Design guide for better usable operable façade elements for offices in the Netherlands

To help enhance the usability of operable façade element design to improve personal control over thermal environment and indoor air quality.

Rolien Wisse
Graduation Thesis
Building Technology
Faculty of Architecture and the Built Environment

Colophon

Master Thesis Building Technology

Name:	Rolien Wisse
Student number:	4154711
Postal Code, City:	Delft
Country:	The Netherlands
E-mail:	rolien.wisse@hotmail.com

University:	Delft University of Technology
Study:	Architecture, Urbanism and Building Sciences
Master track:	Building Technology
Theme:	Sustainable design – Climate & Façade
First supervisor:	Prof. dr. ir. Philomena M. Bluyssen
Second supervisor:	Ir. Frank Schnater
Guest Supervisor:	Dr. ir. Atze Boerstra, BBA Binnenmilieu
Submission Date:	April, 2017

Preface

Graduation, after many inspiring and intensive courses within the Built Environment department this thesis is the final work to be done before graduating for the master's in Building Technology at TU Delft. The project started with great enthusiasm about the subject, company and group of supervisors. The combination between the fields of building physics, building technology and the indoor environment within a familiar company seemed the perfect match. It did indeed turn out to be a pleasure to graduate at BBA Binnenmilieu with nice colleagues and interesting insights in the work they do. Furthermore, the topic is very interesting. However, the process and methods used were quite different from what was expected beforehand. I learned a lot during this project, including competences which I had never before been interested in developing, such as doing an extensive literature survey, which turned out to be fun. Going through all these related studies, feeling that understanding of the documents grows and realizing that people had already done research on these subjects before I was born was fascinating. At a certain point, the documenting part became serious, or let's say went beyond my core competences. Where some relevant information per document had been written down to form some sort of overview, it had to become one properly documented piece of background knowledge. This was quite a challenge to me. During the whole graduation phase, this was kind of a trend. The beginning of a research part is great. But, properly documenting, revising and reconsidering texts was slightly confrontational, I underestimated the complexity.

Acknowledgements

Several people deserve a word of thank. At first, Stanley Kurvers for his enthusiasm about the subject and suggestion to graduate on the usability of operable windows, a topic on the cutting edge of building technical, physical and indoor environmental knowledge and design. I was very glad to work on this topic because "functional design" in especially these directions within the building environment is my main interest. Subsequently, my supervisors Philomena Bluyssen, Frank Schnater and my guest supervisor Atze Boerstra for their guidance along the way and for reviewing several versions. Additionally, Marco Ortiz did help a lot in the design of the context mapping study and the reviewing of chapter four.

During this graduation at BBA Binnenmilieu, Froukje van Dijken and Tim Beuker were also very helpful during our daily talks when they gave me advice and explanations if questions related to the indoor environment or research came to mind.

Finally, I would like to thank the family and friends who supported me during the whole graduation period, especially my parents Ko and Alina Wisse, my sister Moniek and my boyfriend Pim van de Bunt who know me very well and realize that distraction is sometimes needed to gain new insights.

Abstract

In practice, operable façade elements (OFE's) in office buildings are often not appropriate to use to gain control over the thermal environment and indoor air quality. This study was performed to provide the means for architects and façade designers to design better usable OFE's and improve personal control over indoor air quality and thermal environment in the future. Therefore, aspects affecting the usability of OFE's was investigated, followed by determination of requirements, the design of an OFE meeting these requirements (Paragraph 6.2) and the development of a Design Guide. This was done by combining a literature survey, database analysis and context mapping study. The literature studied contained on the one hand very specific information about the use and physical aspects of operable windows and on the other hand more general information on operable windows was part of the greater whole. The database analyses presented that objections of roommates, draught and noise from outside the building revealing the most important reasons for not always being able to open a window when needed. Besides, open answers gave additional practical insight and it was found that the increase in roommates decreased the positive response to always being able to open the window when desired. Thus, mainly explicit and observable knowledge where provided by the literature survey and BBA database analysis. The context mapping study learned that direct communication with users helps to understand their tacit and latent needs, which helped to provide the means to improve OFE designs in the future. The eleven requirements for better usable OFE's are: User-friendly, Clear design intent, Effective, Supply is fresh air of sufficient quality, Fine-tuning capability/adjustable, Low noise ingress, (Mental) connection with outside, Proximal/ highly controllable by occupants, Robust, Parallel use of windowsill and window and Align design and management & security policy. They should be seen in context with the illustrations and explanations in the Design Guide (Appendix N Design Guide).

Executive summary

At present, operable façade elements (OFE's) in offices in the Netherlands are often not appropriately usable for personal control over thermal environment and indoor air quality. A pity and a missed opportunity, because adequate OFE's can provide fresh air and improve thermal comfort and thereby enhance occupants' health, productivity and workplace satisfaction.

A literature survey, database analysis and context mapping study are performed consecutively. Based on this research several products are developed: 11 requirements for better usable OFE's, an OFE design meeting these requirements and a factsheet and Design Guide to help architects use the information for the design of better usable OFE's in the future.

The 11 requirements are described below:
- User-friendly
- Robust
- Effective
- Adjustable/ Fine-tuning capability
- Proximal/ Highly controllable by occupants
- Clear design intent
- Supply is fresh air of sufficient quality
- Low noise ingress
- (Mental) connection with outside
- Parallel use of windowsill and window
- Align design and management & security policy

Subsequently, an OFE design which integrates these requirements is made for a common Dutch office situation. The design helps to visualize what an adequately operable OFE can look like, as well as how specific requirements can be integrated.
Lastly, a factsheet and design guide which include these requirements and OFE design is developed. The guide provides the means to design good usable OFE's. It also helps to inspire and motivate architects and façade designers to design adequately operable OFE's for the users of the building. The factsheet functions as a quick overview.

This study was feasible for providing the means to design better usable OFE's, because requirements are defined and an approachable Design Guide is developed. Although optimizing the requirements would be interesting for further research.

A suggestion for future studies is to further study the relation between OFE design and draught, noise from outside and objections of roommates, to enlarge the knowledge about how these aspects influence the usability of OFE's. Testing and evaluating OFE's in practice, with so called Post-Occupancy Evaluations (POE's), would be valuable as well. It can provide information about the importance of the requirements. In addition, a study how OFE's can provide fresh air of sufficient quality in polluted environments with respect to the characteristic direct effect and ease of use. Lastly, more information about the relation between operable windows and the effect on climate control systems in terms of energy and deregulation would be interesting. Both the information would be valuable, as well as having consistent information for office managers and occupants to prevent miscommunication, discussion and misunderstanding.

The Design Guide is meant to be read by architects and façade designers. Thereby implementation can be strengthened if consultancy companies who advice architects during the design process about creating a healthy building, start using this information as well.

Contents

List of figures and tables

List of abbreviations

Table 1 Explanation of abbreviations

Abbreviation	Explanation
OFE	Operable Façade Element
POE	Post-Occupancy Evaluation
IC	Indoor Climate
IE	Indoor Environment
IEQ	Indoor Environmental Quality
IAQ	Indoor Air Quality
BiU	Building in Use
TUD	Delft University of Technology

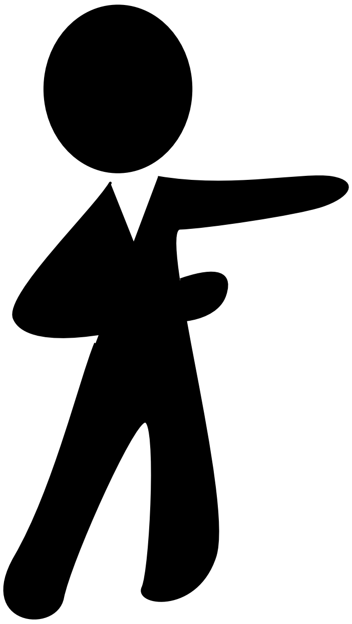
Glossary

Table 2 Definition description

Term	Definition
Operable Façade Elements	Operable parts in façades such as operable windows or shutters.
Design Guide	The design guide is one of the end products of this graduation, a guide for architects to design better operable façade elements
Final OFE Design	The OFE Design made during this graduation, an example of good usable operable façade elements including possible solutions on common barriers
OFE Related aspects	Aspects related to the usability of OFE's.

Ope<u>n</u>able or ope<u>r</u>able windows. Openable windows can be opened. Operable windows can be opened adequately and respond to people their needs.

1. Introduction



1 Introduction

Operable Façade Elements (OFE's) can improve control over the thermal environment and indoor air quality. Improved control over these aspects in an office environment is desirable since much of people's time is often spent in office buildings and many buildings appear to be falling short with respect to the thermal comfort and air quality goals set by various standards (Huizenga et al., 2006). In this respect, it should be noted that in the Netherlands indoor air is often more polluted than outdoor air. Moreover, without personal control it is hard to satisfy every single occupant since everybody is different (e.g. one is more sensitive to air pollution or noise distraction while another might be more sensitive to draughts) and therefore has different priorities when it becomes an indoor environment. Many office buildings in the Netherlands have operable windows or other OFE's such as hatches, doors or ventilation grills that can be applied in very different ways. These OFE's have the potential to improve thermal comfort and indoor air quality but negative aspects, like noise from outside, draughts and the objections of roommates, can outweigh the benefits. Suitable design is needed to profit from potential benefits. Unfortunately, many operable façade elements in the Netherlands are not appropriate for this purpose, for example because of obstructions or direct design related aspects such as being out of reach or not being operable at the right level, in the right way or in the right place (Figure 1). Furthermore, better OFE design can reduce negative external effects caused by, for example, noise from outside, rain and wind.

This master's thesis discusses the positive and negative effects of operable façade elements and how these positive effects can be achieved while the negative effects are reduced. In this respect, it should be mentioned that the indoor environment can be described by the indoor environmental factors air quality, thermal comfort, acoustical quality and lighting quality. This master's thesis mainly focusses on OFE's in relation to air quality and thermal comfort. Noise from outside and sun, and light screens turn out to be important factors to consider when designing OFE elements to gain control over air quality and the thermal environment, since they can cause an OFE to be unusable. Therefore, specifically these aspects of acoustical quality and lighting quality are also considered in this thesis since an unusable OFE, due to this lighting quality assisting elements or for acoustical reasons, will not provide the desired control over air quality and the thermal environment.

Figure 1 Examples of usability reducing aspects. From left to right; Obstacles, Window pattern/obstacles, Out of reach and blown away/too low adjustable (BBA Database).

1.1 Problem Statement

In practice, operable façade elements (OFE's) in offices are often not appropriate to use for control over thermal environment and indoor air quality.

1.2 Objective and research questions

The objective of this research is to develop a design guide for designers of office buildings and façades in the Netherlands, in such a way that it helps to design operable façade elements which are better usable and thereby improve personal control over thermal environment and indoor air quality. Specific research questions were:

1. Which aspects affect the usability of operable façade elements for personal control on thermal environment and air quality?
2. Which requirements help to design better usable operable façade elements which enhance personal control over thermal environment and air quality?
3. How can an operable façade element that properly integrates these requirements look like?
4. How can designers use this information for façade design with better usable operable façade elements?

1.3 Research design

This research contains roughly 3 parts, as can be seen from Figure 2. Aspects related to the usability of operable façade elements are collected through a literature survey, BBA database analysis and a context mapping study. This combination of methods is chosen to widely overview theoretical, practical and user-centred knowledge. This research is broadly intercepted to avoid narrow views and to be able to provide help for better usable operable façade element designs. Thus, information is needed from different points of view, not only from the physical part, practical part or the user's perspective. In other words, to improve a combination is needed. Thereby it is built on existing knowledge and available data and equipment to allow considerable research to take place in such a short timeframe.

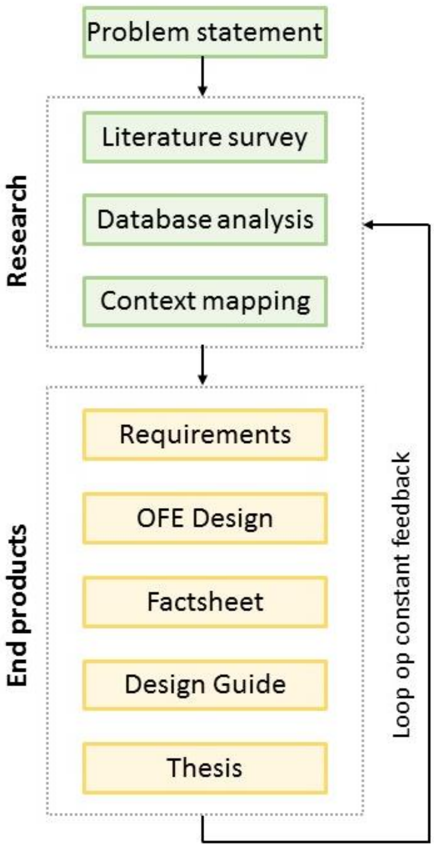


Figure 2 Schematically presented research design

The collection of operable façade element related aspects is then organized, analysed and summarized (Figure 3). Existing OFE's were evaluated on the basis of these aspects to increase the practical and building technical feeling for the meaning of these aspects. If possible, requirements for better usable OFE's are made from the OFE related aspects and the 3 studies together form the final requirements (Table 20). Subsequently, operable façade element variants are designed and the variant where the OFE related aspects were best integrated is worked out to illustrate all the potential solutions. Finally, a factsheet and design guide are made to provide the means to improve the usability of OFE Designs and thus increase the number of OFE's that appropriately provide personal control over thermal environment and indoor air quality.

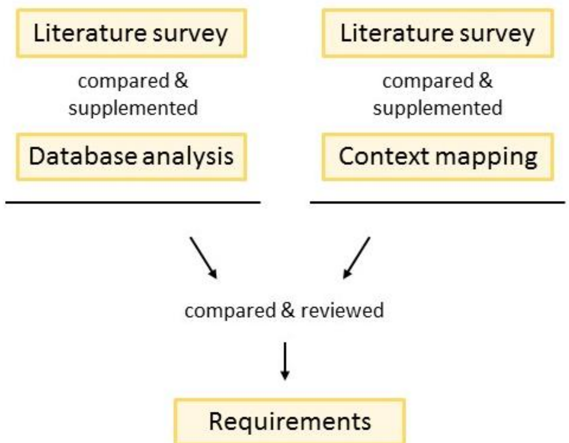


Figure 3 The literature, database and context mapping study results together form the final requirements

1.4 Focus situation

The most common ventilation situation - in the offices in the Netherlands which are in the database of BBA - is mechanical supply in the rooms and central exhaust in the hallways with additional operable windows. Therefore, this thesis focusses on operable windows in addition to mechanical ventilation to improve control over thermal environment and air quality. Thereby desks are often situated in groups of four desks (Figure 5). In Figure 4 a sketch of a standardized office layout in the Netherlands is presented. Groups of four desks with two or more groups of desks per enclosed area is taken as focus situation.

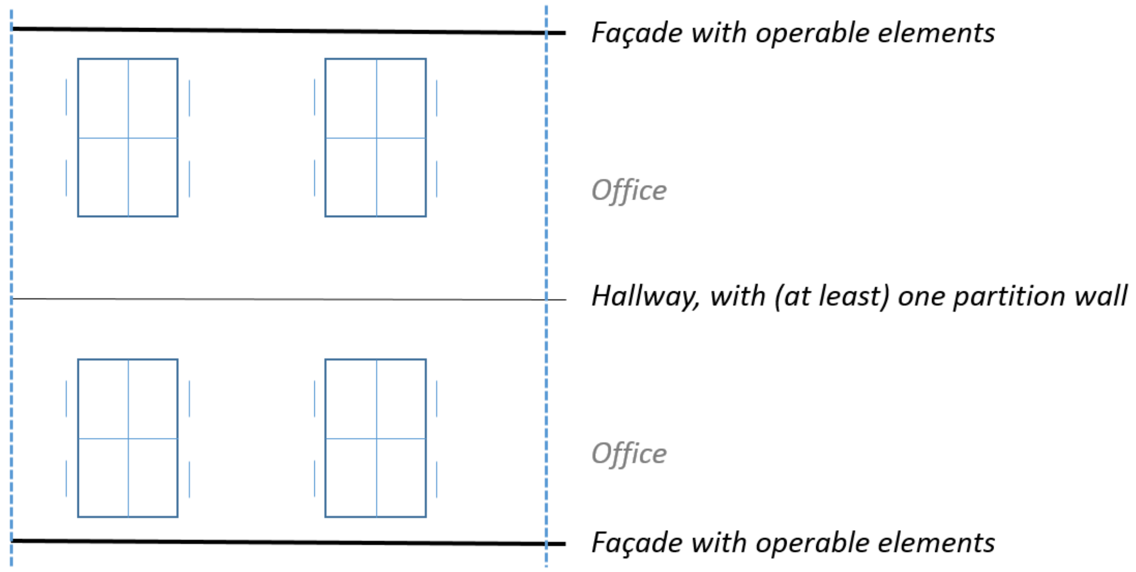


Figure 4 Schematic standardized office layout in the Netherlands

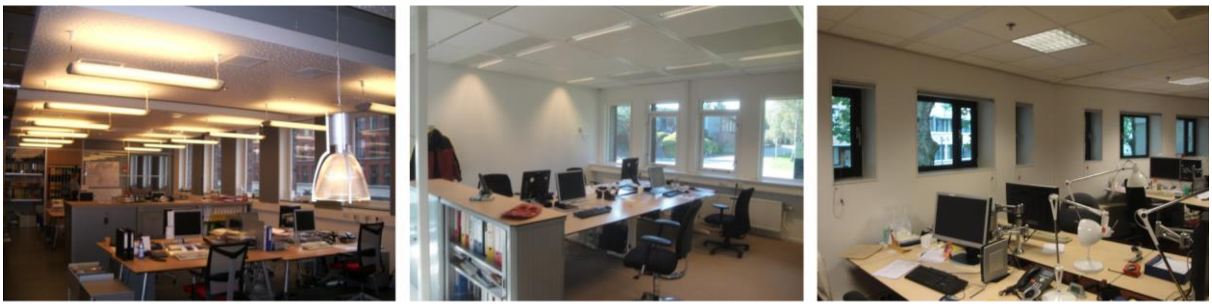


Figure 5 Examples of office settings from the BBA database

PART I. RESEARCH

2. Literature & Background information

2 Literature survey & Background information

This literature survey was performed to find existing knowledge about the office environment, OFE related aspects, effects and use of OFE's and how control of indoor air quality and the thermal environment can be improved by OFE's.

A start was made by studying the books on healthy indoor environments by Philomena Bluyssen (Bluyssen, 2009 and Bluyssen, 2014). Simultaneously this was alternated by using the search portals of Google Scholar and Science Direct. The main searched keywords were: Openable window, operable window, operable façade element, sustainable, (natural) ventilation, environmental psychology and environmental physiology combined with words like adjustable, usability, open plan office, comfort, health, indoor air quality, occupant satisfaction and control.

Thereafter several specific journals were browsed; Building and Environment, Energy and Buildings, Indoor and Built environment, Building Research and Information and Architectural Science Review. The literature found was studied on relevance and references in, and reference lists of, relevant literature was studied subsequently. Besides, Stanley Kurvers and Atze Boerstra suggested relevant literature as well.

The Indoor Air 2016 Conference was visited to gain knowledge and insights on international findings and concerns about indoor air quality. These ways of gaining existing knowledge were chosen on feasibility and are considered to provide a complete overview of the existing topic related knowledge on national as well as international level.

To get an overview, a separation was made in order to clearly present the main information, even though the subjects are connected. However this does not mean that the subjects can be regarded on their own, since there is no such thing as an independent variable in buildings. After the existing knowledge description of these subjects an overview is given of aspects OFE's have a potential effect on and requirements of good usable OFE's and their relation with these aspects.

2.1 Office environment

Many buildings appear to be falling short with respect to thermal comfort and air quality goals set out by standards (Huizenga et al., 2006). Huizenga et al. (2006) found relatively high percentages of dissatisfied occupants on temperature satisfaction votes and air quality satisfaction votes compared with workplace satisfaction votes, as can be seen in Figure 6.

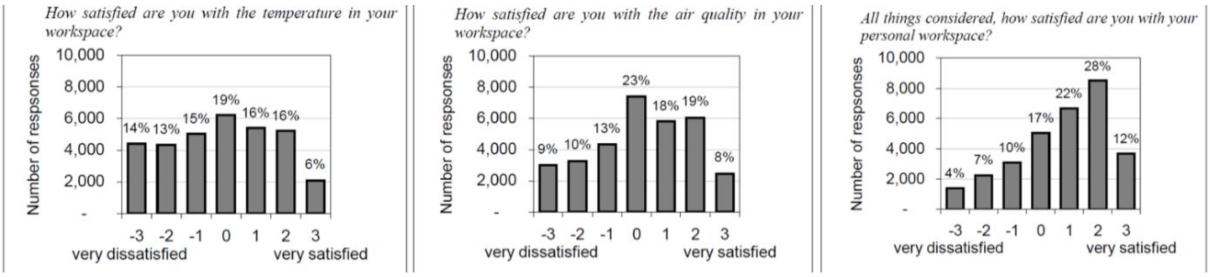


Figure 6 Percentage of occupants dissatisfied with temperature and air quality in offices, adopted from Huizenga et al. (2006)

Similarly, Cox et al. (2005) mentioned that the current situation is far from ideal and the potential for improving the indoor environment is high. Cox et al., 2005 is the final report of the European Project Health Optimisation Protocol for Energy-efficient Buildings (HOPE), which had as goal to provide the means to increase the number of healthy and energy-efficient buildings.

Occupants' comfort is related to the perceived indoor environment (Sakellaris et al., 2016) whereby the relations depend on socio-cultural context, as well as personal and building characteristics. Sakellaris et al. (2016) analysed the results of a questionnaire survey which was administered to 7441 workers in 167 office buildings in European countries within the framework of the European project OFFICAIR. They found the highest association with occupants' overall comfort for "noise", followed by "air quality", "light" and "thermal" satisfaction.

Facility management

Facility management can have a large influence on the satisfaction of occupants. It is important that the managing complexity is in line with the capacity of the building management. Bordass et al. (2001): "don't procure what you can't afford to manage". Thereby is mentioned that occupants like buildings that are able to respond to them and operable windows are noted as a success factor. Responsiveness to user needs is one of the four so called 'killer' variables (Leaman and Bordass, 2000) – variables which have a critical influence - on productivity in buildings which are under the control of designers and managers. Fast and effective response can be provided by personal control but also by rapid actions and anticipation of building management to meet people's needs.

Indoor-environment-related health effects

The indoor environment in total – with all diverse interactions - and specific elements such as high emission materials and the hygienic state and design of HVAC-systems (Heating, Ventilation, Air-conditioning and Cooling – systems) are related to many health effects. Bluyssen (2014, ¶ 1.2.1) summarized from findings of diverse studies that indoor building conditions may be associated with; mental health effects, illnesses that take longer to manifest, asthma-related health outcomes and obesity. Besides, many effects in offices buildings are associated with indoor environmental stressors, building-related illnesses (e.g. humidifier fever) and productivity loss (Bluyssen, 2014).

A performance indicator for health and comfort is the Building Symptom Index (BSI) which can be calculated by the mean number of symptoms reported by occupants. Boerstra et al. (2013) used the HOPE database and found that increase in perceived control over temperature and ventilation reduces the BSI_5.

Savings and productivity gains

A healthy, comfortable, safe and secure office has an economical potential. Many health effects are related to the indoor environment. Improvement of the indoor environment can reduce building symptoms, diseases, allergies and sick leave and increases productivity, an example of potential annual savings and productivity gains can be seen in Figure 7. Good usable operable façade elements can compensate for poor conditions and thus have economical potential.

Box 5.12 Savings and productivity gains

Fisk (2000) estimated the potential annual savings and productivity gains for the US through indoor air quality (IAQ) improvements with the 1996 US$ comprising:

- *Reduced respiratory disease*: US$6 to $14 billion (four common respiratory illnesses cause about 176 million days of lost work and 121 million days of restricted activity: a 100 and 25 per cent decrease in productivity respectively). Assuming a US$39,200 annual compensation, the annual value of lost work is US$34 billion. Healthcare costs are about US$36 billion.This results in an annual cost for respiratory infections of about US$70 billion. Better IAQ could reduce this by 9 to 20 per cent (or 16 to 37 million avoided cases of common cold or influenza).
- *Reduced allergies and asthma*: US$2 to $4 billion (costs for allergies and asthma are approximately US$15 billion (53 million allergy sufferers and 16 million asthma sufferer). A reduction of 8 to 25 per cent is feasible).
- *Reduced SBS symptoms*: US$10 to $30 billion (the number of workers with at least two symptoms is 15 million). Assuming a 2 per cent productivity decrease, the annual cost of SBS symptoms is in the order of US$60 billion. Evidence suggests reductions of symptoms in the order of 20 to 50 per cent.
- *Direct improvements in worker performance that are unrelated to health*: US$20 to $160 billion (to estimate potential productivity gains, only changes in performance that are related to overall productivity in a straightforward manner are considered – for example, reading speeds and time to complete assignments are considered, not error rates). Literature reports performance changes of 2 to 20 per cent; Fisk (2000) estimates 0.5 to 5 per cent. Considering only US office workers, responsible for an annual gross national product (GNP) of approximately US$32 trillion, this performance gain increase is roughly US$20 billion to $160 billion.

Figure 7 Example of estimation potential annual savings and productivity gains. Copied from Bluyssen, 2009.

Productivity mainly depends on four aspects: personal, social, organisational and environmental aspects (Clements-Croome, 2000). The so called 'killer' variables – variables which have a critical influence - on productivity in buildings of Leaman and Bordass (2000) which are under the control of designers and managers are; personal control, responsiveness (of facility management), building depth and workgroups. Personal control and responsiveness can be enhanced by operable façade elements and thus have a positive influence on productivity, if not overruled by possible negative effects such as noise, draught or not allowed to open.

Operable façade elements can also be used as low energy cooling strategy (e.g. Borgeson et al., 2008) and to 'flush' the building at night to prevent discomfort reported by workers in the mornings when they arrive, especially by new buildings and after the weekends (Vischer, 1989). If the building is not 'flushed' during the night there probably is a larger amount of air needed when the building is in use to replenish the stale air (Vischer, 1989).

Another saving potential is mentioned by Paliaga (2009), air movement can be an energy-efficient alternative to air cooling and Kurvers et al. (2013) mentioned in their robustness theory that mechanical cooling has an increased risk on unexpected high energy use.

2.1.1 Office layout

The relationship between façade design and office layout has an effect on the usability of OFE's and whether they provide control over thermal environment and indoor air quality. Paciuk (1989) noted proximity and accessibility to the user for the evaluation of available control which she defined as the degree and type of control made available by the environment.

Brager et al. (2004) studied the varying levels of direct or indirect personal control based on proximity to the operable windows in the studied building and found that subjects on the perimeter who have direct access to operable windows have a higher thermal adaptation (i.e. they assess neutral temperature closer to the average experienced operative temperature) than subjects one desk away from the window. Occupants with lower degrees of control over the window, typically sitting further away from the window, are most likely directly affected by it but have less control over its operation since they must interact with people on the perimeter to use the windows. A seat close to operable windows can also have a negative effect since downdraught is related to weather conditions and the design. If it causes negative sensation is also related to the position and orientation of the occupants. For example, if occupants are situated close to an OFE with their neck facing the air supply or colder glass surface, they are more vulnerable (mostly due to no clothes around neck area) and draught complaints are more likely to occur.

Criteria for air speed and operative temperature are expanded for warm air temperatures in the ASHRAE Standard 55 for people who have local control over air speed. It is a requirement that the control is directly accessible to occupants and it must be provided for every six occupants or less or for every 84 m^2 or less (ASHRAE, 2004; ASHRAE, 2013; Paliaga, 2009), see Figure 11.

Hellwig (2015) mentioned accessibility in the context that large open-plan offices cannot provide access to windows for every occupant. Large depth of plans typically provides less individual control over the space. Leaman and Bordass (2000) noted by their description of 'killer' variable Building depth that "the deeper buildings get, overall satisfaction and productivity tend to go down". They stated that buildings deeper than 15m across are more complicated to service. Given reasons include higher populations with more activities and greater likelihoods of conflicts and higher dependency of technology and management, building services have to be used if the building depth is 15m or more. According to Leaman and Bordass (2000) a depth of about 12m across seems optimal for human performance variables; shallower floor plans tent to cost about £ 50/m^2 more.

In short, it can be said that it is important for the usability of a window that person experiencing air movement from a window also is in proximity to the window.

Open-plan

Occupants in open-plan offices are more likely to perceive thermal discomfort, poor air quality and noise than in single plan office spaces (Bluyssen, 2014). Besides, job satisfaction in open-plan offices is reduced, a higher exposure to viruses occurs and occupants complain more frequently about central nervous system symptoms (e.g. headache), throat and eyes irritation (Bluyssen, 2014). According to a study by Pejtersen et al. (2011) there were 62% more days of sickness absence of occupants in open plan-offices compared to cellular offices.

Hellwig (2015) mentioned that large depth of plans typically provide less individual control over the space and large open-plan offices cannot provide access to windows for every occupant. Yildirim et al. (2007) focused more on privacy in open-plan offices and found that occupants close to a window assed privacy better than occupants away from windows.

2.1.2 Office location

Variables of which the importance for the design of operable façade elements depends very much on the location and orientation of the building are solar load, wind load, noise exposure and outdoor air quality. The impact of exposure to the sun, high wind speeds on the façade, noise from outside and bad outdoor air can be reduced by good design. Occupants will for example not get benefit of control over thermal environment and air quality by an operable window if opening causes; high solar load (i.e. when sun shading and an open window cannot be used at the same time), too high air speed, distracting noise from outside or high car emissions.

Solar load

Sun shading and operable façade elements can often not be used at the same time (BBA database). Especially on sun oriented façades (East, South, West) it is important to integrate the sun shading and operable façade element design.

Wind load and direction
In general, wind load on the façade is higher in case of fewer obstacles and larger height (Figure 8). High wind speeds can cause large pressure on a façade with operable parts which influences desired design or usability of these operable parts. In a dense area at ground floor it can be often wind still causing too low pressure difference and inefficient open parts. Thus the same operable parts will act different in different whether conditions but also on different location, it is good to be aware of the wind characteristics of the location while designing the operable parts.

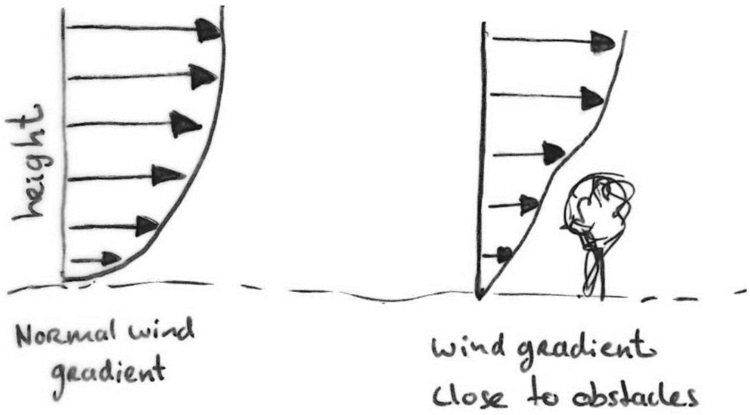


Figure 8 Wind profiles

The position of the OFE's and wind direction have influence on the ventilation rate. In the Netherlands south-west is the most common wind direction. Placing windows in more than one side can enhance the ventilation rate and provide cross ventilation. as in the last two figures of Figure 14.

Furthermore, the needed protection to avoid wind driven rain coming through an OFE depends on the orientation and exposure of the façade, generally the southwest façade is exposed the most to wind driven rain.

Noise exposure & outdoor air quality
The direct environment, which can differ per building side, largely influences the noise exposure and outdoor air quality, e.g. a highway, road, street, airport, parking, factory, square, sea or forest asks for different OFE designs.

2.2 Effects of OFE

Operable windows have the potential to provide the means to improve satisfaction over temperature and air quality (e.g. Huizenga et al., 2006; Kurvers et al., 2013), increase (thermal) adaptation (Bordass et al., 2001; Brager et al., 2004), increase tolerance with the indoor environment, increase overall satisfaction by providing personal control over operable windows (Huizenga et al., 2006), increase perceived control, improve health, provide air movement for comfort, an energy-efficient alternative to air cooling (Paliaga, 2009) and to cool off and 'flush' the building at night.

Operable windows allow occupants for example to align indoor temperature with the current outside temperature, to dilute internally generated pollutants and to increase local air velocity and thereby assisting occupants' physiological cooling (Haldi et al., 2008).
Effective controls can avoid dissatisfaction and a successful control action will be rewarded by pleasure (Cabanac, 2000).

In general it is possible to refer to one of the findings in the HOPE project; operable windows without restrictions to the open windows such as noise, pollution and security have a positive effect on the performance of a building (Cox et al., 2005).

Thermal satisfaction

Huizenga et al. (2006) found that occupants with access to an operable window and/or thermostat were more satisfied with their workplace temperature, which is related to the possibility to control.

In warm or hot weather, air movement is one of the best means of improving thermal comfort (Raja et al. 2001). Although, open windows during a warm day can undesirably increase indoor temperature.

(Down) draught is an important aspect by thermal satisfaction and OFE as well. Figure 9 presents how down draught can be compansated by a radiator.

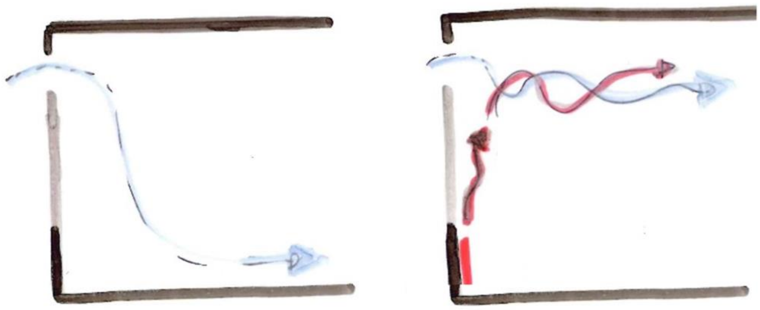


Figure 9 Sketch of down draught and down draught compensation by radiator.

The Coanda effect describes the phenomenon when a jet airflow attaches itself to the nearby surface, for example the ceiling. It can be used to prevent or reduce draught.

Turbulence intensity is the description of fluctuations of air speed and increases the sensation of draught, thus the higher the turbulence intensity caused by a window the larger the risk of draught.

In a heated room a vertical thermal gradient occurs. In winter air which is supplied at the upper part of the façade will thus heat up faster than air supplied at the lower part.

Indoor Air Quality (IAQ)

Figure 6 presents that in many offices it is not managed to reach a satisfying air quality. Operable windows offer the opportunity to dilute internally generated pollutants (Haldi et al., 2008) and enhance the indoor air quality. For more information about the indoor air (Bluyssen, 2015) provided an overview named "All you need to know about the indoor air".

Personal control

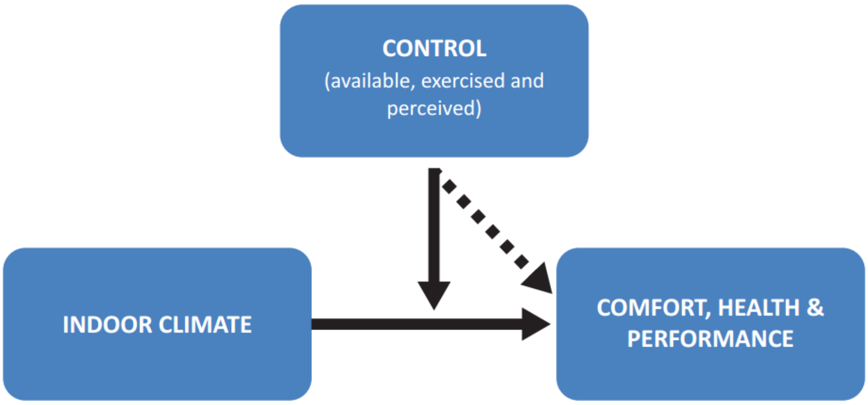


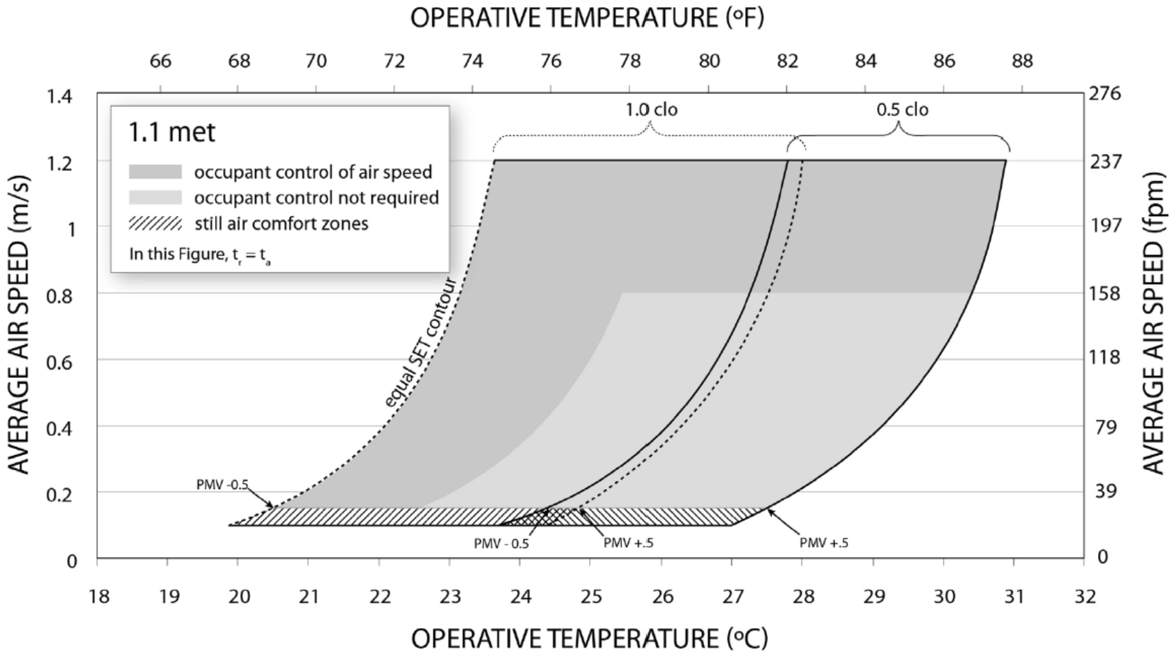
Figure 10 Personal control a moderator between indoor climate and comfort, health & performance as well as direct affecting (Boerstra, 2016)

Personal control acts as a moderator between the indoor climate (IC) and the comfort, health and performance of the occupants (Figure 10). Personal control also directly influences people's comfort, health & performance due to the positive effect of knowing that we have the opportunity to control (Figure 10). Leaman and Bordass (2000) described that people's perception of control over their environment affects their comfort and satisfaction. The faster the perception of response the higher the comfort scores.

Brager et al. (2004) studied the varying levels of direct or indirect personal control based on their proximity to the operable windows, as also described in 2.1.1 Office layout. They found that subjects on the perimeter who have direct access to operable windows had a higher thermal adaptation (i.e. they assess neutral temperature closer to the average experienced operative temperature) than subjects one desk away from the window. Occupants with lower degrees of control over the window, typically located farther away from the window, are most likely directly affected by it but have less control over its operation since they must interact with people on the perimeter to use the windows. It should also be mentioned that sun shading is an important building control to help building occupants perceive a sufficient degree of control over their indoor climate (e.g. Boerstra et al., 2013).

Yun et al. (2008a) found that occupant perception on controllability and thermal comfort was closely related with façade design whereby the highest degree of thermal satisfaction and perceived controllability of an occupant was found in an office with a user-friendly window that allows secure night-time ventilation. In a west-facing office with a high glazing-to-wall ratio was the lowest perceived controllability was found.

Kurvers et al. (2013) described lack of individual control over the indoor environment as decreasing the robustness and increasing the probability that the actual situation differs from the desired situation. As can be seen in Figure 11 the acceptable ranges of operative temperature extend in case of occupant control over air speed, the required conditions for occupant control according to ASHRAE (2013) are described at section 2.1.1 Office layout.



5.3.3A Acceptable ranges of operative temperature (t_o) and average air speed (V_a) for the 1.0 and 0.5 presented in Figure 5.3.1.1, at humidity ratio 0.010.

Figure 11 Acceptable ranges of t_o extend if occupant control over air speed (ASHRAE, 2013)

In summary it can be said it is important for the usability of an OFE that it is user-friendly. Control over indoor climate influences comfort, health & performance of occupants whereby directly accessible OFE's improve the degree of control.

Perceived control

Perceived control is linked to people's experiences and their personality. Relations between aspects are described underneath and presented in Figure 12.

Buildings with sealed windows have a low value of perceived control, this increases by a factor of 2.5 in mechanically ventilated buildings with operable windows (Hellwig, 2015). Yun et al. (2008a) found that the thermal condition and occupants' perceived control were two important factors on window opening patterns. The higher the perceived control the more frequent the window was used. Bordass and Leaman (1997) characterized actual control, fine-tuning capability and speed of response as the components of perceived control.

Hellwig (2015) is referenced a couple of times in the literature survey, an overview of the relation of aspects related to perceived control is shown in Figure 12. Some aspects in the scheme are highlighted in this paragraph to explain the scheme and provide more understanding of the meaning of personal control, for more detailed information about the scheme it would be wise to take a look at the paper of Hellwig (2015). The building's responsiveness including the façade and space layout influence the potential control strategies and constraints. The social environment influences personality, experiences, skills and knowledge of the potential control strategies, locus of IE control (expectancies for control of the behaviour outcome) and self-efficacy (believe in his/her own competences).

The evaluation system contains expectations and the actual preferences and constraints felt by a person. If an occupant is dissatisfied, control behaviour is required and thus outcome selection of the available control will be done and exercise will take place. If an occupant is satisfied, no action is required. In other words, people are motivated by needs. Choice overload can demotivate and make people more dissatisfied with the choices they made (Hellwig, 2015).

To summarise it can be said that perceived control is a key factor for satisfaction which is influenced by the stimulus (including the building's responsiveness) and the person's state (including experiences and the social environment). OFE's that are responsive to users' needs can improve perceived control and achieve satisfaction.

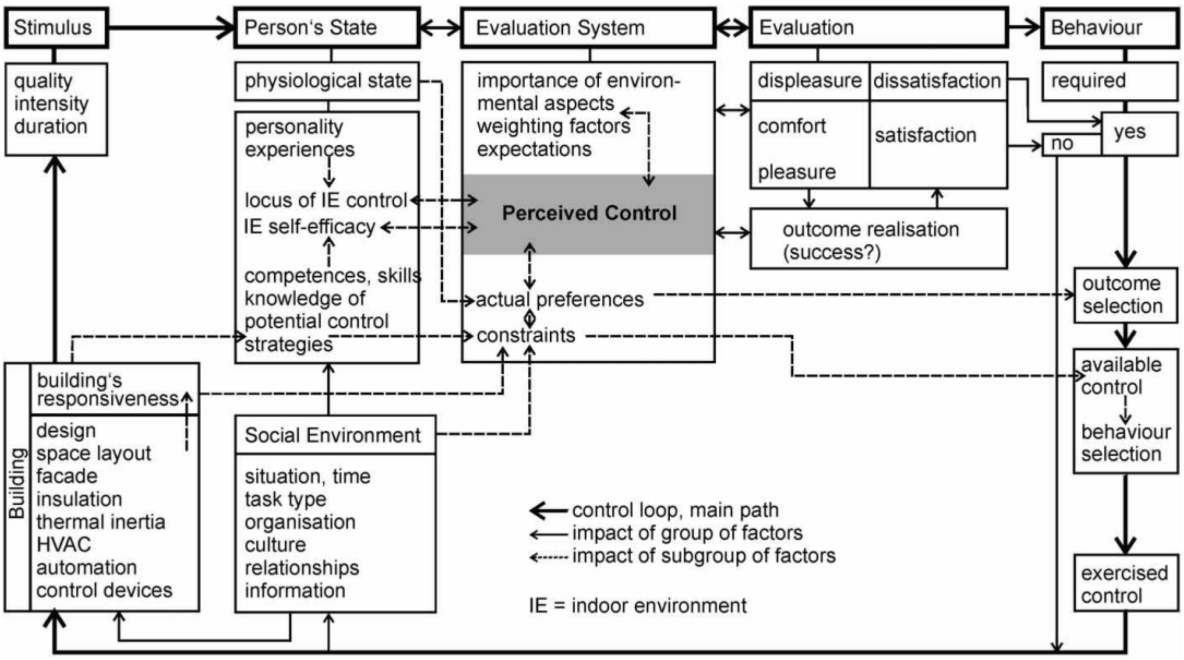


Figure 8 The newly proposed conceptual approach explaining perceived control as a key factor for satisfaction

Figure 12 Overview aspects related to perceived control. Copied from Hellwig (2015)

Ability to adapt

The Adaptive Model is a way of interpreting thermal comfort, according to Nicol et al. (2012). The basis of this adaptive model is made by the use of surveys to understand comfort. Nicol and Humphreys (1978) interpreted results of field surveys of thermal comfort and found that unpleasant sensations prompt reactions from people and cause them to make changes in the comfort control system. The Adaptive Model is governed by the adaptive principle (Nicol et al., 2012): *If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort.*

The final report of the HOPE project (Cox et al., 2005) also showed the need for adaptive opportunity; in their description of how healthy and energy-efficient buildings can be assured is mentioned that users should be able to adapt his indoor environment to his needs.

(Baker et al., 1996) mentioned that it is widely believed that occupants prefer a high degree of adaptive opportunities. Adaptive opportunity (e.g. control over an operable window) extends the comfort zone beyond the neutral zone while in closely controlled environments the neutral zone is narrowed (Bordass et al., 2001) (Figure 13). When the adaptive opportunity is zero, any departure from neutrality immediately causes stress or dissatisfaction.

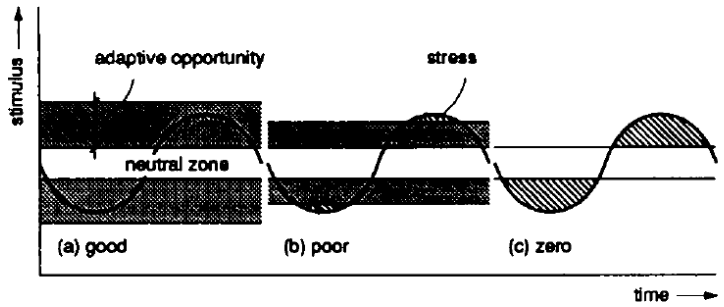


Fig. 5. Comfort zone is extended beyond the neutral zone by adaptive opportunity.

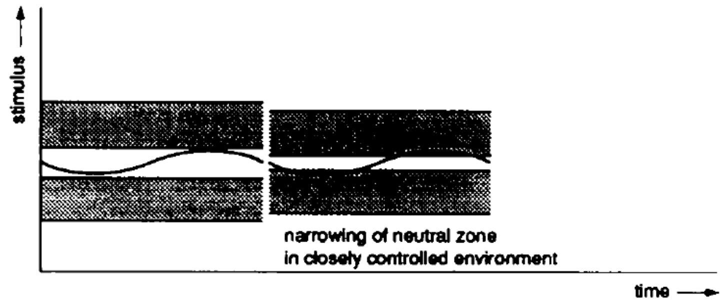


Fig. 6. Neutral zone is narrowed in a closely controlled environment.

Figure 13 Effect adaptive opportunity on comfort zone compared to closely controlled environment. Copied from Baker et al. (1996)

Brager et al. (2004) studied the varying levels of direct or indirect personal control based on their proximity to the operable windows. They found that subjects on the perimeter who have direct access to operable windows had a higher thermal adaptation (i.e. they assess neutral temperature closer to the average experienced operative temperature) than subjects one desk away from the window. Thereby should be mentioned that (mental) connection with outdoor climate provides higher acceptance of thermal variation.

Shortly summarized can be said that users should be able to adapt their indoor environment to their needs to assure healthy and energy-efficient buildings. People should have the opportunity to restore their comfort if (thermal) discomfort occurs.

Forgiveness/ tolerance with indoor environment

There is more 'forgiveness' of buildings in which occupants have more access to building controls (Leaman and Bordass, 2000). The forgiveness factor is an attempt at quantifying how occupants extend their comfort zone by overlooking inadequacies of their thermal environment. Thereby users appear to be happier if they understand how the building is supposed to work either because the design intent is made clear (Deuble et al., 2012) and/or because the controls are easy to understand and work well (Hellwig, 2015). Occupants are also more forgiving when (thermal) variations come from a known source with predictable behaviour. The more control opportunities available (e.g. switches, blinds and opening windows) the more tolerant people were of conditions like temperature. Much research is done about the higher tolerance and preference of wider ranges of temperatures in natural ventilated buildings (e.g. Brager et al., 2004). Baker et al (1996) also described the potential to save energy by relaxing thermal comfort standards and allowing more variable temperatures. Deuble et al. (2012) found that significantly higher environmental attitudes were present for occupants possessing greater tolerance of their building's thermal environment.

Experience of pleasure triggers motivation

According to Cabanac (2000) successful behaviour will be rewarded by pleasure and this seems to be a strong motivator to exercise effective behaviour. Hellwig (2015) also described that evaluation results effects motivation for behaviour (figure 7) and that sensory pleasure is a strong motivator for behaviour. Moreover the need for opening windows larger is in an indoor environment with poor conditions than in an indoor environment with good conditions.

Effects on health

The indoor air is often more polluted than the outdoor air. Opening windows allows occupants to dilute internally generated pollutants (Haldi et al., 2008). An open window can enhance the air quality and reduce complaints such as a headache and dry eyes. Especially if there are low ventilation rates compared to the number of people and relatively many other pollutant sources with high emissions such as printers and some carpets or furnishes, it can be a real relief to open a window.

Operable windows offer control to occupants, personal control reduces Indoor Environmental Quality (IEQ) related sick leave (Boerstra, 2016). If the outdoor air is more polluted than the indoor air, for example along a busy road, opening a window will have contrary effect and reduce the indoor air quality.

Cross-ventilation

In NEN 1087:2001 Ventilation in buildings paragraph 5.4 describes how the capacity of an operable window should be determined. The size and maximum degree of opening are considered for calculating the effective area (A_{eff} = A xJ(Ψ)). The airflow rate (q_v) is calculated by the sum of the effective area A_{netto} multiplied by the air velocity (v) in the purge component multiplied by 1000 (q_v = A_{netto} x v x 1000). According to the NEN 1087:2001 the air velocity (v) in the purge component becomes 4 times higher in case of cross-ventilation (purge components in non-adjacent façades) than in case of single-sided ventilation, from 0,1 m/s to 0,4 m/s.

Cross-ventilation increases the effectiveness of operable façade elements and thus has a positive effect on temperature decrease, smell decrease and supply of fresh air can happen faster. Nevertheless the main wind direction should also be looked at since cross-ventilation will not per definition happen, see chapter 12.1 Natural driving forces for ventilation.

Bangalee et al. (2014) focussed on the effects of lateral window position and wind direction on wind-driven natural cross ventilation. Thereby they found that the overall ventilation performance is dependent on the lateral window position by approximately 20%. They also found that with diagonal window arrangement the volumetric flow rate through the inlet/outlet is relatively smaller compared to face-to-face window arrangement. Diagonal window arrangement (Figure 14) provides more mixing with the indoor air and is therefore more effective.

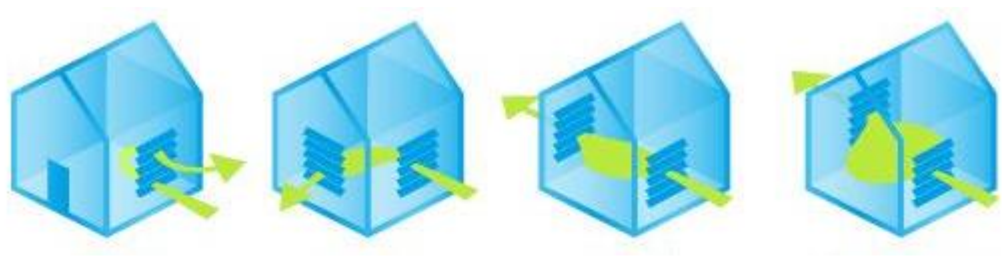


Figure 14 Window positions (The house designers, 2014)

2.3 OFE related aspects

The type of OFE and control is related to the ease of use and effort needed for the use of the operable façade element. If occupants are capable and willing to open the OFE is dependent on the occupants. In this matter, it can be said that for some occupant's extra attention for ease of use of the OFE can be required. Location, tasks and occupants can also require extra attention for effectiveness, airflow characteristics, pollution filtering, air temperature regulation or the acoustic performance of the operable façade element.

Effectiveness

The effectiveness of operable windows is depending on temperature differences (buoyancy), momentary weather conditions such as wind load and direction but also on aspects like office layout and characteristics of operable parts, as also shown by measurements of Boerstra et al. (2016). They found that the time it takes to decrease the CO_2 concentration and air temperature (in non-summer circumstances) differs a lot per situation. For example, if cross-ventilation occurs, a much larger air flow rate is coming through the same window than in case of single-sided ventilation.

Knaack et al. (2011) explained and illustrated functions of façades and façade principles in the book Gevels. Thereby they illustrated the amount of air diverse opening types can let trough, see Figure 15.

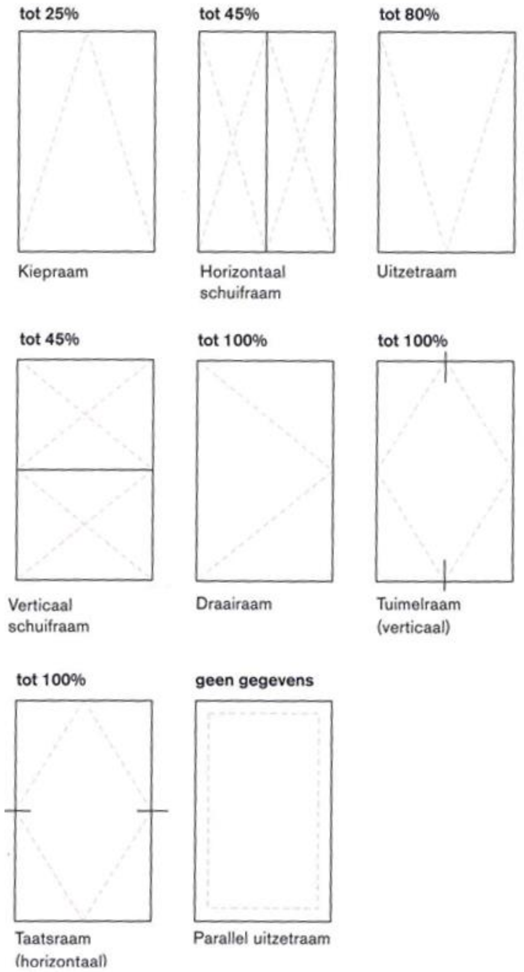


Figure 15 Types of opening and the amount of air they can let through. Copied from Knaack et al. (2011).

Airflow characteristics

Heiselberg et al. (2001) researched the performance of windows in relation to providing fresh air and their impact on thermal comfort and draught risk. The type of window, the effective opening area (A_{eff}) and the type of ventilation (i.e. cross/stack ventilation or single-sided ventilation) affect the airflow and penetration depth (distance from operable part to point were the jet no longer attaches to the ceiling). Their results of the bottom hung window, situated just under the ceiling, showed that the smaller the effective opening area the longer the penetration depth.

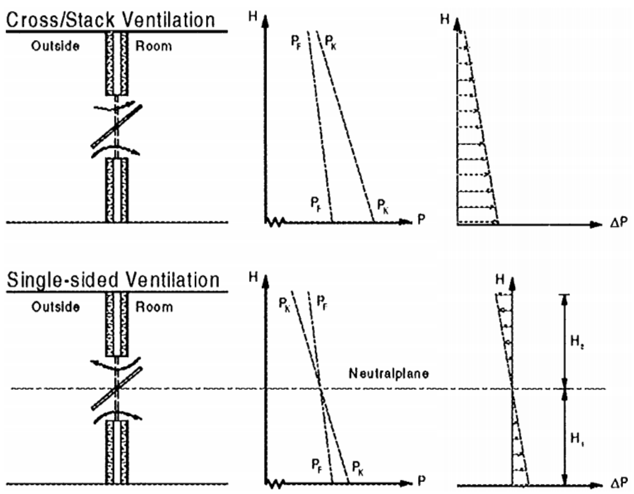


Figure 16 Air flow through window with single sided and cross-ventilation strategy. Copied from Heiselberg et al. 2001.

Figure 16 shows that supply air is coming in at the bottom and exhaust air is going out at the top in case of the single-sided ventilation. In case of cross-ventilation air is coming in at one side and going out at the other side of the building.

Heiselberg et al. (1999) experimented with three window types, Figure 17. They observed the airflow through these window types with single-sided as well as cross-ventilation by experiments.

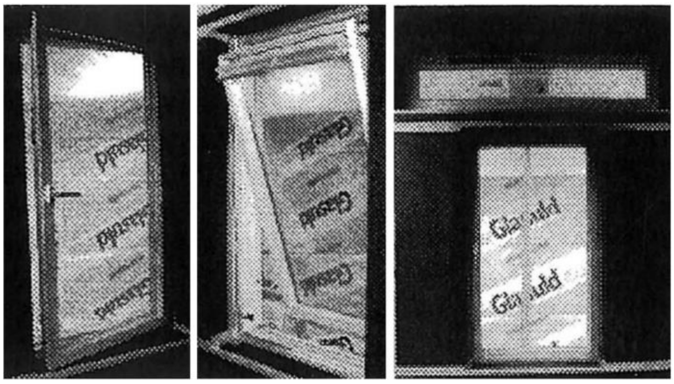


Figure 17 Three window types, from left to right type 1, 2 and 3 (top window). Copied from Heiselberg et al. (1999).

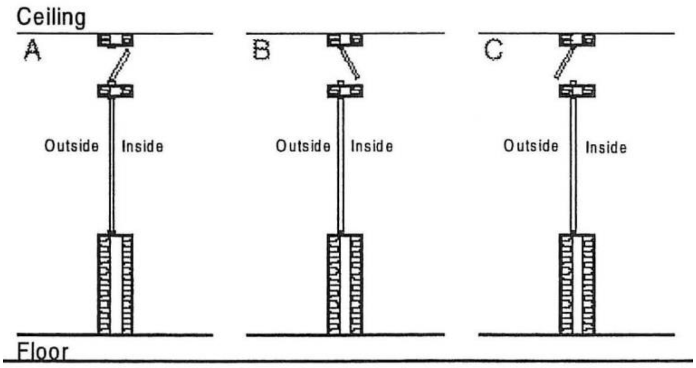


Figure 18 Indication three configurations of window type 3 (Figure 17). Copied from Heiselberg et al. (1999).

Figure 19 and Figure 20 present results from their tests of type 3 (Figure 17) with configurations A and B (Figure 18). Type 1 and 2 supply air in the occupant zone and are difficult to control because the air velocity and amount of air increases rapidly by increasing the opening angle. Type 3 supplies air outside the occupant zone and can be better controlled by changing the opening angle. In summer type 3 will not be able to supply enough air in the room. Therefore, they suggest to combine type 3 with type 1 or 2 to be able to supply fresh air in summer and winter.

For cross- ventilation in winter situation they advise type 3 bottom hung opening in Figure 20 because the supplied air travels the largest distance before it reaches the occupant zone and is therefore less cold while felt by the occupants. Configuration C (Figure 18) acted like configuration A (Figure 20A) but the distance along the ceiling was longer for configuration A, which makes A more feasible for the winter situation.

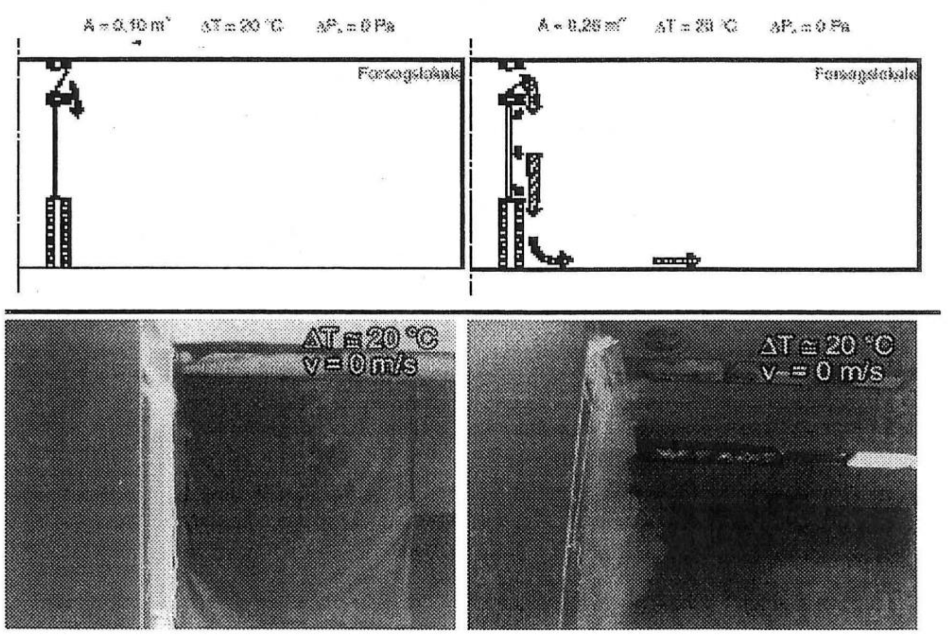


Figure 19 Air flow through window type 3 (Figure 17; Bottom hung, opening in) with A=0,10m² and A=0,25m², single-sided ventilation and a temperature difference of 20°C. Copied from Heiselberg et al. (1999).

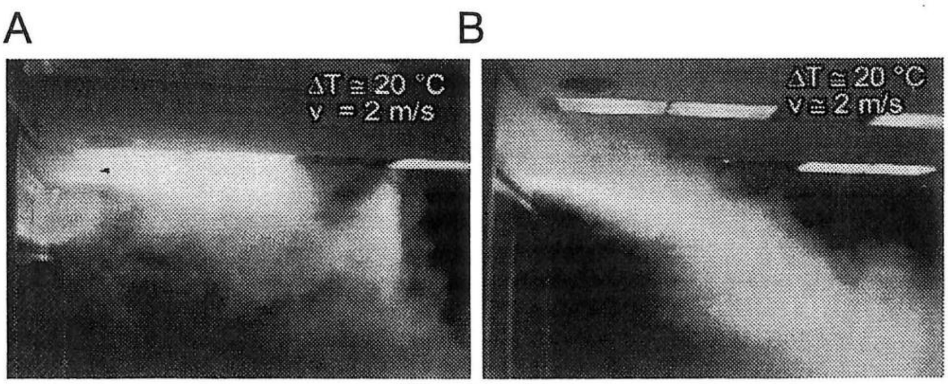


Figure 20 Air flow through window type 3 (Figure 17) with cross- or stack ventilation and a temperature difference of 20°C. A) Bottom hung, opening in. B) Top hung, opening in. Copied from Heiselberg et al. (1999).

Karava et al. (2011) researched the airflow in naturally cross-ventilated buildings with diverse sizes, locations and inlet-to-outlet ratio's to provide more insights and enable improved design and control of operable façade elements to enhance space cooling using natural ventilation. They found the following effects of design and control of openings in buildings with cross-ventilation;

- Higher airflow rates for configurations with symmetric openings, inlets located at the mid-height of the building or above and for inlet-to-outlet ratio's < 1. This could be beneficial for night ventilation but should be avoided by the natural ventilation for thermal comfort control, inlet-to-outlet ratio >1 will result in lower room air velocities.
- If the position of the outlet location is near the exposed thermal mass night cooling is more effective.

In short it can be said that controllability of air velocity and amount of air by varying opening angle is influenced by the type of window and influences thermal comfort and draught risk, as well as position of the supply does (in or out the occupant zone). The type of window has an influence on if enough air can be supplied, façade design with OFE's should incorporate both to offer personal control on thermal environment and air quality.

Filtering of outdoor pollutions

If the outdoor air is more polluted than the indoor air (e.g. because of a busy road nearby) it can be needed to filter the outdoor air before it enters the room. Though it is important to stay aware of the fact that filters form a risk to become a pollution source themself and they should be replaced frequently to work properly. Besides, filters reduce the effective opening area. For buildings in high pollutant exposure areas should therefore be considered if they are feasible for OFE's.

Pollen are only of issue if occupants are allergic. Jantunen et al. (2009) researched about the intrusion of airborne pollen through windows and doors. When the occupants are allergic to pollen it would be wise to look at the research of Jantunen et al. (2009) and use the information for design input for the OFE's.

An example of a filter that can be placed in window openings to prevent pollen coming is Poll-Tex®. A screen of an electro static coated polyester mesh that prevents insects, pollen and dust coming in. It has an air permeability of 1600 L/m^2 x s (20Pa) with 10% tolerance and is highly transparent (Van Heek Textiles, 2008). The conclusive test report and product specifications of Poll-Tex can be downloaded at: http://www.pollenguard.com.au/#!poll-tex-pollen-screen/c1e1.

Air temperature regulation

Incoming outdoor air can provide undesired draughts, pre-heating incoming air can prevent this and help to get fresh air at a more comfortable temperature, an example of air preheated by the sun in the cavity (greenhouse effect) is given in Figure 21. Thereby the indoor element could be a solid panel and the outdoor panel transparent.

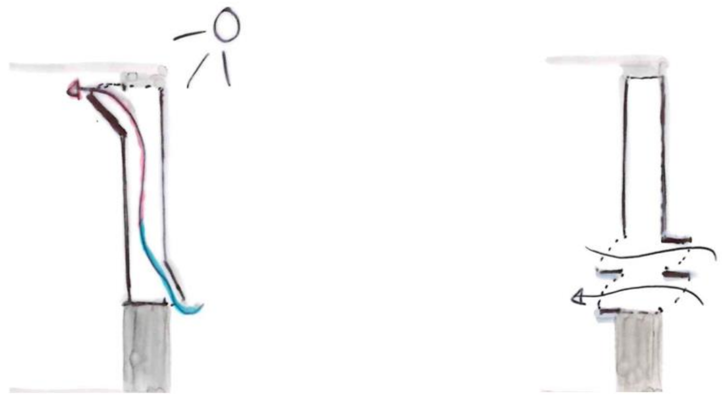


Figure 21 Indirect fresh air preheated by sun in winter vs. supply direct in occupant zone in summer.

It is important to be aware of that if the sun does not shine and the mass in the cavity is not warm, the incoming air will be barely pre-heated. Moreover it is not guaranteed that occupants know how to use it, e.g. they have low understanding of physics and the design intentions can be unclear because they will not always experience pre-heated air.

Acoustic performance

Reducing noise ingress through open windows can enhance possibilities for natural ventilation and OFE use on noisy sites. Nunes (2016) of Mach Acoustics developed and used Mach's FDTD software to visualize sound through several window designs to inform designers, see Figure 22. It should be mentioned that the sound source is located right in front of the window in Figure 22 and Figure 24. the influence of the location of the sound source can be seen in Figure 26.

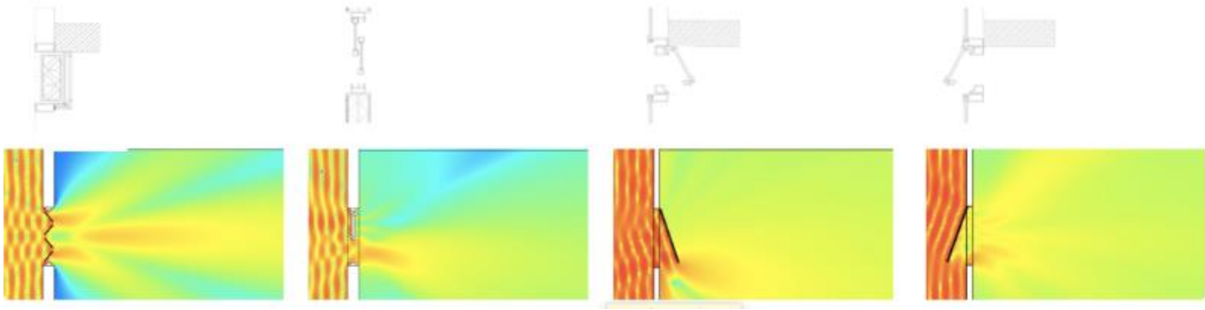


Figure 22 Effect of opening directions on noise ingress (Nunes, 2016)

An extended window frame can reduce sound passing through the window opening, an example is shown in Figure 23. The effect of extending the extension of the window in Figure 23 on the reduction of noise ingress is shown in three steps in Figure 24.

Figure 23 Extended window frame (Nunes, 2016)

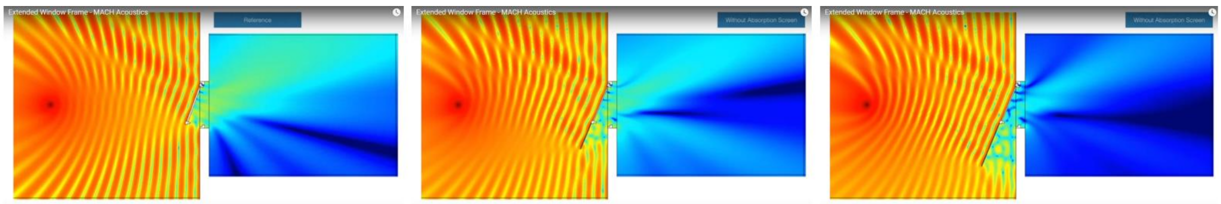


Figure 24 Effect of extending the window frame; Reference, half long, long (Nunes, 2016)

Adding acoustic absorption on the inside of the extended panel can enlarge the reducing of sound passing through the window opening, as can be seen in Figure 25.

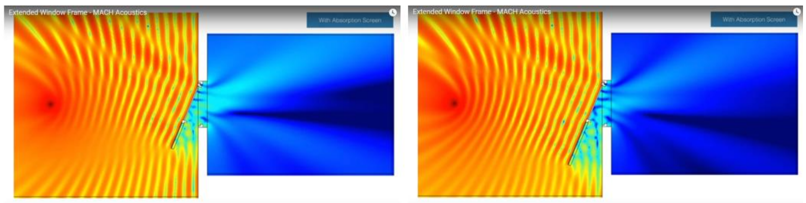


Figure 25 Effect of adding acoustic absorption on the insight of the extended panel; half long, long (Nunes, 2016)

Another example of an extended window frame is given in Figure 28, the fifth from left. Internal baffles can also improve the sound reduction as can be seen in the same figure, the fourth from left.

When noise will come mostly from the right (e.g. road) it would be better to open the windows to the left, thus opening against the direction of the sound. As illustrated in Figure 26 where the horizontal angle of incident sound influences the attenuate of sound.

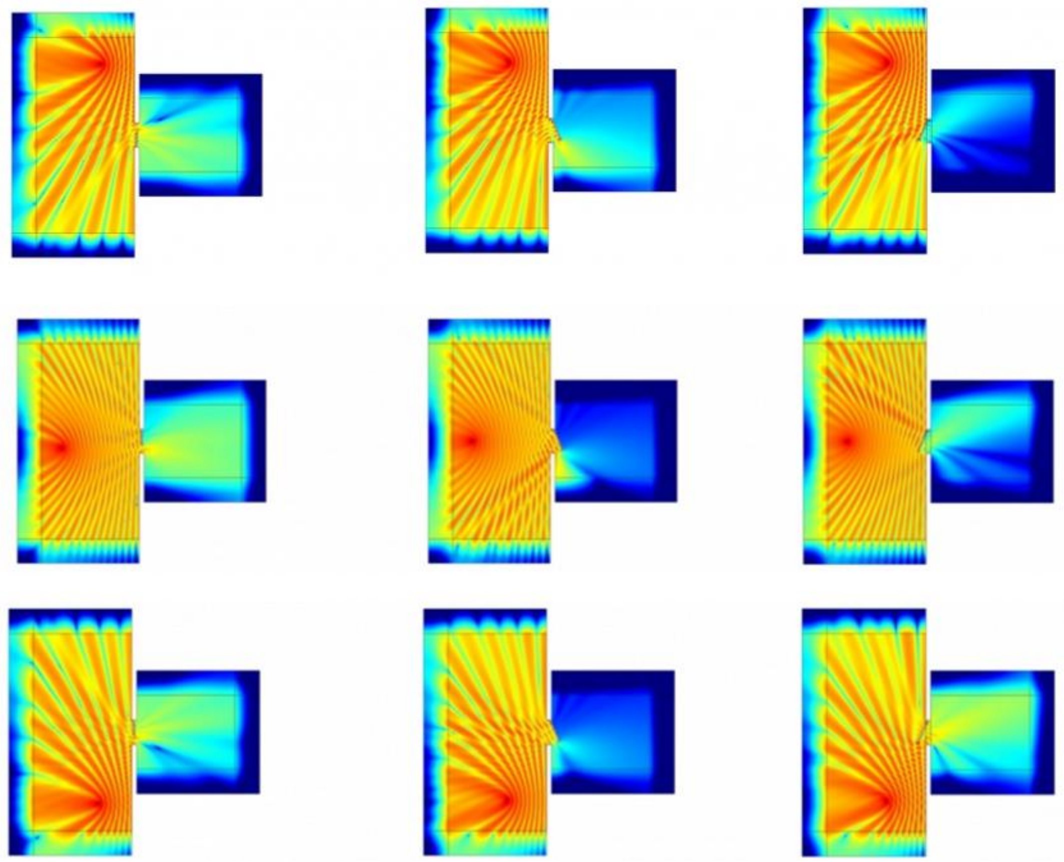


Figure 26 Influence of sound direction and direction of window opening on noise levels inside. Adopted from http://www.machacoustics.com/explore/books/open-windows/modelling-testing-results/

Angled façades can combine solar shading and acoustic shading to provide noise control and prevent over-heating, Figure 27 shows four examples simulated and presented in (Nunes, 2016). A sound right in front of the window is the most reduced by the third composition; the sound cannot enter the space between baffle and façade on the left side, while the window opens at the left side, thereby there is less noise bouncing to the ground of the baffle into the void than in the fourth composition.

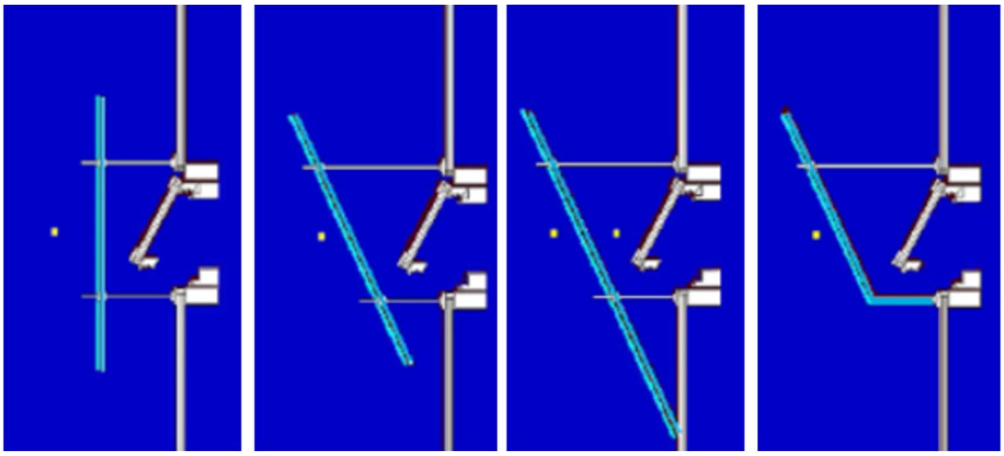


Figure 27 Examples of external baffles which are simulated (Nunes, 2016)

The indicative noise map of MACH Acoustics (http://www.machacoustics.co.uk/NoiseMap.v1.6.php) makes it possible to better idea of the ventilation possibilities for the needed acoustic performance in a certain situation. Figure 28 and Figure 29 present design directions which can be thought of for the required difference between external and internal noise level. Ventilation possibility ideas with increasing noise reduction from left to right in Figure 28; sash window, outwards tilt window, inwards tilt window, internal baffles, extended window frames with absorbing material on the inside of the panel, external baffles and a solution more focussed on sound absorbing (e.g. the NAT Vent Attenuator of MACH acoustics, with honeycomb shaped acoustic foam).

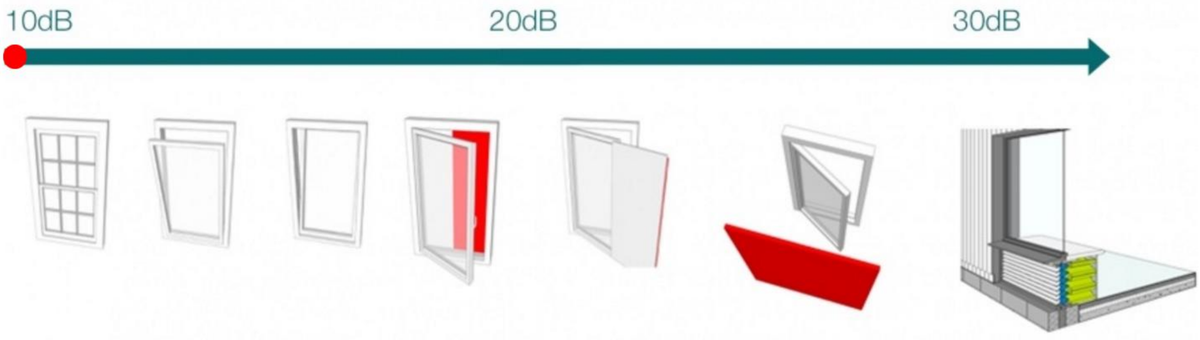


Figure 28 Optional design directions to reduce noise ingress. Copied from: http://www.machacoustics.co.uk/NoiseMap.v1.6.php

	Sash	Top hung inwards	Top hung outwards	Extended pane 0 2m absorptive	Extended pane 0 4m absorptive	Extended pane 0 6m absorptive	External baffle 1m away absorptive 1 5m long	External baffle 1m away absorptive 2m long	External baffle 1m away absorptive 2 5m long	Internal baffle 0 3m absorptive	Internal baffle 0 5m absorptive	Internal baffle 0 7m absorptive
X	-10.1	-10.4	-7.3	-7.6	-8.7	-8.0	-6.8	-6.5	-6.1	-5.8	-4.4	-2.8
Rw	12	14	18	21	26	27	25	28	28	20	20	22

Figure 29 Sound reduction OFE's. Copied from: http://www.machacoustics.com/explore/books/open-windows/modelling-testing-results/

Larger openings provide poorer acoustic protection with measured weighted differences limited to 1 and 2 dB for open area increases from 0.05 m² to 0.1 m² and from 0.1 m² to 0.2 m² respectively (Walters-Fuller et al., 2007).

The style of window opening has also influence on the level of sound insulation when it is open. They have compared the windows presented in Figure 30 and found that window B - the side swing reversible – provided the poorest sound insulating performance because the main air paths on either side of the opening form a sound channel reflecting off the open light towards the room. They did not find any opening style providing significantly better insulating characteristics but did find that the inwards turn and tilt Window C and Sliding sash Window D without extending opening parts were among the best sound insulating windows. Especially in case of angled sources of noise, thereby they mention that the lack of an extending opening is potentially advantageous by avoiding further in-bound reflections. The turn and tilt window improved the 'unprotected' sliding sash window when the source was normal to the façade. Windows with an outward opening which protects the open void from direct sound generally performed similarly well.

Term	Description	Configuration
A-1	Window A, outward opening casement - left hand side	
A-2	Window A, outward opening casement - right hand side	
A-3	Window A, top hung outward opening casements	
B	Window B, side swing reversible	
C-1	Window C, horizontal inward tilt	
C-2	Window C, vertical inward turn	
C-3	Window C, laminate glass, bottom hung inward tilt	
C-4	Window C, laminate glass, side hung inward tilt	
D-1	Window D, sliding sash upper section open	
D-2	Window D, sliding sash lower section open	
D-3	Window D, bottom hung inward opening	
E	Window E, top hung outward opening (PVC-U)	
F	Window F, top hung outward opening (Aluminum)	
G	Window G, side hung outward tilt (timber)	

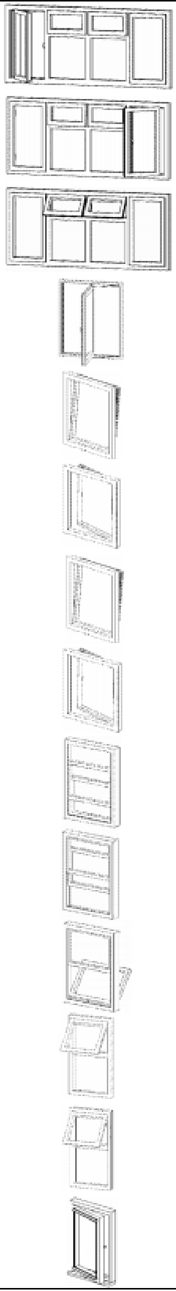


Table 3.2 – Window test configurations

Figure 30 Windows tested in the research of Walters-Fuller et al. (2007)

To summarize it can be said that taking the location of sound sources into account by designing OFE's and their opening direction can improve the acoustic performance, reduce disturbance from noise from outside and thereby improve the usability of OFE's. External baffles, extended frames and acoustical absorbing materials can help as well. In general counts, the larger the opening area the poorer the acoustic protection.

2.4 OFE usage

The focus is on windows with occupant control to improve thermal environment and indoor air quality. Haldi et al. (2008) described the treatment of actions on windows in a scheme (Figure 31). The key-stimuli to open a window are indoor temperature and indoor pollution level. Brager et al.

(2004) mentioned similar results, they found that windows are often used “to feel cooler” or “to let in fresh air”.

The left part of Figure 31 shows that external stimuli e.g. outdoor temperature, noise and wind and/or rain may act to reduce the probability with which windows are opened or the duration for which they are left open. These are not prioritised because it is likely to be different per person e.g. one could place the benefit of the incoming fresh air above noise from outside while someone else could be too much distracted by the noise and want it closed.

Raja et al. (2001) noted that the use of windows varies from person to person and the seating position. In the 14 buildings, they studied during peak summer months in the UK respondents reported open windows ranged widely, from 81% to 11% percent with an average of 62%.

Rijal et al. (2007) found that in most buildings (study in UK) the proportion of windows open is lowest in winter (0.14), medium in spring and autumn and highest in summer (0.69).

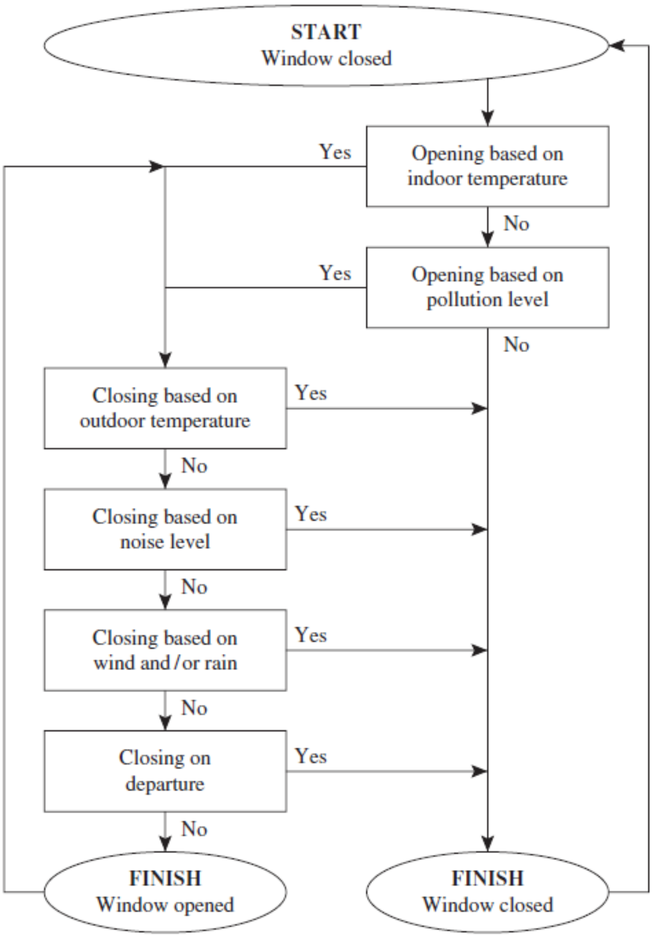


Fig. 15. Scheme for the treatment of actions on windows.

Figure 31 Treatment of actions on windows. Scheme of Haldi et al. (2008)

Yun et al. (2008b) stated that in offices with and without night-ventilation activity of window control mostly occurred during arriving and stayed the same during intermittent hours (occupied hours except arriving and departure) and is thus time dependent. The opening is also indoor temperature related; the higher the indoor temperature at arrival, the more frequent the windows were opened (private and two-person offices in the UK in summer).

The relation with indoor temperature is also found by Raja et al. (2001), they found that at indoor temperatures more than 20°C the number of subjects reporting the opening of windows rises steeply. Another variable announced by Yun et al. (2008b) related to activity of window control is the previous window state. In offices without night ventilation the state of the window before arrival was closed while in offices with night ventilation the state before arrival was mostly slightly opened. In night ventilated offices there is less activity of window control at arriving, the state is more often already the desired state. Wide variety in predicted window-opening probability at 23°C was explained; the windows in offices with occupants more actively adjusting the window have a higher predicted probability to be opened at 23 °C than those with passively adjusting occupants.

Yun et al. (2008a) found that the thermal condition and occupants their perceived control were two important factors on window opening patterns, the higher the perceived control the more frequent the window was used.

The use of windows is also influenced by the design and position of the window. Herkel et al. (2006) compared the opening of small windows (top hung opening to inside) situated at the top with large windows (tilt turn opening to inside) situated under the small window at desk height. They found that the small windows were opened less frequent but on average for a longer length of time than the large windows. The large windows were mostly opened completely at arriving and the second most after lunchtime.

In summary the results of Raja et al. (2001), Rijal et al. (2007), Yun et al. (2008b) and Herkel et al. (2006) showed that the use of OFE's is dependent on the indoor temperature, pollution level, OFE's, occupants, season, weather, noise level, arriving/departure, time of the day and previous state. The use of OFE's is influenced by the design and position of the window (the exercise is influenced by the desired outcome e.g. much or few supply in or out the occupant zone) as well.

Relation to outdoor temperature

Opening windows allows occupants to align indoor temperature with the current outdoor temperature and increase local air velocity assisting occupants' physiological cooling (Haldi et al., 2008). Outdoor temperature is related to the comfort temperature in free-running buildings (Humphreys, 1978), though comfort temperature cannot be calculated just by the outdoor temperature since that would ignore many factors (Nicol and Humphreys, 2001).

Clothing insulation is influenced by outdoor temperature (Bluyssen, 2009; Haldi et al., 2008). Haldi et al. (2008) found that outdoor temperature can be used to acceptably model clothing levels, actions on fans and blinds and the consumption of cold drinks.

Yun et al. (2008b) explains that much previous research explained occupant interaction with window controls as a function of external temperature since it is an independent variable while indoor temperature is a dependent variable and relatively hard to obtain. The indoor temperature varies with e.g. orientation, façade design, thermal mass of the building structure and internal heat gains. They describe that therefore an occupant model in which occupant behaviour is explained by outdoor stimulus would result in identical prediction of behavioural patterns even if the indoor thermal stimuli are different and thus the prediction as a function of external temperatures cannot be considered as an intrinsic result. Instead they linked indoor temperature with window-opening behaviour patterns and found that, in summer, windows were opened more frequent when higher indoor temperatures occurred.

Haldi et al. (2008) also concluded that indoor temperature significantly influences the predictions of the probability of opening windows while the link with outdoor temperature is less convincing and can be discarded as a driving stimulus for opening windows. However, they announce that outdoor temperature cannot be rejected as a valid parameter influencing the opening/closing of windows for example to avoid draughts, excess heat gains or to promote free cooling. They describe outdoor temperature as an external stimulus which may act to reduce the probability with which windows are opened or the duration for which they are left open (left part Figure 31).

Herkel et al. (2006) found that the correlation with the seasons (in 21 buildings in Freiburg, Germany, from July 2002 till July 2003) and the percentages of open windows and frequency with which windows are opened or closed is strong. In summer the highest percentage of windows is opened and the frequency of opening is small. In autumn, the percentage of open windows decreases to a small percentage in winter were after it increases to become high in summer again. The frequency of window opening and closings is the largest in spring and autumn, according to them probably because the weather conditions are changing drastically. Thereby they noted that future field studies should include e.g. indoor temperatures (as mentioned by Yun et al. (2008b) and Haldi et al. (2008)) and wind, incident radiation, noise level, indoor air quality and buildings with different HVAC concepts and space typologies)) to enhance the validity of their developed probability function. Though the probability does provide insight in the use of different windows, opening level and duration of opening per season.

Heiselberg et al. (2001) also mentioned that it depends per season which window situation is best feasible.

In summary can be said that feasibility and use of OFE's as well as clothing levels are influenced by season and outdoor temperature.

Night ventilation

Night ventilation can be used for free cooling of the building mass and to 'flush' the building which means reducing concentrations of emissions and CO_2 during the night to provide a fresh air in the morning.

The parameters influencing the possibility for night ventilation are described by Roetzel et al. (2010) and shown in Figure 32. The wish for night ventilation could be considered by the design of the OFE to prevent burglary and for example rain coming in or the blowing away of papers.

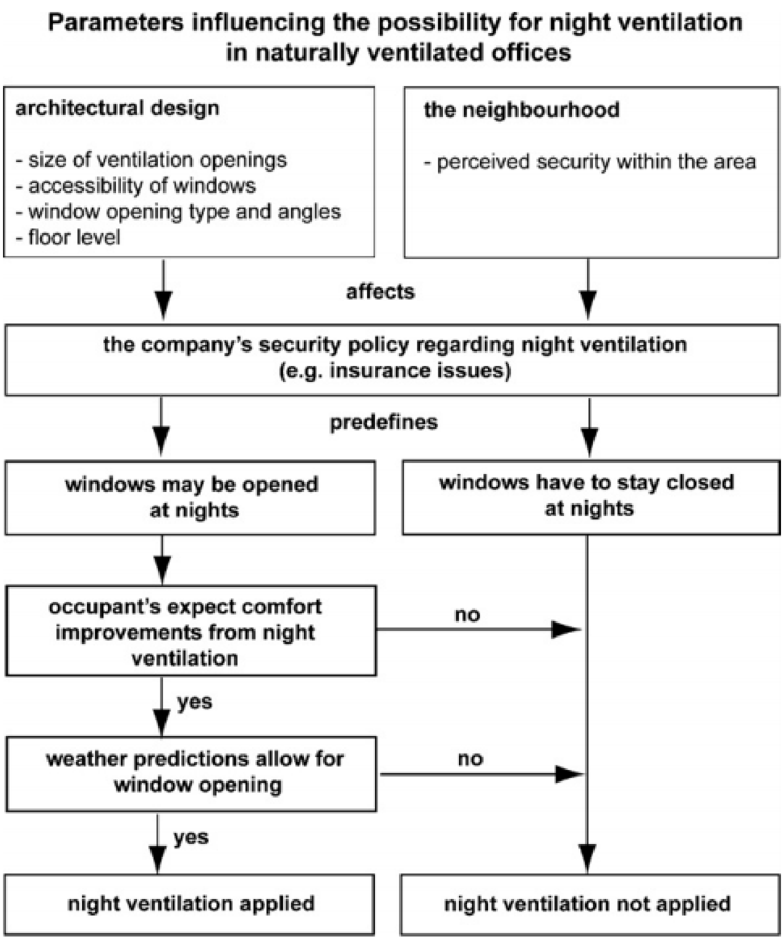


Fig. 11. Hierarchical scheme of parameters influencing whether or not night ventilation might be possible.

Figure 32 Hierarchical scheme whether or not night ventilation might be possible in naturally ventilated offices. Copied from Roetzel et al. (2010)

2.5 Literature findings

During the literature survey much information was found. Background information as preparation and foundation for the research is studied and described earlier in this chapter. OFE's can have effects related to several disciplines e.g. physical, physiological and psychological effects. Aspects OFE's (potential) have an effect on (Table 3 and Table 5) and requirements for good usable OFE's and their relation with the (potential) OFE effects (Table 4 and Table 6) are researched in depth during the literature survey and mentioned per subject through the whole chapter. In this paragraph, all the aspects and requirements are summarized and the paragraph and literature references where more information can be found are given in the right-hand columns.

Requirements for good usable OFE's

Good usable OFE's offer the opportunity to profit from potential positive effects while potential negative effects could be reduced. They should provide the means to compensate for uncomfortable temperatures or bad air qualities and adjust the indoor climate to their comfort temperature and to variations over time. The requirements positively influence aspect(s) OFE's have (potential) effect on. A description of the requirements for good usable OFE's and their relation with the potential OFE effects (Table 3) is given in Table 4. Within the description several sub-requirements are mentioned as well. These sub-requirements are not described separately to prevent distraction from the essential information. In general, it is desired to increase building performance, personal control, perceived control, health, comfort, productivity and satisfaction of the occupants by providing OFE's with fast and effective responses to occupants' needs.

The "aspects OFE's have (potential) effect on" provide an overview of background knowledge. The "requirements for good usable OFE's" are an overview of the prior knowledge about aspects that affect the usability of OFE's for personal control on thermal environment and air quality. As well, knowledge about how some of these aspects affect the usability of is found.

Table 3 Overview aspects OFE's have (potential) effect on based on literature

Aspects OFE's have (potential) effect on:
Building performance
Burglary risk
Experience of weather conditions
IAQ (Indoor Air Quality)
Ingress of noise from outside
(Local) Air movement
(Local) Indoor temperature
Motivation to control
Occupant's wellbeing
Personal control
Relation with outside
Responsiveness to users' needs
Robustness
(Sensory) Pleasure
(Thermal) Adaptation
Tolerance/ Forgiveness

Table 4 Overview requirements for good usable OFE's based on literature

Requirements for good usable OFE's
User-friendly
Clear design intent
Effective
Fine-tuning capability/ Adjustable
Match company's security policy and OFE design
Low noise ingress
(Mental) connection with outdoor climate
Proximal/ highly controllable by occupants
Robust
Additional requirement for perceiving control by OFE's over thermal environment & indoor air quality
Cultural/social attitudes match

Table 5 Explanation aspects OFE's have (potential) effect on based on literature

Aspects OFE's have (potential) effect on:	**Explanation how OFE's can have effect on the aspects**	**Paragraph**	**Literature references**
Building performance	Operable windows without opening restrictions such as noise, pollution and security have a positive effect on the performance of a building. Air movement can be an energy-efficient alternative to air cooling and due to increase of robustness, by offering individual control, the risk on unexpected high energy use is reduced. People have a higher perception of performance if they think that the buildings' systems responds rapidly to their needs, OFE's can assist in this.	2.1; 2.2	Cox et al., 2005 Kurvers et al., 2013; Leaman et al., 2000; Paliaga, 2009.
Burglary risk	Open windows generally decrease burglary resistance. The perceived security in the area and the company's security policy regarding night ventilation (e.g. insurance issues) can predefine that windows have to stay closed at night.	2.4	Roetzel et al., 2010
Experience of weather conditions	(Mental) connection with outdoor climate provides a higher acceptance of thermal variation. Wind, rain, sun and scent can be desired e.g. nice breeze, birds singing and fresh air. But can also cause discomfort e.g. incoming rain, high air speeds, blinding sun or bad smells. The experience of the weather conditions depends on location of the building, seat in the building, orientation, weather conditions and building design including OFE design.	2.1.2; 2.4	Baker et al., 1996; Haldi et al., 2008; Roetzel et al., 2010
IAQ (Indoor Air Quality)	Diluting of internally generated pollutants can improve IAQ by reducing concentration of emissions. It can cause a feeling of relief, decrease smell and reduce complaints about e.g. headaches and dry eyes. Supply of outdoor air can provide fresh air and a fresh feeling but can also bring in undesired pollutions from outside e.g. along a road during a traffic jam, intrusion of airborne pollen or insects. Night ventilation or 'flushing' dilutes internally generated pollutants and can provide a fresh feeling, prevent discomfort at arriving and reduce the amount of fresh air needed during the day. If the outdoor air is colder than the indoor air (e.g. at night) cooling of indoor air and building mass occurs, this can be beneficial in summer but undesired in winter.	2.1; 2.2; 2.4	Bluyssen, 2009; Haldi et al., 2008; Jantunen et al., 2009; Roetzel et al., 2010
Ingress of noise from outside	Noise from outside can enhance the relation with outside (e.g. birds) but could also cause distraction (traffic, conversations), high noise levels are bad for your health. The size of opening, type of window, whether there is an external baffle, acoustical absorption, opening direction and the direction of the sound source influence the amount of noise ingress through the OFE. Depending on the location there should be extra attention for the	2.3	Nunes, 2016

	acoustical performance of the OFE's.		
(Local) Air movement	Open windows can cause air movement and provide desired physiological cooling but also draught. How air movement is sensed depends on temperatures, amount of air, air flow, place, clothing, turbulence intensity and metabolic rate. Rate of air movement is one of the best means of improving thermal comfort in warm or hot weather, which can be an energy-efficient alternative to air cooling. Having the option to fine-tune the amount, place and/or direction can help to adjust the air movement to preferred places and velocities and prevent draught.	2.2	Haldi et al., 2008; Heiselberg et al., 2001; Knaack et al., 2011; Paliaga, 2009; Raja et al., 2001
(Local) Indoor temperature	Opening a window aligns indoor temperature with outdoor temperature. The (local) experienced temperature, with outdoor air entering a room through an open window, depends on several aspects: in- and outdoor temperature, humidity, air velocity, amount of air supply, place and orientation of the supply (in or out the occupant zone), position of the occupant, height of the supply (the higher the warmer due to vertical thermal gradient), mixing with indoor air, penetration depth, Coanda effect, air flow characteristic and turbulence intensity (fluctuation of air speed, increases the sensation of draught). The incoming air can also be pre-heated, but making use of smart design by integrating above aspects seems to make more sense.	2.2; 2.3	Boerstra et al., 2016; Haldi et al., 2008; Heiselberg et al., 2001;
Motivation to control	Successful control action will be rewarded by pleasure, a strong motivator to exercise effective behaviour. Choice overload can demotivate and make people more dissatisfied with the choices they made.	2.2	Hellwig, 2015
Occupant's wellbeing	OFE's can improve the wellbeing (quality of life) including satisfaction, health and comfort as well as productivity. Increase of perceived control, compensation for poor conditions and improvement of IEQ can reduce building symptoms, diseases, allergies and sick leave and increase productivity. These savings and productivity gains offer economic potential. Besides, knowing that they have the opportunity to control already has a positive health effect. Personal control and responsiveness to users' needs increases productivity whereby perceived control a key factor is to satisfaction. Occupants with access to an operable window and/or thermostat are more satisfied with their workplace temperature. A successful control action can provide satisfaction and dissatisfaction can be avoided by providing effective controls. High noise levels and incoming of polluted air should be avoided.	2.1-2.4	Bluyssen, 2009, 2014; Boerstra, 2016; Hellwig, 2015; Huizenga et al., 2006; Leaman et al., 2000;
Personal control	Personal control acts as a moderator between the indoor climate and the comfort, health & performance of occupants. It also directly influences people's comfort, health & performance due to the positive effect of knowing that they have the opportunity to control, as	2.1; 2.2	Bluyssen, 2014; Boerstra et al., 2013; Boerstra, 2016; Hellwig, 2015; Huizenga et

	well as it increases overall satisfaction. The degree of personal control is depended on the proximity and accessibility to the user. Higher perception of personal control over the environment positively affects comfort and satisfaction. Building responsiveness, person's state, social environment and the evaluation of the control action influence perceived control. Increase of perceived control (over temperature and ventilation) reduces sickness symptoms.		al., 2006; Leaman et al., 2000; Paciuk, 1989
Relation with outside	(Mental) connection with outdoor climate provides a higher acceptance of thermal variation.	2.2	Baker et al., 2004
Responsiven-ess to users' needs	Fast and effective response to meet people's needs (e.g. provide fresh air or feel cooler) can be provided by personal control and increases perceived control and productivity. People's perception of performance is also linked to how rapidly they think the buildings' systems respond to their needs, the faster the better. The faster the perception of response the higher the comfort scores.	2.1	Bordass et al., 1997. Leaman et al., 2000.
Robustness	Successful buildings, which are more likely to meet the desired energy and comfort levels, are characterized as more 'robust'. More robust buildings offer e.g. personal control with controls that are intuitive and easy to operate. This, can be provided by OFE's.	2.2	Kurvers et al., 2013
(Sensory) Pleasure	A successful control action will be rewarded by pleasure and seems to be a strong motivator to exercise effective behaviour.	2.2	Cabanac, 2000; Hellwig, 2015
(Thermal) Adaptation	OFE's are part of adaptive opportunities. Subjects who have direct access to operable windows assess neutral temperature closer to the average experienced operative temperature. Meaning that adaptive opportunity extends the comfort zone beyond the neutral zone and increases thermal adaptation. Allowing more variable temperature also provides a saving potential.	2.1.1 ; 2.2	Baker et al., 1996; Bordass et al., 2001; Brager et al., 2004.
Tolerance/ Forgiveness	People who have limited or no control over their office thermal environment, tend to be less tolerant and accepting of suboptimal thermal environmental conditions. Occupants are more forgiving when they have more access to building controls, when (thermal) variations come from a known source with predictable behaviour and when (mental) connection with outside occurs. All three can be provided by an OFE. Allowing more variable temperatures can save energy. People with an environmental attitude also tend to be more forgiving and extend their comfort zone by overlooking inadequacies of their thermal environment.	2.2	Brager et al., 2004; Deuble et al., 2012; Leaman et al., 2000

Table 6 Explanation requirements for good usable OFE's based on literature

Requirements for good usable OFE's which provide personal control over thermal environment and indoor air quality	**Description and relation with (potential) OFE effects**	**Paragraph**	**Literature references**
User-friendly	An user-friendly OFE is easy to use and understand, works well and provides occupants of a high perception of controllability. It is important to prevent making the OFE too complicated or unpredictable. Occupants are more forgiving when thermal variations come from a known source with predictable behaviour.	2.2	Baker et al., 1996; Bordass et al., 2001; Deuble et al., 2012; Hellwig, 2015; Paciuk et al., 1989; Yun et al., 2008a.
Clear design intent	Users tend to be happier if the design intent is clear and they understand how the building is supposed to work.	2.2	Deuble et al., 2012.
Effective	Effective OFE's are fast in response to users needs, can dilute internally generated pollutants, avoid dissatisfaction about the IE and positively influence productivity, comfort and people's perception of building performance. In case of slow responsiveness, the occupant will not receive immediate evidence of the success of control behaviour which may not be awarded by pleasure. The effect of opening a window, the occupant experiences, in terms of air quality and thermal environment, is influenced by air velocity, amount of displaced air, air temperature, penetration depth, mixing of outdoor air with indoor air, turbulence intensity and air flow characteristic, which is influenced by weather conditions, ventilation type, location, orientation, window characteristics, position of the OFE and position of the occupant. If the outdoor air quality is (temporary) of bad quality, the desired effect will not be reached at that moment. Instructions when opening is effective or diluting the pollutants before the air comes in can prevent this.	2.1; 2.3	Boerstra et al., 2016; Bordass et al., 1997; Bordass et al., 2001; Cabanac, 2000; Knaack et al., 2011; Hellwig, 2015
Fine-tuning capability/ Adjustable	Fine-tuning capability offers the option to adjust e.g. amount, place and/or direction of the air flow to user's needs. In winter, it can be preferable to supply the cold outdoor air in the upper part of the façade by indoor opening bottom hung windows. Making use of the vertical thermal gradient to heat the incoming air before it reaches the occupant zone, larger penetration depth, more mixing with the indoor air (than e.g. inwards turning windows) and easier controlling and	2.2	ASHRAE, 2013; Bordass et al., 1997; Bordass et al., 2000; Brager et al., 2000; Haldi et al., 2008; Heiselberg et al., 1999; Paliaga, 2009.

	dosing the amount of air and air velocity can prevent draught. In summer, direct supply, larger amounts and higher air velocities can be preferable to provide physiological cooling. Regulation of the experience of weather conditions indoors (e.g. wind, rain and sun) offers personal control and can prevent negative side effects. The possibility of adjustment in preventing ingress of pollen or insects can be desirable, but keep it user-friendly and robust.		
Match company's security policy and OFE design	The company's security policy and OFE design should match to allow opening (at night). Burglary resistance while windows are open is influenced by the OFE design (e.g. height and size). It is important to prevent that perceived security in the area, insurance issues or other security reasons predefine that windows must stay (completely) closed (at night).	2.4	Roetzel et al., 2010
Low noise ingress	Noise ingress can either be low because of low sound source outside or because of good acoustic performance of the OFE. Take the sound sources and their direction into account while designing the OFE's.	2.3	Nunes, 2016
(Mental) connection with outdoor climate	Provide (mental) connection with outside e.g. visual connection to get higher forgiveness factors and acceptance of thermal variation.	2.2	Baker et al., 1996
Proximal/ highly controllable by occupants	Forgiveness factor, thermal adaption, personal control and perceived control increases for subjects who have direct access to operable windows, thus proximal OFE's. According to ASHRAE (2013) the occupant has control over air speed if: ≤ 6 occupants per window or ≤ 84 m^2 per window.	2.1.1; 2.2	ASHRAE, 2013; Brager et al., 2004; Leaman et al., 2000; Paciuk, 1989; Paliaga et al., 2009; Yun et al., 2008a
Robust	OFE's should offer a high degree of personal control and be intuitive and easy to operate. Choice overload should be avoided, it can demotivate and make people more dissatisfied with the choices they made, it influences perceived control. Low exercise or effort should be needed for controlling the OFE, therefore it should be properly maintained and cleaned. Managing complexity should be in line with the capacity of building management.	2.1; 2.2	Bordass et al., 2001; Kurvers et al., 2013 Hellwig, 2015
Additional requirement for perceiving control by OFE's over thermal environment & indoor air quality			
Cultural/social attitudes match	Differences in people's experiences and (environmental) attitude can influence how willing they are to exercise, adapt and forgive inadequacies. This can cause difference in preferences (of roommates).	2.2	Deuble et al., 2012; Hellwig, 2015; Paciuk, 1989

2.6 Discussion

The literature study is performed to find existing knowledge about the office environment, OFE related aspects, effects and use of operable façade elements and how control over indoor air quality and the thermal environment can be improved by OFE’s. Existing explicit and observable knowledge about OFE’s and the context of OFE’s as well as theoretical background is found.

The “aspects OFE’s have (potential) effect on” do provide an overview of background knowledge, as aimed. The “requirements for good usable OFE’s” provides an overview of the prior knowledge about aspects that affect the usability of OFE’s for personal control on thermal environment and air quality. Knowledge about how some of these aspects affect the usability of is also found but less into depth than expected.

Possible sources of error

Explicit and observable knowledge do not provide information about the deeper levels of knowledge. Therefore, some aspects can differ from the core information to provide the means to improve the usability of OFE’s.

The effects, use and perceived control of OFE’s are related to climate, culture and other environmental aspects. The studies are not all conducted in the Netherlands, based on diverse people and environmental aspects differ. Therefore, it is valuable for which aspects affect the usability of OFE, but how the aspects influence the usability of OFE’s can differ.

The studies about personal control, including examples with OFE’s, had a wider scope. Though, results from these studies are interpreted as directly related to the usability of OFE’s and the personal control (over thermal environment and air quality) they provide.

3. BBA Database analysis

3 BBA Database analysis

BBA Binnenmilieu has performed many complaint inventories in several buildings in the Netherlands to help solve problems with the indoor environment. In doing so they have collected many digital questionnaires over the years. The questionnaires, which are part of the "Building in Use" (BiU) studies[1], contain questions on personal-, general-, health-, thermal environment-, indoor air quality-, noise-, light/view- issues and more. The results of questionnaires, generated in 37 office buildings in the Netherlands over the past 10 years, are used for this BBA Database analysis.

Apart from the answers from the questionnaire, pictures were also available for most of the buildings, made by BBA during the Building in Use building visits. These provide information of the building, office layout and operable elements.

The database and pictures are analysed to discover which aspects affect the usability of operable façade elements in practice, and if derivable from the open answers, how these aspects affect the usability of operable façade elements. Reasons for not always being able to open the window when they have the need to do so, described by the occupants at an open answer option were often very practical, rule or colleague related.

[1] The "Building in Use" (BiU) research of BBA is carried out in buildings with problems or complaints over the indoor environment. The Building in Use research starts with a questionnaire for the users of the building. The questionnaire results provide insight in the occurring problems. Subsequently a building visit follows to investigate the actual situation and cause of the problem.

3.1 Method

Firstly, all office buildings that had "Building in Use" research done by BBA Binnenmilieu in the past 10 years were selected. Secondly, the questionnaire answers of those 37 buildings were put together in one database.

The answers on the most relevant questions (Table 7) for finding aspects that affect the usability of the operable elements are analysed together with the average general assessment of the indoor environment of each building. Per building and over the whole database is analysed what percentage of respondents; has an operable window, can open it when needed and answered the certain answer category reasons - why respondents cannot always open a window when needed. The three open answer questions are analysed by looking through

The appendices, which are described underneath, are saved in separate documents on the repository. These are named 4154711 Appendices A-L, 4154711 Poster Factsheet and 4154711 (Poster) Design Guide. This separation in files is made to keep the documents comfortable readable.

Appendix A BBA Database - Answers open questions while remarking all answers that potentially affect the usability of-, and control perceived by OFE's with a marker. Subsequently the comments at the open answers in relation with the pictures and prior knowledge from literature were analysed to find which OFE design aspects seem to relate to the given reasons.

Table 7 BBA questionnaire questions and translations used in report

Precise questions in questionnaire	**Translation in report**
Wat is uw algemene oordeel over het binnenklimaat in het gebouw? Geef een rapportcijfer tussen 0 en 10.	AV_Gen_ass_IE. What is your Average General assessment of the Indoor Environment of the building? Rate on a scale from 0 to 10.
Heeft u nog andere opmerkingen over het thermisch binnenklimaat? ZO JA, omschrijf deze.	Do you have other comments about the thermal indoor environment? If yes, describe these.
Is de ruimte waar u werkt voorzien van een te openen raam? Ja/Nee	Has the room where you work an operable window?
ZO JA, kunt u het raam altijd openen wanneer u daar behoefte aan heeft? Ja/Nee	If yes, can you always open the window when you got the need to do so?
Indien u het raam niet altijd kunt openen wanneer u daar behoefte aan heeft, wat is hiervan dan de reden? U kunt meerdere redenen aangeven. *Antwoordcategorieën:* - Je kun niet gemakkelijk bij het raam komen - De lichtwering zit in de weg - Het raam is niet in de goede stand open te zetten - Er is (soms) hinder van tocht - Er is hinder van geluid van buiten - Bezwaren van kamergenoten - Anders	If you cannot always open the window when needed, what is/are the reason(s) therefore? *Answer categories:* - You cannot easily reach the window - The glare control is in the way - The window is not operable in the right level - Draught occurs (sometimes) - Noise from outside - Objections of roommates - Other reason
Heeft u nog andere opmerkingen over de luchtkwaliteit? ZO JA, omschrijf deze	Do you have other comments about the air quality? If yes, describe these

3.2 Corrections

In the database, some corrections were needed to avoid misleading results. An overview of the corrections is given in this paragraph.

212 occupants who responded that they do not have an operable window, responded on the follow up question "If yes, can you always open the window when you got the need to do so?" while they should have left the answer blank.

205 of these occupants answered with no and 7 answered with yes. This follow up question should not have been asked to the occupants who do not have an operable window and therefore these 205 answers where deleted. Since 2010 the follow up question has only been asked to the occupants who responded positively to having an operable window. Therefore, this mistake in the questionnaire does not occur in the 16 newest buildings in the used database.

The buildings 08-030 and 08-055 do not have operable windows, 115 of the occupants who answered that they do not have an operable window (as is indeed true) did answer the follow up question. These answers on the follow up questions are deleted to gain better insight in the total ratio of windows that are operable when the occupants have the need to open them. For the people who clearly had no operable window because they complained about the fact that they do not have an operable window, the answer to on the follow up question was also deleted, this occurred 28 times.

In building 08-046 (N=99) it was often, in 28 responses, unclear if there was no operable window or if it was not allowed to open the window, e.g. some people noted that due to the climate regulations the windows were permanently closed by screws. These 28 responses are excluded from the analysis.

For 38 occupants, it was not clear which conflicting answer was wrong. Either, they did not have an operable window and therefore answered that they were not able to open it when they had the need to do so. Or, they physically had an operable window but answered that they did not have one because they could not or were not allowed to open it. Yet another option, is that one of the two answers was a mistake. These 38 responses with unclear conflicts were deleted.

After the corrections N=2918 for the total responses of 37 buildings.

The data of the two follow up questions about their operable window are corrected for the respondents who do not have an operable window. In the questionnaire, the occupants could give multiple reasons.

3.3 Results and conclusions

The aim of this research was to find aspects that affect the usability of the operable elements by analysing the relevant questions of the existing database (Table 7). Per building and over the whole database it is analysed what percentage of respondents: has an operable window, can open it when needed and answered the certain answer category reasons - why respondents cannot always open a window when needed (Figure 33c).

81% of the occupants responded positively to having an operable window (N=2354) of which 38% responded that it could not always be opened when they felt the need to (Figure 33a, b). 2046 of the 2354 gave the reasons why they could not always open the window when needed.

Draught, objections of roommates and noise from outside are the most announced reasons why occupants cannot always open the window when they have the need to do so (Figure 33c).

In rooms with more roommates, the negative response is higher on the question if they can always open the window when they feel the need to do so (Figure 34). Draught and objections of roommates are relatively more frequently announced as reason in these higher occupied rooms. It should be mentioned here that increase of room size, which is mostly the case with the increase of roommates, is probably related to the relatively higher percentages of draught as reason in higher occupied rooms.

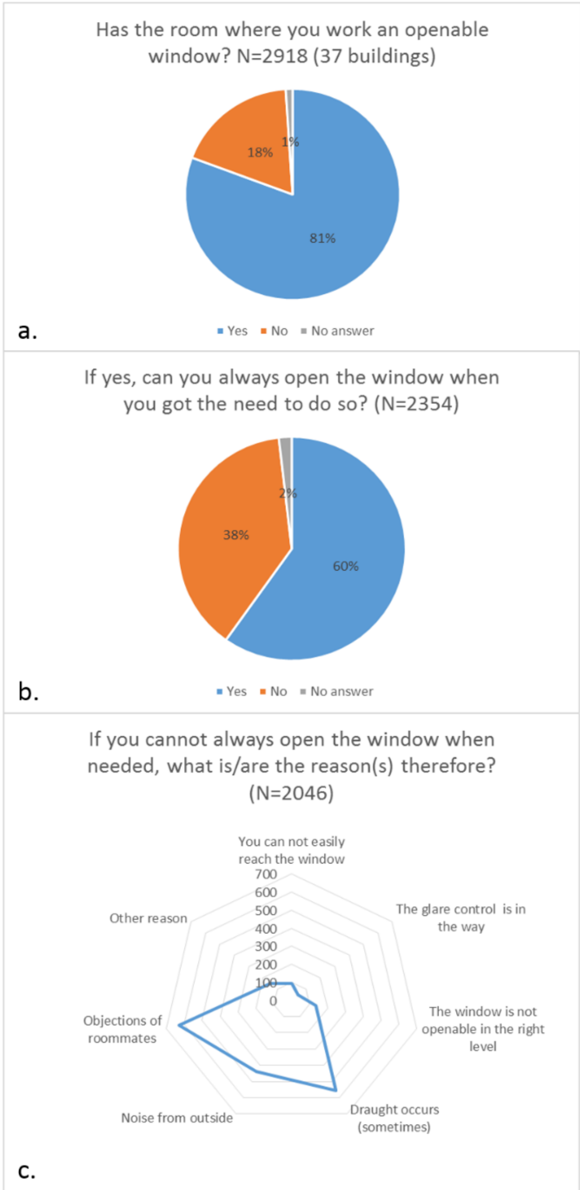


Figure 33 Overall results BBA database analysis

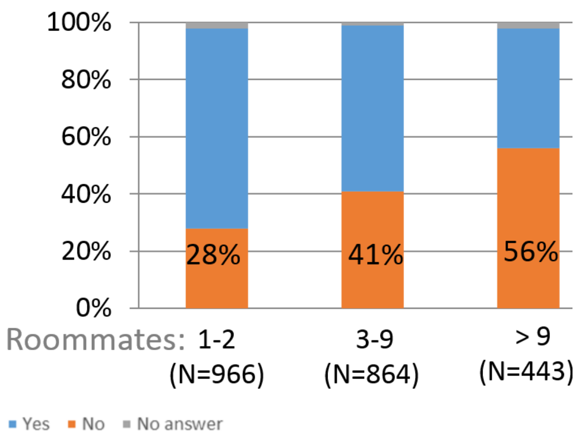


Figure 34 Answers of occupants if they can always open the window when they feel the need to do so, compared per number of roommates.

Table 8 presents the percentages of respondents over the whole database and per building.

Table 8 Overview results BBA Database analysis

Building number	ID	total amount of respondents	AV_Gen_ass_IE*	% with operable window	% cannot always open the window when needed	You cannot easily reach the window				The glare control is in the way				The window is not openable in the right level				Draught occurs (sometimes)				Noise from outside				Objections of roommates				Other reason			
						All	0-2	3-9	> 9	**All**	0-2	3-9	> 9	**All**	0-2	3-9	> 9	**All**	0-2	3-9	> 9	**All**	0-2	3-9	> 9	**All**	1-2	3-9	> 9	**All**	0-2	3-9	> 9
AV_all_building		**2918**			**38%**	**4%**	4%	3%	5%	**2%**	2%	2%	1%	**6%**	7%	5%	5%	**24%**	19%	25%	30%	**19%**	17%	19%	20%	**27%**	16%	32%	49%	**6%**	7%	6%	6%
1	06-013	41	6,7	76%	16%	**3%**				**0%**				**0%**				**3%**				**3%**				**10%**				**10%**			
2	06-052	38	6,3	97%	35%	**3%**				**3%**				**0%**				**22%**				**16%**				**32%**				**5%**			
3	07-022	45	6,4	91%	39%	**0%**				**0%**				**15%**				**24%**				**5%**				**32%**				**15%**			
4	07-056	23	6,3	74%	41%	**6%**				**0%**				**29%**				**12%**				**24%**				**12%**				**12%**			
5	08-021	78	6,2	82%	38%	**5%**	5%	8%	0%	**0%**	0%	0%	0%	**8%**	10%	8%	6%	**28%**	10%	46%	31%	**9%**	5%	4%	25%	**33%**	10%	50%	50%	**13%**	5%	8%	25%
6	08-030	63	4,8	0%	-	-				-				-				-				-				-				-			
7	08-032	55	5,6	95%	31%	**2%**				**6%**				**4%**				**31%**				**12%**				**23%**				**6%**			
8	08-046	71	6,4	48%	56%	**15%**				**3%**				**15%**				**29%**				**24%**				**38%**				**26%**			
9	08-052	53	5,8	100%	53%	**4%**				**0%**				**2%**				**25%**				**42%**				**38%**				**4%**			
10	08-055	202	4,2	0%	-	-				-				-				-				-				-				-			
11	09-001	57	6,0	98%	57%	**0%**				**2%**				**2%**				**25%**				**59%**				**21%**				**13%**			
12	09-027	119	5,2	85%	54%	**0%**	3%	3%	0%	**0%**	0%	0%	0%	**16%**	8%	23%	9%	**32%**	8%	26%	38%	**50%**	18%	39%	28%	**32%**	0%	3%	47%	**9%**	5%	6%	9%
13	09-031	12	5,3	100%	67%	**0%**				**0%**				**0%**				**25%**				**25%**				**50%**				**25%**			
14	09-039	89	6,5	98%	21%	**17%**	17%	13%	n.a.	**0%**	0%	0%	n.a.	**8%**	9%	4%	n.a.	**13%**	10%	17%	n.a.	**5%**	4%	4%	n.a.	**13%**	10%	21%	n.a.	**8%**	9%	4%	n.a.
15	09-045	28	4,7	82%	26%	**22%**				**9%**				**4%**				**9%**				**17%**				**9%**				**4%**			
16	09-047	42	5,8	100%	38%	**5%**				**14%**				**10%**				**21%**				**43%**				**38%**				**0%**			
17	09-050	40	5,6	75%	50%	**13%**				**0%**				**20%**				**23%**				**17%**				**27%**				**10%**			
18	09-067	270	5,8	95%	41%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**30%**	25%	30%	31%	**17%**	18%	13%	31%	**25%**	11%	32%	58%	**9%**	5%	13%	12%
19	10-004	216	5,7	99%	30%	**1%**	0%	2%	3%	**5%**	3%	7%	6%	**7%**	11%	2%	2%	**25%**	25%	24%	25%	**24%**	22%	22%	30%	**23%**	21%	22%	32%	**8%**	8%	7%	6%
20	10-023	80	4,8	86%	16%	**1%**	3%	0%	0%	**0%**	0%	0%	0%	**1%**	3%	0%	0%	**16%**	9%	19%	33%	**6%**	0%	11%	0%	**22%**	20%	26%	33%	**6%**	6%	0%	22%
21	10-033	30	6,0	97%	38%	**3%**				**3%**				**0%**				**34%**				**3%**				**28%**				**3%**			
22	10-036	29	5,6	97%	25%	**0%**				**0%**				**4%**				**21%**				**18%**				**11%**				**4%**			
23	10-041	115	5,7	6%	46%	**3%**	5%	8%	n.a.	**1%**	0%	0%	n.a.	**4%**	10%	8%	n.a.	**23%**	10%	46%	n.a.	**30%**	5%	4%	n.a.	**30%**	10%	50%	n.a.	**18%**	5%	8%	n.a.
24	11-006	28	5,8	89%	32%	**4%**				**12%**				**16%**				**24%**				**28%**				**16%**				**4%**			
25	11-012	98	6,5	80%	31%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**3%**	5%	0%	0%	**14%**	12%	14%	22%	**5%**	0%	4%	33%	**14%**	4%	29%	22%	**4%**	2%	7%	0%
26	11-022	28	5,4	64%	39%	**6%**				**0%**				**22%**				**39%**				**28%**				**17%**				**6%**			
27	11-038	47	5,7	85%	25%	**10%**				**3%**				**5%**				**20%**				**10%**				**13%**				**3%**			
28	11-062	206	5,2	78%	42%	**5%**	7%	5%	0%	**2%**	3%	1%	0%	**6%**	8%	4%	4%	**25%**	25%	23%	35%	**13%**	17%	9%	17%	**27%**	19%	29%	52%	**4%**	2%	6%	0%
29	11-085	187	5,8	94%	32%	**0%**	0%	0%	0%	**0%**	0%	0%	0%	**3%**	1%	6%	5%	**18%**	16%	22%	15%	**13%**	16%	11%	5%	**27%**	22%	38%	25%	**1%**	1%	0%	0%
30	13-054	140	5,4	91%	56%	**7%**	0%	20%	6%	**2%**	0%	0%	2%	**4%**	0%	0%	4%	**31%**	0%	40%	30%	**16%**	100%	10%	14%	**55%**	n.a.	60%	51%	**0%**	0%	0%	0%
31	13-066	84	5,2	79%	45%	**20%**	14%	21%	75%	**9%**	12%	5%	0%	**23%**	23%	21%	25%	**24%**	23%	21%	50%	**24%**	21%	26%	50%	**11%**	15%	5%	0%	**2%**	0%	5%	0%
32	14-0047	18	4,8	78%	7%	**0%**				**0%**				**0%**				**7%**				**0%**				**0%**				**0%**			
33	14-0790	31	5,9	94%	14%	**0%**				**0%**				**0%**				**3%**				**0%**				**14%**				**0%**			
34	14-0848	56	5,2	88%	31%	**2%**				**2%**				**0%**				**18%**				**12%**				**22%**				**2%**			
35	14-1293	40	4,8	100%	50%	**5%**				**5%**				**8%**				**40%**				**20%**				**43%**				**3%**			
36	14-1322	64	3,9	73%	47%	**0%**				**0%**				**6%**				**23%**				**15%**				**36%**				**0%**			
37	16-0173	95	4,9	97%	42%	**2%**	0%	0%	4%	**0%**	0%	0%	0%	**1%**	0%	0%	2%	**20%**	6%	13%	29%	**8%**	6%	3%	11%	**39%**	13%	42%	47%	**2%**	6%	0%	2%

*AV_Gen_ass_IE, AVerage General assessment Indoor Environment of the building.

The percentages of 13 of the 37 buildings are also given per number of occupants who share the room (Table 8). The results of the buildings in which less than 60 respondents had an operable window are not divided per number of occupants who share the room. Too low amounts of respondents per category would occur. More information about these 13 buildings can be found in Appendix B BBA Database – Pie & Radar charts and Appendix C BBA Database – Tables percentages per answer category. In these 13 buildings, more than 60 respondents had an operable window

The percentages of respondents who cannot always open the window when needed range from 7% to 67% (fourth column of Table 8) with an average of 38% per building (Figure 33). Reasons seem OFE design related as well as related to other building aspects. To give an example: in building 13 (67%) the most recorded reasons were objections of roommates, noise from outside and draught (Table 8). In this building, side hung windows generally opened in the occupant zone, could not be opened ajar and half of the time opened into a hallway. Also, there was no basic ventilation provision.

The three open answer questions were analysed by marking aspects relevant to the usability of and control perceived by OFE's, in The appendices, which are described underneath, are saved in separate documents on the
repository. These are named 4154711 Appendices A-L, 4154711 Poster Factsheet and 4154711 (Poster) Design Guide. This separation in files is made to keep the documents comfortable readable.

Appendix A BBA Database - Answers open questions. The open answer question results contained similar answers which seems to be relevant aspects for the usability of operable façade elements.

The comments that are related to the usability of an OFE are summarized in Table 9 in the lower part of the left column. Examples of comments are given in the right column. The exact given answers per building per open answer question can be found in The appendices, which are described underneath, are saved in separate documents on the repository. These are named 4154711 Appendices A-L, 4154711 Poster Factsheet and 4154711 (Poster) Design Guide. This separation in files is made to keep the documents comfortable readable.

Appendix A BBA Database - Answers open questions.

Table 9 Reasons for not always being able to open window when needed, related to the usability of OFE´s.

Answer category reasons	***Examples meeting the category, given at other reason***
You cannot easily reach the window	Out of reach, obstruction in front
The glare control is in the way	Blinds
The window is not operable in the right level	Not adjustable enough, desire for opening ajar, desire for opening to larger angle.
Draught occurs	Position, place, size and opening direction of the window
Noise from outside	Road, railway, street, activities
Objections of roommates	Diverse positions and sensitivities of roommates to distraction, draught, temperature and stale air
Other reasons summarized	***Examples***
Not allowed	Due fair for failure of climate control or burglary risk
Miscommunication rules of use	Unclear when allowed and/or wise to use the windows
Slamming windows or doors	Not fixable in combination with wind
Obstructions	Columns, closets, plants, additional windows, desks, full windowsills, blinds, sun shading
Wind	Papers blow away, slamming windows, draught, noise *"jammer dat er geen kiepramen zijn. Als er wat wind staat en je opent de draairamen tocht het direct en alle papieren waaien van je buro af"*
Rain is coming in	Papers are getting wet
Thermal discomfort	Too hot or cold outside, air velocity causing feeling of discomfort
Not effective enough	Too low air speed,
Opens into atria or hallway	Noise, bad smells, warm, bad smell, not fresh
Too far from workplace	Lay out, building depth
Car fumes outside	Road, canopy effect
Maintenance/cleaning related	Defects, pests
Lost separate element	Key, control stick
Not fixable in desired level	Slamming windows, not fixable in desired level e.g. ajar

Table 9 presents several comments related to the usability of OFE's and perceived control. Several comments remark OFE design aspects such as size, position, way of opening and control options as reason why the OFE cannot always be opened when needed. Though, not all comments help to provide the means to improve the usability of OFE designs to increase the number of OFE's that properly provide personal control over thermal environment and indoor air quality. The comments with a more direct relation to OFE design aspects are summarized in Table 10. The examples presented underneath are also considered in Table 10. The reasons that were given in the open answers are not prioritized. Conversely, objections of roommates, draught and noise from outside were answer categories which could be prioritized.

Examples

Pictures made in buildings that are part of the BBA database present examples of decreased usability. Some of the operable façade elements are not easy to use, not adjustable enough and/or not effective enough. Comments of respondents cannot be directly related to the windows on the pictures because the exact location of the respondents and pictures were unknown, and most of the buildings had different window types. Though for some OFE's on the pictures the reason seems rather clear. Several of these pictures of OFE’s in Dutch offices that cannot always be used when needed are presented underneath.

Not easy to use

a. b. c. d. e.

Obstructions: a. Blinds, b. Sun shading, c. Stuff on windowsills, d. Mismatch layout and window pattern. e. Out of reach.
d. The desire to fix the window and open it ajar is mentioned in this building (thus not adjustable enough).

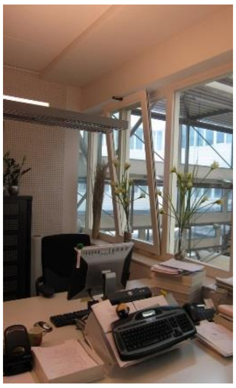
Not adjustable enough

a. b. c. d. e.

a. Not operable in the right level (13-066 (relatively often mentioned)).
b. Answer of occupant in questionnaire interpreted as: having no opportunity to dilute indoor air pollutants without the blowing away of paper in winter with windy weather.
c. Draught and objections of roommates are mostly announced. It seems that the draught is partly caused by the design of the windows, since they are large, high (efficient) and at occupant height, where there is no opportunity to slightly open an operable façade element.
d. Many issues played a role in this building, but the size and position of the window do not seem very well chosen in terms of personal control over thermal environment in summer and winter as well.
e. Draught is the main issue due to the large and high operable parts at occupant level.

Not effective enough

Window opens into atrium thus not providing fresh outdoor air.



Too open layout

No room separating walls causing objections of colleagues one floor below and in the next room (about rooms near the façade, not in the atria).

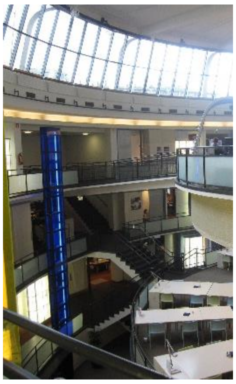


Table 10 Reasons for not always being able to open the window when needed, related to OFE design aspects

Given reasons	***Related comments relevant for OFE design***	***OFE design aspects that seem to relate to the given reason***
1. Objections of roommates	Thermal reasons, some are more sensitive to distraction	Position & opening direction (one most affected should have most control), controllability of amount and position of supply (in and out occupant zone). Increasing acoustical performance may also reduce objections of roommates.
2. Draught	Due to position, when windy, too large OFE	Position (in or out occupant zone), place, size, type, opening direction
3. Noise from outside	Road, railway, street, activities	Acoustical performance OFE (size, type, opening direction, acoustical absorption)
Not adjustable enough/ Not operable in the right level	Not operable ajar, maximum opening angle is too small	Controllability: min. and max. opening area, step width. Not operable in right level.
Thermal discomfort	Too hot or cold outside, air velocity causing feeling of discomfort	Position (in or out occupant zone), type, size
Not effective enough	Too small OFE, to low air speed, along hallway or atria	Type, size, position (OFE should be along outdoor area to respond to people's needs)
Opens into atria or hallway	Noise, draughts	
Out of reach/ not easily reachable	Control is too high or far away	Position, place
Too far from workplace	Lay out, building depth	Proximity
Obstruction(s)	Columns, additional windows, desks, full window sills, blinds, sun	Integration of OFE design with: structural elements (e.g. columns), additional windows, windowsills in use, blinds, sun shading

	shading	
Papers blow away	Too large, position, opening direction	Size, position, opening direction, control, fixing ability
Slamming windows	-	Fixing ability
Wind	slamming windows, draught, noise	Type, opening direction. Integration of wind situation in façade and OFE design.
Rain is coming in	Papers are getting wet	Façade and OFE design which prevent incoming rain. Take wind situation into account to prevent wind driven rain coming in.
Car fumes outside	Road, canopy effect	Position, opening direction, filtering (prevent that the filters become an even larger? pollution source itself)
Lost separate element	Key, control stick	Avoid separate elements which can get lost (e.g. not fixed control elements, keys and remote controls)
Maintenance/ cleaning related	Defects, pests	Robustness, manageability
Not allowed	Due fair for failure of climate control or burglary risk	Integration of OFE design with safety and management policy company. (Can prevent restrictions e.g. OFE with low burglary resistance if open, as well as frustrations due to the restrictions)

Shortly summarized, it can be concluded that, overall, the most important reasons why OFE's cannot always be opened when needed are: objections of roommates, draught and noise from outside. Moreover, the larger the number of occupants the more often respondents announced that the OFE's cannot always be opened when needed.
Several other specific reasons are announced of which most can be related to the literature findings. How these most important and specific reasons are related to OFE design aspects can partly be clarified with the comments, pictures and prior knowledge from literature (Table 10) and used for better usable OFE designs. Thus, this research has not discovered which OFE design aspects influence the usability of OFE's significantly and how they do so. However, it can help to improve OFE designs for higher usability's and levels of personal control over thermal environment and air quality.

3.3.1 Relation to literature findings

Comments or umbrella terms for comments in the BBA database analysis that indicate that the OFE does not appropriately meet the requirements are described in Table 11. Additionally, the findings from the BBA Database analysis are compared to the literature findings and a suggestion is made to include quality of the air supply, allowance to open OFE and preventing too high managing complexity in the final requirements.

Table 11 Relation BBA Database results and the requirements, based on literature, for good usable OFE´s

Requirements for good usable OFE's based on literature	Comments or umbrella terms for comments in the BBA database analysis that indicate that the OFE does not appropriately meet the requirements
User-friendly	Out of reach, not easy to reach/to open, heavy to close, opening or control is obstructed (by blinds, sun shading, full windowsills)
Clear design intent	Miscommunication/ unclear rules of use, different ideas of what is wise in terms of energy use and climate control causing objections of roommates

Effective*	Not effective enough because: too small, too low air speed, too far away and/or opens into hallway/atria
Fine-tuning capability/ Adjustable	Draught, OFE not operable in right level (e.g. not operable ajar or maximum opening angle is too small), too large OFE, thermal discomfort, slamming windows/ not fixable, rain is coming in, blowing away (of papers)/ too high air velocities
Match company's security policy and OFE design**	Not allowed for burglary or climate control reasons (potentially it would have been allowed to open the OFE if it looked different)
Low noise ingress	Noise from outside, distracted by noise from outside and objections of roommates that are distracted by noise outside
(Mental) connection with outdoor climate	Thermal discomfort (might have been less if the (mental) connection with outdoor climate was higher), objections of roommates (might have been less as well due to higher tolerance with thermal variation)
Proximal/ highly controllable by occupants	OFE is too far away or out of reach (due to obstruction in front), occupants in perimeter have more control/ are leading in the decision to open or close the OFE
Robust	Broken, lost or defect (control) element, not easy to open or reach, not clean
Additional requirement for perceiving control by OFE's over thermal environment & indoor air quality	
Cultural/social attitudes match	Objections of roommates (might have been less if sensitivities/ preferences were more similar). Thermal discomfort (might have been less if the occupants were more forgiving/higher environmental attitude)

* Car fumes outside are mentioned as well, as a reason for not always being able to open the window. Bad outdoor air quality makes the OFE ineffective in supplying fresh air. It is suggested to include "Supply is fresh air of sufficient quality".

** Suggestion to change "Match company's security policy and OFE design" into "Match company's management & security policy and OFE design". Because opening allowance seems to be important and this reviewed requirement would include matching OFE design with the company's management. If OFE's are designed in agreement with the company's management, it should be possible to avoid the situation in which it is not allowed to open the OFE's. Also, overdue maintenance can be avoided by designing OFE's that are manageable for the company.

Objections of roommates seem to be the most important reason for not always being able to open the OFE (Figure 33). The objections of roommates are in some cases related to thermal discomfort (draught, cold, gets warmer if warm outside), distraction (noise, slamming windows, blowing away of paper), rules (not allowed, might be not allowed) or belief (not wise to open). Therefore, (in brackets) clear design intent, adjustability, low noise ingress, (mental) connection with outdoor climate and cultural/social attitudes match are related to objections of roommates. That is, it seems to be likely that roommates will object less if there is no miscommunication or misunderstanding what is allowed and wise, if they do not perceive thermal discomfort and are not distracted or less distracted. However, to the knowledge of the author, no other research about objections of roommates in relation to OFE's has been performed.

3.4 Discussion

This study seems to have found the most important reasons why OFE's in offices in the Netherlands cannot always be opened when needed: respectively objections of roommates, draught and noise from outside. Whether or not these three aspects on average are also the most important reasons in all Dutch offices, is not found within this research. The data does not reflect all Dutch offices in the Netherlands because an existing database is used, containing only buildings where complaints about the indoor environment occurred. Moreover, which OFE design related aspects influence whether objections of roommates, draught and noise from outside occur, cannot directly be derived from this study.

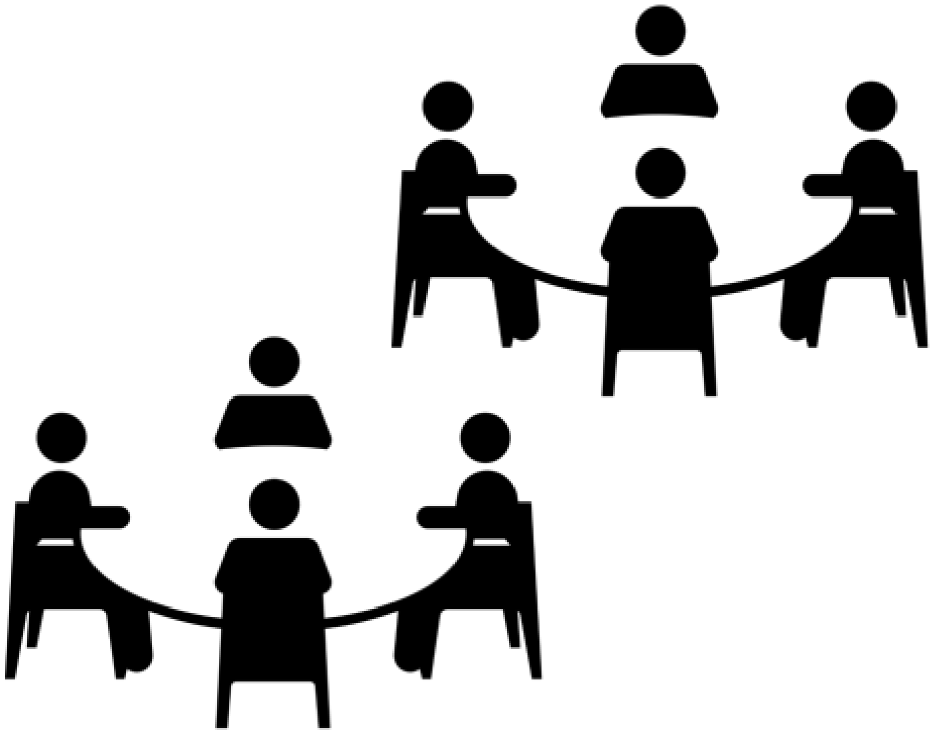
The percentage of respondents who cannot always open their window when needed, relates to more than OFE design aspects. Ventilation type also influences the airflow through an OFE, as well as other influencing aspects derived from the BBA reports about the complaint inventories in the specific building. Therefore, not much further attention is given to these percentages. Merely, that it did point out that an OFE along a hallway or atria is generally more often considered to be not always operable when needed, than OFE's along an outdoor area. This matches the theories about perceived control; a control action should response to the needs of people (Hellwig, 2015). An OFE which opens into a hallway or atria does not respond to the needs of people. Windows are often used "to feel cooler" or "to let in fresh air" (Brager et al., 2004) window openings into a hallway or atria seem to provide different effects.

The database contained the questions "Does the room where you work have an operable window?", "If yes, can you always open the window when you got the need to do so?" and "If you cannot always open the window when needed, what is/are the reason(s) for this?" With the answer categories: You cannot easily reach the window; The window is not operable in the right level; The glare control is in the way; Draught occurs (sometimes); Noise from outside; Objections of roommates; Other reason.

Due to the varying types of OFE's within the buildings and the fact that the workplace of the respondent was not precisely known, these comments could not be widely compared. If a questionnaire would have been made especially for this research, other questions would have been asked to gain more specific knowledge. And then the data would have been collected in such a way that the workplace of the respondent was known.

OFE design aspects that seem to relate to the given reasons (Table 10) are made by analysing the comments, pictures and the prior knowledge from literature in relation to the given reason. The table can be used in order to design better usable OFE's for personal control over thermal environment and air quality. Though, further research is needed to get to know which OFE design aspects have significant effect, and how these can significantly reduce the percentage of occupants that cannot always use an OFE when needed, or how these can significantly improve the usability of an OFE. Sub-studies could for example focus on how to reduce objections of roommates, draughts and noise from outside. Ze Nunes has already done some interesting research on how noise from outside can be reduced. An environmental psychologist can probably be helpful in research on reducing objections of roommates.

4. Context mapping



4 Context mapping

Context mapping can be used for mapping the context of people's interaction with products (Visser et al., 2005) to get to know tacit knowledge and latent needs to understand what people know, feel and dream. Within context mapping studies generative sessions are used to get to this deeper level of knowledge, as schematically illustrated in Figure 35. A generative session is a form of qualitative research whereby a group of people is asked to explain and express their experiences, preferences and expectations through writing, sketching, talking and other activities.

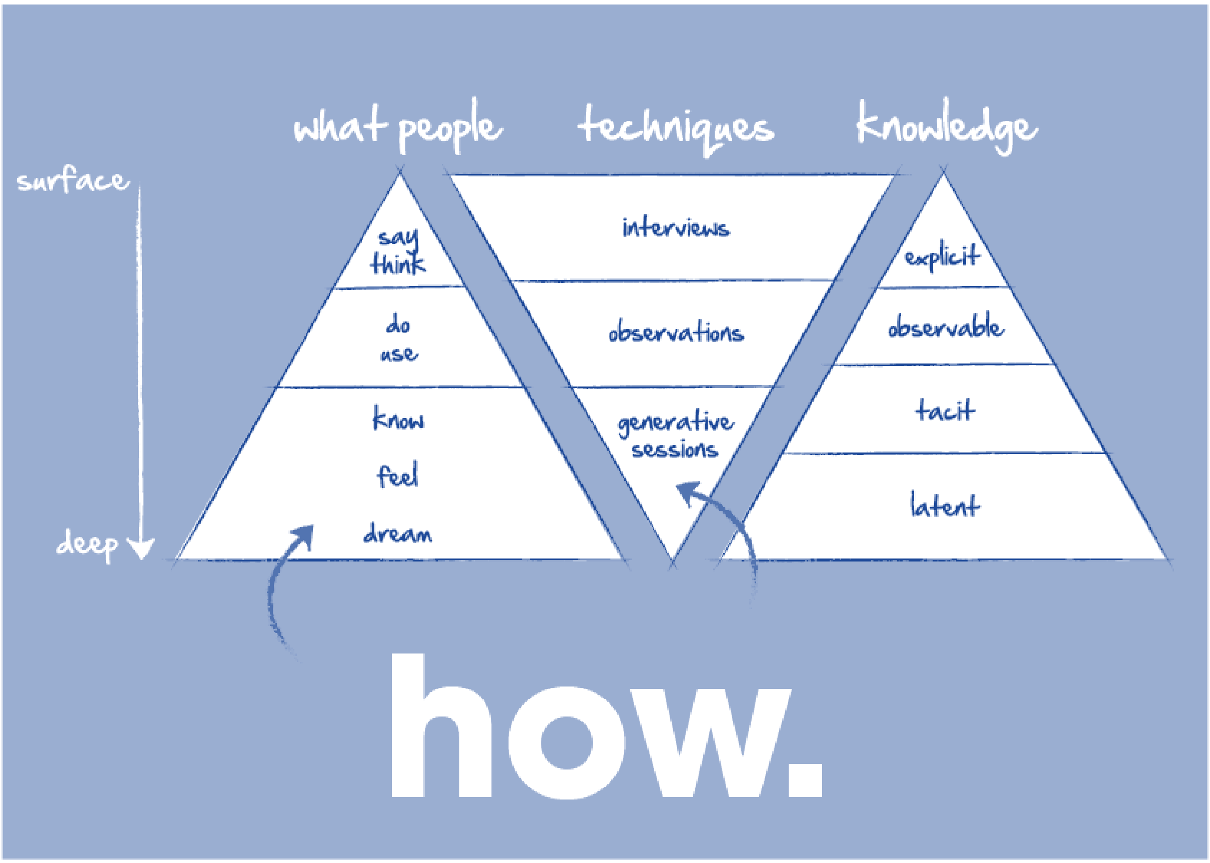


Figure 35 Generative sessions (Luke, 2012). (Similar figure in Visser et al., 2005))

The literature study and BBA database analysis provided mainly explicit and observable knowledge about what people, say, think, do and use. This literature mostly provided information in the context of perceived control, influence on indoor environmental quality and use of OFE's. The BBA database provided mainly information of explicit reasons, given by occupants of offices in the Netherlands, as to why their operable windows cannot always be opened when needed. The database also provided observable knowledge by pictures of the offices and their operable windows. There are two main reasons to conduct a context mapping study in addition to the aforementioned literature. On the one hand to avoid a narrow view and overlooking of essentials, and on the other hand to communicate directly with users of OFE and understand their tacit and latent needs to be able to help improve OFE designs for the future.

The research question was: What do people prefer and expect from operable windows and why do they do so?

In this chapter, a general overview of the study is given at first, followed by a description of materials and methods, results and analysis, a description of the application of results and ends with a discussion and recommendations.

4.1 General overview of the study

The described literature survey and BBA databases analysis were carried out before the context mapping study. These studies formed the main background knowledge of the topic of this study. Building on this knowledge the context mapping study was prepared with the help of several handed documents. The participants were sensitized and participated in the session where “Make & Say” and a Discussion took place for the generation of knowledge and the collection of user insights. Subsequently analysis and documentation of the session are done to be able to share and communicate the information, see Figure 36. This sequence of research steps is inspired on meetings with Marco Ortiz and typical steps within a context mapping study (Visser, 2005).

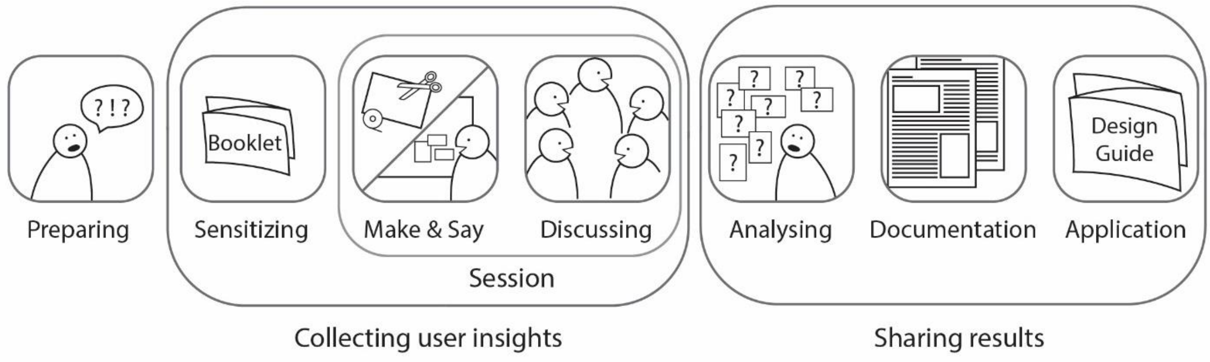


Figure 36 Schematic overview context mapping study procedure

4.2 Materials and methods

In this section the materials and methods used are described as well as the reasons why they are chosen and how the methods are developed.

4.2.1 Preparation

At first the meaning of a focus group and context mapping was studied. Stanley Kurvers handed Mangone (2015) as example of documentation of evaluating office worker preferences. Marco Ortiz handed several other informing documents; IDEO Method Cards (2003), Kistemaker (2010), Visser et al. (2005) and the sensitizing booklets of Jotte de Koning (De Koning, 2012) and of his own graduation project (Ortiz, 2014) for the master Industrial Design at Delft University of Technology (TUD).

4.2.1.1 IDEO Method Cards

The 51 IDEO Method Cards (IDEO, 2003) show some of the techniques IDEO keeps people at the centre of the design process. IDEO is a company which helps other companies innovate. They create strategies for innovation and design products, spaces, services and experiences. They note the insights they derive from understanding people and their experiences, behaviours, perceptions and needs as their key to success. The cards were first used exploratorily, to get an idea of which generative tools exist and how and for what purpose they can be used. Secondly, they were studied more into depth and selected on feasibility. The “Unfocus Group”, “Card Sort” and “Collage” were found most relevant for the focus group (Figure 37a, b and c).

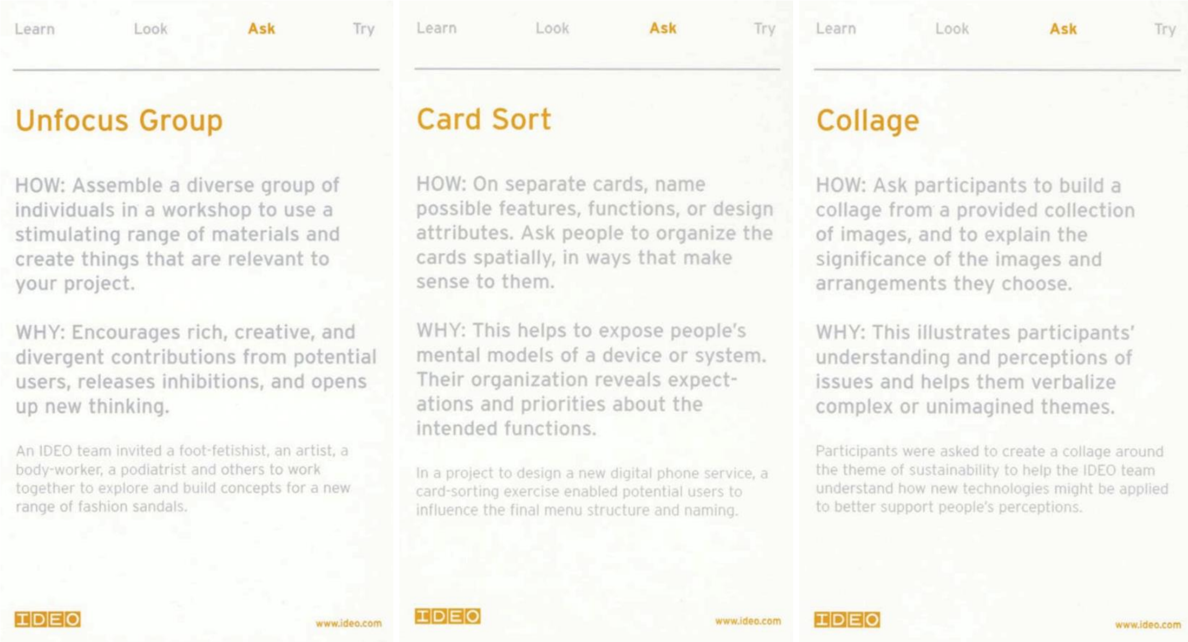


Figure 37 Most relevant IDEO Method Cards. Copied from IDEO (2003)

The “Unfocus Group” technique describes a focus group and as the name suggests; it opens up new thinking. The Card Sort card inspired to test whether the found OFE related aspects are clearly named and to reveal expectations and priorities of these aspects. The Collage card inspired to include collage making in the focus group session.

4.2.1.2 Laddering Questions Practice

The “Five Whys?” method (Figure 38) was used as preparation for the focus group to practice asking supplementary questions (Figure 39 and Figure 40) to get to elicit people’s goals and their underlying values.

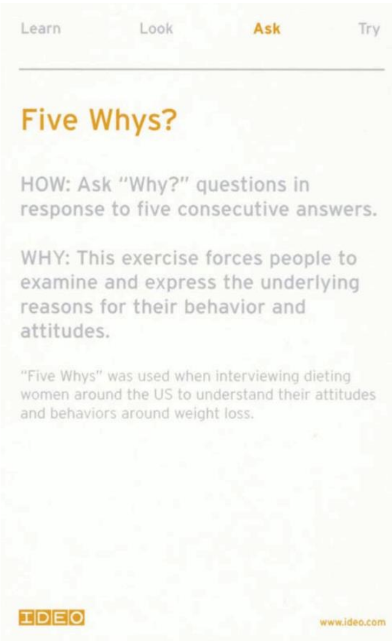


Figure 38 IDEO Method: Five Whys? Copied from IDEO (2003)

Real Life Scenario:

The daily office situation is taken as practice scenario and described in this section. At the office of BBA Binnenmilieu Tim and Arjen sit face to face along a façade with an operable window on each side. At a certain moment both windows were open and while Tim was away from his place for a moment, and could not hear the conversation with Arjen, Arjen was asked why he opened the window (Figure 39). A moment later Tim was asked the same question (Figure 40).

Arjen Raue

> Waarom heb je zojuist het raam open gedaan?

< Ik had het warm en behoefte aan bewegende lucht.

> Waarom had je behoefte aan bewegende lucht?

< Omdat dat mij het gevoel gaf dat er geventileerd wordt.

> En waarom had je het gevoel dat er niet geventileerd werd?

< Omdat ik geen lucht voelde bewegen.

> Dus als je de lucht niet voelt bewegen heb je het gevoel dat er niet geventileerd werd?

< Ja

Betere vraag was geweest (ik heb hem 10 min later als nog gesteld)*;*

> Waarom wil je het gevoel hebben dat er geventileerd wordt?

< Gevoel van basis veiligheid en een gezonde werkomgeving.

> En waarom heb je de behoefte naar basis veiligheid en een gezonde werkomgeving?

< Om te overleven en goed mijn werk te kunnen doen.

Figure 39 Supplementary questions asked to Arjen Raue

Tim Beuker

> Waarom heb je zojuist het raam open gedaan?

< Ik dacht goed idee, laat ik hem ook open doen toen Arjan hem open deed.

> Waarom leek het jou een goed idee om het raam open te doen?

< Niet het gevoel dat ik echt frisse lucht had of echt fit was. Ja, ja waarom heb je behoefte aan meer ventilatie he? Kijk als het muf is als je terugkomt van de wc dan weet je dat het niet echt fris is. En als ik duf wordt probeer ik minder duf te worden door het raam open te doen, je kan het op zijn minst proberen. Kijk op temperatuur heeft het direct effect maar als je gewoon de hele tijd in een ruimte bent merk je de luchtkwaliteit niet echt.

Figure 40 Supplementary questions asked to Tim Beuker

Discussing ideas context mapping study

After studying the meaning of focus groups, context mapping and the IDEO Method Cards a first set up of the sensitizing booklet and session was made and discussed in a meeting with Marco Ortiz. He gave feedback on the set up and plan, he advised to bring magazines of diverse topics to provide materials for the participants to express their tacit and latent knowledge via a collage. In general, he mentioned to keep questions simple and let the participants freely express themselves. Thus, avoid steering them in answer directions.

4.2.2 Location

The MultiSense, Perceptual Intelligence Lab 32-C-2-200 in the faculty of Industrial Design (ID) of Delft University of Technology (TUD).

The room with two tables and nine chairs (Figure 41a), is equipped with two cameras and an audio installation (Figure 41b) that can be watched in the control room next door (Figure 41c). The tables were placed in such a way that the setting is like the setting focussed on in this research. This room is especially designed for group sessions. Besides, organizational help was offered by Bertus Naagen, who also provided furniture and assistance to test and properly set up the equipment. The session took place on Monday, October 24th, 2016 in the evening.

a.
b.
c.

Figure 41 MultiSense, Perceptual Intelligence Lab at ID faculty TUD

4.2.3 Participants

The participants consisted of four women and five men, all of them students of vary backgrounds, and consisted mainly of housemates and neighbours. These participants with varying educational backgrounds were selected to participate instead of master students with the same study direction or colleagues to avoid a narrowed view. Both male and female participants were recruited because in general, there are different gender preferences and both matter in the office environment as well as the interaction between them. A feasibility estimation is encountered in the decision to ask housemates and neighbours to get at least eight participants together with a balanced gender composition and diversity in study backgrounds. Age range was not very large 18-24, which is considered as good thing from the perspective that they are similar types of people, in the same phase of life (student).

Participant's background

The participants have a different study background and are between 18 and 24 years old.

Name	**Age**	**Study**	**Educational institution**
Floor	(18);	Bachelor Bouwkunde (1st year)	TU Delft
Beau	(19);	Sabbatical year after trying a Biotechnologie at	Inholland (AMS*)
Frank	(20);	Bachelor Civiele techniek (2nd year)	TU Delft
Eline	(21);	Bachelor Bouwkunde (3th year)	TU Delft
Michiel	(21);	Master Systems Engineering, Policy analysis and Management	TU Delft
Lian	(23);	Master Architecture	TU Delft
Niels	(23);	Master Industrial Design	TU Delft
Ryan	(23);	Bachelor Werktuigbouwkunde	Haagse Hogeschool
Robbert	(24);	Master Construction Management and Engineering	TU Delft

*AMS = Amsterdam

4.2.4 Sensitizing

Sensitization is the process in which participants are made aware and more responsive to certain ideas, situation, or stimuli; in this case about window control. It is important to prepare the participants for the session because making them more aware of the topic at forehand will improve the quality of the session. In order to sensitize the participants, a week before the session the participants were asked to fill in a sensitizing booklet. The sensitizing booklet is developed with knowledge gained within the literature study and BBA Database analysis, input from Marco Ortiz, handed documents and feedback from Marco and five other PhD students (Figure 42).

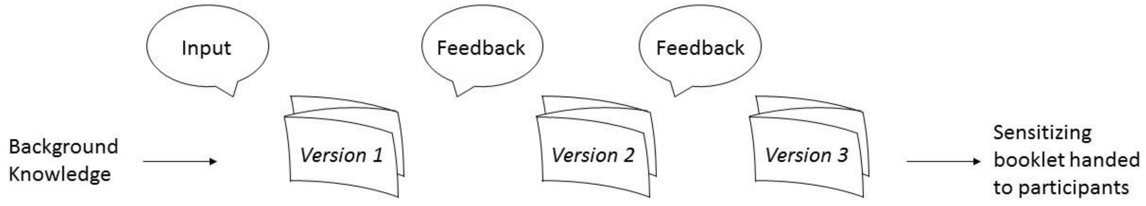


Figure 42 Schematic overview sensitizing booklet development

4.2.4.1 Content set up sensitizing booklet

Kistemaker (2010) generally recommends to start a sensitizing booklet with factual things and to discuss memories before dreams and fears (Figure 43), in such a way, participants are brought back to the past before being led to the future (Figure 43). That helps to gain knowledge about their latent needs. This recommendation is kept in mind while setting up the content of the sensitizing booklet.

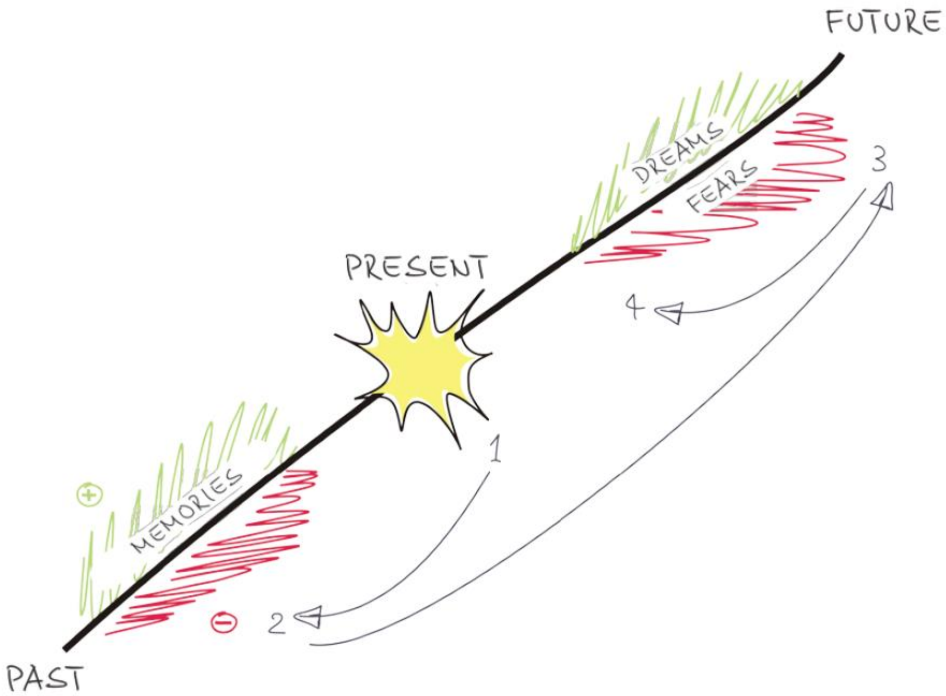


Figure 43 Process scheme generative session (Kistemaker, 2010)

The final version of the sensitizing booklet, which is handed to the participants, is presented and described underneath. In the next paragraph the received feedback on version 1 and 2 is described.

Front page

The questions are presented in a "Diary of three days", this format is inspired on the sensitizing booklets of Marco Ortiz and Jotte de Koning (De Koning, 2012). Besides this format is in line with the recommendation to make the participants more aware of the topic in small steps (Kistemaker, 2010).

Figure 44 Front page Sensitizing Booklet

Introduction

The booklet starts with a small explanatory text and some personal factual questions.

From the BBA Database analysis, it was known that people can feel cold while others feel warm and that it can be the same person who is often feeling cold or often feel warm (described as "zij heeft het altijd koud"). From this perspective raised the question whether sensitivity to temperature, air quality or distraction influences experiences, expectations and preferences of OFE's.

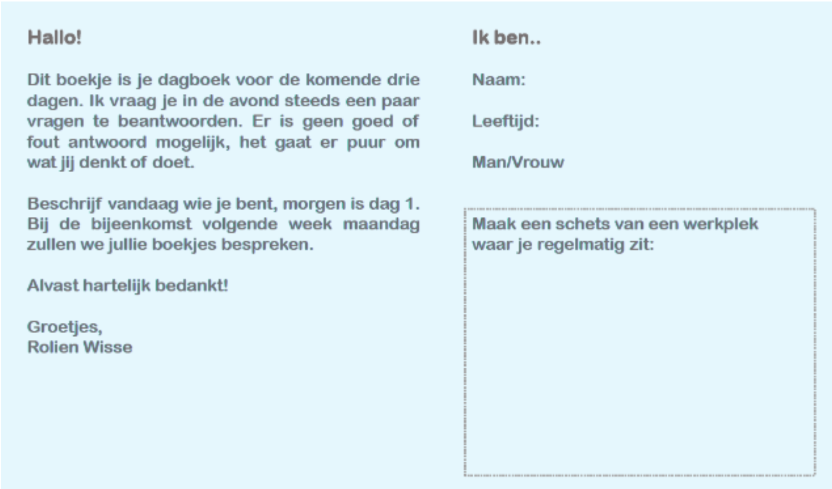


Figure 45 Introduction and factual questions Sensitizing Booklet

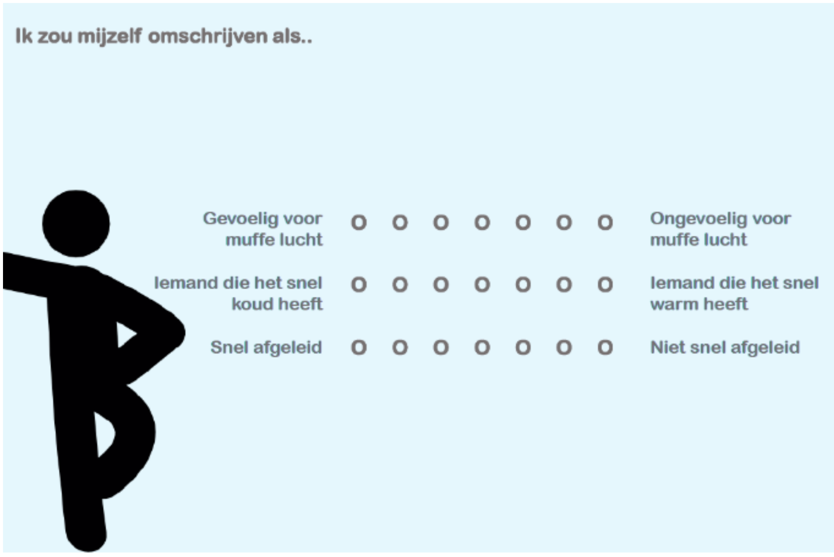


Figure 46 Personal questions Sensitizing Booklet

Day 1

The questions on day 1 of the sensitizing booklet bring participants back to the past by letting them emphasize in a situation with or without operable windows or shutters. It is meant to provoke free expression of memories.

Dag 1

Te openen ramen of luiken

Stel je loopt een ruimte binnen zonder TE OPENEN ramen of luiken, kun je uitleggen hoe je je zou voelen? (vaste ramen zijn wel aanwezig)
De manier waarop je dit doet is vrije keuze, bijvoorbeeld m.b.v. een smiley, steek woorden, schetsjes of een verhaaltje.

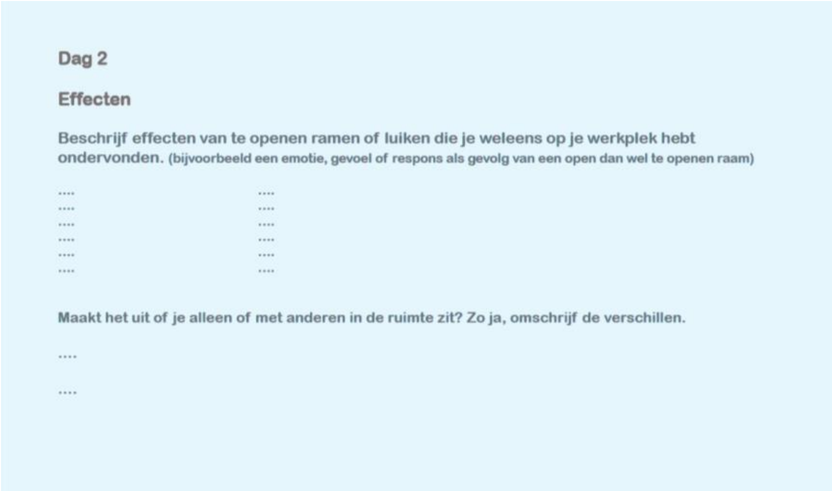
Stel je loopt een ruimte binnen met TE OPENEN ramen of luiken, kun je uitleggen hoe je je zou voelen? (vaste ramen kunnen ook aanwezig zijn)
De manier waarop je dit doet is vrije keuze, bijvoorbeeld m.b.v. een smiley, steek woorden, schetsjes of een verhaaltje.

Figure 47 Questions day 1 Sensitizing Booklet

Day 2

The questions on day 2 make the participants think deeper about memories of operable windows or shutters. They are asked about experiences in positive and negatives effects of operable windows and shutters to explore the current situation of people and gain insight into their experiences under the condition 'here and now'.

To get insights into the hierarchy within aspects the participants were asked to situate them in a pyramid. They were firstly asked to describe the effects and later to place them in a pyramid to avoid asking too many at once.



Dag 2

Effecten

Beschrijf effecten van te openen ramen of luiken die je weleens op je werkplek hebt ondervonden. (bijvoorbeeld een emotie, gevoel of respons als gevolg van een open dan wel te openen raam)

....
....
....
....
....
....

Maakt het uit of je alleen of met anderen in de ruimte zit? Zo ja, omschrijf de verschillen.

....

....

Figure 48 Questions day 2 Sensitizing Booklet

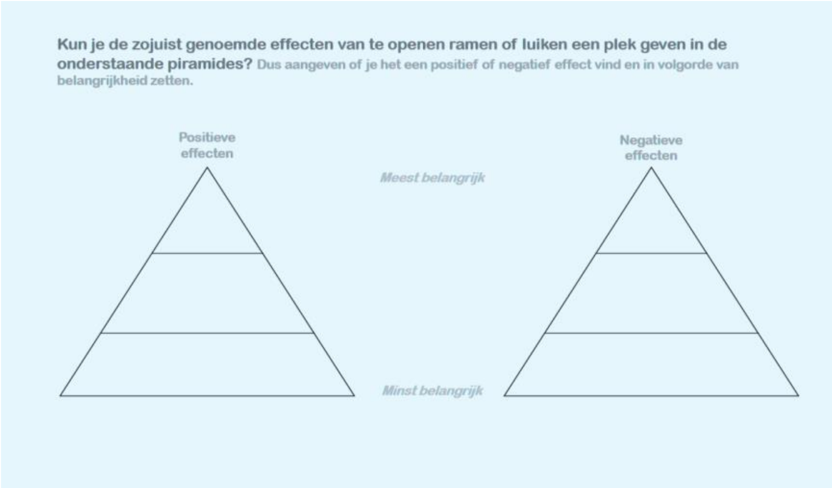


Figure 49 Follow-up question day 2 Sensitizing Booklet

Day 3

For the last question of the booklet, the participants were asked to draw an ideal operable window or shutter and explain why they think it is ideal. This is done to get more insights into people's dreams and fears.

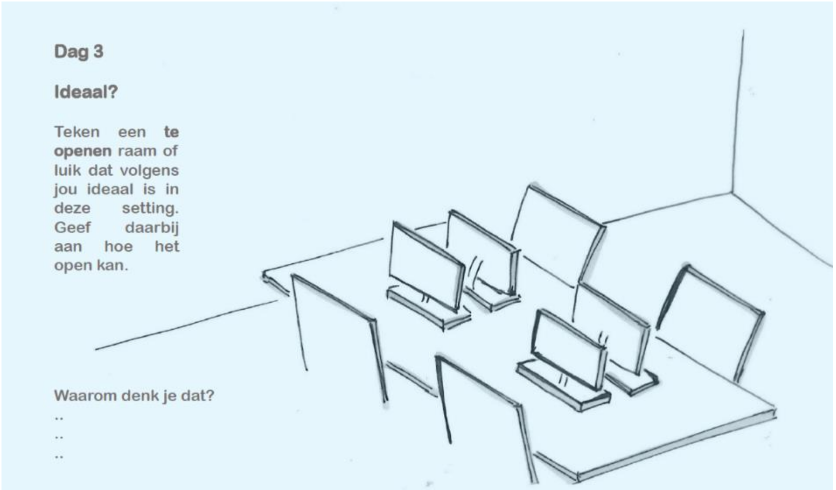


Figure 50 Questions day 3 Sensitizing Booklet

4.2.4.2 Feedback on version 1 and 2 of the sensitizing booklet

The first version of the sensitizing booklet was evaluated by Marco Ortiz, a PhD student of the chair of Indoor Environment within the faculty of Architecture at Delft University of Technology (TUD). Marco has experience in doing and using generative sessions as research method, which he learned during his master of Industrial Design at the TUD. Marco gave feedback on formulations of questions and initiated to add the hierarchy pyramid to the questions of day 2 to make it easier for participants to express positive and negative aspects of OFE's in hierarchy. The second version was evaluated by Marco and five other PhD students of the chair of Indoor Environment and Building Physics. They provided feedback to questions and layout which were considered unclear or improvable.

Firstly, the choice to talk about "operable façade elements", was considered unnecessary difficult. Instead it would be better to discuss "operable windows or shutters". Day 2 was one page with follow up questions in the first version, it was unclear to which previous question the questions referred and therefore the follow up questions were changed into two separate questions in the third version. In the second version of the booklet was asked to sketch the situation they were thinking of while answering the questions of day 2. They advised to ask for a sketch of an often-used workplace in the beginning of the booklet instead, to prevent unclearness and overkill of questions on one page. Some didn't sketch any operable windows when asked on day 3 about how they think an ideal operable window looks. Therefore, in the third version of the booklet, "operable" is written in bold letters and instructions to specify how it opens are added.

4.2.5 Group session

The goal of the session was to understand what people prefer and expect from operable windows and why they do so. The IDEO Method Cards, other described documents and conversations with Marco Ortiz inspired to the session composition as described hereafter.

4.2.5.1 Timetable group session

In the group session, the sensitized participants came together to share their experiences. They brought their sensitizing booklet to the session. A session usually contains two to three exercises and lasts about two hours (Visser, 2005). This session contained three exercises and took almost three hours', excluding dinner and cycling (see timetable underneath).

Time	Action
45 min	Dinner
10 min	Cycling
5 min	Arriving (Turn Audio and Camera on, give drinks and snacks to participants)
2 min	Introduction
10 min	First group question
5 min	Discuss Sensitizing booklet page (Figure 46)
Exercise 1 Collage making	
30 min	"Make" part
35 min	"Say" part, explanation to whole group
20 min	Group OFE Design
Exercise 2 Top 6 of OFE variants	
20 min	"Make" and "Say" individual explanations why others continued
Exercise 3 Priority of OFE related aspects	
25 min	"Make" and "Say" individual explanations why others continued
5 min	Further clarifications of context
10 min	Evaluation & debrief

During the whole session, there was room for discussion, clarifying and supplementary questions were asked and summaries were made to find out whether interpretations were made correctly.

Dinner

A pre-session dinner was prepared and served to let the participants get to know each other. Marco Ortiz advised to do this to put the participants more at ease and raise the chance that they will freely express themselves in the session. The diner was prepared and served at home because mainly housemates and neighbours were the participants and it had the organizational benefit that it was more likely that everyone would be on time. After the dinner, the whole group cycled ten minutes to the faculty of industrial design on the TUD campus.

4.2.5.2 Session

Make & Say

Everyone took a seat (in the composition of Figure 41a), the camera and audio were turned on and an introduction was given. Subsequently the participants were asked if they would like to have an operable window at a workplace or not and why they do so. During the session, questions from the booklet and given answers were discussed while related to the conversation. Participants were discussing, explaining and making collages, a top 6 of OFE variants and sorted OFE related aspect cards on priority.

Exercise 1 Collage making
The IDEO Method Card Collage (Figure 37c) was an inspiration for this assignment to get to know more about the dreams and fears of the participants. The participants were asked to make a collage to express what they find important in operable windows or shutters. Pencils, markers, scissors and magazines were placed on both tables and each participant received a blank A3 paper. The participants were told to express themselves in any way they like, either; drawing, writing, sketching and cut and paste things from magazines.

Figure 51 Exercise 1 “make” part and “say” part

Group OFE Design
The participants were told that the next exercise would become a group OFE design while they were listening to each other’s collage explanation. It was mentioned that groups could be made based on preference matching. It was expected that priorities would become clearer if they had to compromise. After the groups formed their main ideas, some needed a break and it was decided to continue with exercise 2 to avoid waiting and save time.

Exercise 2 Top 6 of OFE variants
The participants were asked to make a top 6 of OFE variants (Figure 52) and write down the advantages and disadvantages of the variants. The arguments why variants are better or worse than others express preferences and priorities.

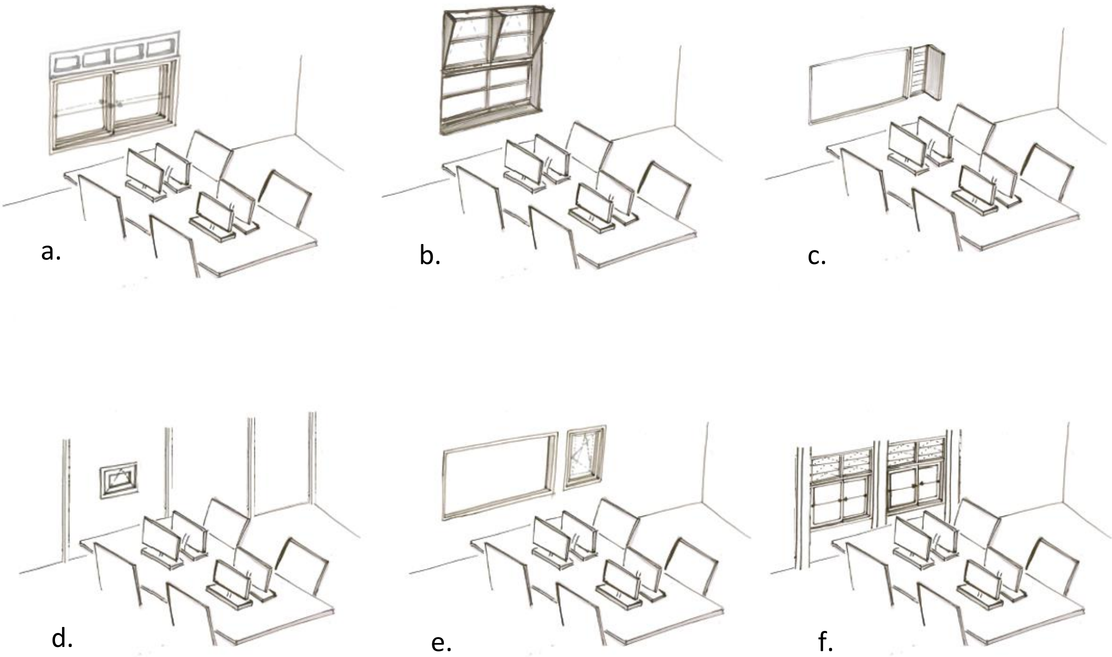


Figure 52 The OFE Variants

Exercise 3 Priority of aspects

In this exercise the participants were asked to prioritize the 18 OFE related aspects which are a summary of the OFE related aspects found in literature and the BBA Database. Thereby was told that these aspects are a summary of aspects found in research for my graduation. They were asked to prioritize the aspects on what they think architects should consider if they design an operable window for an office they goanna work in. The participants were also asked to leave an aspect out if it was considered irrelevant and note or suggest a different name it if the meaning was unclear. It was also mentioned that if they had suggestions for more aspects they were welcome to add them in the stack of cards.

The aspects were presented in English words and if desired explained in Dutch. The IDEO Method Card "Card Sort" (Figure 37b) inspired this assignment. It was meant to test whether the descriptions of the aspects are clear and which hierarchy the participants give to the OFE related aspects.

Further clarification of context

The context of graduation and this session were explained more in depth. This was done at the end of the session to avoid influencing the thoughts of participants'. Reasons behind questions, personal reasoning and struggles were explained. For example, the difficult balance between fine-tunability and ease of use.

Evaluation & debrief

At the end of the session a short summary was made and an evaluation was done, what did they think of the session and why do they think so. The context of the research was clarified and participants asked questions about the graduation project and they were asked if they know buildings with good operable windows and if they remember an experience where they were not satisfied with their operable window and what the reason for it was. At the very end, participants were thanked and chocolates were given to them.

Figure 53 Discussing collages during the group session

4.3 Results

In this paragraph, the results of all parts of the context mapping study are described. Starting with the sensitizing booklet results followed by the session in the sequence of the performed session and ending with a summary of the overall results.

4.3.1 Sensitizing booklets

The answers in the sensitizing booklets are overviewed in this section together with additional mentioning's during the session. The exact answers in the sensitizing booklets of the participants can be found in Appendix E Context mapping - Sensitizing booklets.

Personal questions

Figure 54 presents an overview of the answers to the three personal questions. Seven of the nine participants describe themselves rather sensitive than non-sensitive to stale air. Five of the nine participants describe themselves as someone who is rather gets cold fast than warm. Participant 'Niels' positioned his answer in the middle and explained in the session that that he would rather describe himself as sensitive to temperature than fast warm or cold, as well did Frank who positioned the dot one left from the middle in his booklet. Others also reacted approvingly, sensitive to temperature vs. non-sensitive to temperature would have been a more feasible question according to most participants.

Furthermore, none of the participants described him or herself as not fast distracted, even 4 out of 9 participants describe themselves as fast distracted. The difference turned out to be not very large. The largest contradiction was between Floor and Michiel. Floor described herself as fast cold (2/7) and insensitive (6/7) to stale air while Michiel described himself as fast warm (6/7) and sensitive to stale air (2/7).

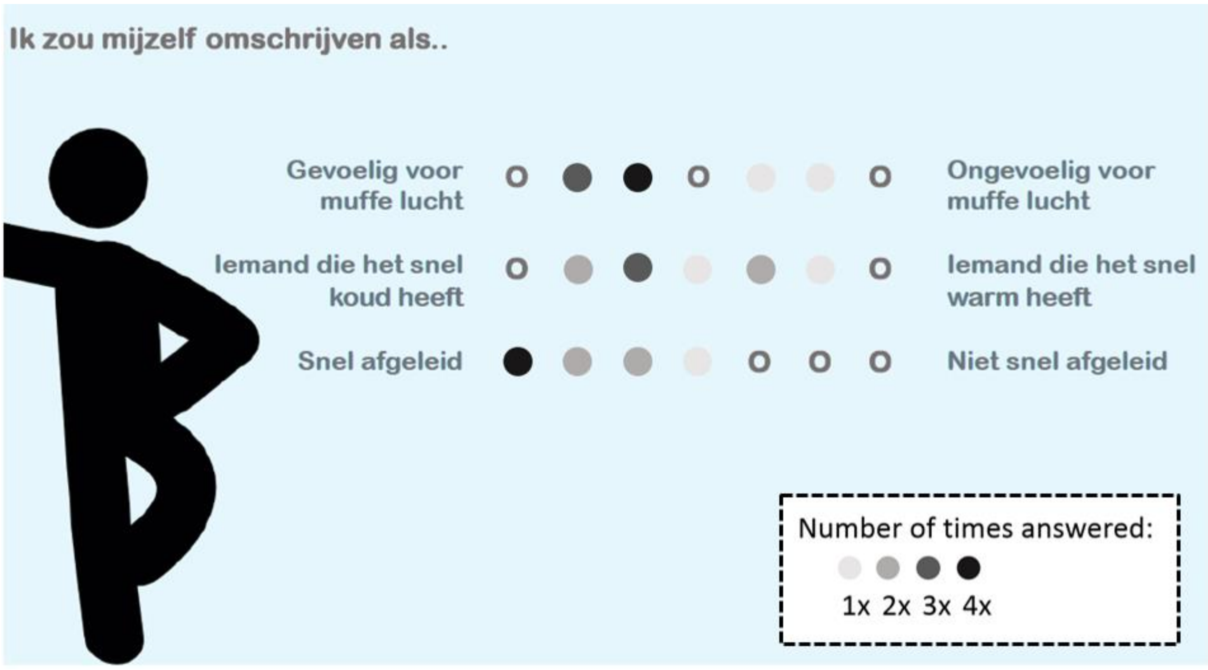
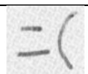
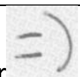


Figure 54 Answer overview personal questions Sensitizing Booklet

Day 1

Table 12 presents an overview of the answers to the two open questions. It can be summarized that the presence of an operable window does primarily influence their feeling when it is warm and stuffy and in case of high occupation or longer stay. A room without operable windows can cause a trapped, restricted and disappointed feeling. If temperature and air quality are good and it feels fresh, it will not (directly) be mentioned or does not really matter to 8 of the 9 participants whether there is an operable window or not. While the presence of an operable window in a room is described as giving a safer, open, nice, free and happy feeling compared to a room without operable windows. Besides, they generally appreciate it to have the option to influence air quality and temperature. Though, it is mentioned as well that it can be unpleasant if people quickly open the window.

Table 12 Answer overview questions day 1 sensitizing booklet

	Imagine you walk into a room <u>without</u> OPERABLE windows, can you describe how you would feel? (fixed windows are present) *(Stel je loopt een ruimte binnen <u>zonder</u> TE OPENEN ramen of luiken, kun je uitleggen hoe je je zou voelen? (Vaste ramen zijn wel aanwezig))*	**Imagine you walk into a room <u>with</u> OPERABLE windows, can you describe how you would feel? (fixed windows are present)** *(Stel je loopt een ruimte binnen <u>met</u> TE OPENEN ramen of luiken, kun je uitleggen hoe je je zou voelen? (Vaste ramen zijn wel aanwezig))*
Frank	If warm and tight → trapped feeling Enough distraction (as well indoors as outdoors) can reduce this → I would often leaf the door open	When I arrive from outside/ from the fresh air → Save open feeling → Directly open windows From indoors → Open windows at later moment or not.
Eline	It would not really matter at first instance if temperature and air quality are comfortable. At a certain moment, it can become oppressive/ restrictive. For example, if a room is warm or highly occupied. There is in this case no option to keep it comfortable.	Nicer. It is nice to be able to influence the air quality and temperature.
Niels	If temperature and fresh air are good  If not 	King of the Climate 
Michiel	As long as the temperature is normal and the air is fresh I would probably not realize that there is no operable window.	Practically the same, but fresh is air often nice in case of longer stay.
Ryan	Beginning, ok, it would not get much attention. At the end, trapped.	 Nice because you can determine by yourself whether they are open or closed.
Floor	Trapped. Bit tight chest  But I would not really mention it at first instance.	A bit freer  but only when I realize there is an operable window.
Robbert	If the room is fresh, light and has a nice climate → modern. No problem If stale air/dark→ Disappointment	The same, slightly happier. Always nice to have the option
Beau	 Would not notice if too warm	 "

Lian	Does not matter in winter, in summer it does matter.	Sometimes it is unpleasant if people open the window. It is practical if it is warm and stuffy of course.

Day 2

The participants were asked to describe the effects of operable windows or shutters they had experienced on their workplace. Subsequently they were asked if it matters whether you are alone or sharing a room with others and to describe the differences, if it does matter (Table 13). Answers show that, in their memory or empathy attendance of roommates can cause; different desires, awkward feeling by opening, the need to consider preferences of others and choice influence.

Table 13 Influence of sharing the room with others.

Describe effects of operable windows or shutters you have experienced on your workplace. Followed by:	
	Does it matter if you are alone or with others in the room? **If yes, describe the differences.**
Frank	No, unless the occupancy is such high that tight chest occurs
Eline	Yes, the Climarad (climate control with sensor) turns on sometimes if the room is higher occupied.
Niels	Yes, with others it can be awkward to open a window because their opinion is unknown.
Michiel	Yes, others feel faster cold than me. It occurs that they want it closed, while I still appreciate the open window.
Ryan	Not really, maybe for concentration.
Floor	Yes, different desires in terms of open or closed.
Robbert	Yes, you have to consider the preference of others.
Beau	No, unless the room is highly occupied, it can cause tight chest.
Lian	Yes, I cannot choose by myself if the room is shared with others

Thereafter they were asked to position the just mentioned effects in the pyramids (Figure 55). The words in Figure 55 are located on the average position in the pyramid and number of participants who announced the effect is written behind the word, the larger the font size the more often noticed. The individual pyramids can be found in Appendix E Context mapping - Sensitizing booklets.

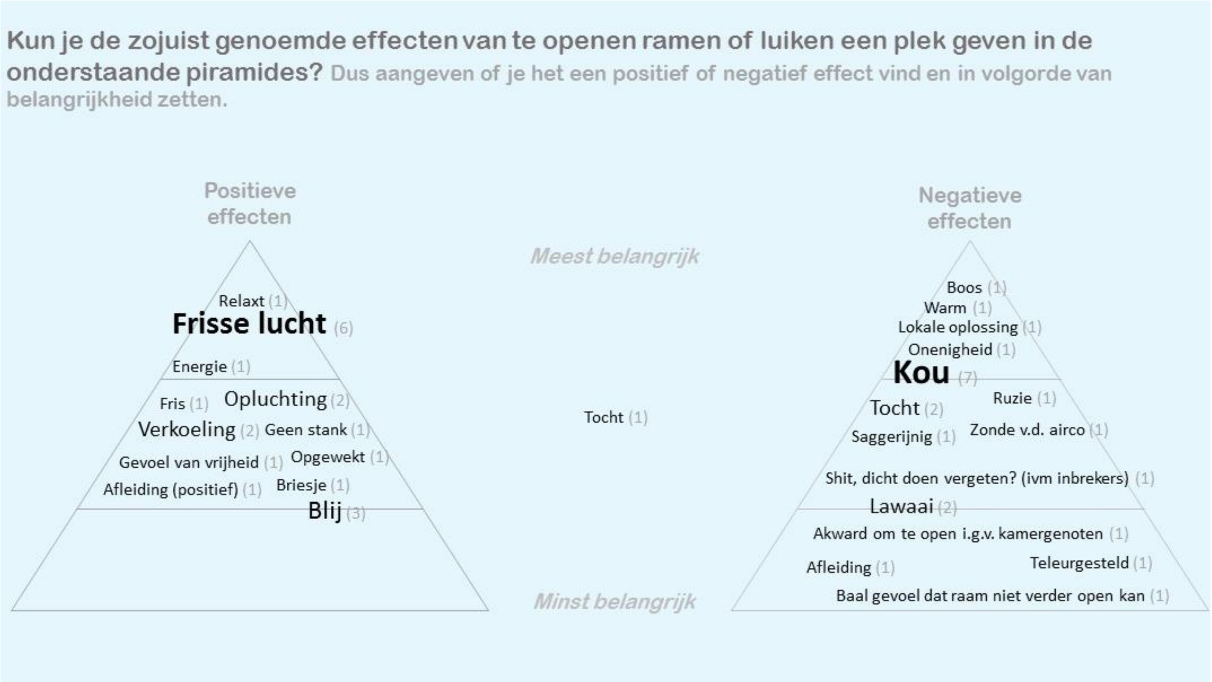


Figure 55 Answer overview positive and negative effects of OFE's in hierarchy

"Kou" (Cold) was the most frequent noted negative effect, noted by 7 of the 9 participants. "Frisse lucht" (Fresh Air) was the most noted positive effect, noted by 6 of the 9 participants. A variety of other effects can be seen in (Figure 55). The described and prioritized experienced positive effects of operable windows or shutters are; Fresh air, relive, happy, cooling effect, relaxed, giving energy, fresh, no smell, excitement, sense of freedom, fresh breeze and positive distraction.

The described and prioritized experienced negative effects are; Cold, draught, noise, angry, warm, local solution, disagreement, argue about, waste of the airco, grumpy, fear of forgetting to close/ fear for burglary, awkwardness, disappointment (that cannot be opened further) and distraction. In a sequence from most mentioned and important to least mentioned and important.

Day 3

On day 3 the participants were asked to sketch their ideal operable window (Figure 56). Their sketches and argumentations show preference for:

- Bottom hung inwards opening windows, which provide the workplace indirectly with fresh air and prevent cold or distraction compared to turning windows.
- Side hung inwards turning windows, which provide the workplace directly with fresh air and have much effect.
- Operable parts on both sides of the table, feels more as "you own personal window".
- Preference for windowsills with place for stuff was mentioned and widely confirmed.
- Easy operable
- Adjustability, much and few amounts of air.
- Eline, Niels and Robbert prefer one operable part, the other participants prefer more operable parts.

The largest contradiction in personal description (Figure 54) was between Floor and Michiel. Floor described herself as fast cold (2/7) and insensitive (6/7) to stale air while Michiel described himself as fast warm (6/7) and sensitive to stale air (2/7). Surprisingly their "ideal windows" (Figure 56) are quite similar.

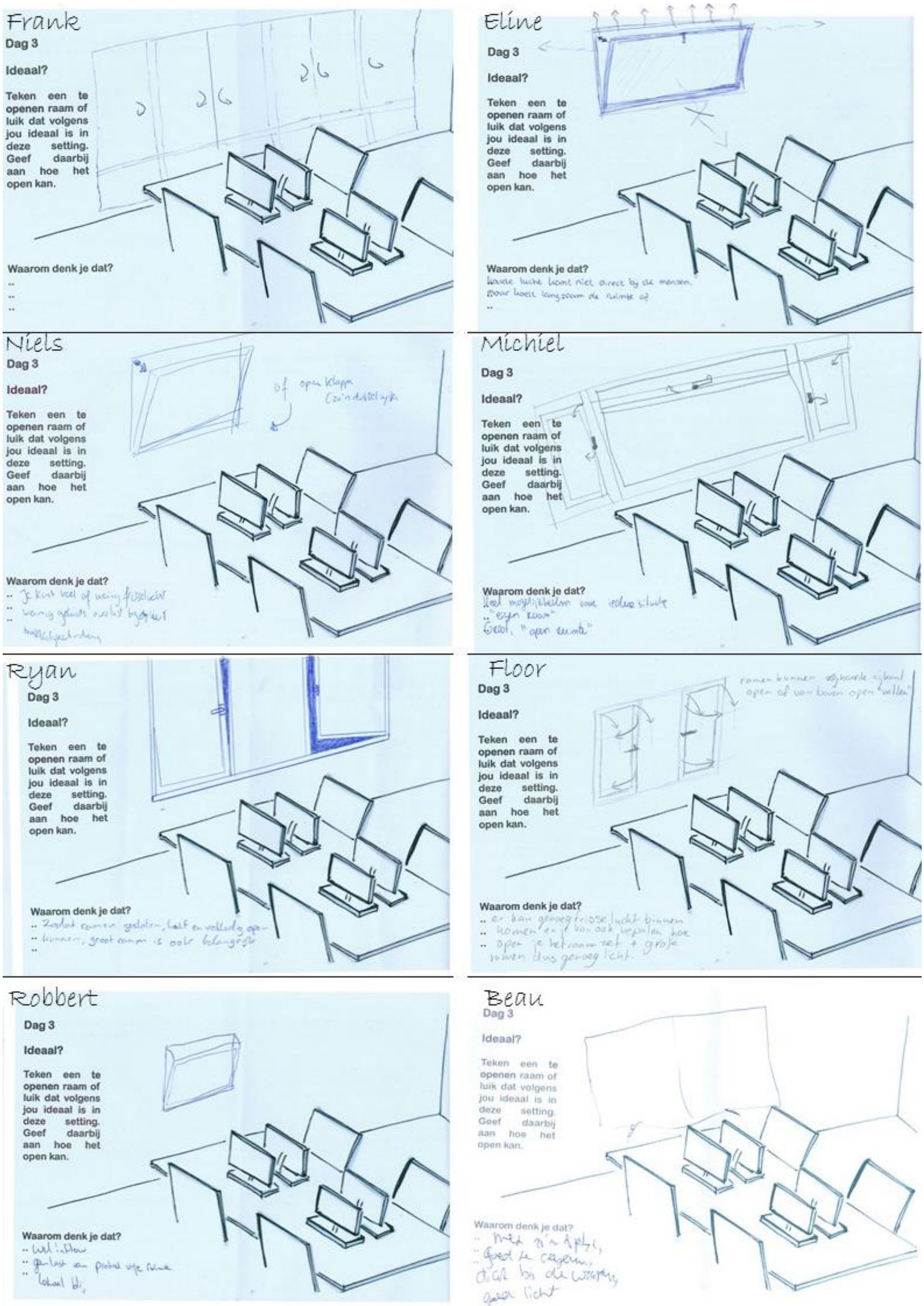


Figure 56 Ideal window sketches sensitizing booklets

The sketch of the ideal operable window of Lian can be seen in Figure 60.

4.3.2 The session

First question - Group question 1

The participants were asked if and why they would like to have an operable window. Summarized can be said that reasons why participants would like to have an operable window are; sense of control and secureness that you can work pleasantly and have personal control over temperature, indoor air quality and air movement. Thereby was mentioned that moving air feels fresh and outdoor air has added value, feels better and enhances performance.

Reasons why Niels, Robbert and Floor not necessarily want an operable window: If temperature can be regulated or if the indoor climate is good no operable window is needed. If the indoor climate is not properly managed, e.g. stale air, it is pleasant that something can be opened and to have that control but not per definition necessary. Floor would prefer something which provides fresh air on (desired) temperature.

Exercise 1. Collages

"Make" part

The participants were asked to express in a collage (Figure 57-Figure 62) what they find important in operable windows or shutters and why they find it important. During the "Make" part several conversations happened while others were working on their collage.

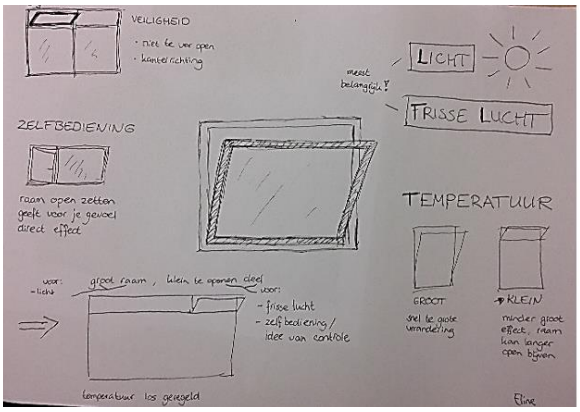


Figure 57 Collage Eline

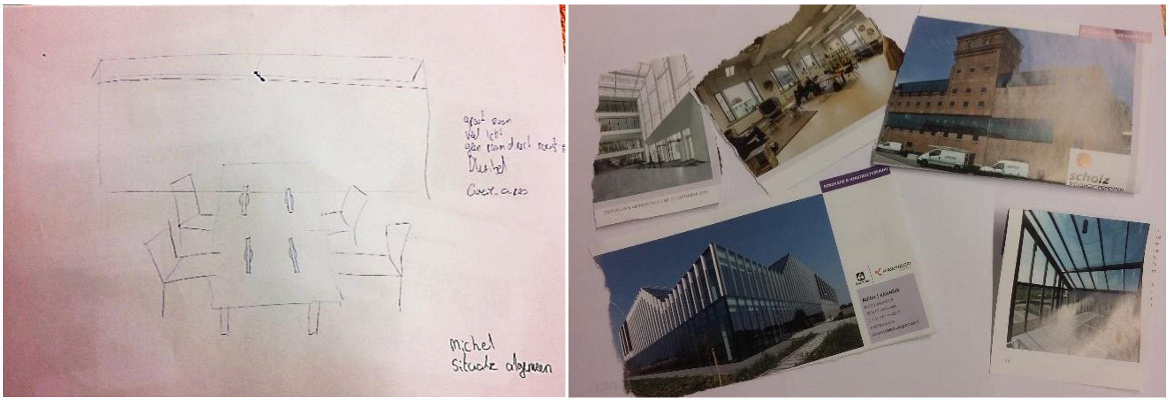


Figure 58 Collage Michiel. Front (preferences) and back (references)

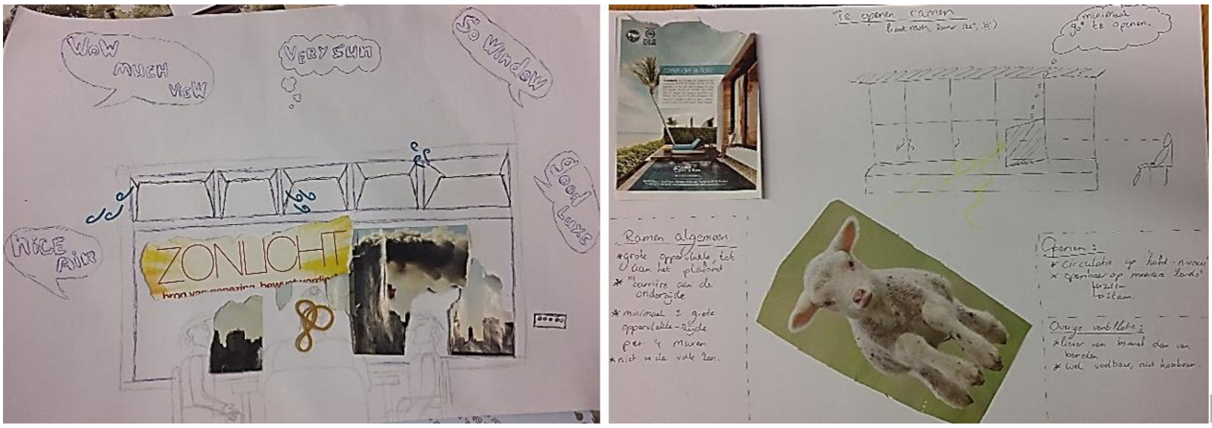


Figure 59 Collage Ryan and Frank

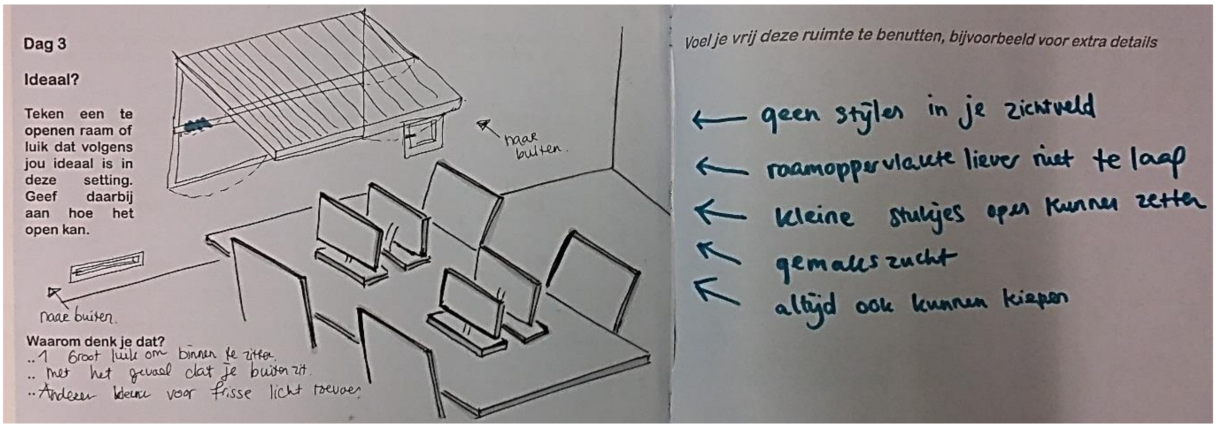


Figure 60 Collage Lian (due to delay she used her ideal sketch for explanation)

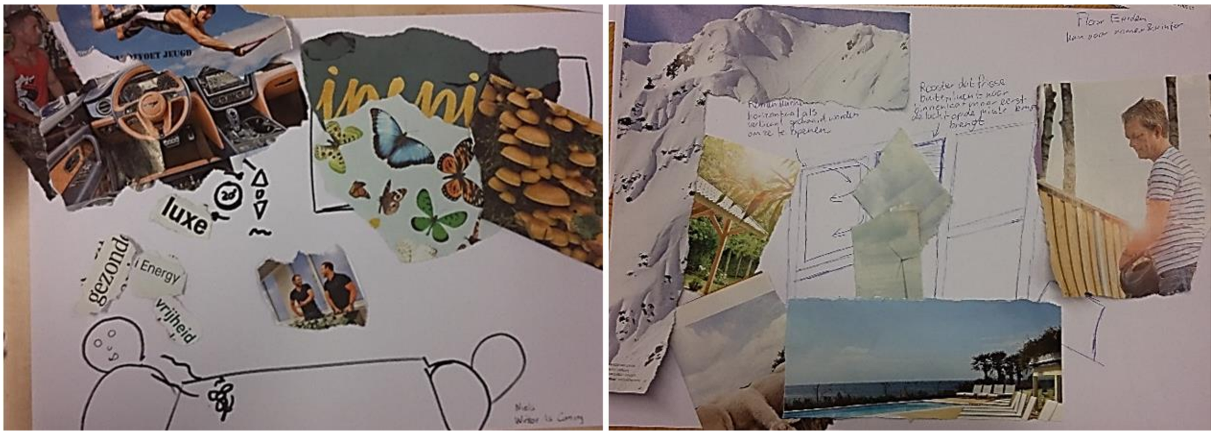


Figure 61 Collage Niels and Floor

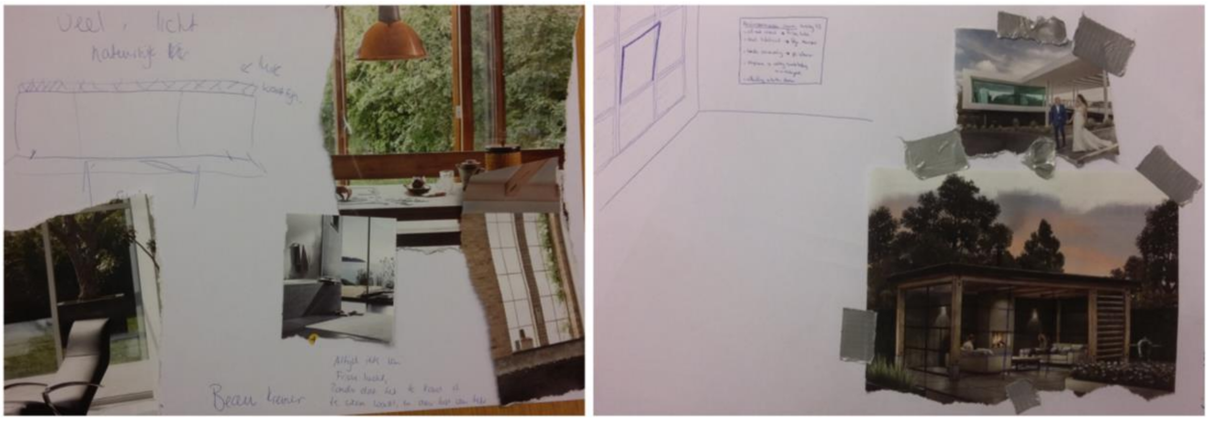


Figure 62 Collage Beau and Robbert

“Say” part

The participants explained their collage in front of the group and told what they find important in operable windows or shutters and why they find it important. A summary of their explanations is presented in table 11.

The largest contradiction in personal description (Figure 54) was found between Floor and Michiel. Floor described herself as fast cold (2/7) and insensitive (6/7) to stale air while Michiel described himself as fast warm (6/7) and sensitive to stale air (2/7). Their ideal operable window sketches were surprisingly quite similar. Their collages reveal the difference in personal description more clearly; Michiel describes the preference to have one large operable window while Floor prefers a smaller operable part, which can be tilted and turned and a grill that can bring in fresh air on desired temperature.

Table 14 Summary “Say” part Collage making

Important in or preferences of operable windows and shutters	**Mentioned by**
Large part of façade glazed (light and view)	Niels, Eline, Ryan, Robbert, Beau, Frank, Floor
Option to vary (dose) between few and much effect in relation to temperature, air movement and place of supply.	Michiel, Frank, Floor, Beau, Ryan, Lian
Easy to use and understand	Eline, Michiel, Beau
Providing fresh air	Floor, Beau, Niels, Eline, Ryan
Only smaller changes thus small opening angle (easier agreement with roommates)	Eline
Offering direct control, sense of (direct) control	Niels, Eline
Supply not in face (cold air, getting a cold, comes at you)	Michiel, Eline, Robbert, Lian (in winter)
Operable façade in summer (sense of sitting outside)	Lian
Supply in face (moving air at face level, where freshest feeling is sensed)	Frank
Window not till floor (pleasant, ability to place stuff in front)	Frank, Robbert
Usable windowsill	Frank, Niels
Ideal	
Temperature and fresh air can be regulated separately	Floor, Niels
Regulation independent from colleague’s, freedom to control	Niels

Group OFE Design

The groups, their main ideas and remarks are presented Table 15.

Table 15 Formed groups and their main idea

Groups	Main idea	Remarkable
Frank & Ryan	"Wall size windows" with multiple operable parts	Idea conform collages (Figure 59), wall size is of higher priority than manual or electric control.
Eline, Beau & Floor	Large fixed window with small operable part which supply out occupant zone to prevent cold and large effect on temperature.	Their preferences were quite aligned.
Robbert, Niels, Michiel & Lian	Good climate control with slightly operable part. Above 20 degrees' outdoor temperature, the large operable part (idea Lian (Figure 60)) may be opened.	Robbert and Niels agree to the large operable part, on the precondition only above 20 degrees, while in contrast with their 'waste of the airco' comments.

Exercise 2. Top 6 of OFE variants

The participants made a top 6 of the OFE variants (Figure 64) and wrote down the advantages and disadvantages (Figure 64). The average top 6 of OFE variants can also be seen in Figure 64. An overview of how the answers are summarized into an overall top six can be found in Figure 64. A summary of the pros and cons by OFE variants is presented in Table 16.

Table 16 Mentioned pros and cons by OFE variants summarized

Pros mentioned	Mentioned by
Large part of façade glazed (much light and view)	Frank, Eline, Niels, Michiel, Floor, Robbert, Beau, Lian
Many options, flexible, variation possible	Niels, Michiel, Beau
Enough fresh air possible/ opening possibility large enough	Floor, Lian, Michiel, Niels
Easy to control	Niels, Beau
Prevents draught in winter	Niels
Operable in upper part of façade	Eline, Lian
Supply at head height	Frank
Supply separately possible on both sides of table	Lian
Aesthetic reasons (nice, playful)	Lian, Beau (Floor at ideal window)
Functional	Eline
Basic, one option	Eline
Cons mentioned	
Small part of façade glazed (few light and view)	Eline, Floor, Robbert, Beau, Frank
Small operable part, too less to open, too less control	Frank, Floor, Robbert, Michiel, Lian, Beau
Large operable part, too large change	Eline
Too many options	Lian
→ Discussion	Eline
→ Complicated	Niels

Aesthetic reasons (weird, ugly, feels less open)	Niels, Eline, Michiel, Robbert, Beau, Lian,
→ Feels less fresh	Frank
Not functional	Lian
Opening option at only one side of the table	Lian
Difficult to clean	Lian
Ryan did not give comments on the top 6 of OFE variants	

Large incidence of light and aesthetic value turned out to be very important to the participants for the position in the top 6. Lian mentioned while explaining her top 6 that she did not think of differences in amount of air through operable parts.

Other mentioned pros related to the OFE variants were: ease of control, options to vary the amount of air, enough fresh air possible/large enough, operable in upper part of façade (operable while less cold and distracted), functional and basic.

Mentioned cons related to the OFE's were: too small part of façade is glazed, too small OFE, too large OFE, too many options (too difficult and causes discussion), ugly and difficult to clean

Figure 63 Ranking 6 OFE variants

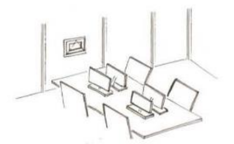
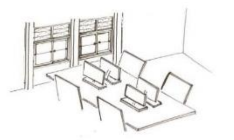
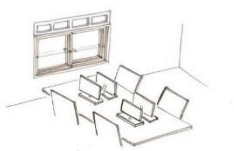
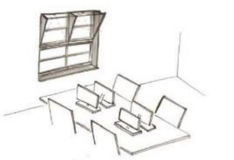
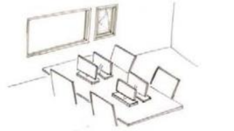
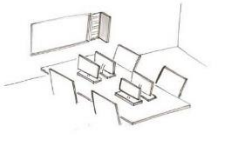
		Reasons		
Average Top 6 of OFE variants	Personal ranking		Positive	Negative
	2	Frank	+ veel lichtinval	- kleine opening
	2	Eline	+ veel glas/ veel uitzicht	- te openen raampje verpest grote vlak
	3	Niels	+ veel glas	- ziet er raar uit
	1	Michiel	+ veel ramen	/
	6	Ryan	/	/
	6	Floor	+ veel raam, + veel licht	- klein te openen deel (te klein
	1	Robbert	+ veel licht, + glazen pui, + kan open	- klein raam wat open gaat
	1	Beau	+ veel lichtinval, + oogt ruimtelijk	- weinig invloed over regulatie van frisse lucht
1	2	Lian	++ mooi uitzicht met raam luchten draaikiep	/
	1	Frank	+ veel raam, + schuifraam op hoofdniveau	/
	3	Eline	/	- te veel opties voor kantoor --> veel discussie
	2	Niels	+ veel opties	/
	5	Michiel	+ wel flexibel	- lelijk
	4	Ryan	/	/
	3	Floor	+ genoeg frisse lucht	- (iets) minder licht
	4	Robbert	+ raam open	- rooster
	2	Beau	+ redelijk veel lichtinval, + veel variatie mogelijk met het openen en sluiten van ramen	- kleiner raam
2	1	Lian	+++ mooi schuiven, zo groot als je wilt te openen en plaatsen draaikiep. 2 kanten op schuiven is een +	3 is een beetje overdreven (gaat over de lamellen)
	3	Frank	+ schuiframen op hoofd niveau	/
	5	Eline	/	- te veel hokjes, - liever klein dan groot raam open
	1	Niels	+ IO !, + kan makkelijk, + verstellen	/
	4	Michiel	+ kan veel open	- kleine
	5	Ryan	/	/
	2	Floor	+ genoeg lucht, + genoeg licht	/
	2	Robbert	++ open, veel licht	- raar bovenraampje
	3	Beau	+ speels ontwerp, + frisse lucht is makkelijk te reguleren	- oogt minder ruimtelijk, - kleiner raam
3	3	Lian	+ leuke vakjes, speels, zo groot als je wilt te openen	- lastig schoon te houden
	5	Frank	/	- voelt minder fris
	1	Eline	+ gedeelte open aan bovenkant, + 1 optie	- raam had groter gemogen
	4	Niels	+ geen kou in de winter	- lelijk
	6	Michiel	/	- lelijk
	1	Ryan	/	/
	1	Floor	+ genoeg lucht, + genoeg licht	/
	3	Robbert	+ veel licht, + open	- smal raam
	4	Beau	+ frisse lucht is redelijk te regelen	- raam is smal
4	6	Lian	/	- - lelijk, onfunctioneel, weinig te openen
	4	Frank	+ Relatief groot oppervlak	/
	4	Eline	Basic, wel functioneel	Liever 1 geheel glas
	5	Niels	+ heel veel opties voor raam	- ingewikkeld!
	2	Michiel	+ open raam	/
	2	Ryan	/	/
	4	Floor	+ redelijk licht	+ weinig lucht
	5	Robbert	+ veel licht, + comfortabel	- klein gedeelte wat open kan
	5	Beau	+ extra raampje	- oogt kleiner
5	4	Lian	+ veel uitzicht, frisse lucht	helaas aan 1 kant
	6	Frank	/	- voelt minder fris, - geen 'licht' functie vanuit luik
	6	Eline	/	- latjes belemmeren open gevoel
	6	Niels	+ kan helemaal open	- spijlen lijken op een gevangenis
	3	Michiel	+ open raam	/
	3	Ryan	/	/
	5	Floor	/	- iets minder licht, - niet veel lucht
	6	Robbert	+ groot open raam	- rooster
	6	Beau	+ vrij groot	- tralies voor bijraampje
6	5	Lian	/	- tralies

Figure 64 Top 6 of OFE variants

Exercise 3. Priority of OFE related aspects

The participants prioritized cards with OFE related aspects (Figure 65). The average priority, given to the OFE related aspects is presented in Figure 66. The comments on the cards are presented in Appendix H Context mapping – Priority of aspects – Comments. The top 3 of each participant is given in Table 17, the complete list of cards of each participant is shown in Appendix I Context mapping – Priority of aspects – Results.

Figure 65 Card sort exercise

Match with HVAC, effort to control and fine-tunable are given the highest priority on average.

It is unsure how “Match with HVAC” is interpreted. It was named as OFE related aspect because it should be allowed, ventilation type influences air flow and sensors for heating should for example not be located closely by an OFE. Comments of the participants on this card were “precondition for good design”, “OFE’s are part of HVAC”, “definitely a must → “spreading” fresh air through the room”. It seems that desire for good IEQ with good HVAC is the main motivation to give high priority to this aspect. The second and third highest prioritized “effort to control” and “fine-tunable” matches other comments and seem to be interpreted as intended. Namely as described in the literature about perceived control, controlling the IE should not take too much effort and fine-tuning capability of a control helps to meet people their needs.

	Priority
Match with HVAC (Heating, Ventilation, Air conditioning & Cooling)	**Highest**
Effort to control	
Fine-tunable	
Avoid ingress of water (wind driven rain)	
Match with layout	
Adjustable	
Avoid ingress of pollution	
Avoid ingress of thief's	
Avoid ingress of noise	
Robust	↓
Ability to Cross-ventilate	
Avoid ingress of wind	
Match with solar shading	
Ability for Night Ventilation	
Avoid ingress of insect's	
Match with facility management	
Match with blinds	
Match with culture	**Lowest**

Figure 66 Average priority OFE related aspect cards.

Table 17 The 3 most important OFE related aspects per participant

Priority:	**1**	**2**	**3**
Frank	Match with HVAC	Ability for Night Ventilation	Fine-tuneable
Eline	Robust	Avoid ingress of pollution	Effort to control
Niels	Fine-tuneable	Adjustable	Effort to control
Michiel	Adjustable	Fine-tuneable	Avoid ingress of pollution
Ryan	Match with layout	Match with HVAC	Avoid ingress of thief’s

Floor	Effort to control	Avoid ingress of thief's	Avoid ingress of water
Robbert	Match with HVAC	Avoid ingress of thief's	Avoid ingress of water
Beau	Adjustable	Robust	Match with HVAC
Lian	Match with layout	Match with culture	Effort to control

Frank mentioned the façade of a mosque in relation with "match with culture", it seems to be interpreted as an aesthetic match with culture. Frank left the card "adjustable" out because fine-tuneable covers the meaning of adjustable already in his opinion. As he said "an OFE is adjustable if you can tune it". Niels did not agree "fine-tuning is finer, subtle".

Group question 2

Who would like to have a summer and winter option and who would not like that? Can you explain where you think of and why you want it or not?

Table 18 Answers on preference for summer and winter option?

Answer	Participant
Yes	Eline, Beau, Ryan, Frank, Lian
No	Michiel, Robbert, Niels
Neutral	Floor

Arguments for "Yes": In summer the opportunity to open windows, in winter opportunity to get some fresh air through a grill (Ryan & Frank). The sense of being outside due to a large operable part can be preferable in summer but is undesirable in winter (Eline). In summer, almost whole façade open, in winter fresh air through grill (Lian).

Arguments for "No": Climate control regulates the indoor climate, a summer and winter option are not needed for a small, just additional window (Robbert). I do not want that people have the opportunity to open much window in summer causing warm temperatures inside while the airco properly works. People cannot properly use large operable windows in summer (Niels). Robbert agrees.

Evaluation & debrief

A short summary of the session results and an explanation about the context of the research were given and followed by questions from the participant's. Frank mentioned that it was good that he did not know the background information before the session.

Buildings with good operable windows mentioned by the participants when asked for were: The Edge, TNT Hoofdkantoor, VPRO office in Hilversum and Berlumo. Supplementary questions pointed out that it was not based on experience of working there but on what they had heard about it.

Remarkable note: Robbert mentioned that he knows buildings where the indoor climate is regulated well. Lian responded surprised, does it really happen that it is properly regulated? This experience difference seems to be reflected in their ideal windows sketches and other comments and preferences.

Mentioned situations with large desire for a (good) OFE were: A warm and muggy train without OFE's. Mentioned reasons for not properly usable OFE's: too heavy, crank out of reach and high burglary risk.

Summary overall results

The presence of an operable window in a room is by some participants described as giving a safer, open, nice, free and happy feeling compared to a room without operable windows. Thereby some mention to appreciate the option of influencing the air quality and temperature with OFE (when necessary).

Preference to have an OFE is argued by: sense of control, secureness that you can work pleasantly and personal control over temperature, indoor air quality and air movement. It was also mentioned that moving air feels fresh and outdoor air has added value, feels better and therefore enhances performance. Generally, large operable parts for the summer and small operable parts for the winter were preferred by those participants.

No necessarily preference for an OFE is argued by: "If temperature can be regulated or if the indoor climate is good no OFE is needed" and "If the indoor climate is not properly managed (e.g. resulting in stale air) it is pleasant that something can be opened and it is nice to have control, but it is not by definition necessary". Besides is mentioned that the temperature of air supply through a window cannot be regulated/ cause cold.

Described experienced positive effects of operable windows or shutters are: Fresh air, relive, happy, cooling effect, relaxed, giving energy, fresh, no smell, excitement, sense of freedom, fresh breeze and positive distraction.

Described experienced negative effects are; Cold, draught, noise, angry, warm, local solution, disagreement, argue about, waste of the airco, grumpy, fear for forget to close/ fear for burglary, awkwardness, disappointment (that cannot be opened further) and distraction. In a sequence from most mentioned and important to least mentioned and important. "Cold" and "fresh air" were mentioned considerably more frequent.

An easily operable, effective and adjustable (can provide both small and large amounts of air) OFE, controllable by opening area and/or multiple windows, not indoor space away taking windows, in a façade with usable windowsills, much light and view to outside is mainly considered ideal. Besides, they generally preferred much light and view to the outside, as illustrated among others in the OFE ranking.

Having roommates can cause, according to the participants; different desires, awkward feeling by opening, the need to consider preferences of others and choice influence.

4.4 Discussion

The results are much related to prior knowledge, though, on itself not properly generalizable since only one group session was done. Several insights in the preferences and expectations from operable windows of the participants are found. But, their experiences, preferences and expectations varied quite much, asking for more insight in how broad-based these are. The mentioned or illustrated findings are considered usable in relation to the requirements for good usable OFE's which are based on literature (Table 19). Namely, it seems to lead to plausible usable new insights and valuably extend the meaning of the requirements and empathy in the consequences of the requirements for OFE design.

It would be interesting to research if (and how) it is possible to have an OFE that only affects air quality and doesn't affect temperature but does have the characteristic direct effect and clear design intent. Subsequently it would be interesting if people appreciate the OFE in such a version as much as they do appreciate a "normal OFE". Besides it would be of interest if it reduces discussions with roommates and sense of cold and draught.

4.4.1 Relation to literature findings

The context mapping study findings are compared to the literature findings. Related mentioned or illustrated preferences, positive effects and pros are described as well as negative effects and cons (Table 19).

That operable windows were mainly considered valuable when it is warm and stuffy or in case of high occupation or longer stay seems to relate to the adaptive principle (Nicol et al. 2012) "If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort".

Table 19 Results context mapping study related to literature findings

Requirements for good usable OFE's based on literature	Related preferences of participants of the context mapping study	Related positive effects/ pros mentioned or illustrated by participants of the context mapping study	Related negative effects/cons mentioned or illustrated by participants of the context mapping study
User-friendly	Easy to control, low effort to control		Too complex
Clear design intent	Not too complex		Waste of the airco, too complex
Effective	Enough fresh air possible/large enough, nice breeze, option to dilute indoor air pollutants and/or bad smell, cooling effect	Fresh air, relieved, happy, excitement, options to vary amount of air	Disappointment
Fine-tuning capability/ Adjustable	A controllable opening area and/or multiple OFE's, options to vary amount of air	Option to have direct much supply in summer and indirect less supply in winter	Cold, draught, disappointment, too large OFE, too small OFE
Match company's security policy and OFE design*			Fear for forget to close/ fear for burglary.
Low noise ingress			Noise, distraction
(Mental) connection with outdoor climate		View to outside is highly appreciated, feeling more free	Cold
Proximal/ highly controllable by occupants	Sense of control, personal control		
Robust	Easy to control		Too many options. Difficult to clean
Additional requirement for perceiving control by OFE's over thermal environment & indoor air quality			
Cultural/social attitudes match**			Disagreement, different desires, people cannot properly use a large OFE

*Suggestion to change it into "Align company's security policy and OFE design". Because "Match" was often interpreted differently than intended.
** Suggestion to change it into "Avoid large differences in cultural/ social attitudes of roommates".

The preference for windowsills is related to the OFE design but not directly related to a requirement based on literature. This could be included in the final requirements.

4.4.2 Limitations

Only one group session was done, therefore the found preferences and expectations are very specific for these nine participants. The participants were mainly technically educated and had low experience and empathy in office situations. This can either be a good thing because it brings insights from outsiders to the office context. Expectations of HVAC performance of some participants seem to be better than in actual practice.

The card sort exercise contained aspects which were unclear and the OFE variants varied not only in operable window design but also, largely, in façade design.

An unexperienced person leaded the session and no one was seated in the control room, therefore the deeper meaning of comments was not always found.

Male and female housemates and neighbours were recruited because of feasibility (all living in Delft and willing to make time, free of charge), varying educational backgrounds, similar age and phase of life (student). It was considered more feasible compared to students with the same study direction or colleagues, due to risk on narrowed view. Being the session leader was for me, Rolien, an interesting exercise as well as from educational point of view. Due to limited time was chosen to do only one group session.

To overcome the limitations in the future it is suggested to do multiple group sessions, use a (more) experienced session leader and situate at least one person, experienced with context mapping studies, in the control room to observe the session and suggest laddering questions. Besides, is recommended to reconsider the OFE related aspects of the card sort exercise and the OFE variants.

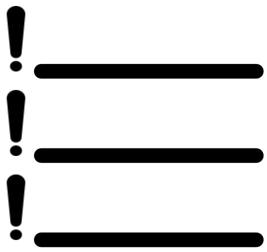
4.5 Conclusion

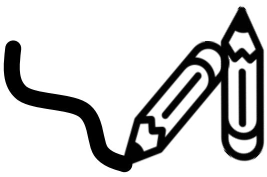
The objective was to find out what people prefer and expect from operable windows and why they do so. Operable windows were mainly considered valuable when it is warm and stuffy or in case of high occupation or long stay in a room. In such a situation, participants expect that presence of OFE's would give a safer, open, nice, free and happy feeling, compared to rooms without operable windows. Note that these are mentioned by at least one participant, not presenting general expectations. Low effort to control and fine-tuning capability are preferred by most of the participants, these were given high priority and often announced during several parts of the session, as well as ease of use. Thereby fine-tuning capability seems to mean preference for a controllable opening area and/or multiple OFE's. Generally, is expected that open windows let in fresh air of outdoor temperature and provide air movement.

It seems to depend on the participant's experiences and expectations if control over operable windows for thermal comfort or rather only HVAC for thermal regulation (e.g. to prevent incorrect use and discussions/annoyance) is preferred.

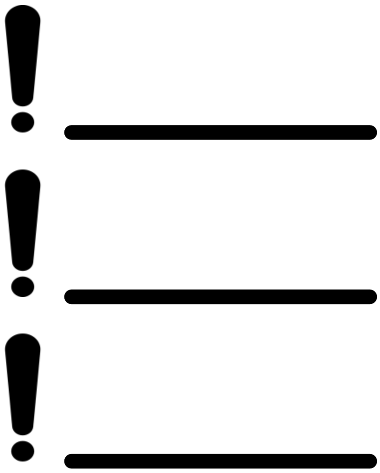
The option to offer at least an open a window when it is warm and stuffy is recommended. Ease of use, effort to control and fine-tuning capability should be considered while designing OFE's. As well, usable windowsills should be integrated in the OFE design (prevent obstruction of opening if stuff in windowsills).

PART II. END PRODUCTS





5. Requirements for better usable OFE



5 Requirements for better usable OFE

In sections 3.3.1 and 4.4.1 respectively results of the BBA database and context mapping study are compared to the literature findings. The literature study, BBA database analysis and context mapping study results are compared and merged with the help of Table 6 and these two sections (3.3.1 and 4.4.1) into one overview in Table 20. Changes from the "requirements based on literature" are marked with asterisks and explained under Table 20. The explanations and examples include OFE related aspects and sub requirements. Some requirements cover more than might be expected at first instance; the requirements are not split into more requirements to keep the overview of requirements clear.

Table 20 Final requirements for good usable OFE's and their definition

Requirements for good usable OFE's based on the three studies*	Explanation	Examples of "to avoid situations"
User-friendly	A user-friendly OFE is easy to use, understand and reach, costs low effort to control, works well and provides occupants a high perception of controllability.	-Complicated/unclear -Choice overload -Out of reach -Heavy to control -Obstructed opening (Blinds, sun shading, full windowsill, desks)
Clear design intent	An OFE with clear design intent has a clear purpose: offers personal control to air quality and thermal environment.	-Complicated -Choice overload -Low level of personal control -Along indoor area (hallway/atria) -Miscommunication or unclear rules of use
Effective	An effective OFE has an effective opening area, sufficient to dilute internally generated pollutants, provide fresh air and to make people feel cooler by air movement.	-Small maximum effective opening area (too small OFE or too small opening angle) -Along hallway/atria -Too far away
Supply is fresh air of sufficient quality**	An OFE that provides fresh air and dilutes indoor air pollutants is desired. On locations with (occasionally) highly polluted outdoor air there must be searched for a feasible solution (e.g. signal light about indoor and outdoor air quality or an automatic system which can be overruled (keep distraction in mind by an automatic system).	-A largely opened OFE to the busy road (e.g. in traffic jam) nearby
Fine-tuning capability/ Adjustable	An OFE which is adjustable and has fine-tuning capability offers the option to control the amount, place and direction of the airflow to user's needs. The OFE is fixable in divers levels (to avoid slamming OFE's).	-Draught by open OFE & blowing away of papers (which both cannot be avoided by other way of opening)

		-Only one large, not in divers levels fixable, OFE that turns in occupant zone (hard to control). -Non fixable, slamming
Low noise ingress	An OFE with good acoustical performance reduces noise ingress and can thereby reduce distraction by noise from outside. Acoustical absorption and opening direction are influencing the acoustical performance.	-An OFE with low acoustical performance and high noise levels or distracting noise (e.g. conversations) outside
(Mental) connection with outdoor climate	A (mental) connection with outside, e.g. view, can increase forgiveness to inadequacies and acceptance to thermal variation.	-OFE's causing large thermal variations with low connection to outside
Proximal/ highly controllable by occupants	OFE's that are proximal and highly controllable by occupants are easy to reach and control. Direct access to OFE's increases perceived control, thermal adaptation, forgiveness to inadequacies and satisfaction with the IE. To reduce objections of roommates the one most affected should have most control over the OFE.	-Too far away -"Sharing" OFE with too many occupants
Robust	A robust OFE should offer a high degree of personal control, can be used intuitively, is easy to open and of reliable quality.	-Fragile elements -Separate control elements (that can get lost) -Complex -Out of reach -Choice overload -Difficult to clean and maintain -Incoming rain
Possibility to use windowsill and OFE parallel***	The use of windowsills seems to be highly appreciated, design space to facilitate usable windowsills and OFE's at the same time can prevent obstruction by stuff in windowsills.	-OFE's that turn inwards just above windowsills (will be obstructed when stuff is in the windowsill)
Align company's management & security policy and OFE design****	Opening OFE's will be allowed if the company's management & security policy and OFE design align. If not, it can become forbidden to open the OFE's for security or climate control reasons. This can cause occupants to be frustrated. Moreover, management should be able to align layout with OFE pattern to offer high levels of personal control.	-Large OFE's at ground floor in rooms with valuables and strict policy for climate control -Façade patterns and window type combinations that are hard to align with office layouts

*"Avoid large differences in cultural/ social attitudes of roommates" is taken out in the final requirements for good usable OFE's, it is not related enough to the OFE design.

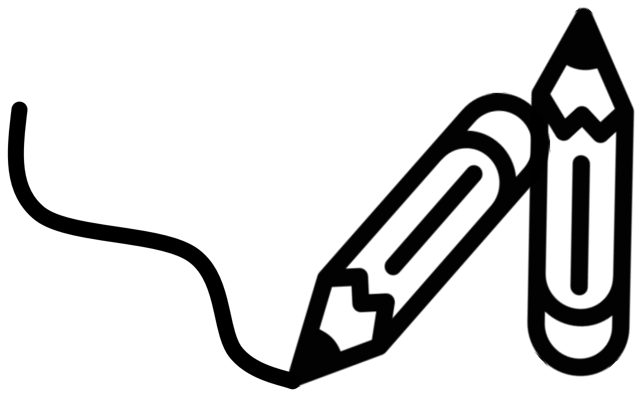
**Car fumes outside are mentioned in the comments of the BBA database as a reason for not always being able to open the window. Bad outdoor air quality makes the OFE ineffective in supplying fresh air. Therefore, "Supply is fresh air of sufficient quality" is included in the requirements.

*****Windowsills** were considered as potentially obstructing the opening of windows after studying the BBA database. The context mapping study turned windowsills in a different perspective, the participants highly appreciate windowsills and the option to use them. The often-used windowsills in offices (with often low space storage) most likely originates from the same preference. Therefore, “Possibility to use windowsill and OFE parallel” is included as a requirement for better usable OFE’s, also responding to avoid obstructions.

****“Match company’s security policy and OFE design” is changed into “Align company’s management & security policy and OFE design”. Because: 1) in the BBA database analyses allowance of opening turned out to be important and the new requirement includes company’s management which can cover this as well. 2) In the context mapping study “Match” was often interpreted differently than intended, therefore “Align” seems clearer.

Objections of roommates seem to be the most important reason for not always being able to open the OFE (Figure 33). The objections of roommates are in some comments of the BBA database related to thermal discomfort (draught, cold, gets warmer if warm outside), distraction (noise, slamming windows, papers blowing away), rules (not allowed, might be not allowed) or believe (not wise to open). Therefore, an OFE with clear design intent, fine-tuning capability, low noise ingress and (mental) connection with outdoor climate might also reduce objections of roommates. That is, it seems likely that roommates will object less if there is no miscommunication or misunderstanding on what is allowed and wise, that they do not perceive thermal discomfort and are not distracted or less distracted. However, to the knowledge of the author, no other research about objections of roommates in relation to OFE’s has been performed.

6. Final OFE design



6 Final OFE design

The final OFE design integrates the requirements for better usable OFE's made within this study. It can help designers visualize how the aspects can be integrated in OFE's designs, it is not meant to be the only option.

6.1 Method

The literature survey, BBA database analysis and focus group have provided information of OFE related aspects. Immersing the information, overviewing the OFE related aspects and requirements and rating existing OFE's (Appendix D OFE's rated with rating list) has led to insights in relations between OFE types and OFE related aspect ratings. Several sketches were made (some are presented in Appendix K Design process – Sketches) during the process. The information and insights were considered in the design process, leading to ideas for the final OFE Design. Additionally, existing OFE's seen during graduation also inspired for designs.

6.2 Result

The final OFE design (Figure 67) integrates the requirements defined within this research. A description of the integration of requirements in the final OFE design is given in Table 21. The technical drawings of the final OFE design can be found in Appendix L Final OFE Design – Technical drawings.

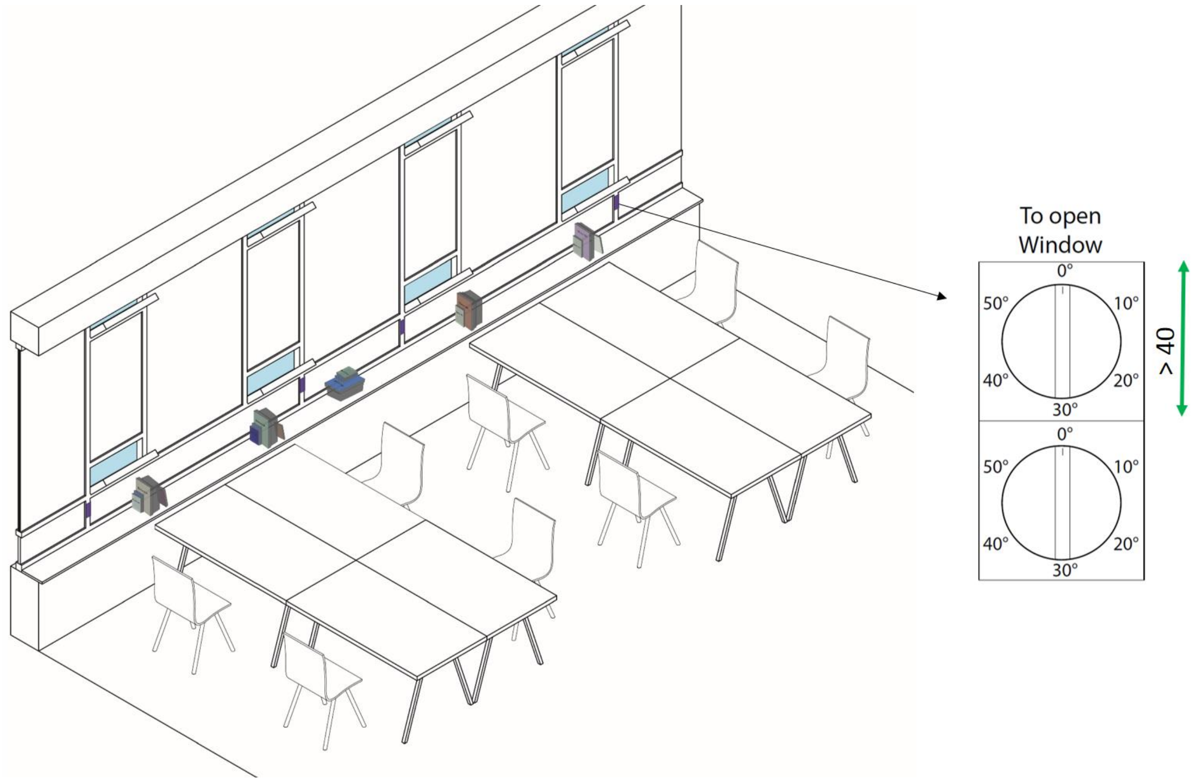


Figure 67 Final OFE design (With fixed electric control as zoom out on the right side)

Table 21 Description of the integration of requirements in the final OFE design

Requirements for good usable OFE's based on the three studies* **	**Integration in final OFE design**	**Compromise/ Remark**
User-friendly	Easy to use and reach control, obstruction of opening by blinds and sun shading are avoided (Figure 71).	Design of the user interface of an electric control can be a study on itself. Based on personal testing and discussions with friends, the rotary switch with degrees of opening and a measure of 40mm is chosen.
Clear design intent	Recognizable bottom hung windows	
Effective	The two OFE's per two workplaces and total amount of OFE's together provide much effective opening area. It is assumed, here, that central exhaust in the hallways occurs (1.4 Focus situation) and thus presence of a driving force. The OFE's opens along an outdoor area.	
Supply is fresh air of sufficient quality	The window opens along an outdoor area of which is assumed that the air quality is sufficient.	On locations with (occasionally) highly polluted outdoor air there must be searched for a feasible solution (e.g. signal light about indoor and outdoor air quality or an automatic system which can be overruled (keep distraction in mind by an automatic system).
Fine-tuning capability/ Adjustable	Supply in and out the occupant zone (indirect and direct). The bottom hung window can control the air speed and amount of air (better than large indoor turning windows). The control is electric which avoids slamming, being out of reach and is stepless controllable.	
Low noise ingress	The bottom hung window reduces more noise than inwards turning, the opening area is not very large.	Additionally, acoustical absorbing materials and external baffles can be used in case of a noisy environment.
(Mental) connection with outdoor climate	Outside view through glass and open window is provided.	
Proximal/ highly controllable by occupants	Façade pattern and layout are aligned to provide a more "personal" window (Figure 68). One most affected has most control (Figure 69) to increase controllability and potentially	

	reduce objections of roommates.	
Robust	Proximal and easy usable and reachable control. The control is fixed to the wall so it will not get lost and the risk on demolishing is reduced.	Designing a robust electric control can be a study on itself. Based on personal testing the measure 40mm is chosen.
Possible to use windowsill and OFE parallel	The windowsill can be in use while the OFE is open (Figure 71).	
Align company's management & security policy and OFE design	The electric control offers the opportunity to automatically close or reduce the opening of the OFE's to a desired level, for example at closing time. This can also avoid fear of forgetting to close the OFE and frustration that opening is not allowed. Also the façade pattern is easy to align with the desks.	

Visual explanation integration of requirements in final OFE design

Illustrated below is the integration of the requirements and sub requirements for good usable OFE's that offer control over indoor air quality and thermal environment.

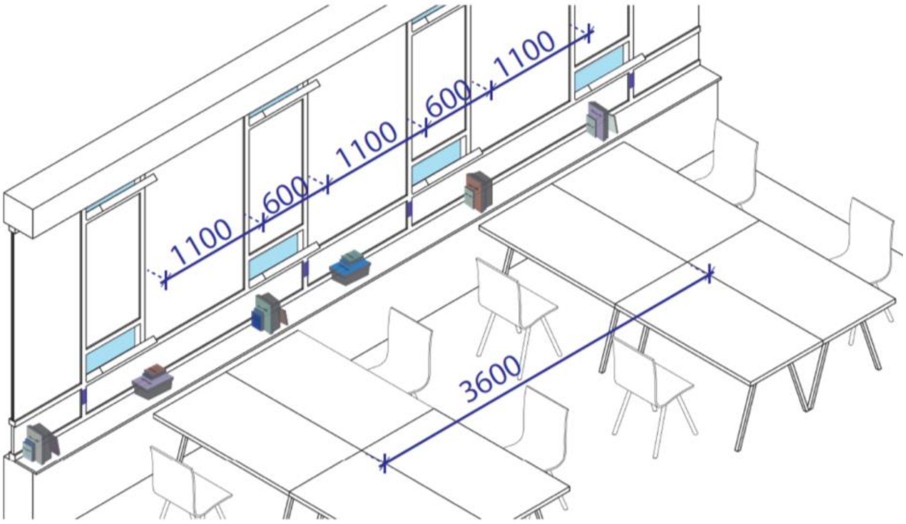


Figure 68 Façade pattern and layout are aligned to provide a more "personal" OFE.

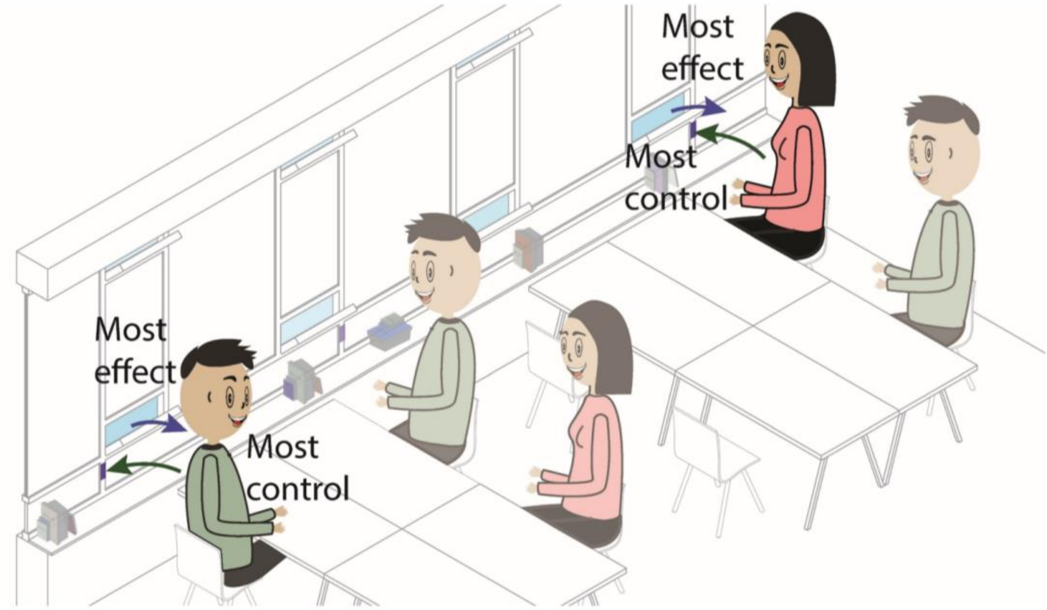


Figure 69 The one most affected by the OFE has most control over it.

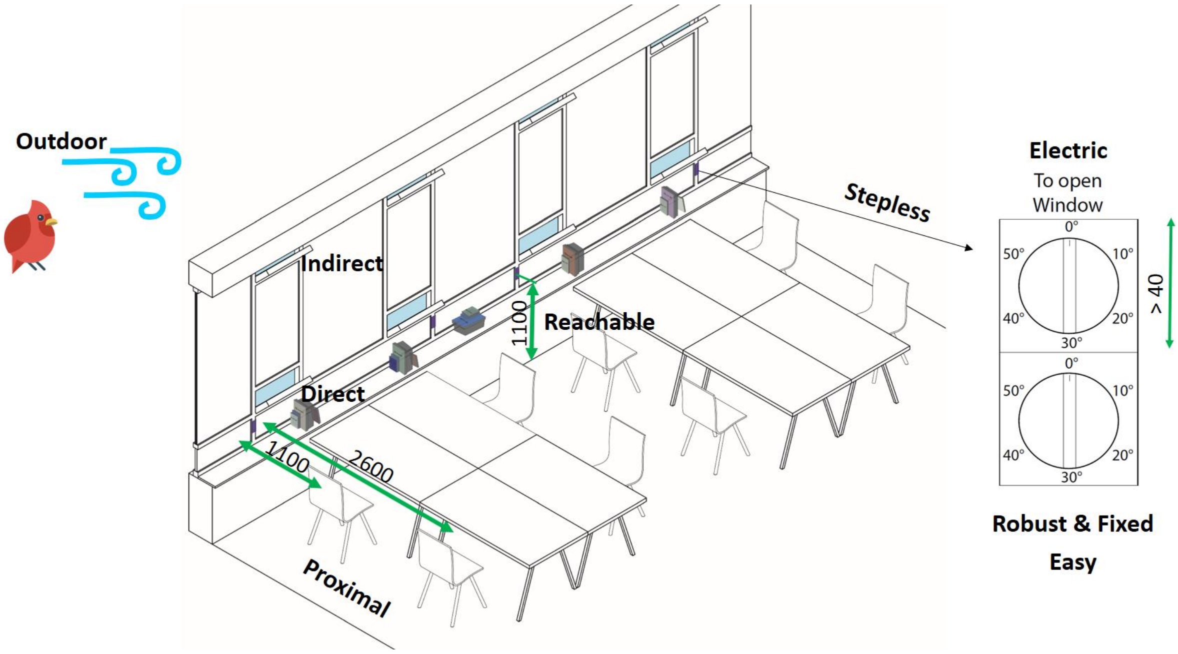


Figure 70 Easy, proximal, reachable and stepless controllable OFE's with direct and indirect supply.

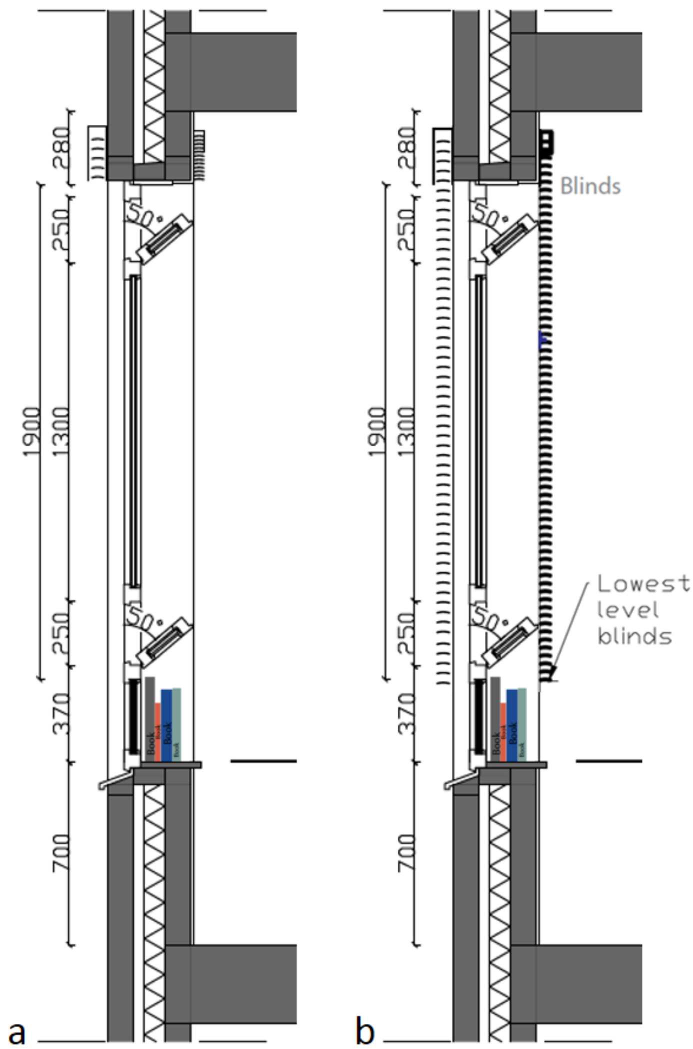


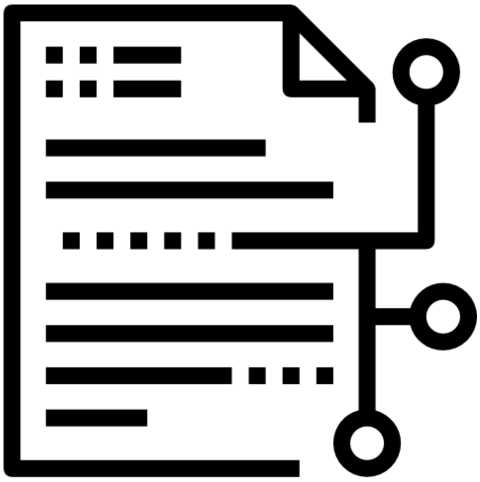
Figure 71 Sections with windowsills in use, sun shading and blinds are: a) up and b) down.

6.3 Discussion and conclusion

An OFE design which meets the requirements defined within this research (Table 20) can look like the final OFE design presented in Figure 67. It can be discussed how far the requirements reach and what they exactly mean in terms of design. The requirements are not exact and therefore some space for interpretation is left. This research especially aims to provide the means to enhance the usability of operable façade element designs, to improve personal control over thermal environment and indoor air quality. This final OFE design aims to help inspire and visualize the requirements and to be of help for the Design Guide. For more exact/precise criteria further research is needed. This research mainly overviews OFE related aspects, attends to prior knowledge about OFE's, helps to avoid making the same mistakes as already made in practice before, and to get more insight in preferences and expectations of OFE's.

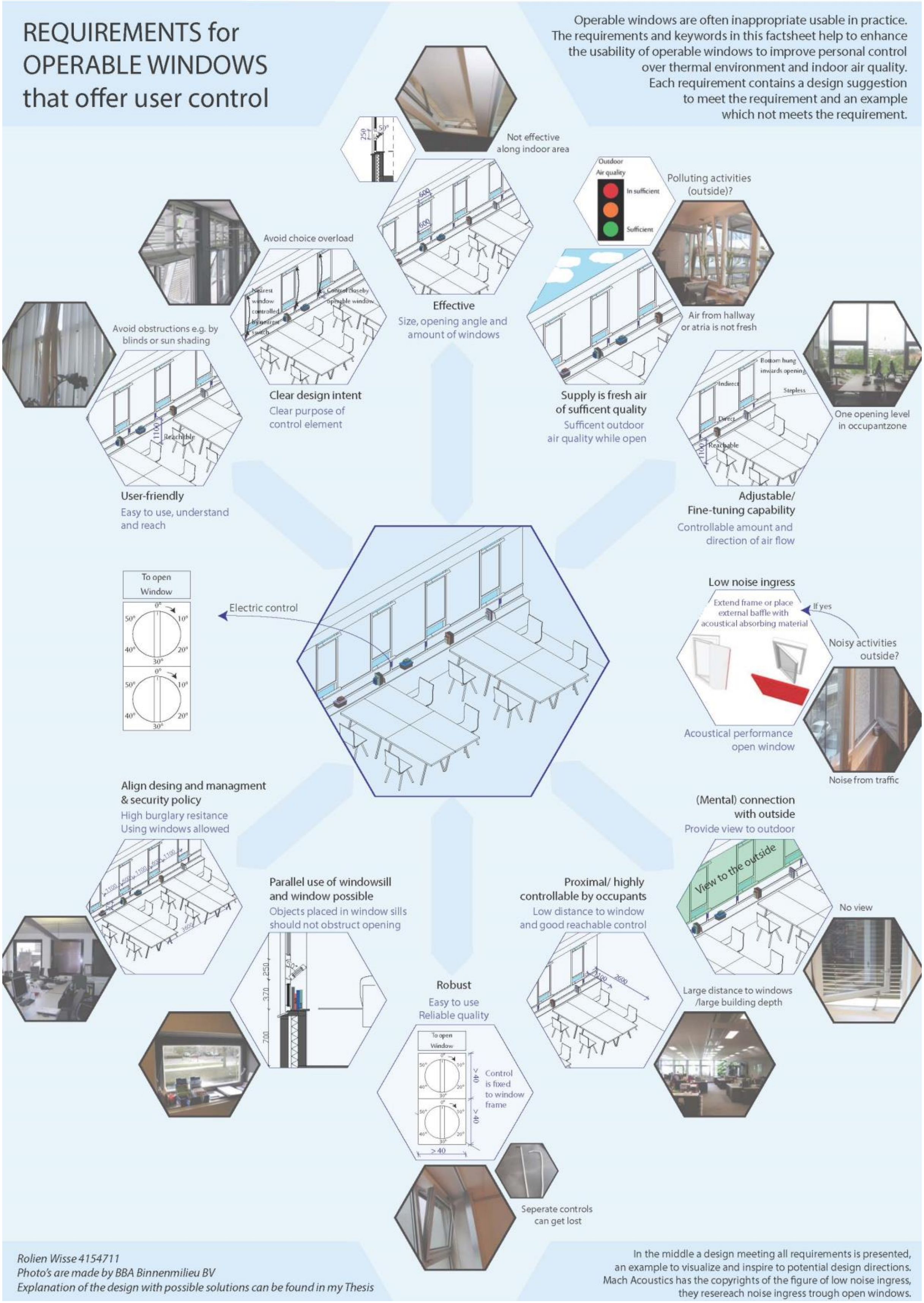
Because of the room for interpretation someone else could have made different compromises and measures for the final OFE design. An optimization study and tests could give input to make this less designer depended. Though, in terms of design freedom, it can be desirable that the requirements are less strict.

7. Factsheet

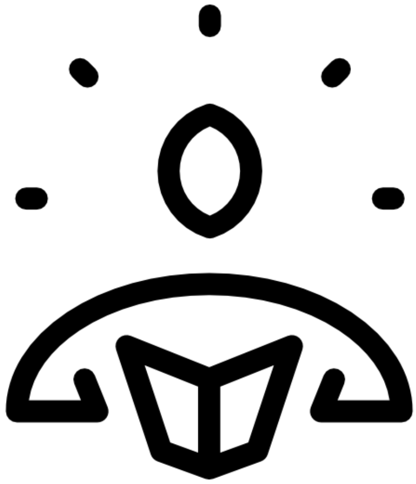


7 Factsheet

The factsheet provides an overview of the requirements for good usable OFE's with short explanations. Appendix M Factsheet in larger size.



8. Design Guide



8 Design Guide

A design guide has been developed for the design of operable façade elements that are appropriate for personal control over thermal environment and indoor air quality (Appendix N Design Guide). It is meant to inspire architects and motivate them to design operable façade elements that are appropriate for personal control over thermal environment and indoor air quality. It contains an introduction to explain the potential benefit of operable windows, followed by eleven requirements with examples meeting the requirements, design suggestions, examples from practice not meeting the requirements and building technical examples for further explanation and improve recognition of the requirements in building technical drawings. Ending with a chapter "Designing by sub-choices", which can guide architects through the design of better usable operable façade elements. It divides the design process in sub-choices and describes requirements which should get extra attention in the certain phase of the design.

8.1 Design Guide Testing

A test among an architect and students of architecture has been performed to discover whether the Design Guide helps designers of office buildings and façades to design better usable operable façade elements.

Figure 72 Elke looking at the Design Guide

8.1.1 Method

The Design Guide was given to them, questions asked where:

1) What is your first impression of this booklet?
2) Do you think it will help to design better usable operable façade elements? Why or why not?
3) Do you have suggestions for improvement?
4) Do you think a Design Guide is the way to reach architects, or would you suggest a different way?

Test panel:

Name	**Architectural company**	**When**	**Job title**
(a) Merlijn Huijbers	MVRDV	(2008-2009)	*Architect*
	Kraaijvanger Urbis	(2005-2008)	*Architect*
(b) Elke Janssens	TAK Architecten	(2015 – today)	*Architectural assistant*
(c) Roel Schiffers	Farrells	(2016)	*Architectural assistant*
	The Cloud Collective	(2014)	*Intern*
(d) Lian Blok	Onix	(2015)	*Intern*

8.1.2 Results

In this section, the answers of the test panel are presented per question.

What is your first impression of this booklet?

a. The size and layout makes it inviting to read.

b. Very compact, that's nice and makes it attractive. Inviting to read. Nice double size pictures with low amount of text.

c. Compact, convenient size, specific and clear because same style of drawing repeats.

d. Clear, maybe a bit childish. The large pictures in the beginning are nice. It helps to get empathy in the situation.

Do you think it will help to design better usable operable façade elements? Why or why not?

a. Yes, it raises awareness and makes people think in a different way. It makes architects think further than deciding if a window should be fixed or operable, it makes them think about the use of the operable window.

b. Yes, it is good for making people more conscious of the importance of fresh air and how you can provide it.

c. I don't know, I wonder if there is time for it in practice. Maybe if good operable windows are available as Revit components they will be used by architects. The information is very specific, I never thought about it. There are so many things to think of, depending on the working method of the Architectural office, in the end somebody just decides.

d. Yes, I think so. I would take the booklet easily with me because of the nice "bag size". Though you need to read it before you understand it. Nice that it provides you of quite some information.

Do you have suggestions for improvement?

a. Several small remarks about layout and text were made including alignment and readability of the text in the design suggestions.

b. One picture is a bit pixelated, that could be improved. A hard cover would make you read the text on the back of the book.

c. It would improve implementation if it would become part of a greater whole such as Neufert.

d. Make the colour transitions softer, leave the repetition of the title away on the second page and write Design Suggestion and Building Technical example under the figure. More white space between text and title. Maybe write the text on the back at the cover. The titles should be shorter.

Do you think a Design Guide is the way to reach architects, or would you suggest a different way?

a. Yes, the size is appropriate for taking a quick look and the pictures make it feasible to get their interest.

b. I like the colours, the overview with the pictures and technical drawings and the smiley's make it directly clear that it is about a good or bad example.

c. It might just end in the waste paper bin if you give it to an architect. Maybe architects would use it if it was part of something like Neufert. But it is very specific and might be not of interest to the Architect.

d. I would like to have the booklet, and the size makes it attractive to take a look at it. Maybe an architect does not find airco interesting enough to read it completely.

Summarized can be said that the size of the booklet is considered good and inviting. Some small layout remarks were made by the test panel and incorporated before the final version, overall it was considered clear in communicating the information.

8.2 Conclusion

According to the test panel the Design Guide will indeed help designers of office buildings and façades to design better usable operable façade elements. It would potentially be of help to make the Guide part of a greater whole or to extend the target group with consultancy companies who advice architects in designing a healthy building.

9. Discussion & Recommendations

9 Discussion & Recommendations

This study is meant to provide the means to design better usable OFE's. It contains a literature survey, database analysis and context mapping study. Most results are directly related to prior knowledge. Some findings seem to relate indirectly to literature. For example, the BBA database analysis shows that objects placed in windowsills can obstruct the opening of OFE's. The context mapping study also showed that using windowsills for objects is preferred. Literature describes that available control, ease of use and proximity influences personal control. Obstructing stuff in windowsills can be seen as a more specified practical example which reduces these aspects described in literature.

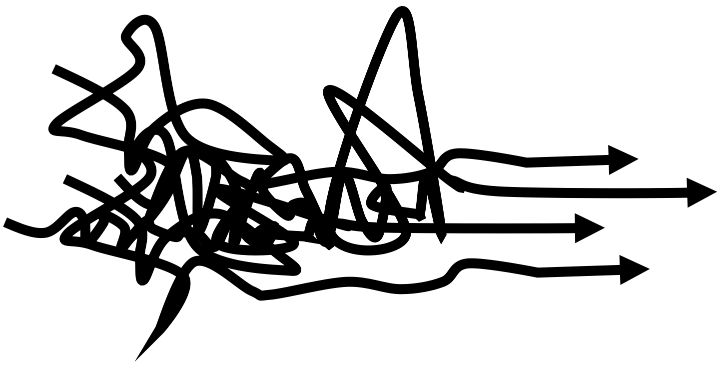
The outcome of the BBA database analysis is that draught, objections of roommates and noise from outside are relatively important in feeling able to open a window when needed. Also, practical examples that do not meet requirements are very useful in getting a better understanding of practise, as well as in visualizing and explaining the requirements in the Design Guide.
The context mapping study contributes to prior knowledge by giving new and more specific insights in some OFE related aspects and deeper reasons for preferences and expectations.

There were limitations by combining the varying result of the 3 research pars. Outcomes varied much and were therefore not directly comparable. The choice was made to describe the relations at the end of each research part, followed by overviewing self-defined explanations and "to avoid situations", that enlarge the meaning of the requirements and increase insight in the consequences of design decisions on usability of the OFE's in practice. Different versions of requirements were made, which points out that this method does not lead to a "one and only outcome". Overall, this research project is considered as a step forward in providing the means to design better usable operable windows. However, optimisation of the defined requirements would be interesting for further research.

It has not been tested, and therefore it is still not known, whether the Final OFE Design is desired by occupants or whether it does provide personal control over air quality and thermal environment. The Design Guide was tested among an architect and architecture students. They think the Design Guide will indeed help to design better usable OFE's. If it indeed leads to better usable OFE's is not tested. A recommendation for further research is to test OFE's that are designed with the help of the Design Guide, followed by an evaluation and upgrade of the booklet.

This study collects many aspects and turns them into means to design better usable OFE's for Dutch office buildings in general. However, the 'ideal window' does not exist due to varying parameters. Suggestions for further sub-studies are researching the relation between 1) objections of roommates and operable window types and situations 2) the acoustical performance of open windows, potentially in collaboration with Nunes (2016) 3) draught and window types. Furthermore, in response to this study is suggested to research how operable windows can provide fresh air of sufficient quality in polluted environments. That, while the control still provides the characteristic direct effect and stays easy to use and understand. Lastly, more information about the relation between operable windows and the effect on climate control systems in terms of energy and deregulation would be interesting. Both, the information would be valuable, as well as having consistent information for office managers and occupants to prevent miscommunication, discussion and misunderstanding.

10. Conclusion



10 Conclusion

OFE’s in Dutch offices are often not appropriately usable for control over thermal environment and indoor air quality in daily practice. Aspects influencing the usability of OFE’s are for example noise ingress, responsiveness to users’ needs and burglary risk.

The developed requirements help designers to design better usable OFE’s that enhance personal control over thermal environment and indoor air quality. The requirements incorporate the OFE’s need to offer high levels of personal control by being proximal, adjustable and effective in providing fresh air of sufficient quality, air movement and influencing temperature. The requirements user-friendly, clear, robust, noise reducing and aligned with the management & security policy, reduce risks on interfering factors. Besides mental connection with outside it increases tolerance with thermal variation which also enhances the usability of OFE’s.

The developed Design Guide explains the relevance of good usable OFE’s and subsequently illustrates and explains the requirements by design suggestions, building technical explanations and good and bad examples. The last section of the booklet “designing by sub-choices” helps to think of the most relevant requirements per sub-phase of the OFE design. The Design Guide helps designers to integrate the requirements in their OFE design which tends to enhance personal control over thermal environment and indoor air quality, and thereby improve occupants’ health, productivity and satisfaction with the working environment.

Reflection

Within this research several products are developed: 11 requirements for better usable OFE's, an OFE design meeting these requirements and a factsheet and Design Guide to help architects in using the information for the design of better usable OFE's in the future.

The process preliminary to these products originates from the interest in operable windows or shutters, which has already been there for years. During an internship at DGMR, in the summer of 2015, Atze Boerstra suggested graduating at BBA Binnenmilieu. Just after that, in September 2015, Stanley Kurvers initiated researching Design Criteria for operable windows because some openable windows are not operable in practice. From there, the rough research design was developed. The graduation project started with a literature survey about office environments, effects of Operable Façade Elements (OFE's), aspects of OFE's and usage of OFE's with a focus on the indoor environmental factors thermal environment and air quality. An analysis of the BBA database provided knowledge why OFE's cannot always be opened adequately in practice. An interesting alternation between theoretical and practical information. Subsequently, a context mapping study was done to avoid a narrow view and overlooking essentials and to communicate directly with users. One of the lessons learned is that qualitative research by using generative sessions can lead to new insights for improvement or the design of new products.

This combination of methods provided a wide overview of theoretical, practical and user-centred knowledge. Due to varying types of information, the results were not directly comparable and difficult to systematically turn into final requirements. In this respect, it is learned that using diverse methods is valuable for a broader interception but combing results merit attention.

Within the study a rating list was made to help architects in their design of better usable OFE's. This turned out to be a complicating approach. Therefore, the factsheet and Design Guide were developed instead. The learning point was the value of more intensive preparation, especially to empathize the target group more deeply in advance.

This broadly intercepted research leaves room for optimization. Tests and evaluation of OFE's designed with the help of the Design Guide, for example the OFE design made in this study, would give more insight if the goal is reached. Though, making a 1:1 element and properly test whether it improves the usability or not was considered not feasible within the resting timespan.

This study identifies a broad spectrum of OFE related aspects and suggests sub-studies which would be interesting for further knowledge in enhancing the usability of OFE's. Means for designing better usable OFE's are provided, despite the difficulties with aggregation of the results and absence of tests in practice.

The developed requirements were the input of the OFE design, which is made to provide an example for inspiration in which design directions can be thought to meet the requirements and design better usable OFE's. The relation between research and design could be called "research for better design". The subject of this research fits within the Sustainable Design graduation studio, because it assists in improving the amount of OFE's designs that are appropriately usable in practice. In addition, in my opinion it is sustainable to offer user control and opportunity to improve air quality to occupants, which generally improves their health and workplace satisfaction while it does not need to cost extra energy, money or material. This affects a wider social context because it even leads to reduced sick leave, more productive occupants and better work.

References

ASHRAE Standard 55 (2004). Thermal Environmental Conditions for Human Occupancy

ASHRAE Standard 55 (2013). Thermal Environmental Conditions for Human Occupancy

Baker, N., & Standeven, M. (1996). Thermal comfort for free-running buildings. Energy and Buildings, 23(3), 175-182.

Bangalee, M. Z. I., Miau, J. J., Lin, S. Y., & Ferdows, M. (2014). Effects of Lateral Window Position and Wind Direction on Wind-Driven Natural Cross Ventilation of a Building: A Computational Approach. *Journal of Computational Engineering*, *2014*.

Bluyssen, P.M. (2009) The indoor environment handbook: how to make buildings healthy and comfortable, London: Earthscan.

Bluyssen, P.M. (2014) The Healthy Indoor environment: how to assess occupants´ wellbeing in buildings, London: Earthscan.

Bluyssen, P.M. (2015) All you need to know about the indoor air. Delft Academic Press VSSD.

Boerstra, A. C. (2016) Personal control over indoor climate in offices: impact on comfort, health and productivity. Technische Universiteit Eindhoven, 2016.

Boerstra, A. C., Raue, A. K. (2002). B. I. E. Feelgoodbuilding: IEQ dissemination reinvented. In Proceeding Indoor Air 2002

Boerstra, A., Beuker, T., Loomans, M., & Hensen, J. (2013). Impact of available and perceived control on comfort and health in European offices. Architectural Science Review, 56(1), 30-41.

Boerstra, A., Loomans, M., & Hensen, J. (2016) Effectiveness of operable windows in office environments. In Proceedings of 9th Windsor Conference

Bordass, B., Leaman, A. (1997). From feedback to strategy. Buildings in Use '97: how buildings really work, Londen.

Bordass, B., Leaman, A., & Ruyssevelt, P. (2001). Assessing building performance in use 5: conclusions and implications. Building Research & Information, 29(2), 144-157.

Borgeson, Sam; & Brager, Gail. (2008). Occupant Control of Windows: Accounting for Human Behavior in Building Simulation. UC Berkeley: Center for the Built Environment. Accessed on June 14, 2016. Retrieved from http://eprints.cdlib.org/uc/item/5gx2n1zz

Brager, G., Paliaga, G., & De Dear, R. (2004). Operable windows, personal control and occupant comfort. Center for the Built Environment.

BREEAM (2016) Hea 7 - Natuurlijke ventilatie. Accessed on May 18, 2016. Retrieved from https://www.breeam.nl/hulp/nieuwbouw/Gezondheid/17330/Hea%207%20-%20Natuurlijke%20ventilatie

Cabanac, M. (2000). Pleasure and joy, and their role in human life. Creating the Productive Workplace, 40-50.

Clements-Croome, D.J. (2000) Indoor environment and productivity. Creating the Productive Workplace, 3-15

Cox, C. (ed.) (2005) Health optimisation protocol for energy-efficient buildings, final report, 25 february, 2005, TNO, Delft, The Netherlands. Retrieved from: http://hope.epfl.ch/results/results-intro.htm

De Koning, J. (2012) Sensitizing Booklet. Accessed on October 18, 2016. Retrieved from https://cogreencreation.wordpress.com/2012/09/10/workshop-preview/

Deuble, M. P., & De Dear, R. J. (2012). Green occupants for green buildings: the missing link? Building and Environment, 56, 21-27.

IDEO, I. (2003). IDEO Method Cards: 51 ways to inspire design. *Palo Alto*. Accessed on October 10, 2016. Retrieved from https://www.ideo.com/eu/post/method-cards. Download: http://passthrough.fw-notify.net/download/753900/http://portiaplante.com/android2/lectures/pdf/ideomethodcards.pdf

Kim, J., & de Dear, R. (2012). Impact of different building ventilation modes on occupant expectations of the main IEQ factors. *Building and Environment*, *57*, 184-193.

Kistemarker, S. (2010). Contextmapping, the basics!. Rich Insights, 8-9.

Kurvers, S. R., Raue, A. K., Van den Ham, E. R., Leijten, J. L., & Juricic, S. M. M. (2013). Robust Climate Design Combines Energy Efficiency with Occupant Health and Comfort. In ASHRAE IAQ 2013 Proceedings: Environmental Health in Low Energy Buildings, Vancouver, Canada, 15-18 October 2013. ASHRAE.
Haldi, F., & Robinson, D. (2008). On the behaviour and adaptation of office occupants. Building and environment, 43(12), 2163-2177.
Heiselberg, P., Dam, H., Sørensen, L. C., Nielsen, P. V., & Svidt, K. (1999). Characteristics of Air Flow through Windows. Aalborg: Dept. of Building Technology and Structural Engineering, Aalborg University. (Indoor Environmental Engineering; No. 103, Vol. R9940).
Heiselberg, P., Svidt, K., & Nielsen, P. V. (2001). Characteristics of airflow from open windows. Building and Environment, 36(7), 859-869.
Hellwig, R. T. (2015). Perceived control in indoor environments: a conceptual approach. Building Research & Information, 43(3), 302-315.
Herkel, S., Knapp, U., & Pfafferott, J. (2006). Towards a model of user behaviour regarding the manual control of windows in office buildings. Building and environment, 43(4), 588-600.
Huizenga, C., Abbaszadeh, S., Zagreus, L., & Arens, E. A. (2006). Air quality and thermal comfort in office buildings: results of a large indoor environmental quality survey. Proceeding of Healthy Buildings 2006,
Humphreys, M. (1978). Outdoor temperatures and comfort indoors. *Batiment International, Building Research and Practice*, *6*(2), 92-92.
Jantunen, J., & Saarinen, K. (2009). Intrusion of airborne pollen through open windows and doors. *Aerobiologia*, *25*(3), 193-201.
Karava, P., Stathopoulos, T., & Athienitis, A. K. (2011). Airflow assessment in cross-ventilated buildings with operable façade elements. *Building and Environment*, *46*(1), 266-279.
Knaack, U., Klein, T., Bilow M., Auer, T. (2011) Gevels – principes van het construeren, Amsterdam, Uitgeverij SUN.
Krueger, R.A. (2002) Designing and conducting focus group interviews. Accessed on January 10, 2017. Retrieved from: http://www.eiu.edu/ihec/Krueger-FocusGroupInterviews.pdf
Leaman, A. and Bordass, B. (2000). Productivity in building the 'killer' variables. Creating the Productive Workplace, 167-189.
Levins, R., & Lewontin, R. C. (1985). *The dialectical biologist*. Harvard University Press.
Luke (2012) Contextmapping, design research, How. Accessed on December 22, 2016. Retrieved from http://contextmapping.nl/how-does-contextmapping-work/
MACH Products (n.d.). Key Features. Accessed on August 15, 2016. Retrieved from http://www.machproducts.co.uk/
MACH acoustics (19-07-2016) Sustainable acoustics (updated). Accessed on July 28, 2016. Retrieved from https://www.youtube.com/watch?v=FlmSNR05Oq0
Mangone, G. (2015). Performative Microforests: Investigating the potential benefits of integrating spatial vegetation environments into buildings, in regards to the performance of buildings, their occupants+ local ecosystems (Doctoral dissertation, TU Delft, Delft University of Technology).
Nicol, J. F., & Humphreys, M. A. (2002). Adaptive thermal comfort and sustainable thermal standards for buildings. *Energy and buildings*, *34*(6), 563-572.
Nicol, F., Humphreys, M., & Roaf, S. (2012). *Adaptive thermal comfort: principles and practice*. Routledge.
Nunes, Zé (05-2016). How to design sustainable buildings on noisy sites. MACH Acoustics. Accessed on July 27, 2016. Retrieved from https://www.linkedin.com/pulse/how-design-sustainable-buildings-noisy-sites-ze-nunes?trk=pulse-det-nav_art
NEN 1087, 2001, Ventilatie van gebouwen Bepalingsmethode voor nieuwbouw, Nederlandse norm, ICS 91.140.30
Ortiz, M. A. (2014) Welcoming insects at the table: designing a new experience of eating insects. Accessed on March 8, 2017. Retrieved from: uuid:3a1e446e-17d1-4efe-86f0-3508ab5fe410

Paciuk, M. (1989). The role of personal control of the environment in thermal comfort and satisfaction at the workplace (Doctoral dissertation, University of Wisconsin-Milwaukee).
Paliaga, G. (2009). Moving air for comfort. ASHRAE journal, 51(5), 18.
Pejtersen, J. H., Feveile, H., Christensen, K. B., & Burr, H. (2011). Sickness absence associated with shared and open-plan offices—a national cross sectional questionnaire survey. Scandinavian journal of work, environment & health, 376-382.
Raja, I. A., Nicol, J. F., McCartney, K. J., & Humphreys, M. A. (2001). Thermal comfort: use of controls in naturally ventilated buildings. Energy and Buildings,33(3), 235-244.
Rijal, H. B., Tuohy, P., Humphreys, M. A., Nicol, J. F., Samuel, A., & Clarke, J. (2007). Using results from field surveys to predict the effect of open windows on thermal comfort and energy use in buildings. *Energy and buildings*, *39*(7), 823-836.
Roetzel, A., Tsangrassoulis, A., Dietrich, U., & Busching, S. (2010). A review of occupant control on natural ventilation. Renewable and Sustainable Energy Reviews, 14(3), 1001-1013.
Sakellaris, I. A., Saraga, D. E., Mandin, C., Roda, C., Fossati, S., de Kluizenaar, Y., ... & Hänninen, O. (2016). Perceived Indoor Environment and Occupants’ Comfort in European “Modern” Office Buildings: The OFFICAIR Study. International journal of environmental research and public health, 13(5), 444
The House Designers (2014) Cross-Ventilation. Accessed on August 6, 2016. Retrieved from https://www.thehousedesigners.com/blog/4-ways-cool-home/
Van Heek Textiles (2008). “Poll-Tex”. Retrieved from: http://www.vanheektextiles.nl/nl/poll-tex.html
Vianna, M., Vianna, Y., Adler, I., Lucena, B., & Russo, B. (2012) Design thinking business innovation, MJV press, Brazil. Retrieved from: http://www.designthinkingbook.com/#baixar
Vischer, J.C. (1989). Environmental quality in offices. New York: Van Nostrand Reinhold
Visser, F. S., Stappers, P. J., Van der Lugt, R., & Sanders, E. B. (2005). Contextmapping: experiences from practice. CoDesign, 1(2), 119-149.
Yildirim, K., Akalin-Baskaya, A., & Celebi, M. (2007). The effects of window proximity, partition height, and gender on perceptions of open-plan offices. Journal of Environmental Psychology, 27(2), 154-165.
Waters-Fuller, T. Lurcock, D. (2007). “NANR116: Open Closed Window Research”. Napier University, School of the Built Environment. Accessed on July 28, 2016. Retrieved from http://researchrepository.napier.ac.uk/4780/1/NO01076_8134_FRP.pdf
Yun, G. Y., Steemers, K., & Baker, N. (2008a). Natural ventilation in practice: linking facade design, thermal performance, occupant perception and control. Building Research & Information, 36(6), 608-624.
Yun, G. Y., & Steemers, K. (2008b). Time-dependent occupant behaviour models of window control in summer. *Building and Environment*, *43*(9), 1471-1482.

APPENDICES

The appendices, which are described underneath, are saved in separate documents on the repository. These are named 4154711 Appendices A-L, 4154711 Poster Factsheet and 4154711 (Poster) Design Guide. This separation in files is made to keep the documents comfortable readable.

Appendix A BBA Database - Answers open questions

Appendix B BBA Database – Pie & Radar charts

Appendix C BBA Database – Tables percentages per answer category

Appendix D OFE's rated with rating list

Appendix E Context mapping - Sensitizing booklets

Appendix F Context mapping – Collages

Appendix G Context mapping – Top six of variants – Comments

Appendix H Context mapping – Priority of aspects – Comments

Appendix I Context mapping – Priority of aspects – Results

Appendix J Design process – Variants analysis

Appendix K Design process – Sketches

Appendix L Final OFE Design – Technical drawings

Appendix M Factsheet

Appendix N Design Guide