Windows and blinds selection for enhancing subjective well-being

Licentiate thesis

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WINDOWS AND BLINDS SELECTION FOR ENHANCING SUBJECTIVE WELLBEING
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Abstract

Earlier studies in the context of windows and blinds selection have mostly tried to increase the awareness regarding various effects of windows and blinds selection on subjective well-being, including their effect on visual comfort, thermal comfort, energy consumption and life cycle cost. However, the main problem is the potential conflicts between visual comfort, thermal comfort, energy consumption and life cycle cost. Increased awareness about the contradictory effect of windows and blinds selection on subjective well-being on one hand and lack of a feasible method in managing the conflicts on the other hand may bind individuals, as decision-makers, in a situation where they follow the immediate economic benefits rather than the long-term visual and thermal benefits.

To solve the mentioned problem, this study analysed first the degree of the conflicts between average daylight illuminance and total energy consumption in Sweden. This decision was made due to large variation in solar elevation angle and solar intensity between summer and winter in Sweden, which has significant effects on daylight illuminance and total energy consumption. Analysing the conflicts was accomplished by developing two multivariate linear regression models for calculating average daylight illuminance and total energy consumption. Comparison and analysis of the multivariate linear regression models showed the existence of a high degree of conflicts, which makes window and blind selection a rather complex multidimensional problem.

Specifying the degree of the conflicts formed a hypothesis as: “A multi criteria decision-making method increases the controllability and manages the conflicts in selecting windows and blinds”. The developed hypothesis was later tested by employing analytical hierarchy process, as widely used multi criteria decision-making method. The analytical hierarchy process prioritizes decision-maker’ preferences and introduces a desired trade-off solution. The results of employing analytical hierarchy process showed the capability of it in managing the conflicts among visual comfort, thermal comfort, energy consumption and life cycle cost. Finally, the application of the analytical hierarchy process was expanded by integrating it with nondominated sorting genetic algorithm-II, as an optimization algorithm. Through this integration, optimization algorithm combines windows’ and blinds’ design variables and analyses a large number of solutions, while analytical hierarchy process ranks the solutions based on decision-makers’ preferences and introduces a desired trade-off solution. The integration between analytical hierarchy process and the nondominated sorting genetic algorithm-II was presented later as a conceptual framework. The developed conceptual framework can be used for selecting windows and blinds in both residential and commercial buildings. In selecting windows and blinds, the conceptual framework is a novel solution to the lack of a feasible method for increasing the controllability for decision-makers and obtaining a desired trade-off solution.

Keywords: Subjective well-being, Perceived control, Controllability, Analytical hierarchy process, Nondominated sorting genetic algorithm-II

Sammanfattning

Tidigare studier avseende val av fönster och solskydd har främst försökt fastställa olika effekter som valet av fönster och solskydd har på det subjektiva välbefinnandet. Detta inkluderar dessa föremåls effekt på den visuella komforten, den termiska komforten, energiförbrukningen och livscykelkostnaderna. Det huvudsakliga problemet är dock de potentiella konflikterna mellan visuell komfort, termisk komfort, energiförbrukning och livscykelkostnader. Avsaknaden av en metod för att hantera denna konflikt leder till att beslutfattaren fastnar i en situation där de snarare gör sitt val utifrån omedelbara ekonomiska fördelar än de långsiktiga visuella och termiska fördelarna.

För att lösa ovan nämnda problem analyserades konflikterna mellan det genomsnittliga dagsljusinsläppet och den totala energiförbrukningen i Sverige. En av huvudanledningarna till konflikterna är att solens infallsvinkel och intensitet varierar kraftigt mellan sommar och vinter i Sverige. Detta har betydande effekter på dagsljusinfallet och den totala energiförbrukningen. Konflikterna analyserades genom att utveckla två multivariata linjära regressionsmodeller för att beräkna det genomsnittliga dagsljusinfallet och den totala energiförbrukningen. En jämförelse och analys av de multivariata linjära regressionsmodellerna påvisade en hög grad av konflikter, vilket gör valet av fönster och solskydd till ett komplext och flerdimensionellt problem.

Bestämningen av graden av konflikt formade följande hypotes: ” En multikriterieanalysbaserat beslutsstöd ökar kontrollerbarheten och hanterar konflikter vid valet av fönster och solskydd”. Den utvecklade hypotesen testades senare med hjälp av Analytical Hierarchy Process (AHP), en ofta använd multikriterieanalys metod för beslutsfattande. Metoden tar fram lösningar genom att göra prioriteringar enligt beslutsfattarens preferenser. Resultaten av att tillämpa metoden visade metodens förmåga att lösa konflikterna kring visuell komfort, termisk komfort, energiförbrukning och livscykelkostnad. Slutligen utökades metoden genom att integrera AHP med optimeringsalgoritmen Non-dominated sorting genetic algorithm-II. Genom denna integrering kombinerar optimeringsalgoritmen fönstrens och solskyddens design variabler till ett stort antal lösningsförslag. Dessa lösningsförslag analyseras och till sist rangordnas lösningsförslagen med hjälp av AHP baserat på beslutsfattarnas preferenser. Integreringen av AHP och optimeringsalgoritmen presenterades som ett konceptuellt ramverk. I valet av fönster och solskydd är det konceptuella ramverket en ny lösning för att öka den upplevda kontrollen och därmed förstärka det subjektiva välbefinnandet.

Nyckelord: subjektiva välbefinnande, upplevd kontroll, kontrolbarhet, Analytical hierarchy process, Nondominated sorting genetic algorithm-II

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Elaheh Jalilzadehazhari
Växjö, 3th May 2017

Appended papers and authors’ contribution

Paper I

Jalilzadehazhari, E. and Mahapatra, K. (2016). Multivariate linear regression model for estimating average daylight illuminance. International Conference on Architecture and Built Environment – ICABE2016. October 5–6, 2016, Kuala Lampur, Malaysia.
Accepted for publication in Advanced Science Letters Journal (Peer-reviewed paper and Presented in conference).

Contribution to paper I: First author carried out literature study, performed the simulations and analyses. The co-author provided comments and checked the quality of the paper. First author was the corresponding author and presented the paper in the conference.

Paper II

Jalilzadehazhari, E. and Mahapatra, K. (2016). Multivariate linear regression model for estimating energy consumption. 3rd Asia conference on International Building Performance Simulation Association - ASim2016. November 27-29, 2016, Jeju (Cheju), South Korea. (Peer- reviewed paper and Presented in conference).

Contribution to paper II: First author carried out literature study, performed the simulations and analyses. The co-author provided comments and checked the quality of the paper. First author was the corresponding author and presented the paper in the conference.

Paper III

Jalilzadehazhari, E., Johansson, P., Johansson, J. and Mahapatra, K. (2017). Application of analytical hierarchy process for selecting an interior window blind. Accepted for the publication in Architectural engineering and design management journal

Contribution to paper III: First author carried out literature study, performed the simulations and analyses. The co-authors provided comments and checked the quality of the paper. First author was the corresponding author in submitted paper.

Paper IV

Jalilzadehazhari, E., Mahapatra, K. and Johansson, P. (2017). A conceptual framework for enhancing subjective well- being in selecting windows and blinds. Submitted in Architectural engineering and design management journal

Contribution to paper IV: First author carried out literature studies and performed analyses. The co-authors provided comments and checked the quality of the paper. First author is the corresponding author.

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List of abbreviations

SWB	Subjective well-being
AHP	Analytical hierarchy process
HVAC	Heating, ventilation and air conditioning
WWR	Window wall ratio
DGI	Daylight glare index
DA	Daylight autonomy
DGP	Discomfort glare probability
PPD	Predicted percentage dissatisfaction
CR	Consistency ratio
DP	Double pleated
VB	Venetian blind
R	Roller blind
NSGA-II	Non-dominated sorting genetic algorithm-II
MSE	Mean square error
Std.Err	Standard error
IGU	Insulating glass unit

Used simulation tools and programmes

	Papers	Motivation
COMFEN	I and II	CONFEN has a simplified user interface and provides possibilities to simulate and analyse of energy performance, comfort conditions and cost for multiple window and blind models.
STATA	I and II	STATA programme is used for performing statistical analyses. This programme provides a possibility of developing a multivariate linear regression model by considering factor variables.
Rhino and Diva for Rhino	III	Rhino and Diva for Rhino plugin enables to accomplish a series of advanced visual comfort evaluations
IDA ICE	III	IDA ICE is a simulation tool for analysing energy performance and thermal condition of a building. This simulation tool includes various of heating, cooling and ventilation systems which are commonly used in Sweden. Hence, it requires relatively less effort in determining and modelling various heating, cooling and ventilation systems. However, IDA ICE is not capable of performing advance visual evaluations.
MakeitRational	III	MakeitRational was specified as an eligible programme which provides an opportunity of using analytical hierarchy process
EnergyPlus	IV	EnergyPlus enables to calculate various metrics for evaluating visual comfort, thermal comfort, energy consumption and life cycle cost simultaneously. Furthermore, it can be integrated with other tools, including modeFrontier for performing optimization and further decision-making analyses.
moreFrontier	IV	modeFrontier allows to use an extensive number of optimization algorithms and is capable of performing decision-making analyses using analytical hierarchy process.

1 Introduction

Window manufacturing in Sweden has been greatly evolved during last centuries. In *18th* and *19th* centuries wood-frame windows were designed and produced in the form of single and double-pane outward openings (Antell et al., 1988). In designing these windows carpenters and architects put their own character and were heavily involved in the aesthetical aspects of the window manufacturing. However, these windows were limited in size and form due to large inherent weight of heartwood used in windows' frame (Antell et al., 1988). Later, in 1945 the window manufacturing in Sweden became more industrialized and lead to a uniformity in window design. Along with these modifications in appearance of the windows, the oil crisis in 1973 obliged Swedish government to issue strict regulations considering energy performance of windows (Bülow-Hübe, 2007). According to these regulations, which was known as SBN 75, windows with maximum 15% of wall area and u-value of 2 (W/m^2. K) were required. Confining the u-value of windows reduced the total heat loss through the transmission and decreased the total heat demand. Accordingly, the dependency on foreign oil was decreased. Changes in energy regulations and u-value of the windows were a strong case for developing triple-pane sash windows. These windows consist of three individual sashes, holding three separate glass sheets. Parallel with these developments, windows with sealed insulating glass unit (IGU) were invented (Bülow-Hübe, 2007). IGU was developed by sealing two glass sheets, separated by a dry air space. Later, the structure of traditional wood-frame windows was modified as the inner sash was capable of maintaining IGU (Bülow-Hübe, 2007).

Further changes in energy regulations in 1988, known as NR1 BFS 1988:18, had laid down requirements on whole building performance rather than buildings' envelopes (National board of housing building and planning, 1988). This means that windows with larger u-value than 2 (W/m^2. K) could be used in building if the average u-value of all envelopes did not exceed an admissible value. The BFS regulations were modified a several times. The current BFS

2015:3[1], which is applicable at the time of conducting this study (2017), not only demands to calculate the average u-value but also obliges architects, designers and building engineers to consider the interior comfort (National board of housing building and planning, 2015)

Rassia et al. (2012) discussed that architectural design, especially decisions regarding selection of windows and blinds, are relevant not only to improve energy performance or comfort condition, but a successful architectural decision should contribute to the enhanced well-being. This statement necessitates clarifying the available theory-based formulations of the well-being which can be relevant and applicable in selecting windows and blinds.

1.1 Well-being

Traditionally, well-being has been studied within two overlapping, yet distinct traditions: the Eudaimonic tradition, which relies on realisation of human potential and tries to realise the true nature of a human (Ryan et al., 2001), and the Hedonistic tradition, which concentrates on human pleasure and happiness (Ryan et al., 2001). However, the most contemporary approach in studying well-being is Subjective Well-Being (SWB), discussed by Diener (1984). SWB comprises two main components, including *core affect* and *satisfaction* (Cummins, 2010; Kryza-Lacombe, 2016). Core affect refers to generation of pleasant and unpleasant feelings (Russell, 2003) and satisfaction refers to ability of individuals to perform cognitive interpratation, including memorising, concentrating, reasoning, planning and solving tasks[2] (Zhang et al., 2016). Figure 1 shows two main beforementioned components of SWB.

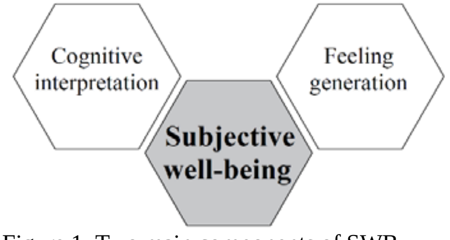

Figure 1. Two main components of SWB

[1] BFS 2016:12 is available. However, it provides only new revision considering energy performance.
[2] Studies by Diener (1984) and Diener et al. (1999) considered pleasant and unpleasant feelings as two separate components. Accordingly, Diener (1984) proposed three main components for SWB including pleasant feelings, unpleasant feelings and cognitive interpretations. However, Cummins (2010) concurred with Russell (2003) that pleasant and unpleasant feelings are both emotional reactions. For this reason, studies which follow Cummins' theory in SWB consider two main components, including affective integration or core affect and cognitive interpretation.

Earlier studies have mostly evaluated SWB within two main themes, including *maintaining SWB* and *enhancing SWB*. Maintaining SWB has been mostly explored using Diener (1984)'s and Cummins (2010)'s theories. According to Diener (1984), when an event takes place, life domain factors such as health, economy, personality, demographic[3] and behaviour[4] variables affect individuals' cognitive interpretation of the event and generation of feelings about the event [5],[6]. If the event is interpreted as negative, then individuals exploit homeostasis (Cummins, 2010) and coping systems (Diener, 1984) to maintain SWB respectively (Figure 2). Homeostasis is a neuroendocrine system which tries to maintain the SWB by providing a stable condition in the body[7] (Boyle, 2013), while coping is defined as an individual's effort to manage the encountered negative events (Mitrousi et al., 2013). The coping system depends on personal and social resources (Zeidner et al., 1996). Personal resources refer to individual abilities in facing a negative event, including self-efficacy and optimism[8] (Zeidner et al., 1996) and are affected by individuals' health (Reinhardt et al., 2009). Social resources comprise perceived emotional support from family and friends (Zeidner et al., 1996). In either case, if the homeostasis and coping systems are unsuccessful in managing the negative event, SWB will be diminished. Diminished SWB refers to a situation where individuals experience dysfunctions (Boyle, 2013) and depression (Cummins, 2010)[9].

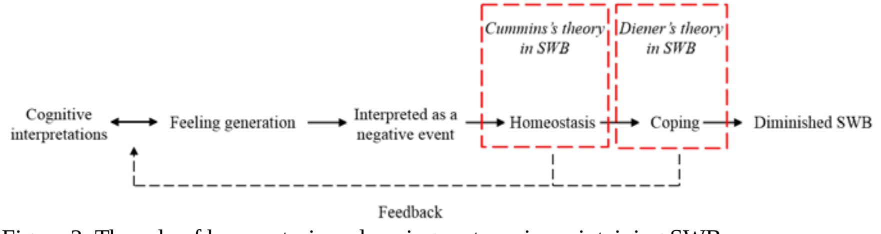

Figure 2. The role of homeostasis and coping systems in maintaining SWB

[3] Demographic variables include age, gender, race, employment, education and marriage (Diener, 1984).
[4] Behaviour variables include social contact and physical activities (Diener, 1984).
[5] However, among the life domain factors, health and economy show stronger and more positive correlations with SWB (Diener, 1984). This correlation remains even when other life domain factors are controlled (Diener, 1984). Altogether, improved health and better economy can contribute to generation of pleasant feelings and higher ability to perform cognitive interpretation that prevents the appraisal of an event as negative.
[6] Multiple theories, including activity theories, judgment theories and assimilationistic theories have been discussed considering the way life domain factors affect cognitive interpretations and generation of feelings (Diener, 1984). However, exploring these correlations is beyond the aim of this study.
[7] Extra and detailed information regarding the homeostasis system can be found in *Anatomy and Physiology* (Patton et al., 2015) Chapter 2.
[8] In general, individuals with higher levels of self-efficacy and optimism tend to face a negative event in an active style and try to resolve the situation (Zeidner et al., 1996).
[9] Further details about how individuals exploit homeostasis and coping systems in maintaining SWB can be found in appendix 1.

However, the proposed theories by Cummins and Diener provide little understanding about how SWB can be enhanced. At this point, Fishman (2014) and Reich et al. (2016) have discussed that enhanced SWB is associated with a higher level of perceived control. Perceived control is defined as the belief that individuals are capable of influencing encountered events to bring about their desired outcomes (Fishman, 2014; Reich et al., 2016). A higher level of perceived control can improve individuals' ability to perform cognitive interpretations and generates pleasant feelings (Fishman, 2014). According to Fishman (2014), perceived control has two main principles: individuals' internal locus of control, and their awareness regarding outcomes of their own behaviour. A stronger internal locus indicates that individuals consider themselves responsible for the outcomes of their behaviour (Fishman, 2014). Awareness refers to a situation where individuals understand the consequences of their behaviour (Fishman, 2014). Increased awareness obliges individuals to concentrate mostly on the outputs of their behaviour, later they try to find out how an event can be controlled to bring about their desired outcomes (Fishman, 2014). This last statement highlights the importance of increasing individuals' awareness regarding the consequences of their behaviour (adopted in facing an event) and increasing controllability for achieving their desired outcomes, which can enhance SWB. Figure 3 summarises and illustarates two main themes in evaluating SWB, maintaining SWB (dark green diamond in figure 3) and enhancing SWB (dark blue diamond in figure 3). Furthermore, figure 3 shows Diener's and Cummins' theories regarding mainitaining SWB (light green diamonds) and Fishman's concept in enhancing SWB (upper light blue diamond). In addition, figure 3 domenstrates increased awareness and control (ligh blue diamond below) as one of the main principles of the perceived control.

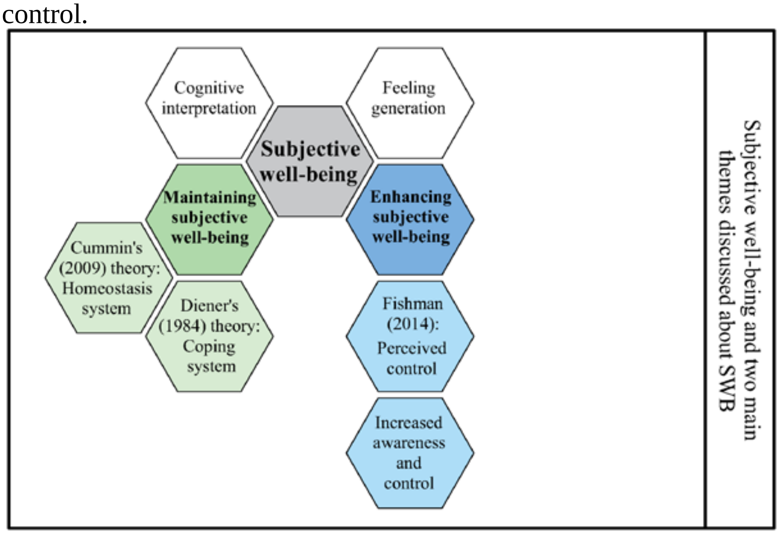

Figure 3. Maintaining and enhancing SWB

1.2 Windows and SWB studies

Existing studies in the context of window selection have mostly tried to increase perceived control first by increasing awareness regarding outputs of windows selection. These studies concentrate mainly on daylight penetration and provided insight regarding the benefits of daylight in generating pleasant feelings and improving individuals' ability to perform cognitive interpretations (Krieger et al., 2002). Furthermore, existing studies have tried to control window selection in such way that individuals gain the highest benefits from providing daylight (Mangkuto et al., 2016; Ochoa et al., 2012).

1.2.1 Daylight and SWB

Providing daylight can contribute to the generation of pleasant feelings such as happiness, calmness, safety (Boyce et al., 2003; Yacan, 2014) and vitality (Smolders, 2013). This process can be explained by exploring the effect of daylight on production of serotonin and melatonin hormones. Serotonin is most known for its effect on feelings, stress and depression (Azmitia, 2009), as lower levels of serotonin are thought to contribute to development of depression and feelings of sadness. Exposure to daylight stimulates the photoreceptors in the retina, the innermost layer of the eye (Vickers et al., 2017). The stimulated receptors send their signals to the brain, which contributes to serotonin production. Azmitia (2009) found that blood serotonin level increased after repeated daylight exposure.

Melatonin affects circadian cycles. Circadian cycles refer to the neurological response to presence and absence of daylight that synchronises and regulates the internal clock to twenty-four hours (Araji, 2008). Similar to serotonin production, the stimulation of photoreceptors sends their signals to the brain, which contributes to production of melatonin. Melatonin affects sleep quality and feelings (Aries et al., 2015). The effect of daylight on sleep quality and generation of feelings is used as a treatment for seasonal affective disorder, known as winter depression (Araji, 2008). However, daylight exposure provides further benefits regarding visual comfort and health, including vision-myopia, eye strain and headache[10] (Aries et al., 2015). As mentioned previously, improving health, as a life domain factor, contributes to a higher ability to perform cognitive interpretations and also boosts coping mechanisms (Diener, 1984; Reinhardt et al., 2009).

Figure 4 shows the increased awareness regarding windows and blinds selection specially daylights role (light cyan diamonds in figure 4) in improving cognitive

[10] Further details regarding daylight's effect on visual comfort, vision- myopia and eye strain-headache can be found in appendix 2.

interpretation (path a), generating pleasant feelings (path b) and boosting coping system (path c).

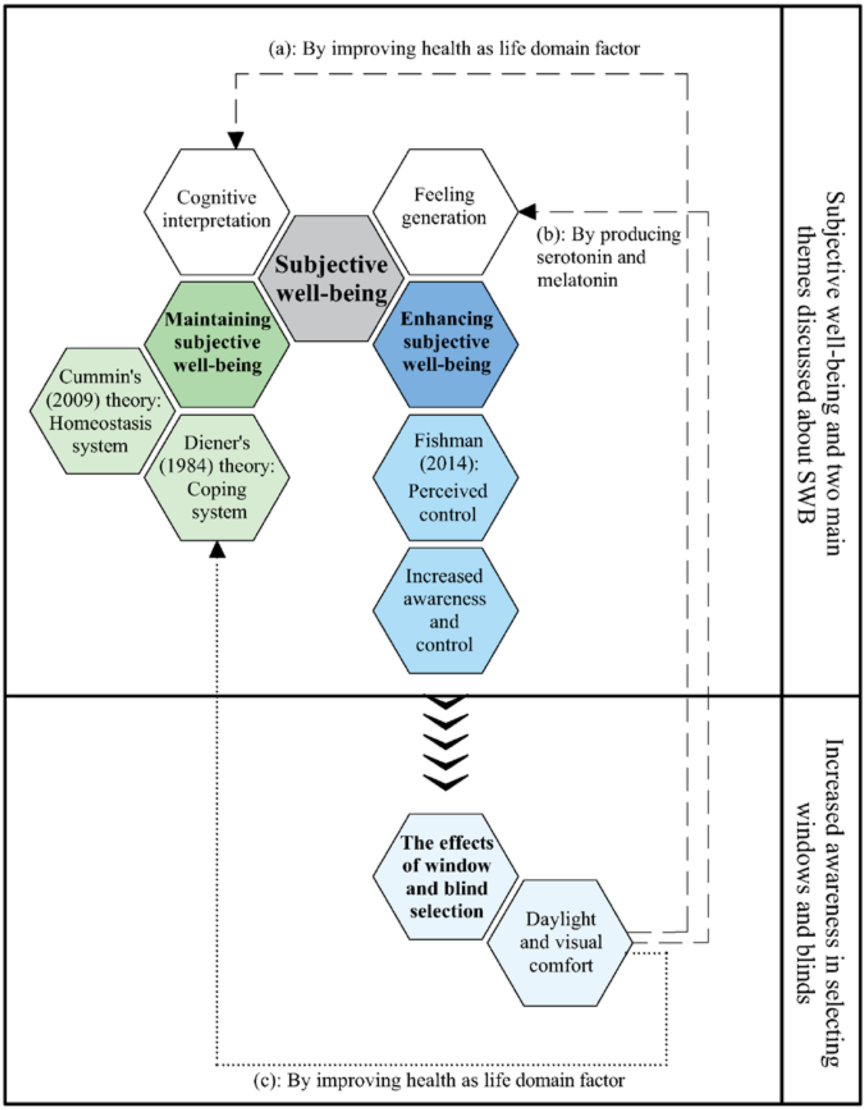

Figure 4. Schematic illustration of effect of daylight on cognitive interpretation, feeling generation and coping mechanisms

1.3 Problem areas

Increased awareness regarding the benefits of daylight and its role in enhancing SWB can become a strong case for having an enlarged window area for increasing daylight penetration and improving visual comfort (Mangkuto et al., 2016). However, larger windows increase the risk of overheating and glare (Al horr et al., 2016; Lee et al., 2007; Taylor et al., 2014). At this point, having blinds can largely help to control solar gain through windows and reduce overheating and glare (Avasoo, 2007; Lee et al., 2007). Controlling overheating improves individuals' health (Mostavi et al., 2017) and consequently boosts their ability to perform cognitive interpretation (Zhang et al., 2016). Results presented by Zhang et al. (2016) show that a cooling set point of 22°C promoted cognitive performance slightly among university students, while a cooling set point of 24°C caused a decline in cognitive performance. Furthermore, results confirmed that complex cognitive tasks are more likely sensitive to changes in the cooling set point than simpler tasks (Zhang et al., 2016). In a similar way, controlling glare contributes to better ability to perform cognitive interpretations (Rodriguez et al., 2016).

However, larger windows together with blinds increase the life cycle cost by increasing energy consumption, investment (O'Brien et al., 2013) and maintenance cost (Nikoofard et al., 2014). According to Jorgenson et al. (2014), increased life cycle cost has a negative impact on SWB (Welsch et al., 2014), since economy as a life domain factor affects the generation of feelings and ability to perform cognitive interpretations. However, no existing study to the best of the author's knowledge addresses the effect of life cycle cost or economy on boosting or diminishing coping mechanisms.

Figure 5 shows an overview of increased awareness regarding four main effects of windows and blinds on SWB, including visual comfort, thermal comfort, energy consumption and life cycle cost (light cyan diamonds). Path (a) and (c) show the effect of thermal comfort and visual comfort (light cyan diamonds on right side) in improving health and consequently improving individuals' ability to perform cognitive interpretations and coping respectively. Path (b) illustrates the role of daylight in generating pleasant feelings by affecting the production of serotonin and melatonin hormones. Finally, path (d) demonstrates the influence of the energy consumption and life cycle cost (light cyan diamonds on left side) on cognitive interpretations and feeling generation by affecting economy as life domain factor.

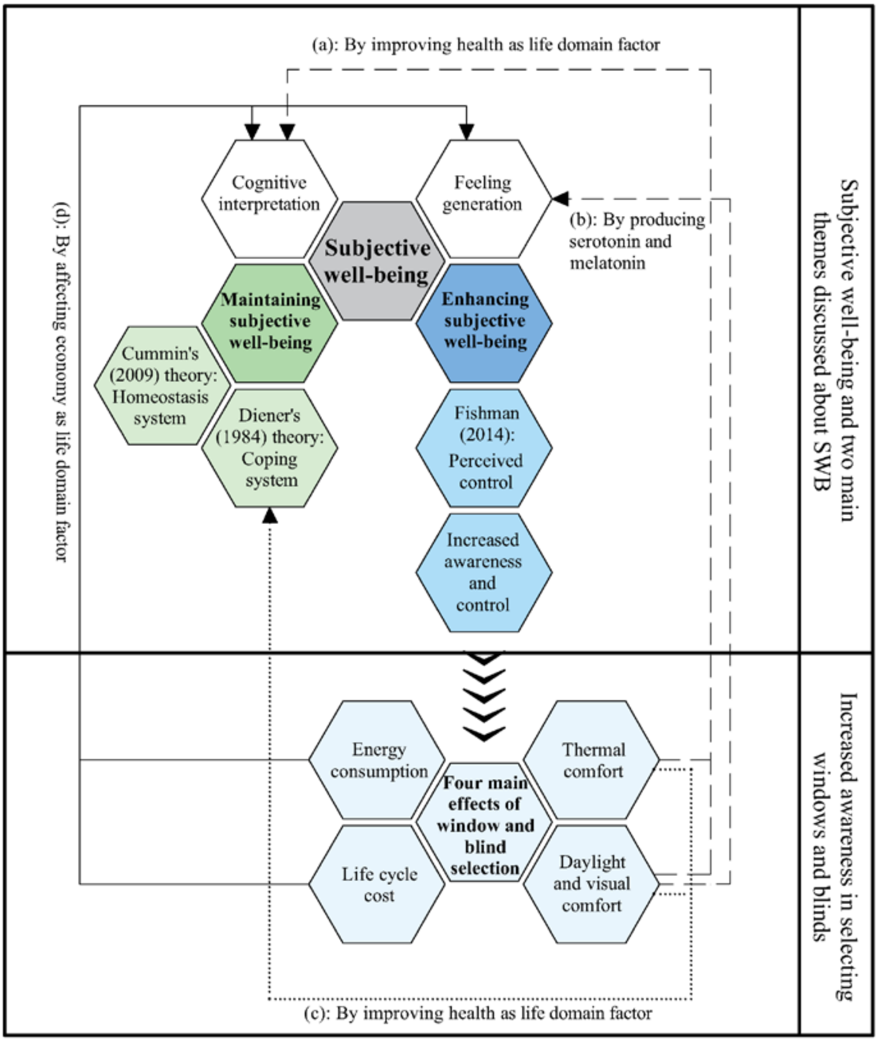

Figure 5. Different effects of window and blind selection on SWB

Altogether, selection of windows and blinds has contradictory effect on SWB. These complications make the selection of windows and blinds a rather complicated multidimensional problem. This problem may bind individuals, as decision-makers, in a situation where they follow the immediate economic benefits (personal interview, Inwido 2017) rather than the long-term visual and thermal benefits.

Recalling the first section of this study, once awareness regarding the consequences of window and blind selection is augmented, controllability should be increased for achieving individuals' desired outcomes. Increasing controllability for solving the mentioned problem translates into the process of managing the conflicts (among visual comfort, thermal comfort, energy consumption and life cycle cost) by prioritising decision-makers' preferences. Prioritising decision-makers' preferences in selecting windows and blinds prevents decisions which are motivated solely by decreasing cost (immediate benefits) or for improving visual and thermal comfort (long-term benefits). Instead, it helps to obtain a desired trade-off solution. Accomplishing this process relies on using "model-driven decision support system". According to Power et al. (2007), model-driven decision support system "provides a simplified representation of a situation that is understandable to a decision-maker" (page 1045). According to Mattiussi et al. (2014), multi criteria decision-making (MCDM) and optimization are two methods which actualize the model-driven decision support system in practice.

Though multiple studies have analysed the effects of window and blind selection on visual comfort, thermal comfort, energy consumption and life cycle cost in Sweden (Bülow-Hübe, 2007; Dubois, 2001), no attempt has been made to study the degree of the above-mentioned conflicts nor to use model-driven decision support system in increasing controllability in selecting windows and blinds. Specifying the degree of conflict helps to determine whether conflicts are small enough to be ignored or should be controlled and managed using a model-driven decision support system.

For this purpose, this study attempts to fill these gaps by first studying the degree of conflict, especially between total energy consumption and average daylight illuminance. This decision was made due to large variation in solar elevation angle and solar intensity between summer and winter in Sweden, which has significant effects on daylight illuminance and total energy consumption (Bülow-Hübe, 2007; Dubois, 2001). Later, this study exploits the main methods of the model-driven decision support system in increasing controllability for decision-makers and managing conflicts by prioritising decision-makers' preferences.

1.4 Aim and objective

This study attempts to address the apparent problem discussed before and aims to enhance SWB by selection of suitable windows and/or blinds. However, to approach this aim, there is a need for a framework which can be used in practice while selecting windows and blinds. Hence, the objective of this study is:

To develop a framework that is applicable in practice in selection of windows and blinds.

The attempt at fulfilling the objective of the study begins by obtaining a better understanding of the degree of conflict in selecting windows and blinds, especially in Sweden. Furthermore, this study attempts to determine whether employing two main methods of model-driven decision support system can increase controllability for decision-makers and how it can be applied in practice. Considering this attempt, two main research questions were defined as below.

1.5 Research questions

1-What are the current difficulties and conflicts in designing windows?

2- How can controllability in selection of windows and blinds be increased?

1.6 Limitations

The limitations of this study are defined as follows:

1- Since this study concentrates on window and blind selection in Sweden, analyses and simulations were performed from a Swedish standard perspective. Furthermore, all simulations were accomplished using Swedish climate data, as simulation models should mimic the real environment to produce accurate results. For instance, the properties of used materials, heating, ventilation and air conditioning (HVAC) systems and other attributes of buildings are based on common construction practices in Sweden.

2- In performing this study, the acoustic performance of windows was not analysed. Acoustic performance is highly dependent on the structure of a window (including its mass, cavity gap width, airtightness and acoustical isolation around the cavity space) and is affected by window production and manufacturing process (Muneer et.al, 2000). But, the window and blind selection deals with products which are already available in Swedish market.

3- The correlation between indoor air quality and operability of windows was not studied, because air quality should be analysed together with ventilation systems (Al horr et al., 2016), which requires good understanding of different components of the ventilation system. Furthermore, it requires an in-depth study considering the performance of various ventilation systems available in the Swedish market.

4- In this study, the correlation between the nature view (quality of view)[11] through windows and SWB has not been studied. This decision was made due to difficulties in assessing whether a window provides a nature view. Providing a nature view depends strongly on building location and urban design.

5- Only energy demand for electric lighting, heating, cooling (to a certain temperature) and fans for artificial ventilation has been calculated. Energy demand was not converted to primary energy, as this requires several assumptions regarding the supply system. For instance, a supply system can be district heat and cooling system, onsite heat-pump, solar panel and photovoltaic or fossil fuel boiler. Converting the energy demand to the primary energy requires further evaluations regarding the efficiency of the supply system, which is beyond the aim of this study.

[11] The correlation between nature views and SWB has been studied using stress recovery theory (Ulrich et al., 1991) and attention restoration theory (Kaplan, 1995). According to stress recovery theory, since humans evolved over a long period of time, people are physiologically adopted to nature (Ulrich et al., 1991). For instance, exposure to a natural view has a direct effect on levels of cortisol, also known as the stress hormone, in urine and blood (Ulrich et al., 1991). Attention restoration theory studies the correlation between nature views and health (a life domain factor) in terms of mental fatigue and information processing (Kaplan, 1995). According to this theory, natural views have less complexity than urban or artificial views. An increase in complexity obliges people to pay more involuntary and/or voluntary attention to their environment, which requires a good deal of effort and can cause mental fatigue (Kaplan, 1995). Having a nature view decreases mental fatigue (Kaplan, 1995) and improves ability to perform cognitive interpretation, and is associated with enhanced SWB.

2 Methodology

2.1 Research design

This study follows the traditional positivist approach in research design. The traditional positivist approach attempts to find connections between causes and effects. This approach sees the world as a collection of events and facts which can be observed and measured (Williamson, 2002). The positivist approach has a fixed and linear procedure, and often uses quantitative methods for gathering data.

The first step in performing the traditional positivist approach is to specify the topic of interest. The topic of this study was defined as “Window and blind selection for enhancing subjective well-being”. The second step is to specify the problem area and to develop research questions. To perform the second step, a literature study was conducted which helped to gain new and deep understanding of theory-based formulation of SWB, that help to determine the role of the controllability in enhancing SWB. Furthermore, literature study was used for analyzing studies conducted earlier in the context of window and blind selection and SWB. Analyzing these studies together with theory behind SWB helped in specifying the problem area and delineating the research questions. Accordingly, two research questions were developed. First research question was then studied and addressed in Paper I and II. The obtained results of these papers show a clear picture of difficulties and conflicts in selecting a suitable window and blind. They also explain that current process, used in selecting windows and blinds is incapable of managing the existing conflicts that may diminish SWB. The third step in performing the traditional positivist research is to develop a hypothesis. According to Williamson (2002), a hypothesis is a “scientific guess about the relationship among variables … [which] must be tested” (p. 54). A hypothesis should be related to at least one of the research questions (Williamson, 2002). In this study, the results of studying first research question formed a hypothesis as “A multi criteria decision-making method increases the controllability and manages the conflicts in selecting windows and blinds”. The hypothesis test, which is the forth step, was carried while answering the second research question and addressed in Paper III. This paper employed analytical hierarchy process as a multi criteria decision-making method to determine whether it increases the controllability and manages the conflicts by prioritizing decision-makers’ preferences. Finally, Paper IV expands the application of analytical hierarchy process and develops a conceptual framework by integrating analytical hierarchy process with optimization. Figure 6 illustrates the research process and the coherence of the papers considering the research questions and the objective of the study.

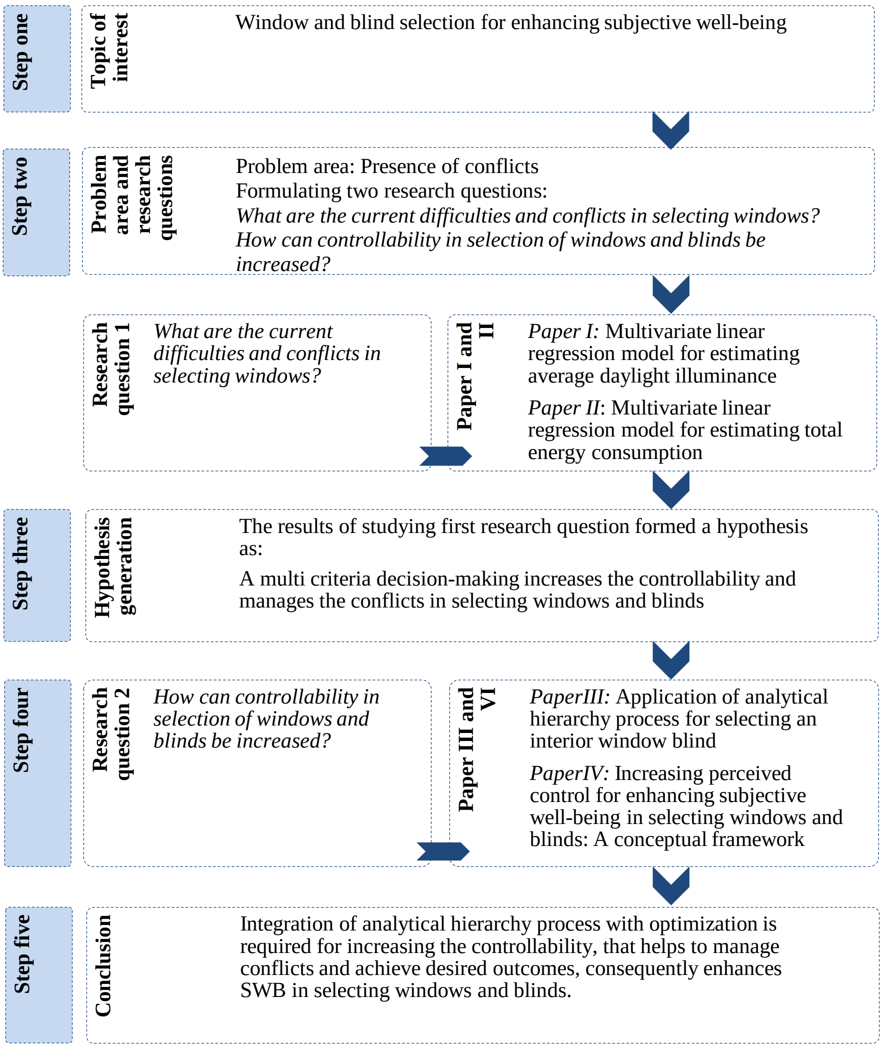

Figure 6. The procedure of applying traditional positivist approach and coherence of papers

2.2 Data gathering and data analysis methods

Data gathering refers to the process of collecting and measuring relevant data. This process can be accomplished by selecting and using relevant methods. Selection of methods depends strongly on the aim of the study. The aim of this study is to enhance SWB by selecting a suitable window and blind. As mentioned before, a literature study was conducted for exploring the theory-based formulations of SWB. The literature, including books, conferences, journal papers and reports, were searched and gathered mainly via Scopus database. Boolean, simple operations and strings were used to seek the literature in an efficient manner. To select the most relevant literature, the abstracts, keywords and conclusions of papers were read. The online process of seeking literature is comprised of the following (Rumsey, 2008).

1. Plan: identify the terms and formulate the research strategy
2. Run the search
3. Retrieve relevant results
4. Evaluate results
5. Save relevant results
6. Modify and re-run the search

The search for relevant studies considering available theories of SWB was performed in the Scopus database using three main keywords: “well-being”, “subjective well-being” and “theory” (Table 1). In total, 102 studies were found. Later, the search was limited to English language studies within the psychology subject area. Altogether, 55 studies were found.

Table 1. Search terms in Scopus

Database	Searched keywords	Found studies	Eligible after pre-selection
Scopus	Well-being and subjective well-being and theory	102	55

The abstracts of the 55 studies were analysed and relevant ones were selected and read. Furthermore, additional studies, cited as references within the evaluated studies, were also analysed.

As pointed out before, the results of literature study were later analysed and evaluated for specifying the problem area and defining the research questions. The literature study was also conducted as the choice of method for studying the research questions and performing evaluations.

2.2.1 Research question 1: Degree of conflict

Research question 1 (section 1.5, page 10) tries to determine current difficulties in selecting windows and blinds. This research question is answered in Paper I and II. These papers together evaluate the degree of conflict between average daylight illuminance and total energy consumption in Sweden. For this purpose, a multivariate linear regression model was developed in each paper. A multivariate linear regression model considers the relationships between various independent variables and one dependent variable and fits a linear equation among them. A multivariate linear regression model allows the inclusion of various independent variables, shows their effect on a dependent variable and gives the opportunity to compare the effect of the independent variables.

The data gathering process for developing multivariate linear regression models was accomplished by performing simulations. Simulation helps to provide a basis for gathering data about a phenomenon and then experimentation to predict the behaviour of the system under different settings (Williams, 2002). The model developed by simulations is an abstract of a real situation (real system) to study the system's behaviour without disrupting the environment of the real system (Davis et al., 2007; Gilbert et al., 2005). Simulations were performed using the COMFEN simulation tool. COMFEN uses Energy Plus to simulate the effects of windows and blinds design variables on visual comfort, thermal comfort, energy consumption and life cycle cost (Lawrence Berkeley National Laboratory, 2016). The results from the Energy Plus simulations are presented in graphical and tabular format within the simplified user interface for comparative window and blind selections that helps users move toward optimal design choices for their project (Lawrence Berkeley National Laboratory, 2016).

To perform the simulations, a 9m² prototype of a hypothetical office room in Gothenburg, Sweden was modelled in COMFEN. Room size, heating, ventilation and air conditioning system, envelopes construction and occupancy schedule were based on common practice in the construction sector (Table 2).

Table 2. Office room simulation conditions

	Content
Location	Gothenburg
Dimension (W.D.H)	3m x 3m x 2.7m
Exterior wall u-value	0.19 W/K.m²
HVAC	Packaged single zone
Set point	Heating: 18˚C Cooling: 24˚ C
Equipment load	8 W/m²
Lighting control	None
Lighting load	10 W/m²
Number of occupants	1

2.2.1.1 Simulation process

The effect of four window design variables including design model (form and position), window size, orientation and glazing system were studied with respect to average daylight illuminance and total energy consumption. The average daylight illuminance was calculated at 0.76m above the floor level (standard value in COMFEN). The total energy consumption comprised energy demand for heating, cooling, electricity for lighting and fans for artificial ventilation. The window design variables had been specified beforehand by the literature study.

To perform the simulations, four groups of window design models have been defined (Figure 7), which differ in window form and position. The minimum window size of each design model (WWR: window wall ratio) was 10% which was later increased by 5% up to 90% in all groups. Furthermore, the performance of the four design models with different WWR was compared for four cardinal orientations (east, west, north and south).

Figure 7. Window design models within four groups
*WWR: 15%, 25%, 35%, 45%, 55%, 65%, 75%, 85% were not illustrated in figure 7.

Additionally, two glazing systems were studied: non-operable Elit Orginal and electrochromic SageGlass. Elit Orginal consists of three sheets of 4mm thick glass with two air gaps between (Elitfonster, 2016) (Figures 8 and 9). The interior gap is filled with 10% air and 90% argon while the exterior one is filled with only air (Elitfonster, 2016). The interior sheet is laminated with low e-coating, while the middle and exterior sheets are clear without coating (Elitfonster, 2016). Elit Orginal has a wooden frame with external aluminium cladding (Elitfonster, 2016). This window was modelled with an interior venetian blind with 2.54 cm (1-inch) louver width. The visible transmittance and reflectance of the blind was 0% and 70% respectively. The venetian blind was automatically controlled and was completely lowered in the presence of glare during the daylight hours.

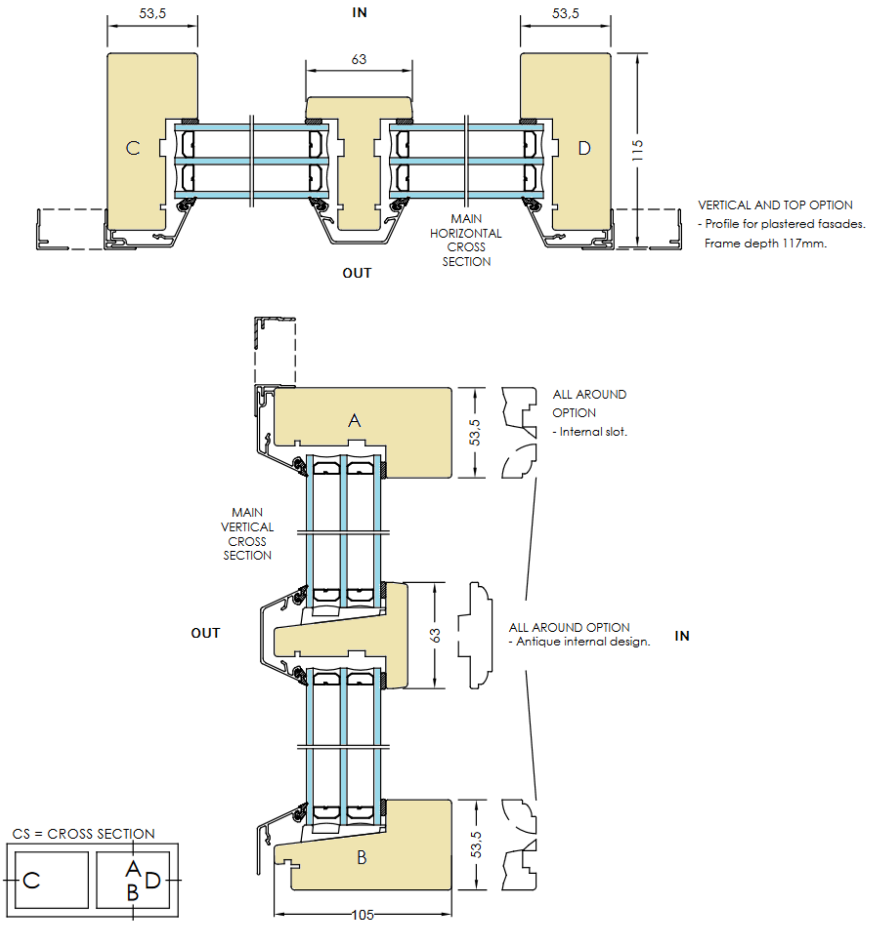

Figure 8. Cross section of Non-operable Elit Orginal window (The dimension unit is mm) (Elitfonster, 2016)

Figure 9. Non-operable Elit Orginal window (Elitfonster, 2016)

The electrochromic window[12] has a 6mm heat treated clear float sheet as exterior glass and a 6mm electrochromic SageGlass sheet as interior glass (Tavares et al., 2014) (Figure 10). The 12.7 mm air gap between the two sheets is filled with 10% air and 90% argon (Tavares et al., 2014). Similar to the Elit Orginal, the electrochromic window has a wooden frame with external aluminium cladding (Tavares et al., 2014). This window was also controlled and tinted in the presence of unappreciated glare.

The glare control in both glazing systems follows Hopkinson Cornell- BRS statements as the maximum daylight glare index (DGI) for office work should not be greater than 22 ("just uncomfortable") (Lee et al., 2007) .

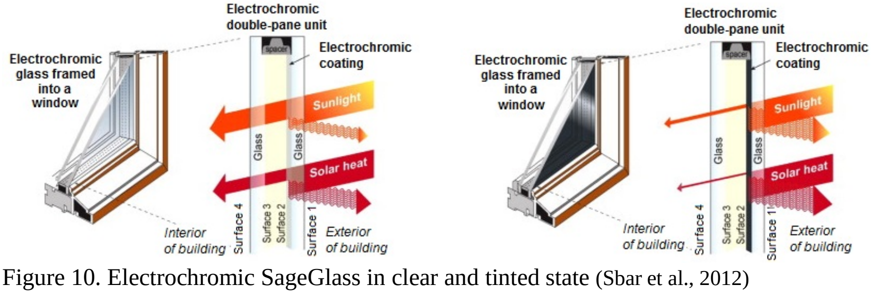

Figure 10. Electrochromic SageGlass in clear and tinted state (Sbar et al., 2012)

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[12] Electrochromism refers to revisable changes in the optical properties of material, which is achieved by applying a low electric voltage (Piccolo et al., 2009). The underlying process is the concurrent movement of both electrons and positive-charge ions to an electrochromic (EC) thin film, placed on conductive glass (Sbar et al., 2012). However, applying EC film on glass can affect the durability and tolerance of the glass under a variety of climate conditions (Sbar et al., 2012). To solve this problem, ceramic metal oxides, including lithium-based films, have been introduced due to similarity of their thermal expansion coefficient to the glass substrate (Sbar et al., 2012). SageGlass uses a lithium-based EC film. Switching the EC SageGlass requires less than 5 voltage DC power, which can be controlled by integrating EC glass into building management systems. This dynamic control of EC glass is gaining interest among researchers as it allows for control of solar heat gain and glare without blocking the view.

Table 3 shows the differences in visual transmittance and u-value of the non-operable Elit Orginal and the electrochromic SageGlass.

Table 3. Window properties

Windows		Visible Transmittance	U-value
SageGlass	Clear	63	1,3
	Intermediate 1	21	
	Intermediate 2	6	
	Fully tinted	2	
Non-operable Elit Original	-	66	1

Once all design variables were defined in the COMFEN simulation tool, 544 simulations were executed based on combination of four groups of design models, 17 window sizes, four cardinal orientations and two glazing systems. Calculated average daylight illuminance and total energy consumption in all 544 simulations were saved in an Excel file for further analyses.

2.2.1.2 Developing multivariate linear regression models

The data gathered from 544 simulations were saved in Excel files and used later for developing two multivariate linear regression models with the STATA programme. STATA is a package for analysing data using various statistic tests (STATA, 2016). The data was first analysed by performing a two-way ANOVA test for detecting possible interactions between four independent design variables: design model (form and position), window size, orientation and glazing system. The interaction occurs when the effect of an independent variable on average daylight illuminance or total energy consumption differs based on changes in the other independent variables (de González et al., 2007; STATA manuel, 2016). Later, analysis of the distribution of 90% of the dataset[13] showed that average daylight illuminance and total energy consumption were not normally distributed. Hence, the natural logarithm of average daylight illuminance and total energy consumption were determined while the skewness[14] was close to zero (equation 1 and 2). Normally distributed data is required to develop accurate multivariate linear regression models.

$$\text{Ln-average daylight illuminance} = \text{Ln (average daylight illuminance - K)} \qquad \text{Eq. 1}$$

$$\text{Ln-total energy consumption} = \text{Ln (total energy consumption - K)} \qquad \text{Eq. 2}$$

[13] Among 544 data obtained from simulations, 490 were randomly selected and used in developing the multivariate linear regression model.

[14] Skewness refers to asymmetry of data distribution.

Two multivariate linear regression model based on 90%[15] of dataset were then developed in Paper I and II. Equation 3 shows the mathematical formulation for a multivariate linear regression model:

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p \qquad \text{Eq. 3}$$

Where X_i is the *i*th variable;
β_i is the respective coefficient; and
α is the constant value in the multivariate linear regression model

However, the multivariate linear regression models were developed further by considering interaction and defining factor variables. This decision was made because considering interaction increases the accuracy of the models (de González et al., 2007; STATA manuel, 2016). A multivariate linear regression model with interaction effect can be shown as;

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_{ij} X_i X_j + \cdots + \beta_p X_p \qquad \text{Eq. 4}$$

Defining factor variables refers to the creation of dummies for different groups of categorical variables. Developing a multivariate linear regression model with factor variables introduces different coefficient values for each group and shows their effect. For instance, if the X_1 in equations 3 and 4 above is a categorical variable with two groups, the multivariate linear regression model can be written as equation 5 and 6:

$$Y_{group\ 1} = \alpha + \beta_{11} X'_1 + \beta_2 X_2 + \cdots + \beta_{ij} X_i X_j + \cdots + \beta_p X_p \qquad \text{Eq. 5}$$

$$Y_{group\ 2} = \alpha + \beta_{12} X'_2 + \beta_2 X_2 + \cdots + \beta_{ij} X_i X_j + \cdots + \beta_p X_p \qquad \text{Eq. 6}$$

In developing the multivariate linear regression models, window size was always kept as a continuous variable, while the glazing system, design model and orientation were first considered as categorical variables one by one and two by two. Later, they were accounted as categorical variables all at once. This process was used to find the best fit. Finally, a multivariate linear regression model was developed in each paper by considering the detected interactions and

[15] In general, there is no clear formulation which specify the percentage of the dataset required for developing a multivariate linear regression model. Hence, two separate multivariate linear regression models based on 90% and 50% of the dataset were developed in both Paper I and II. This decision was made to determine whether the size of the dataset affects the accuracy of the models. Further details can be found in Paper I and II.

defining window size, design model and glazing system as continuous variables and only orientation as a categorical variable.

2.2.2 Research question 2: Hypothesis test

Research question 2 (section 1.5, page 10) tries to test the developed hypothesis: “A multi criteria decision-making method increases the controllability and manages conflicts in selecting windows and blinds”. This question is answered in Paper III and IV.

Paper III employs the analytic hierarchy process (AHP) as a multi criteria decision-making method to test whether it manages the conflicts (between visual comfort, thermal comfort energy consumption and life cycle cost) by performing a prioritisation. The data gathering process in Paper III involved performing simulations and mathematical calculations in Excel. In this paper, the performance of commonly used interior blinds including roller blinds, double pleated blinds and two types of venetian blinds with louver slats at 0° and 45° was studied in an office room located in Gothenburg, Sweden. The height of the blinds was changed from 10% to 100% of the window’s height and increased in 10% increments. This decision was made to determine whether a small blind has a positive effect in cutting the investment cost. Figure 11 shows a schematic illustration of the blinds and window heights studied. Four blinds and ten heights created forty different possible combinations. Later, the performance of all forty blinds was studied with respect to visual comfort, thermal comfort, energy consumption and life cycle cost.

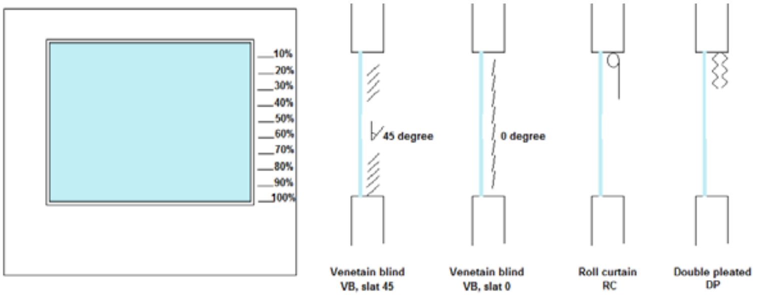

Figure 11. Studied window blinds

2.2.2.1 Simulation process

The performance of each blind considering visual comfort was studied using the Rhinocore tool (Rhino3d, 2016) and the Diva for Rhino plugin. Rhinocore is used to develop 3D models for further analyses (Rhino3d, 2016), while Diva for Rhino makes possible a series of visual comfort evaluations (Diva4Rhino, 2016). In Paper III, the data gathering process was started by developing a 3D model of the office room in Rhinocore. The 3D model was later followed out by defining the reflectance of interior surfaces including walls, ceiling and floor as 60%, 80% and 20% respectively. The values follow the Swedish standard recommended reflectance for walls, ceiling and floor (Månsson et al., 2003). The office room was also equipped with an Elit Orginal window (the specifications of this window were explained in section 2.2.1). The mentioned forty blinds were later modelled in Rhinocore as separated 3D layers. During the simulations, only one layer at a time was activated while the rest were turned off. This process helped to evaluate the performance of all forty blinds while only one 3D model was developed for the office room. Later, Diva for Rhinocore was employed for analysing the performance of the blinds by calculating mean daylight autonomy (DA), discomfort glare probability (DGP) and uniformity.

The energy performance of each blind was studied using IDA ICE, a dynamic simulation tool which is widely used to study the energy and thermal performance of a room and/or building. The physical models of IDA ICE are adapted to local requirements in Sweden including climate data, standards and material data (IDAICE, 2016). A 3D model of the room was also developed. The dimensions and specifications of each blind were defined and saved separately, which meant that forty IDA ICE simulation files, each representing one single blind, were generated. The heating, ventilation and air conditioning (HVAC), occupancy and thermal characteristics of the office room were similar in all forty IDA ICE simulation files. To set a similar blind control in IDA ICE, the detailed dynamic blind timetable (timetable for dynamic control of blinds) produced by Diva for Rhinocore was utilised. The energy consumption of all forty blinds comprised the annual electricity demand for lighting, and annual energy needs for heating and cooling.

In terms of thermal comfort evaluation, operative temperature and predicted percentage of dissatisfaction (PPD), as two widely used metrics (Linden et al., 2008), were obtained for all forty blinds using IDA ICE.

The life cycle cost evaluation for each blind was determined by calculating the present value per 1m² of the room area in Excel. Equation 7 shows the mathematical formulation of present value.

$$K_n = \sum_{t=0}^{n} (D_t + U_t) * \frac{1}{(1+r)^t} + I_0 \qquad \text{Eq. 7}$$

$$D_t = E * \alpha(1+\beta)^t$$

Where;
K_n is present value during lifespan of n year;
U_t is annual maintenance cost;
D_t is annual energy consumption cost;
r: is interest rate;
t: is lifespan of n years;
E is annual energy consumption (kWh/m²);
α is energy price per kwh/m²;
β is inflation in energy price (%); and
I_0 is the investment cost.

The life cycle cost analysis includes: i) the initial investment cost of the blind which was collected from a company catalogue in Sweden and calculated considering the size of each blind; ii) the cost of energy used during the life span of the blind which was determined according to the presented results for annual district heating and cooling by the IDA ICE (1SEK/ kWh); and iii) the annual maintenance cost which was collected from a company in Sweden and assumed to be the same for all design alternatives.

2.2.2.2 Analytical hierarchy process

The analytic hierarchy process (AHP) is widely utilised for increasing controllability in order to help to manage encountered conflicts in different fields such as indoor environment quality (Lai et al., 2009), passive design (Chong et al., 2014), sustainability (Alwaer et al., 2010; Bhatt et al., 2010; Chandratilake et al., 2013; Markelj et al., 2014; Wong et al., 2008), and daylight performance (Arpacioglu et al., 2013). According to Podgórski (2015), the AHP method is implemented following these steps:

1. Breaking down the multi criteria decision-making problem into several stages, including the goal, the objectives of AHP and their respective criteria. This process creates a hierarchy model (Figure 12).

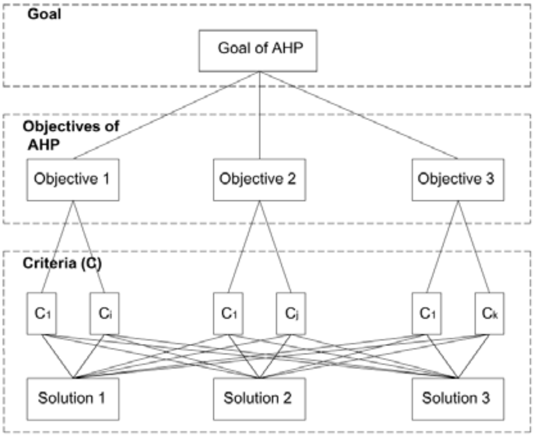

Figure 12. Illustration of AHP hierarchy model

2. Performing pairwise comparisons among the objectives of AHP and later among their respective criteria. The pairwise comparisons should be conducted following the numerical ratings presented in Table 4.

Table 4. Pairwise numerical rating
(Saaty, 2008)

AHP, Relative importance		Numeric rating
Equal importance	Two factors contribute equally to the objective	1
Somewhat more important	Experience and judgment slightly favour one over the other	3
Much more important	Experience and judgment strongly favour one over the other	5
Very much more important	Experience and judgment very strongly favour one over the other. Its importance is demonstrated in practice	7
Absolutely more important	The evidence favouring one over the other is of the highest possible validity	9
Intermediate values	When compromise is needed	2,4,6,8

This process generates a comparison matrix. Matrix A shows the developed comparison matrix among criteria.

$$
A= \begin{array}{c} \\ \text{Criterion 1} \\ \text{Criterion 2} \\ \text{Criterion 3} \\ \text{Criterion 4} \end{array}
\begin{array}{cccc} \text{Criterion 1} & \text{Criterion 2} & \text{Criterion 3} & \text{Criterion 4} \\ \end{array}
\begin{bmatrix} 1 & a_{1,2} & \dots & a_{1,n} \\ 1/a_{1,2} & 1 & \dots & a_{2,n} \\ \dots & \dots & 1 & \dots \\ 1/a_{1,n} & a_{n,2} & \dots & 1 \end{bmatrix}
$$

Where $\boldsymbol{a_{i,j}}$ means that criteria i being compared to criteria j. On the diagonal of the matrix, $\boldsymbol{a_{i,j}}$ is equal to 1 since i = j. When the comparison matrix is developed, the weight of each criterion should be calculated by:

- Calculating the sum of each column in the matrix ($\sum \boldsymbol{a_j}$).
- Dividing each $\boldsymbol{a_{i,j}}$ in column *j* by the calculated $\sum \boldsymbol{a_j}$ in the previous step (normalisation of the matrix).
- Obtaining the average of each row in the normalised matrix ($\overline{\boldsymbol{a'_i}}$). $\boldsymbol{a'_i}$ is representing the weight of a criterion in row *i*.

3. Evaluating the performance of the solutions with respect to each criterion and obtaining the weight vector for the solutions. For this reason, a comparison matrix should also be developed by comparing the solutions in relation to each criterion (Matrix B). The weight calculation process is similar to step 2.

		Solution 1	Solution 2	Solution 3	Solution 4
B=	Solution 1	1	$a_{1,2}$	...	$a_{1,n}$
	Solution 2	$1/a_{1,2}$	1	...	$a_{2,n}$
	Solution 3	...	...	1	...
	Solution 4	$1/a_{1,n}$	$a_{n,2}$	...	1

4. Determining the global weight vector for each solution and ranking them for achieving a trade-off solution. The solution with highest global weight is known as the trade-off solution. The global weight is the sum of products of the weight of a given solution and weights of the criteria. For instance, if $\boldsymbol{W_{s,1}}$ is the weight of the first solution and $\boldsymbol{W_{c,i}}$ is the weight of the criteria *i*, then the global weight of the first solution is as equation 8:

$$\text{Global weight of solution 1 } (GW_1) = \sum_{i=1}^{i=n} W_{s,1} \times W_{c,i} \qquad \text{Eq. 8}$$

Pairwise comparisons should be performed based on decision-makers' preferences, by eliciting qualitative data from the decision-makers (Triantaphyllou et al., 1995). However, qualitative data cannot be considered as absolute data. Hence, decision-makers are asked to use Table 4 and express their preferences by determining the *relative* importance of visual comfort, thermal comfort, energy consumption, life cycle cost and their relative criteria. Since pairwise comparisons are based on qualitative data which are crucial in the decision-making process, their consistency in comparison matrixes should be tested. For this reason, consistency ratio (CR) can be calculated for each matrix following equation 9. According to Ordouei et al. (2015), CR should be smaller than 0.1 and 0.08 for matrices with n > 3 and n = 3 respectively.

$$CR = \frac{\lambda_{max} - n}{(n-1) \times RI} \quad \text{Eq. 9}$$

Where;
λ_{max} is the maximum eigenvalue of the developed matrices in step 2;
n is the number of elements in the developed matrices;

RI or the random consistency index in eq. 9 is a reciprocal matrix (Hotman, 2005). The average RI of sample size n = 10 is shown in Table 5.

Table 5. Random consistency index (RI)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Figure 13 shows the schematic hierarchy model developed in paper III.

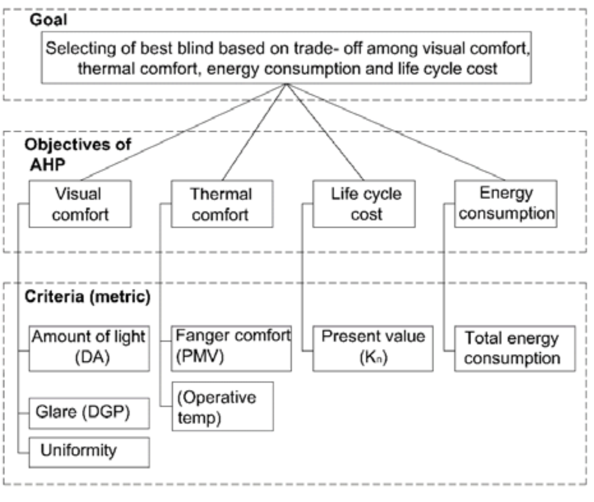

Figure 13. Developed hierarchy model for analysing 40 window blinds

The pairwise comparisons between visual comfort, thermal comfort and energy consumption and life cycle cost were performed based on results presented by Kats et al. (2003). According to them, improving visual comfort and thermal comfort presents approximately seven times more economic benefits than energy consumption. Comparisons between visual comfort and thermal comfort follow the results presented by Frontczak et al. (2012). They analysed occupants' satisfaction with the overall indoor environment in correlation with their satisfaction with visual comfort, thermal comfort, air quality and acoustics. The correlation was studied by obtaining Spearman's correlation coefficient. Comparing the coefficient values shows that visual comfort has slightly more effect than thermal comfort on occupants' satisfaction of the overall indoor environment. Matrix A shows the pairwise comparisons performed among visual, thermal, energy consumption and life cycle cost.

A=		Visual comfort	Thermal comfort	Energy consumption	Life cycle cost	Weight
	Visual comfort	1	2	7	7	0.52
	Thermal comfort	1/2	1	7	7	0.36
	Energy consumption	1/7	1/7	1	1	0.06
	Life cycle cost	1/7	1/7	1	1	0.06

Pairwise comparisons among visual comfort criteria were also performed by conducting the literature study. According to Chung et al. (2016), the amount of light is more important than glare to a small degree. Furthermore, it is slightly more important than daylight uniformity (Chung et al., 2016). Matrix B presents the applied comparisons between visual comfort criteria.

B=		Amount of light	Glare	Uniformity	Weight
	Amount of light	1	2	3	0.54
	Glare	1/2	1	2	0.3
	Uniformity	1/3	1/2	1	0.16

However, in developing the comparison matrix for thermal comfort criteria, since operative temperature and PPD evaluate the thermal conditions in relation to occupants' satisfaction (Linden et al., 2008), it was assumed that operative temperature has equal importance in relation to PPD (Matrix C).

C=		Operative temperature	PPD	Weight
	Operative temperature	1	1	0.5
	PPD	1	1	0.5

The pairwise comparisons between energy performance criteria were accomplished by comparing the average demands for district heating, district cooling and the electricity demand for lighting (between forty blinds). The average district heating and cooling demands were 82.2 kWh/ (m^2 year) and 26 kWh/ (m^2 year) respectively. The electricity demand for lighting was 11.6 kWh/ (m^2 year) for each blind configuration. Matrix D shows the pairwise comparisons between heating, cooling and electricity for lighting demands.

D=		Heating demand	Cooling demand	Electricity for lighting	Weight
	Heating demand	1	3	6	0.67
	Cooling demand	1/3	1	2	0.22
	Electricity for lighting	1/6	1/2	1	0.122

Considering life cycle cost, only present value has been calculated for evaluating the performance of the blinds.

Application of AHP was performed using the MakeitRational programme (MakeitRational, 2016) due to its simplicity. MakeitRational is an online programme designed for implementing the AHP method. The eligibility of this programme has been discussed and found appropriate by other studies (Ishizaka et al., 2013; Sabharwall et al., 2011).

Furthermore, the sensitivity of the results, obtained by AHP, was studied. According to Leonelli (2012), since global weights are obtained by performing qualitative pairwise comparison, it is necessary to control the sensitivity of the results. Performing this kind of analyses helps to make an informed decision (Leonelli, 2012). Sensitivity test evaluates the variation of global weights with respect to change in criteria's weight (criteria' weight can be changed by changing the pairwise comparisons). In this process, the global weight of an alternative is expressed as a linear function of the criteria weight (Leonelli, 2012). The linear function can be developed using equation 10.

$$(\mathrm{GW_i}) = \frac{\mathrm{GW_i''} - \mathrm{GW_i'}}{\mathrm{W_{c,j}''} - \mathrm{W_{c,j}'}} \times \left(\mathrm{W_{c,j}} - \mathrm{W_{c,j}'}\right) + (\mathrm{GW_i'}) \qquad \text{Eq.10}$$

Where

GW_i is the global weight of *i*th solution when the weight of *j*th criteria is $W_{c,j}$

GW_i' is the global weight of *i*th solution when the weight of *j*th criteria is changed to $W_{c,j}'$

GW_i'' is the global weight of *i*th solution when the weight of *j*th criteria is changed to $W_{c,j}''$

GW_i and $W_{c,i}$ are obtained following four steps, described before. $W_{c,j}'$ can be calculated by changing the pairwise comparisons in matrix A. Later, GW_i' should be obtained based on $W_{c,j}'$ and using equation 3. In using equation 10, only two iterations are required to develop linear function between global weight and criteria weight (Leonelli, 2012). However, the accuracy of the linear function can be tested by calculating $W_{c,j}''$ and GW_i'' and testing whether or not it lies on the linear function.

2.2.3 Research question 2: Framework development

Paper IV expands the application of the analytic hierarchy process (AHP) in selecting windows and blinds. This paper first explains the formulation of SWB theory and highlights the importance of controllability in enhancing SWB.

Later, a discussion considering the advantages and limitations of employing a multi criteria decision-making and optimisation, in increasing the controllability, were discussed. Finally, a conceptual framework for increasing controllability was developed. The framework integrated the AHP with an optimisation algorithm. Through this integration, the optimisation algorithm combines window and blind design variables and analyses multiple solutions, while the AHP ranks the solutions based on decision-makers' preferences to obtain the desired trade-off solution.

The conceptual framework was developed following three main phases including pre-processing, optimisation and post-processing (Mosavi, 2010). The three phases are used to integrate multi criteria decision-making with optimisation (Mosavi, 2010).

The pre-processing phase comprised:

1. Specification of main variables which have impact on visual comfort, thermal comfort, energy consumption and life cycle cost. Furthermore, the main criteria, which were frequently used by previous studies for evaluating visual comfort, thermal comfort, energy consumption and life cycle cost, were specified.
2. Determination of proper metrics for quantifying the main criteria. According to Carlucci et al. (2015a), selection of proper metrics increases the adoption of an optimisation-based design.

The optimisation phase included:

1. Formulation of the optimisation problem. Objective functions of the optimisation problem are the metrics which are specified in the pre-processing phase.
2. Selection of an efficient optimisation algorithm for solving the formulated optimisation problem.
3. Selecting an integration platform. The platform enables to integrate the AHP with optimisation.

The post-processing phase comprised:

1. Describing the AHP which would be integrated with optimisation.

Required data for performing the pre-processing, optimisation and post-processing phases was gathered by conducting the literature study. The search for relevant studies was performed using Scopus database. The initial search terms are shown in Table 6.

Table 6. Search term in Scopus

Database	Search term	Found studies	Eligible after pre-selection
Scopus	(visual comfort OR light quality OR thermal comfort OR energy consumption OR life cycle cost) AND (window OR blind OR shading)	131	33
Scopus	(visual comfort OR light quality OR thermal comfort OR energy consumption OR life cycle cost) AND (window OR blind OR shading) AND (optimisation)	79	23
Scopus	(visual comfort OR light quality OR thermal comfort OR energy consumption OR life cycle cost) AND (window OR blind OR shading) AND (decision-making)	62	12

Each search term was later limited to find only English language studies published between 2001 and 2015. Furthermore, the subject areas were limited to engineering, energy, environmental science, economics, econometrics and finance, computer science and mathematics. 31 keywords and phrases were excluded from the query, including skylight, carbon emission, climate change, photovoltaic effects, roof(s), semitransparent photovoltaics, solar power generation, atrium, CO2 mitigation, carbon credit, carbon dioxide, domes, ecosystems, electric generators, integrated optics, photovoltaic system, physiology, bio sensing techniques, boiler plants, passive solar design, renewable energy generation, structural design, age-related macular degeneration (AMD), age-related macular degeneration, ageing population, animal(s), ballasts (lamp), biodiversity, biomass, biomolecular interaction analysis, and computer hardware.

Later, each query was combined once with “optimisation” and then with “decision-making”. In total, 272 studies were found. However, books and book series were later filtered. Altogether, 68 studies were found. The abstracts of the studies were analysed and the relevant ones were read. Furthermore, additional studies, cited as reference within the 68 studies, were specified and read for gaining in-depth knowledge.

Data analysis in Paper IV refers to categorisation of data in an Excel file. The results of literature study for performing the pre-processing phase were categorised into seven main categories: window design variables, external horizontal flat panel variables, interior horizontal flat panel variables, external roller blind variables, interior roller blind variables, external venetian blind variables and internal venetian blind variables. These seven categories were specified in the first two columns in the first sheet of the Excel file. The criteria, frequently used for evaluating visual comfort, thermal comfort, energy consumption and life cycle cost, were also categorised into different categories. These categories were specified in first row of the first sheet in the Excel file. This process created a table. Figure 14 shows a part of the table, where window design variables are presented in the first two columns and various criteria of energy consumption are shown in the first two rows. The table shows which variable has been frequently studied regarding a specific criterion. The next sheet of the Excel file comprises the recommended metrics for evaluating each criterion by the literature.

	A	B	C	D	E	F	G
1	Design variables		Energy consumption (kWh/m²)				
2			Heating	Cooling	El for lighting	Total energy demand	Artificial ventilation
3	Window design variable	Window size (width and length of window)	Atzeri et al. (2013)	Atzeri et al. (2013)	Acosta et al. (2015)	Kim et al. (2014)	Wetter et al. (2003)
4			Wetter et al. (2003)	Wetter et al. (2003)	Atzeri et al. (2013)	Lee et al. (2007) Znouda et al. (2007)	Ochoa et al. (2012)
5			Ochoa et al. (2012)	Ochoa et al. (2012)	Wetter et al. (2003) Ochoa et al. (2012)		
6		Orientation	Atzeri et al. (2013)	Atzeri et al. (2013)	Atzeri et al. (2013)	Kim et al. (2014)	Wetter et al. (2003)
7			Wetter et al. (2003)	Wetter et al. (2003)	Wetter et al. (2003)		
8		Window position and form			Acosta et al. (2015)	Lee et al. (2007)	
9						Kämpf et al. (2010)	
10		Glazing system (light and solar transmittance of window)	Atzeri et al. (2013)	Atzeri et al. (2013)	Atzeri et al. (2013)	Kim et al. (2014)	
11						Lee et al. (2007)	
12						Papaefthimiou et al. (2006)	
13						Contreras et al. (2016)	
14						Znouda et al. (2007)	

Figure 14. Data analysis in Paper IV

Gathered data for performing the optimisation and post- processing phases were also categorised. Finally, when all data were categorised, they were synthesised following three main phases and visualised as a framework.

2.3 Validity and reliability

Validity and reliability are two major and complex terms in considering the credibility of a study. There are three major types of validity in quantitative research: internal validity, external validity and construct validity (Creswell, 2013).

Internal validity refers to whether the measures taken comply with what the study claims to measure. Furthermore, it controls whether the researcher draws correct results from the gathered data. However, a concern may be raised considering the accuracy of simulation tools used in this study. Achieving this kind of validity is difficult, because unexpected errors can occur due to a mistake in programming or a bug (Axelrod et al., 2005).

In Paper I, the internal validity of the developed multivariate linear regression model was tested in two steps. First, the predicted average daylight illuminance of the remaining 10% of the dataset obtained by the developed multivariate linear regression model was compared with simulated values by COMFEN. Then, the validity of the first multivariate linear regression model, developed based on 90% of the dataset, was retested by comparing it with another multivariate linear regression model developed based on 50% of the dataset (instead of 90% in the first model). A similar validity test was accomplished in Paper II.

In Paper III, in order to control whether correct results were obtained from the MakeitRational programme, a literature review was conducted to study the eligibility of the programme. According to Sabharwall et al. (2011) and Ishizaka et al. (2013), MakeitRational presents reasonable and accurate results.

Considering Paper IV, since this paper develops a theoretical framework, no analyses were performed for studying internal validity.

External validity discusses whether the achieved results are generalizable (Creswell, 2013). Increasing generalizability in this study is a difficult task, since all simulations were performed following Swedish standard perspective. Furthermore, the properties of used materials, heating, ventilation and air conditioning (HVAC) system and other buildings' attributes were based on common construction practices in Sweden. However, all models developed in simulation tools have been saved for further control. In Paper I and II, gathered data from COMFEN were saved in Excel files. Furthermore, the results achieved from STATA were saved as pdf files. In Paper III, the gathered data from Diva for Rhinocore and IDA ICE were saved in Excel files, while the results from MakeitRational were saved as a Microsoft Word document. This document was generated automatically by MakeitRational. In Paper IV, since the data gathering method consisted of only the literature study, all reviewed studies were documented and saved.

Construct validity confirms that data collection is based on a logical process that maintains consistency, from the research question to the conclusions (Creswell, 2013). However, there is no single solution that provides a complete representation for construct validity (Creswell, 2013). Considering this limitation, the procedure for conducting this study is described clearly. This process may help the reader to understand what was done and to evaluate the quality of the study.

The test for reliability verifies the consistency of a measure (Heale et al., 2015). One of the attributes of the reliability in quantitative research is stability, which tests whether the same results are obtained by repeating the measure (Heale et al., 2015). For this reason, the process of conducting this study is described in detail to allow the reader to follow the process and repeat the simulations and analyses to control the reliability of the study.

3 Results and analyses

3.1 Research question 1: Degree of conflicts

The degree of conflicts was studied considering the first research question (section 1.5, page 10) and addressed in Paper I and II. Accordingly, two multivariate linear regression models were developed in Paper I and II, which show the effect of various window design variables on average daylight illuminance and total energy consumption, respectively. In developing the multivariate linear regression models, window size, glazing system and design model were considered as continuous variables, while orientation was defined as a categorical variable.

The developed multivariate linear regression model in Paper I explains how changes in window design variables affect average daylight illuminance. The model was developed based on 90% of the dataset (490 simulation results from 544) which was selected randomly. Analysing 90% of the dataset showed that average daylight illuminance was not normally distributed. For this purpose, the natural logarithm of average daylight illuminance was determined while the skewness was close to zero (equation 11).

$$\text{Ln-average daylight ill} = \text{Ln}\,(\text{average daylight illuminance} + 176.08) \qquad \text{Eq.11}$$

When the “Ln_ average daylight ill” was defined, a multivariate linear regression model based on 90% of dataset was developed. Table 7 shows the model developed in Paper I. As seen in this table, the R^2[16] value reached 96% and Root Mean Square Error (MSE)[17] was not significant. In addition, the results show the statistical significance of the regression coefficients. Furthermore, the developed multivariate linear regression model was validated

[16] R^2 shows how well observed data can be replicable by a multivariate linear regression model.
[17] MSE is the average of the square of the errors.

in two steps. A detailed explanation of the validation process can be found in the attached Paper I.

Table 7. Developed multivariate linear regression model for calculating Ln_ average daylight ill.

Ln_ average daylight ill.	coefficient	Std. Err[18]	t	P> | t |	95% conf. Interval	
Window size	0.011	0.0003	30.15	0.000	0.010	0.011
Glazing system	-0.096	0.009	-10.57	0.000	-0.114	-0.078
Design model	-0.089	0.004	-21.82	0.000	-0.097	-0.081
Orientation						
North	0					
South	0.405	0.028	14.11	0.000	0.348	0.461
East	0.228	0.028	7.95	0.000	0.172	0.285
West	0.264	0.029	9.10	0.000	0.207	0.321
Orientation* Size						
North	0					
South	0.007	0.0005	14.96	0.000	0.006	0.008
East	0.005	0.0005	9.98	0.000	0.004	0.006
West	0.006	0.0005	11.75	0.000	0.005	0.007
Constant	5.632	0.026	214.50	0.000	5.581	5.684

R^2	0.96
F (9, 480)	1380.99
Root MSE	0.10

The first developed multivariate linear regression model for studying average daylight illuminance in Paper I can be written as:

Ln_ average daylight ill. for north (base case) =0.011 Window size -0.096 Glazing system- 0.089 Design model+ 0 orientation_ north+ 0 Orientation* Size_ north+ 5.632 — Eq.12

Ln_ average daylight ill. for south = 0.011 Window size- 0.096 Glazing system -0.089 Design model+ 0.405 orientation+ 0.007 Orientation* Size_ south +5.632 — Eq.13

Ln_ average daylight ill. for east = 0.011 Window size - 0.096 Glazing system - 0.089 Design model+ 0.228 orientation+ 0.005 Orientation* Size_ east +5.632 — Eq.14

Ln_ average daylight ill. for west = 0.011 Window size - 0.096 Glazing system - 0.089 Design model+ 0.264 orientation+ 0.006 Orientation* Size_ west +5.632 — Eq.15

The sign of variables' coefficients in equations 12 to 15 show the direction of their effect. Analysing the coefficient of window size, glazing system, design model and orientation in equations 12 to 15 shows that:

[18] Standard error represents the standard deviation of dataset distribution.

1. If glazing system, design model and orientation are kept constant, then increasing window size by 5% (for example WWR: 10% to WWR: 15%), increases the “Ln_ average daylight ill” by 0.011. Higher daylight illuminance is generally considered as a favourable effect.

2. If window size, design model and orientation are kept constant, then changing the glazing system from Elit Orginal to electrochromic SageGlass decreases the “Ln_ average daylight ill” by -0.096, which shows a higher performance by Elit Orginal in penetrating daylight into the interior environment.

3. If window size, glazing system and orientation are kept constant, then changing the design model (window form and position) from group 1 to 2, or 2 to 3, or 3 to 4, decreases the “Ln_ average daylight ill” by -0.089., which explains that the group 1 design model (centrally located window) has better performance in providing daylight.

4. If window size, design model and glazing system are kept constant, then changing orientation from north to south, east and west increases the “Ln_ average daylight ill” by 0.405, 0.228 and 0.264 respectively. This means that south orientation has better performance in providing daylight.

5. Comparing the absolute coefficient of variables in equations 12 to 15 shows that changing orientation has greater effect on “Ln_ average daylight ill” than other variables (table 8).

Table 8. Comparing the absolute coefficient of variables

Change in variables	Effect on “Ln_ average daylight ill”
Changing window size by 5%	|0.011|
Changing glazing system from Elit Orginal to electrochromic SageGlass	|0.096|
Changing design model from group 1 to 2, 2 to 3 and 3 to 4	|0.089|
Changing orientation	
North to south	|0.405|
North to east	|0.228|
North to west	|0.264|

The developed multivariate linear regression model in Paper II explains how changes in window size, glazing system, design model and orientation affect the total energy consumption. The total energy consumption comprises energy demand for heating, cooling, electricity for lighting and artificial ventilation. The multivariate linear regression model was developed based on 90% of the dataset, selected randomly. Since the 90% of the dataset was not distributed normally, the natural logarithm of the total energy consumption was defined while the skewness was close to zero (equation 16).

Ln- total energy consumption = Ln (total energy consumption+ 5.3) Eq.16

Later, a multivariate linear regression model was developed, presented in Table 9. The R^2 value of the multivariate linear regression model was exceeded to 94% and the Root MSE was not significant, and indicates that the developed model has a good fit to calculate the “Ln_ total energy consumption”. The second multivariate linear regression model was validated within two steps, which was described in Paper II.

Table 9. Developed multivariate linear regression for calculating Ln_ total energy consumption

Ln_ total energy consumption	coefficient	Std. Err	t	P> | t |	95% conf. Interval	
Window size	0.015	0.000	83,98	0.000	0.014	0.015
Glazing system	0.038	0.009	4.38	0.000	0.209	0.055
Design model	-0.004	0.004	-3.47	0.001	-0.021	-0.006
Orientation						
North	0					
South	-0.129	0.012	-10.49	0.000	-0.153	-0.104
East	-0.068	0.012	-5.48	0.000	-0.091	-0.043
West	-0.059	0.012	-4.88	0.000	-0.084	-0.035
Constant	2.802	0.204	137.03	0.000	2.762	2.843

R^2	0.94
F (9, 480)	1210.59
Root MSE	0.09

The developed multivariate linear regression model for calculating “Ln_ total energy consumption” can be written as:

Ln_ total energy consumption for north (base case) =0.015 Window size +0.038 Glazing system- 0.004 Design model+ 0 Orientation_ north+ 2.802 Eq.17

Ln_ total energy consumption for south =0.015 Window size +0.038 Glazing system- 0.004 Design model- 0.129 Orientation_ south+ 2.802 Eq.18

Ln_ total energy consumption for east =0.015 Window size +0.038 Glazing system- 0.004 Design model- 0.068 Orientation_ east+ 2.802 Eq.19

Ln_ total energy consumption for west =0.015 Window size +0.038 Glazing system- 0.004 Design model- 0.059 Orientation_ west+ 2.802 Eq.20

Analysing the coefficient of window size, glazing system, design model and orientation in equations 17 to 20 shows that:

1. If glazing system, design model and orientation are kept constant, then increasing window size by 5% (for example WWR: 10% to WWR: 15%), increases the “Ln_ total energy consumption” by 0.015.

2. If window size, design model and orientation are kept constant, then changing the glazing system from Elit Orginal to electrochromic SageGlass increases the “Ln_ total energy consumption” by 0.038. This occurs due to the smaller u-value of the Elit Orginal window in comparison with electrochromic SageGlass.

3. If window size, glazing system and orientation are kept constant, then changing the design model (window form and position) from group 1 to 2, or 2 to 3, or 3 to 4, decreases the “Ln_ total energy consumption” by -0.004.

4. If window size, design model and glazing system are kept constant, then changing orientation from north to south, east and west decreases the “Ln_ total energy consumption” by -0.129, -0.068 and -0.059 respectively. This means that south orientation has better energy performance.

5. Comparing the absolute coefficient of variables in equations 17 to 20 shows that changing orientation has greater effect on “Ln_ total energy consumption” than other variables (table 10)

Table 10. Comparing the absolute coefficient of variables

Change in variables	Effect on “Ln_ total energy consumption”
Changing window size by 5%	|0.015|
Changing glazing system from Elit Orginal to electrochromic SageGlass	|0.038|
Changing design model from group 1 to 2, 2 to 3 and 3 to 4	|0.004|
Changing orientation	
North to south	|0.129|
North to east	|0.068|
North to west	|0.059|

3.1.1 Simultaneous analysis of results obtained from Paper I and II

When the multivariate linear regression models were developed and studied, a simultaneous analysis was performed to show the degree of the conflicts. For instance, analysing the coefficient of window size, glazing system, design model and orientation in equations 12 and 17 shows that;

1. If glazing system, design model and orientation are kept constant, then comparing the coefficient of window size in equations 12 and 17 shows that increasing the window size by 5%, (for example changing WWR from 10% to 15% or 20% to 25%) increases the “Ln_ average daylight ill” by 0.011, while increases the “Ln_ total energy consumption” by 0.015.

   Ln_ average daylight ill. for north (base case) =0.011 Window size -0.096 Glazing system- 0.089 Design model+ 0 orientation_ north+ 0 Orientation* Size_ north+ 5.632 Eq.12

   Ln_ total energy consumption for north (base case) =0.015 Window size +0.038 Glazing system- 0.004 Design model+ 0 Orientation_ north+ 2.802 Eq.17

   It should be mentioned that increasing average daylight illuminance is generally considered as a desirable effect of increased window size, while increasing total energy consumption is considered as an unfavourable effect.

2. If window size, design model and orientation are kept constant, then evaluating the coefficient of glazing system in equation 12 and 17 shows that changing the glazing system from Elit Orginal to electrochromic SageGlass decreases “Ln_ average daylight ill” by -0.096, while it increases the “Ln_ total energy consumption” by 0.038.

   Ln_ average daylight ill. for north (base case) =0.011 Window size -0.096 Glazing system- 0.089 Design model+ 0 orientation_ north+ 0 Orientation* Size_ north+ 5.632 Eq.12

   Ln_ total energy consumption for north (base case) =0.015 Window size +0.038 Glazing system- 0.004 Design model+ 0 Orientation_ north+ 2.802 Eq.17

   This means that changing the glazing system has an unfavourable effect on both average daylight illuminance and total energy consumption, but changing the glazing system has about 3 times more impact on “Ln_ average daylight ill” than “Ln_ total energy consumption”.

3. If window size, glazing system and orientation are kept constant, then comparing the coefficient of the design model in equation 12 and 17 shows that changing the design model from group 1 to 2, or 2 to 3, or 3 to 4 decreases the “Ln_ average daylight ill” by -0.089, while it decreases the “Ln_ total energy consumption” by -0.004.

   Ln_ average daylight ill. for north (base case) =0.011 Window size -0.096 Glazing system- 0.089 Design model+ 0 orientation_ north+ 0 Orientation* Size_ north+ 5.632 Eq.12

Ln_ total energy consumption for north (base case) =0.015 Window size +0.038 Glazing system- 0.004 Design model+ 0 Orientation_ north+ 2.802 Eq.17

At this point, decreasing average daylight illuminance is considered as an unfavourable effect of changing the design model, while decreasing energy consumption is counted as a desirable effect. It should also be mentioned that comparing coefficients (-0.089 and -0.004) shows that changing the design model has about 22 times more impact on "Ln_ average daylight ill" than "Ln_ total energy consumption".

4. If window size, glazing system and design model are kept constant, then comparing the coefficient of orientation in equations 12 and 13 shows that changing orientation from north to south increases the "Ln_ average daylight ill" by 0.405, while it decreases the "Ln_ total energy consumption" by -0.129 in equations 17 and 18. This means that changing orientation from north to south has about 3 times more effect on "Ln_ average daylight ill" than "Ln_ total energy consumption".

Ln_ average daylight ill. for north (base case) =0.011 Window size -0.096 Glazing system- 0.089 Design model+ 0 orientation_ north+ 0 Orientation* Size_ north+ 5.632 Eq.12

Ln_ average daylight ill. for south = 0.011 Window size- 0.096 Glazing system -0.089 Design model+ 0.405 orientation+ 0.007 Orientation* Size_ south +5.632 Eq.13

Ln_ total energy consumption for north (base case) =0.015 Window size +0.038 Glazing system- 0.004 Design model+ 0 Orientation_ north+ 2.802 Eq.17

Ln_ total energy consumption for south =0.015 Window size +0.038 Glazing system- 0.004 Design model- 0.129 Orientation_ south+ 2.802 Eq.18

However, changing orientation from north to east (equations 12 and 14) increases the "Ln_ average daylight ill" by 0.228, but decreases the "Ln_ total energy consumption" by 0.068 (equations 17 and 19). This means that changing orientation from north to east has about 3.35 times more effect on "Ln_ average daylight ill" than "Ln_ total energy consumption".

Ln_ average daylight ill. for north (base case) =0.011 Window size -0.096 Glazing system- 0.089 Design model+ 0 orientation_ north+ 0 Orientation* Size_ north+ 5.632 Eq.12

Ln_ average daylight ill. for east = 0.011 Window size - 0.096 Glazing system - 0.089 Design model+ 0.228 orientation+ 0.005 Orientation* Size_ east +5.632 Eq.14

Ln_ total energy consumption for north (base case) =0.015 Window size +0.038 Glazing system- 0.004 Design model+ 0 Orientation_ north+ 2.802 Eq.17

Ln_ total energy consumption for east =0.015 Window size +0.038 Glazing system- 0.004 Design model- 0.068 Orientation_ east+ 2.802 Eq.19

Changing orientation from north to west (equations 12 and 15) increases the “Ln_ average daylight ill” by 0.264, but decreases the “Ln_ total energy consumption” by 0.059 (equations 17 and 20). This means that changing orientation from north to west has about 4.5 times more effect on “Ln_ average daylight ill” than “Ln_ total energy consumption”.

Ln_ average daylight ill. for north (base case) =0.011 Window size -0.096 Glazing system- 0.089 Design model+ 0 orientation_ north+ 0 Orientation* Size_ north+ 5.632 Eq.12

Ln_ average daylight ill. for west = 0.011 Window size - 0.096 Glazing system - 0.089 Design model+ 0.264 orientation+ 0.006 Orientation* Size_ west +5.632 Eq.15

Ln_ total energy consumption for north (base case) =0.015 Window size +0.038 Glazing system- 0.004 Design model+ 0 Orientation_ north+ 2.802 Eq.17

Ln_ total energy consumption for west =0.015 Window size +0.038 Glazing system- 0.004 Design model- 0.059 Orientation_ west+ 2.802 Eq.20

3.2 Research question 2: Hypothesis test and framework development

Research question 2 (section 1.5, page 10) tests the developed hypothesis which was: “A multi criteria decision-making increases the controllability and manages conflicts in selecting windows and blinds”. This research question is answered in Paper III and IV.

The obtained results show the ability of the AHP in managing the conflicts by performing a prioritisation. Furthermore, AHP provides possibilities to accomplish sensitivity analyses. The sensitivity analysis shows how changing the prioritisations affects the results.

The obtained results from the MakeitRational programme show that the venetian blind with slats at 0° and drawn 100% (VB slat 0°, 100%), roller blind drawn 100% (R, 100%) and double pleated blind drawn 100% (DP, 100%) gained the highest global weight among other blinds. This occurs due to their strength in reducing significantly the risk of glare and improving visual comfort. In this context, visual comfort, which was identified as the most important objective in Matrix A, plays a greater role in achieving a higher global weight than other objectives. Accordingly, the global weight of VB slat 0°, 100%, R, 100% and DP, 100% are significantly larger than the global weight of other blinds. The variance in the global weights of other blinds is very small due to similarity of their performance (Figure 15).

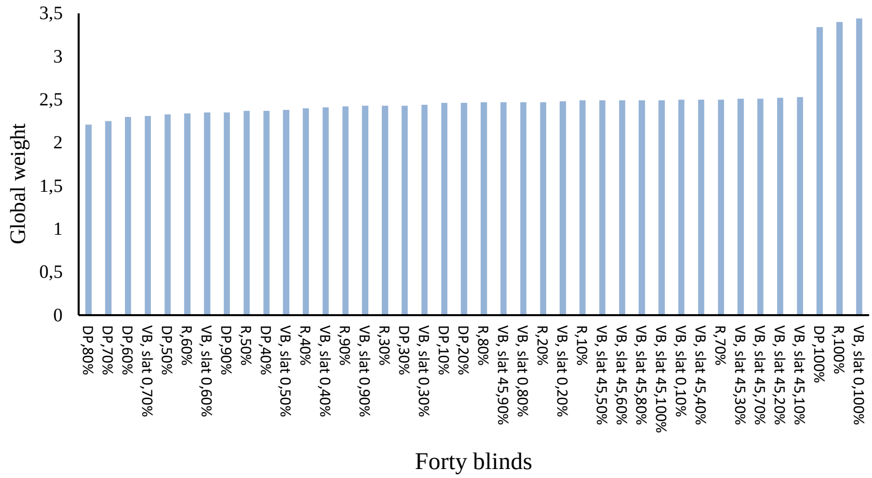

Figure 15. Global weight of each window blind

One of the main restrictions in using AHP is the feasibility of analysing a limited number of windows or blinds (for instance, in Paper III forty blinds were analysed and compared). Hence, Paper IV attempts to expand the application of the AHP by integrating it with optimisation. This process helps to analyse a large number of windows and blinds by optimisation. Later, AHP can rank and prioritise the analysed windows and blinds.

Expanding the application of AHP in Paper IV has been accomplished by 1) determining main window and blind design variables; 2) specifying the main criteria for evaluating visual comfort, thermal comfort, energy consumption and life cycle cost and their metrics; 3) formulating the optimisation problem; 4) specifying NSGA-II as a proper algorithm for solving the optimisation problem; 5) selecting EnergyPlus as a suitable simulation tool for calculating metrics and modeFrontier as a suitable platform for performing optimisation; 6) explaining the process of employing AHP as a suitable decision-making method; and 7) developing the conceptual framework.

Figure 16 shows the developed conceptual framework for analysing the performance of multiple windows and blinds configurations and performing a prioritisation by AHP. This process helps to achieve decision-makers' desired trade-off outcome.

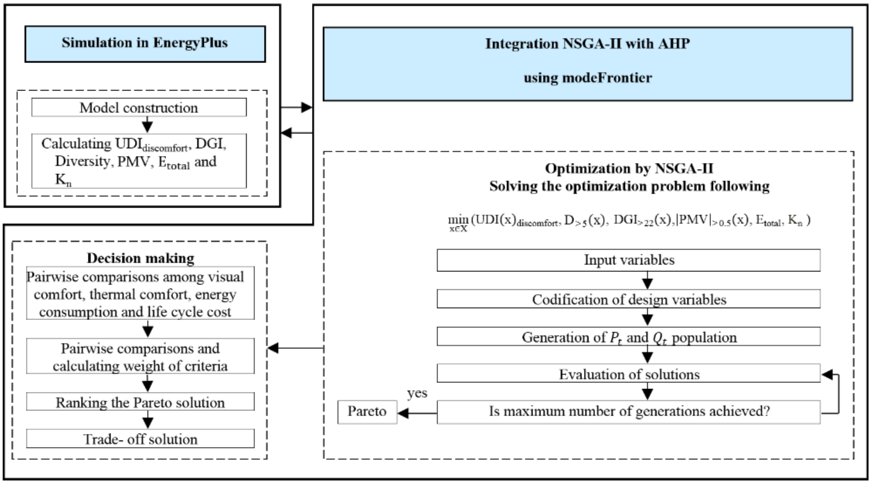

Figure 16. Developed conceptual framework

4 Application of the framework

This section explores the possible application of the developed conceptual framework in practice for selecting windows and blinds. It attempts to answer questions regarding why, when and how the framework can be used. Furthermore, this section discusses the possible users of the framework, the types of buildings which can be addressed and the main effects of windows and blinds covered by the framework. Figure 17 shows a schematic illustration of the framework's application in selecting windows and blinds.

Who can use the developed conceptual framework, for what purposes and to what extent?

The conceptual framework can be used by architects, designers and building engineers to increase controllability for decision-makers and to obtain their desired outcomes. Architects and designers are responsible for the development of an architecture model while building engineers analyse the performance of various equipment needed for operating a building.

Architects, designers and building engineers need to elicit qualitative data from individuals as decision-makers. In this process, the decision-makers are asked to express their preferences by determining the relative importance of visual comfort, thermal comfort, energy consumption, life cycle cost and their relative criteria. Later, architects, designers and building engineers should contribute in i) developing a simulation model using EnergyPlus; ii) exploiting NSGA-II in modeFrontier to analyse a large number of window and blind solutions; and iii) bringing preferences into the decision-making process to obtain the desired trade-off solution.

When the conceptual framework can be used?

The conceptual framework can be used during the both design and renovation phases. In design phase, the results of direct contribution between architects, designers, engineers and individuals may contribute to further changes and/or improvements in the architecture model.

Opportunities in analysing various window and blind design variables in design phase may be larger than renovation phase. For instance, changing orientation may not be feasible in renovation phase.

Why was the conceptual framework developed?
The conceptual framework is a novel solution to the lack of a feasible method in increasing controllability for decision-makers and enhancing SWB while selecting windows and blinds.

What types of relations between SWB and window and blind selection are considered in the conceptual framework?
The developed conceptual framework considers visual and thermal comfort as long-term benefits of windows and blinds for enhancing SWB. Higher level of visual and thermal comfort contributes to the generation of pleasant feelings, improve individuals' ability to perform cognitive interpretations and boost coping by improving health. Furthermore, the conceptual framework cinsiders the effects of window and blind selection on energy consumption and life cycle cost. Inappropriately selected windows and blinds can have negative impact on economy by increasing investment, consumption (energy) and maintenance cost.

How can increased perceived control be represented in using the conceptual framework?
As discussed previously, increasing perceived control relies on increasing the controllability for bringing about desired outcomes. The conceptual framework considers the contradictory effects of window and blind selection on SWB, including visual comfort, thermal comfort, energy consumption and life cycle cost. Furthermore, it increases the controllability and manages the conflicts by prioritising decision-makers' preferences. This process prevents making decisions which are solely motivated by decreasing cost (immediate benefits) or improving visual and thermal comfort (long-term benefits). Instead, it helps to obtain a desired trade-off solution.

Which types of buildings can be addressed with the conceptual framework?
The conceptual framework can be used in selecting windows and blinds for both residential and commercial buildings. However, there are various types of spaces in buildings and each space has its own functionality and characteristics. For instance, in a residential building, living room, bed room, kitchen and dining room have their own attributes. Accordingly, individuals' expectations concerning windows and blinds may vary based on the functionality of each space. Hence, in using the conceptual framework, pairwise comparisons should be performed for spaces with different functionalities.

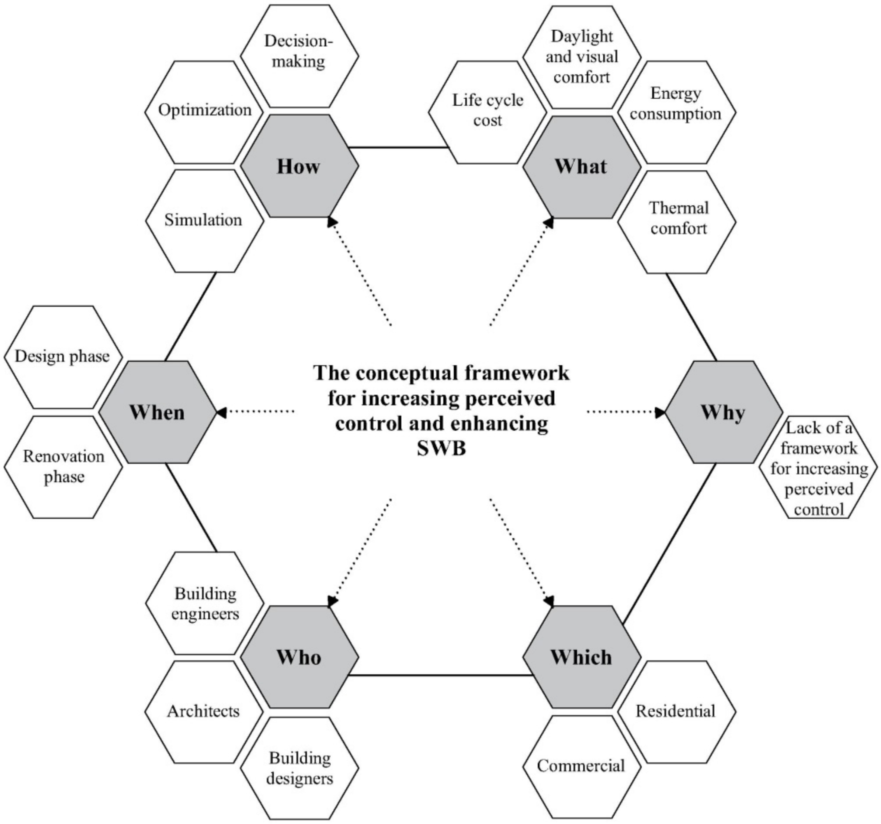

Figure 17. Application of the conceptual framework

5 Conclusion

The aim of this study was to enhance subjective well-being (SWB) in selecting windows and blinds. SWB has two main components: core affect, which refers to the generation of pleasant and unpleasant feelings, and satisfaction, which refers to an individual's ability to perform cognitive interpretations.

The result of literature study shows that enhanced SWB is associated with a higher level of perceived control. One of the main principles of perceived control is awareness, which refers to a situation where individuals understand the consequences of their behaviour. Increased awareness obliges individuals to focus on the outputs of their behaviour and determine how an event can be controlled to bring about their desired outcomes.

Increased awareness regarding the contradictory effects of window and blind selection on subjective well-being, including visual comfort, thermal comfort, energy consumption and life cycle cost, may bind individuals as decision-makers in a situation where they follow the immediate economic benefits rather than long-term visual and thermal benefits. To solve this problem, this study analysed first and foremost the degree of conflicts involved in window and blind selection, which was addressed in first research question. Two multivariate linear regression models were developed for calculating average daylight illuminance and total energy consumption. This decision was made due to large variation in solar elevation angle and solar intensity between summer and winter in Sweden, which has significant effects on daylight illuminance and total energy consumption.

Comparison and analysis of the multivariate linear regression models shows the existence of a high degree of conflicts, which makes window and blind selection a rather complex multidimensional problem. The obtained results from Paper I and II formed a hypothesis as: "A multi criteria decision-making increases the controllability and manages conflicts in selecting windows and blinds". In this study, increasing controllability was addressed in the second research question and translated to a process where conflicts among visual comfort, thermal comfort, energy consumption and life cycle cost are managed by prioritising decision-makers' preferences.

The developed hypothesis was later tested using the analytic hierarchy process (AHP) as a multi criteria decision-making method. The obtained results show the ability of the AHP to manage the conflicts by performing a prioritisation. Furthermore, AHP provides possibilities to perform sensitivity analyses. The sensitivity analysis shows how changing the prioritisations affects the results. However, one of the main restrictions in using AHP is the feasibility of analysing the performance of a limited number of windows or blinds. In order to overcome this limitation and expand the application of AHP, a conceptual framework was developed by integrating AHP with nondominated sorting genetic algorithm-II (NSGA-II) as an optimization algorithm.

Application of the conceptual framework in selecting windows and blinds offers the opportunity to include different variables in the design process and analyse a large number of design solutions. This process increases the likelihood of finding a suitable solution that considers decision-makers' preferences. Furthermore, the conceptual framework exploits the AHP method to quantify decision-makers' qualitative preferences and integrates them into the decision-making process. The transmission of preferences is the key point in enhancing subjective well-being since it helps to bring about desired outcomes. In the context of window and blind selection, the conceptual framework is a novel solution for enhancing subjective well-being.

The developed conceptual framework can be used by architects, designers and building engineers, during both design and renovation phases, to bring about individuals' desired outcomes. Furthermore, the conceptual framework is applicable in selecting windows and blinds for residential and commercial buildings. But, individuals' expectations concerning windows and blinds may vary based on the functionality of different spaces in residential and commercial buildings. Hence, in using the conceptual framework, pairwise comparisons should be performed for spaces with different functionalities. The conceptual framework is a novel solution to the lack of a feasible method in increasing the controllability for decision-makers and enhancing SWB while selecting windows and blinds.

6 Future work

Future work in this study will include:

1- Specifying actual preferences regarding visual comfort, thermal comfort, energy consumption and life cycle cost and their respective criteria in Sweden.

In using AHP, pairwise comparisons among objectives of the hierarchy model (visual comfort, thermal comfort, energy consumption and life cycle cost) and their respective criteria were applied by conducting a literature study. Therefore, it would be interesting to specify the actual preferences in Sweden. This investigation will be performed by conducting a survey during autumn, winter 2017 and spring and summer 2018 in order to understand whether changes in climate conditions affect individuals' preferences. Furthermore, the survey will analyse individuals' preferences regarding various view types. According to Altomonte (2009), a good view should include both the foreground and skyline. This analysis helps to determine whether having a good view is equally important as visual comfort, thermal comfort, energy consumption and life cycle cost. In such a case, a minimum window size for providing a good view should be defined in performing simulations. The survey will be conducted in single side-lit office rooms in commercial buildings

2- Testing the developed conceptual framework in a case study and evaluating its capability in increasing controllability for obtaining decision-makers' desired outcomes.

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Appendix 1

Existing studies have mostly discussed about multi dimensionality of SWB and tried to define it as a balance between positive and negative events (Ormel et al., 1991; Ormel et al., 1991; Suh et al., 1996). According to Diener (1984), when an event takes place, life domain factors such as health, economy, personality, demographic[19] and behavior[20] variables affect individuals' cognitive interpretation of the event and generation of feelings for the event [21]. Following Diener's theory, if the event is interpreted as negative event, then it generates unpleasant feelings. At this point individuals exploit the *coping* system to maintain the SWB (Diener et al., 1999). Coping is defined as individuals' effort to manage the encountered negative events (Mitrousi et al., 2013). According to Diener (1984), if the coping system is unsuccessful in managing the negative event then SWB will be diminished. Diminished SWB refers to a situation where individuals experience dysfunctions (Boyle, 2013) and depression (Cummins, 2010).

The other theory considering SWB, proposed by Cummin (Cummins, 2010), is also in line with previous studies and considered SWB as an equilibrium between positive and negative events. However, Cummins's theory concentrates mostly on *strength* of negative events (also called challenging agents by Cummins), rather than existence of them and describes how they affect SWB. In evaluating SWB, this theory provides a set-point between 70 to

[19] Demographic variables include age, gender, race, employment, education and marriage (Diener, 1984).

[20] Behaviour variables comprise such as individuals social contact and their physical activities (Diener, 1984).

[21] However, among the life domain factors, health and economy show stronger and more positive correlation with SWB (Diener, 1984). This correlation remains even when other life domain factors are controlled (Diener, 1984). Altogether, improved health and better economy can contribute in generation of pleasant feelings and higher ability in performing cognitive interpretation, that prevents the appraisal of an event as a negative event.

80 margins[22] (Figure i) (Cummins, 2010). According to Cummins' theory, if the positive events are dominated then the state of SWB will be tended to upper margins and be enhanced (phase a in Figure i) (Cummins, 2010). Enhance SWB refers to a situation where individuals experience pleasant feelings and have higher level of motivation and encouragements[23] (Sin et al., 2009).

Following Cummins' theory, if the strength of the negative events become stronger, individuals exploit *homeostatic defense system* to maintain SWB. Homeostasis is a neuroendocrine system which tries to maintain the SWB around set-point by maintaining a stable condition in the body (Boyle, 2013). Therefore, SWB remain steady until homeostasis defense system is effective (phase b in Figure i). Once the strength of negative events become too strong for homeostasis defense system, the SWB will be fallen into phase c and be diminished.

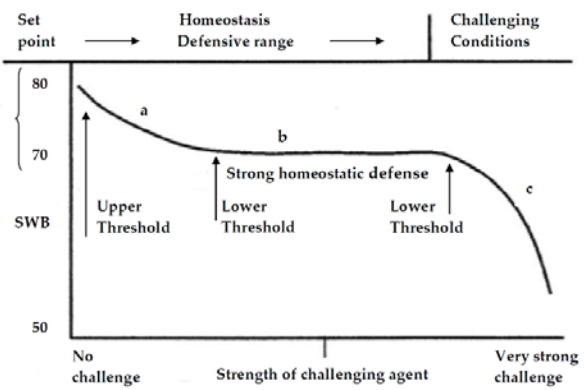

Figure i. Cummins' SWB theory

Understanding the way negative events affect individuals' SWB and how they use coping and homeostasis systems to maintain SWB, relies in exploring the phenomenology of the individuals' physiological response to the negative events. When an event takes place, it stimulates sensory receptors[24] located in

[22] The theory was developed by studying data from performed surveys in different western countries. These surveys had been conducted for evaluating individuals' SWB. Since surveys were conducted during 1970-1990 and different scale of measurements were used, the results were transformed onto a 0-100 scale. The mean of all surveys was 75 point with a standard deviation of 2.5. The SWB margins were obtained using two standard deviation on either side as 75 ± 5 or 70-80. The stability of SWB was also studied using 21 Australian Unity Wellbeing Index surveys, which were conducted between 2001-2009.

[23] However, enhance SWB for individuals with depression refers in reduced depressive symptoms (Sin et al., 2009).

[24] Some receptors in central nervous system included vision, auditory, smell and taste receptors, while some of the receptors located in peripheral nervous system comprise pain, touch and temperature receptors on skin (Patton et al., 2015).

central nervous system[25] (brain and spinal cord) and peripheral nervous system[26] (all nervous excluding central nervous system) (Patton et al., 2015). The stimulated receptors send their impulses toward the brain (Boyle, 2013). At this point, individuals try to interpret the event (cognitive interpretation). This interpretation can be explained using cognitive appraisal theory (Oliver et al., 2002). According to this theory, individuals first try to determine whether or not an event have a negative implication, which is progressed under influence of life domain factors[27] (Boyle, 2013). Once an event perceived as a negative event, the brain initiates neurological triggering mechanism, that targets the neural, homeostasis and endocrine systems (Boyle, 2013). Neural system is the first and quickest response and has an immediate effect on target organs[28]. Higher level of negative event triggers the homeostasis system (Boyle, 2013). Homeostasis system is the adaptational effort of the body to maintain the internal balance. Endocrine system is the most chronic response, where activation of it require greater intensity of a negative event (Boyle, 2013).

Activation of neural, homeostasis and endocrine systems, increase, inhibit or catabolize the normal activities of target organs that maintains a stable condition in the human body. For instance, activation of neural system can cause to dilate or constrict of pupil of eye, thick or water secretion, increase or decrease of heart rate (Boyle, 2013). Homeostasis system activation can lead to increase blood flow to brain, increase arterial blood pressure, increase stimulation of skeletal muscles and decrease in blood flow to skin (Boyle, 2013), while activation of endocrine system can cause to appetite suppression, feeling of depression and helplessness and suppression of immune mechanism (Boyle, 2013). Activating the target organ increases individuals' ability in dealing with the negative event.

An effective homeostasis system means that individuals are successful in dealing with the negative event (Cummins, 2010). Accordingly, the negative event will no longer be appraised as negative one, consequently SWB will remain steady (Feedback in figure ii). But, if homeostasis system is ineffective in activating target organ then the negative event will cause to dysfunction, disease (Boyle, 2013) and depression (Cummins, 2010), consequently diminishes SWB. But, Boyle argued that individuals take some further actions to manage the negative event before SWB is diminished. Accordingly,

[25] Central nervous system contributes in decoding and interpreting of received signals from other organs, communication ability, presiding over imagination, solving tasks, planning, controlling emotions and vegetative functions including heartbeat and respiration (Boyle, 2013).
[26] Peripheral nervous system is responsible to regulate body's internal environment and maintenance of the homeostasis and innervates an organ with other organs (Boyle, 2013).
[27] Life domain factors were called as "Source for coping" by Boyle (2013).
[28] Some of target organs comprise the gastrointestinal system, cardiovascular system, the immune system, skin, brain and mental status (Boyle, 2013).

individuals exploit coping system as the subsequent step, to deal with the negative event. The coping system depends on individuals' personal and social recourses (Zeidner et al., 1996). Personal resources refer to individuals' personal abilities in facing with a negative event including their self-efficacy and optimism (Zeidner et al., 1996) and is affected by individuals' health (Reinhardt et al., 2009).

Social resources comprise individuals' perceived emotional support from their family and friends (Zeidner et al., 1996) (page 31). In either way, if the coping mechanism is successful then homeostasis system is re-established (Feedback in figure 3) (Boyle, 2013). But if coping mechanism is unsuccessful then it increases the risk for diseases and depression (Boyle, 2013), consequently diminishes SWB.
Exploring physiological response to an event shows how cognitive interpretations and feeling generation contribute to perception of an event as positive or negative. Furthermore, it helps to understand proposed theories by Diener (1984) and Cummins (2010) and explains how homeostasis and coping mechanisms work to maintain SWB.

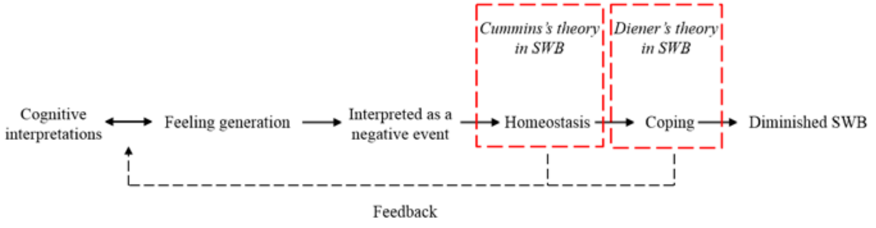

Figure ii. The role of homeostasis and coping systems in maintaining SWB

Appendix 2

Vision and myopia: Human vision is regulated by cone and/or rod photoreceptors (Aries et al., 2015). Human vision under an adequate amount of light is controlled by cone photoreceptors (Aries et al., 2015). Darkness vision is regulated by rod photoreceptors and vision in dim light is controlled by both cone and rod photoreceptors (Aries et al., 2015). Light falling in the eyes stimulates the optic nerves and triggers the visual cortex in the brain. Transition from engagement solely of rod to engagement of cone photoreceptors is under the direct influence of the amount of light. According to Aries et al. (2015), the performance of human vision is generally better in daylight. Furthermore, improving vision can reduce depression (Aries et al., 2015) and boost cognitive performance. This connection in which the visual environment affects individuals' vision is defined as visual comfort (European standard EN 12665). Visual comfort has mainly been analysed by studying the relationship between individual needs and light environment (Carlucci et al., 2015a).

Eye strain and headache: Eye strain refers to fatigue of the eyes and is often accompanied by headaches (Aries et al., 2015). Eye strain occurs due to tightness of ciliary muscles which changes the shape of the lens in the eye (Aries et al., 2015). According to Aries et al. (2015), eye strain is strongly related to the spectrum of light. Because daylight provides the best light spectrum, it can significantly reduce the risk of eye strain (Aries et al., 2015). Eye strain can cause difficulties in learning and information processing, which diminishes cognitive interpretation (Edwards et al., 2002). Furthermore, it leads to higher levels of stress and anxiety (Edwards et al., 2002). According to Boyce et al. (2003), repeated experience of eye strain and headache can generate unpleasant feelings.