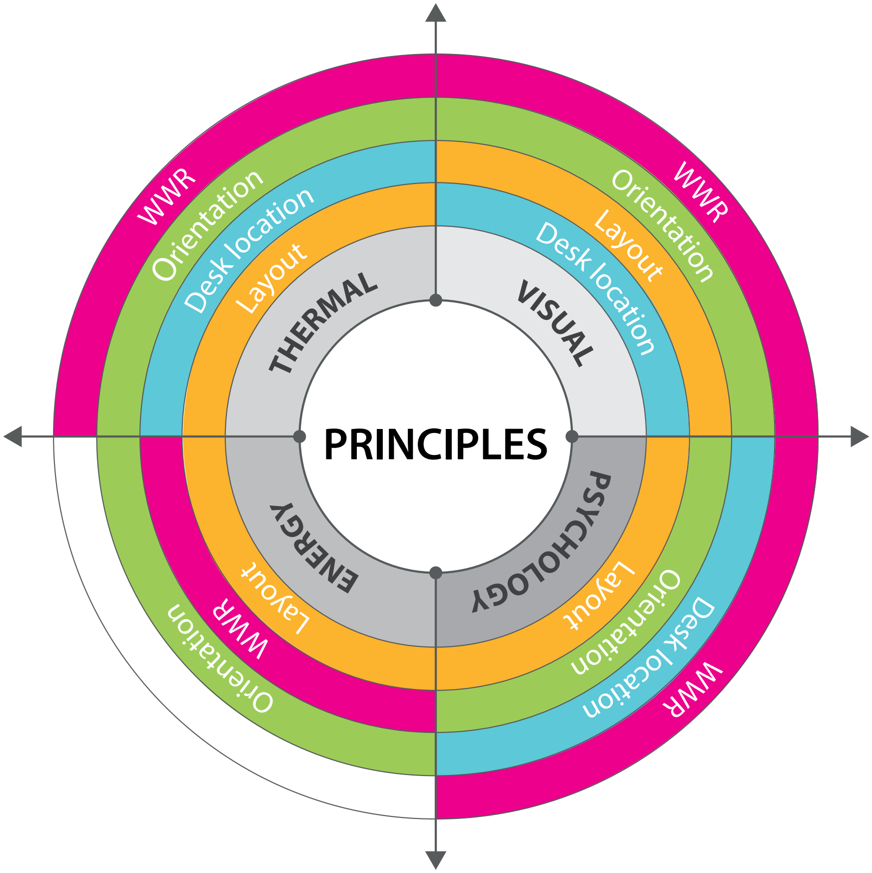


FIG. 8.1 User-focused design principles for energy-efficient offices (Radial axes moving outwards from the centre mean decreasing importance)

Five design principles for energy efficient office renovation were built based on FIG. 8.1 considering design factors and energy efficiency.

Principle 1: Focus on user satisfaction with thermal comfort

To increase user satisfaction with thermal comfort, the floor layout should be considered as first priority since it is the most influential factor for the users' thermal satisfaction, followed by desk location, orientation, and WWR (see FIG. 6.4). In contrast, the WWR has the smallest impact on thermal satisfaction. Firstly, cellular and flexible office layouts can be recommended to improve thermal satisfaction, followed by the combi office. Secondly, desks located over 4 metres away from windows can provide better thermal conditions. In addition, there is no significant difference between desk locations 0 – 2 metres away and 2 – 4 metres away from windows, showing considerably lower thermal satisfaction. Finally, workspaces orientated north-west provide the optimal condition for thermal satisfaction.

Principle 2: Focus on user satisfaction with visual comfort

Organising the optimal desk location can contribute to the user's visual comfort. Similar to the recommendation for thermal satisfaction, desk locations far away from windows are better for overall visual comfort than close to windows. Following common sense, people prefer to sit next to windows. However, the findings in this research show the opposite results. The reason why is assumed to be that visual comfort indicates not only outside view but also lighting quality, and light and glare might be too bright next to the windows. Therefore, to sit far away from a window may improve the overall visual comfort. Layout is the second most important contributor to visual satisfaction. The flex office is recommended as first option, followed by the combi or cellular office. There is no big difference in the level of visual satisfaction between cellular and combi offices. A north-west orientation is found to be optimal, followed by south-east. Visual satisfaction can fluctuate through different seasons in the north-east orientation. The WWR is considerably more important for intermediate seasons but not for summer or winter. A larger WWR tends to bring higher visual satisfaction.

Principle 3: Focus on user satisfaction with psychological comfort

Chapter 2.2 explained the user satisfaction variables based on literature. Psychological comfort here considers five variables: privacy, concentration, communication, social contact, and territoriality. Layout and orientation are the main factors that contribute to psychological satisfaction. However, layout is not a statistically significant factor for social contact. Although desk location does not highly contribute to the user's psychological satisfaction, the factor needs to be considered mainly for social contact. Cellular and combi office types can be applied when high privacy and concentration are required. On the other hand, open and flex offices are not recommended for privacy and concentration. The orientation brings very diverse results according to psychological variables; therefore, there is no definite suggestion. Similar to the recommendation for thermal comfort, desks located over 4 metres away from a window are optimal for satisfaction while putting them 2 – 4 metres away from a window is not recommended for the function of full-day working spaces. Furthermore, either more than 80% or less than 30% WWR can bring better concentration to the occupants (FIG. 6.5).

Principle 4: Focus on energy efficiency

As FIG. 7.5 shows in chapter 7, office layout and WWR are the main design factors when considering energy savings. A larger WWR leads to more energy use in a workspace. The cellular office is the most energy-efficient layout, followed by the flex office. The combi office can also be applicable in practice. However, the office layout should only be designed with a WWR smaller than 50%, otherwise the energy efficiency will drastically drop. The open plan office is the least energy-efficient layout among the four types studied. Even though an open plan office combined with the smallest WWR can be a positive option, this type still can consume a considerably large amount of total energy, similar to the combi office designed with a WWR greater than 80%. The orientation is not a critical factor for the total energy use of an office building since office buildings often have two opposite sides of glazed or opaque façades. In addition, the orientation is already decided in renovation.

Principle 5: Focus on the degree of personal control

Personal control is directly and indirectly related to user satisfaction. This research revealed that the users' thermal and visual satisfaction can be increased by providing more personal control of the work environment. At the same time, personal control is highly connected to psychological impact. A façade-related factor such as the WWR is important in terms of the energy consumption of a building, while it is relatively less important for user satisfaction. Nevertheless, the façade-related factor cannot be excluded in user studies. Chapter 5 concludes that façade-related aspects can be explained by personal controllability.

The degree of personal control is defined in chapter 5 as follows:

- Complete control: no central control system and full control by users, and they have wide range of temperature control.
- Partial control: having set-points, occupants are allowed to control their own environment within the limited thermal range.
- No control: fully centrally controlled conditions, the control system is installed, but people are not allowed to use it.
- Do not have: no user control system is installed.

The summary of the relationship between personal control and thermal and visual satisfaction is listed below, mentioning the most important factor first and the least last.

Thermal comfort

- In intermediate seasons for heating and ventilation (openable windows): ‘complete’ > ‘partial’ > ‘do not have’ > ‘no control’,
- In intermediate seasons, for cooling: Do not have > complete > partial > no control,
- In summer, for cooling: ‘complete’ > ‘partial’ > ‘do not have’ > ‘no control’,
- In summer, for ventilation: ‘do not have’ > ‘complete’ > ‘partial’ > ‘no control’,
- In winter, for heating: ‘complete’ > ‘partial’ > ‘do not have’ > ‘no control’,
- In winter, for ventilation: ‘do not have’ > ‘complete’ > ‘partial’ > ‘no control’

Visual comfort

- Occupants can easily accept that they do not have personal control than that they cannot use the available control system.
- Sunshades: the degree of control of ‘complete’ > ‘partial’ > ‘do not have’ > ‘no control’ is suggested in intermediate seasons and summer.
- Sunshades: in winter, ‘complete’ > ‘partial’ > ‘no control’ > ‘do not have’ can be recommended for lighting, and ‘partial’ > ‘complete’ > ‘no control’ > ‘do not have’ for the aspect of view to the outside.
- Artificial lighting: the degree of control of ‘complete’ > ‘partial’ > ‘no control’ > ‘do not have’ is suggested for the intermediate seasons and winter.
- Artificial lighting: in summer, ‘partial’ > ‘complete’ > ‘no control’ > ‘do not have’ is suggested for the design of the degree of personal control.

These results show that complete control is not always the best solution for visual comfort. In summer, the predicted visual comfort according to the degree of personal control is different from other seasons.

8.3 Overview of predicted satisfaction models

The design principles illustrated in the previous section have varying degrees of importance for user satisfaction in energy-efficient office renovations. However, all design factors influence each other in the actual work environment which leads to a multiplicity of satisfaction models. 144 are visualised graphically to show the overview of predicted satisfaction values, based on the combination of design variables in FIG. 8.2. By means of this figure, designers can predict the degree of user satisfaction regarding thermal, visual, and psychological comfort, according to the combination of different design factors. As chapter 2 has shown, the occupant's physical comfort, such as thermal and visual comfort, should be considered as first priority since they are highly related to health and productivity. When thermal and visual conditions, as basic requirements for a workspace, are not met, occupants will not perform efficiently, and severe dissatisfaction may occur.

Coloured dots and lines indicate the mean value and quartile of predicted satisfaction with thermal, visual, and psychological comfort. The numbers mean: 2 = dissatisfied, 3 = neutral, and 4 = satisfied. The scale 1 and 5 are excluded since there is no case around the scale. A higher number means greater satisfaction. Orientation is placed in the centre of this graph because the orientation is an unchangeable condition in building renovation. Recommended design options are highlighted in this graph. There are several options, using different design principles, for each layout to increase satisfaction. However, due to the lack of cases for the combi office, finding an option that satisfies the users is difficult.

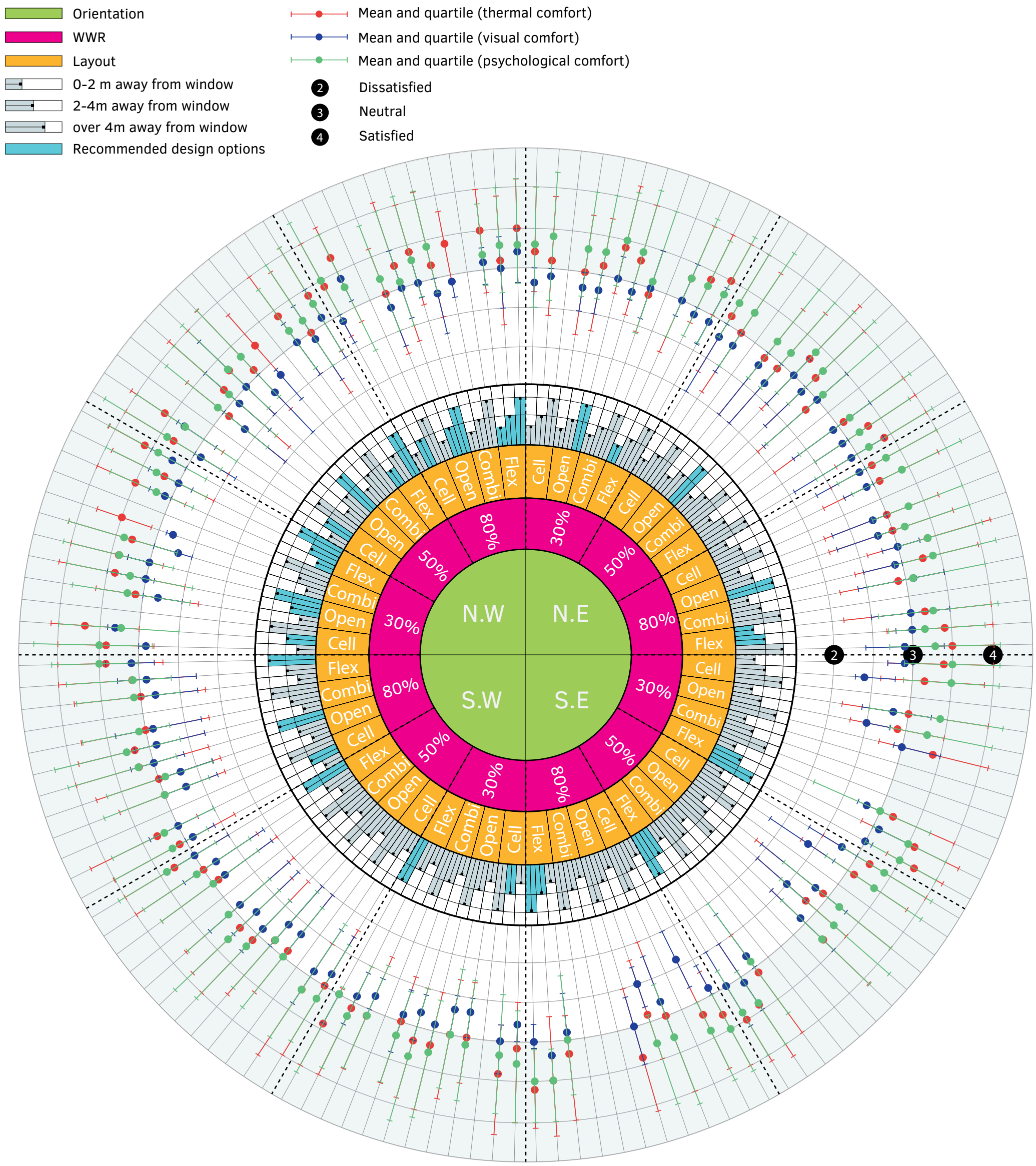


FIG. 8.2 Overview of predicted user satisfaction according to the combination of office design factors

8.4 Overview of energy-efficient office types

TABLE 8.1 shows the overview of energy-efficient office types that can improve both satisfaction and energy efficiency. This overview helps to identify the possible office typologies depending on the aim of the renovation projects. On average, office buildings with glazed façades facing north-west/south-east are recommended to create better work environments for occupants than the ones facing north-east/south-west. In terms of user satisfaction, the flex office can be highly recommended to increase the users' thermal, visual, and psychological satisfaction, regardless of desk location or WWR for north-west oriented workspaces. For energy efficiency, cellular and flex-offices are the most energy-efficient types, regardless of the orientation, and a WWR not greater than 80% should be designed for office renovations. The design options suggested for energy efficiency can achieve 23% to 28% of total energy savings compared to open plan office types with a larger WWR. Furthermore, the percentage of energy savings are not significantly different among the suggested design options. Therefore, the design alternatives are not strictly limited to several office types.

TABLE 8.1 Overview of energy-efficient office types

Energy	Orientation	WWR	Layout	Percentage of saving
	N.W/S.E	30	Cellular	6.3%
	N.E/S.W	30	Cellular	6.3%
	N.E/S.W	30	Flex	3.4%
	N.E/S.W	50	Flex	3.1%
	N.W/S.E	50	Flex	2.9%
	N.W/S.E	30	Flex	2.9%
	N.W/S.E	50	Cellular	2.7%
	N.E/S.W	50	Cellular	2.7%
	N.E/S.W	30	Combi	1.8%
	N.W/S.E	30	Combi	1.1%
	N.W/S.E	50	Combi	0.1%
	N.E/S.W	50	Combi	Standard

8.5 Application

This section explains how the principles and the overview graph can be applied during a renovation process. This applies to Cfb climate zone. Other climates or the Southern Hemisphere would require additional research. FIG. 8.3 shows the application process. Following the application process leads to the suggested renovation solutions to optimise satisfaction. The first step is finding the current physical office condition of existing buildings in the predicted satisfaction model, and second checking the satisfaction value (see FIG. 8.2). The third step is checking which satisfaction categories need to be improved. If the existing type is one of the recommended cases it is still advisable to check which factors can still be improved. After that, the application process proposes to go back to FIG. 8.1 and follow the order of important design factors to improve satisfaction with thermal, visual, and/or psychological comfort.

In reality, because of the conditions of the specific office, the possibilities to renovate in a certain direction are limited. For example, sitting far away from a window is illogical in the cellular office, due to the spatial efficiency and the size of a room. Therefore, it could be difficult to apply the renovation options recommended. In this case, the aspect of building services (designing the degree of personal control) can be a way to enhance user satisfaction through office designs. When it is possible to find the optimal design combination to improve user satisfaction, the energy performance of the option can be determined. Finally, the recommended degree of personal control can be applied.

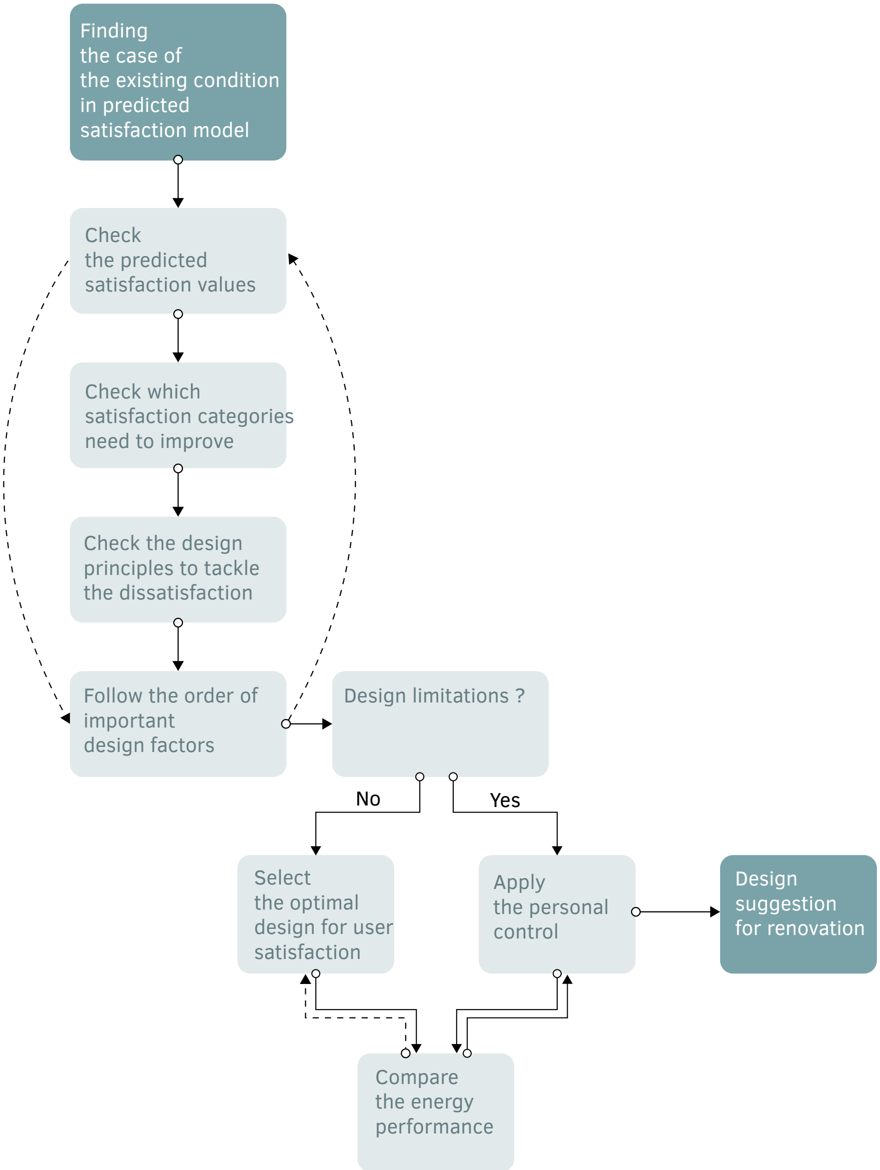
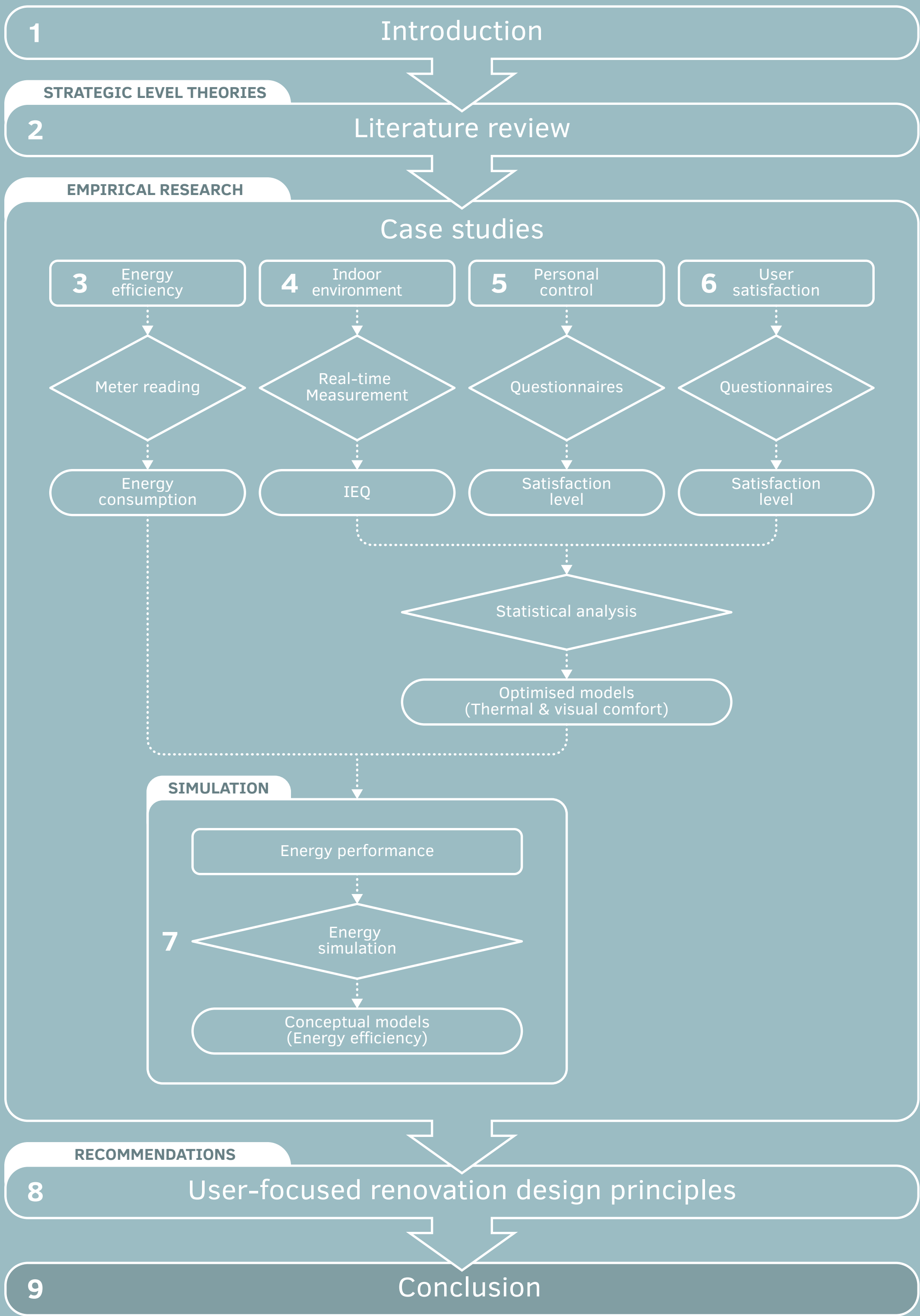


FIG. 8.3 Application of design principles in renovation process

8.6 Conclusion

The aim of this chapter is to elaborate how can the user-focused design principles be applied by architects, facility and real estate managers to energy-efficient office renovations during the design process, and how should they follow the principles and the predicted satisfaction overview model. To achieve this aim, the degree of importance of design factors for user satisfaction and energy efficiency was illustrated through the multidisciplinary analyses, and the application process is developed to guide people who will use the principles. Architects, facility and real estate managers should check the actual conditions of the existing office building, then explore the optimal combination of design factors with the predicted satisfaction value. What needs to be highlighted in this research is that the open plan office layout is a common type in office buildings, because the openness of the workspaces increases communication between employees, and is more space efficient, thereby cost efficient. However, in this research, the open plan office is not only a type that requires more energy, but also causes user dissatisfaction. For this reason, designing an open-plan office requires more attention and research to tackle these problems. Furthermore, there is not one answer to satisfy both energy efficiency and user satisfaction. In practice, these suggestions may be compromised by aesthetic issues or other factors, and technical building conditions can affect these design options as well. Therefore, it is important to make a balance between design considerations, energy performance and user satisfaction, and finding the optimal design solution instead of giving weight to only one aspect.


1 Introduction
STRATEGIC LEVEL THEORIES
2 Literature review
EMPIRICAL RESEARCH
Case studies
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Meter reading
Real-time Measurement
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9 Conclusions

9.1 Introduction

This research has explored the relationship between user satisfaction and design factors for office renovations considering energy efficiency. The findings of this research strongly support user-focused renovations of office buildings. My motivation for this research started from the consideration of comfort and satisfaction of building users and the focus on providing better and comfortable work environments for office users. The focus on user comfort and satisfaction is important, because literature shows that the increase of user satisfaction leads to the improvement of productivity and less absenteeism in workspaces.

This research has been conducted by applying diverse research methods and analyses, such as monitoring the indoor climate of office buildings, interviewing architects and facility managers, conducting user surveys, and conducting statistical analyses. This chapter presents the conclusions by answering the main research question and corresponding sub-questions of each chapter. This chapter also includes the general conclusions highlighting the scientific contributions to the body of knowledge of the built environment and limitations of the research.

9.2 Answers to the research questions

9.2.1 Sub-questions

What are the main parameters that are currently applied to evaluate user satisfaction in office buildings? (Chapter 2)

This question was aimed to identify the influential parameters of user satisfaction and office renovations as found in literature studies of relevant research. To develop this research topic, it was essential to understand user satisfaction and essential parameters that need to be considered for user-related studies. Scientific journal articles published in the period of 2000-2019 were reviewed as main input to explore the user-related studies. User-related research in the field of the built environment as well as building management has been continuously studied until now.

The main finding is the definition of ten parameters which are most important for user satisfaction in office buildings. The ten parameters consist of physical and psychological aspects and are classified by three categories: physically, functionally and psychologically related comfort. The theories related to human comfort support this classification of the priority of user satisfaction to increase their satisfaction.

What renovation strategies are applied in office renovations and how do they perform between renovated offices and non-renovated offices? (Chapter 3)

The building façade is often considered as the major part of a building renovation. The building façade is an important building component since it contributes to the energy performance of a building and to the indoor climate. Therefore, chapter 3 investigated the application of different façade renovation strategies in actual projects and their impact on energy performance, and henceforth the building characteristics of renovated offices were classified based on a cross-case analysis. Façade renovations can be classified by four different scales or types: passive add-in, replace, climate skin, and active add-in. This classification is re-defined based on literature. Based thereon, four office buildings, which were recently renovated and which are representative for these types, were selected for further study.

Although the office buildings were renovated towards energy label A, the actual energy consumption of these buildings was not particularly efficient. In addition, it is difficult to compare energy consumption of buildings. The international unit kWh/m^2.year is used in general to compare energy consumption of buildings. However, this unit does not consider energy use according to occupancy. Therefore, the unit Wh/m^2.h, which can be used to calculate the annual energy consumption per square meter, divided by the total occupied hours per year, needs to be included to make a real comparison of the energy consumption of office buildings.

The scale of façade renovation is often determined by the original structure. Interestingly, the actual result after renovation sometimes caused unexpected outcomes compared to what would be expected from the theoretical renovation planning. The differences are caused in the different stage of the renovation process: during design, construction, and operation phases.

How does the indoor climate affect user's thermal satisfaction and perception, and what are the predicted indoor thermal condition to increase user satisfaction in workspaces? (Chapter 4)

From the literature study, thermal comfort is a fundamental factor for the indoor environmental quality and its impact on the users' thermal perception. Due to the direct connection of thermal condition to the users' health and well-being, it is necessary to investigate the optimal thermal condition for users.

This question is answered by monitoring indoor temperature, humidity in intermediate, summer and winter and by conducting user surveys. The questionnaires comprised of thermal sensation, preference, and satisfaction. Moreover, the different orientation of workspaces in the same office building were also compared to figure out whether there is a difference in satisfaction according to the orientation of the workplace.

The main finding is that renovated offices that obtained an energy label A do not always provide comfortable thermal conditions. Furthermore, the indoor climate recommended by the Dutch NEN norm is slightly different from the preferred range of temperature in workspaces for office users. People tend to feel comfortable in cooler temperatures in winter than in summer. This suggests that the gap between the outdoor and the indoor temperature should not be too large, as found by many scholars called adaptive comfort. Chapter 4 suggests predicted thermal conditions, which enable users to feel comfortable and which are acceptable.

How does person control effect on the user satisfaction with thermal and visual comfort? (Chapter 5)

Personal control is one of the important factors to increase individual users' thermal comfort and satisfaction. Moreover, office users' interaction with building services/ systems is directly related to energy consumption. For these reasons, personal control should be included in user satisfaction studies. In order to answer the question, a user survey was conducted, next to collecting building information related to the degree of personal control over the work environment quality.

This chapter examined the tendency of user satisfaction with thermal and visual comfort according to the degree of personal control of heating, cooling, ventilation, sun-shades, and lighting. The key point in this chapter is which degree of personal control should be designed to increase user satisfaction. Overall, building users who have more freedom to control their thermal and visual comfort tend to be more satisfied with their work environment. Interestingly, the psychological impact of personal control was also observed during the study. For example, people more easily accept a work condition without personal thermal control than the condition that they cannot use an already available control system. With regard to visual control, people want to have full control over the sun-shading and lighting, unless the dissatisfaction can increase drastically. Exceptionally, when the thermal and visual condition are well controlled in workspaces, the impact of personal control on satisfaction is low.

How do the office design factors affect user satisfaction with physical and psychological comfort? (Chapter 6)

User satisfaction may be influenced by many physical conditions in a building. For office renovations, it is important to understand how the main design factors do affect physical and psychological satisfaction of users. Chapter 6 aimed to answer this question. The main design factors, such as office layout, orientation, window-to-wall ratio (WWR), and desk location, were selected based on the literature dealing with the relationship between office environment and user comfort. Data were analysed by applying a factor analysis, and by categorical and logistic regression tests. Through the factor analysis, the 10 variables related to user satisfaction (in chapter 2) were clustered in two groups: thermal comfort and visual comfort.

The influential weight of each design factor on thermal, visual, and psychological comforts were predicted in this chapter. The most important design factor for both thermal and visual satisfaction is desk location, followed by layout. WWR is the least influential design factor, and over a year the factor is significantly more related to thermal satisfaction than visual satisfaction. In terms of psychological satisfaction, five variables are considered (e.g. privacy, concentration, communication, social contact, and territoriality). Office layout and orientation are the most important factors to predict the users' psychological satisfaction.

Former user studies often focus on one aspect of user satisfaction instead of developing overall, or holistic, knowledge about the topic. The findings in this chapter however, provide an overview of the impact of different design factors on user satisfaction. The findings can also contribute to develop standard design principles for the early renovation design phase.

To what extent do the design factors contribute to energy demand in different energy categories? and which combination of design parameters are the optimal scenarios for energy-savings? (Chapter 7)

For energy-efficient office renovations, an effective combination of design parameters is essential to optimize energy savings because the design parameters can affect the amount of energy consumption of buildings. Therefore, chapter 7 aimed to investigate the optimal combination of design parameters of office layout, orientation, and WWR for energy savings. Mainly office layout and WWR are crucial factors in energy-efficient office design. On the other hand, orientation is not an influential factor on energy demand.

Unlike the results from the previous chapters, WWR significantly influences energy savings. The larger WWR consumed more heating and cooling energy, but had less energy demand for lighting. Interestingly, the office layout is also an important factor in energy savings. Having more rooms such as cellular offices requires high energy demand for space heating. In terms of total energy demand, 24 models were tested, of which 12 models with the combination of design parameters can be recommended to decrease energy consumption. The 12 models are cellular, flex, and combi-offices with a WWR of 30% or 50%, regardless of orientation. Particularly, the flex office with a WWR of 30% or 50% reduces the total energy demand considerably, regardless of orientation. Although the cellular office with 30% WWR has the least total energy demand, it was predicted that the cellular type with 50% WWR will use more energy than the flex office with a WWR of 30% or 50% WWR, north-east- or south-west-oriented office.

How can user-focused design principles be developed for and applied to the renovation design phase in order to optimise user satisfaction and energy performance? (Chapter 8)

The findings from the previous chapters cover a wide range of factors that are important for user satisfaction. The findings show that physical design variables can affect different degrees of user satisfaction. In order to make it applicable in practice, the results need to be integrated into a form that architects, designers and facility managers can understand and implement during a renovation process. The impact of the design variables can be summarised as follows:

- Office layout has the greatest impact on user satisfaction with thermal and psychological comfort, and it is also an important factor for saving energy;
- Desk location has the greatest influence on the satisfaction with visual comfort;
- Orientation has an impact on the user's thermal, visual, and psychological satisfaction, but it is not as important as office layout;
- The window-to-wall ratio (WWR) is significantly more related to energy savings than user satisfaction

The key focus of this research is the increase of the users' thermal, visual, and psychological satisfaction and the energy savings in office renovations. Therefore, the design principles are formulated and integrated towards the research aims. A flow chart is introduced to find an optimal renovation solution during the design process. The implementation process is created systemically based on the design principle and on the overview of predicted satisfaction. An additional consideration is to reflect the actual building conditions in the integrated flow chart. In reality, the design principles do not always lead to the optimal solution due to practical reasons. Providing personal controllability over indoor environment to users can be a solution to tackle this issue. An important finding in this research is that the degree of personal control strongly affects the users' thermal and visual comfort.

9.2.2 Main research question

How can the design principles for energy efficient office renovation be developed, based on the evaluation of user satisfaction?

The starting-point of this research derived from the lack of involvement/ consideration of users in the building renovation process. User involvement in building design is often regarded as complicated work since the opinion of users is subjective. However, through the field studies and statistical analyses of this research, the degree of user satisfaction could be consequently predicted with 95% of confidence, which means the results are reliable. Various research methodologies also contributed to user studies to reveal results in a scientific way. For this research, key points were how to methodologically compare quantitative and qualitative data, and how to find the relationship between them.

As a result, the design principles created in this research provide an indication of the increase of user satisfaction compared to renovation results without considering the user's perspective and applicable during the renovation design stage. It also provides a comparison of different combinations of design variables and their impact on user satisfaction. The design principles in FIG. 8.3 are structured considering three categories: user satisfaction, personal control, and energy performance. By following the design principles, architects, designers and facility managers can compare the possible renovation options.

9.3 General conclusions

9.3.1 Scientific contribution

The main scientific contribution of this research to the body of knowledge is the development of the design principles focused on the users' environmental satisfaction in office buildings. This research bridges the gap between energy-focused office renovations (technical consideration) and the users' perception and requirements (non-technical consideration) towards a better work environment.

Many scientific studies have analysed the impact of design parameters on user satisfaction, and the relationship between indoor climate and comfort. This research covers the influential design factors on user satisfaction with thermal, visual, and psychological comfort in workspaces. The overarching contribution in the field of the user-related studies is that this research did analyse not only the impact of each design parameter on user satisfaction but also suggested alternatives for office design that can improve both user satisfaction and energy efficiency. At the same time, the existing theories related to user satisfaction in workspaces were verified in a complex point of view by considering various design parameters as a whole.

Exploring the relationship between user perception and design factors can be used to develop guidance to overcome the dissatisfaction and health-related issues in office buildings. The systematic overview of the predicted user satisfaction can be further expanded to add missing values of various design factors. The methodology used for analysing user satisfaction can be applied to similar user-related studies.

9.3.2 Social contribution

Human health and well-being have been crucial issues over time. People spend over 80% of their time indoors and a third of their time working in offices. Moreover, the reason of existence of office buildings is to provide efficient and comfortable work environment for the users. For this reason, the workspace should play a major role in the users' health and well-being. This understanding could also shift the perspective of the owners, real estate and facility managers from energy-focused office renovation towards both energy and user-focused office renovation. Consequently, buildings should be designed with consideration of the end-users.

From the perspective of societal sustainability, building users should be a major consideration in the built environment. Unhealthy and uncomfortable work environment can cause complaints, absenteeism, and less productivity of office workers. Further, the poor indoor environmental quality may lead to vacant offices. The type of business is changed from supply-driven to demand-driven, in which user satisfaction is very important, and if considered well can prevent the vacancy of office buildings. In that sense, satisfying users' requirements can be a significant factor to increase a successful market value as well as the demand of comfortable offices.

Office renovations are often appealing by the energy and economical savings. Achieving high user satisfaction through office renovation can encourage office renovations that contribute to the development of sustainable offices. User-focused design principles therefore should be promoted for users' health and well-being in workspaces, which can contribute to social sustainability as a result.

9.3.3 Limitations of the research

Various methods have been used to identify users' satisfaction regarding work environment, including measuring indoor climate, user survey, statistical analysis, interviews, and energy simulation. The integrative design principles consider the multiple criteria for a better working environment. Nevertheless, there are several limitations that need to be addressed in order to give a guide for developing further research in this field.

First, although the results are statistically significant and valid for generalising and transferring the outcomes, the types of case studies are not various enough to investigate all combinations of the four design factors. Moreover, some design combination of office samples did not exist (e.g., cellular offices with work place over 4m away from a window, and combi-office oriented to the south-east) due to the local conditions in the Netherlands, and the common office types and design.

For these reasons, several missing values of predicted satisfaction are shown in FIG. 8.2. The main reason is that the types of office cases are not diverse enough to cover these design variables. For example, there are few cases of the combi-office space oriented to the south-east side, and cellular office space with work-desks placed over 4m away from a window. For this reason, the predicted user satisfaction values were not statistically significant, therefore the values were excluded in the prediction model.

Second, the deficiency of measuring data for indoor climate can be seen in this study. Since the limited number of equipment and access to the case buildings, the methodology regarding adaptive thermal comfort could not be used to investigate the acceptable indoor condition precisely.

Last, the façade renovation was the most important factor in energy-related office renovation at the start. However, the façade design strategies became less important than general design factors since the façade-related design factors are not considered in various ways. Focusing on the relationship between the façade-related design factors with a consideration of the financial aspect and users' thermal and visual satisfaction can be worthwhile to study in future research.

9.3.4 Recommendations for further development

Several recommendations for further research and development in similar studies and within the field can be given. First, there is a need to investigate user-related topics on smaller scale. The results in the research serve the overarching aim of attempting to increase user's satisfaction in their working environment. This research has covered a wide range of subtopics regarding user satisfaction, indoor climate, personal control, and energy efficiency. Thus, the outcomes of this study should be used for the preliminary design, not yet for the definitive design. Furthermore, experimental research on the small-scale of workspaces instead of many different office types needs to be conducted to explore the direct correlation between thermal and visual conditions and users' satisfaction. Moreover, analysing the same parameters based on user types or individual level can be of great importance to user-related research.

Similarly, personal control over indoor environment in user studies needs to be encouraged for further research. The impact of personal control over indoor climate has been dealt with in a few studies and in chapter 5 of this research. This thesis has revealed that having individual control over indoor environment can increase the user satisfaction. In order to increase the user satisfaction for thermal and visual comfort, decentralised systems with a consideration of energy performance can be promoted as the next step of this research.

Next, there were barriers to find renovated offices that achieved high energy saving goals (higher than energy label A) in this research. The topic of nearly zero energy renovation has been abundantly investigated in academic research. However, realising it may take some time in practice. It is expected that nearly zero energy office buildings will be built more frequently in the near future, as building laws and regulations require more sustainable buildings, and as office organisations and users get more knowledge about the contribution of their accommodation to a sustainable built environment. For further research, the energy saving goal in user-related studies can be more ambitious to achieve nearly zero energy buildings and at the same time improving users' satisfaction. In addition, the individual level of energy consumption based on occupancy time and personal control needs to be explored, as this may more accurate to compare energy use according to occupancy instead of the office area.

Last, more diverse design elements need to be considered to explore the relationship between users and physical conditions in workspaces. For instance, integrating the technical studies such as designing façade and HVAC systems into user studies will be beneficial to more precisely design a comfortable indoor climate. The design elements can also be considered in an aspect of floor efficiency and building cost.

9.3.5 Final statement

This research has explored the potential user satisfaction in relation with design factors for energy-efficient office renovation. The findings from field studies and literature indicate that design parameters significantly affect users' thermal, visual and psychological satisfaction. Those design parameters have a significant influence on energy consumption and creating a comfortable indoor environment. The design principles suggested in this research are developed for office renovations. For planning new office buildings, it is possible to refer to this principles. Nevertheless, the application process shown in FIG. 8.3 should be restructured to make it suitable for the office design for new buildings.

Above all things, the degree of personal control is an important parameter, and highly correlated to energy use and user's fundamental requirement. Regarding this point, one question that can be used for further research is how to optimise users' satisfaction on an individual level. To answer to this question, classifying different user types and analysing their characteristics are required.

Appendices

APPENDIX A

Questionnaire

General Information

Q1 What is your gender?

Male	Female

Q2 What is your age?

18 - 29	30 – 39	40 – 49	50 – 59	60 – 69	Over 70

Q3 What is your contract type?

Full-time employee *	Part-time employee

** at least 36 hours per week*

Q4 What types of space do you work?

Own desk	Shared desk*	Can choose randomly

** sharing a desk with fixed member of around 2-3 people*

Q5 Where do you work most of your work?

Work at home	Work at the office	Visit customers and other third parties	Visit and work in other offices

Q6 How many hours do you spend in the office per week?

Under 10 hours	10 - 20 hours	20 - 30 hours	30 - 40 hours	40 - 50 hours	Over 50 hours

Q7 How many hours do you work away from your desk per day (for teamwork, meetings, breaks etc.)?

None	1 hour	2 hours	3 hours	4 hours	5 hours
6 hours	7 hours	8 hours	9 hours	> 10 hours	

Q8 How many times do you take a break each day?

1	2	3	4	5	Over 6

Q9 How long is each break for one time?

Around 10 min.	Around 15 min.	Around 20 min.	Around 25 min.	Around 30 min.

Q10 How many hours do you spend for taking breaks or socialising in the office per day (including taking a cup of coffee, having lunch, etc.)?

1 hour	2 hour	3 hour	Over 3 hour

Q11 In which space do you mainly spend time for breaks? (multiple answers possible)

Outside of a building	Coffee lounge	Breakout area*	Canteen Own desk	Own desk

** e.g. informal meeting spaces*

Q12 Which floor do you work in?

Indoor Environmental Quality

Q13 Can you indicate how satisfied you have been with your work environment during spring/autumn?

	Extremely dissatisfied	Somewhat dissatisfied	Neither satisfied nor dissatisfied	Somewhat satisfied	Extremely satisfied
Temperature					
Artificial light					
Daylight					
Air quality					
View to outside					
Noise					
Humidity					
Overall comfort					

Q14 Can you indicate how satisfied you have been with your work environment during summer?

	Extremely dissatisfied	Somewhat dissatisfied	Neither satisfied nor dissatisfied	Somewhat satisfied	Extremely satisfied
Temperature					
Artificial light					
Daylight					
Air quality					
View to outside					
Noise					
Humidity					
Overall comfort					

Q15 Can you indicate how satisfied you have been with your work environment during summer?

	Extremely dissatisfied	Somewhat dissatisfied	Neither satisfied nor dissatisfied	Somewhat satisfied	Extremely satisfied
Temperature					
Artificial light					
Daylight					
Air quality					
View to outside					
Noise					
Humidity					
Overall comfort					

Q16 How do you sense the indoor temperature of your workspace?

	Cold	Cool	Comfortably cool	Comfort-able	Comfortably warm	Warm	Hot	Cold
Spring & Autumn								
Summer								
Winter								

Q17 Would you like it to be?

	Cooler	No change	Warmer
Spring & Autumn			
Summer			
Winter			

Q18 Where is your desk located?

0 -2 m away from windows	2-4 m away from windows	over 4 m away from windows	No window

Q19 Which direction does your window face?*

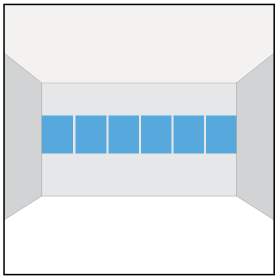
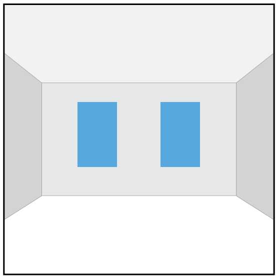
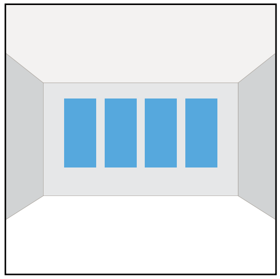
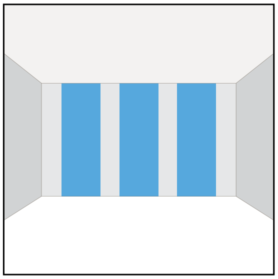
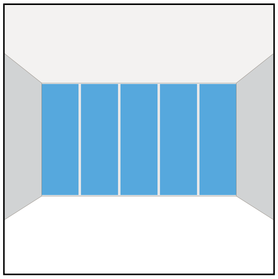
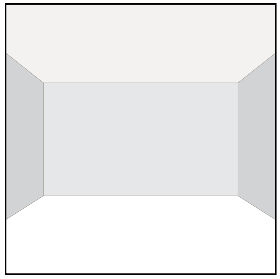
I do not know	South	East	North	West
	Southeast	Southwest	Northeast	Northwest

Please check the link (http://suncalc.net/#/52.0805,4.3327,18/2017.03.20/12:19).

Q20 Does natural light interfere your PC screen or desk (Glare)?

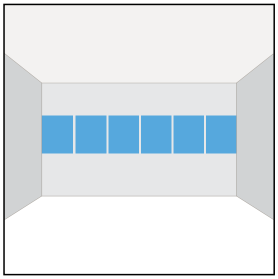
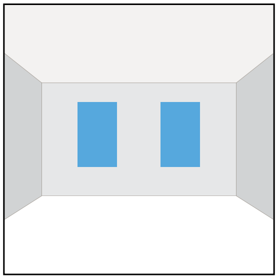
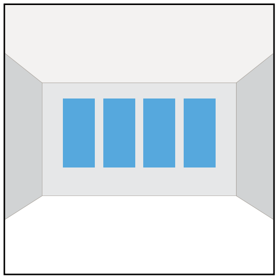
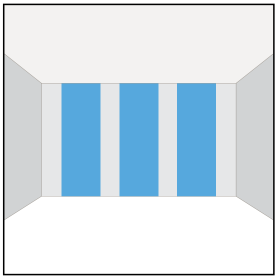
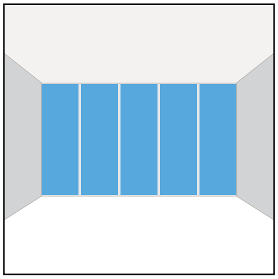
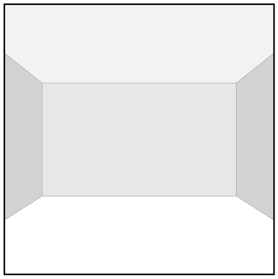
Yes	Sometimes	No

Q21 What types of windows does your workspace have?*

		
		
Others		

You should choose what comes closest to your situation.

Q22 What types of windows do you prefer?

Q23 Does the building have openable windows?

Yes	No

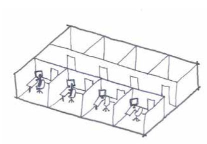
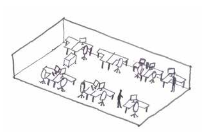
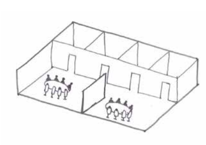
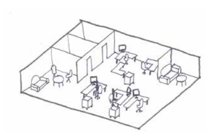
Q24 To what extent can you control the following aspects of your workspace?

	Complete control	Partial control	No control	I do not have
Heating				
Cooling				
Opening windows				
Daylight/sun shading				
Artificial light				

Q25 To which extent can you control your personal comfort considering the following aspects of your workspace?

	Completely	Partially	Not at all
Heating			
Cooling			
Opening windows			
Daylight/sun shading			
Artificial light			

Q26 What type of space layout do you work at?

Cellular	Open plan	Combi-office	Flex office
			

Q27 What is the size of your office room or workspace you work at (m2)?

Q28 How satisfied are you with the following?

	Extremely dissatisfied	Somewhat dissatisfied	Neither satisfied nor dissatisfied	Somewhat satisfied	Extremely satisfied
Privacy during work at your desk					
Opportunities to concentrate for work					
Opportunities to communicate for work					
Social contact with colleagues in the office					
Feeling of territoriality/ownership					

Q29 What are the most important issue for the better work environment?

Individual spaces for concentration	Meeting rooms for team work for communication	Lounge/Cafeteria for social interaction	Privacy

Q30 How many people are you sharing your workspace with?

alone	2 - 3	4 - 6	7 - 9	Over 10

Q31 How many people can you share a space with?*

alone	2 - 3	4 - 6	7 - 9	Other numbers

** maximum number of people do you feel comfortable*

Thank you for your engagement. If you have further remarks about your workspace that we have not addressed, please write them down. Also, if you are interested in the final result of this survey or joining the further survey please inform your contact e-mail.

APPENDIX B

Comparison table of case studies

		Passive add-in	Replace	Climate skin	Active add-in
WWR	≤ 20% ≤ 40 % ≤ 60 % ≤ 80 % ≤ 90 %	≤ 30 %	≤ 80 %	≤ 50 %	≤ 50 %
Sun shading		External blinds (south only)	Internal blinds (all sides)	External blinds (all sides)	External screens (south only)
Glazing type		HR ++	HR ++	HR ++	HR ++
Renewable energy		.	Wind energy from own electricity grid, Sun collecter heater	Acquifer system	.
Climate ceiling		O	O	O	O
Temp. Set point		21 ± 2 °C	21 ± 3°C	20 ± 3°C	20 ± 3°C
Heat recovery		O	O	O	X
Openable windows		O	X	O	O But not allow to open
System running hours	per week	35 - 45 h	55 h	60 h	80 h

Building information of renovated office cases

Curriculum Vitae

2005 - 2011	Bachelor of Science in Architecture, Chonnam National University, South Korea
2009 - 2010	Architecture Engineer, Yangwoo Landscape Architecture Co., South Korea
2012 - 2014	Master of Science in Architecture, Urbanism and Building Sciences, TU Delft, The Netherlands Dutch Architect
2015 - 2016	Assistant architect at Ketting Huls Architecten and van Bergen Kolpa Architecten in the Netherlands
2016 - 2020	PhD researcher/Lecturer, Climate design and Sustainability, Dept. of Architectural Engineering + Technology, Faculty of Architecture and the Built Environment, TU Delft, The Netherlands

Publications

Journal papers

Kwon, M., Remøy, H. and van den Bogaard, M., 2019. Influential design factors on occupant satisfaction with indoor environment in workplaces. *Building and Environment*, *157*, pp.356-365. doi: 10.1016/j.buildenv.2019.05.002

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Conference papers

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Kwon, M., Van den Dobbelsteen, A., Remøy, H., 2019, May. User Perception of Indoor Temperature and Preferences in Energy-Efficient Office Renovation Cases in the Netherlands. *In CLIMA 2019: 13th REHVA World Congress CLIMA, Bucharest, Romania*

20#01

Energy-Efficient Office Renovation

Developing design principles based on user-focused evaluation

Minyoung Kwon

The topic of this research is developed based on my motivation towards architecture design and society. My question in the built environment is are people happy to stay in a good energy-labelled building. If we consider the users in the renovation design phase, how can the design approach be different from how we are doing now. This thesis is, therefore, written in consideration of people who work in an office. It deals with four sub-topics related to office renovation: energy consumption, indoor climate and users' thermal comfort, personal control, and user satisfaction.

This research is targeted at the architects or facility managers who are interested in user-focused office design, energy efficiency, or office renovation. The results contribute to developing design principles for office renovations with integrated user perspectives, that improve users' satisfaction and comfort, as well as energy efficiency. I expect the design principles resulted from this research will not only contribute to an increase in the value of a building but also serve as a stepping stone for user-focused office designs or user-related aspects of the built environment.

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