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Adaptive human behaviour and well-being in office buildings

Master's thesis in Structural Engineering and Building Technology

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A picture of Nya Regionens hus, an office building in Gothenburg.

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Abstract

The constructions sector holds for a third of the global energy consumption and the energy demand in the world is constantly increasing. Since occupants spend over 80% of their time indoor they play a significant role in the operation phase of the buildings and their behaviour have a great impact on the energy consumption and indoor environmental quality. The purpose with this thesis is to improve the understanding of adaptive human behaviours in office buildings. Adaptive behaviours are undertaken to improve comfort that will entail changes in the indoor environmental quality that could trigger new behavioural actions. For each comfort aspect there are several different related actions and affecting factors. The relation between indoor environmental quality parameters and behavioural actions and energy usage is investigated with an aim to find the most energy demanding behaviours and how these can be optimised while still maintaining a comfortable indoor environment.

A literature review of previous studies is performed, to map the relations between different parameters and behaviours. A questionnaire as a part of a possible subjective method is then developed from the findings. To investigate the behaviours and the impact on energy consumption and comfort in office buildings, a case study in Sweden was made by simulating combinations of energy consuming behaviours. The result show that behaviour connected to artificial light has the largest energy impact.Individual adjusted parameters and contextual factors has the greatest influence on the thermal comfort. Different combinations of adaptive behaviours affect the energy efficiency and indoor comfort to different degrees, such as different schedules connected to internal gains. The optimal solution is a combination of automatic systems to minimise the energy consumption when many occupants share the same space.

Key words: Energy performance, Indoor Environmental Quality, Thermal comfort, Adaptive behaviour, Occupant behaviour, Office building.

Användarnas adaptiva beteende och välmående i kontorsbyggnader

Examensarbete inom Konstruktionsteknik och Byggnadsteknologi

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Sammanfattning

Byggsektorn står för en tredjedel av den globala energikonsumtionen och energibehovet i världen går ständigt uppåt. Eftersom människan spenderar över 80% av sin tid inomhus spelar användarna en viktig roll i byggnadens användningsfas. Deras beteende har därför en stor inverkan på energikonsumtionen och kvalitén på inomhusmiljön. Syftet med detta arbete är att förbättra förståelsen av användarnas adaptiva beteende i kontorsbyggnader. Adaptiva beteende genomförs för att förbättra komforten vilket kommer medföra förändringar i inomhusmiljökvalitén som i sin tur kan trigga nya beteendeåtgärder. För varje komfortaspekt finns det flera relaterade beteenden och påverkande faktorer. Relationen mellan inomhusmiljökvalitéts parametrar, beteendeåtgärder och energianvändning undersöks med avsikt att hitta de mest energikrävande beteendena och hur dessa kan bli optimerade samtidigt som man behåller en komfortabel inomhusmiljö.

En litteraturstudie har gjorts på tidigare genomförda studier, för att kartlägga relationen mellan olika parametrar och beteenden. En enkät togs fram från resultatet som en möjlig del av en subjektiv undersökning. För att undersöka beteenden, påverkan av energikonsumtion och komfort i en kontorsbyggnad i Sverige gjordes en fallstudie genom att simulera olika kombinationer av energikrävande beteenden. Resultatet visar att beteenden som är kopplade till lampor har den största energipåverkan. Individuellt justerade parametrar och kontextrelaterade faktorer har störst påverkan på termisk komfort. Olika kombinationer av adaptiva beteenden påverkar energiåtgången och inomhusklimatet till varierande grad, såsom olika scheman av interna laster. Den optimala lösningen är en kombination av olika automatiska system för att minimera energikonsumtionen när många användare delar samma utrymme.

Nyckelord: Energiprestanda, Inomhusmiljö kvalité, Termisk komfort, Adaptivt beteende, Användarbeteende, Kontorsbyggnad

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Malin Eriksson & Felicia Spaak, Gothenburg, June 2021

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Nomenclature

ABC	Attitude behavioural context
AHU	Air handling unit
AUX	Auxiliary
CLO	Clothing level
CO	Carbon
CO_2	Carbon dioxide
DV	Design value
DVUT	Dimensioning winter outdoor temperature
HVAC	Heating, ventilation and air conditioning
IAQ	Indoor air quality
IDA ICE	IDA indoor climate and energy
IEC	Indoor environmental control
IEQ	Indoor environmental quality
IR	Infra-red
MET	Metabolic rate
NAM	Norm activation model
OCC	Occupancy
PMV	Predicted mean vote
PPD	Predicted percentage of dissatisfied
RFID	Radio frequency identification
RH	Relative humidity
SBS	Sick building syndrome
SMHI	Swedish meteorological and hydrological institute
TPB	Theory of planned behaviour
VAV	Variable air volume
VOC	Volatile organic compoun

1. Introduction

The first chapter introduce the background of the subject together with purpose. It is followed by aim and objectives that present the research questions that are used for this thesis. Here the scope and limitations that are chosen is presented as well. This chapter also includes a summarize of this thesis structure and where the research questions are answered.

1.1. Background

Buildings and the construction sector constitute a third of the global energy consumption in the world today, and the demand is constantly increasing (International Energy Agency (IEA), n.d.). Even though new buildings are more energy efficient due to measures and innovations, the consumption will continue to increase due to the expanding building stock (Abel & Elmroth, 2007). As well as the importance of energy efficient building components and installations, more than 80 % of the energy consumption comes from the operational stage (Salimi & Hammad, 2020). In general, there is a growing demand for energy in buildings, which is a result of increased usage of appliances and a rising demand for energy in building systems (Abel & Elmroth, 2007). Generally, the parameter that has the largest energy usage in commercial buildings, summarized over the world, is heating of the building (Roetzel et al., 2010). But with the changing climate and extreme weather as a sequel, the usage of cooling devices and cooling in HVAC-systems has accelerated in comparison to heating additions in buildings (IEA, 2020). In a warm climate the energy is mainly consumed for cooling and air-conditioning and in a cool climate primarily used for heating (Ürge-Vorsatz et al., 2015), in Sweden the heating corresponds to 45% of the energy use in office buildings (Trüschel, personal communication, November 3, 2020). In commercial buildings the focus is normally on lowering the heat surplus since heat gain increase the cooling demand (Abel & Elmroth, 2007). To make it more energy efficient for the future, a deeper understanding for occupant-building interaction is needed for the operational stage (Heydarian et al., 2020).

In recent years occupant-related information have gotten a larger focus on account of its influences on energy consumption in the developed parts of the world (Wagner et al., 2018). Occupants have a significant role regarding variations of energy use in buildings (Xu et al., 2021), but at the same time the influences are ignored or simplified when estimating the energy demand (D'Oca et al., 2018). Especially for commercial buildings, the understanding for human factors is being disregarded in design and can be seen as the "back side" of energy consumption. In practise, the energy consumption of a building in use can be both higher and lower depending on how well the building is designed and adapted to a specific use already from the start (Xu et al., 2021).

1.2. Purpose

The purpose of this thesis is to improve the understanding of adaptive human behaviours in office buildings and to achieve a better insight in how to design an energy efficient and occupant-centric building.

1.3. Aim and objectives

The aim is to explore what kind of actions occupants undertake to adjust the indoor climate to their comfort level but also how the indoor environmental quality influences mentioned behaviour. This thesis will study how the occupants behave due to changes of indoor climatic parameters and map occupant related assumptions and behaviour parameters in relation to the building design. Furthermore, the aim is to relate the parameters and behavioural actions to energy consumption and how the human factors influence energy efficiency. Based on different scenarios and assumptions, the following questions will be investigated.

1.3.1. Research questions

- Which are the main aspects in indoor environmental quality and how can they be controlled?
- What are the most common adaptive human behaviours related to the mentioned aspects?
- Which parameters and behaviours have the biggest impact on energy consumption and comfort and how could these be optimized?
- What are the methodologies to collect occupant behaviour-related information, e.g., questionnaire, measurement?

1.4. Scope and limitations

The energy usage and occupant behaviour in buildings include many associated parameters. This thesis will investigate an office building in Gothenburg, Nya Regionens Hus. The simulations and data will mainly be focusing on occupant related aspects in building design and the input parameters of temperature, illuminance, and the possible control within these that are related to the energy usage and comfort. Since the parameters are highly affected of the season in question the result will be adjusted to a specific time frame or treated as a mean value. The consequences the environment has on the human health will not be considered. Psychological aspects such as behaviour models have briefly been introduced but not further investigated in the case study.

One of the most extensive limitations is the Covid 19 pandemic. Because of the pandemic replanning and changes have been made along the work. The case study is made on distance, without a site visit. No current data can be provided for the building since measurements cannot be done, design data and assumptions are therefore used for the case study. Since many occupants in Nya Regionens Hus are working from home the questionnaire cannot be handed out, this because the low occupancy rate does not correspond to the designed occupancy rate and will therefore not give accurate results.

The literature study mainly focuses on office buildings and, in some cases, commercial building in general, when usage is not specified. The buildings studied are mainly located in Europe or in similar climate as Sweden (Subarctic or humid continental climate). Literature from other countries is disregarded unless the information does not have a relation to the location or climate. The building codes used in the thesis are codes from Sweden and other are not considered.

The thermal comfort will thoroughly be investigated throughout the thesis. Air quality, acoustic comfort and visual comfort will be investigated in the literature study and used in the subjective study. Parameters connected to these subjects are used as input data (set-points for CO_2 and illuminance), but the comfort related aspects (air quality, acoustic comfort and visual comfort) will however not be investigated further in the case study since it would get too extensive.

In the case study the literature is scaled down and mainly focuses on thermal comfort and energy performance. The study is limited to one floor of the building, to ease the simulation time. The thermal comfort study is limited to six rooms which consist of three equal zones in usage, to compare result in two different orientations. The remaining zones are not studied since they are equal to investigated zones or less relevant in terms of occupancy and usage. The energy study contains delivered energy from heating, cooling, HVAC system, equipment and lighting. Other energy systems such as domestic hot water are disregarded.

1.5. Structure of the thesis

The structure for this thesis contains three different main parts, a literature review, a case study and a questionnaire design. The thesis is divided into several chapters according to the structure below.

Literature Review
The second chapter is the literature review where the method is presented followed by the theory. Background information and data from other cases will be included in this review. The theory includes supporting literature about indoor environmental quality, energy performances, the human behaviour, Swedish standards and methodologies from existing studies. The first and second research questions are answered in this chapter. The fourth question is answered here and is used as a base of the questionnaire.

Case Study
The third chapter present the method and the result from the case study which regards simulations of the thermal comfort and energy performance of the building. They investigate the result of different combinations of human behaviour and IEQ-related parameters. The third research question is answered in the case study and is supported by theory from the literature review.

Questionnaire
The fourth chapter include the method and form of the questionnaire which is made with the theory as a base. It is structured to be a subjective survey that includes the most adaptive behaviours and comfort related parameters.

Discussion
The fifth chapter is a discussion and analysis of the findings from the result in comparison to the mapping in theory chapter.

Conclusions
The sixth chapter presents the conclusion and answers to the research questions. Here is also a short paragraph with possible further studies of the subject.

2. Literature Review

This chapter includes a literature review of relevant theory in connection to the subject of this thesis. The main topics are indoor environmental quality, occupant behaviour, occupant related information in building design and methodologies to collect and analyse the behaviour.

2.1. Method

The literature library was collected from different platforms as Scopus, Google scholar, Chalmers library and their database. When considering the relevance of articles, reports and books the time limit for the work is 10 years back with some exceptions, such as information that has remained the same with time. Since this is a relatively new study genre the relevance of time was considered for each piece. When collecting literature, keywords was used in the search process. Mainly it was keyword regarding categories of energy, behaviour, indoor environmental quality, office buildings, building codes and standards and methods for questionnaire, data collection and case study.

Following search word has been implemented on its own or combined with other:

- *Energy consumption, energy performance, occupant, office*
- *Indoor environmental quality, comfort, thermal comfort, visual comfort, acoustic comfort, air quality.*
- *Indoor environmental control, behaviour, adaptive behaviour, behaviour models.*
- *Method, questionnaire, case study, simulation*
- *Building code, building standard, stakeholder, design phase*

2.2. Theory

This section presents the findings from the literature review. It includes indoor environmental quality, adaptive occupant behaviours, occupant related information in the design phase and occupant behaviours in building design. It also includes methodologies on how to collect occupant related data. This section is completed with a mapping of behaviours and indoor environmental quality parameters.

2.2.1. Main factors affecting the human behaviour

The individual is able to adjust the indoor environment in many ways. For the human to perform a behaviour, triggering factors must lay ground for it (Chen et al., 2020). When an occupant is dissatisfied with the environment, actions could be taken to make him/her feel more comfortable. The parameters affecting the behaviour that are studied in this thesis are mainly the ones connected to indoor environmental quality.

2.2.1.1. Indoor Environmental Quality, IEQ

Indoor environmental quality, IEQ, is related to the well-being of the building users (Chen et al., 2020). The term regards all parameters affecting the environment inside a building. The building design has a major impact on the human behaviour, productivity and health. There are four main aspects when talking about IEQ (Teli, n.d.); thermal comfort, air quality, visual comfort and acoustic comfort. Since people spend over 80%

of their time indoors, the aim is to reach a high level of IEQ since a low level could lead to negative health effects and a lower productivity (Chen et al., 2020).

2.2.1.1.1. Thermal Comfort

Thermal comfort is the state of the thermal environment at which the occupant express satisfaction (ASHRAE, 2010). It is not the same for every individual since the comfort is based on both psychological and physiological factors and differs between individuals. Comfort depends on several variables, the primary parameters are air temperature, air speed, humidity, radiant temperature, clothing level and metabolic rate (activity) (ASHRAE, 2010). The first four parameters are based on the environment and the last two are personal factors (Al horr et al., 2016). Based on this there are large variations between individuals and thereby hard to satisfy all occupants in a space. The thermal adaptation of occupants is based on climate, geographical location, season, gender and age (Quang et al., 2014) and are therefore different for each individual. When the occupant sense thermal discomfort, it will likely take action to adapt the surrounding environment by adjusting controls (Al horr et al., 2016). The final adaptation and perception of thermal comfort for an occupant can be defined by behavioural adjustment, physiological adaptation and psychological habituation or expectation.

According to Public health agency of Sweden, recommended values for the operative air temperature lays between 20 and 23 degrees Celsius but the guidelines say that the value should not decrease under 18 degrees and above 24 degrees for a long period of time and 26 for short period (Folkhälsomyndigheten, 2014). The upper limit for temperatures according to the guidelines can be an additional 2 degrees higher during the summer season.

There are several methods on how to measure thermal comfort, but the most common metrics are Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfaction (PPD). PMV is the mean value of the votes from a group of people, answered on a 7-point scale (ASHRAE, 2010). The heat balance is influenced of known variables like the factors affecting the thermal environment, such as mean radiant temperature and air velocity. It is also influenced by activity and clothing level of the occupants. When the occupants' heat production is the same as the heat loss equilibrium is reached. PPD is the satisfaction level of the people in the building, where a higher value means higher percentage of dissatisfaction of the occupants. There is a relation between PMV and PPD, shown in *Figure 2.1*, if the PMV is "neutral" the PPD will be low and when the mean vote is close to 3 or –3 the PPD is high.

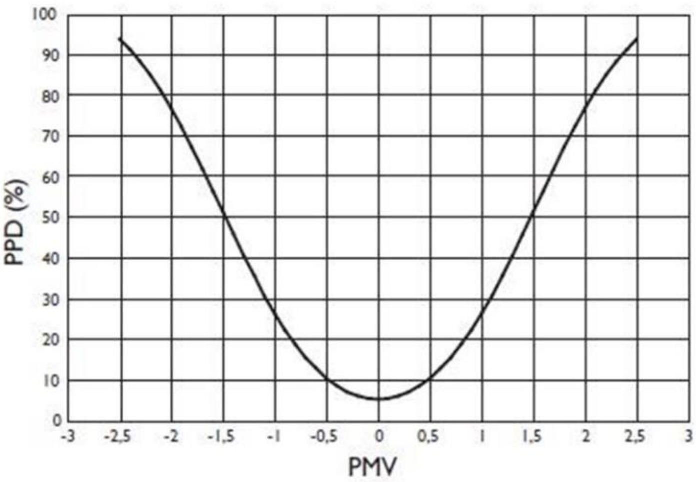

Figure 2.1 *Relation curve between PPD and PMV. "File:PMV PPD v1.jpg" by Benjamin BERT is licensed with CC BY-SA 4.0. To view a copy of this license, visit http://creativecommons.org/licenses/by-sa/4.0. 2020 (https://commons.wikimedia.org/w/index.php?curid=90120763)*

2.2.1.1.2. Air Quality

The definition of air quality refers to the concentration of pollutants in the air that affect the human negatively (ASHRAE, 2019). It can be pollutants that are dangerous for the human to inhale or other pollutants that are unwanted in the air. Air quality is measured in how clean it is and is seen as good if at least 80% of the occupants exposed are satisfied with it and if the pollutions are at a low healthy level (ASHRAE, 2019; Frontczak & Wargocki, 2011). Poor indoor air quality can lead to short- and long-term health impacts (Mentese et al., 2020). Apart from temporary health effects such as headache and concentration difficulties, bad air quality can lead to diseases like asthma, hypersensitivity pneumonitis or cancer.

According to Al horr et al. (2016) and Mentese et al. (2020) Particulate matter (PM) and Ozone are two types of pollution that affects the well-being. Other pollutants in the air can be volatile-, and semi volatile organic compounds, formaldehyde, carbon dioxide, carbon monoxide and other airborne bacteria and fungus (Mentese et al., 2020). There are two ways to adjust the air quality levels, either by increasing the ventilation rate to reduce the pollution or by reducing it at the source. The source of the pollution is often on the outside, but it can also come from inside the building, such as building material or technical equipment.

There is usually a difference in indoor air quality between buildings that are naturally ventilated and buildings that are mechanically ventilated (Al horr et al., 2016). If the building has a mechanical HVAC system, the air is cleaned through a filter before entering the building. In a natural ventilated building, the air comes in through openings and leakages though the building envelope without being filtered.

2.2.1.1.3. Visual Comfort

The visual comfort is the perceived relation between quantity and quality of light within a space and relates to the performance factors; illuminance, glare, distribution and direction (Davoodi et al., 2020). Visual comfort is based on daylight, which is the origin of light for the human being and results in different psychological and physiological responses from the body (de Giuli et al., 2008). Daylight in comparison to artificial light is dynamic, flicker free (natural light without small variations in brightness) and has a variating spectrum but cannot be the only source of light due to variety from seasonal differences.

Windows are important for visual comfort, it gives access to direct daylight and contribution of natural scenery together with reduced feelings of claustrophobia in smaller rooms (Aries et al., 2010). Daylight is also significant for the occupant's well-being and helps improve efficiency and productivity (Kunwar et al., 2020). Although too much daylight can result in glare which leads to discomfort. It could also result in UV radiation and thermal discomfort (Teli, n.d.). A balance of natural light and artificial light is necessary for the occupants to be comfortable (Kunwar et al., 2020). Research show that visual discomfort also could affect the well-being after leaving the building, such as worse sleep (Al horr et al., 2016;Teli, n.d.).

2.2.1.1.4. Acoustic Comfort

The acoustic comfort is the capability to offer an acoustic environment suitable for its purpose and to protect the occupants from noise (Al horr et al., 2016). Acoustic related problems can origin from airborne sounds, outdoor noise, noise from adjacent spaces or noise from nearby facilities or similarities. When looking at office's spaces or general shared spaces, the sound could be divided into lack of privacy for own communication and irritation of different kinds of noises. The level of disturbance depends on the level of noise, the spectrum of sounds and the variation of time that the noise appears. A general perception is that a lot of variation in sounds create a larger discomfort than a more steady sound (Veitch et al., 2002). The ultimate acoustic comfort is reached if desired sound can be maximized and noise is avoided (Teli, n.d.). According to a study made in Germany a high amount of noise can lead to concentration difficulties, stress, increased heart rate and blood pressure (Tiesler et al., 2015).

2.2.1.2. IEQ in office buildings

The indoor environment is important in office buildings since it has a large influence on the working environment, productivity and well-being (Chen et al., 2020). The IEQ in an office building foremost regard the thermal comfort, air quality and ventilation but also the lighting and acoustics. The lighting refers to both sunlight and artificial lighting. According to a study made by Chen et al. (2020), poor IEQ in an office can result in discomfort and health related issues such as headache and concentration difficulties.

The perceived comfort related to IEQ are affected by different parameters, which vary within the occupants and the performed tasks (Kang et al., 2017). The parameters could be demographic variables, such as age and gender, the layout of the building or the ability to control the environment (Frontczak & Wargocki, 2011). Layout includes office type, type of furniture and its orientation. The climate and location of the building have a large influence on the IEQ as well, since parameters like outdoor temperature and solar intensity depends on the weather and building orientation which contribute with heat gains to the building (Al horr et al., 2016). The indoor comfort, as well as the energy consumption, will most likely differ throughout the year because of different seasons with varying weather (Rupp et al., 2015). A general perception of the indoor climate is that an occupant has a larger range of satisfaction regarding comfort in a residential building than an office building, due to sense of control of environment (de Dear et al., 2020). In an office building the adaptive opportunities are quite restrained due to predefined settings in larger shared spaces and a stricter attire.

2.2.1.2.1. Office Layout

The indoor environment quality is heavily dependent on the design of the office (Chen et al., 2020). Quality levels differ a lot if the space is open plan compared to if it is a closed office. With an increased quantity of people the space for each occupant will be less and consequently open plan offices can hold a larger number of occupants (Kang et al., 2017). Shared offices also lead to less privacy for the building users compared to private offices. Another consequence is the increase of unintended conversations and disturbance of co-workers.

Chen et al. (2020) mention a school which have researched influence of layout, where it argues that open plan offices ease the possibility of collaboration and interaction within the occupants. Although there is a possibility of collaboration in an open plan office, research have shown that the outcome of an open layout is often the opposite. Another school have studied the same topic and the result show that the open layout decreases the social interaction together with aspects as increased distraction and concentration issues. Other studies, which agree with the second study, show that open plan offices decrease social interaction due to the increased interaction with computers and other electronics (Bernstein & Turban, 2018). Closed offices are not only better in psychological aspect but also in physical, since the IEQ in an open office is in general worse (Chen et al., 2020).

2.2.1.2.2. Comfort related IEQ parameters

The IEQ parameters are related to each other in many ways both direct and indirect and need to be studied in a holistic perspective (Al horr et al., 2016). One parameter could directly influence the human behaviour in form of a lower motivation or attitude. This can have indirect effects on the productivity of the occupant and other occupants in the office. The parameters related to comfort can, according to researchers, be divided into physiological, psychological and physical environmental conditions (Chen et al., 2020). These are connected to the IEQ parameters which depends on both demographic data and type of climate and performed task (Kang et al., 2017).

Air quality and thermal comfort are two of the IEQ aspects that affects the human most in a commercial building environment (Che et al., 2019). These are significant regarding well-being and productivity, both are highly connected to the HVAC-system which regulates the temperature and air quality through heating, ventilation and air conditioning. Thermal comfort has a large impact on the productivity and concentration levels of the human (Kang et al., 2017) and can also affect the ability to learn and solve problems (Che et al., 2019). A research made by Kaushik et al. (2020) show that optimal temperature for an office building is between 21 and 25 degrees Celsius since this is when the occupants reach the highest level of comfort. The most productive temperature varies within the interval depending on the task that is performed. According to Kang et al. (2017) creative work requires a higher temperature than other tasks, to be ultimately preformed. Temperatures above 25 degrees has been proven to worsen the productivity and performance of the occupants noticeably (Rupp et al., 2015; Kang et al., 2017).

According to several studies made, thermal comfort has shown to be the most important IEQ aspect in office buildings according to occupants (Frontczak & Wargocki, 2011; Kang et al., 2017). Depending on if the office is naturally ventilated or air conditioned the occupants have a different attitude towards the temperature in the building (Frontczak & Wargocki, 2011). Occupants in natural ventilated offices has shown to be more accepting towards high temperatures in the warmer seasons and cooler temperatures during cold seasons, compared to occupants in air-conditioned offices.

If the indoor air quality in an office is low, the occupants can experience lower productivity and eventually even sick building syndrome (SBS), which is a group of health issues due to the poor indoor environment (Kang et al., 2017). Others causes could be unpleasing temperature, humid air, bad ventilation or mould (Wahab, 2011), that could lead to irritated eyes, throat or nose, headache, cough and skin irritation (Mentese et al., 2020). Better indoor air quality also means that the users of the building are satisfied and are able to perform better (Kang et al., 2017). If the air is stuffy, it can generally be improved by letting more fresh air in by increasing the ventilation rate of the HVAC-system. It is an effective measure to get rid of air pollutants indoor, but it could in some cases lead to more pollutants from the outside getting in, especially in cities with a lot of pollutions in the air (Che et al., 2019). Another common factor that influences the air quality negatively is odour. Bothering odour could also lead to lower cognitive capacity as well as lower productivity, and well-being (Kang et al., 2017).

In office buildings the visual comfort is one of the most important aspect since it can lead to lower productivity and well-being (Al horr et al., 2016). Good visual comfort is favourable for the eye comfort and tiredness of the occupants, primarily in open offices where the lights are more difficult to control (Kang et al., 2017). The amount of natural light in office buildings is necessary both from physical conditions, like the view from the workplace and psychological conditions. The natural light is rarely enough as a light source in office buildings, so a sufficient amount of artificial light is needed. The light levels of both artificial and natural light depend a lot on season and weather conditions. A too high amount of artificial light lead to discomfort. The amount which satisfies the occupants varies between the people and task performed. Occupants working in front of a screen (computer etcetera) usually feel more visual comfort in less light than occupants working with other tasks.

Acoustic comfort is a common issue in open offices. According to Kang et al. (2017) the experienced noise is typically caused by traffic, other occupants talking or their activities, and installations. It has been proven that noise connected to activities of the occupants have a larger disturbance on people with lower productivity while other type of noises usually affects all occupants negatively. Noise made from conversations are the most common in open offices and the most difficult to avoid. This type of noise has also been shown to lead to the largest occupant dissatisfaction.

2.2.2. Behaviour and actions of occupants in office buildings

Indoor comfort can be achieved in several ways but a prevalent action is to adjust the surrounding environment. In this chapter indoor environmental control in form of behavioural actions and models from earlier studies will be presented.

2.2.2.1. Indoor Environmental Control, IEC

The ability to control the indoor environmental quality is called IEC. It can refer to installations or a building part that can be manually controlled (Chen et al., 2020). Examples of this is a window, light systems and adjustable thermostats. The IEC is one of the most important aspects when looking at high level of IEQ. If the occupant can control the systems, the indoor environment quality most likely will be higher than if they are predefined. This means that the occupant will reach a better well-being both in physical and psychological aspects.

A study made by Chen et al. (2020) strengthen the theory about the different office types and IEC. It shows that people with access to the thermostat controls and window shading/blinds believed that it increased their productivity which result in a higher level of IEQ. People with access to the windows experienced a better air quality and lighting than the remaining occupants. It can be connected to the office type, result showed a lower productivity for open-plan offices. In that type of office, the possibility to control lighting and thermostats are lower than for closed offices. This causes a lower IEQ than for the other office type, according to the study.

2.2.2.2. Adaptive behaviours

The interaction between the occupant and the building systems can be triggered from external or internal factors, external acts on the individual from the outside and the internal comes from within the individual (Day et al., 2020). The behavioural actions the occupant undertake can be based on several influencing parameters which can be divided into categories of driving factors, factors that drive the occupant of wanting to adjust their surroundings due to discomfort (Fabi et al., 2011). The categories are physical environmental factors, contextual factors, psychological factors, physiological factors and social factors (Fabi et al., 2012). The first one is basic measurable parameters in the indoor climate like temperature, humidity, noise, illumination etcetera while the second one has to do with requisites of the environment such as typology of space, orientation and heating systems. The psychological and physiological are directly related to the individual since it regards features as expectations, attitude, awareness, cognitive resources and age, gender, clothing and metabolic rate. As for the social factors, it is the interaction between occupants and who is responsible for which actions.

Humans have both conscious and unconscious behaviour responses to stimulus. Behaviours can be habits or routines that are based on knowledge or actions related to impulse of a stimulus (Fabi, 2012). There are three categories for adjustment. The first is changes to alter the environment, like opening/closing windows, switching on/off lights, adjust shadings, blinds and heating set-points. The second one is adaptation of the occupant itself, like adjusting clothing, change body posture and intake of food and drinks. The last one is based on changes that are made to indirectly affect the indoor climate, like appliances and equipment, hot water use and activities. Both the indoor environment quality and the energy consumption are outputs in a behavioural adjustment process (Fabi et al., 2011). They depend on several parameters which all have a wide range of variability and will result in a circle where the outputs will induce adjustment behaviour in the occupant.

2.2.2.2.1. Common behavioural actions

Window opening is one of the most common used adaptive actions occupants undertake to adjust their environment (Stazi et al., 2017). Several studies have shown that the main reasons for window opening are related to temperature differences and quality of indoor air (Schakib-Ekbatan et al., 2015). When analysing the triggering factor of the action it can be the outdoor temperature, indoor temperature or the concentration of pollution in the air that induce the action (Schweiker et al., 2018; Stazi et al., 2017). In general, it is the change of environmental climate that entail the actions of an occupant and as Zhang & Barrett (2012) states, the occupants in office buildings generally open windows after drastical changes in the environment. When coming from the outdoor air that is perceived as fresher air, the occupant is generally more likely to open windows when arriving to the office (Stazi et al., 2017). This is especially applied for the morning arrival but also a common behaviour after lunch when returning to the office. Closing of windows has a correlation to presence of occupants and is driven by arrival and departure (Schweiker et al., 2018). The daily routine and schedule of the occupants play a significant role for the energy use that is linked to this (D'Oca & Hong, 2014). Habits and personality traits can have a large impact on the energy usage as well and are both important variables in prediction of behaviour (Schweiker et al., 2018).

Behaviour regarding artificial light is in general more related to habit and occupancy than environmental factors (Stazi et al., 2017). Since electric light is directly related to energy consumption the occupants often have the intention of turning off the light when daylight illuminance is sufficient, but habit is to leave it on (Heydarian et al., 2020). The light is often left on because the occupants do not acknowledge it or leave it on in advance to prevent a sudden illuminance drop. Studies show correlation between light switching and outdoor daylight level, which have a direct impact on indoor illuminance (Schweiker et al., 2018). The layout and interior space influence the illuminance levels at the work plane which correspond to the visual comfort of the occupant (Yun et al., 2012). Switching on lights often occurs in relation to entering the room or for an illuminance level below 100 lux at the workstation (Stazi et al., 2017). With multiple occupants sharing a space, they are more likely to leave the lights on throughout the day (Lo et al., 2014) and solely switch the light off at departure (Schweiker et al., 2018).

Shading is mostly used to protect the occupant from high illuminance, glare and solar radiation which can bring on heat load (Stazi et al., 2017). As for many other behaviours, use of shading and blinds does not follow a pattern of triggers or have an explicit driving factor (Schweiker et al., 2018). Adjustments are often driven by a drastic change in environment followed by discomfort and are often more precise in lowering then raising due to maintaining desirable internal illuminance (Haldi & Robinson, 2010). The occupant is more likely to adjust the shadings and blinds upon arrival and it will often be kept longer periods then needed since occupants often show no intention to act upon departure. Closing of blinds is triggered by parameters like indoor temperature, solar intensity and illuminance, when undrawing is primarily related to parameters as outdoor illuminance, solar radiation and occupancy (Schweiker et al., 2018). Generally, shading is more of seasonal use and therefore kept in the same position during longer time periods (Stazi et al., 2017), as long as the occupant does not feel discomfort regarding visual factors and view of the outside (Schweiker et al., 2018). This may not have a great impact on energy consumption but when keeping blinds down for longer than necessary, the occupants will most likely use artificial lights more frequently to compensate the modification.

Behaviour regarding adjustments of thermostat is not as commonly used in office buildings as in residential buildings. In offices, more occupants share the same space, and the system is not always reachable for the occupants which induces other types of adjustments (Stazi et al., 2017; Schweiker et al., 2018). The thermal comfort in a space is strongly affected by individual factors as habits, schedule, time of the day and clothing. The more frequent adjustment is adaptation of clothing since it only involves the one discomforted occupant. Clothing options for the occupants often has a correlation to temperature, both indoor and outdoor temperature, and thereby to seasonal conditions (Morgan & de Dear, 2003). When reviewing the clothing level in an office building, a general implication is that the occupants have a dress code and consequently limited options of adaptions during the day. Women normally wear more clothing than men during the cold season and less during the warmer season. Another personal adjustment is intake of hot or cold beverages or adjusting the body posture and activity level (Fabi et al., 2012). Intake of beverage is driven by temperature while adjustment of posture and activity level have no specific trigger factor but is based in unconscious behaviour (Schweiker et al., 2018).

2.2.2.3. Energy related behaviours

The human behaviour highly influences the energy consumption, since the individual can impact the indoor environment by control systems in the building (Stazi et al., 2017). Different behaviour effect the energy usage in varying degree and up to 80% of the consumed energy variations are due to human behaviour (Xu et al., 2021). The type of performed behaviour and its effect on energy consumption is highly connected to factors like season and weather but also to location and climate (Stazi et al., 2017). Other factors that could affect is the age, gender of the occupants and their metabolic rate etcetera (Al horr et al., 2016). Actions as adjusting windows and blinds, operating lighting and utilisation of appliances are common adaptive behaviours that affect the energy demand in office buildings (D'Oca et al., 2018).

The occupants in the building regulate the windows to improve natural ventilation in the building and thereby improve the energy usage in the building (Roetzel et al., 2010). By opening windows both the air quality and indoor temperature improves. However, this is most effective when the differences in temperature indoor and outdoor is large and when the weather is not windy, rainy or snowy. In bad weather conditions, occupants will likely close windows and during warmer seasons the outdoor temperature will not cool the indoor temperature significantly.

By letting in natural light from the sun, less artificial light is needed which saves energy. The transmitted sunlight can also help increasing the indoor temperature and thereby decreasing the energy usage when the building requires heating (Kunwar et al., 2020). During summer, temperature gain is unwanted since it generally is warmer indoor and cooling demands increase in the building. When automatic shading is used in a building, the shades are usually drawn in the summer which results in less illuminance and natural light in the building than during winter (Imperadori et al., 2020). There are different types of automatic shading, there are shading which with sensors identify where the occupants are located. They are drawn in the occupied areas which is good from an illuminance perspective (Luo et al., 2021). It will protect the occupants from direct sunlight but still allow the unoccupied areas to get sun. This can lead to some energy savings during cooler seasons compared to automatic shadings without occupancy-controlled sensors, since they would shade all areas equally. According to Kunwar et al. (2020), studies show that shading which is controlled by the occupants usually are not ideal in providing the natural light as well as preventing solar heat gain during warmer seasons. It is shown that energy usage due to light can improve by 43% if the shading is controlled based on both daylight and the occupants. If it is controlled based on daylight, without recognizing the unoccupied areas, 28% of energy usage for lights can be saved.

A study made by Lee and Malkawi (2014) is looking at what behaviour that effect the energy performance. Different cities in north America were studied with an agent-based modelling which imitates a human behaviour in the commercial building (Lee & Malkawi, 2014). The study for Philadelphia, with a mixed climate, showed that the least effective energy consumption (most energy demanding) behaviours are connected to windows, then metabolic rate (activity level), amount of clothing and the most effective behaviours were connected to blinds and fans. In the same study made for Calgary (Canada), with a cold climate, the most effective behaviour was connected to the fan or heater. The least effective behaviour here was connected to clothing level and then windows. Corresponding studies also shows that the energy demand for occupant related behaviour could decrease up to 50% with a preventive awareness for energy consumption in their behaviour (D'Oca et al., 2018).

Similar parameters have been used in a study made by Bonte et al. (2014). The behaviour regarding, blinds, lights, windows, set-point temperature, fans and clothing are investigated using design of experiments (DOE). It studies both oceanic and Mediterranean climate in office buildings in France (Bonte et al., 2014). The result show that the most energy demanding parameter is the set-point temperature. Blinds and lights are not as energy demanding as the set-point temperature but still significant. The energy demand of the light could differ depending on if it has a predefined schedule for the workdays or if it is controlled by the occupants. According to the study, windows improve the energy demand by lowering the indoor temperature and then the heat deficit. This method does not take energy demand due to fans or clothing level into account since they do not have a direct impact on the performance of the building.

The climate is not the only reason why behaviour influences the energy in varying degree. The layout of the office effect the availability to control the different parameters, and as a result the behaviour and energy usage are different (Xu et al., 2020). The occupants in closed offices have easier to control the indoor environment and thereby the energy usage while occupants in shared offices do not control as many parameters themselves, mainly because of respect and care to other occupants. Then the predefined settings of the installations will control the environment. According to Xu et al., a study show that an office with many occupants have a higher occurrence in behaviour connected to windows regulation and clothing level than in an office with fewer occupants. Behaviour connected to fans are however more occurring in closed offices. Another study show that internal blinds are more commonly used in closed offices than open.

2.2.2.4. Models of behaviour

Behaviour models are used to learn about occupant's behaviour and habits (Heydarian et al., 2020). It can be divided into psychological, sociological and economical models. The psychological aspect is frequently used for modelling the human behaviour in building and in interaction with other occupant or systems. According to the article written by Chen et al. (2020) there are two main models that can be implemented when talking about IEQ in office buildings, TPB and ABC. However, the pro-environmental model NAM is also applicable when energy consumption is to be investigated (Onwezen et al., 2013).

2.2.2.4.1. Theory of planned behaviour, TPB

The first one is called the Theory of Planned Behaviour (TPB). According to an article by Du and Pan (2021) the theory refers to the predicted behaviour of a human and its behavioural intentions. The model is built on three aspects: the belief of the consequences or intentions of the behaviour, the normative expectations and perceived behavioural control, see *Figure 2.2*. When a person's behavioural need or purpose is reached, the person will perform a behaviour which follows up by an action (a consequence of the behaviour; Chen et al., 2020). The normative expectations could be what the individual believe is expected from other people or what other norms say (Heydarian et al., 2020). Attitude belief regards the individual's opinion and judgement about the implementation of the behaviour. The attitude could be either positive or negative depending on the behaviour. Perceived behavioural control could be explained as the belief of the ability to implement the behaviour of the occupant and what influence the individual has over the behaviour.

The theory of planned behaviour is commonly studied when looking at occupants' behaviour regarding energy consumption (Heydarian et al., 2020). It could be the planned behaviour of turning off the computer or lights after a workday or choosing alternative solutions instead of traveling for meeting. It could also be recycling, or other actions connected to IEQ.

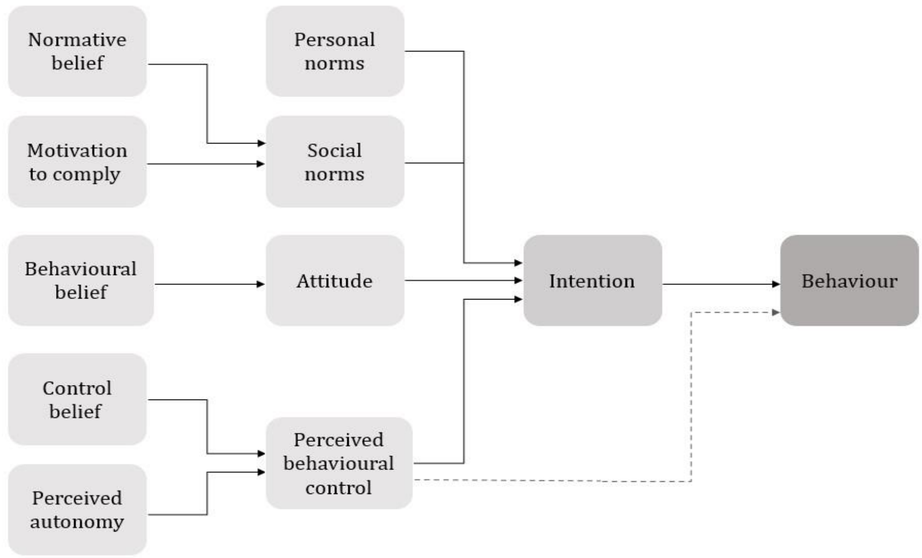

Figure 2.2 *Illustration of theory of planned behaviour, TPB.*

2.2.2.4.2. Attitude-behaviour-context theory, ABC

Another model that can be implemented for IEQ in office buildings is Attitude Behaviour Context (ABC). The model looks at the relation between the attitude (A), behaviour (B) and context (C) (Chen et al., 2020). The behaviour is highly associated with the attitude which is internal factors of the individual, like beliefs and intentional behaviour. Additionally, it is also correlated to the context which corresponds to external factors such as physical environment, economical aspects and individual capability (Guagnano et al., 1995). Both attitudes and context have a range of variation, from positive to negative, where a positive position induces a behavioural adjustment while a negative position does not generate a behaviour, see *Figure 2.3*. It is rather the correlation between attitude and context that decides the behaviour, than the factor itself.

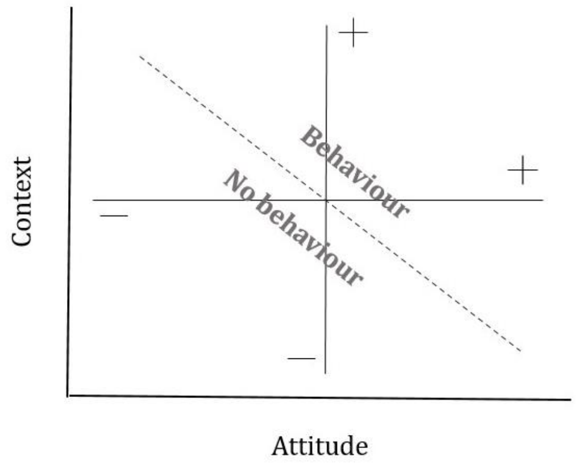

Figure 2.3 Illustration of attitude-behaviour-context theory, ABC. Above the line the occupant will undertake adjusting behaviour.

2.2.2.4.3. Norm Activation Model, NAM

The model Norm Activation Model (NAM) is a psychological theory model that explain individual behaviour that is selfless and pro-environmental (Onwezen et al., 2013). The model is based on the moral responsibility which means that instead of personal intentions the occupant feel a personal norm or obligation to behave in a certain way. According to Onwezen et al., the personal norms in the model are based on two aspects. The first one is the consciousness of the consequences that is brought with the implementation of the behaviour and the second is the responsibility that is felt after the implemented behaviour. The model is built up on awareness of the consequences followed by the responsibility of the individual, then personal norms and then ending with the behaviour (Onwezen et al., 2013), see *Figure 2.4*. This means that before feeling responsible for a behaviour one must be aware of its consequences. Responsibility will affect the personal norm or moral obligation which then affect the behaviour. The NAM is applicable in the behaviour of energy efficiency. According to Van Der Werff and Steg (2015), personal obligation and responsibility are important factors in prediction of energy savings. In this context the model explain how environmental behaviour and interest are chosen over personal interests. By acting in favour of the environment the individual will feel good. Although a behaviour that is difficult to imply or that is too costly will make the individual less likely to act with their personal norms.

The two factors influencing NAM can be applied for behaviour of energy savings. The awareness of the consequences is knowing what energy use will lead to and what issues it brings (Van Der Werff & Steg, 2015). Issues such as air pollution, climate change etcetera. The second factor, responsibility, is the feeling that they can make a change and help the environment by implementing the behaviour. By actively saving energy and act energy efficient the individual should feel that they affect the environmental issues in a positive way by decreasing them.

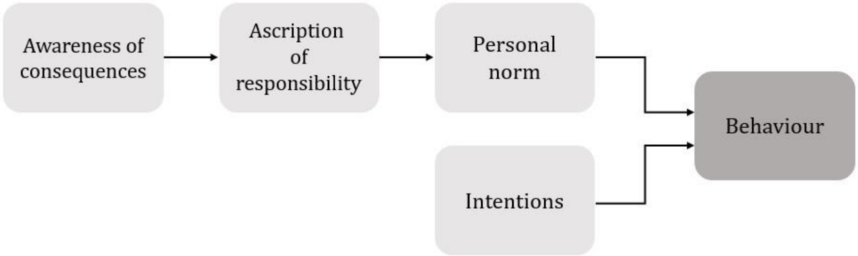

Figure 2.4 *Illustration of norm activation model, NAM.*

2.2.3. Occupant related information needed in the design phase

The initial design stage is significant for the prediction of future energy consumption for which the occupant related information is the primary focus (Zou et al., 2018). For many buildings the energy performance gap is substantially larger than desired which implies that the human factor has an essential role in creating a sustainable building (D'Oca et al., 2018). Occupant related information are hard to predict in an early state, because of its stochastic nature, but could have a great contribution to the energy performance if done well (Ahl et al., 2019). Stakeholders of importance in the design process are architects, energy modelers, HVAC engineers and building developer (D'Oca et al., 2018). Different stakeholders need different kind of occupant related data to do an accurate estimation of the energy consumption but generally applies that information about usage or occupancy in the building is relevant.

The energy modeler is in need of specifications regarding operational schedules for the different building systems and its correlation to occupancy rate (Azar et al., 2020). The degree of occupancy needs complimentary information as clothing insulation, metabolic rate and desired set-point. In more detail, the energy modeler requires information about type of HVAC system, lighting, equipment and appliances together with level of occupant interaction with each system and the building envelope (D'Oca et al. 2018). HVAC systems have great impact on the energy consumption in commercial buildings therefore an accurate design in an early stage is of importance (Zou et al., 2018). To start, the HVAC engineer need knowledge about occupancy and operation to select a suitable system. Dimensioning details are schedules of occupancy and operation, set-point temperatures and layout of different types of building zones (Yang et al., 2016). Ventilation systems in commercial buildings most often run on a predefined schedule (Salimi & Hammad, 2020) and the set-point temperatures should be kept during the hours of the workday. During the night, a setback temperature is defined to keep a lower temperature when it is unoccupied. This can lead to more energy usage than intended, especially in shared offices where the activities and habits differ within the office.

Architects design buildings for the occupants, to meet their needs and desire in operation. In several situations the predication of occupancy and behaviour can be difficult, and the architect must base their work on intuition and previous knowledge

(Zhang et al., 2019). The architect benefits from knowing occupancy rates in a space and the corresponding schedule together with the area of usage to design an adequate space that fulfils the desired comfort.

2.2.4. Occupant behaviour parameters in building design

A building's design and properties are regulated by building codes to provide a minimum standard that secure a sustainable environment regarding fire safety, accessibility, durability and good indoor environment (Boverket, 2018). To follow a code when designing has benefits to a great extent as long as the codes are up to date with relevant information. Swedish building codes and guidelines are generally well covered, but just as for most building codes they lack regarding occupant behaviour and the relation to energy consumption (O'Brien et al., 2020). To improve the energy performance of buildings, the building codes and regulations would need a development considering the variations and details in the human behaviour models. There are two ways in governing the building energy codes, through a prescriptive-based or a performance-based regulation. A prescriptive-based path is a distinct way to pursue a set goal with easy target requirements for more individual system of the building. In comparison the performance-based path has more of a comprehensive view since it evaluates the final energy consumption and is best used in comparison to reference building with minimum requirements.

Even with behaviour models and research the human behaviour is difficult to predict due to uncertainty of utilization and the particular usage (O'Brien et al., 2020). Since the occupant has such a large impact on the energy consumption, they have a significant role in the final output. The adjustment behaviour of the occupants is included in the building codes but considerably simplified to meet the general needs. It is not treated as the variation and feature that are included in human adaptation, but more like a boundary condition with prefixed schedule and limits. Many modelers have responded according to Gilani et al. (2016) that they use the assumptions/simplifications stated in the code to evade responsibility for the occupants' behaviour and the output. Even if the actions often are unsuited for the actual use or behaviour, it will still be used in the design process although the code often allows variability and flexibility (O'Brien et al. 2020). These assumptions are frequently made in lack of more specific information or knowledge and will be modelled with generalised time schedules. This leaves a rather large performance gap regarding the energy performance (Gilani et al., 2016).

2.2.4.1. The Swedish National Board of Housing Building and Planning

The Swedish building code to follow regarding energy consumption is BFS 2017:6 - BEN 2; The Swedish National Board of Housing, Building and Planning's regulations on amendments to the regulations and general advice (2016:12) on the determination of the building's energy use during normal use and a normal year. This one is required by law to follow to get a permit for construction (O'Brien et al., 2020). An energy consumption calculation is supposed to be done with respect to several parameters and timesteps of one hour. Most of the parameters are related to the building properties, as layout, thermal properties and building systems, and then some related with outdoor climate and orientation. For the occupant related data, it is quite simplified in this code. The occupancy density is 0.05 person/m^2 (Boverket, 2017), but this could differ in practise depending on the exact use and layout of the space. The occupancy schedule that should be used for energy calculations is nine hours per day, five days a week, and 47 weeks per year. The internal gain from occupants should be 5.4 W/m^2 according to the code.

The indoor temperature is set to 21 degree Celsius at a minimum and 23 degree Celsius at a maximum (Boverket, 2017), which means that the temperature theoretically always will be within this span. Since an office has a large amount of internal gains and uneven schedules this will presumably not always be true, and the temperature will probably have a larger difference. For how the occupants are treated in the code, mentioning of occupants barely exists in a straightforward context. The code focuses more on specifics in design and requirements for the building systems (O'Brien et al., 2020). All recommended values according to the Swedish National Board of Housing Building and Planning are collected in *Table 2.1*.

Table 2.1 *Design values for calculating energy consumption in an office building, by the Swedish National Board of Housing Building and Planning.*

Parameter		Value
Occupant	Density [pers /m^2]	0.05
	Internal gain [W /m^2]	5.4
	Schedule [h/days/weeks]	9/5/47
Temperature	Minimum [°C]	21
	Maximum [°C]	23

2.2.4.2. Sveby Standard

Sveby is an industry standard to calculate the energy performance and consumption and stands for Standardize and Verify Energy Performance in Building (Sveby, 2014). It is a cross-industry program that was produced to standardize occupant input data and to easier verify the result of energy calculations. The guidelines can only be classified as design recommendations and are not legally required (O'Brien et al., 2020), even though it to a large extent is based on the Swedish building code (Swedish National Board of Housing). These guidelines have a more extensive database for input than the Swedish building code. To maintain a good indoor air quality a minimum hygienic ventilation flow of 0.35 l/s·m^2 is recommended (Sveby, 2014). The recommended ventilation rate that should be used for energy calculations is 1.3 l/s·m^2, which is based on the basic flow for hygienic reasons and the occupancy density in an office (Sveby, 2013). This is to be applied for five days a week with a schedule of 07-19 and considered shut off the rest of the time.

Regarding light and equipment, the actual values could differ a lot depending on the type of task that is performed. The energy consumption of lighting is 7.6 W/m^2 for an occupancy of 100% and 5.3 W /m^2 for an occupancy of 70% (Sveby, 2013). The recommended value for illuminance at the work plane is in the span of 300 to 600 lux in an open plan office. In reality these settings will correspond to the usage of lights which results in change of energy consumption. As for control of lighting during the workday, the standard states that it does not consider the presence and absence of occupants together with the daylight variations. Energy consumption for equipment and appliances is 9 W/m^2 with full occupancy and 6.3 W/m^2 with 70% occupancy. This includes computers, copier, printer, chargers and similar appliances that are in use during a normal workday from 8-17 and with assumption of no consumption during the rest of the day. The equipment is assumed to automatically go in to sleeping mode when not used. All recommended design values from Sveby are collected in *Table 2.2*.

Table 2.2 *Recommended design values for calculating energy consumption in an office building, according Sveby.*

Parameter		Value
Ventilation	Hygienic rate [l/sm²]	0.35
	Recommended rate [l/sm²]	1.3
Lighting	100% occupancy [W/m²]	7.6
	70% occupancy [W/m²]	5.3
	Work plane illuminance [lux]	300 – 600
Equipment	100% occupancy [W/m²]	9
	70% occupancy [W/m²]	6.3

2.2.5. Methodologies to collect behaviour data in buildings

There are various ways of collecting data in buildings. Two types are subjective and objective methods. Using these methods together will give a result that is based on both measured data and subjective beliefs of the occupants (Yan et al., 2018).

2.2.5.1. Subjective method

A subjective method accents peoples' experiences and beliefs (Oxford University Press, n.d.-b). One type of subjective method is a questionnaire which analyse the personal perspective and feelings of the occupants, for example regarding their comfort in an office building. This gives a subjective result on how the occupants act and their personal attitude and behaviour towards the comfort in the building.

2.2.5.1.1. Questionnaire

Questionnaires are a common method in collecting data connected to occupants' behaviour in buildings (Dykes & Baird, 2013). The purpose of this type of surveys are to collect the users' opinions and experiences in the building although the focusing aspects of the surveys could differ. By comparing seven methods of questionnaires made by different authors some general methods and reoccurring questions could be recognized. Surveys with different aspects have been studied to include relevant information that can serve as a basis for the questionnaire in this thesis.

Surveys focusing on the social psychological factors and IEQ in an office building are beneficial in investigating the occupant behaviour, and what factors that affect the occupant's decision to act. A questionnaire made by Chen et al. (2020) was sent to office occupants in six different countries over the world, with varying climate. Gender, age and occupation at the office was the initial information collected. The questionnaire investigated different aspects influencing the behaviour. Context of the office is an important aspect, such as office layout and accessibility for the occupants to control the environment. The questions were related to the perceived IEQ, the availability of IEC and their attitude towards the sharing of controls. Norm related questions were also included to see how the occupants are affected by other occupants and what they believe are expected from them. Questions regarding behaviour and attitude related to thermal comfort and controls was investigated with a 7-point scale, the rest of the questions were answered with a 5-point scale.

A questionnaire was implemented for a commercial building in Italy to investigate the IEQ in different areas of the building (Castaldo et al., 2018). It included questions regarding IEC and habits, visual-, acoustic- and thermal comfort (IEQ). Also questions about other influencing parameters and personal information were included. The study made by Chen et al. (2020) was to a large extent focused on IEC, the attitudes and norms that affect the behaviour, while Castaldo et al. (2018) was more focused on the perceived indoor climate and what parameters that were the basis for the result. The study incorporated a 5-point scale for the perceived IEQ questions while questions related to habits were in the form of yes/no questions. The questionnaire was handed out and collected during four occasions, during each season to map out the IEQ differences during a whole year. In similarity to these studies, Putra (2017) made a study to investigate the IEQ in an office building located next to a factory in Malaysia. The first part, like previous studies, collected personal occupant information and the second part collected satisfaction towards thermal comfort and air quality, answered with a 5-point scale of satisfaction degree.

In comparison to earlier studies, a survey by Agha-Hossein et al. (2013) compared two buildings performances with the same occupants. It was carried out in London and investigated the change in satisfaction, well-being and energy consumption between two office buildings (Agha-Hossein et al., 2013). The same participants have responded to both questionnaires because of a move to a new office building. The same type of questions concerning personal information were initial, just as for previous discussed surveys. Remaining parts included questions connected to aspects regarding IEQ and IEC, such as thermal comfort in winter versus summer and personal control of the environment. In addition, this survey also investigated the occupants' satisfaction with the layout of the space, as well as questions regarding the occupants' experienced productivity, well-being and amusement at work. All questions in this survey were answered with a 5-point scale except for information about the occupant. Another study performed in London also looked into the thermal comfort and energy consumption (Rijal et al., 2007), but due to window opening instead of change of location. The survey was implemented in 9 different commercial buildings to result in a more widespread mapping, where the majority of the buildings were natural ventilated and the rest were air conditioned. It is built upon three different questionnaires. The initial one collected information about the occupants such as personal information, attitude towards the building and their experiences of it with answers on a 4-point scale from never to often. The second questionnaire was answered verbally once a month and included questions about the thermal comfort, clothing and activity level and their control and behaviour regarding the windows. The third questionnaire was answered by the occupants four times a day to track the thermal comfort and their behaviour throughout the day. Along with this study, the temperature was measured to research the correlation between the temperature and thermal comfort.

In the Netherlands a questionnaire was handed out to occupants in buildings located in four different parts of the country, to investigate the energy consumption and the existing behaviour models (Lo et al., 2014). The majority of the questions were answered with a 5-point scale, where 1 is the least pro-environmental answer and 5 is the most pro-environmental. It was divided into multiple parts where the first regarded occupants’ behaviour connected to energy savings. Corresponding questions included scenarios connected to habits and actions in the building such as light switch or computers and other equipment. The questions were formulated in two ways, as past/present behaviours and future intentions. Meaning how the occupants' behaviour has been, what their habits are now and also what behaviour the occupant wants to improve in the future. Another part of the questionnaire included questions about the attitude and thoughts regarding the behaviour. These were answered with adjective pairs, where answers could be “difficult-easy” and “negative-positive” depending on the behavioural question. Last part of the survey was connected to moral. The questions were formulated in a way that referred to the whole company, instead of the occupant alone, to not keep the users from answering. It included behavioural scenarios where the answers were either agree or disagree but also question about norms connected to certain people.

Another study which also included behaviour models was one made by D’Oca et al. (2017), although this was mainly focused on the theory of planned behaviour. The survey aimed to find how different parameters affect the occupants’ behaviour and identify their actions rather than satisfaction of IEQ. Just as for the surveys made by Chen et al. (2020) and Rijal et al. (2017), the questionnaire was distributed over several countries and buildings (D’Oca et al., 2017). In comparison to Lo et al. (2014), D’Oca et al. investigated how the occupants were triggered by different parameters before implementing their behaviour in shared offices, such as intention, behavioural- and normative beliefs. The investigated behaviours were connected to blinds, windows, thermostats and artificial light. Apart from the questions connected to behaviour, it also included personal information about the occupants themselves, as for previous studies, together with information about the building. Other questions included were related to the experience of the IEQ, IEC and the productivity in the office. Answers regarding the experienced climate, like thermal comfort, were compared to meteorological data of their position. This was to find a correlation between the outdoor and the indoor environment based on the effect of productivity and comfort. The questions which were not control-related variables were answered with a 5-point scale, which regarded beliefs, satisfaction, productivity and ease of control.

Although the questionnaires focused on different aspects and investigated deeper in certain subjects many parts and questions were included in almost all the surveys. One part like this were questions related to demography and information about the occupants and the office design. Virtually, all the investigated surveys included a part with questions about the perceived IEQ and the most common way of answering these was with a 5-point scale. With 5 being the most satisfied answer. Most of the questionnaires included questions about attitude and parameters influencing the behaviour to some extent. Some of them had those type of questions as a main focus with more detailed focus on the behaviour models, with questions regarding normative beliefs and intentions etcetera. While some had more general questions about the subject or questions regarding the occurrence, such as time and quantity of action.

A conclusion from the mentioned surveys can be drawn that the most common way of expressing the answers is with a 5-point Likert scale or possibly a 7-point scale, depending on how detailed answers that is wanted. Questions are seldom asked with a yes/no answer. Instead, the questions are formed to ask the degree of agreement/disagreement on a scale.

2.2.5.1.2. Common questions used in questionnaires

The questions in the different questionnaires are formulated in some different ways, but most of the surveys reach similar conclusions. Although they ask different questions and look deeper into some parameters, the outcome can still be similar.

Basic questions that are included in most questionnaires mentioned, are personal informational and building characteristic questions. These include age, gender, occupancy, type of office (open/closed office), IEC accessibility and number of occupants sharing the controls (Chen et al., 2020; Castaldo et al., 2018; Rijal et al., 2007; Putra, 2017;D'Oca et al., 2017).

Questions regarding the perceived IEQ are used in the surveys. Chen et al. (2020) formulated the questions like "I am satisfied with …", with the "…" being parameters of IEQ such as indoor temperature, indoor air quality etcetera. They were then answered with a scale of how satisfied the occupants were and the other surveys included a similar way of asking about IEQ. The questionnaire made by Lo et al. (2014) not only included questions about the experienced indoor comfort when answering, but also the ideal comfort temperature during different seasons. Other common questions about IEQ were formulated to investigate the effects of the occupant's productivity and their well-being. Chen et al. included the question "I think … influences my productivity…" regarding different IEQ parameters, answered with a scale of how positively/negatively the productivity is affected. Agha-Hossein et al. (2013) ask the occupants "to what extent the well-being is affected by the work environment", as well as the affected productivity. These questions were answered with a similar scale.

Questions related to IEC usually are included in the questions regarding the office design, like how many occupants that share the controls in the office. Other questions about control, related to personal feelings, usually are included in its own section of the questionnaire. Those could regard the attitude towards sharing controls and the general experience of how well sharing controls with other occupants' work, answered on a scale (Chen et al., 2020). Common questions were also to what degree the occupant adapt to the other occupants' behaviour. The surveys that were more focused on the behavioural perspective and the actions usually had parts of the questionnaire that go into detail about controls and behaviour. The behavioural part often included questions connected to occupants' habits. Castaldo et al. (2018) studied behaviour that affected the comfort and included detailed questions about the occupant's habits. The questionnaire included questions asking if doors/windows usually were open when working and if the occupant turned the computer or lights off when leaving. Lo et al. (2014) asked similar questions in form of statements, such as "I routinely..." that were answered with a scale of how much the occupant agreed. Normative triggers are also formulated into questions like "My co-workers expect me to..." (Chen et al., 2020) or "My colleagues think I should..." (Lo et al., 2014) with "..." being a behaviour such as "turn the lights off".

By asking questions like the ones mentioned, a subjective perspective of indoor environment and the parameters affecting the behaviour are collected. The data from these questionnaires can then be further investigated in the survey through objective methods (Salimi & Hammad, 2020).

2.2.5.2. Objective Method (Measurements)

An objective method is based on non-personal information which regards an object or function (Oxford University Press, n.d.-a). Measurements to some extent, is an example of an objective method. In buildings, when occupant behaviour is investigated, a common objective method to use is various types of measurements to collect data. This type of method gives more accurate information for further investigations like simulations since the subjective method is based on the occupants' memory and the number of respondents and therefore is less reliable (O'Brien et al., 2018).

2.2.5.2.1. Methods for measurements

Different types of measurements can be done to objectify occupants' behaviour in a building. A common way in surveys is to make a subjective method through a questionnaire and then combine it with data collected from measurements (Castaldo et al., 2018; Putra, 2016; D'Oca et al., 2017). One way to collect objective data is to measure parameters like air temperature, relative humidity and air flow etcetera (Castaldo et al., 2018; Putra, 2016). Air flow can be measures with an anemometer while air temperature and RH could be measured with a thermal hygrometer (Castaldo et al., 2018). Both types, Castaldo et al. used in their survey which to compare zones in a building during different seasons with a microclimate station. They also used a surface and air temperature sensor to record the temperature of the floor and the air temperature at floor height. Other sensors that were used in their survey are a Black globe radiant temperature sensor to measure average radiant temperature and luxmeter to measure illuminance in the zones and a radiometer for radiant asymmetry. CO_2-, VOC- and CO-sensors were used to measure their concentration in the zones. The survey made by Putra (2016) which investigated the indoor climate in a building also used an anemometer for air flow but used an IAQ-monitor for the indoor temperature and RH. The position of the sensor is important when measuring how parameters affect the human behaviour. If the occupants are working at a desk, the sensors could preferably measure at a distance of 1.1 m from the floor, since this is a common height of seated occupants (Castaldo et al., 2018; Hwang & Kim, 2013).

While the mentioned sensors measure parameters influencing the behaviour there are sensors that are more direct connected to occupant behaviour. A common sensor is image-based sensors which includes a way of monitoring behaviour through images (Dong et al., 2018). In office buildings it is mainly used for following the occupant's movements through a space and analyse their behaviour towards controls. This type of sensor could according to Dong et al. be infrared cameras that convert infrared energy into temperature, visible light cameras that convert visible light into images or luminance cameras which translates an image into luminance. The first mentioned camera is the least commonly used since it is the most expensive sensor. Of the other two, the visible light camera has commonly been used for tracking behaviour connected to blinds since it is an economical solution and is able to do so by time-lapse. A disadvantage with this is that it does not take surrounding information and parameters into account, that triggers a behaviour. Other disadvantages that are applicable for all camera types, are the issue about the occupants' privacy (Ding et al., 2011) and that the data from the sensors must be analysed manually for it to be as precise as it can be (Dong et al., 2018).

Apart from image-based sensors there are different kinds of mechanical and motion sensors (Dong et al., 2018). Mechanical and threshold sensors are commonly used for observing behaviour connected elements or systems in buildings. One common example of this is reed contacts, which is a threshold sensor that mainly is used to track the opening and closing of doors, windows and air conditioners by a magnetic field. The reed contact is a good sensor to use since it is relatively low in price and is easy to install and do not have the same privacy difficulty as an image-based sensor (Ding et al., 2011). However, the sensor can briefly sense an object, for example it can feel if the object is open or closed but not to a certain degree. It could be fallacious if the object does not entirely close (Dong et al., 2018). Piezoelectric mats are another type of sensor that could be connected to the occupant's behaviour. It is a mat which feels when a person is stepping on it. This could be used for detecting how often occupants move close to building components, such as how often people walk to the windows. However, it only works if the occupant step on the mat long enough for it to sense the person. Two types of mechanical sensors are door badges and IR-beams, which both are used to detect people in a building. Door badges counts the occupants in a building or area by letting the occupants swipe their card to enter. IR-beams uses infra-red light to sense if something if passing the beam. This is commonly used for counting occupants passing in a specific area. This method is however not completely reliable since it could count fallaciously if more than one occupant walks by at the same time or if another object passes the light.

There are also motion sensors which is, what the name suggests, a sensor that observe the occupants' motion by feeling their attendance and identifying their location (Ding et al., 2011). The most common is called passive infrared sensor (PIR-sensor) and is used for multiple reasons, such as automatic light controls and detect presence of people in a building (Dong et al., 2018; Erickson et al., 2011). They work best if a large area is covered by the sensor and works poorly if the occupancy rate is low, since the sensors easily turn off if the motion is low (Dong et al., 2018). The motion sensor only has two modes, it is active when it feels motion and unactive when it does not and cannot feel how many occupants that are in the area (Page et al., 2008; Erickson et al., 2011). Another way to collect data about people in a building is through radio signals (Dong et al., 2018). There are multiple types of radio signal sensors, some uses identification tags which transfer data through radio waves to a reader, to recognize occupants and other things in the building (Radio frequency identification; Ding et al., 2011). Some other uses Wi-Fi, GPS etcetera which can be used to observe the position of occupants or objects (Dong et al., 2018). To track specific occupants there are sensors that can observe occupants' behaviour by wearing it. It can be set up in clothing or accessories, like glasses and watches (Ding et al., 2011). An example of a worn sensor is the radio frequency identification sensor (RFID) which could be used to observe the behaviour of occupants by sensing when the person (reader) touches an item containing a tag.

The optimal way to study occupants' behaviour is to combine multiple sensors (Dong et al., 2018). By pairing different sensors more accurate data can be provided than for one sensor alone. For example, combining sensors that detect occupants gives a more sufficient value of the occupancy level than with only one sensor (Erickson et al., 2011). These sensors could then be connected to sensors regulating the ventilation system and could from the given occupancy data regulate the indoor climate. The most accurate method for measuring a behaviour is manual observation (Dong et al., 2018). This means that people are used for analysing actions and tracking data made by occupants instead of using equipment or sensors. The person could manually count how many times a window is opened or how many occupants enter a space or watch by watching a video provide information shown. It could also be used in comparison to other sensors to see how accurate they are. According to Dong et al. it is the only method that accurately could observe occupant's clothing level and both psychological and physical environmental factors. However, the method is expensive since people need to be hired to observe the occupants and sensors mainly cost to buy and install.

2.2.6. Mapping of behavioural aspects and parameters

To conclude all aspects and parameters from the literature, maps have been created. The main outcome of the IEQ is energy consumption, comfort and well-being of the occupant and productivity. The IEQ is both affected by and affects adaptive behaviours and non-adaptive behaviours, see *Figure 2.5*, meaning that the IEQ triggers the behaviours but also changes due to the behaviours in a building. There are two types of adaptive behaviour, environmental and occupant behaviour. The environmental behaviour refers to the behaviour that affect the office in general and the other occupants, while the occupant behaviour refers to the behaviour that affect the occupant alone. The IEQ consists of the four comfort aspects, visual, thermal, air quality and acoustics, which are all connected to the adaptive behaviour. The IEQ is also affected by non-adaptive behaviours, meaning behaviours that will remain regardless of comfort level such as equipment and appliance use. Another parameter that affects the IEQ but is not controllable for the occupants is the occupancy rate.

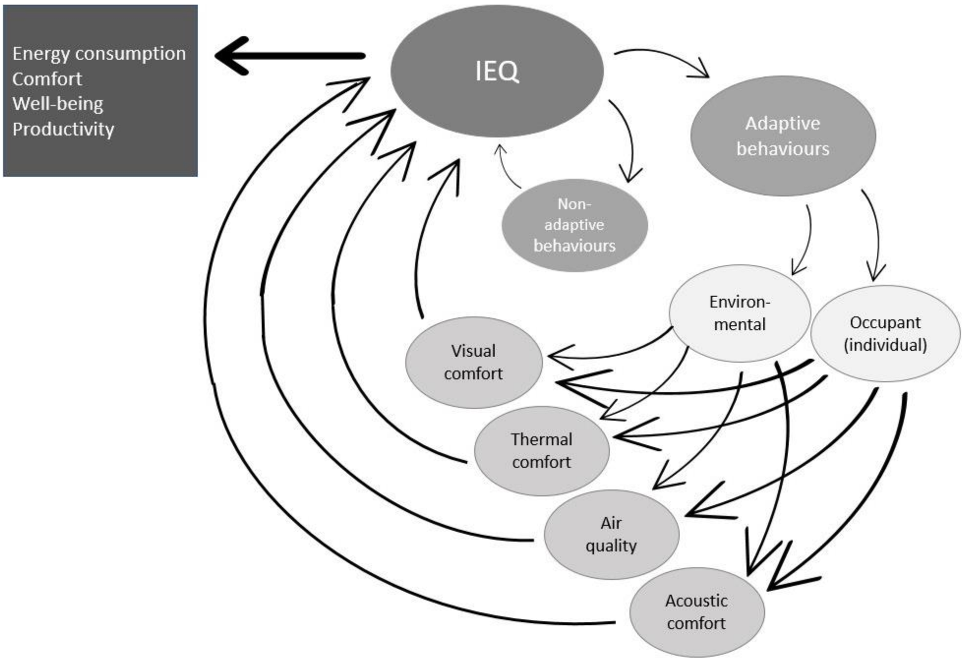

Figure 2.5 *A flow chart of IEQ. Relations between behaviours, the environment, its affect on comfort and its certain outcomes.*

Looking further into adaptive behaviour, the environmental and individual adjustments are connected to different parameters that the occupant can act upon to receive a better IEQ, shown in *Figure 2.6*. The behaviour will then lead to different outcomes depending on the regarding aspect. The environmental behaviour affecting the visual comfort can be control of artificial light, shading or blinds and the occupant behaviour can be orientation and location of the occupant. The visual comfort is a measure of amount of illuminance and glare. The environmental parameters regarding thermal comfort are adjustment of blinds, shading, fans, thermostat temperature set-point, control of ventilation flow, ideal heater or cooler and window opening. The occupant related parameters are location, metabolic rate (activity level), amount of clothing, posture, intake of beverage and food. The thermal comfort is a measure of the amount of moisture and temperature. The main parameter influencing the occupant behaviour is the location of the person and the main parameters influencing the environmental behaviour are control of ventilation flow and window opening. The behaviour will influence the amount of pollution, odour, dryness and humidity of the air. The environmental parameters affecting acoustic comfort are mainly ventilation control to adjust noise from the HVAC-system, and window opening to adjust noise from the outside. The main occupant related parameters are orientation and location of the occupant and the acoustic comfort is measured in amount of noise. There are some factors affecting the adaptive behaviour that are fixed and not affectable of the occupants. These are contextual factors like orientation and location of the building, the climate, season and the layout of the office.

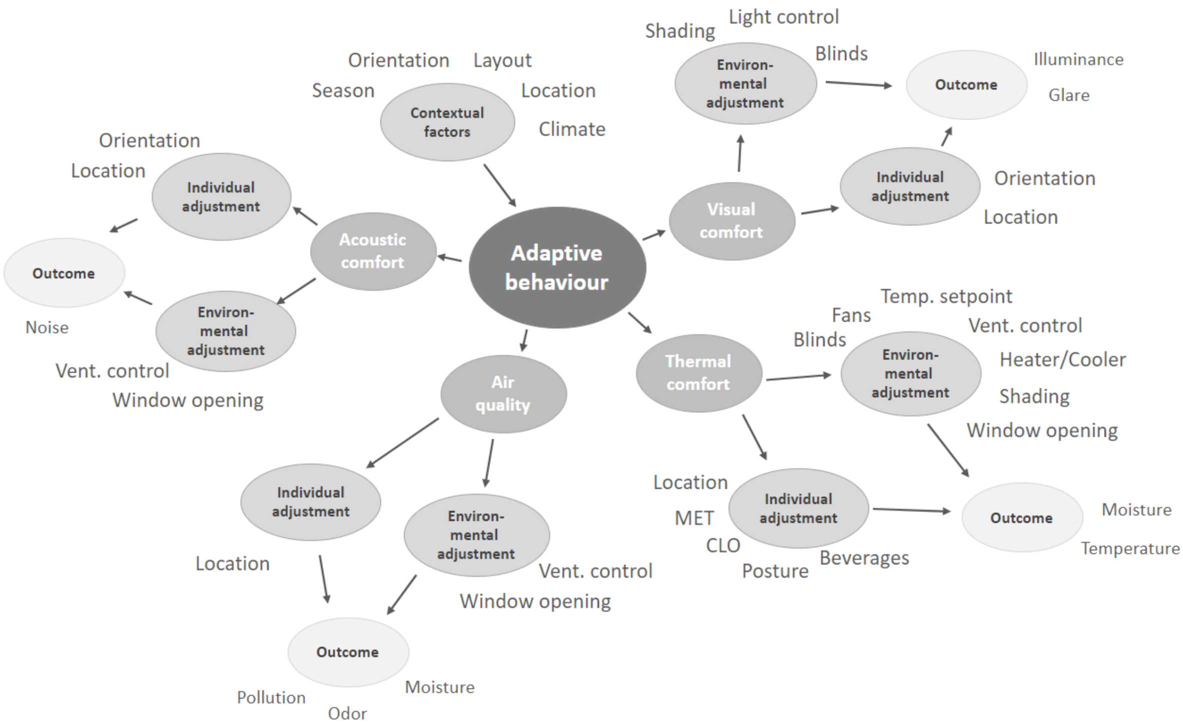

Figure 2.6 *Adaptive behaviours divided by comfort aspects and their influence on adjustments with common outcomes.*

3. Case Study

In order to investigate how different parameters influence the energy consumption and thermal comfort, a case study was made in a newly built office building. The result from this study could then be put in comparison to the findings from the literature review.

3.1. Method

The case study is explained with input data, limitations, program software and investigated parameters. In this section the building is presented together with assumptions and simplifications that were made to simulate the energy consumption and performance.

3.1.1. Case building - Nya Regionens Hus

Nya Regionens Hus in Gothenburg is multistorey office building with smaller office spaces, conference establishment, restaurants and similar spaces. It is used as the object for the case study and is newly built with modern installations. The building consists of two parts, one tower block with fifteen storeys and one lower rise block with five storeys. The study is limited to one floor, seen in *Figure 3.1*, in the high-rise part of the building for convenience in size. It includes open plan office spaces, smaller closed offices, meeting rooms, lounges and other smaller common areas. Some of the smaller rooms such quiet rooms/group rooms and details are simplified or neglected since they will not be of importance in the analysis. The tower block building consists of eleven floors of the same type which means that majority of the floors will have similar energy consumption as the simulated.

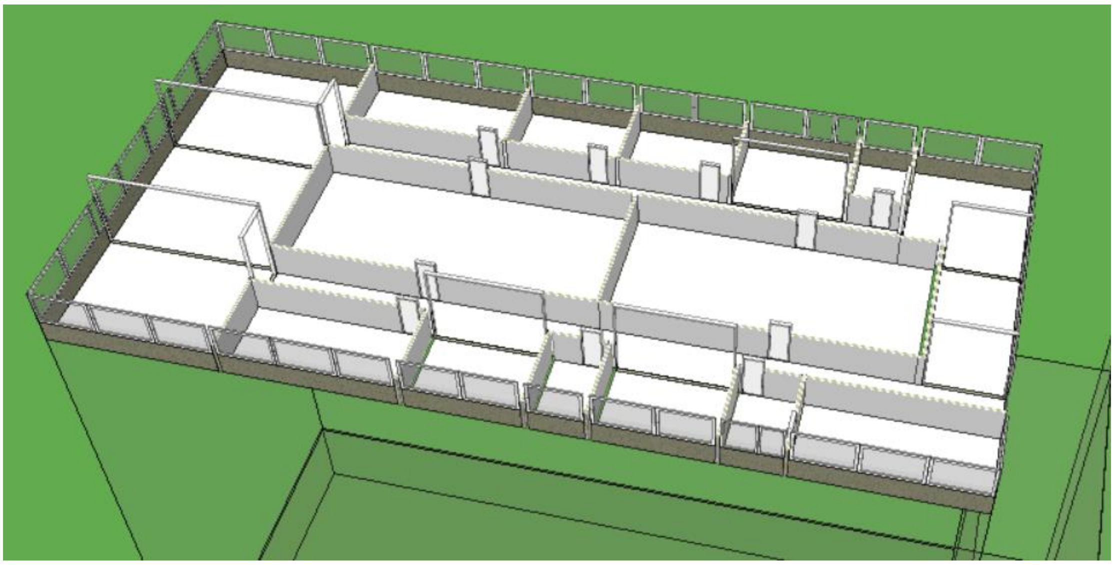

Figure 3.1 *The building floor investigated in the Case study.*

One floor has an area of 605 m^2 and the floor plan that is used in modelling is presented in *Figure 3.2*. Floor areas for each zone can be found in *Appendix A*. The building envelope consist of large windows and a glass facade with a total U-value of 0.36 $W/m^2{*}K$, specific values can be found in *Appendix A*. The climate data used is from

Sveby and is based on real weather data from SMHI (Swedish Meteorological and Hydrological Institute).

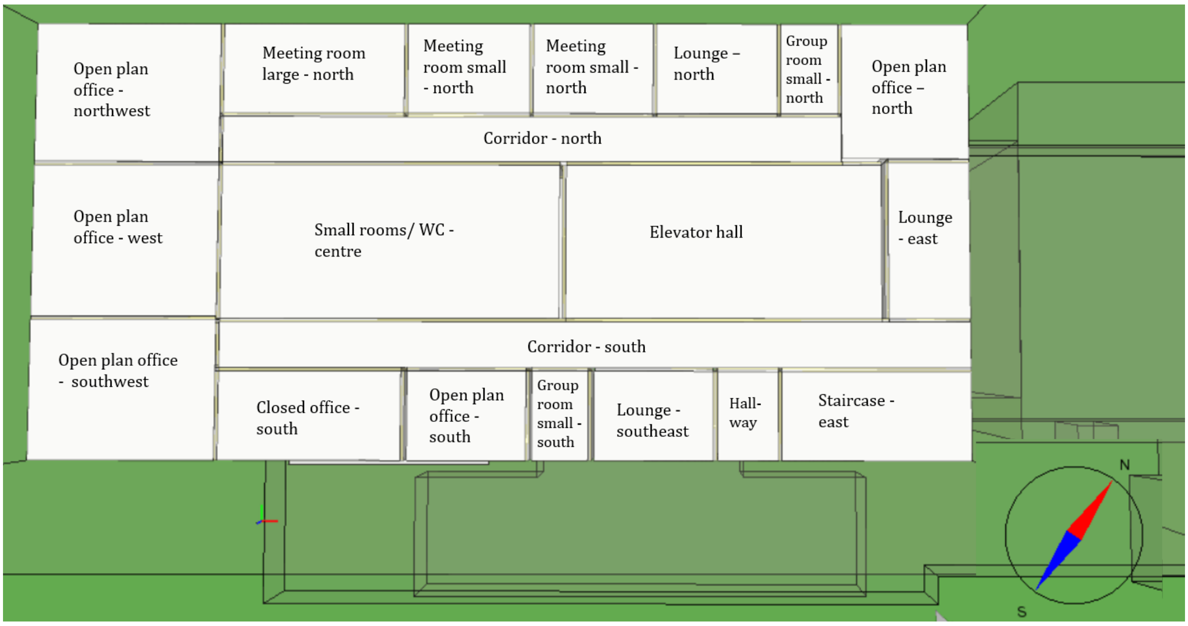

Figure 3.2 *The building floor investigated in the Case study, seen from above.*

As for the installations in the building, the ventilation system has supply and extract air with heat recovery and cooling. It has a variable air volume (VAV) system that is adjusting the air flow by temperature and CO_2 set-points. The temperature set-point control with a minimum temperature of 21 and a maximum of 25 degrees Celsius during the hours 07-17 and a minimum of 20 and a maximum of 26 degrees Celsius for remaining hours. More specific details and set-points for each zone can be found in *Appendix A*. The lights have an effect of 6 W/m^2 in corridor areas, 8 W/m^2 in the lounges and closed office, 9 W/m^2 in the meeting rooms and 10 W/m^2 in the open plan offices. Since the lights are controlled manually the power is reduced to between 71% and 100%, depending on area (Ljuskultur, n.d). The equipment has a power of 100 W per occupant for the various zones. The equipment is set to 60% of a fully occupied building for all occupancy schedules, as a simplification.

3.1.2. IDA ICE

The case study is made with the software IDA Indoor Climate and Energy (IDA ICE), version 4.8 expert edition, from EQUA. It runs whole year studies to calculate the energy consumption from the heating- and cooling-load needed in each zone together with predicting of thermal comfort and indoor air quality (Azar et al., 2020). The simulations are dynamic with a 14 day start up period where supplied heat and heat losses are calculated and equilibrized by time-step simulation based on the governed set-point temperature in the system. To investigate how the occupants' behaviour affect the energy efficiency, four different simulations are made in IDA ICE. An energy simulation is made for each of the mentioned cases, to show the system energy and delivered energy and how the delivered is divided. The energy simulation gives the energy demand for a whole year. A heat simulation is made during the coldest day with a DVUT of –12.3 degrees (Gothenburg) and an air velocity of 0.15 m/s. From the heat simulation the maximum and minimum operative temperatures is collected, as well as Fangers comfort indices (PPD and PMV) of the occupants. This gives a relation between indoor temperatures and the perceived comfort of the occupants. Further, the given temperatures in the different zones are compared to guidelines and recommendations. The third simulation is a custom one, made during the warmer months, March 15 to September 15 and with an air velocity of 0.2 m/s. From this simulation the maximum solar heat gain is collected. The last simulation is overheating, it is done for the whole year. This gives Fangers comfort indices of the occupants during the warmest days of the year and the yearly number of hours that are considered as overheated in the different zones.

3.1.3. Parameters investigated in the Case study

From the previous chapter it can be concluded that several different parameters influence the energy consumption and indoor environmental climate. As described for the case building, some parameters are fixed or regulated by sensors which does not make them available for occupant adjustment. To limit the case study a few occupant related parameters where selected, presented in *Table 3.1*. The occupant schedule is adjusted to investigate potential effects of another occupant presence and distribution. Related to the occupant, the clothing insulation (CLO) is changed to evaluate differences between seasons and attires. The metabolic rate (MET) is also adjusted to simulate activity's influence on the comfort and energy consumption. Regarding visual comfort, artificial light and blinds can be adjusted by occupants which will be simulated from different aspects.

Since a questionnaire was difficult to implement during the pandemic period for collecting real data on the occupant's behaviour, some simplifications were made for the simulations. To illustrate an as realistic manual behaviour as possible set-points was used. The same way an occupant would adjust the environment due to discomfort, the set-point will make the changes due to discomfort limits. In cases where the experienced comfort was neglected, schedules were used to turn the systems on/off after certain hours. This to compare different occupant behaviour to each other.

Table 3.1 *Measurements implemented in the IDA ICE simulations.*

Aspect	Parameter	Measure
General	Occupancy	Different occupancy schedules
Thermal comfort	MET (Activity level)	Different MET depending on zone in the building
Thermal comfort	CLO (Clothing level)	Different CLO depending on season
Visual comfort	Artificial Light	Different light schedules (acc. to occupancy)
Visual comfort	Artificial Light	Different gap for daylight set-point [lux]
Visual comfort	Daylight Solar radiation	Implementation of manual blinds and with different occupancy schedules

In more detail, some specific values were changed to be able to compare different scenarios. According to Boverket (2017) internal gains from occupancy should be nine hours a day, therefore a workday of ten hours was chosen with an opportunity to a flexible workhour in the morning/afternoon. The occupancy schedule was set to 07-17, Monday to Friday, with different densities in different spaces. There are two different occupant schedules that are investigated, where the occupancy density was assumed to compare different scenarios, see *Table 3.2*. One called intermediate, which represent an assumed average value of the occupancy in the building with the recommended office hours as a base. The working hours are 07-17 and with a bit less occupancy density than what the building is capable of. The second case is an assumed maximum occupancy schedule, which represent a more occupied building. This case includes working hours from 07 to 19. This also means that the occupancy schedule excides the hours for when the HVAC-system operate for working hours (07-17). This is remained the same for both occupancies for simplification and to investigate the occupant behaviour with predefined settings from the given design. The occupancies are presented in more detail in *Table 3.2*. The schedule is more dynamic in the Maximum case than the Intermediate, since the occupancy is less in the morning, during lunch and late afternoon/early night. The occupants in each room symbolises where the operative temperature is measured, and it was adjusted to be 1 meter from a window (in the middle of the room if no window) and 0.8 meter from the floor level. 0.8 meter is a chosen value within the span, which is recommended by Sweden Green Building Council (Sweden Green Building Council, 2020). The span is normally the desk height for a seated working occupant and where discomfort occurs.

Table 3.2 Occupancy schedules for the simulations.

Occupancy schedule			
Room type	Units	Intermediate Schedule	Maximum Schedule
Lounge Southeast/ North/ East	5	07-17 20% 09-10 100% 14.30-15.30 100%	07-17 20% 09-10 100% 14.30-15.30 100%
Corridor South /North	1	07-17 100%	07-17 100%
Staircase East/ **Elevator hall/ Hallway**	1		
Small rooms / WC Centre	5	07-17 30% 11-13 15%	07-17 30% 09-10 100% 11-13 15% 14-15 100%
Open plan office South	7	07-17 60% 11-13 30%	07-08 50% 08-17 100% 11-13 30% 17-19 30%
Open plan office North	10		
Open plan office West/Southwest/Northwest	8		
Closed office (room) South	6	07-17 60% 11-13 30%	07-08 50% 08-17 100% 11-13 30% 17-19 30%
Meeting room Large North	10	07-17 30% 11-13 15%	07-17 30% 09-10 100% 11-13 15% 14-15 100%
Meeting room Small North	8		
Meeting room Small North	6		
Group room South/North	4	07-17 30% 11-13 15%	07-17 30% 09-10 100% 11-13 15% 14-15 100%

Initial, the value for metabolic rate was 1.1 MET in all zones, which correspond to a sitting occupant typing. This value was adjusted according to more specific use of space, in the second case, according to ASHRAE (2010). In open office spaces it was set to 1.2 MET that correspond to standing relaxed or a more active working situation. In the lounge area it was increased to 1.4 MET that corresponds to a mean value of walking and sitting, and last for the corridors and staircase/elevator the MET was set to 1.7 (walking). The two cases are presented in *Table 3.3*.

The clothing insulation was from start set to 0.5 CLO, which correspond to short sleeve shirt, according to ASHRAE (2010). Three different cases were done, presented in *Table 3.3*, one for all year simulations with a mean clothing level of 0.8 CLO and variation of 0.3 CLO. Then one summer case with 0.55 ± 0.05, which correspond to trousers and short sleeve shirt, and a winter case with 0.95 ± 0.1, which correspond to long sleeve and jacket, was done as well.

__Table 3.3__ Settings for metabolic rate and clothing insulation, both design and new cases.

	MET		CLO			
Room type	Design value	Adjusted	Design value	Year	Summer	Winter
Lounge Southeast/ North/East	1.1	1.4	0.5 ± 0	0.8 ± 0.3	0.55 ± 0.05	0.95 ± 0.1
Corridor South/North	1.1	1.7	0.5 ± 0	0.8 ± 0.3	0.55 ± 0.05	0.95 ± 0.1
Staircase E/ **Elevator hall/ Hallway**	1.1	1.7	0.5 ± 0	0.8 ± 0.3	0.55 ± 0.05	0.95 ± 0.1
Small rooms/ WC Centre	1.1	1.2	0.5 ± 0	0.8 ± 0.3	0.55 ± 0.05	0.95 ± 0.1
Open plan office South/North/ West/SW/NW	1.1	1.2	0.5 ± 0	0.8 ± 0.3	0.55 ± 0.05	0.95 ± 0.1
Closed office South	1.1	1.2	0.5 ± 0	0.8 ± 0.3	0.55 ± 0.05	0.95 ± 0.1
Meeting room Large/Small North	1.1	1.1	0.5 ± 0	0.8 ± 0.3	0.55 ± 0.05	0.95 ± 0.1
Group room South/North	1.1	1.1	0.5 ± 0	0.8 ± 0.3	0.55 ± 0.05	0.95 ± 0.1

For artificial light the first case “Partly on – due to sun” was defined with a schedule to be on during office hours, together with set-point regulations of minimum 300 and maximum 500 lux (Sveby, 2013). This means that the lights turn on below 300 lux and turn off at values above 500 lux, in between the light has an ability to adjust the intensity. This will represent an optimal case as if the occupants would turn the lights off during the hours when the sensor (set-point) would. For the case “Always on” the lights are not controlled by light intensity (set-point), they are instead fully on during the scheduled hours. This corresponds to a case where the occupants always would leave the light on during the office hours. The third case “Partly on – due to occupancy” represent a case where the lights are turned off according to the occupancy rate. The meeting rooms have a different light schedule to show the effect of turning the lights of when a room is not in use. The lights are presented in *Table 3.4*.

Table 3.4 *Schedules with set-point for artificial lights with intermediate occupancy, parentheses correspond to maximum occupancy.*

Artificial light						
	Partly on – due to sun		Always on		Partly on – due to occupancy	
Room type	**Set point Min/Max [lux]**	**Schedule**	**Set point Min/Max [lux]**	**Schedule**	**Set point Min/Max [lux]**	**Schedule**
Lounge SE/N/E	300/500	07-17 100%	n.a.	07-17 100%	n.a.	07-17 100%
Corridor S/N	300/500	07-17 (07-19) 100%	n.a.	07-17 (07-19) 100%	n.a.	07-17 (07-19) 100%
Staircase E/ **Elevator hall/ Hallway**	300/500	07-17 (07-19) 100%	n.a.	07-17 (07-19) 100%	n.a.	07-17 (07-19) 100%
Small rooms/ WC Centre	300/500	07-17 100%	n.a.	07-17 100%	n.a.	07-17 30%, 11-13 15%, 09-10 & 14-15 100%
Open plan office S/N/W/SW/NW	300/500	07-17 (07-19) 100%	n.a.	07-17 (07-19) 100%	n.a.	07-17 (07-19) 100%
Closed office S	300/500	07-17 (07-19) 100%	n.a.	07-17 (07-19) 100%	n.a.	07-17 (07-19) 100%
Meeting room Large/Small N	300/500	07-17 100%	n.a.	07-17 100%	n.a.	07-17 30%, 11-13 15%, 09-10 & 14-15 100%
Group room S/N	300/500	07-17 100%	n.a.	07-17 100%	n.a.	07-17 30%, 11-13 15%, 09-10 & 14-15 100%

The design values for drawn blinds are defined by solar intensity of 30 W/m^2 on the inside of the window glass. The second case is never drawn which mean that the full effect of solar radiation and daylight will reach the building. For the third case, partly drawn, the control is based on solar intensity and schedule to only have the possibility of being drawn between 07 and 17 (weekdays). In the last case the blinds are always drawn in the defined schedule of 07-17 (weekdays) and never drawn between September 16th to March 14th since this is the time period of the simulated winter season. The Blinds are presented in *Table 3.5*.

Table 3.5 *Schedules with set-point for blinds.*

Blinds							
Design value		**Never drawn**		**Partly drawn**		**Always drawn**	
Set-point [W/m^2]	**Schedule**	**Set-point [W/m^2]**	**Schedule**	**Set-point [W/m^2]**	**Schedule**	**Set-point [W/m^2]**	**Schedule**
30	n.a.	n.a.	Never drawn	30	07-17	n.a.	07-17
						Never drawn Sept 16th - Mar 14th	

The simulations consist of various combinations divided into two parts. The first part includes simulations to investigate the influence of the metabolic rate, clothing level and occupancy rate, presented in *Table 3.6*. In the first part, the first simulation combination is made with the design values for all parameters such as MET, CLO, occupancy schedule, blinds and lights. Then MET, CLO and occupancy are adjusted, one at a time, to investigate how much each of the parameters affect energy consumption and thermal comfort.

Table 3.6 *Combinations used in the first part of the Case study.*

	Adjustment				
Combination	**MET**	**CLO**	**OCC**	**Lights**	**Blinds**
1	Design value	Design value	Intermediate	Partly on by sun	Design value
2	Adjusted	Design value	Intermediate	Partly on by sun	Design value
3	Design value	Year/Summer/ Winter	Intermediate	Partly on by sun	Design value
4	Design value	Design value	Maximum	Partly on by sun	Design value

The second part includes the adjusted values of clothing level and metabolic rate and investigates the influence usage of blinds and artificial lights can have, presented in *Table 3.7*. Nine different combinations of light and blind schedules are used to investigate their impact on energy consumption and comfort. All nine combinations are simulated with maximum occupancy to investigate how a full occupied building would act. Four of them are then simulated with intermediate occupancy. The chosen cases are two that are likely to give the lowest energy consumption and two that are likely to give the highest energy consumption. The cases with always drawn blinds and partly on lights controlled by occupancy are excluded.

Table 3.7 *Combinations of lights and blind schedules used in the second part of the Case study*

	Adjustment				
Combination	**MET**	**CLO**	**OCC**	**Lights**	**Blinds**
1	Adjusted	Year/Summer/ Winter	Maximum/ Intermediate	Partly on by sun	Never drawn
2	Adjusted	Y/S/W	Max/Interm.	Always on	Never drawn
3	Adjusted	Y/S/W	Max	Partly on by occupancy	Never drawn
4	Adjusted	Y/S/W	Max/Interm.	Partly on by sun	Partly drawn
5	Adjusted	Y/S/W	Max/Interm.	Always on	Partly drawn
6	Adjusted	Y/S/W	Max	Partly on by occupancy	Partly drawn
7	Adjusted	Y/S/W	Max	Partly on by sun	Always drawn
8	Adjusted	Y/S/W	Max	Always on	Always drawn
9	Adjusted	Y/S/W	Max	Partly on by occupancy	Always drawn

3.2. Result

The result is divided in two main sections. The first part presents the influence of metabolic rate, clothing level and occupancy level and the second part presents the nine different combinations of light and blind schedules with improved MET and CLO.

3.2.1. Influence of metabolic rate, clothing level and occupancy

The first part of the case study is an investigation to help clarify how single parameters related to the occupant affect the energy consumption and comfort. It is done by an evaluation of four different cases, one with design values, one with changed metabolic rate adjusted to the use of space, one with changed clothing insulation and one with increased occupancy.

3.2.1.1. Energy performance

The energy is presented as system energy and delivered energy in different formats. System energy is the needed energy to keep desired indoor climate and are measured in kWh per year. It includes zone heating, the needed heat transfer from radiators, and air handling unit (AHU) heating which is the energy needed to heat the supply air to the required temperature. The same applies for the cooling, zone cooling is the energy needed to cool the space and AHU cooling is the energy needed to cool the supply air. The delivered energy is the actual energy usage, divided into HVAC aux, cooling, heating, lighting and equipment presented as kWh/m^2. HVAC aux is the energy usage to run the ventilation system, such as fans and pumps. As for cooling and heating it is the total energy usage per year for adjusting the temperature according to set-points, the total sum for these will be the same as for respectively in system energy. The last ones, lighting and equipment is the total energy usage of occupants by these that are regulated by schedules.

In *Table 3.8* the system energy is presented, it shows that the zone heating decreases slightly with the adjusted metabolic rate to the higher in certain areas. MET also has an impact on the cooling, which has an increased demand since the internal gains are increased and therefore also the indoor air temperature. The reason why the result does not show any zone cooling is because the zone does not have an ideal cooler or other cooling appliances. The energy for cooling demand is related to the HVAC system and is presented in both *Table 3.8* and *Figure 3.3*. By changing the clothing insulation, the heating and cooling will not be affected since it does not increase the internal gains. The largest influence will be a change of occupancy since it correlates to several different parameters of internal gains and regulating set-points. With an extended occupancy presence and higher occupancy rate, the internal gains from occupants, lights and equipment will increase at the same time as the heating and cooling will be activated more and further. However, after the hour pass 17 the set-point for heating and cooling will be set to one degree higher/lower, the accepted temperature span increases. This makes the energy demand lower for heating in the winter and cooling in the summer than if the "working day" set-points would be extended to the same time as the changed occupancy schedule (19). As shown in *Figure 3.3* the heating will decrease, and the cooling will increase with increased occupancy.

Table 3.8 *System energy for the building with design data for one floor of the building.*

System Energy	Design values	DV + changed MET	DV + changed CLO	Changed occupancy
Zone heating [kWh]	1524.7	1454.7	1524.5	1066.7
AHU heating [kWh]	21.17	21.63	21.18	26.97
Zone cooling [kWh]	0	0	0	0
AHU cooling [kWh]	5622.5	5732.4	5621.3	60467.6

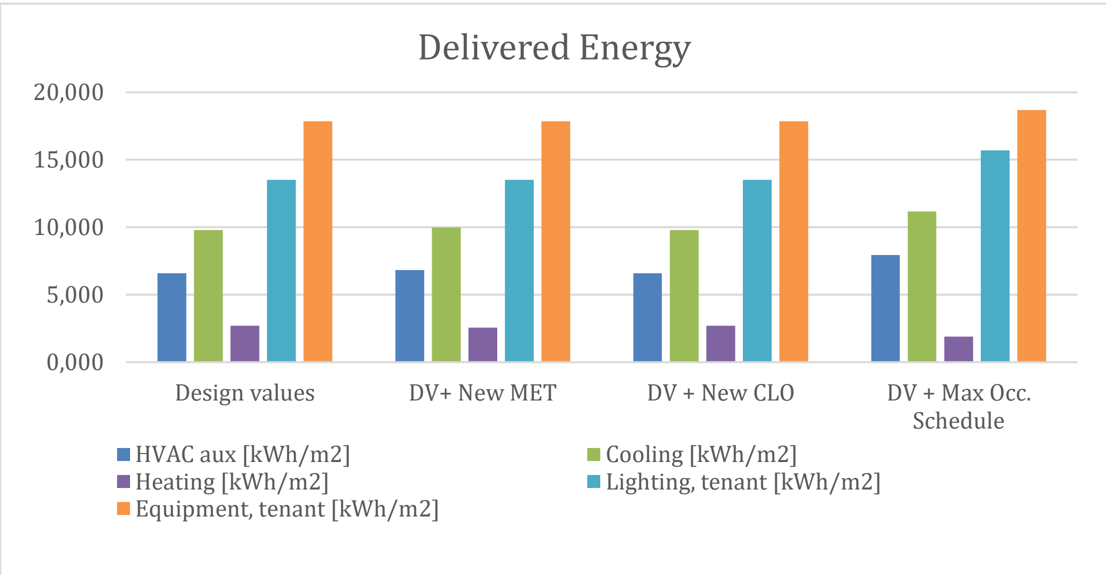

Figure 3.3 *The delivered energy with design values, adjusted metabolic rate, adjusted clothing level and increased occupancy.*

In *Figure 3.4* the total energy delivered during a year is shown, and as can be seen the extension of the occupancy schedule, and increase in occupants, is the most energy demanding case.

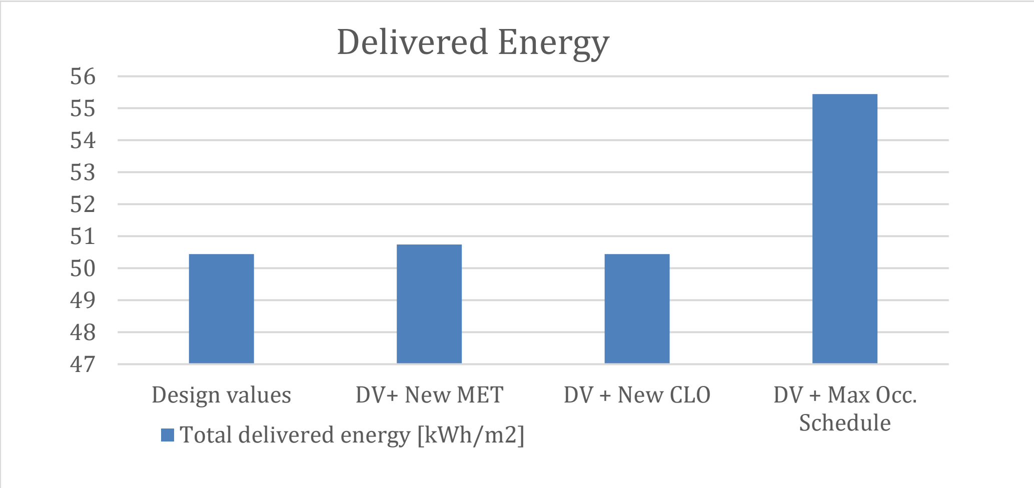

Figure 3.4 *The total delivered energy with design values, adjusted metabolic rate, adjusted clothing level and increased occupancy.*

In *Figure 3.5*, the heating and cooling for the simulated floor are shown under a duration of a year with the design values. The cooling will have higher peaks than the heating but with less consistency during operation and a shorter period of time. The peak demand for energy will be almost the same for the different cases, the ones that differ a bit is the heating and cooling demand, specifics are presented in *Appendix B*. These are also the ones that are affected by the changes of metabolic rate and changed occupancy. Highest cooling demand and lowest heating demand occur with changed occupancy due to significant increase of internal gains.

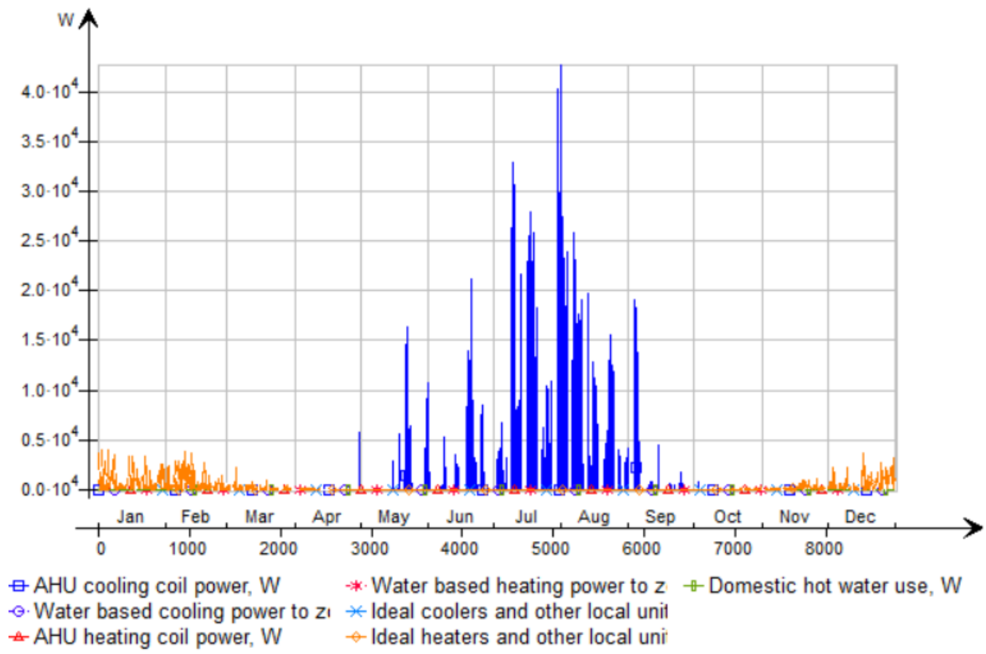

Figure 3.5 *Total heating and cooling, for the simulation with design values*

3.2.1.2. Solar heat gain and comfort during summer

To present the result in a more convenient way, some zones were chosen for comparison of indoor climate and indexes. Since focus is on office rooms two open plan offices in different locations was chosen, north and southwest, a closed office in south and a large meeting room in north, see *Figure 3.6*. Also, two common areas in form of lounges were chosen, one in north and another in southeast.

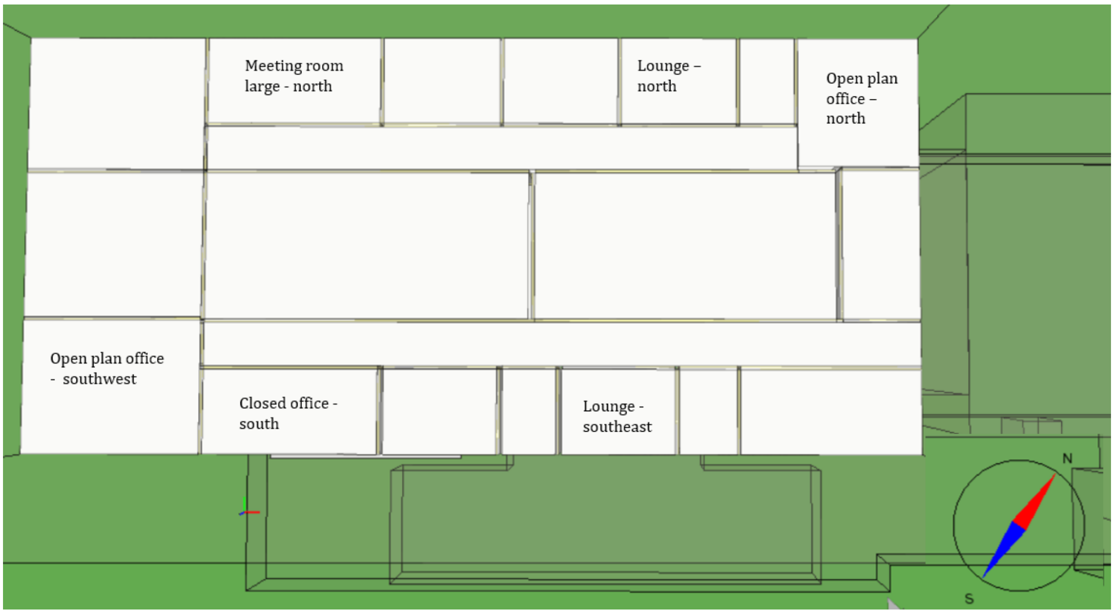

Figure 3.6 *The investigated zones in the building.*

The temperature inside needs to fulfil certain requirements. Acceptable temperatures are up to 24 degrees Celsius during the year, although during summer the temperature could temporarily be up to 26 degrees (Arbetsmiljöverket, 2021). Nya Regionens Hus is designed according to requirements by Västfastigheter. These allow for air temperatures between 22 and 25 degrees Celsius in the summer, but with an allowed temperature of above 25 degrees for maximum 120 working hours during the year (Västfastigheter, 2017). The hours of overheating correspond to the time when the temperature is above 25 degrees Celsius during the working day.

When studying the cases with design values, changed MET and CLO, the space with most overheating hours is the lounge in southeast direction, which is above the limit but because it is not a specific office space it is acceptable. The rest of the spaces is well within the requirement of 120 h, with the different values presented in *Appendix B*. When occupancy is changed and extended 2 hour (to 19 instead of 17) the overheating hours rises above 120 h for most spaces. On the basis that the working day ends at 17 the set-points are set to accept higher temperatures (26 degrees) after 17, which results in an extensive increase of over heating hours. Regarding the temperatures, for the first three cases it will barely go higher than 25 degrees and for most areas less than 1 hour above 26 degrees. Although the one with changed occupancy has many hours above 25 degrees it barely has any hours with higher temperatures than 26 degrees, this because the set-point allow for 26 degrees after 17 and most of the overheating occurs in the afternoon.

The comfort aspect is presented by the indexes PPD in different zones, see *Figure 3.7*. In correspondence to overheating hours, a large number of overheating hours indicates a higher PPD. This relation is not certain since PPD is only measured when the space is occupied at a specific point and time, whereas overheating happens during all office hours. Hence PPD does not exist in some zones due to no overheating, such as the large meeting room. It has very few overheating hours and a very low occupancy throughout the day. Comparing the two cases "design values" and "changed CLO" shows the impact of CLO. They both have similar overheating hours but the case with increased clothing level have larger PPD since it affect the occupancy's comfort rather than the indoor temperature. When metabolic rate was changed the PPD was increased in all areas except the closed office and the meeting room since the MET was remained the same as the design values here.

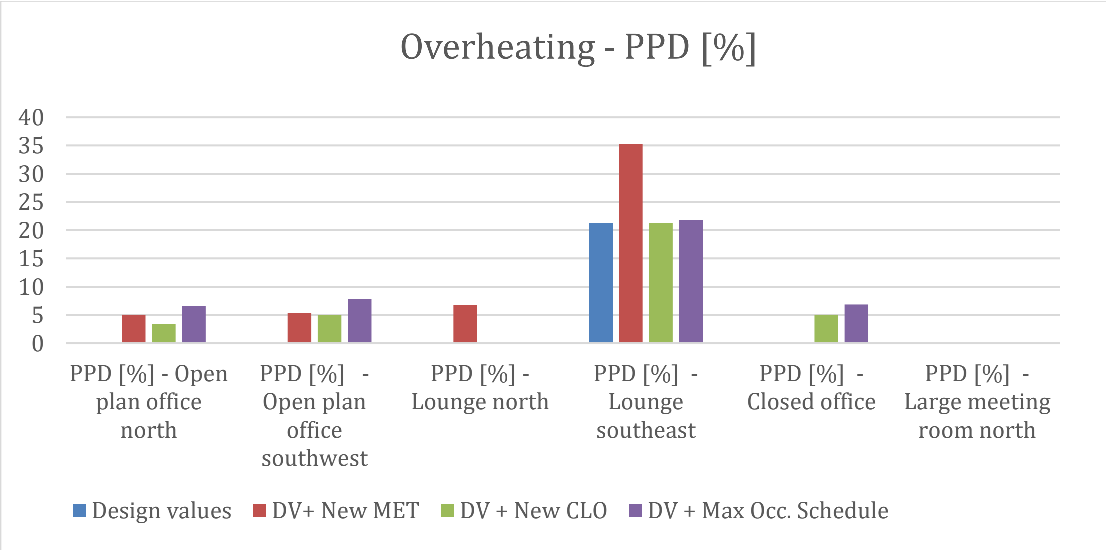

Figure 3.7 *The perceived comfort, PPD, in different zones when the largest overheating occurs.*

3.2.1.3. Air temperature and comfort for the coldest day of the year

The coldest day was simulated with dimensioning winter outdoor temperature for Gothenburg (-12.3 degrees Celsius), which illustrate worst-case scenario. According to Västfastigheter the required indoor winter temperatures are allowed to be maximum 23 degrees and minimum 21 degrees Celsius in an office space (Västfastigheter, 2017). As shown in *Table 3.9* the lowest temperature is just below 20 degrees which agree with the requirement of Arbetsmiljöverket for office space of 20 degrees Celsius (Arbetsmiljöverket, 2021) but not Västfastigheter's requirement. The reason for this is because the set-point temperatures are set to a minimum of 21 degrees between 07 and 17 but remaining hours will have a set-point of 20 degrees. Since the occupancy schedule continue until 19, the coldest hour will occur sometime after 17. The system is controlled by a set-point of minimum 20 degrees as the lowest temperature during the day, small temperature difference occurs when the heating system balance back due to thermal inertia. During the workday (07-17) the temperature is set to 21 degrees Celsius which is the reason that the highest temperature is just above 21. When the temperature reaches 21 degrees the heating will be turned off and the temperature will balance out. The reason why the temperatures are almost the same is simply because the worst-case is simulated without internal gains and the same set-points, the HVAC system adjust the indoor climate due to set-point which will result in similar temperatures. Without any impact of internal gains, the different cases will have the same affecting input data.

Regarding PPD, they are all close to each other except for the one with changed clothing. Since this is heavily increased for all zones, it will have a major impact in contrast to the changed MET. The worst PPD occurs in the meeting room where the MET remains the same as for design values and accordingly will be similar.

Table 3.9 *Mean air temperature and max perceived comfort of the occupants, for the coldest day of one floor of the buildings.*

	Design values	**DV + changed MET**	**DV + changed CLO**	**Changed occupancy**
Max mean air temperature [°C]	21.04	21.03	21.04	21.03
Min mean air temperature [°C]	19.97	19.97	19.97	19.97
Max PPD [%]	86.78	85.36	21.21	86.77

Changing the clothing insulation has the largest effect on the occupant comfort during the coldest day, because of the large increase of clothing level. In comparison to overheating, the change of CLO has a greater impact here due to larger acceptable clothing insulation. What also can be seen in *Figure 3.8* is the variation of PPD that different MET contributes to. The lounges have the greatest increase of metabolic rate which leads to almost as low PPD as for changed clothing level. The MET is slightly increased for open plan offices which result in a lower PPD but still too high to be acceptable. To deduce, changing the schedule will not affect the maximal PPD but it could have an impact with larger change in schedule. For these cases the worst PPD will appear during the workday and therefore not be affected by an extension of occupancy.

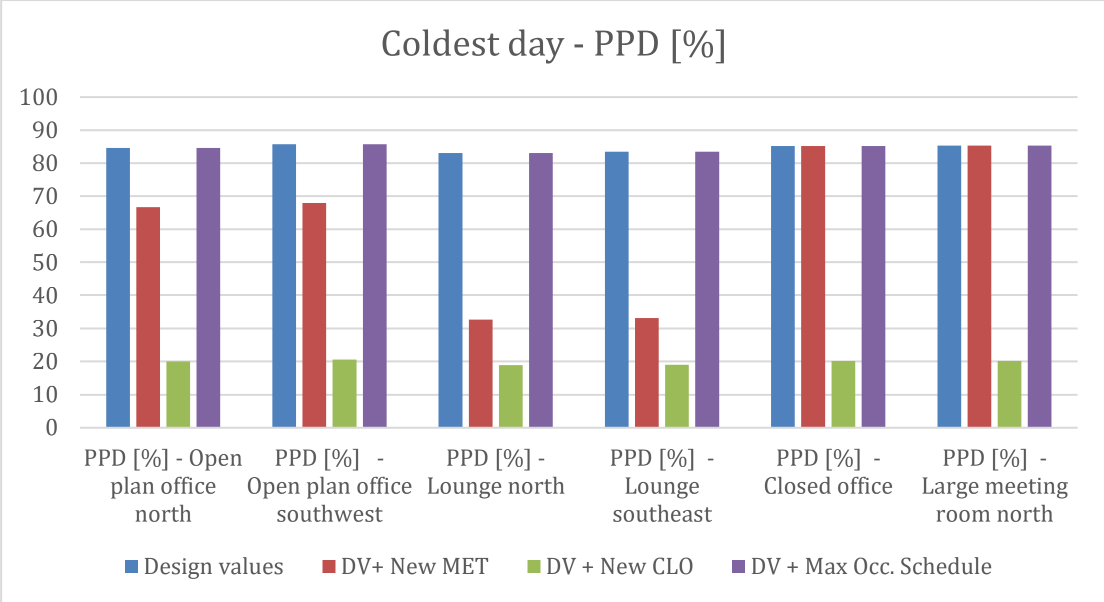

Figure 3.8 *The perceived comfort, PPD, for the occupants during the coldest day in different zones of the building.*

3.2.2. Simulation with varying blind and light schedule.

To investigate how the parameters influences each other several combinations was made with different blind and light schedules together with the new values of metabolic rate, clothing level and occupancy schedules according to section 3.1.3 (*Table 3.7*). The values of MET and CLO was evaluated after the past simulation. The conclusion from the simulation is that the adjusted MET and CLO help saving energy during the winter and increases the comfort for the occupants to a reasonable level. The design values used for the building was not adjusted to the performed tasks in the different zones of the building.

3.2.2.1. Energy performance with maximum occupancy

From an energy perspective, the largest total consumption comes from the case with lights always on and blinds never drawn as seen in *Figure 3.9*. The cases with lights always on are the ones that contribute to the largest energy usage. This because of the high usage of artificial light resulting in higher internal gains and thereby a high cooling demand. On the contrary the lowest energy consumption is the one with lights partly on due to illuminance (sun) and blinds never drawn. The reason this case has a lower energy demand than the case with lights controlled by the sun together with partly drawn lights, is because the artificial lights are used less if the blinds always are up. The energy saved by turning the lights off is higher than the energy used for cooling the solar heat. The cases with lights adjusted by illuminance are the ones with the lowest energy consumption due to decreasing hours of artificial light and thereby a decreasing cooling demand. Although the delivered energy is the lowest with never drawn blinds and lights partly on due to sun, this does not mean that it is the optimal case through a comfort perspective.

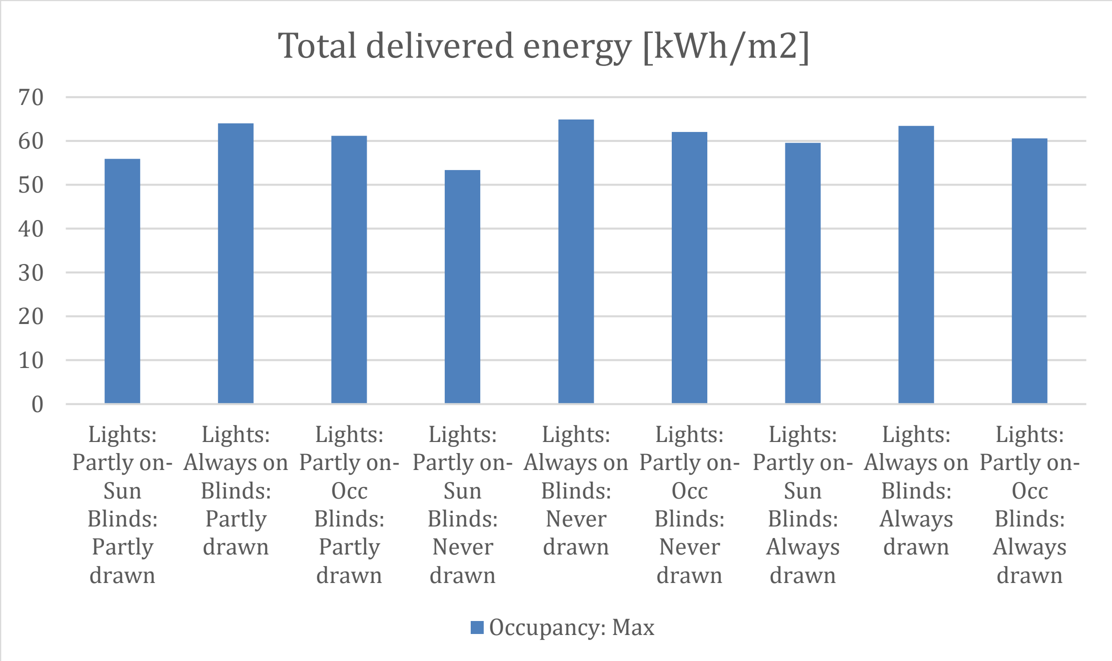

Figure 3.9 *A comparison of the total delivered energy when we have maximum occupancy schedule with the adjusted value of MET and CLO.*

By dividing the energy consumption into different systems, *Table 3.10*, the result show that cooling is the governing part for the energy consumption. The case with the largest cooling demand is the one with lights always on and blinds never drawn, since it has the largest internal gains from lights and solar heat gain. It is followed by the case with lights partly on due to occupancy which is almost the same as always on for most rooms. Lowest cooling demand corresponds to lights partly on due to sun with blind partly drawn or never drawn. When looking at heating demand, the case with lights partly on due to occupancy and blinds partly drawn has the highest energy consumption since it contributes with less internal gains and effectively blocking the solar heat gain. Blinds always drawn will not be drawn during winter since that would give a smaller heat gain. The lowest heating demand is for the case with lights always on and blinds never drawn or always drawn, since these will be the same during heated months.

Table 3.10 *System energy for the building with design data for one floor of the building with maximum occupancy.*

System Energy	Lights: **Partly on-Sun** Blinds: **Partly drawn**	Lights: **Always on** Blinds: **Partly drawn**	Lights: **Partly on-Occ** Blinds: **Partly drawn**	Lights: **Partly on-Sun** Blinds: **Never drawn**	Lights: **Always on** Blinds: **Never drawn**	Lights: **Partly on-Occ** Blinds: **Never drawn**	Lights: **Partly on-Sun** Blinds: **Always drawn**	Lights: **Always on** Blinds: **Always drawn**	Lights: **Partly on-Occ** Blinds: **Always drawn**
Zone heating [kWh]	949.2	826	994.3	929.0	749.3	907.2	930.4	752.6	910.9
AHU heating [kWh]	26.83	27.07	28.34	28.34	26.46	27.74	28.34	26.46	27.74
Zone cooling [kWh]	0	0	0	0	0	0	0	0	0
AHU cooling [kWh]	6673	7334	7124	6741	7686	7478	6989	7124	6917

By studying the remaining energy usage, shown in *Figure 3.10*, it can be concluded that the energy usage for lights has a strong correlation to the light set up. For the cases where the lights are always on and for the cases where light is controlled by occupancy the lighting make up for the largest part of the energy consumption. On the contrary from the fixed lights, the lights adjusted by the sun differ between the three cases. The lowest is for lights that are partly on by sun in combination with the never drawn blinds. The equipment schedule remains the same regardless light and blind combination, which make its energy demand equal in all cases.

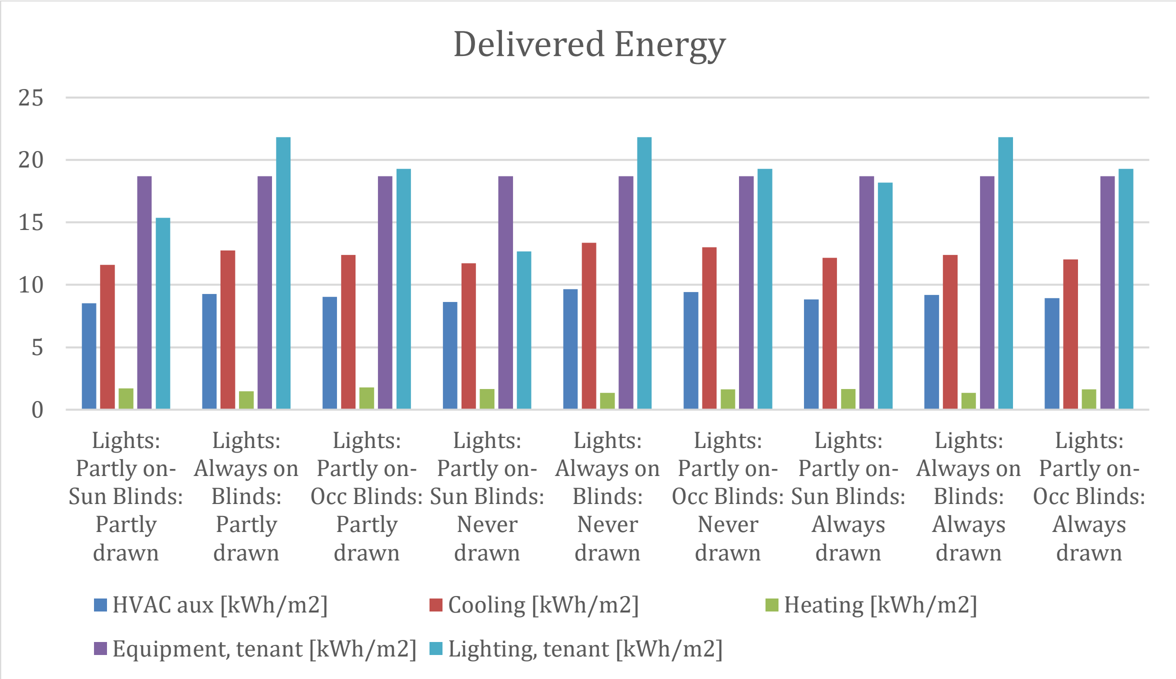

Figure 3.10 *The delivered energy for the building with the new MET and CLO and maximum occupancy. The diagram shows the different combinations of light and blind schedules.*

As for the previous combinations the peak demand for delivered energy is almost the same for all cases with some variations regarding heating and cooling. The largest peak demand is for cooling, almost 7 times as large as for heating. It is reasonable that cooling has a significant larger peak demand since the building has a greater energy consumption related to cooling.

3.2.2.2. Energy performance with intermediate occupancy

To investigate how the occupancy affects the energy consumption, only four of the previous cases was simulated. The selected cases were the two with highest energy consumption, lights always on together with blinds partly drawn and never drawn, and with lowest consumption, lights partly on due to sun together with blinds partly drawn and blinds never drawn. During the majority of the days in the summer season the partly drawn blinds will be fully drawn for better part of the day, which imitates blinds always drawn, and thereby will give a similar result. Beyond that, fully drawn blinds during all summer days is an unlikely behaviour for the occupants.

As shown in *Figure 3.11* the energy consumption for intermediate occupancy is slightly lower than for maximum occupancy. The reduction from maximum to intermediate is around 9 % for all cases, and the same pattern could most likely be applied for the remaining cases and also for other occupancy schedules. To conclude, a lower occupancy corresponds to a smaller energy consumption since the internal gains are directly linked to the occupancy schedule/rate.

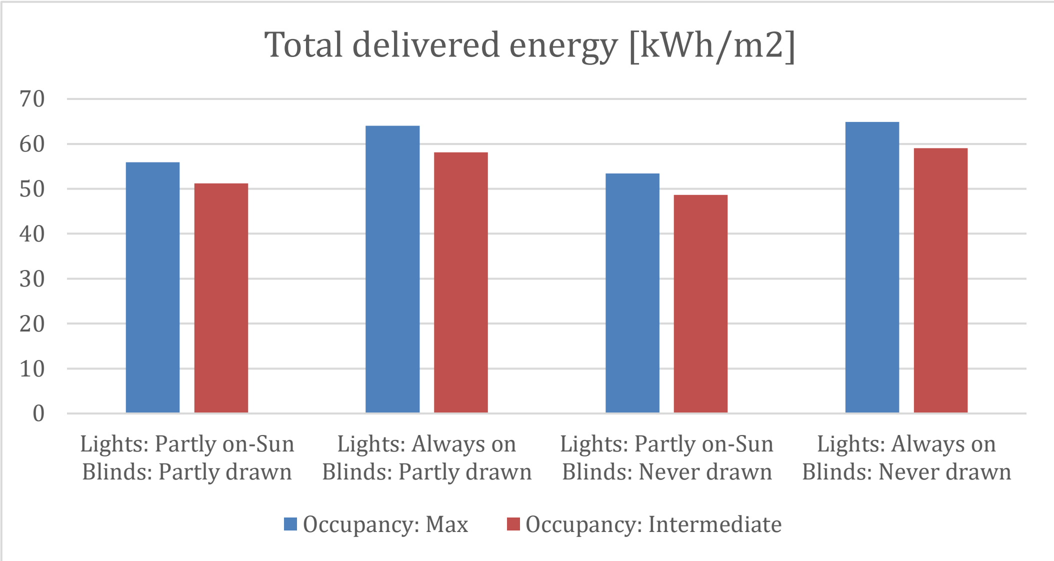

Figure 3.11 *A comparison of the total delivered energy when we have maximum occupancy and intermediate occupancy schedule.*

In comparison to the case with maximum occupancy, the zone heating has increased with around 200-300 kWh and the air handling unit (AHU) heating has decreased with around 6-8 kWh. To fulfil the temperature set-point of the room, it can be adjusted by increasing heat from the ideal heaters or the HVAC-system. The HVAC-system does also adjust the CO_2 concentration in the room, which will have an increased concentration with increased occupancy (max). The air flow will thereby be higher in the maximum case to reduce the CO_2 concentration, than for the case with intermediate occupancy rate. With a higher air flow, a larger contribution of heat will come from the air handling unit and thereby a smaller heat demand from radiators. The increased heating demand for intermediate occupancy is partly based on the decreased density of occupants together with a decrease in equipment and lights. As shown in *Table 3.11*, the total heating has increased at the same time as the cooling has decreased.

Table 3.11 *System energy for the building with design data for one floor of the building with intermediate occupancy*.

System Energy	Lights: **Partly on-Sun** Blinds: **Partly drawn**	Lights: **Always on** Blinds: **Partly drawn**	Lights: **Partly on-Sun** Blinds: **Never drawn**	Lights: **Always on** Blinds: **Never drawn**
Zone heating [kWh]	1371.6	1196.2	1354.4	1087.1
AHU heating [kWh]	21.59	21.01	21.97	20.54
Zone cooling [kWh]	0	0	0	0
AHU cooling [kWh]	5891.1	6476.3	5969.4	6870.7

The internal gains in form of lights and equipment have decreased due to lower occupancy than in the case with maximum occupancy (*Figure 3.12*). The relation between the different parameters in each combination will stay the same for both cases since the heating and cooling are a result of internal gains.

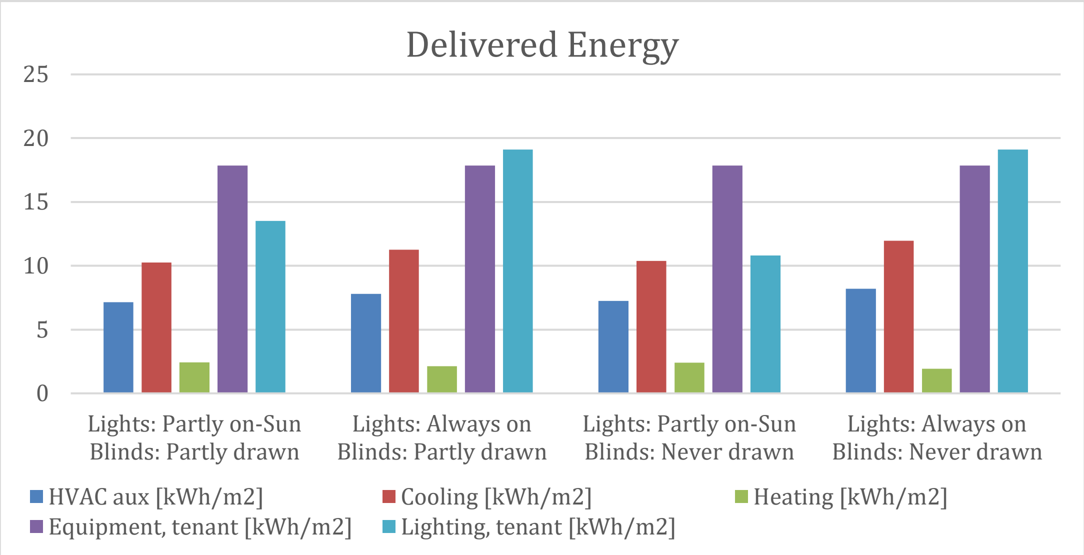

Figure 3.12 *The delivered energy for the building with the new MET and CLO and intermediate occupancy. The diagram shows the different combinations of light and blind schedules.*

Cooling has the larger energy demand compared to heating which is why the cooling peak demand is significantly higher, specific values are presented in *Appendix B*. However, this theory cannot be applied for all categories. Light and equipment have a higher total demand that consist of an equal spread throughout time in comparison to cooling and therefore a relatively low energy peak demand. The cooling demand is maximized at times and non-active during large parts of the year (similar to *Figure 3.5*), which makes the peak higher. With lots of internal gains and warm outside temperature the cooling will need to have a higher effect to balance out to the right set-point temperature.

3.2.2.3. Solar heat gain and comfort during summer with maximum occupancy

The maximum solar heat gain is compared for one weekday in March since the absolute maximum for each combination occurs at different dates (weekdays and weekends). The date March 30th was chosen for comparison since the maximum solar heat gain for weekdays occurs this day. The highest solar heat gain occurs when the blinds never are drawn, with a value around 94W/m^2. The combinations with partly drawn blinds and always drawn blinds have similar max solar heat of around 66 W/m^2, see *Appendix B* for exact values. This because, during the days with a lot of illuminance the partly drawn blinds will be drawn during almost a full day and will get similar values as the always drawn blinds. All blinds are programmed to rise at 17 when the usual workday is out but will not make a difference since the highest solar intensity occurs during the day.

To relate the solar heat gain to overheating hours the combinations with the highest solar heat gain also have the highest number of overheating hours, compared to the corresponding light schedule. Blinds that are always drawn lead to the least overheating hours compared to the cases with the same light schedule and blinds that are never drawn to most overheating hours. The reason why the cases with lights partly on due to solar intensity are the lowest three is because these are strongly connected to the blind settings. With blinds always drawn the lights will be turned on for longer periods than for partly drawn and create larger heat gain inside. When comparing the combinations with lights always on and partly on due to occupancy, the last will be slightly lower. For all rooms expect the meeting room, the lights will be on all day while it will be turned off during several hours in the meeting room. This leads to a larger percentual difference for the meeting room compared to the other rooms. For the open plan offices there are significant more overheating hours in north than southwest which is because of the higher occupant density in north (smaller floor area). The reason why the lounge in the southeast has a higher number of hours than the one in north is due to higher heat load from the sun and adjoining rooms.

The majority of the rooms have less than 120 overheating hours between 07-17 (official workday) which is the requirement. Studying this further, with maximum occupancy there are people present until 19 which will give more overheating hours than accepted. The set-point gets a higher limit after 17 that leads to temperatures up to 26 degrees. Most of the overheating hours occurs during the summer season. There is no presence of occupants in the meeting room or lounge after 17 which is why they are excluded in that regard.

The thermal comfort in the summer climate for each room is somewhat similar between the different light and blind combinations. This was expected since the clothing level, metabolic rate and occupancy rate are the same for all combinations in the same type of zones. Shown in *Figure 3.13*, the worst case for all rooms is the one with lights always on and blinds never drawn. It is simply due to maximal internal heat gains both from artificial lights and solar heat. The case with lights partly on due to occupancy and blinds never drawn is almost the same since the light will be fully on in all rooms except for meeting rooms and group rooms. Although the light intensity will not be reduced in the analysed rooms, they will still be affected by the adjoining rooms that are reduced. As the figure shows the lounge southeast have significant higher indexes. It could be due to several reasons such as it has a high metabolic rate and a high density of people at times together with the constant contribution from the sun during the work hours. It is also a small room with large windows and openings to other spaces with higher metabolic rate and the staircase and hallway as adjoining zones with very high temperatures and PPD. The staircase does not have as strict control of the climate and requirements as the office rooms and is therefore not investigated further.

The most optimal case regarding comfort is the one with lights partly on due to sun and blinds partly drawn. This case adjusts the lights based on illuminance and the blinds on solar intensity which leads to ultimate balanced circumstances. On a typical sunny summer day, the blinds will be drawn almost all day which will imitate the case where the blinds are always drawn and therefore will these cases have very similar PPD values. When blinds are always drawn, the PPD will be consistent with lights always on and partly on due to occupancy since these are very similar in contributing heat gains. If using lights that are controlled by light intensity the PPD will decrease slightly due to less internal heat. Comparing the open plan offices, the one in southeast has PPD between 14-20% and the one in north 11-14% which is reasonable. With direct sun all day the variation should be larger due to greater heat gain throughout the different cases in contrast to the one in north where the sun will not reach with the same intensity.

For all cases the blinds will go up at 17, since that is when the general workday is over, even though it still will be occupants left in some rooms. For the cases that are controlled by light intensity they would have gone up by 17 anyway because of the large decrease in solar intensity in the afternoon/evening. The maximum PPD for the areas that are occupied until 19 occurs between the hours 17 and 19, because of the additional heat gain. The heat gain mainly occurs from the extended set-point temperatures, solar heat and internal gains. The reason the meeting rooms does not have any PPD registered is because it does not occur any overheating here. It is presumably due to the orientation in north without any direct solar heat, low occupancy, low metabolic rate and relatively low temperatures in adjoining rooms.

The maximum PPD for the areas that are occupied until 19 occurs between the hours 17 and 19, because of the additional heat gain. The heat gain mainly occurs from the extended set-point temperatures, solar heat and internal gains. The reason the meeting rooms does not have any PPD registered is because it does not occur any overheating here. It is presumably due to the orientation in north without any direct solar heat, low occupancy, low metabolic rate and relatively low temperatures in adjoining rooms.

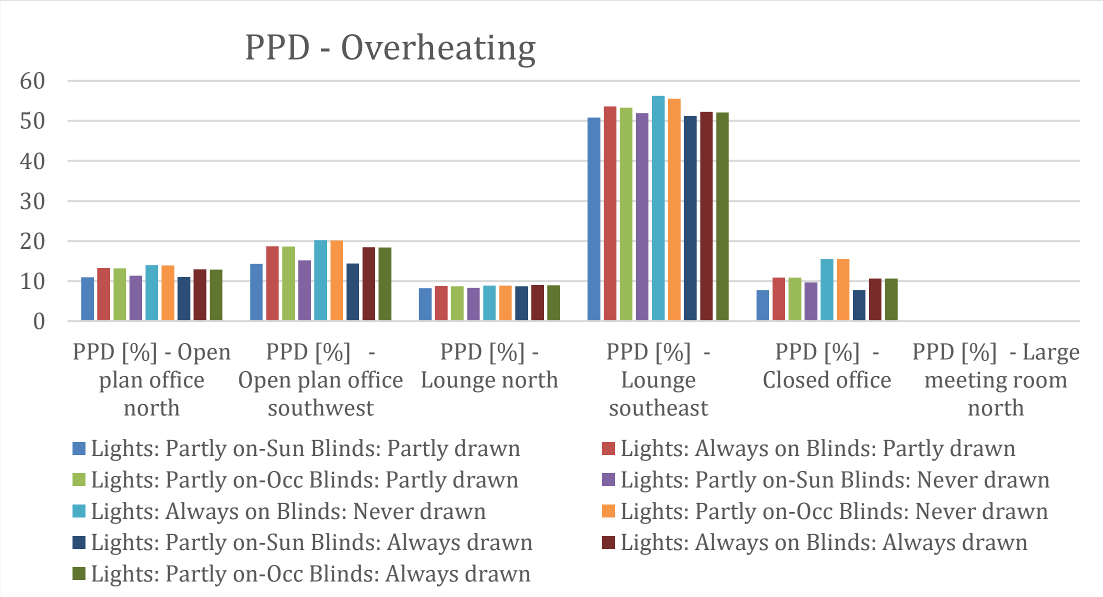

Figure 3.13 *The perceived comfort, PPD, for the day where the largest overheating occurs. The diagram shows different areas in the building with max occupancy and adjusted MET and CLO.*

3.2.2.4. Solar heat gain and comfort during summer with intermediate occupancy

Maximum solar heat gain for intermediate occupancy is almost the same as for maximum occupancy which makes the same reason apply. The solar heat gain is lower when the blinds are drawn to decrease the transmitted solar heat. For intermediate occupancy the same limit of maximum 120 overheating hours still applies which most is well within the limit. Lower occupancy rate contributes to less internal heat gain from occupants and equipment which clearly shows in comparison to maximum occupancy. All rooms except the meeting room have a significant decrease of hours. Due to a lower heat load (less internal gains) and shorter occupancy schedule the balancing of the temperature will occurs faster, at a lower temperature.

The relation between the blind and light combinations in the different zones follow the same pattern as for maximum occupancy. The comfort level is generally good with PPD values below 10%, (*Figure 3.14*) except for the lounge in southeast. This zone has the significant highest number of overheating hours which directly relates to why it has the largest PPD of about 50 %.

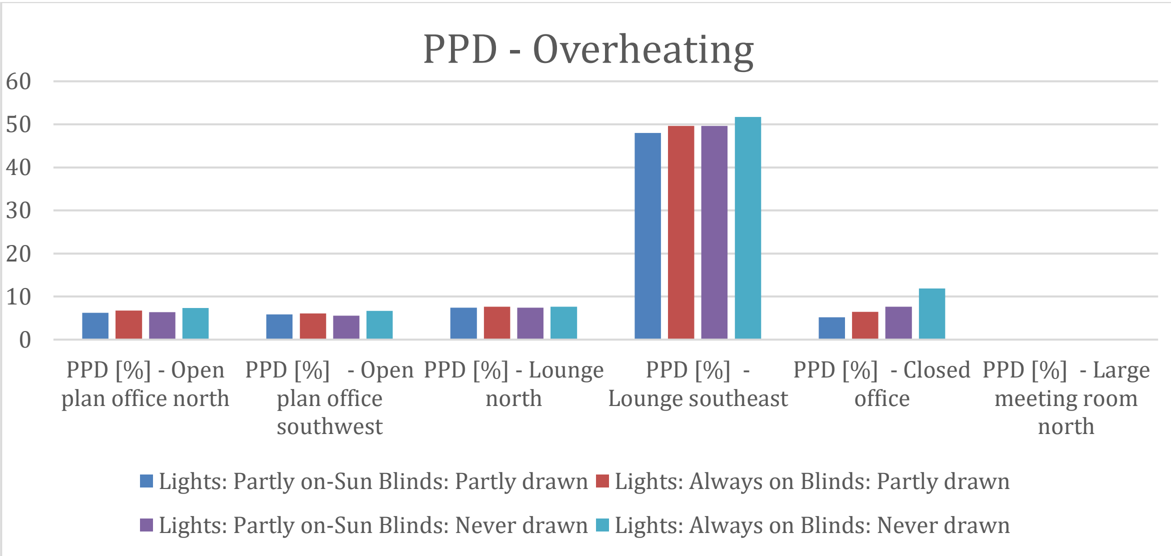

Figure 3.14 *The perceived comfort, PPD, for the day where the largest overheating occurs. The diagram shows different areas in the building with intermediate occupancy.*

3.2.2.5. Air temperature and thermal comfort for the coldest day of the year with maximum occupancy

Simulations for the coldest day of the year are implemented without any internal gains to get the worst scenario in terms of cold indoor climate. Since it is only the addition of internal gains that differ between cases the air temperature and PPD will be the same for all combinations of lights and blinds and the combinations are therefore neglected. The result of the coldest day without internal gains are presented in *Figure 3.15*. For the maximum and minimum air temperature it will be the same as in the first part of the Case study, see Table 3.9.

The PPD for winter season are relatively good, *Figure 3.15*, lower than 15 % for the open plan offices that contain the main presence of occupants. For both the closed office and the meeting room the PPD is slightly higher which most likely is due to lower metabolic rate and occupancy rate (less internal gains). The coldest temperature that occurs within usual working hours (07-17) occurs in the morning, when the occupants start their workday. This is also where the highest PPD occur since it is directly related to the mean indoor air temperature. The PPD for the open offices are high in the morning and between 17-19 where the indoor temperature in the zone is at its lowest. However, the reason for why the PPD is higher in the morning than when the coldest indoor air temperature occurs is because the radiant temperature of the building envelope is lower, which affect the thermal comfort. There is a large heat loss in the morning because the building envelope have been cooled down during the night. Even though the heaters heat the indoor air temperature relatively fast, it will take longer to heat up the building envelope because of its high inertia. The comfort in the morning is also seen as more important than the last two hours, because it has a higher occupancy rate.

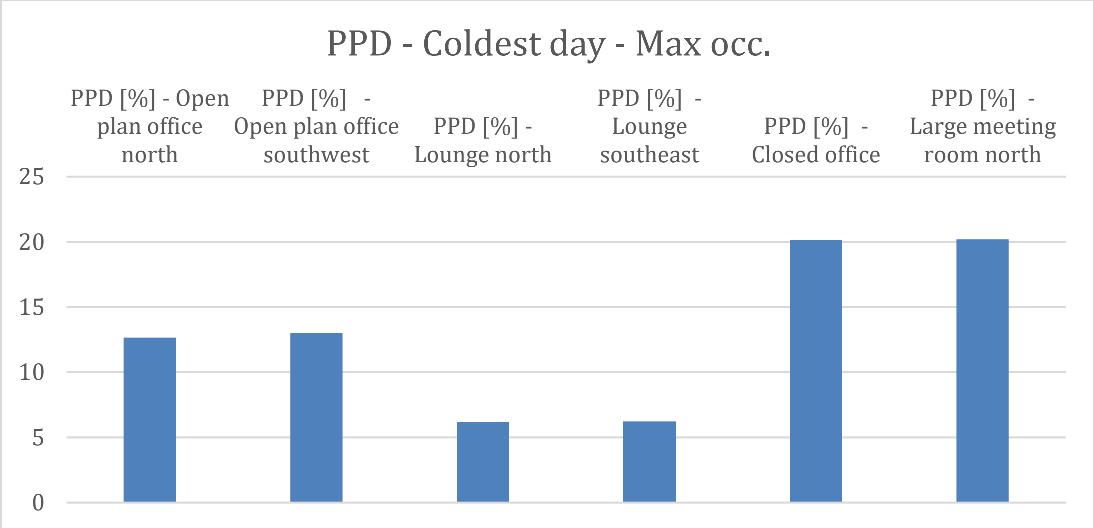

Figure 3.15 *The perceived comfort, PPD, for the coldest day of the year. The diagram shows different areas in the building with max occupancy*

3.2.2.6. Air temperature and thermal comfort during the coldest day of the year with intermediate occupancy

Maximum and minimum temperature for the coldest day of the year, with intermediate occupancy, will as describe previously be the same for all combinations since the additional heat gains are excluded. The calculated comfort index, PPD, for the coldest day will be the same for both maximum and intermediate occupancy. Comparing maximum and intermediate occupancy, the PPD is the same for both as shown in Figure 3.16. This is the expected result since both cases exclude internal gains and since the largest PPD occurs in the morning for all cases.

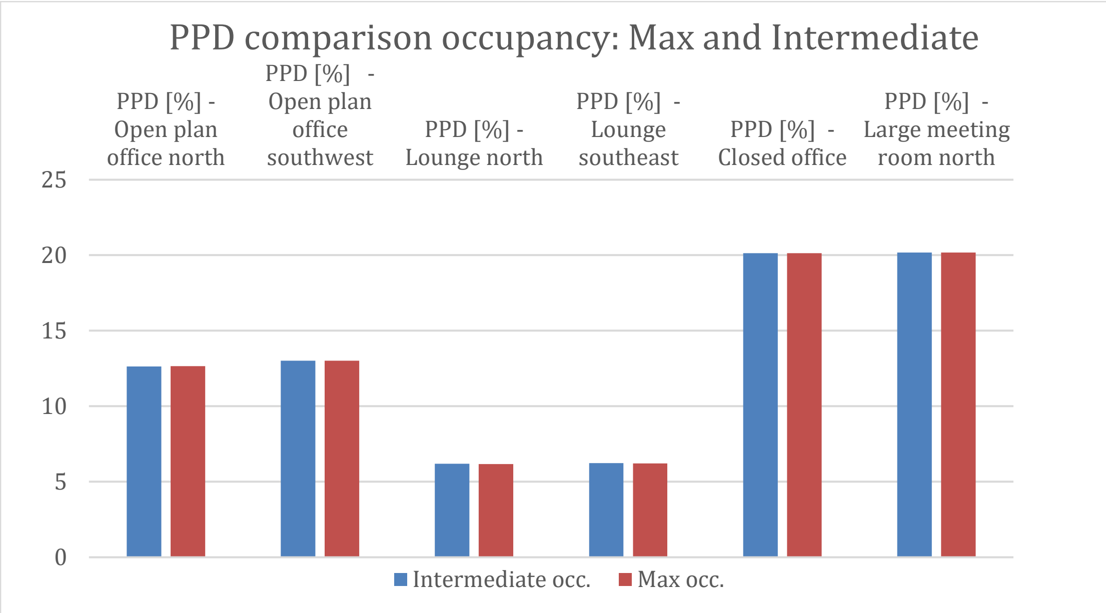

Figure 3.16 *A comparison between the perceived comfort, PPD, for the case with maximum and intermediate occupancy, for the coldest day of the year*

4. Questionnaire

This chapter includes the method of the questionannire and the questionnaire form that could be used to collect occupant related information and behaviours. The questionnaire was prevented from being sent out due to circumstances of the pandemic and the form could be used for future studies on the subject.

4.1. Method

The created questionnaire is of the form self-completion where the occupant answers the questionnaire by filling in the form on their own. Since the survey most likely will get a more validated and accurate outcome with a larger number of responses, a questionnaire is better than interviews to collect answers (Bryman & Bell, 2011). It is always a risk in using questionnaire to collect data from occupants, since participants cannot be educated in the same way as interviewers. Therefore, it is particularly significant how the questions are structured and asked to be easily understood and followed by the respondent (Ejlertsson, 2014).

To start with the questionnaire is kept relatively short to maintain the focus and quality in the responses together with completion of the form (Ejlertsson, 2014). Open questions were avoided due to difficulty since questions with tick box answers or answering on a scale is easier to interpret correctly (Bryman & Bell, 2011). These types of structured questions are more beneficial as the answers can be categorized although the sectioning of questions is equally important. The first section of questions is about basic personal information of the occupant such as gender, age and occupancy. They are simple questions with multiple choice answers that place the responder in a category, but they do not feel too personal to answer (Ejlertsson, 2014). It is useful to start off with questions that are easy to answer, questions that the responder already know the answer to, but not questions of a too personal nature.

The next part has to do with perception of the indoor climate and comfort related parameters as temperature, light, noise, bad air quality etcetera. This section contains attitude questions with answers on a Likert scale to report how frequent the discomfort is perceived. It is introduced with a holistic general question followed by specific questions of each comfort aspect.

These questions are followed by control-related questions to comprehend what kind of actions the occupant undertake to adapt due to certain discomforts. It is personal questions with focus on behaviour to answer with multiple choice answers. The behaviour that is asked of the occupants is both of action kind and time related. This is an aspect that could differ a lot between the respondents which make the formulation of the question important, for the respondent to interpret the question with the right purpose (Bryman & Bell, 2011). The time related answers are categorized into different time frames, for example morning, lunch and afternoon, to define actions to some extent since answer that are too specific and based on respondent's memory abilities often can generate inaccurate data (Ejlertsson, 2014).

Lastly the questions in the end belong to normative actions and values, with focus on normative actions and interactions with other occupants. Questions regarding normative actions does often have a connection to belief or attitude questions (Bryman & Bell, 2011), here with more focus on beliefs about others perception of the environment. These questions are answered with a Likert scale to see the variations of the respondents' beliefs.

4.2. Questionnaire form

The responses will be a fundamental contribution to the case study that will map the adaptive behaviour of occupants in office building and its impact on energy consumption.

DEMOGRAPHICS

Age:

- ❑ Under 25
- ❑ 25 - 39
- ❑ 40 - 54
- ❑ 55 and over

Gender:

- ❑ Woman
- ❑ Man
- ❑ Other

How many people share the same office/room as you? (You included)

- ❑ Private
- ❑ 2 - 3 people
- ❑ 3 - 4 people
- ❑ 5 or more people
- ❑ Open floorplan

INDOOR ENVIRONMENTAL QUALITY – COMFORT

How do you experience the indoor environment in the building in general?

•-------------•-------------•-------------•-------------•-------------•-------------•

Very dissatisfied Very satisfied

How frequent do you experience these parameters related to thermal comfort in your office/working area?

	Never	Rarely	At times	Often	Always
Cold temperature during winter season	•	•	•	•	•
Cold temperature during summer season	•	•	•	•	•
Warm temperature during winter season	•	•	•	•	•
Warm temperature during summer season	•	•	•	•	•
Draughty air	•	•	•	•	•

How frequent do you experience these parameters related to visual comfort in your office/working area?

	Never	Rarely	At times	Often	Always
Excess of natural daylight	•	•	•	•	•
Deficit of natural daylight	•	•	•	•	•
Glare due to daylight	•	•	•	•	•
Lack of outside view	•	•	•	•	•
Poor/insufficient artificial light (office light)	•	•	•	•	•
To bright/excessive artificial light	•	•	•	•	•

How frequent do you experience these parameters related to indoor air quality in your office/working area?

	Never	Rarely	At times	Often	Always
Stuffy air	•	•	•	•	•
Bothering odour	•	•	•	•	•
Dry air	•	•	•	•	•
Humid air	•	•	•	•	•

How frequent do you experience these parameters related to acoustic comfort in your office/working area?

	Never	Rarely	At times	Often	Always
Noise from human activities	•	•	•	•	•
Noise from conversations	•	•	•	•	•
Noise from appliances /installations	•	•	•	•	•
Noise from traffic and sources outside the building	•	•	•	•	•

INDOOR ENVIRONMENTAL CONTROL

I have access to adjust the following controls in my workspace to reach a more comfortable environment.

	Easy access				No access
Thermostat (temperature)	•	•	•	•	•
Ventilation (redirect/flow)	•	•	•	•	•
Opening of windows	•	•	•	•	•
Natural light (blind/shading)	•	•	•	•	•
Artificial light	•	•	•	•	•
Change room/workspace	•	•	•	•	•

What are you actions regarding your discomfort due to cold temperature or draughty air? And at what times do you usually implement these actions?

Answer options:

1. Morning (08-11)
2. Noon (11-14)
3. Afternoon (14-17)
4. Usually throughout the whole day
5. I have never acted in a consistent time pattern
6. I never act due to discomfort

	1.	2.	3.	4.	5.	6.
Increasing thermostat	❑	❑	❑	❑	❑	❑
Opening the office/workplace door	❑	❑	❑	❑	❑	❑
Adjust ventilation	❑	❑	❑	❑	❑	❑
Adjusting clothing	❑	❑	❑	❑	❑	❑
Move to different room/area	❑	❑	❑	❑	❑	❑
Other	❑	❑	❑	❑	❑	❑

What are you actions regarding your discomfort due to warm temperature? And at what times do you usually implement these actions?

Answer options:

1. Morning (08-11)
2. Noon (11-14)
3. Afternoon (14-17)
4. Usually throughout the whole day
5. I have never acted in a consistent time pattern
6. I never act due to discomfort

	1.	2.	3.	4.	5.	6.
Decreasing thermostat	❑	❑	❑	❑	❑	❑
Opening the office/workplace door	❑	❑	❑	❑	❑	❑
Opening window	❑	❑	❑	❑	❑	❑
Adjust ventilation	❑	❑	❑	❑	❑	❑
Adjusting clothing	❑	❑	❑	❑	❑	❑
Move to different room/area	❑	❑	❑	❑	❑	❑
Other	❑	❑	❑	❑	❑	❑

What are you actions regarding your discomfort due to bad air quality? And at what times do you usually implement these actions?

Answer options:

1. Morning (08-11)
2. Noon (11-14)
3. Afternoon (14-17)
4. Usually throughout the whole day
5. I have never acted in a consistent time pattern
6. I never act due to discomfort

	1.	2.	3.	4.	5.	6.
Opening the office/workplace door	❑	❑	❑	❑	❑	❑
Opening window	❑	❑	❑	❑	❑	❑
Adjust ventilation	❑	❑	❑	❑	❑	❑
Move to different room/area	❑	❑	❑	❑	❑	❑
Other	❑	❑	❑	❑	❑	❑

What are you actions regarding your discomfort due to visual comfort (natural daylight and artificial light)? And at what times do you usually implement these actions?

Answer options:

1. Morning (08-11)
2. Noon (11-14)
3. Afternoon (14-17)
4. Usually throughout the whole day
5. I have never acted in a consistent time pattern
6. I never act due to discomfort

	1.	2.	3.	4.	5.	6.
Turn lights on (up) when too dark	❑	❑	❑	❑	❑	❑
Turn lights off (down) when to bright	❑	❑	❑	❑	❑	❑
Use internal blinds due to sun	❑	❑	❑	❑	❑	❑
Use external blinds due to sun	❑	❑	❑	❑	❑	❑
Move to different room/area	❑	❑	❑	❑	❑	❑
Other	❑	❑	❑	❑	❑	❑

NORMATIVE ACTIONS

I experience that my co-workers share the same preferences regarding indoor clime as me.

•-------------------•-------------------•-------------------•-------------------•

Strongly disagree Strongly agree

Expectations from other occupants prevent me from controlling the indoor climate when I feel discomfort.

•-------------------•-------------------•-------------------•-------------------•

Strongly disagree Strongly agree

Environmental impact influences my energy related actions.

•-------------------•-------------------•-------------------•-------------------•

Strongly disagree Strongly agree

Do you have any additional comments related to the indoor climate in your office building?

5. Discussion

This section covers discussions and analysis of the result and findings from the theory. It is divided in categories, the heating and cooling demand of the building, adaptive behaviours and methodologies to collect and measure data.

5.1. Heating and cooling demand

As mentioned in the background heating covers the majority of the energy usage in office buildings both in Sweden and globally (Roetzel et al., 2010; Trüschel, personal communication, November 3, 2020). According to IEA (2020) the use of cooling is increasing in the world due to climate change and global warming. Looking at the case study of Nya Regionens Hus, the heating hold for 3-5% for the simulation cases which is lower than the Swedish mean value of 45% in office buildings. The reason for this is the large amount of energy use from lighting and equipment (around 30% each), apart from those cooling holds for 20% of the delivered energy.

The global warming is probably not the main reason for why the building has a larger cooling demand than heating demand, although it most likely has an impact and will have a larger influence in the future as the global warming increases the outdoor temperature. One impact that has to do with the weather however is the amount of sun that reach the glass windows and façade, because of the location and height of the building. This contributes to a lot of heat gain from the sun and is a reason for why not as much heating is needed to be used. Compared to older office buildings with less windows in Sweden, the amount of solar heat will most likely be larger even in the wintertime. The building is new and a modern type of office building with low U-values and thermal bridges in the building envelope, in that way a lot of heat remains in the building and lower the heating demand. Another large cause of why the heat demand is low is because of the large energy demand from equipment and light. Why the equipment has such a large demand is because of the large occupancy rate in the building which means a large need of equipment such as computers and printers. The light and equipment parameters not only affect the energy demand in operative energy, but it also affects the heating and cooling demand. The usage of the parameters will deliver a lot of heat in form of internal gains, this will contribute to the indoor temperature and increase the cooling demand during summer. The aim with Nya Regionens Hus should be to limit the surplus of the heat since the cooling demand is very high during the warmer months.

5.2. Adaptive behaviours impact on energy demand and comfort

The most common adaptive behaviours in commercial buildings according to the literature study are window opening, artificial light control and use of shading or blinds (Stazi et al., 2017). Manual control of the temperature in an office building could be difficult depending on the existing HVAC-system (Stazi et al., 2017; Schweiker et al., 2018), because of this control of external heaters or fans is more common. In Nya Regionens Hus there is no data on what behaviours that are most common since no subjective survey was made. Instead, some chosen behaviours from the literature were investigated in the case study, to see the influence of different behaviours. The main behaviours that were investigated were blind and light use since the remaining controls are automatic or uncontrollable, such as unopenable windows. The results show that, especially during summer, when the building receives the highest heat load the ultimate behaviour is to turn the lights off during the hours where the sun is the strongest, as well as using the blinds during the most part of the day. To receive a good thermal comfort during the summer the heat surplus needs to be decreased. When looking at the results from the different light and blind combination, it is shown that the behaviour which affect the comfort the most is the control of artificial lighting. Since there are many lights in the building with high power, the control of them makes a large difference in heat demand. The case study results show that the most energy efficient combination is to use lights that are controlled by the light intensity together with never drawn blinds. This is however not the optimal combination overall since the result also show that the comfort level is better for blinds adjusted by the sun together with lights adjusted by the sun. By turning the lights off in the middle of the day when the solar intensity is the strongest, the thermal comfort will increase. The behaviour connected to the blinds also makes a large difference in thermal comfort. During the days with the largest solar intensity, the blinds should be drawn during almost the whole working day to receive the best comfort. Although both parameters improve the comfort on their own, the ultimate behaviour would be to use them together. If the blinds are drawn at the hours with a high solar intensity, the lights could still be turned off or dimmed and still be able to deliver a good thermal and visual comfort.

When looking into energy consumption and its relation to occupant behaviour the result differs. Since research in office buildings in Sweden are scarce has been done in office buildings in Sweden, the result from Nya Regionens Hus can somewhat be compared to results from similar climate. From the literature, studies showed that in mixed climate the least effective way of improving energy use was window opening then metabolic rate, followed by clothing level (Lee & Malkawi, 2014). The most effective way was to use fans or blinds. For cold climate, the most energy demanding behaviours are clothing level followed by windows. The most energy efficient behaviour are connected the fans and heaters (ideal heaters etcetera). Other studies, made in France, include set-point temperature as an option (Bonte et al., 2014). These result show that the set-point temperature contributes to the largest energy usage, followed by blinds and lights. Comparing these results to Nya Regionens Hus it is shown that the set-points represent a large part of the energy usage in the building. If the set-points would change, a lot of energy could be saved. However, the thermal comfort gets worse when the set-point temperatures increase with one degree during summer and decrease with one degree during winter. Even though the set-point control could be more energy efficient, it would be a matter of choosing the comfort of the occupants or the energy usage of the building. Since the occupants' comfort is the priority, the energy connected to set-point control would be very energy demanding. Since Nya Regionens Hus has a VAV-system to control the set-points, the occupants are not able to control it and therefore not seen as a behaviour in this study. Out of the two investigated behaviours in this study, blind and light control, turning the lights of would be the most energy efficient. By turning the lights of during the hours where there is enough solar intensity in the rooms, more energy could be saved than having the lights on and only use blinds to prevent solar heat. Also turning the lights of when leaving a room will have a larger impact on the energy, than using blinds. The use of blinds will however still improve the energy performance, though not as effective, by blocking solar heat from entering less cooling will be needed to keep the wanted indoor temperatures. Instead of manually using blinds and turning off the lights when the illuminance is at a certain level, automatic blinds and lights could be used. They would be controlled by sensors which automatically draws the blinds and adjust the lights at the set-points used in the case study. The optimal case would be to use sensors for these parameters but then yet be able to control them manually if wanted, since not all the occupants have the same experienced comfort. A sensor which could be used is the occupancy-controlled lights. This will according to the case study result decrease the energy consumption and improve the thermal comfort, although not to the same extent as solar controlled lights. The three sensors together (blinds and lights controlled by sun and lights controlled by occupancy) would most likely be an even better solution to save energy, although this would need further investigations to be clarified.

Many studies exclude the impact of clothing insulation in relation to energy consumption since change of clothing level have no direct impact on energy usage (Bonte et al., 2014). The case study showed the same result, that only changing the clothing level will have no effect on the energy consumption. On the other hand, it will have larger impact on the comfort level of the occupants. This is shown both in the case study and stated in the literature that one of the more common behaviour regarding thermal comfort is adjusting of clothing (Stazi et al., 2017; Schweiker et al., 2018). Although the occupants may have a dress code to follow it will still be possible to adjust over the seasons which significant increase the comfort level according to the case study (Morgan & de Dear, 2003). As mention in the literature, clothing level is a personal reference as well, where women have a larger desire to varying the clothing according to season than men to fulfil comfort. The study of Nya Regionens Hus was made with focus on several rooms, with the conclusion that a higher and more adjustable clothing level gives significant increase of thermal comfort during the coldest day. In the literature it is also shown that in shared space, like open plan office the occupants are more likely to change their personal attire instead of room installations (Xu et al., 2020). The result from the summer season in the case study show that the PPD is increased for most rooms when the clothing is increased from the design values. Some of the room in the north direct with lower occupancy rate throughout the day will not get overheated and thereby no comfort level to compare with. A study in Canada states that changing of clothing level is least effective from an energy usage perspective (Lee & Malkawi, 2014). The same study in Philadelphia states that metabolic rate is the second largest contribution to high energy consumption. The case study of Nya Regionens Hus also shows that a new metabolic rate increases the energy usage, it is a significant increase of cooling and a slight decrease of heating. The comfort is quite varying due to different metabolic rate as they have mostly improved during the coldest day and got worse during the summer season.

Both clothing insulation and metabolic rate has great impact on the thermal comfort which has a direct impact on the energy consumption. Occupants are prone to adjust their personal attributes or surrounding to adjust the comfort. If the metabolic rate could be correctly assumed from start it would probably decrease the energy consumption in the long run. Since metabolic rate is a contribution of internal gains the cooling demand would increase if the set-point temperatures are set too high, to fulfil optimal comfort. On the other side, the energy consumption would also increase if the metabolic rate is assumed too high and the set-point to low, the heating demand would increase significantly. Clothing does not have the same direct impact with contribution of heat gains but will have the same effect regarding changes due to comfort. The occupants will always strive for comfort and will most likely use heaters or cooling fans to adjust to a desired environment when discomfort is to large. If the MET and CLO could be assumed correct in the designing phase, the set-point could be balanced to meet the desired comfort level. Otherwise the set-point probably would be adjusted later on in the buildings life to balance with the actually metabolic rate and clothing level. An even worse case is that the occupants then will use appliances to adjust the environment that will counteract the set-point and enhance the energy usage. Generally, change that are made after the building is put into operation increases the energy consumption since balancing of internal gains etcetera are not considered.

The significance of room placement and orientation regarding comfort becomes quite clear in the case study. When analysing comfort due overheating it shows that the lounge in southeast has a substantial larger index than the rest of the rooms. The only thing that separates this room from the lounge in north is the orientation of windows and thereby the number of hours with direct solar heat gain. This is not a room occupants stay in for longer periods of time, which is why they probably will not feel as discomfort as they would in an open plan office for example. In the literature it is stated that comfort is strongly connected to routine, schedules and time of day (Stazi et al., 2017). So, the usage of the room has a significance as well. The open plan office in southwest has lower PPD than the lounge but still higher than for the rest of the rooms with maximum occupancy. In comparison to the open plan office in north, it should have lower comfort index due to lower occupancy density and amount of internal gains. It is a direct connection to the importance of solar heat gain since the metabolic rate and clothing level are the same here. As mentioned in the literature, people have a lower desire to adjust the environment in larger shared spaces which will lead to no change in energy consumption and comfort. When the occupants have the choice of choosing their location, maybe they will occupy a less crowded area.

5.3. Methodologies and design values

To collect information in a building there are several of subjective and objective methods. The two mainly used that are described in the literature are measurements and questionnaires. Through measurements objective information is collected. It could be measurements of temperature or air flow etcetera (Castaldo et al., 2018). It could also be different types of sensors to collect building information or occupant information, like occupancy rate (Dong et al., 2018). While questionnaires are commonly used to get subjective information from the occupants. The measured data is not necessarily the same output as the questionnaire data. Therefore, the ultimate methodology, and a common one, to find the optimal indoor climate is to combine a questionnaire with measured data (Castaldo et al., 2018; Putra, 2016; D’Oca et al., 2017). The questionnaire provide information about the experienced climate which together with measured data can give a distinct correlation between the perceived comfort and climate parameters.

If the questionnaire made in this thesis could have been provided to the occupants in Nya Regionens Hus, together with measurements, the simulation results in the Case study could be further verifiedand utilized for future use of the building. Since most of the occupants are working from home and the pandemic prevent site visits, neither measured data or answers from the questionnaire could get provided. Instead, estimated data is used for the case study, which is the data used when designing the building. It is also very likely that parameters and information about the building has changed after the first model was made, which is the model provided to us. Therefore, the results from the simulations are mainly used to detect patterns and possible behaviours in the building, rather than exact values of energy usage etcetera. As shown from the case study result, minor changes in the building, such as set-point temperature or usage of blinds and lights, have a large impact on the outcome. A minor change can lead to a largely increased energy demand or perceived thermal comfort of the occupants. The simulation result of the occupant comfort could differ depending on if only measured data is used as input data or if it is combined with the subjective data. It could be valuable to use measurements as the parameters implemented in a simulation, but then comparing the results to the actual perceived comfort (subjective results). This would give a clear pattern of how the theoretical value perceives in practice and make it easier to detect faults in the building.

To relate the case study of Nya Regionens Hus back to the Swedish building code and recommendations for calculating the energy consumption, it can be concluded that the code is rather simplified. The number of occupants in each space is based on the drawings and design of the building at which even an occupancy rate of 60 % would be larger than the design value from the Swedish National Board of Housing Building and Planning. In the case study it has a direct impact on the internal gains set for equipment etcetera. To start with it is not comparable regarding these parameters. The used schedule and temperature set-point is on the other hand more similar. The case study has somewhat of an extended schedule in comparison, but the intermediate occupancy is quite similar. During the actual working day, the minimum set-point are the same while the upper limit is stricter in the building code compared to the study. Mainly it is the occupancy rate that differ and with it some other parameters. Since these are the parts that may affect the energy consumption the most, it will show result of less energy consuming building following the building code.

6. Conclusion

Which are the main aspects in indoor environmental quality (IEQ) and how can they be controlled? The main aspects in IEQ quality are thermal comfort, visual comfort, air quality and acoustic comfort. The IEQ is highly affected by the occupant behaviour, both adaptive and non-adaptive, which affect both the energy usage in the building and indoor comfort. The IEQ triggers the occupant behaviour and is also influenced of it, which means that they affect each other as well as the energy consumption. Thermal comfort is the most substantial parameter since it can be adjusted by several behaviours where the most common ones are opening of windows, use of blinds and shades, metabolic rate, adjustment of clothing and set-point temperature. The visual comfort mainly can be controlled by behaviours like adjustment of blinds and shades, artificial light and change of occupant location/orientation. Air quality can be adjusted by opening windows, change of location and adjusting the supply air flow. The last comfort aspect, acoustic comfort, is controlled by change of occupant location and adjusting windows.

What are the most common adaptive human behaviours related to the mentioned aspects? There are many parameters that affect the IEQ, most of them connected to the indoor environment of the building. The most common behaviours connected to environmental adjustments are window opening, light control, use of blinds/shading and set-point control (if manually controlled). The most common behaviours connected to the occupant itself are adjustment of the clothes (CLO) or change of activity level (MET).

Which parameters and behaviours have the biggest impact on energy consumption and comfort and how could these be optimized? According to the case study artificial lights and equipment stand for the largest part of the energy consumption, followed by the cooling of the building. By actively turning the lights off when not needed, they save the most energy and give highest level of comfort, which results in the most energy efficient behaviour. The use of blinds is also very effective, by keeping solar heat from the building which lead to a decreased cooling demand and lower indoor temperature during summer (good comfort). The optimal solution is to combine these parameters. The best result according to the case study is given by lights controlled by illuminance (partly on due to sun) and blinds controlled by solar intensity (partly on due to sun), which means that automatic light and blinds will lead to the optimal energy demand and IEQ. However using lights controlled by both illuminance and occupant presence will most likely be the optimal light control from an energy perspective.

What are the methodologies to collect occupant behaviour-related information, e.g., questionnaire, measurement? To minimize the building performance gap and get an as credible outcome as possible both a subjective and objective method should be used. The occupant related behaviour should be collected by using a self-reported questionnaire together with measurements to register alterations in the environment. The questions in a questionnaire are short and formulated in a simple way and are answered individually, which make it possible to collect a large amount of answers which make the result very valid. By using this combined with measurements from different sensors and measurement instruments in a building, both the objective and subjective result can be used to find the optimal indoor environment.

For future research, there is a lot of possible additional studies that can be made. To start with, a more extensive case study could be made with more parameters included and evaluated, such as additional comfort aspects. Both by including several more adaptive behaviours and combinations together with analysis of the visual comfort and air quality a larger mapping could be done. With additional comfort aspects to analyse and consider, other behaviours or combinations could have a more significant role in creating an energy efficient building. To help verifying the result and give a more realistic outcome a more extensive collection of input data could be made, with statistics from self-completed questionnaire and measurements. By comparing the actual behaviour of the occupant by degree of frequency and impact on energy consumption the conclusion could be determine with more certainty.

Further, case studies on multiple buildings for comparison and comprehension of different prerequisites should be done to get a more accurate result. In addition to more realistic simulation the results could be compared with the actual (measured) energy consumption to investigate what the gap in energy performance is based on.

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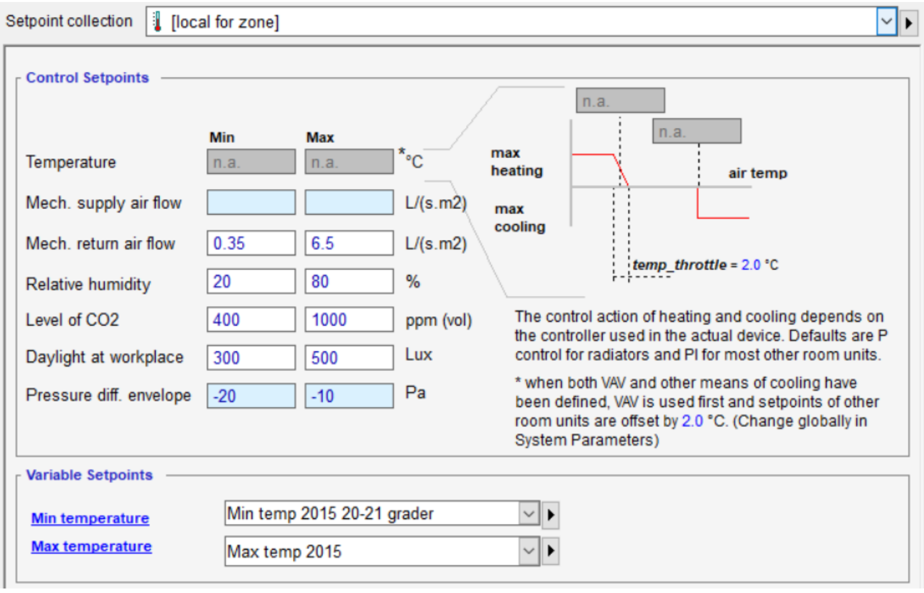
Appendix A

IDA-ICE parameters and in-data used for simulations

Name	Group	Floor height, m	Room height, m	Floor area, m2	Heat setp., °C	Cool setp., °C	AHU	System	Supply air, L/(s.m2)	Return air, L/(s.m2)	Occup., no./m2	Lights, W/m2	Lights, kWh/m2	Equipment, W/m2	Equipment, kWh/m2	Ext win. area, m2	Occup. schedule	Light schedule	Equipm. schedule
Landskap_Nor...		26.4	3.6	37.95	n.a.	n.a.	Air Ha...	VAV, t...	6.5	6.5	0.2108	10.0		21.08	35.21	19.25	8-17 1...	07-19 ...	7-17 6...
Mötesrum_sto...		26.4	3.6	24.22	n.a.	n.a.	Air Ha...	VAV, t...	8.5	8.5	0.4129	6.3		41.29	32.33	10.8	7-17 3...	© 07-...	07-17 ...
Mötesrum_lite...		26.4	3.6	16.35	n.a.	n.a.	Air Ha...	VAV, t...	8.5	8.5	0.4893	6.3		48.93	38.31	7.297	7-17 3...	© 07-...	07-17 ...
Lounge_norr		26.4	3.6	16.18	n.a.	n.a.	Air Ha...	VAV, t...	4.5	4.5	0.309	5.6		0.0	0.0	7.15	7-17 3...	© 07-...	
Landskap_norr		26.4	3.6	25.53	n.a.	n.a.	Air Ha...	VAV, t...	5.5	5.5	0.3917	10.0		39.17	65.43	15.53	8-17 1...	07-19 ...	7-17 6...
Tysta rum_W...		26.4	3.6	76.43	n.a.	n.a.	Air Ha...	VAV, t...	8.5	8.5	0.0654	6.4		6.542	5.122	0.0	7-17 3...	© 07-...	07-17 ...
Lounge_sydöst		26.4	3.6	15.42	n.a.	n.a.	Air Ha...	VAV, t...	4.5	4.5	0.3243	5.6		0.0	0.0	7.046	7-17 2...	© 07-...	
Landskap_söder		26.4	3.6	15.34	n.a.	n.a.	Air Ha...	VAV, t...	7.0	7.0	0.4563	10.0		45.63	76.23	7.018	8-17 1...	07-19 ...	7-17 6...
Kontorsrum_S...		26.4	3.6	23.54	n.a.	n.a.	Air Ha...	VAV, t...	7.0	7.0	0.2549	10.0		25.49	42.58	10.85	8-17 1...	07-19 ...	7-17 6...
Landskap_Sy...		26.4	3.6	38.03	n.a.	n.a.	Air Ha...	VAV, t...	6.5	6.5	0.2104	10.0		21.04	35.14	19.29	8-17 1...	07-19 ...	7-17 6...
Landskap_Väst		26.4	3.6	41.19	n.a.	n.a.	Air Ha...	VAV, t...	5.5	5.5	0.1942	10.0		19.42	32.44	8.993	8-17 1...	07-19 ...	7-17 6...
Lounge_öst		26.4	3.6	18.71	n.a.	n.a.	Air Ha...	VAV, t...	4.0	4.0	0.2673	5.6		0.0	0.0	9.145	7-17 2...	© 07-...	
Trappa_öst		26.4	3.6	24.51	n.a.	n.a.	Air Ha...	VAV, t...	1.0	1.0	0.0408	6.0		0.0	0.0	14.87	7-17 1...	07-19 ...	
Hiss/Hall		26.4	3.6	71.27	n.a.	n.a.	Air Ha...	VAV, t...	1.0	1.0	0.01403	6.0		0.0	0.0	0.0	7-17 1...	07-19 ...	
Korridor_söder		26.4	3.6	50.07	n.a.	n.a.	Air Ha...	VAV, t...	1.0	1.0	0.01997	6.0		0.0	0.0	0.7363	7-17 1...	07-19 ...	
Mötesrum_lite...		26.4	3.6	16.0	n.a.	n.a.	Air Ha...	VAV, t...	8.5	8.5	0.375	6.3		37.5	29.36	7.142	7-17 3...	© 07-...	07-17 ...
Grupprum_lite...		26.4	3.6	7.649	n.a.	n.a.	Air Ha...	VAV, t...	8.5	8.5	0.5228	6.3		52.29	40.95	3.415	7-17 3...	© 07-...	07-17 ...
Grupprum_lite...		26.4	3.6	7.218	n.a.	n.a.	Air Ha...	VAV, t...	10.0	10.0	0.554	6.3		55.42	43.39	3.298	7-17 3...	© 07-...	07-17 ...
Sluss_söder		26.4	3.6	7.772	n.a.	n.a.	Air Ha...	VAV, t...	1.0	1.0	0.1287	6.0		0.0	0.0	3.556	7-17 1...	07-19 ...	
Korridor_norr		26.4	3.6	41.23	n.a.	n.a.	Air Ha...	VAV, t...	1.0	1.0	0.02425	6.0		0.0	0.0	0.0	7-17 1...	07-19 ...	
Total/m2									4.895	4.895	0.181	7.32		14.62	18.7	6.898			



EQUA SIMULATION TECHNOLOGY GROUP		Input data Report	
Project		**Building**	
		Model floor area	574.6 m^2
Customer		Model volume	2068.5 m^3
Created by	Martin Adolfsson	Model ground area	0.0 m^2
Location	Goteborg/Save	Model envelope area	410.5 m^2
Climate file	Gothenburg, Säve-1977	Window/Envelope	37.9 %
Case	SUMMER_PartlySunLight_PartlyDrawn	Average U-value	0.3614 W/(m^2 K)
Simulated	2021-04-23 15:28:14	Envelope area per Volume	0.1985 m^2/m^3

Fixed infiltration airflow rate				6.157 l/s
Building envelope	**Area [m^2]**	**U [W/(m^2 K)]**	**U*A [W/K]**	**% of total**
Walls above ground	**255.12**	**0.07**	**18.15**	**12.23**
Fasad	255.12	0.07	18.15	12.23
Walls below ground	**0.00**	**0.00**	**0.00**	**0.00**
Roof	**0.00**	**0.00**	**0.00**	**0.00**
Floor towards ground	**0.00**	**0.00**	**0.00**	**0.00**
Floor towards amb. air	**0.00**	**0.00**	**0.00**	**0.00**
Windows	**155.38**	**0.79**	**123.39**	**83.17**
Ucw:0,5	155.38	0.79	123.39	83.17
Doors	**0.00**	**0.00**	**0.00**	**0.00**
Thermal bridges			**6.82**	**4.60**
Total	**410.50**	**0.36**	**148.36**	**100.00**

Thermal bridges	**Area or Length**	**Avg. Heat conductivity**	**Total [W/K]**
External wall / internal slab	205.54 m	0.000 W/(m K)	0.000
External wall / internal wall	122.40 m	0.000 W/(m K)	0.000
External wall / external wall	14.40 m	0.356 W/(m K)	5.126
External windows perimeter	352.39 m	0.005 W/(m K)	1.691
External doors perimeter	0.00 m	0.000 W/(K m)	0.000
Roof / external walls	0.00 m	0.000 W/(K m)	0.000
External slab / external walls	0.00 m	0.000 W/(K m)	0.000
Balcony floor / external walls	0.00 m	0.000 W/(K m)	0.000
External slab / Internal walls	0.00 m	0.000 W/(K m)	0.000
Roof / Internal walls	0.00 m	0.000 W/(K m)	0.000
External walls, inner corner	0.00 m	0.000 W/(K m)	0.000
Roof / external walls, inner corner	0.00 m	0.000 W/(K m)	0.000
External slab / external walls, inner corner	0.00 m	0.000 W/(K m)	0.000
Total envelope (incl. roof and ground)	369.98 m^2	0.000 W/(m^2 K)	0.000
Extra losses	-	-	0.000
Sum	-	-	6.818

Windows	**Area [m^2]**	**U Glass [W/(m^2 K)]**	**U Frame [W/(m^2 K)]**	**U Total [W/(m^2 K)]**	**U*A [W/K]**	**Shading factor g**
NE	21.69	0.50	1.74	0.79	17.23	0.31
SE	53.91	0.50	1.74	0.79	42.81	0.31
SW	25.55	0.50	1.74	0.79	20.29	0.31
NW	54.23	0.50	1.74	0.79	43.06	0.31
Total	155.38	0.50	1.74	0.79	123.39	0.31

Air handling unit	**Pressure head supply/exhaust [Pa/Pa]**	**Fan efficiency supply/exhaust [-/-]**	**System SFP [kW/(m^3/s)]**	**Heat exchanger temp. ratio/min exhaust temp. [-/C]**
AHU	560.00/400.00	0.60/0.60	0.93/0.67	0.82/1.00

Appendix B

Results and outcome of simulations in IDA ICE

Light Power

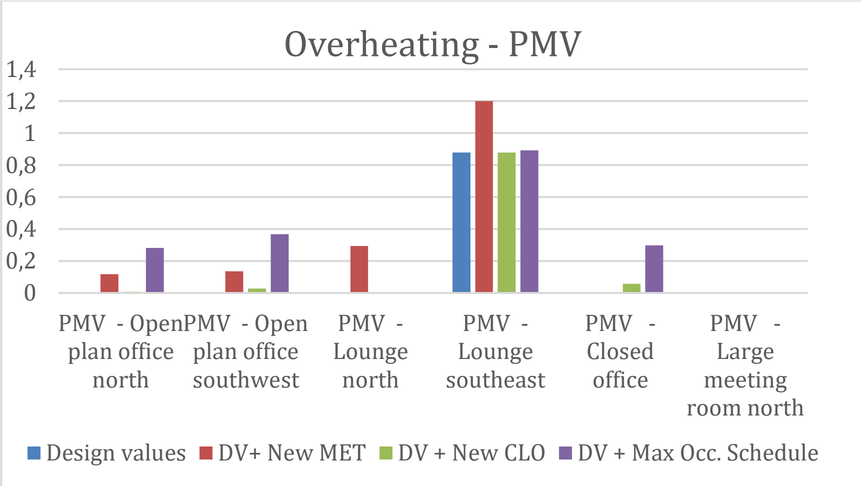
	Watts per unit	Zone area [m^2]	Original Power [W/m^2]	manually controlled	controlled by presence	Power [W/m^2]
Tysta rum_WC_mitten	100	75,35	8	0,8	0,75	6,4
Trappa_öst	100	24,51	6	1	0,75	6
Sluss_söder	100	7,471	6	1	0,75	6
Mötesrum_stort_Norr	100	24,22	9	0,7	0,71	6,3
Mötesrum_litet_norr_2	100	16,09	9	0,7	0,71	6,3
Mötesrum_litet_norr	100	15,59	9	0,7	0,71	6,3
Lounge_sydöst	100	15,42	8	0,7	0,86	5,6
Lounge_öst	100	19,28	8	0,7	0,86	5,6
Lounge_norr	100	16,26	8	0,7	0,86	5,6
Litet_grupprum_söder	100	7,218	9	0,7	0,71	6,3
Landskap_Väst	100	42,2	10	1	0,9	10
Landskap_Sydväst	100	38,41	10	1	0,9	10
Landskap_söder	100	15,34	10	1	0,9	10
Landskap_norr	100	25,53	10	1	0,9	10
Landskap_Nordväst	100	38,42	10	1	0,9	10
Korridor_söder	100	50,07	6	1	0,75	6
Korridor_norr	100	44,37	6	1	0,75	6
Kontorsrum_Söder	100	23,54	10	1	0,9	10
Hiss/Hall	100	68,03	6	1	0,75	6
Grupprum_litet_norr	100	7,691	9	0,7	0,71	6,3

Energy

System energy	**Design values**	**DV+ New MET**	**DV + New CLO**	**DV + Max Occ. Schedule**
Zone heating [kWh]	1524,7	1454,7	1524,5	1066,7
AHU heating [kWh]	21,17	21,63	21,18	26,97
Zone cooling [kWh]	0	0	0	0
AHU cooling [kWh]	5622,5	5732,4	5621,3	6425
Delivered Energy				
HVAC aux [kWh/m2]	6,598	6,820	6,598	7,955
Cooling [kWh/m2]	9,785	9,976	9,783	11,18
Heating [kWh/m2]	2,69	2,569	2,69	1,903
Lighting, tenant [kWh/m2]	13,52	13,52	13,52	15,7
Equipment, tenant [kWh/m2]	17,85	17,85	17,85	18,70
Domestic hot water [kWh/m2]	0	0	0	0
Total delivered energy [kWh/m2]	50,44	50,74	50,44	55,44

Summer

	Design values	DV+ New MET	DV + New CLO	DV + Max Occ. Schedule
Max solar heat gain [W/m2] (Staircase)	66,75	66,71	66,75	66,71
	Design values	**DV+ New MET**	**DV + New CLO**	**DV + Max Occ. Schedule**
PPD [%] - Open plan office north	-	5,036	3,391	6,658
PMV - Open plan office north	-	0,118	0,007457	0,281
Datum		2021-07-30 07:14	2021-07-30 07:10	2021-07-30 19:00
PPD [%] - Open plan office southwest	-	5,376	5,015	7,845
PMV - Open plan office southwest	-	0,1347	0,02688	0,3685
Datum		2021-08-23 13:17	2021-09-04 13:16	2021-07-30 19:00
PPD [%] - Lounge north	-	6,786	-	-
PMV - Lounge north	-	0,2931	-	-
Datum		2021-07-31 17:00		
PPD [%] - Lounge southeast	21,2	35,28	21,3	21,84
PMV - Lounge southeast	0,8761	1,201	0,8788	0,8929
Datum	2021-08-05 13:22	2021-08-05 13:21	2021-08-05 13:24	2021-08-05 13:25
PPD [%] - Closed office	-	-	5,069	6,853
PMV - Closed office	-	-	0,05733	0,2971
Datum			2021-07-30 11:01	2021-07-30 19:00
PPD [%] - Large meeting room north	-	-	-	-
PMV - Large meeting room north	-	-	-	-
Datum				



Hours of overheating	**Design values**	**DV+ New MET**	**DV + New CLO**	**DV + Max Occ. Schedule**
Open plan office north	48,8	51,8	48,3	515
Open plan office southwest	17,2	18,7	16,9	308
Lounge north	1,11	1,39	1,17	10,3
Lounge southeast	194	227	194	261
Closed office	23	24,4	23,2	410
Large meeting room north	0,7	0,3	0,574	124

Winter

	Design values	DV+ New MET	DV + New CLO	DV + Max Occ. Schedule
Max "Mean air temp"	21,04	21,03	21,04	21,03
Min "Mean air temp"	19,97	19,97	19,97	19,97
Max "Op. temp"	21,07	21,07	21,07	21,07
Min "Op. temp"	19,47	19,47	19,47	19,47
Max PPD %	86,78	85,36	21,21	86,77
Min PMV	-2,266	-2,223	-0,8723	-2,266

	Design values	DV+ New MET	DV + New CLO	DV + Max Occ. Schedule
PPD [%] - Open plan office north	84,68	66,62	19,98	84,69
PMV - Open plan office north	-2,21	-1,797	-0,8365	-2,211
PPD [%] - Open plan office southwest	85,75	67,97	20,61	85,75
PMV - Open plan office southwest	-2,239	-1,823	-0,855	-2,239
PPD [%] - Lounge north	83,09	32,71	18,87	83,05
PMV - Lounge north	-2,163	-1,144	-0,806	-2,162
PPD [%] - Lounge southeast	83,52	33,09	19,08	83,48
PMV - Lounge southeast	-2,174	-1,152	-0,8126	-2,173
PPD [%] - Closed office	85,27	85,27	20,14	85,27
PMV - Closed office	-2,221	-2,221	-0,843	-2,221
PPD [%] - Large meeting room north	85,36	85,36	20,18	85,35
PMV - Large meeting room north	-2,223	-2,223	-0,8444	-2,223

ENERGY - MAX OCC

System energy	Lights: Partly on-Sun Blinds: Partly drawn	Lights: Always on Blinds: Partly drawn	Lights: Partly on-Occ Blinds: Partly drawn	Lights: Partly on-Sun Blinds: Never drawn	Lights: Always on Blinds: Never drawn	Lights: Partly on-Occ Blinds: Never drawn	Lights: Partly on-Sun Blinds: Always drawn	Lights: Always on Blinds: Always drawn	Lights: Partly on-Occ Blinds: Always drawn
Zone heating [kWh]	949,2	826	994,3	929	749,3	907,2	930,4	752,6	910,9
AHU heating [kWh]	26,83	27,07	28,34	28,34	26,46	27,74	28,34	26,46	27,74
Zone cooling [kWh]	0	0	0	0	0	0	0	0	0
AHU cooling [kWh]	6672,8	7333,7	7123,7	6740,5	7685,6	7477,8	6988,6	7124,4	6916,8
Delivered Energy									
HVAC aux [kWh/m2]	8,530	9,276	9,041	8,622	9,657	9,42	8,835	9,181	8,943
Cooling [kWh/m2]	11,61	12,76	12,4	11,73	13,38	13,01	12,16	12,4	12,04
Heating [kWh/m2]	1,700	1,485	1,78	1,666	1,35	1,627	1,668	1,356	1,633
Equipment, tenant [kWh/m2]	18,7	18,7	18,7	18,7	18,7	18,7	18,7	18,7	18,7
Lighting, tenant [kWh/m2]	15,38	21,82	19,3	12,68	21,82	19,3	18,19	21,82	19,3
Domestic hot water [kWh/m2]	0	0	0	0	0	0	0	0	0
Total (incl. cooling & heating)	**55,92**	**64,04**	**61,22**	**53,4**	**64,91**	**62,06**	**59,55**	**63,46**	**60,62**
Delivered Energy-Peak demand									
HVAC aux [kW]	3,432	3,433	3,434	3,433	3,442	3,434	3,434	3,434	3,433
Cooling [kW]	53,35	56,27	55,59	53,59	58,4	57,78	55	55,15	54,46
Heating [kW]	8,922	8,389	8,974	8,886	7,906	8,412	8,886	7,906	8,412
Equipment, tenant [kW]	3,93	3,93	3,93	3,93	3,93	3,93	3,93	3,93	3,93
Lighting, tenant [kW]	4,206	4,206	4,206	4,206	4,206	4,206	4,206	4,206	4,206
Total	**73,84**	**76,23**	**76,13**	**74,05**	**77,88**	**77,76**	**75,46**	**74,63**	**74,44**

AVE OCC

System energy	Lights: Partly on-Sun Blinds: Partly drawn	Lights: Always on Blinds: Partly drawn	Lights: Partly on-Sun Blinds: Never drawn	Lights: Always on Blinds: Never drawn
Zone heating [kWh]	1371,6	1196,2	1354,4	1087,1
AHU heating [kWh]	21,59	21,01	21,97	20,54
Zone cooling [kWh]	0	0	0	0
AHU cooling [kWh]	5891,1	6476,3	5969,4	6870,7
Delivered Energy				
HVAC aux [kWh/m2]	7,15	7,795	7,246	8,197
Cooling [kWh/m2]	10,25	11,27	10,39	11,96
Heating [kWh/m2]	2,425	2,118	2,395	1,928
Equipment, tenant [kWh/m2]	17,85	17,85	17,85	17,85
Lighting, tenant [kWh/m2]	13,52	19,1	10,8	19,1
Domestic hot water [kWh/m2]	0	0	0	0
Total (incl. cooling & heating)	**51,2**	**58,13**	**48,68**	**59,04**
Delivered Energy-Peak demand				
HVAC aux [kW]	3,426	3,427	3,427	3,429
Cooling [kW]	43,81	46,48	43,72	49,9
Heating [kW]	10,46	9,891	10,31	9,434
Equipment, tenant [kW]	3,93	3,93	3,93	3,93
Lighting, tenant [kW]	4,206	4,206	4,206	4,206
Total	**65,83**	**67,93**	**65,59**	**70,9**

Summer - MAX OCC

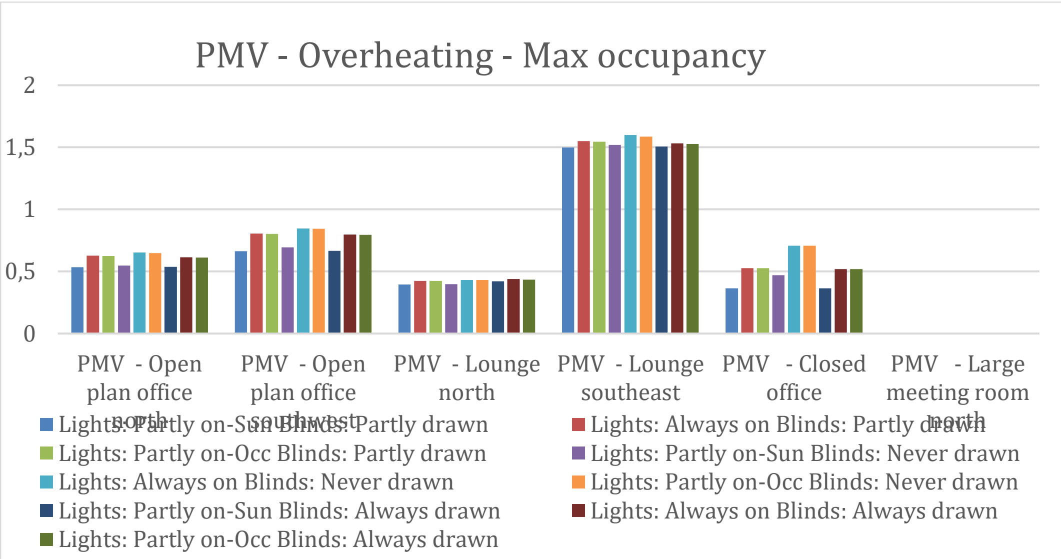
	Lights: Partly on-Sun Blinds: Partly drawn	Lights: Always on Blinds: Partly drawn	Lights: Partly on-Occ Blinds: Partly drawn	Lights: Partly on-Sun Blinds: Never drawn	Lights: Always on Blinds: Never drawn	Lights: Partly on-Occ Blinds: Never drawn	Lights: Partly on-Sun Blinds: Always drawn	Lights: Always on Blinds: Always drawn	Lights: Partly on-Occ Blinds: Always drawn
Solar heat gain - March 30 [W/m2]	66,79	66,63	66,59	93,76	93,72	93,72	65,85	65,85	65,85
Max solar heat gain [W/m2]	93,35	93,43	93,31	93,76	93,72	93,72	93,35	93,43	93,39
Trappa öst									
PPD [%] - Open plan office north	10,98	13,27	13,2	11,32	13,95	13,87	11,04	12,96	12,89
PMV - Open plan office north	0,5341	0,6268	0,6242	0,5486	0,6518	0,6489	0,5364	0,6151	0,6125
Datum	2021-07-30 19:00	2021-07-30 19:00	2021-07-30 19:00	2021-07-30 19:00	2021-07-30 19:00	2021-07-30 19:00	2021-07-30 19:00	2021-07-30 19:00	2021-07-30 19:00
PPD [%] - Open plan office southwest	14,3	18,7	18,64	15,15	20,18	20,1	14,35	18,43	18,37
PMV - Open plan office southwest	0,6644	0,8048	0,803	0,6938	0,8471	0,8447	0,6662	0,797	0,7952
Datum	2021-07-30 19:00	2021-07-30 19:00	2021-07-30 19:00	2021-07-30 19:00	2021-07-30 19:00	2021-07-30 19:00	2021-07-30 19:00	2021-07-30 19:00	2021-07-30 19:00
PPD [%] - Lounge north	8,26	8,762	8,747	8,29	8,892	8,863	8,719	9,006	8,939
PMV - Lounge north	0,3956	0,4248	0,4239	0,3974	0,432	0,4304	0,4223	0,4382	0,4345
Datum	2021-07-31 15:00	2021-07-31 15:00	2021-07-31 15:00	2021-07-31 15:00	2021-07-31 15:00	2021-07-31 15:00	2021-07-31 15:00	2021-07-31 15:00	2021-07-31 14:58
PPD [%] - Lounge southeast	50,8	53,64	53,3	51,95	56,23	55,5	51,22	52,7	52,37
PMV - Lounge southeast	1,498	1,55	1,544	1,519	1,598	1,585	1,506	1,533	1,527
Datum	2021-04-29 14:00	2021-04-29 14:13	2021-04-29 14:06	2021-04-29 14:13	2021-04-29 14:14	2021-04-29 14:05	2021-04-29 14:06	2021-04-29 13:59	2021-04-29 13:51
PPD [%] - Closed office	7,759	10,84	10,84	9,634	15,54	15,49	7,767	10,63	10,64
PMV - Closed office	0,3631	0,5275	0,5275	0,4711	0,7077	0,7061	0,3636	0,518	0,5186
Datum	2021-07-30 19:00	2021-07-30 19:00	2021-07-30 19:00	2021-09-03 13:31	2021-09-03 13:33	2021-09-03 13:32	2021-07-30 19:00	2021-07-30 19:00	2021-07-30 19:00
PPD [%] - Large meeting room north	-	-	-	-	-	-	-	-	-
PMV - Large meeting room north	-	-	-	-	-	-	-	-	-
Datum	-	-	-	-	-	-	-	-	-

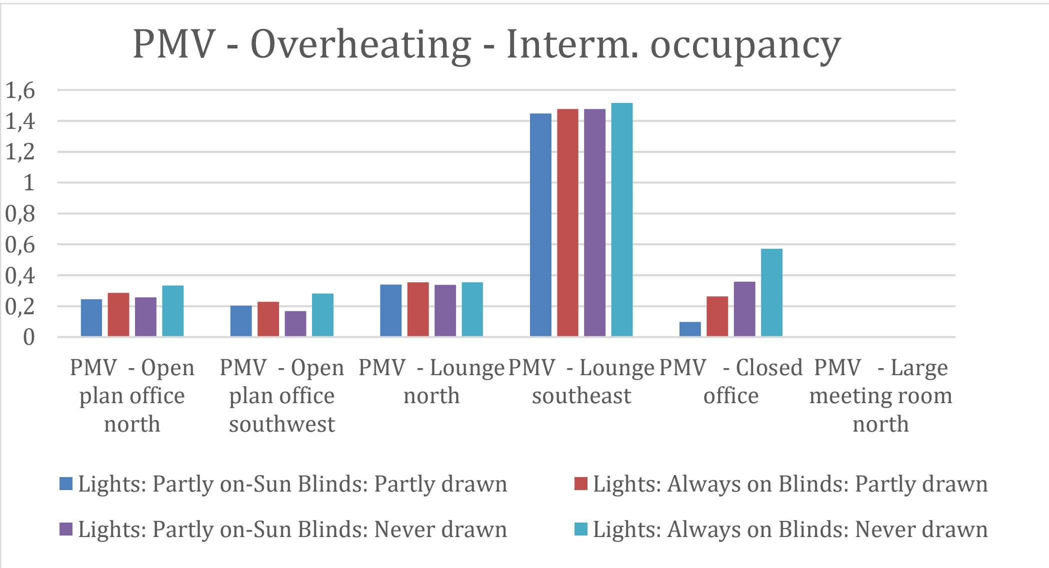
	Lights: Partly on-Sun Blinds: Partly drawn	Lights: Always on Blinds: Partly drawn	Lights: Partly on-Occ Blinds: Partly drawn	Lights: Partly on-Sun Blinds: Never drawn	Lights: Always on Blinds: Never drawn	Lights: Partly on-Occ Blinds: Never drawn	Lights: Partly on-Sun Blinds: Always drawn	Lights: Always on Blinds: Always drawn	Lights: Partly on-Occ Blinds: Always drawn
Hours of overheating (7-17) - Open plan office north	51.3	232	223	97.4	336	329	59	175	169
Hours of overheating (7-19) - Open plan office north	196	448	435	252	561	554	210	376	367
Hours of overheating (7-17) - Open plan office southwest	0.733	14.8	14	6.61	87.4	82.7	0.77	11	10.8
Hours of overheating (7-19) - Open plan office southwest	175	230	228	196	323	316	179	223	222
Hours of overheating (7-17) - Lounge north	1.14	1.53	1.49	1.25	2.47	1.96	1.27	1.42	1.38
Hours of overheating (7-19) - Lounge north	75.7	98.1	94	82.6	111	107	76.2	86.9	84.2
Hours of overheating (7-17) - Lounge southeast	50.3	134	129	70.6	274	265	59.2	119	115
Hours of overheating (7-19) - Lounge southeast	95.6	228	221	131	398	388	113	204	197
Hours of overheating (7-17) - Closed office	10.8	63.1	62.3	88.6	192	192	10.8	61.1	60
Hours of overheating (7-19) - Closed office	235	313	312	321	444	444	251	309	307
Hours of overheating (7-17) - Large meeting room north	0	0.118	0.037	0.17	0,509	0,433	0.0428	0.0848	0.157
Hours of overheating (7-19) - Large meeting room north	83	91.9	86.8	89.9	98.9	93.9	78.3	80	74.1

Summer - INTERMEDIATE OCC

	Lights: Partly on-Sun Blinds: Partly drawn	Lights: Always on Blinds: Partly drawn	Lights: Partly on-Sun Blinds: Never drawn	Lights: Always on Blinds: Never drawn
Max solar heat gain [W/m2]	93,23	93,39	93.72	93,72
Solar heat gain - March 30 [W/m2]	66,75	66,71	93.72	93,72
Trappa öst				
PPD [%] - Open plan office north	6,249	6,715	6,373	7,328
PMV - Open plan office north	0,2443	0,2864	0,2572	0,3345
Datum	2021-07-30 07:17	2021-07-30 07:15	2021-07-30 09:28	2021-07-30 09:33
PPD [%] - Open plan office southwest	5,859	6,077	5,593	6,663
PMV - Open plan office southwest	0,2036	0,2279	0,1691	0,2829
Datum	2021-09-04 13:52	2021-09-04 14:18	2021-09-03 13:28	2021-09-03 15:06
PPD [%] - Lounge north	7,404	7,609	7,383	7,607
PMV - Lounge north	0,3399	0,354	0,3382	0,3538
Datum	2021-07-31 17:00	2021-07-31 17:00	2021-08-06 07:16	2021-08-06 07:16
PPD [%] - Lounge southeast	48,01	49,63	49,64	51,75
PMV - Lounge southeast	1,447	1,477	1,477	1,516
Datum	2021-04-29 14:07	2021-04-29 14:11	2021-04-29 14:00	2021-04-29 14:01
PPD [%] - Closed office	5,198	6,443	7,662	11,87
PMV - Closed office	0,0978	0,2636	0,3576	0,5725
Datum	2021-09-03 12:07	2021-09-03 12:23	2021-09-03 13:19	2021-09-03 13:24
PPD [%] - Large meeting room north	-	-	-	-
PMV - Large meeting room north	-	-	-	-
Datum	-	-	-	-

	Lights: Partly on-Sun Blinds: Partly drawn	Lights: Always on Blinds: Partly drawn	Lights: Partly on-Sun Blinds: Never drawn	Lights: Always on Blinds: Never drawn
Hours of overheating (7-17) - Open plan office north	5.02	47.4	32.2	103
Hours of overheating (7-17) - Open plan office southwest	0.725	0.845	0.758	17.8
Hours of overheating (7-17) - Lounge north	0.81	1.24	1.03	1.41
Hours of overheating (7-17) - Lounge southeast	32.1	85.3	0.758	162
Hours of overheating (7-17) - Closed office	4.41	25.1	43.6	123
Hours of overheating (7-17) - Large meeting room north	0.232	0.243	0.271	0.454





Winter

	Max occupancy	Intermediate occupancy
Max "Mean air temp"	21,03	21,03
Min "Mean air temp"	19,97	19,97
Max "Op. temp"	21,07	21,07
Min "Op. temp"	19,47	19,47
Max PPD %	20,18	20,18
Min PMV	-0,8444	-0,8445

	Max occupancy	Intermediate occupancy
PPD [%] - Open plan office north	12,65	12,64
PMV - Open plan office north	-0,5974	-0,5971
PPD [%] - Open plan office southwest	13,02	13,02
PMV - Open plan office southwest	-0,613	-0,6129
PPD [%] - Lounge north	6,175	6,184
PMV - Lounge north	-0,229	-0,2302
PPD [%] - Lounge southeast	6,223	6,227
PMV - Lounge southeast	-0,2345	-0,2351
PPD [%] - Closed office	20,14	20,14
PMV - Closed office	-0,843	-0,843
PPD [%] - Large meeting room north	20,18	20,18
PMV - Large meeting room north	-0,8444	-0,8445

DEPARTMENT OF ARCHITECHTURE AND CIVIL ENGINEERING
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