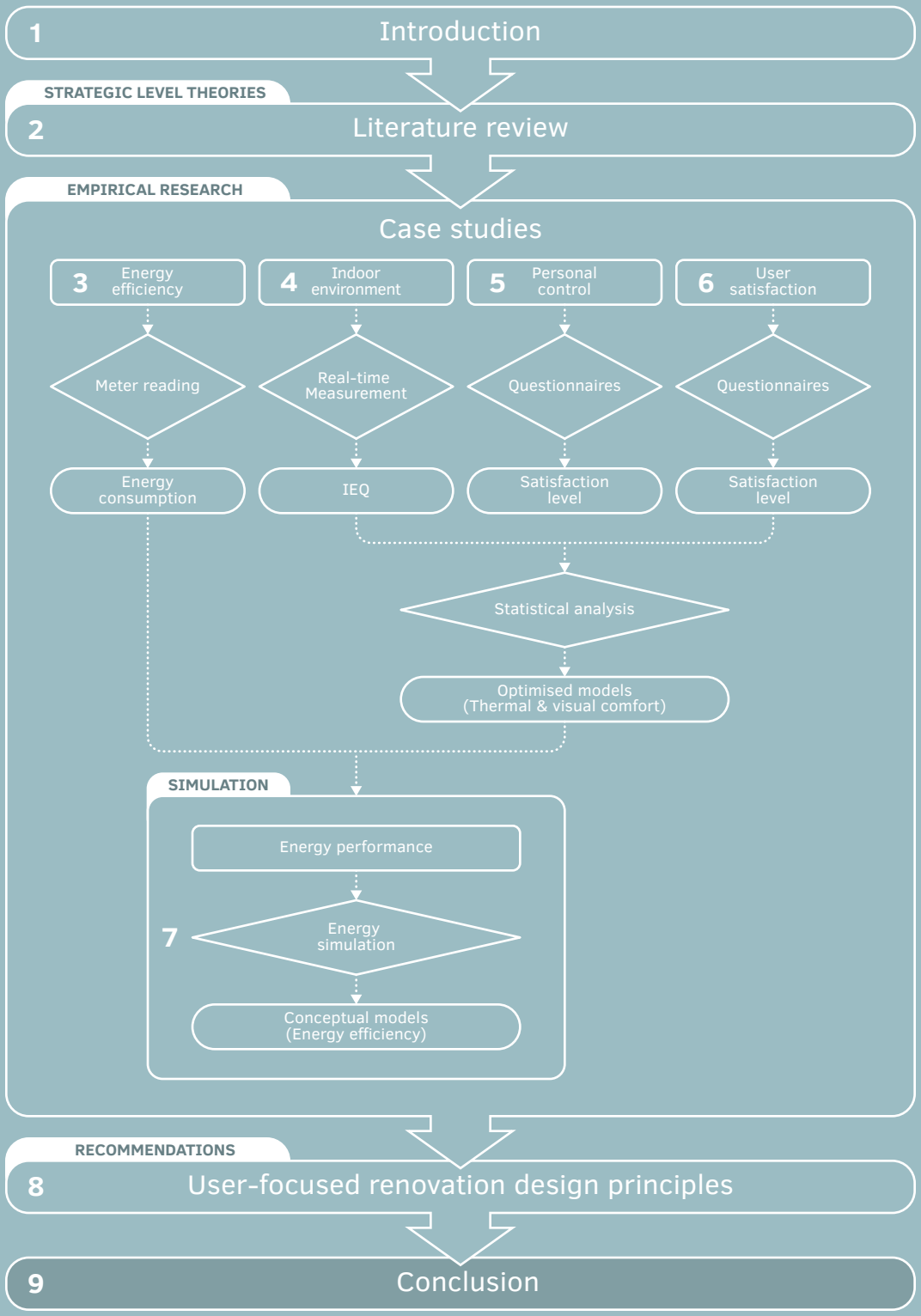

TOC

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.