MASTER THESIS

USERS' BEHAVIOUR AND PERCEPTION OF THE INDOOR CLIMATE IN A MECHANICALLY VENTILATED OFFICE BUILDING

ausgeführt zum Zwecke der Erlangung des akademischen Grades eines
Diplom - Ingenieurin

unter der Leitung von
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Kurzfassung

Diese Arbeit präsentiert die Ergebnisse einer Studie, welche das Verhalten der Benutzer in Bezug auf die Gebäudesysteme in einem Bürogebäude im Süden von Wien, Österreich, die nur mit mechanischen Mitteln belüftet wird, beurteilt, zusammen mit der Wahrnehmung der Benutzer bezüglich der Innenraumklimabedingungen in Ihren Arbeitsbereichen.

Die empirische Datenerhebung über die Innenraumklimabedingungen wurde durch die Messung der Innentemperatur, relative Feuchtigkeit und Beleuchtung mithilfe von Informationssammler, die in verwendeten Büros installiert wurden, über einen Zeitraum von zehn Monaten gesammelt. Informationen über die äußeren Wetterbedingungen wurden von ZAMG, Wien (Zentralanstalt für Meteorologie und Geodynamik, Wien) erhalten. Probendaten über die Belegung und Stand der Gebäudesysteme, welche von den Benutzern (Thermostat, Beleuchtung und Jalousie) kontrolliert werden können, wurden ebenfalls durch stündliche Beobachtungen über einen Zeitraum von sechs Monaten gesammelt. Alle diese Daten wurden zusammen korreliert, verarbeitet und analysiert.

Das Hauptziel der Arbeit ist die Innenraumklimabedingungen in einem Bürogebäude zu beobachten und zu analysieren, allgemeine Muster des steuerorientierten Verhaltens an Ihren Arbeitsplätzen in Bezug auf die Innen-/Außenbedingungen zu identifizieren und zu erforschen und das Wissen über diese Benutzerverhaltensmuster zu verbessern.

Die Ergebnisse tragen zu einem besseren Verständnis des Benutzersverhaltens in Bürogebäuden, die bei der Grundlagenentwicklung für die Einflussbeurteilung der Belegung bezüglich des Energieverbrauchs des Gebäudes, bei der Suche nach besseren und nachhaltigeren Entwürfen, bei der Integration der Verhaltensmodelle in den Anwendungssimulationen der Gebäudeleistungen und bei der Verbesserung der Managementleistungen und der Automatisierungssysteme benutzt werden können.

Abstract

This thesis presents the results of a study which is assessing the users’ behaviour regarding the building systems in an office building located in the south of Vienna, Austria, ventilated by mechanical means only, together with the users' perception of the indoor climate conditions at their workspaces.

Empirical data about the indoor climate conditions was collected by measuring the inside temperature, relative humidity and illuminance with data loggers, which were installed in used offices, over a period of ten months. Data regarding external weather conditions was obtained from ZAMG, Wien (Central Institute for Meteorology and Geodynamics, Vienna). Sample data about the occupancy and the status of the building's systems, which can be controlled by the users (thermostat, electrical lighting and shades), was also collected through hourly observations over a period of six months. All these data was correlated together, processed and analyzed.

The main objective of this thesis is to observe and analyze the indoor climate conditions in an office building, to identify and explore general patterns of occupant’s control-orientated behaviour at their workplaces in relation to the indoor/outdoor conditions and to enhance the knowledge about these user behavioural patterns.

The results contribute to a better understanding of users' behaviour in office buildings, which can be used in developing bases for evaluating the influence of occupancy on building energy consumption, finding better and more sustainable designs, integrating behavioural models in building performance simulation applications and improving building management performance and automation systems.

Keywords: user behaviour, user interaction, occupancy, lighting control, shading control, thermal comfort, data collection

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Finally, but not the least, I would like to thank my family and friends for their constant encouragements and support.

dedicated to my grandmother

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1 Introduction

1.1 Overview

The present thesis describes an effort to observe control-orientated occupant behaviour in an office building which is mechanically ventilated, without having the possibility to open the windows in order to let fresh air in. The office building used as case study is located in the south of Vienna, Austria, and will be further referred of as SV building in this thesis.

As it was proved that the interaction between occupants and building systems affect thermal comfort and energy consumption of the building, the aim of this study is to identify and explore general patterns of control-orientated user behaviour at their workplaces, to enhance the knowledge about these user behaviours in office buildings in connection with the indoor and outdoor environmental conditions and to observe and analyze the indoor climate conditions in relation to the occupants' perception regarding their working environment.

For this purpose, data regarding the indoor and outdoor climate conditions and the occupants' behaviour at workspaces was collected, processed, analyzed and discussed within this study. Accurate measurements of indoor climate parameters were collected in five minutes intervals by data loggers installed in 18 offices, located at the fifth floor in the north part of the building, over a period of ten months (May 2013 – March 2014). Likewise, the occupancy, the status of the electrical lighting, the position of the internal shades and the adjustments of the cooling/heating units were observed and marked down hourly during a number of 66 sample days, over a period of six months (June - November 2013). Weather data was received from ZAMG, Wien (Central Institute for Meteorology and Geodynamics, Vienna). Interviews were conducted in order to assess the occupants' point of view regarding the indoor climate and building's systems.

Chapter 1 of the thesis gives motivation for choosing the research topic and the background presenting the existing approaches in the field of human behaviour in buildings. In Chapter 2 the research methodology is described, presenting the building and the monitored offices, the manner of collecting, processing and analyzing the data. Chapter 3 reveals the results, divided into categories regarding occupancy, adjustment of the heating/cooling units, operation of the electrical lighting, operation of the internal shades, interviews and thermal comfort. The discussions based on the results are presented in Chapter 4, following the same category sequence. Chapter 5 outlines the general conclusion of the study, together with future research in the area of user behaviour.

1.2 Motivation

People working in office buildings spend many hours at their workplaces, therefore it is necessary to provide a good indoor climate and efficient building systems. "The control actions by the inhabitants of buildings can significantly affect the indoor climate, the energy performance of buildings and their environmental impact. In most buildings, occupants operate control devices such as windows, shades, luminaries, radiators and fans to bring about desirable indoor environment conditions" (Mahdavi et al. 2007).

The aim of this thesis is to enhance the knowledge about nature, logic, type and frequency of control-orientated user behaviour in buildings, which can support the development of empirically-based behavioural models of users' interactions with the building's systems. These user behaviour models can be integrated in building performance simulation applications and provide basis for finding better and more sustainable designs. The study can also provide help in improving the building management and automation systems. "Around 70% of electrical energy for lighting could be saved by considering occupancy and daylight in the offices" (Mahdavi et al. 2007). Based on this kind of study, education and information campaigns could be initiated for users regarding the implications of their actions when interacting with the building's control systems and devices, in the hope to determine them to adopt a more conscious behaviour, which can result in buildings' energy conservation and improved indoor climate.

1.3 Background

Multiple studies have been and are being conducted internationally to collect data on building users’ behaviour towards the building control systems and devices, exploring the patterns of actions upon lighting (switching on/off), actions upon shades (opening/closing) and possible dependencies on indoor and outdoor environmental conditions, façade orientation, time of the day, etc. The major findings are summarized as it follows:

Manual operation of electrical lighting

It was discovered that the operation of electrical lighting depends on seasons. Boyce (1980) stated in his study about manual switching of lighting that the total number of luminaires switched on was less in summer than in winter, corresponding to the considerable differences for the two seasons in daylight availability. Carter et al. (1999) established seasonal dependency in the mean lighting load, registering for January a mean lighting load of 53% and for April and May a mean lighting load of 43%.

Hunt (1979) observed that switching the lights occurs mostly at the beginning and the end of the working day for continues occupancy and he stated that the lighting operation is determined by the cycle of occupancy. Reinhart et al. (2003) observed in a study that 86% of switching on actions on lighting are done upon arrival.

Probabilities of switching the lights on upon arrival depending on the working plane illuminance were determined by Hunt (1979), Reinhart (2001), Mahdavi et al. (2007) and other researchers (Love 1998). All three functions state that the probability of switching the lights on is significantly increased by illuminance levels under 100 lx, as it can be seen in Figure 1-1.

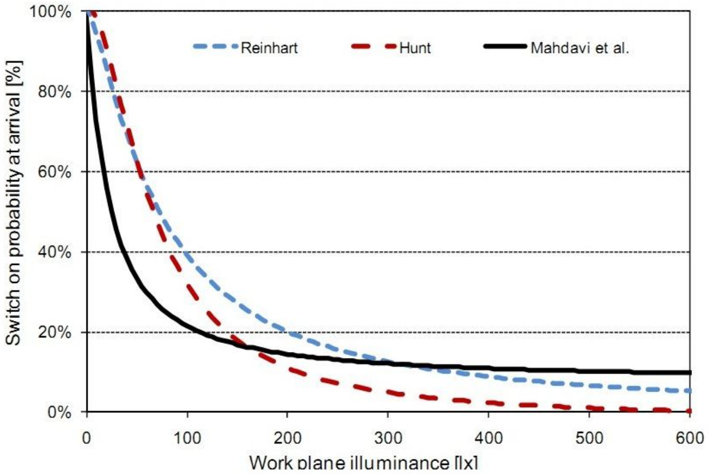


Figure 1-1 Probability of switching the lights on at arrival in the office

A strong connection was found by Pigg et al (1996) between the probability of switching the lights off and the time elapsing until the user returns to his/her office. He stated that people are more likely to switch off the lights when leaving the office for longer periods, which can be seen in Figure 1-2 and it is verified by other studies (Boyce 1980, Reinhart 2001, Mahdavi et al. 2007).

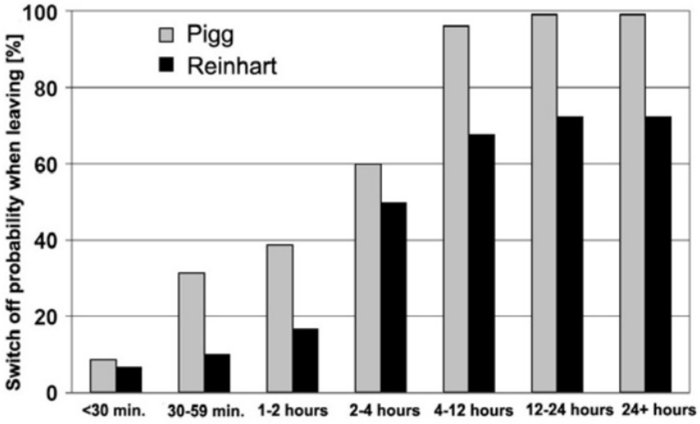


Figure 1-2 Probability of switching the lights off when leaving the office

Manual operation of shades

The operation of the shades depends on the façade orientation. Rubin et al. (1978) discovered that the blind occlusion was higher on the south façade (80%) than on the north façade (50%) for the offices in Maryland, USA. The blind operation was discovered to vary greatly in relation with the buildings' orientation by Inoue et al. (1988) in a study conducted on office buildings in Tokyo, Japan, asserting that the blinds on the east façade were mostly closed in the morning and opened in the afternoon. Mahdavi et al. (2007) noticed a "highly significant difference in the overall shade deployment levels" between a building with offices facing south-west (75%) and another one with offices facing north (10%), both located in Vienna, Austria.

Rubin et al. (1978) found that occupants manipulate their shades mainly to avoid direct sunlight and overheating, dependency which was confirmed also by other studies (Rea 1984, Bülow-Hübe 2000). Inoue et al. (1988) and Reinhart (2001) proved that above a certain threshold of vertical solar radiation, the position of shades depends on the solar penetration depth into the room, which can be seen in Figure 1-3.

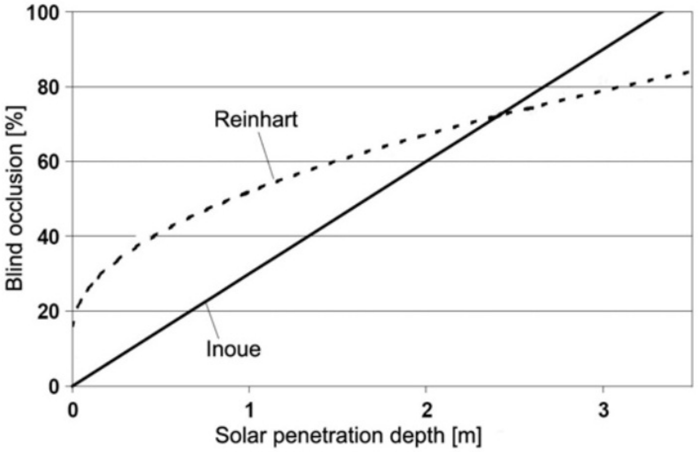


Figure 1-3 Mean blind occlusion in relation to the solar penetration depth on SSW façade, when the vertical solar irradiance is above 50 W/m2

Rea (1984) discovered that people rarely change the blinds through the day and concluded, in agreement with Rubin et al. (1978), that people have a long term perception of solar irradiance. Inoue (1988) observed that the relation between blind operation and incident illumination on the façade followed a curve, which is presented in Figure 1-4. He concluded that people considered long-term irradiance values, while short-time-step dynamics were mostly ignored.

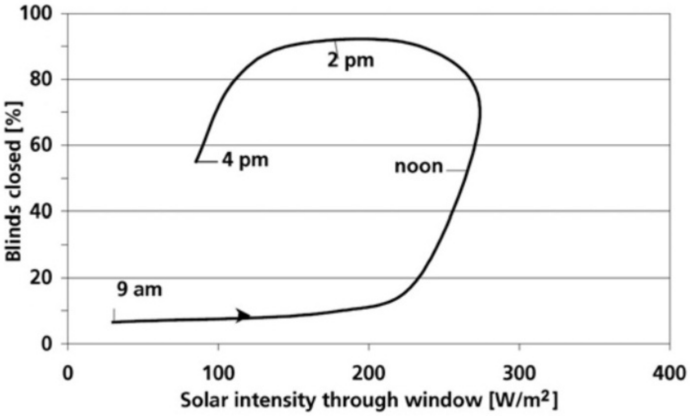


Figure 1-4 Percentage of blinds closed for SSW façade in relation to the vertical solar irradiance

In spite of the common conclusions, the results of past researches reveal many discrepancies, which could be caused by different monitoring and analysis methods and different types of buildings, rooms and shading systems, but also by the fact that occupancy has not been recorded and considered. Therefore, there is a need for further research of user behaviour regarding manual operation of shades, considering the occupancy, which would eliminate the uncertainty whether no or few actions of opening/closing the shades is due to tolerable outside/inside conditions or due to the absence of users from the monitored rooms.

2 Research Methodology

2.1 Overview

This thesis had as case study 22 offices from a building located in the south of Vienna, Austria, hereby referred as SV building. These offices have different orientation (east/west), area (from 13,4 m^2 to 41 m^2) and type (closed/open-space).

Data loggers for measuring indoor parameters such as temperature, relative humidity and illuminance were distributed in the offices considering the orientation and the type of office and they were mounted near or between the workstations. The measured data was collected for a period of 10 months (May 2013 - March 2014).

Outdoor parameters such as temperature, relative humidity and solar irradiance were received from ZAMG, Wien (Central Institute for Meteorology and Geodynamics, Vienna) for the six months of observation period (June - November 2013).

The occupancy level, the operation of electrical lighting, the status of the shades and the adjustment of the heating/cooling units were observed and recorded as hourly sample data over a period of six months (June - November 2013).

At the end of the measuring period, the occupants gave a feed-back regarding their perception of the indoor climate by participating to interviews, which were held based on a questionnaire inspired from the one developed for the project "People as Power Plant" (Mahdavi et al. 2007), divided in five categories of questions: personal information about the users, perception of the indoor climate and control systems, operation and accessibility of the control systems, awareness of the functionality of building control systems and energy conscious behavior, personal preferences and health complains.

2.2 Object Description

2.2.1 Building Description

The main effort of this study is focused on the analyzed SV office building, Austria, which is the main headquarter of an international organization, presenting a fully air conditioned environment and not operable windows.

SV building is orientated on the north-south direction, which can be seen in Figure 2-1, and its offices are facing either east or west side. Figure 2-2 shows the west façade of the building and underlines the monitored offices of this side, which are the same for the east side, located on the fifth floor, north part of the building.

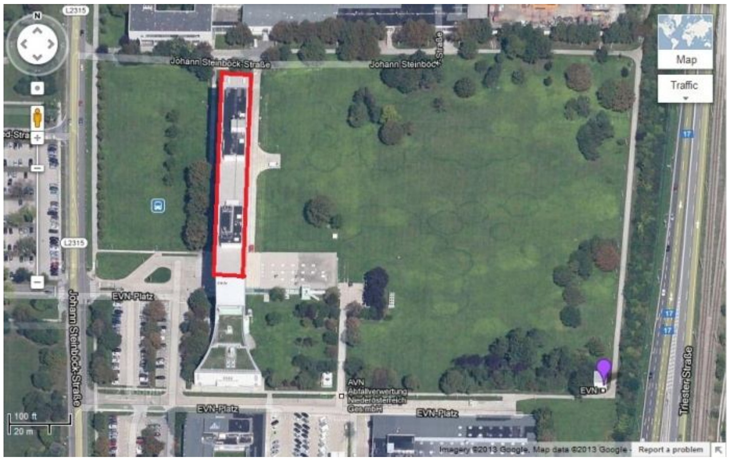


Figure 2-1 Aerial view of SV building

Figure 2-2 View of the west façade of SV building

The building was constructed in 1963 and it is characterized by a flat roofed reinforced concrete frame structure enveloped by curtain façade elements, consisting of alloy metal and insulated glazing. The entire object rests on composite columns, through which a free view is guaranteed for all occupants, exceptions being the northern stairwell, the main entrance together with the entrance hall and the dining room. Two stairwells, each with three elevators, connect the separate floors from the cellar to the roof. The building has 138 m length, 14 m width and 31,5 m height, over its seven floors and setback roof.

2.2.2 Monitored Offices

The 22 offices, where monitoring was allowed, are located at the 5h floor, north half of SV building. Table 2-1 presents the observed offices, together with their orientation, type, area, number of users and type of installed data loggers for indoor parameters.

Table 2-1 Monitored offices of SV building

Orientation	Office	Type	Installed data logger	Users	Area [m2]
East	Office 1	closed	Θ [°C]	1	13.41
East	Office 2	open	Θ [°C], RH [%], Illum. [lx]	4	41.03
East	Office 3	open	Θ [°C]	3	41.03
East	Office 4	closed	Θ [°C]	1	13.41
East	Office 5	closed		1	13.41
East	Office 6	closed		1	27.22
East	Office 7	closed	Θ [°C]	1	13.41
East	Office 8	closed	Θ [°C]	1	13.41
East	Office 9	open		3	27.22
East	Office 10	open	Θ [°C], RH [%], Illum. [lx]	3	41.03
East	Office 11	closed	Θ [°C]	1	13.41
East	Office 12	open	Θ [°C],	3	27.22
West	Office 13	closed	Θ [°C], RH [%], Illum. [lx]	1	13.41
West	Office 14	closed	Θ [°C]	1	13.41
West	Office 15	open	Θ [°C], RH [%], Illum. [lx]	3	41.03
West	Office 16	open		2	27.22
West	Office 17	closed	Θ [°C]	1	27.22
West	Office 18	open	Θ [°C], RH [%], Illum. [lx]	5	41.03
West	Office 19	open	Θ [°C]	2	27.22
West	Office 20	closed	Θ [°C]	1	13.41
West	Office 21	open	Θ [°C]	3	27.22
West	Office 22	closed	Θ [°C], RH [%], Illum. [lx]	1	13.41
			Total	43	530

The offices are facing either east side (12 offices), either west side (10 offices). There are two types of offices, 12 of them are closed offices (with 1 workstation) and 10 are open-space offices (with 2 to 5 workstations). The offices are separated by movable partition walls, made by glass or wood covered with fabric, which allow quick change of the required office dimensions. The plans of the monitored offices can be seen in Appendix A.

Each closed office includes a single working space and it is occupied by only one user. This kind of office has an area that varies between 13,41 m^2 and 27,22 m^2 and it is equipped with one desk, one extra working table, one computer, one telephone, two or three bookshelves and some are also provided with one meeting table and three to seven chairs. An example of single-occupied office is presented in Figure 2-3.

Figure 2-3 Example of closed office (Office no. 13)

The open-space offices are provided with 2 to 5 workstations, but some of them are not occupied. The area of these offices varies between 27,22 m^2 and 41,03 m^2 and the equipment of one workstation consists usually of one desk, one computer, one telephone, one or two bookshelves and one chair. An example of open-space office is given in Figure 2-4.

Figure 2-4 Example of open-space office (Office no. 18)

The offices are partitioned according to the building's axes (modules) and each office has between one and three modules of 250 cm width. The total number of modules within the monitored offices is 39. For each module there are one or two workspaces, a not operable window with internal horizontal blind, one heating/cooling and air-conditioning unit and 2 rows of fluorescent luminaires. The floor surface is covered by grey linoleum and the ceiling is covered with white plate panels. Approximately 70% of the occupants keep plants in the office.

2.2.3 Observed Building Systems

The building systems observed for the purpose of this study are the heating/cooling and air-conditioning units, the luminaires and the shades. Each of them is described as it follows.

Heating/Cooling & air-conditioning units

The centrally controlled heating/cooling and air-conditioning units are placed under each window, functioning with cooled air, hot or cold water. The number of observed units is 39, one for each module. An article written by Sigmund (1964) claims that the basic functions of this system are dictated centrally, but can be readjusted manually to achieve the wanted room temperature individually in the separate offices. The article states that the used air is released from vents opposite to the air inlets, while fresh air is sucked in at roof height and filtered from dust. It explains that the system can pump 180.00 m³ of fresh air into the office spaces, allowing an air-renewal of four times per hour, and like this the renewal of air is much more efficient in comparison to sporadically opening of windows. The system was designed to keep the air humidity at optimal levels for the human body. The operation of the HVAC system is done only during working days, between approximately the hours of 05:00 and 20:00.

Luminaires

The monitored offices are equipped with a total number of 78 fluorescent luminaires, 2 for each module, which contain 2 bulbs of 38 W each. The luminaires are divided in 2 groups: the row close to the window and the row close to the central passage. Both have manually controlled switchers located near the entrance and can be switched on/off independently by the users any time.

Shades

The shading devices are internal horizontal blinds, which and can be operated manually by the users. The number of observed shades is 39, one for each module.

2.3 Data Collection

The collected data is of two types: objective and subjective. The objective data was collected by measuring with HOBO data loggers the indoor climate during the period of May 2013 until March 2014, by observing hourly the occupancy and the status of building's systems in random days between June and November 2013 and by receiving values of outdoor parameters for the observation period from ZAMG, Vienna. The subjective data was collected by conducting interviews of the occupants and assessing their point of view regarding the environmental conditions of their offices and the building's systems.

2.3.1 Internal Environment

A total number of 18 Hobo data loggers were available for this study. 6 of them were able to measure parameters such as temperature [°C], relative humidity [%] and illuminance [lx] (Hobo U12-012), while the other 12 were measuring only the temperature [°C] (Hobo U12-001). For the technical specifications of both types of sensors see Appendix B. Unfortunately, the number of sensors was not sufficient to cover all the offices, therefore they were uniformly distributed over the observed area according to Table 2-1, taking into consideration the orientation and the type of office. The measurements were done with a sample rate of 5 minutes, between May 2013 and March 2014 (more precisely, the recorded measurement data is for the following periods: 24.05-13.07.2013, 12.08-01.12.2013 and 09.12.2013-15.03.2014).

The data loggers were installed horizontally on the panels between the working desks, under the light fixtures, as it can be seen in Figure 2-5, after consulting the occupants in order to get their acceptance. It was tried to avoid direct sunlight when mounting the sensors and the occupants were instructed not to deposit any item on them.

The software application GreenLine was used to launch the loggers and download the data. To visualize the interface of the application see Appendix B.

Figure 2-5 Example of mounting position of sensor (Office no. 15)

2.3.2 Occupancy and Status of Building Systems

The data regarding the occupancy and the status of the building's systems which users interact with (shades, electrical lighting and thermostat) was collected through hourly observations which were marked down in a record log for the purpose of this study between June and November 2013. The exact number of observed days is 66, which are the following: 10-14.06, 17-18.06, 20-21.06, 24-28.06, 01-03.07, 05.07, 08-09.07, 15-16.07, 06-09.08, 12-13.08, 19-20.08, 23.08, 26-30.08, 03-06.09, 09-12.09, 17-20.09, 07-10.10, 29-31.10, 04-07.11, 13.11, 18.11, 20-21.11, 25-27.11.

The occupancy was observed on hourly basis by marking down the number of users present at their work stations for each module (1 up to 2 occupants per module). The modules were previously described in paragraph 2.2.2. The observed offices present a number of 39 modules in total. The status of the building's systems was observed also on hourly basis and for each observed system factors were given in relation to the modules in order to quantify the exact status and perceive the changes. The logic of these factors is described below for each building system.

Heading/Cooling & air-conditioning units

Theoretically, the users can change the air temperature coming out of the units by adjusting between hot and cold. During the cooling period, the adjustment from maximum to minimum decreases the inside temperature by decreasing the flow of cold water running through the system until it is completely stopped when setting to minimum. The heating adjustment is made in the same way, with the difference that from maximum to minimum it is adjusted the flow of hot water. Therefore during cooling period maximum represents cold and minimum hot, while during heating period maximum represents hot and minimum cold. The factors for adjusting these units are given from 0 to 1, representing cold to hot, in steps of 0,1. Figure 2-6 shows how the adjustment can be done and also the given factors. All the observed adjustments were noted down in the record log.

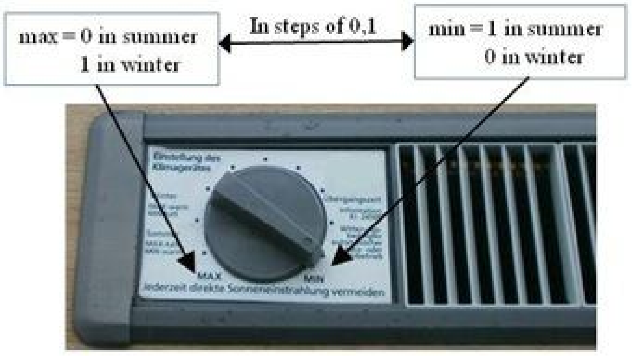


Figure 2-6 Factors given for the adjustments of H/C&AC units

Luminaires

The status of the artificial lighting was marked down by giving values for each module, according to the number of switched on/off rows: value 0 for completely switched off luminaires, value 0,5 for one row of luminaires switched on and value 1 for both rows of luminaires switched on.

Shades

The position of the shades was recorded according to the percentage of shade deployment from completely open shade (0%) to completely closed shade (100%), with intermediary steps of 20% and consequently values were given from 0 to 1, in steps of 0,2, as it can be seen in Figure 2-7.

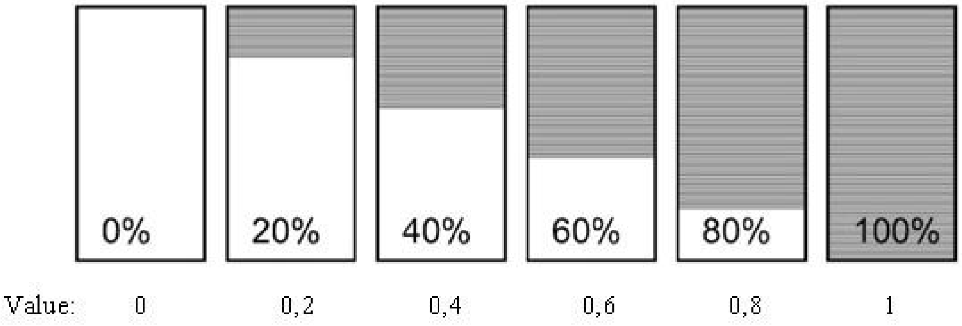


Figure 2-7 Factors given for the position of shades

It was important to consider also the angle of the shades. Values for each angle were given according to the amount of daylight they let in: 1 for completely closed angle on both sides, 0,8 for an angle of 45° upwards, 0,6 for a 90° angle and 0 for an angle of 45° downwards.

2.3.3 External Environment

Measurements of the external parameters such as temperature [°C], relative humidity [%] and solar irradiance [$W \cdot m^{-2}$] for the six months of observation period (June - November 2013) have been requested from ZAMG, Wien (Central Institute for Meteorology and Geodynamics, Vienna) and hourly meteorological data of the weather station "Brunn am Gebirge" has been received.

2.3.4 Interviews

Beside objective data, also subjective data was collected using interviews. The users were kindly asked to answer to a set of questions, based on a questionnaire structured in five sections: personal information about the users, perception of the indoor climate and control systems, operation and accessibility of the control systems, awareness of the functionality of building control systems and energy conscious behavior, personal preferences and health complains. The full questionnaire content together with the results is summarized in Appendix C.

2.4 Data Processing

The time for the entire monitoring and observation period was established for the winter hour of Vienna, UTC/GMT +1 and the considered working hours were from 08:00 until 19:00.

The data measured by Hobo sensors was collected in one standardized Excel table where the first row contained the headers and the first column contained date and time. This data in 5 minutes interval was used to plot the psychrometric charts in Matlab. For the rest of the analysis, it was transformed in hourly intervals by calculating the hourly mean value as the average of twelve 5 minutes values, referring to the past hour (e.g. the value for 08:00 is the average of the values from 07:05 to 08:00).

Regarding the observation data, the occupancy values for the offices were calculated as the sum of the occupancy values of the constitutive modules, as well as the lighting values. The values of the thermostat status were kept for each module in order to analyze each unit. The effective shade deployment for one office was calculated as the average of the shade deployment degree of all constitutive modules, which was considered as the value of the shades' position multiplied by the shades' angle.

The observation data was correlated according to date and time with the mean hourly values of the measurements recorded by the sensors and the values of the external parameters, which can be seen in Table 2-2.

Table 2-2 Part of the table with the processed data

	External conditions			**Office 2 - 809155**								
Time	ϴ °C	RH %	GSI W/m²	ϴ °C O2	RH % O2	Illum. lx O2	Oc. O2	L. O2	Bl. O2	S. AC 2E	S. AC 3E	S. AC 4E
2013.6.10 8:00:00	21.8	68	722	25.8	49.6	909	3	0	1.00	0	0	0
2013.6.10 9:00:00	22.3	65	756	26.3	48.3	485	4	0	1.00	0	0	0
2013.6.10 10:00:00	20.6	70	442	26.4	47.7	286	4	0	1.00	0	0	0
2013.6.10 11:00:00	20.2	76	233	26.2	47.1	296	4	1	1.00	0	0	0
2013.6.10 12:00:00	22	68	556	25.5	51.4	231	0	2	0.87	0	0	0
2013.6.10 13:00:00	20	70	139	25.4	54.0	342	3	2	0.87	0	0	0
2013.6.10 14:00:00	17.9	77	36	25.2	53.7	253	4	2	0.67	0	0	0
2013.6.10 15:00:00	17.6	80	72	24.9	52.7	695	3	3	0.67	0	0	0
2013.6.10 16:00:00	18.4	75	83	24.7	52.5	739	2	3	0.67	0	0	0
2013.6.10 17:00:00	18	78	69	24.5	51.9	681	2	3	0.67	0	0	0
2013.6.10 18:00:00	17.1	79	64	24.0	52.8	67	0	0	0.67	0	0	0
2013.6.10 19:00:00	16.5	79	19	23.5	53.8	12	0	0	0.67	0	0	0

3 Results

3.1 Occupancy

The mean occupancy pattern over the course of a reference day of the entire observation period can be seen in Figures 3-1. These values mark the presence of the users in their office, not their presence in the building. The occupancy patterns can vary considerably from office to office. Figure 3-2 shows the mean occupancy level over the course of a reference day for closed (single-occupied) offices, while Figure 3-3 shows the mean occupancy level over the course of a reference day for open-space offices.

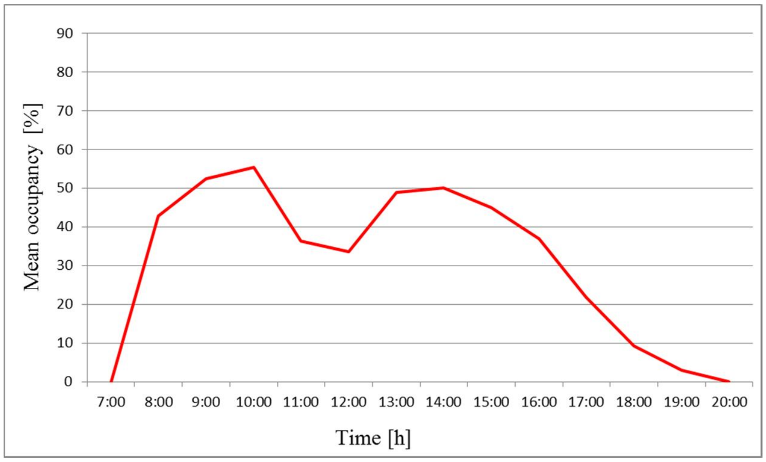


Figure 3-1 Hourly mean occupancy level for a reference day over all offices

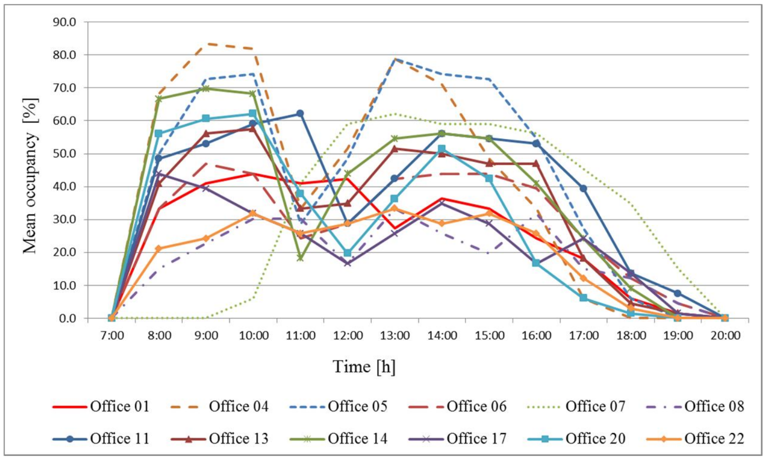


Figure 3-2 Hourly mean occupancy levels for a reference day in closed office

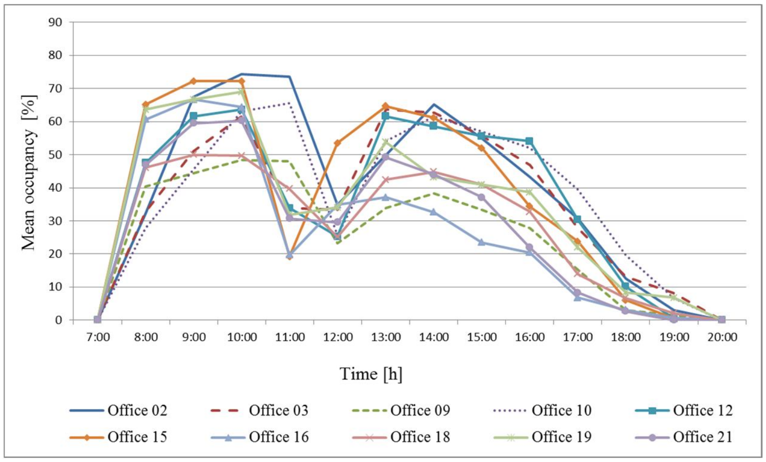


Figure 3-3 Hourly mean occupancy levels for a reference day in open-space offices

Figure 3-4 presents the mean occupancy load in W·m^{-2} over the course of a reference day, which can serve as an input for building performance simulation applications. This has been derived from the mean occupancy level and the calculated heating generation per person 0,2 W·m^{-2}. The heating load per person has been derived from the division of 100 W (standard heating load per person) by 530 m^2 total floor area of the monitored offices.

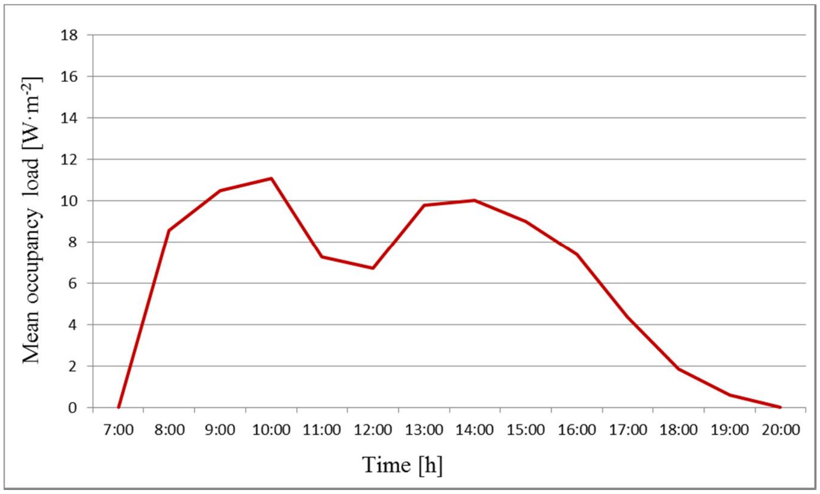


Figure 3-4 Mean occupancy load for a reference day

3.2 Heating/Cooling Units

A total of 39 heating/cooling units were observed. Figure 3-5 shows the number of units in relation to the number of adjustments over the six months of observations. Figure 3-6 illustrates the frequency of adjusting the units in each observed office over the six months of observations.

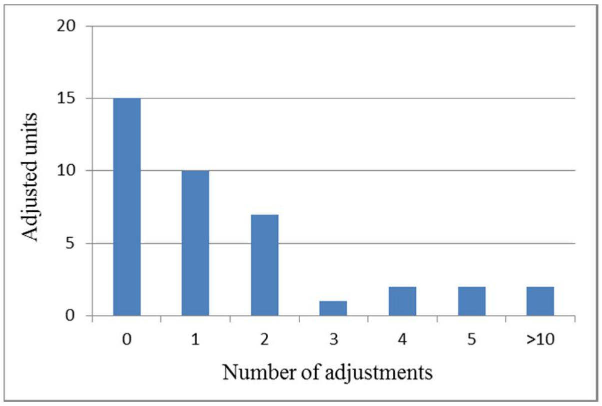


Figure 3-5 Number of adjusted thermostat units in relation to the number of adjustments over the observation period

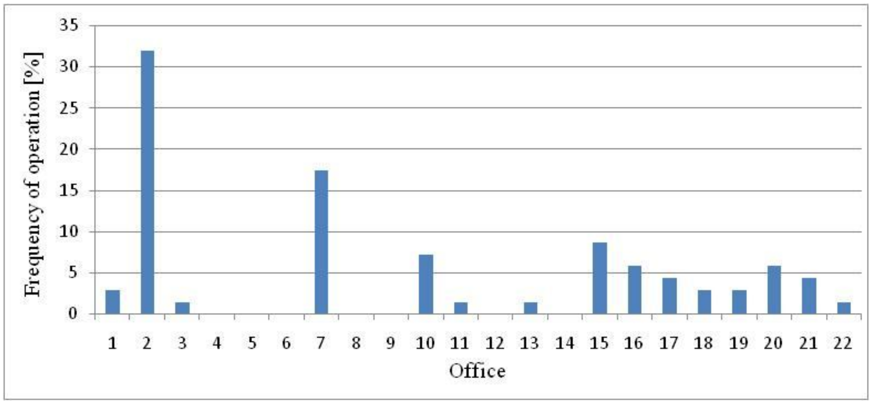


Figure 3-6 Frequency of adjusting the thermostat units in each observed office

Based on the observation data, a monthly frequency was determined for both increasing and decreasing attempts of the indoor temperature. Figure 3-7 shows the monthly frequency of attempts to increase the temperature for all units, while Figure 3-8 shows the frequency of attempts to decrease the temperature.

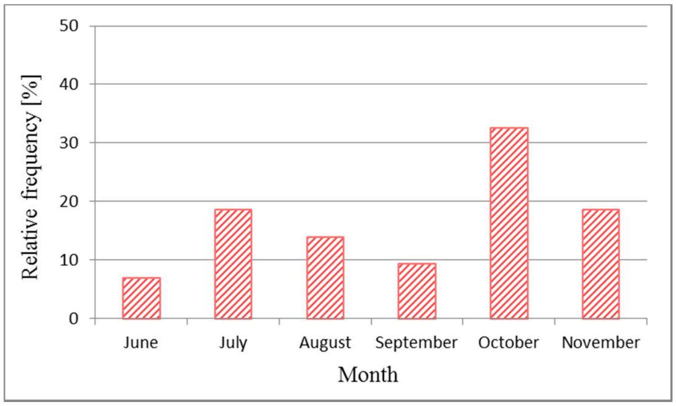


Figure 3-7 Monthly frequency of attempts to increase the temperature

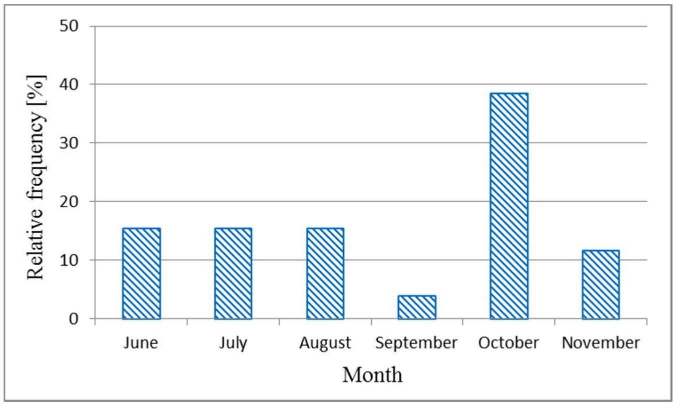


Figure 3-8 Monthly frequency of attempts to decrease the temperature

In order to determine some correlation between the indoor and outdoor temperature and the adjustments of the thermostat, Figures 3-9 and 3-10 show the frequencies of attempts to increase and decrease the temperature as function of the indoor temperature, while Figures 3-11 and 3-12 illustrate the frequencies of attempts to increase and decrease the temperature as function of the outdoor temperature. These were determined based on the indoor/outdoor temperature values when the thermostat was changed and the corresponding number of adjustments for all units.

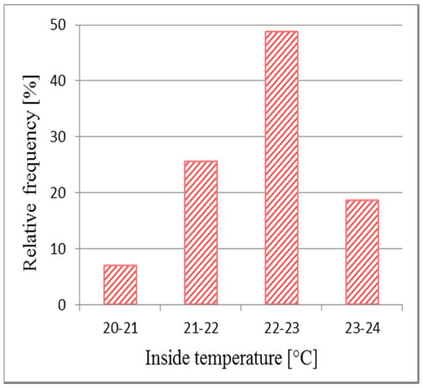


Figure 3-9 Frequency of attempts to increase the temperature as a function of the indoor temperature

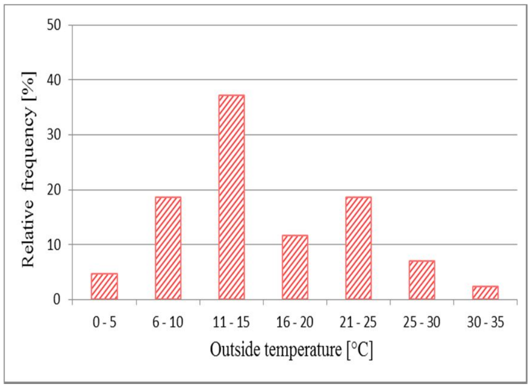


Figure 3-11 Frequency of attempts to increase the temperature as a function of the outdoor temperature

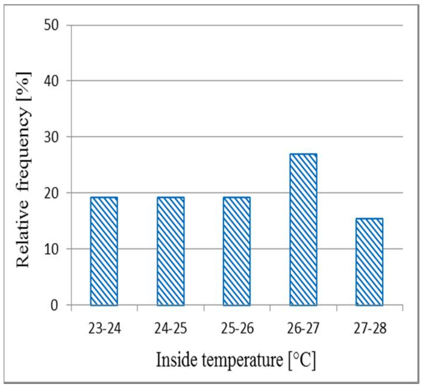


Figure 3-10 Frequency of attempts to decrease the temperature as a function of the indoor temperature

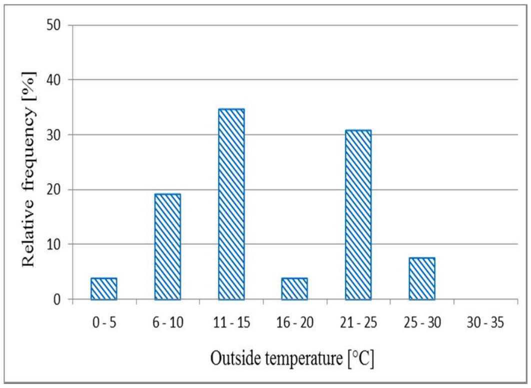


Figure 3-12 Frequency of attempts to decrease the temperature as a function of the outdoor temperature

3.3 Electrical Lighting

3.3.1 Status of Lighting

The mean lighting load during a reference day for the entire observation period, expressed in percentage and in terms of electrical power can be seen in Figures 3-13 and 3-14. The information in these figures concerns the general light usage in all observed offices. The lighting operation has been derived by averaging the percentage of lights on for each hour. The mean lighting load in $W \cdot m^{-2}$ has been derived from the percentage of lighting load and calculated maximum lighting load 11 $W \cdot m^{-2}$. The maximum lighting load was calculated from the total light power of 5928 W (78 luminaires of 76W) divided by 530 m2 total floor area.

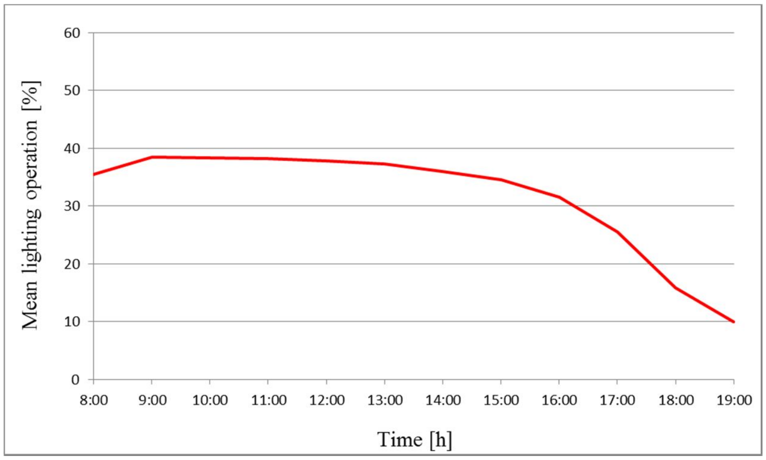


Figure 3-13 Mean lighting operation in SV offices over the observation period

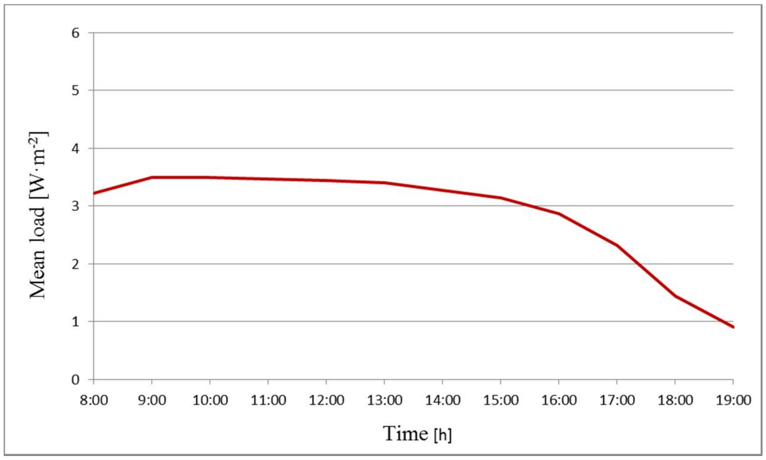


Figure 3-14 Mean lighting load in SV offices over the observation period

The differences in the lighting operation according to the two observed seasons and according to the orientation of the offices have been also explored. Figure 3-15 shows the mean lighting load in percentage over two seasons (June - August and September - November) and Figure 3-16 shows the mean lighting load in percentage split according to the orientation of the offices.

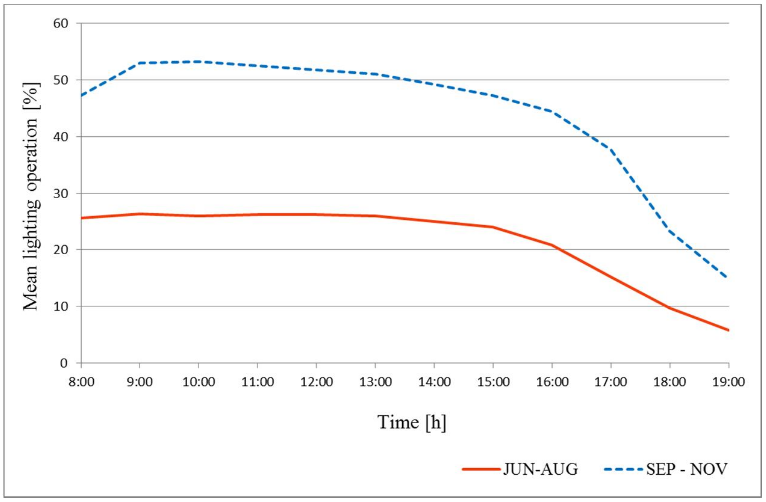


Figure 3-15 Mean lighting operation depending on season in SV offices

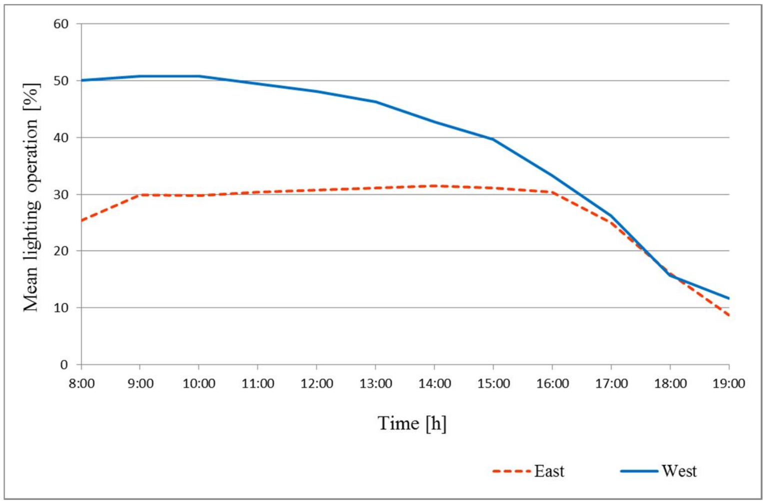


Figure 3-16 Mean lighting operation depending on orientation in SV offices

The above mentioned four figures regarding the mean lighting load over the observed period do not take into consideration the occupancy. With consideration of occupancy, Figure 3-17 shows the status of the lighting in percentage of time during occupied and unoccupied intervals for the entire observation period during working hours and Figure 3-18 shows the percentage of time when the lights were on during occupied and unoccupied period during working hours. The offices 1 until 13 are facing the east side, while the offices 14 until 22 are facing the west side. The lights were considered off when all the luminaires were switched off and they were considered on when at least one luminaire was switched on.

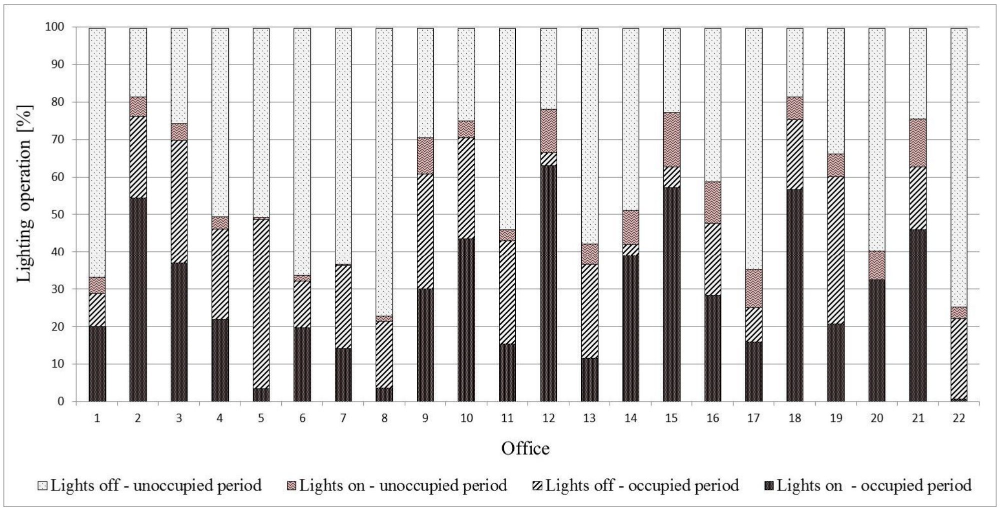


Figure 3-17 Status of the lighting in percentage for each office overall the entire observation period

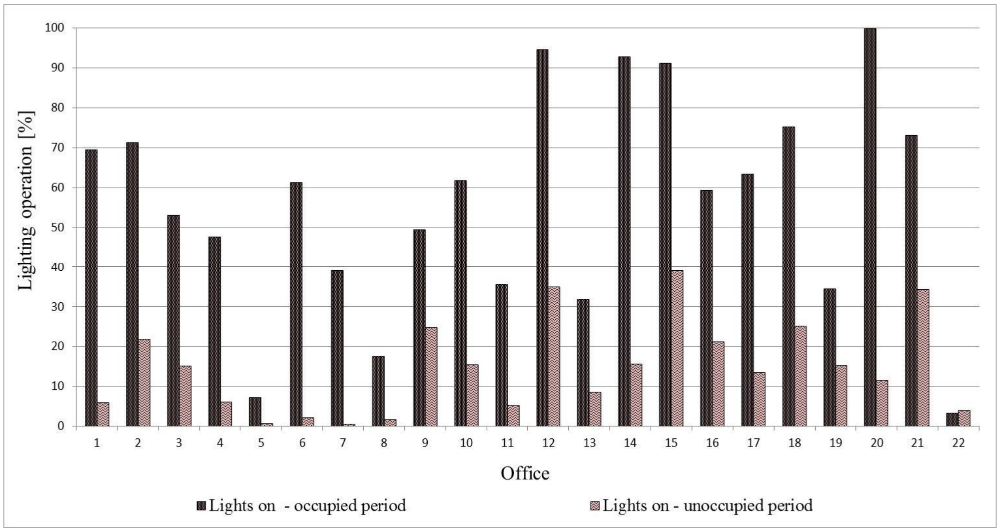


Figure 3-18 Percentage of time when the lights were on during occupied and unoccupied period for each observed

3.3.2 Operation of Lighting

The actions of switching the lights on or off were analyzed. It was explored the probability to switch the lights on upon arrival in relation to the illuminance level. Due to the fact that the data is hourly, the exact time of the actions and the events could not be determined. Therefore, the arrival events were considered every time the occupancy in the office increased, the actions upon arrival were the ones made in the same hour interval and the illuminance level taken into consideration in this analyze was the hourly mean value related to the previous hour interval, before the event occurred. The illuminance range has been divided into bins of 100 lx. For each bin category the total number of switching on actions upon arrival has been divided by the total number of arrival events, expressed in percentage. Arrival events in offices where the light could not be switched on further have not been considered. There were some cases when the lights were already on before the offices were occupied by the users (cleaning ladies coming early in the morning and leaving the lights on or colleagues that have to pass through the respective office in order to get to their office) and they usually remained on regardless the actual necessity of light in the working space. These cases have not been considered in this analyze. Figure 3-19 shows the frequency of switching on the lights upon arrival in the offices (the 6 offices where the illuminance was measured) as a function of the prevailing illuminance level in the office at occupant's arrival time.

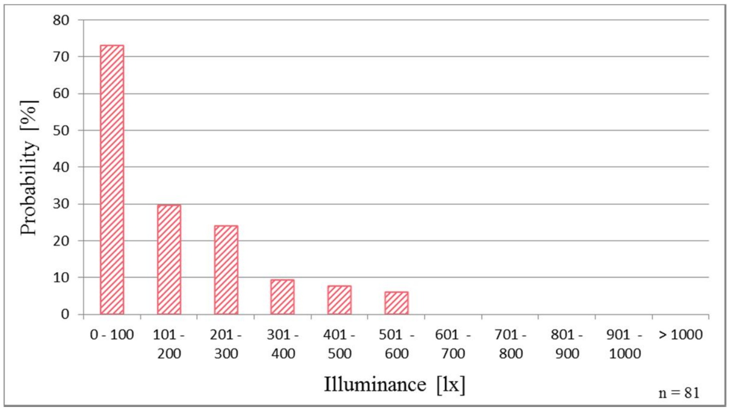


Figure 3-19 Probability of switching the lights on upon arrival in the office as a function of the prevailing illuminance level

Figure 3-20 shows the relative frequency of all switching on actions (upon arrival and intermediate) as a function of the time of the day. The mean global solar irradiance, calculated over the course of a reference day as average for the entire observation period, was also plotted with the intention to compare the daylight availability with the frequency of switching on actions. Figure 3-21 shows the relative frequency of all switching off actions (upon leaving and intermediate) as a function of the time of the day.

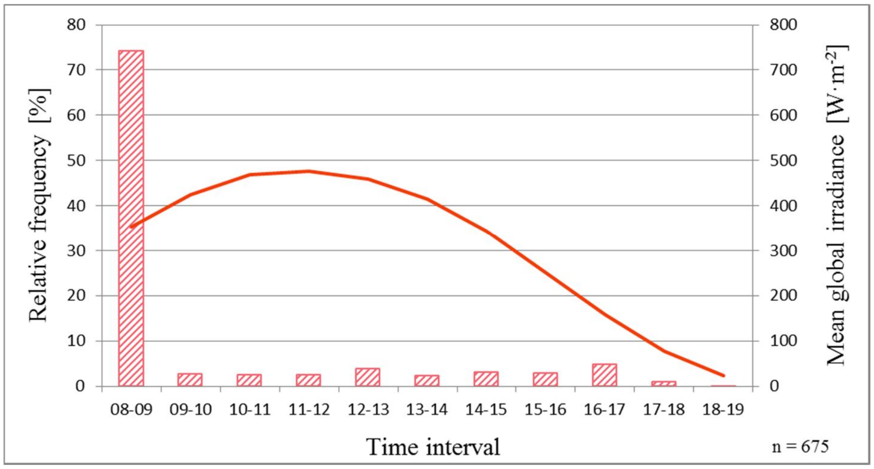


Figure 3-20 Relative frequency of switching the lights on actions over the course of a day

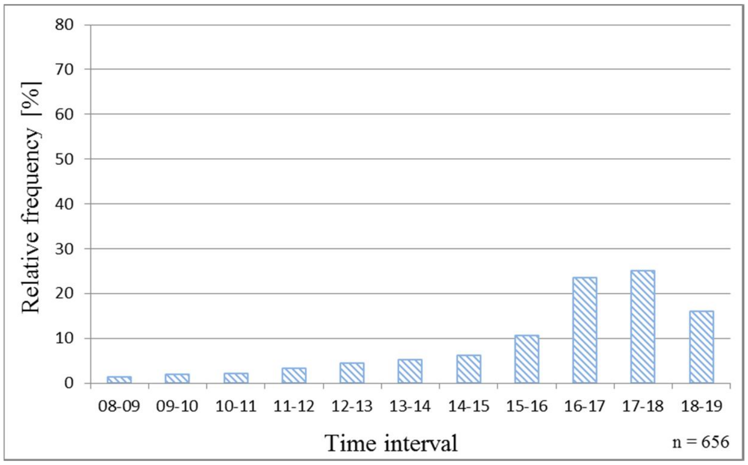


Figure 3-21 Relative frequency of switching the lights off actions over the course of a day

Figure 3-22 shows the probability of switching the lights off upon leaving the office as a function of the duration of absence from the offices. The period of absence has been divided in 60 minutes bins due to the fact that the observation data is hourly. The leaving events were considered every time the office remained unoccupied and they were sorted according to their following absence periods. For each bin, the number of switching off actions upon leaving has been divided by the total number of leaving events. Leavings from unlit offices have not been considered.

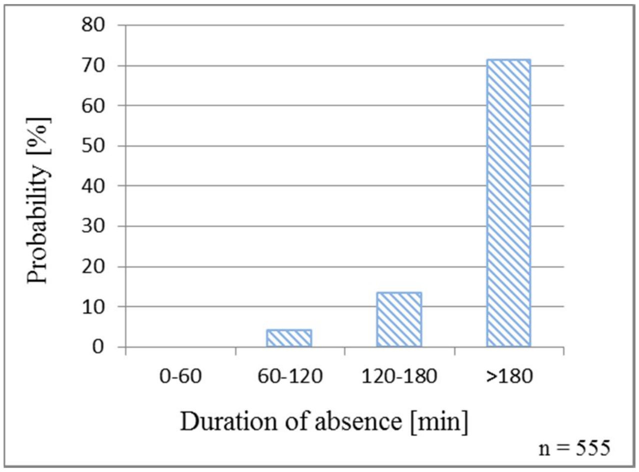


Figure 3-22 Probability of switching the lights off upon leaving the office as a function of the duration of absence from the offices

3.4 Internal Shades

3.4.1 Position of Shades

Seasonal and orientation dependencies of the shade deployment have been analyzed and explored. The monitored offices have two different orientations (east and west) which have to be considered independently when investigating the position of shades. The mean shade deployment degree for a reference day over the observation period for both orientations can be seen in Figure 3-23, where 100% denotes full shades deployment, whereas 0% denotes no shade deployment. Figures 3-24 and 3-25 show the mean shade deployment degree for two different seasons (June-August and September-November) according to orientation.

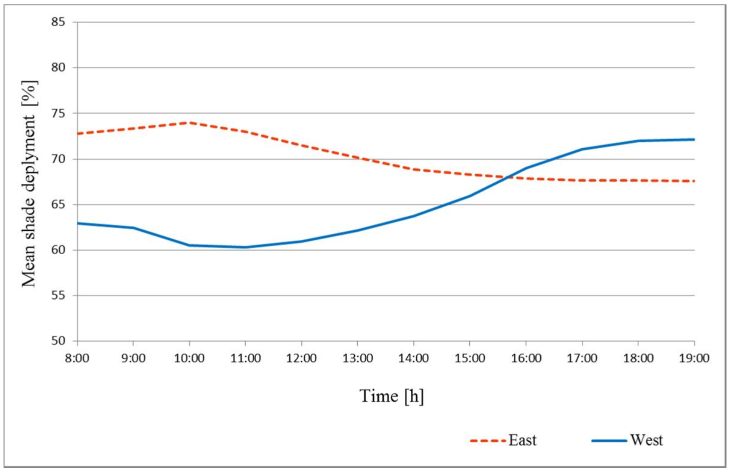


Figure 3-23 Mean shade deployment in SV offices over the observation period

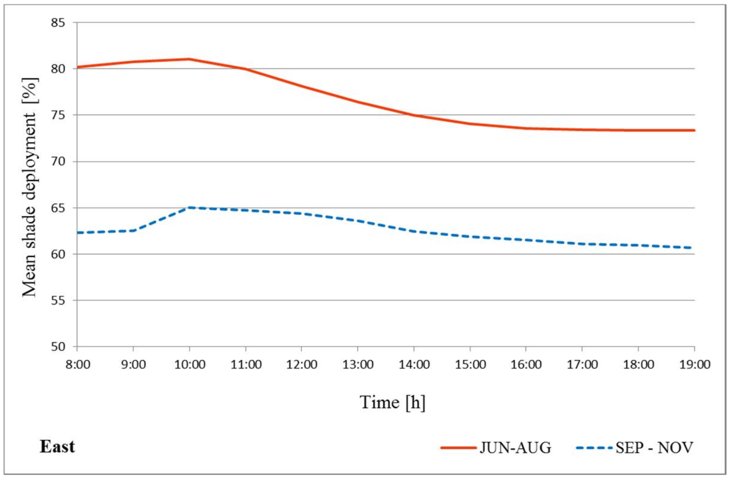


Figure 3-24 Mean shade deployment depending on season for the east façade

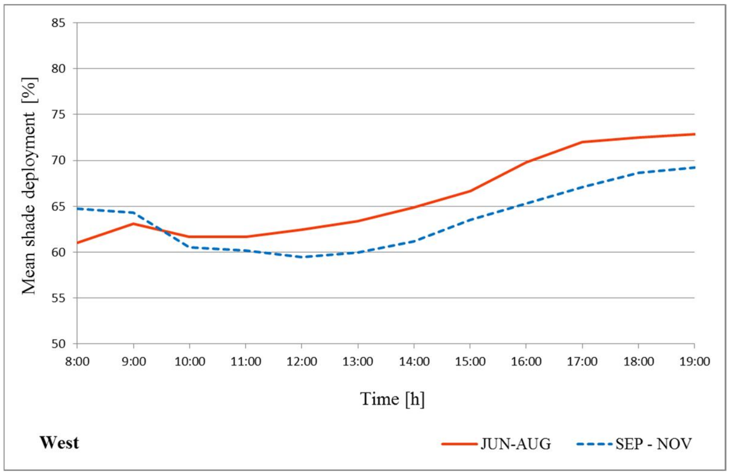


Figure 3-25 Mean shade deployment depending on season for the west façade

The mean monthly shade deployment degree during working hours and the mean monthly global irradiance were calculated in order to see if there is some correspondence between them. Figure 3-26 presents the correlation between these monthly values.

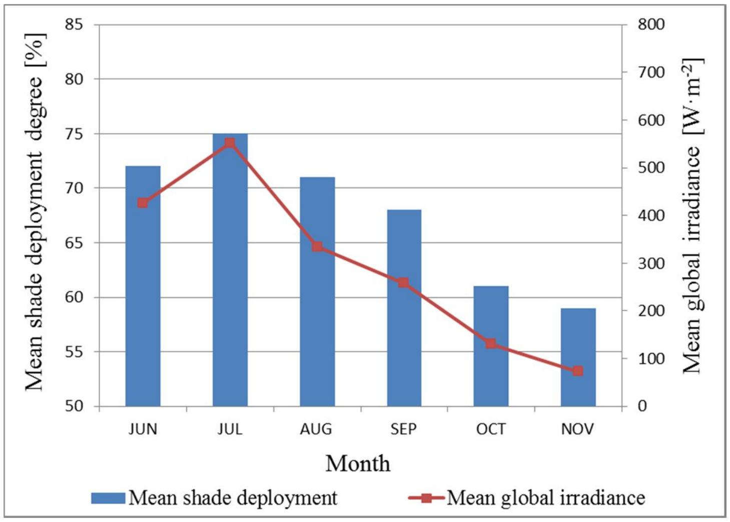


Figure 3-26 Mean monthly shade deployment degree in SV offices together with mean global irradiance

It was explored the relation between the mean shade deployment degree and the external environment factors like global irradiance and outdoor temperature. Figure 3-27 shows the mean shade deployment degree as a function of the global irradiance and Figure 3-28 shows the mean shade deployment degree as a function of the outdoor temperature.

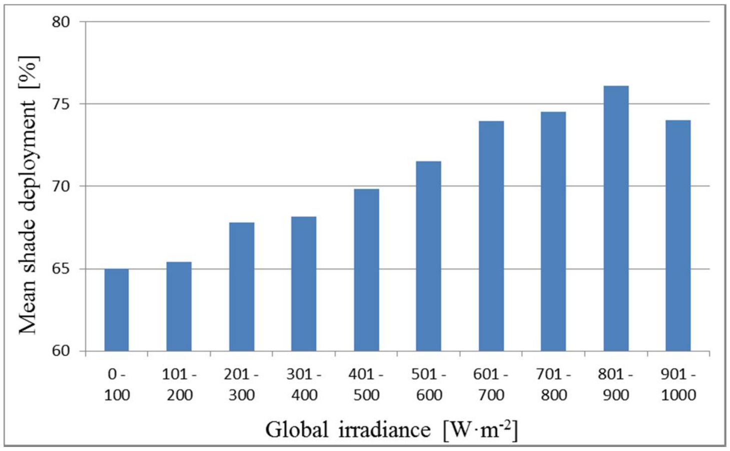


Figure 3-27 Mean shade deployment degree as function of global irradiance

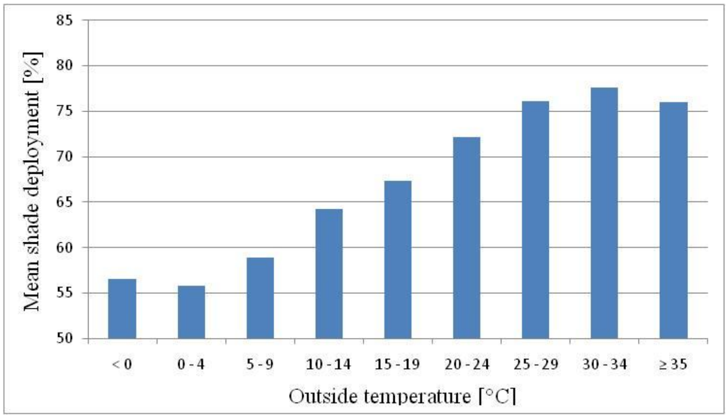


Figure 3-28 Mean shade deployment degree as function of outdoor temperature

3.4.2 Operation of Shades

The actions of opening and closing the shades were analyzed with the purpose to discover possible dependencies on the time of the day, orientation and illuminance level inside the office. Each façade orientation has its own dynamic over the course of a day, therefore the actions of opening/closing the shades in relation to the time of the day for SV offices were considered separately according to orientation. The relative frequencies of these actions can be seen in Figures 3-29 and 3-30.

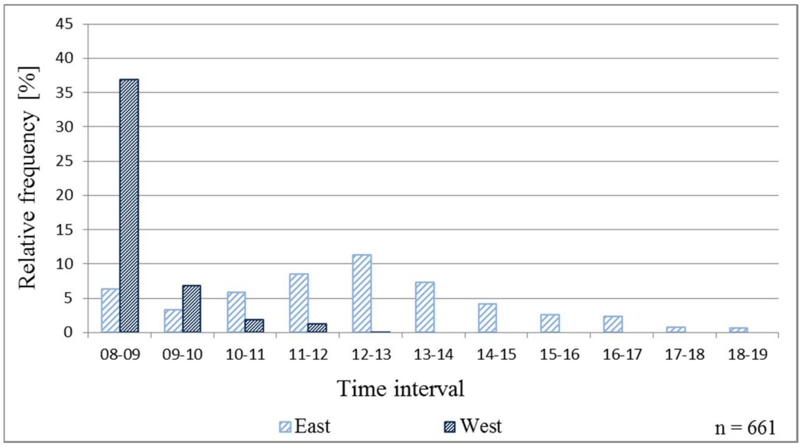


Figure 3-29 Relative frequency of opening the shades by orientation in relation to the time of the day

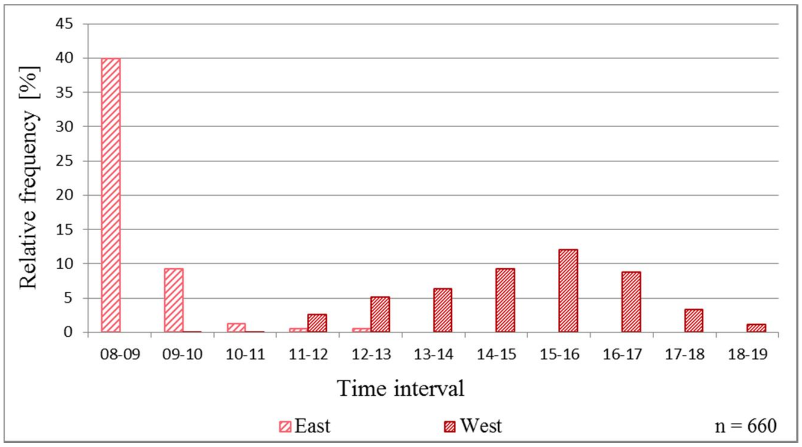


Figure 3-30 Relative frequency of closing the shades by orientation in relation to the time of the day

Figures 3-31 and 3-32 show the frequency of opening/closing the shades as a function of the illuminance in the office (for the 6 offices where the illuminance was measured). The illuminance level taken into consideration in this analyze was the hourly mean value related to the previous hour interval before the action occurred. For the purpose of this analyze, only the occupied time intervals when the lights were completely switched off were considered. The illuminance range has been divided into bins of 100 lx. For each bin category the total number of opening/closing the shades has been divided by the total number of occupied time intervals, expressed in percentage.

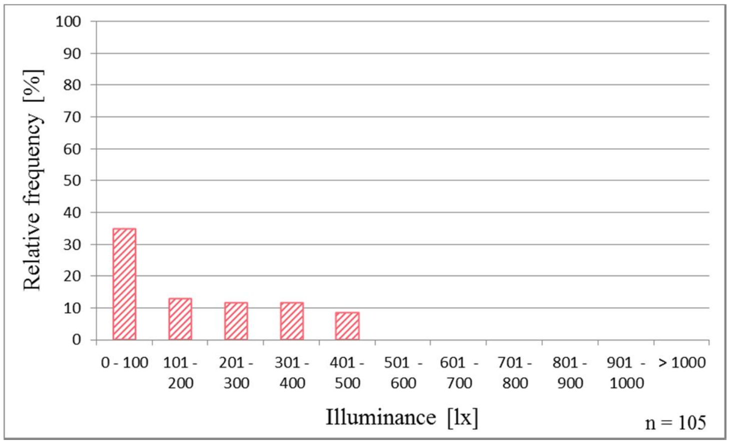


Figure 3-31 Relative frequency of opening the shades as a function of the illuminance in the office

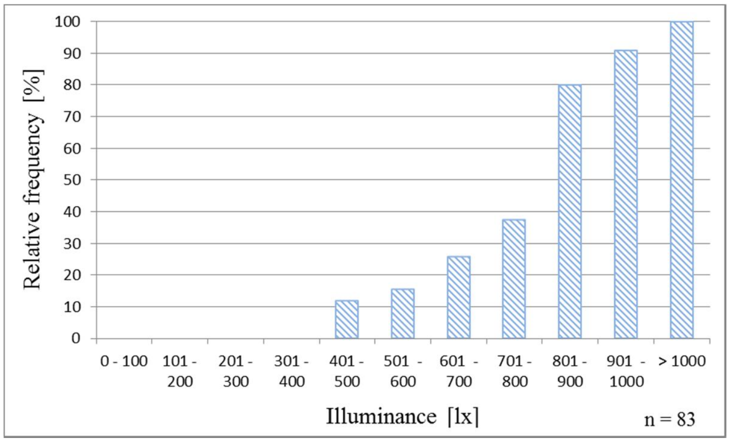


Figure 3-32 Relative frequency of closing the shades as a function of the illuminance in the office

The figures above are not limited only to actions resulting in fully opening/closing the shades. Therefore the frequency of the steps in which the changes were made is presented in Figure 3-33.

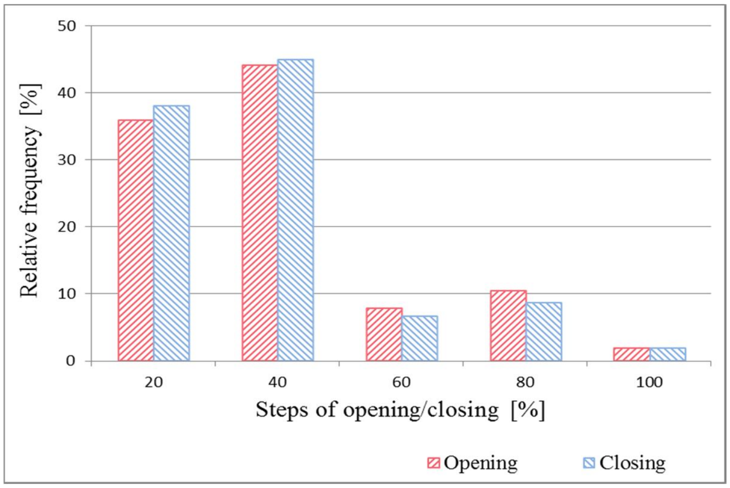


Figure 3-33 Relative frequency of the steps of opening/closing the shades

Due to the fact that the mean shade deployment in the observed offices is quite high, it was interesting to have a general view upon the daylight availability while the lights are completely switched off and the offices are occupied. Figure 3-34 presents the mean illuminance level in the SV offices in relation to the corresponding mean shade deployment and the time of the day.

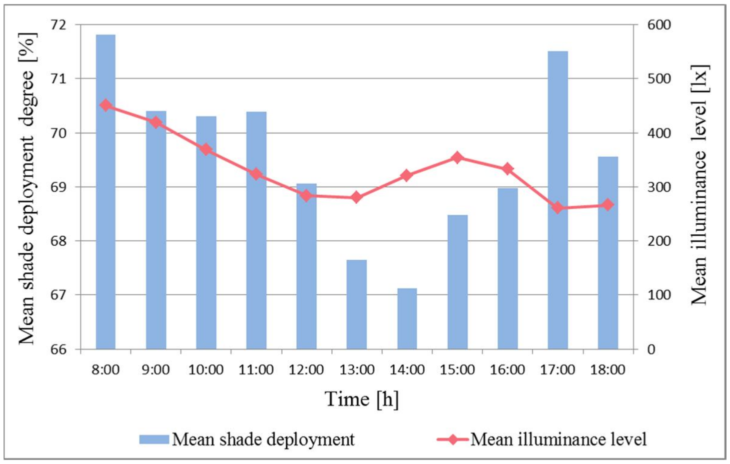


Figure 3-34 Mean illuminance level and mean shade deployment degree when the lights are completely switched off in relation to the time of the day

3.5 Interviews

The outcome of the interviews with the occupants of the monitored offices are summarized in this section. A total of 35 users have been interviewed based on questionnaires, which were divided in five categories of questions: personal information about the occupants; perception of the indoor climate and control systems; operation and accessibility of the control systems; awareness of the functionality of the building control systems and energy conscious behavior; personal preferences of organizing the current/ideal working space and health complains. Appendix C presents the content of the questionnaires together with the answers of the occupants, expressed in terms of percentage of people.

Personal information

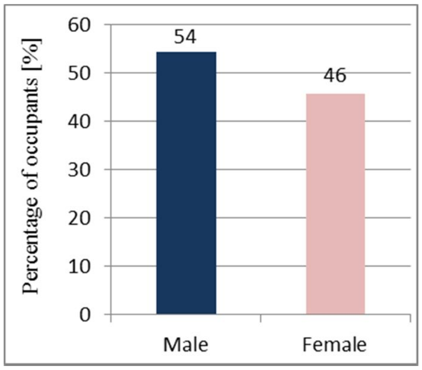


Figure 3-35 Gender of the interviewed persons (1)

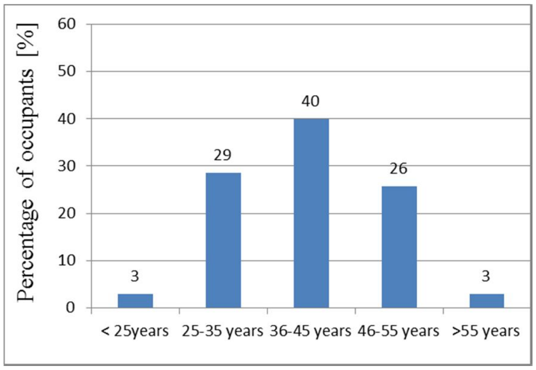


Figure 3-36 Age of the interviewed persons (2)

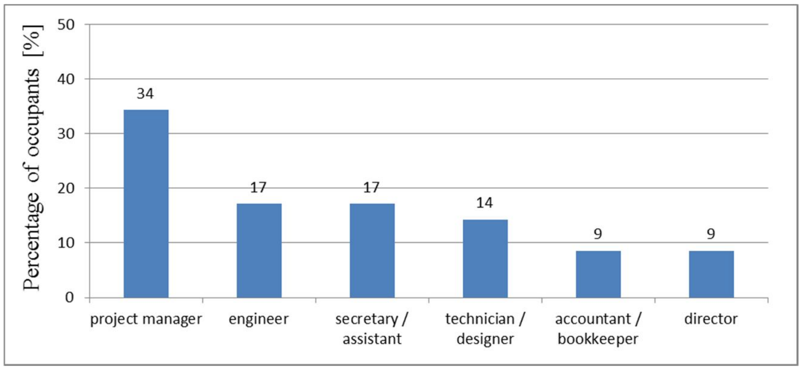


Figure 3-37 Nature of the work performed by interviewed persons (3)

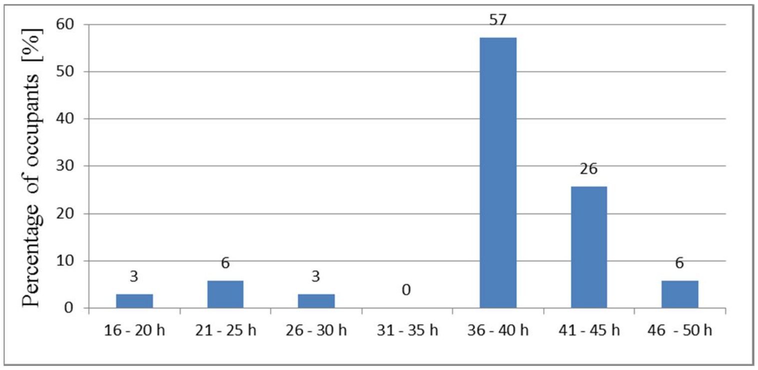


Figure 3-38 Average number of hours spend working per week (4)

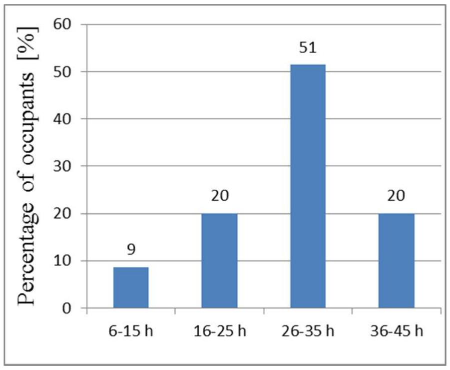


Figure 3-39 Average number of hours spend at the workstation per week (5)

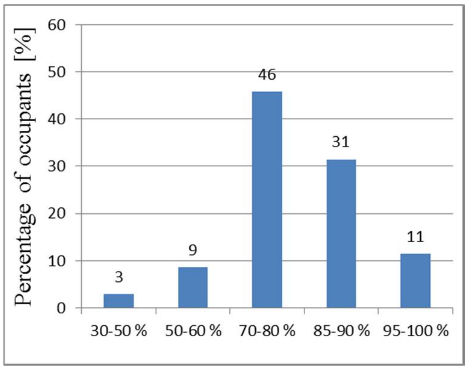


Figure 3-40 Percentage of work performed on the computer (6)

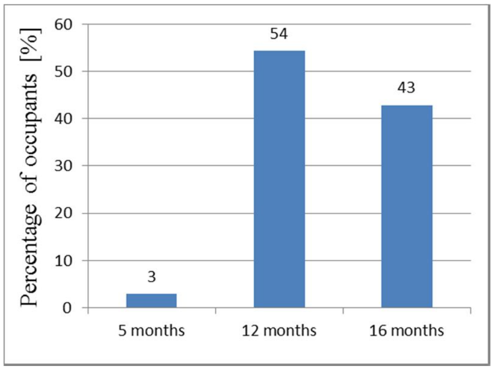


Figure 3-41 Working period in the current office (7)

Perception of the indoor climate and control systems

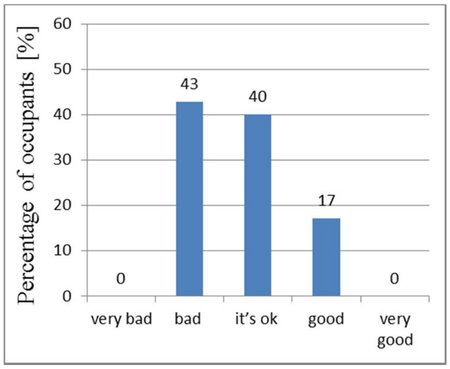


Figure 3-42 Assessment of the air quality in the office (8)

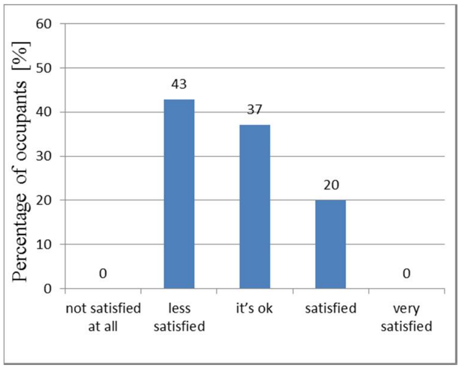


Figure 3-43 Satisfaction with the ventilation in the office (9)

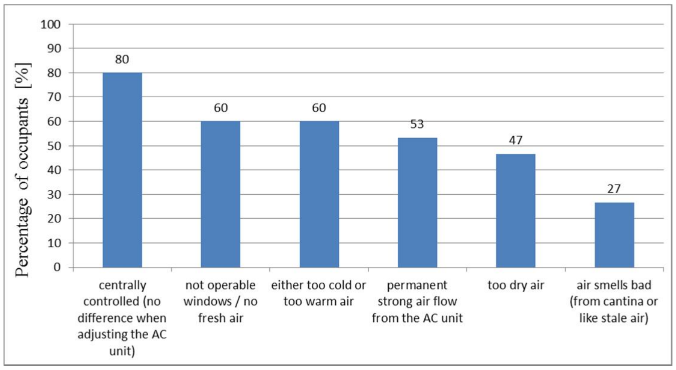


Figure 3-44 Reasons for dissatisfaction with air quality and ventilation (8&9)

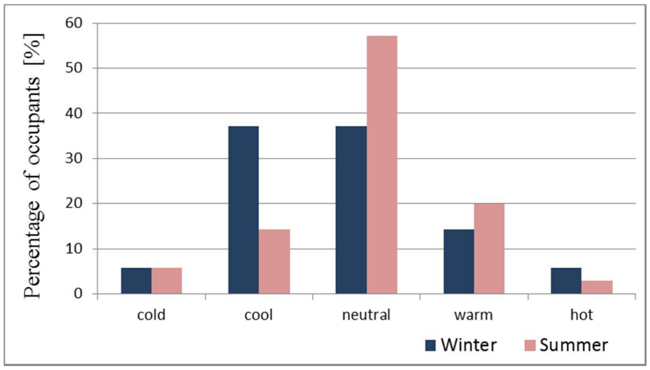


Figure 3-45 Assessment of the average temperature in the office in winter and summer (10&11)

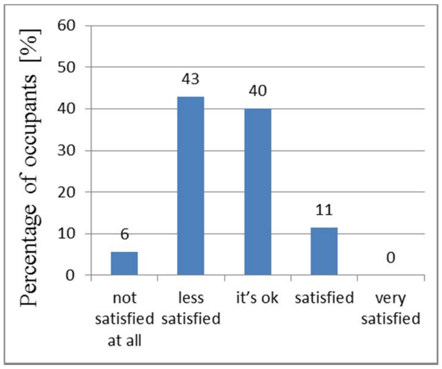


Figure 3-46 Satisfaction with the heating/cooling system in the office (12)

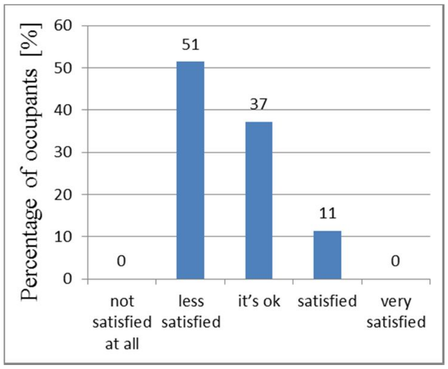


Figure 3-47 Satisfaction with the air-conditioning system in the office (13)

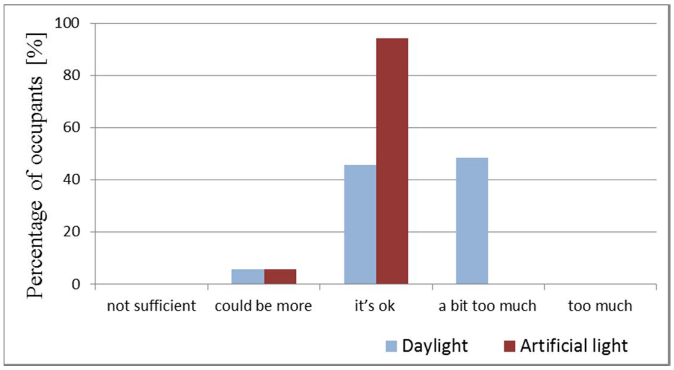


Figure 3-48 Sufficiency of daylight and artificial light in the office (14&17)

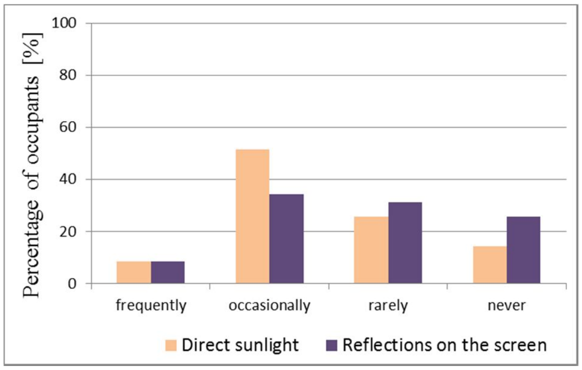


Figure 3-49 Occurrence of direct sunlight and reflections on the computer screen (15&16)

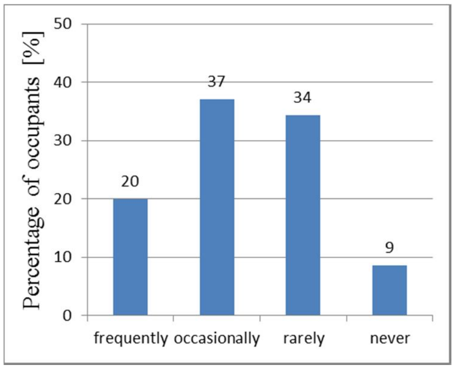


Figure 3-50 Noise disturbance (18)

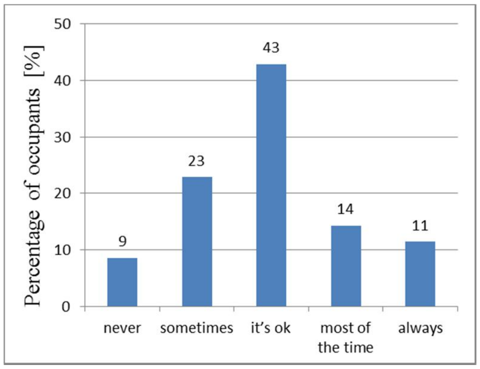


Figure 3-51 Possibility to work undisturbed in the office (19)

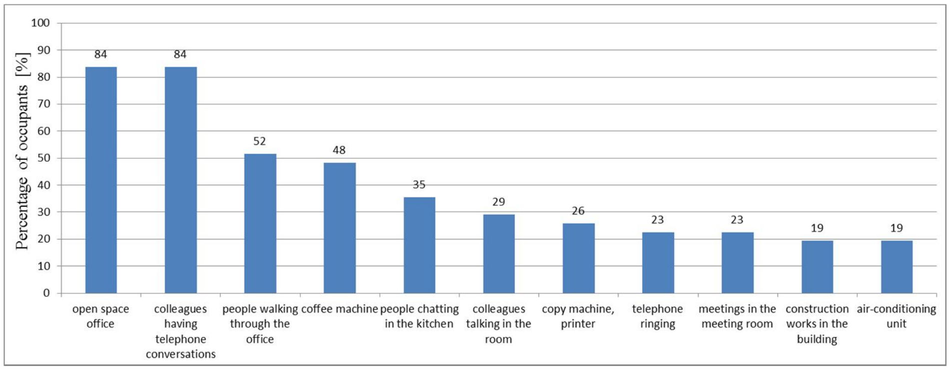


Figure 3-52 Sources of noise and disturbance

Operation and accessibility of the control systems

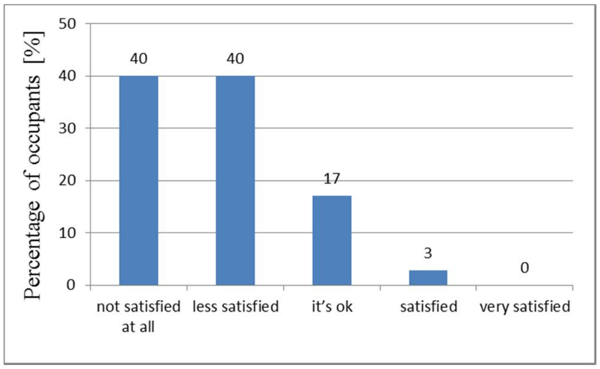


Figure 3-53 Satisfaction with the non-operable windows (20)

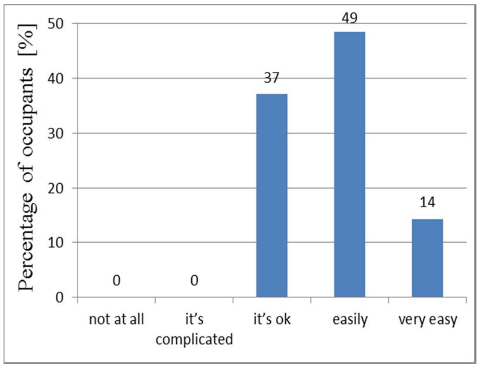


Figure 3-54 Accessibility of the internal shades (21)

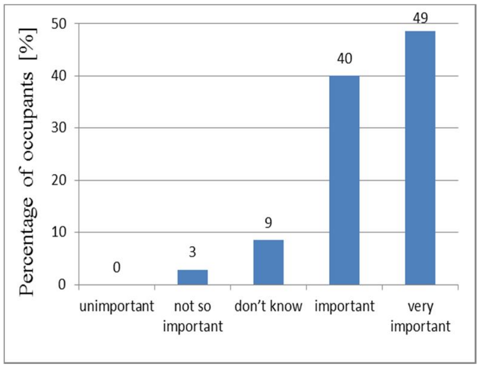


Figure 3-55 Importance of having the possibility to operate the shades (22)

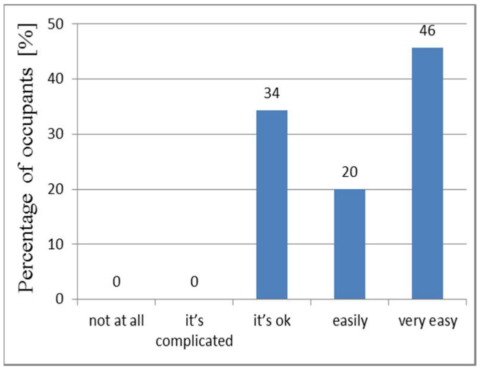


Figure 3-56 Accessibility of the light switch (24)

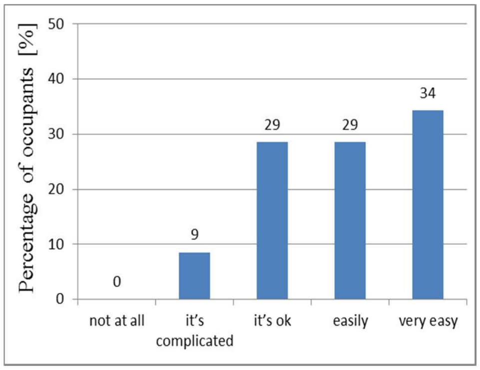


Figure 3-57 Accessibility of the thermostat (26)

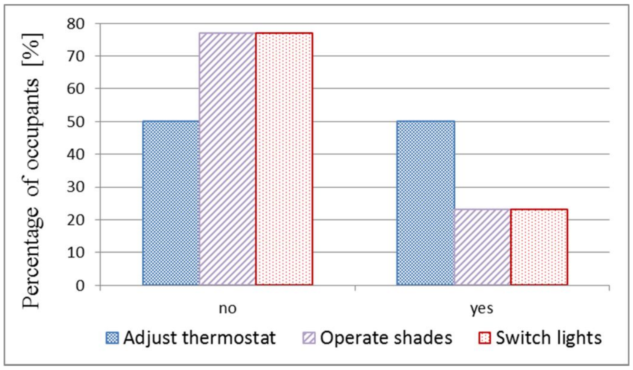


Figure 3-58 Possibility to decide independently when to operate the building's systems (23,25&27)

<u>Awareness of the functionality of the building control systems and energy conscious behavior</u>

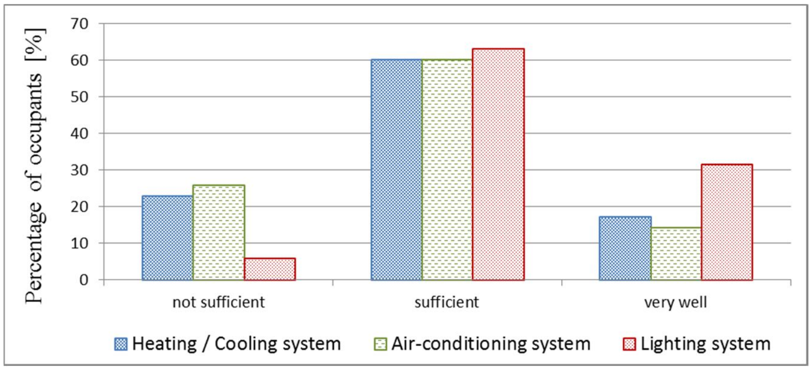


Figure 3-59 Level of information about the building's systems (28)

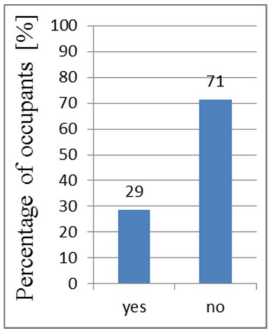


Figure 3-60 Occupants that had a training on building's systems (29)

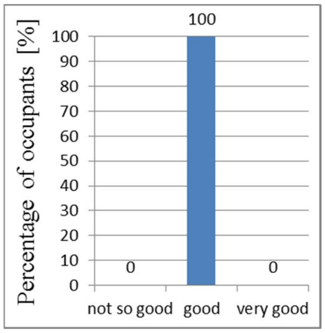


Figure 3-61 Evaluation of the training (29)

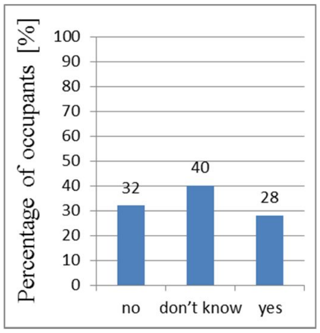


Figure 3-62 Occupants interested in receiving a training (29)

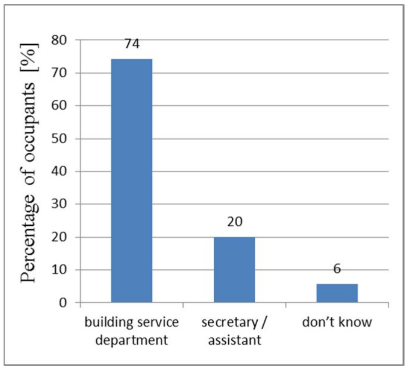


Figure 3-63 Reference in case of a problem with the building system (30)

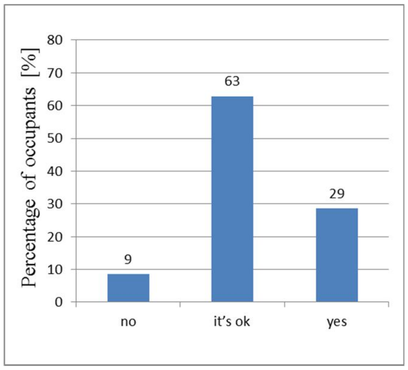


Figure 3-64 Satisfaction with the system services in the office (31)

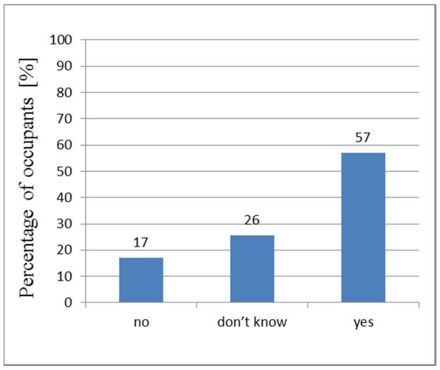


Figure 3-65 Consciousness about the influence on the building energy consumption (32)

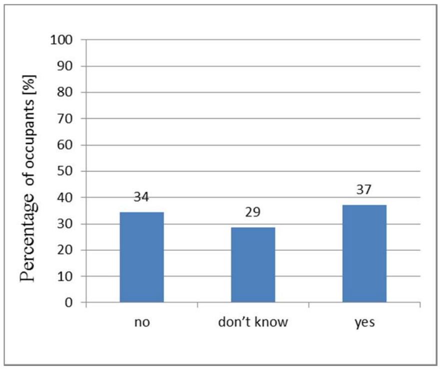


Figure 3-66 Consideration of energy conservation aspect when operating the building's systems (33)

Personal preferences of organizing the current/ideal working space; health complains

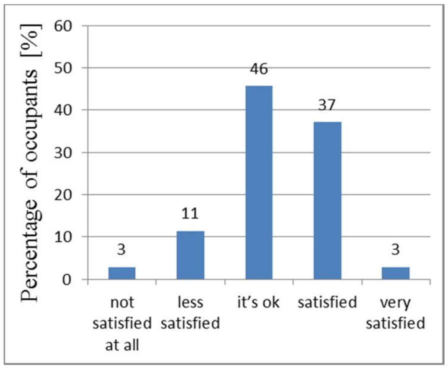


Figure 3-67 Satisfaction with the possibilities to personalize the office (34)

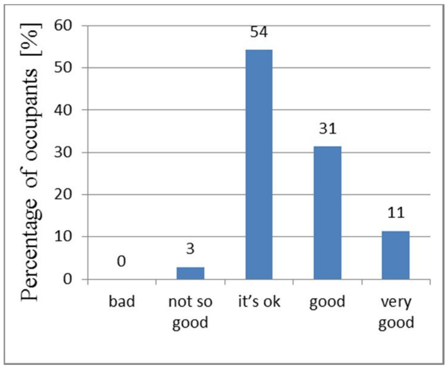


Figure 3-68 General office climate (35)

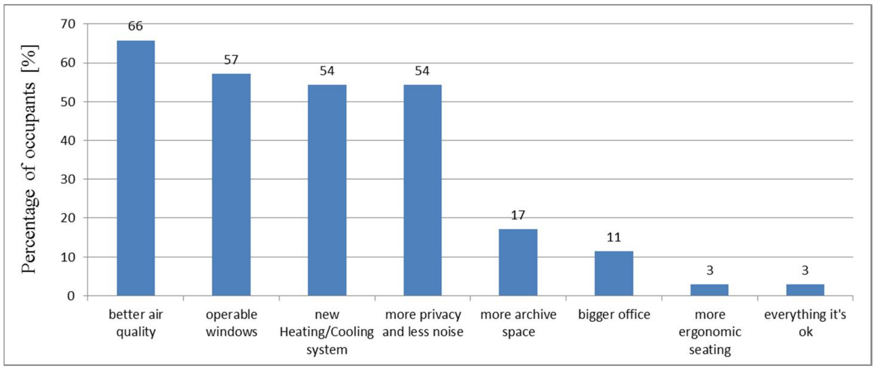


Figure 3-69 Urgent improvement measures in the office from the occupants' point of view (36)

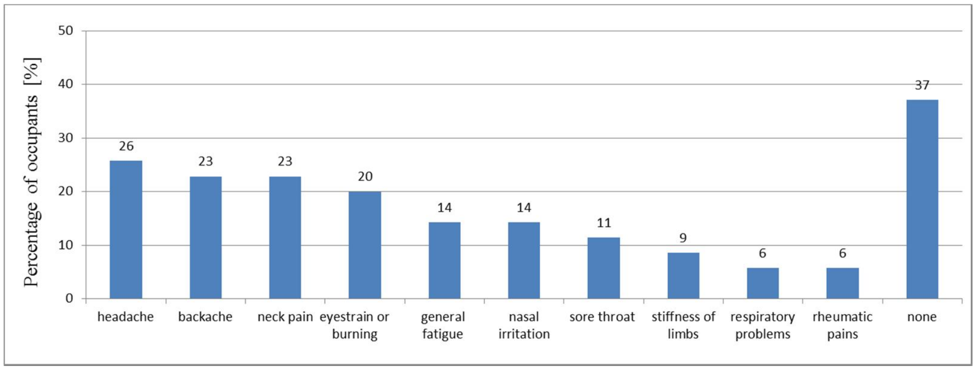


Figure 3-70 Frequency of health disorders (37)

3.7 Thermal Comfort

To derive and analyze the thermal conditions prevailing in the offices, psychrometric charts were plotted for the measured indoor temperature and relative humidity values and they are presented in this section. The limits of the comfort zone were established according to the recommendations of ÖNORM EN 15251: 2007, considering the differences between heating period and cooling period of the year.

The thermal comfort zone was applied to the six offices where the inside temperature and relative humidity were measured (offices 2, 10, 15, 18, 13 and 22) for 4 different season (spring: 24.05- 21.06.2013; summer 21,06-21.09.2013; autumn: 21.09-21.12.2013; winter: 21.12.2013-15.03.2014), only for the working hours (Monday to Friday, 08:00 to 19:00), without considering the business holidays.

The psychrometric charts plotted for the indoor climate conditions during spring are presented in Figures 3-71 until 3-76.

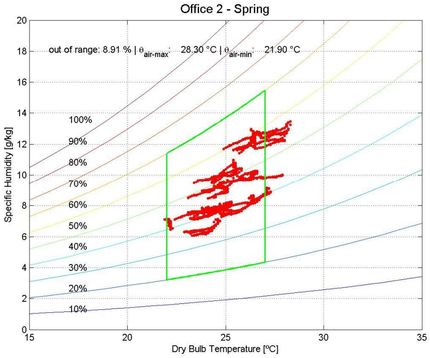


Figure 3-71 Indoor temperature and relative humidity for Office 2 in Spring

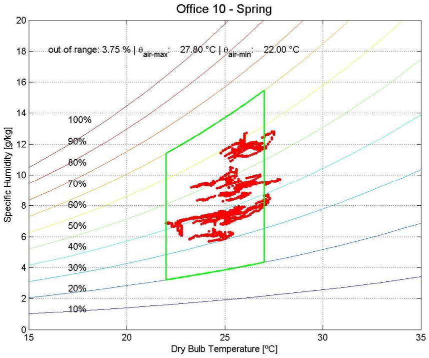


Figure 3-72 Indoor temperature and relative humidity for Office 10 in Spring

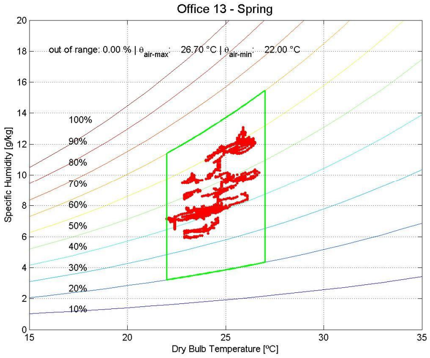


Figure 3-73 Indoor temperature and relative humidity for Office 13 in Spring

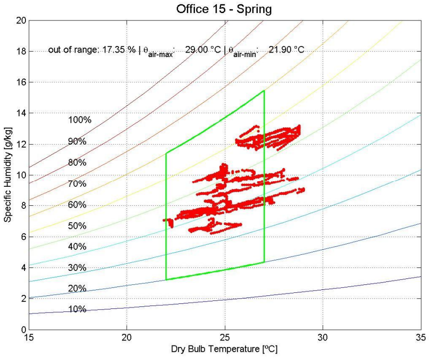


Figure 3-74 Indoor temperature and relative humidity for Office 15 in Spring

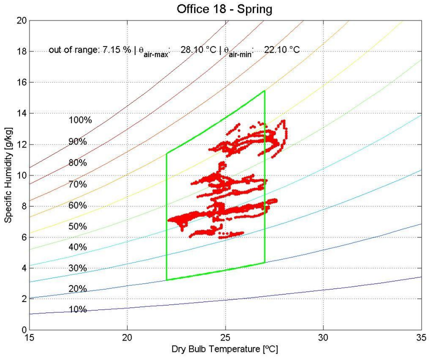


Figure 3-75 Indoor temperature and relative humidity for Office 18 in Spring

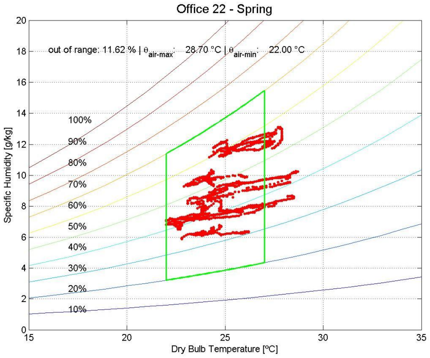
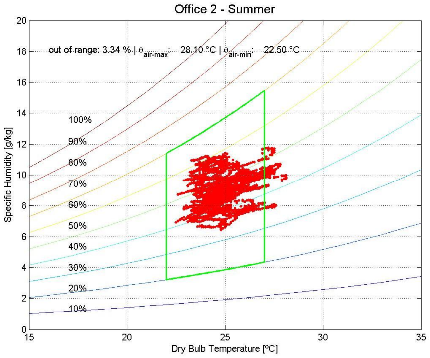


Figure 3-76 Indoor temperature and relative humidity for Office 22 in Spring

The psychrometric charts plotted for the indoor climate conditions during summer are presented in Figures 3-77 until 3-82.



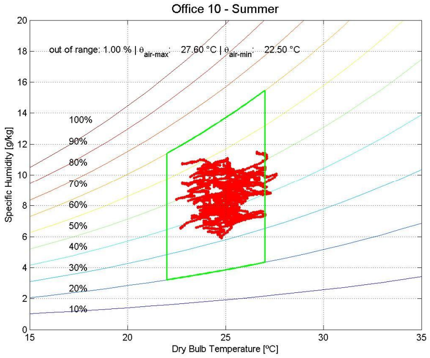
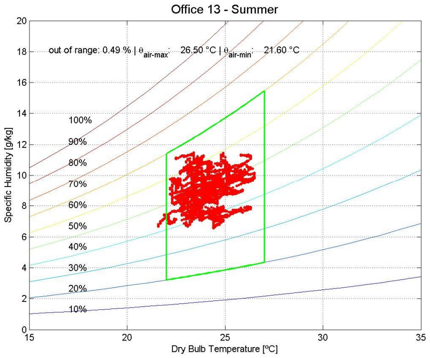


Figure 3-77 Indoor temperature and relative humidity for Office 2 in Summer

Figure 3-78 Indoor temperature and relative humidity for Office 10 in Summer



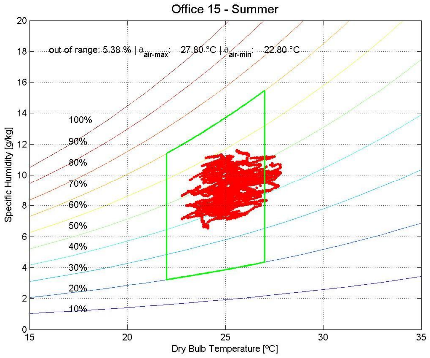
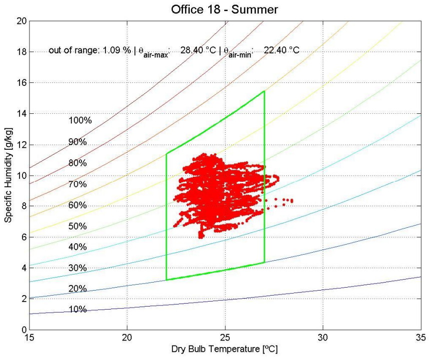


Figure 3-79 Indoor temperature and relative humidity for Office 13 in Summer

Figure 3-80 Indoor temperature and relative humidity for Office 15 in Summer



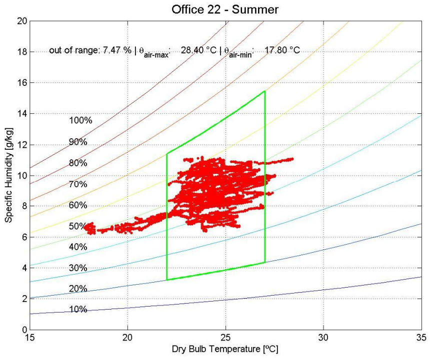


Figure 3-81 Indoor temperature and relative humidity for Office 18 in Summer

Figure 3-82 Indoor temperature and relative humidity for Office 22 in Summer

The psychrometric charts plotted for the indoor climate conditions during autumn are presented in Figures 3-83 until 3-88.

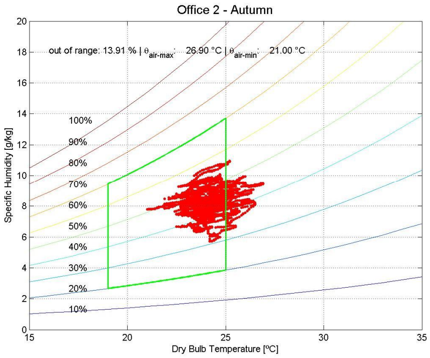


Figure 3-83 Indoor temperature and relative humidity for Office 2 in Autumn

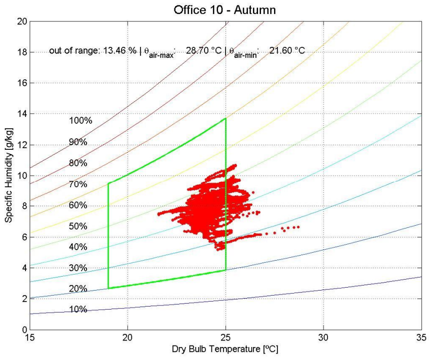


Figure 3-84 Indoor temperature and relative humidity for Office 10 in Autumn

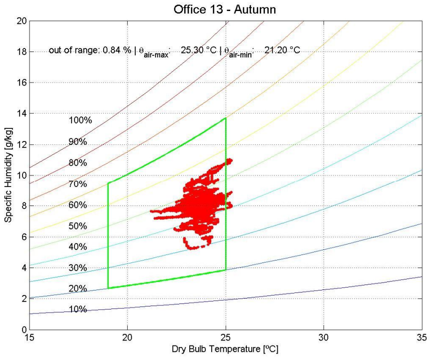


Figure 3-85 Indoor temperature and relative humidity for Office 13 in Autumn

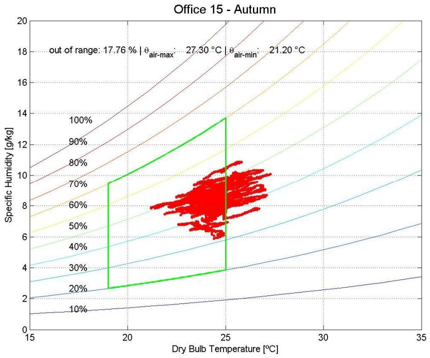


Figure 3-86 Indoor temperature and relative humidity for Office 15 in Autumn

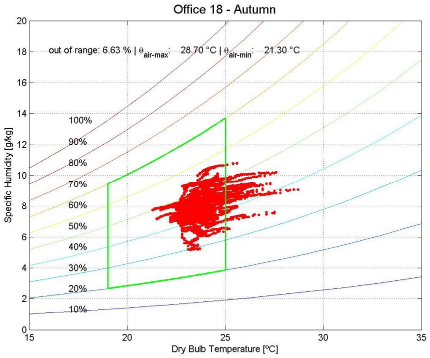


Figure 3-87 Indoor temperature and relative humidity for Office 18 in Autumn

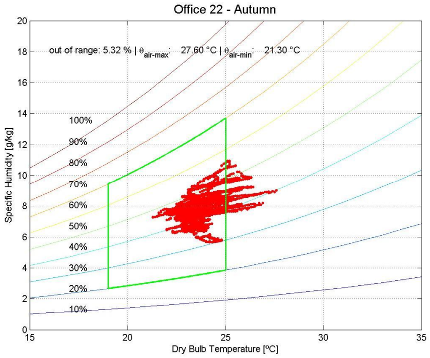


Figure 3-88 Indoor temperature and relative humidity for Office 22 in Autumn

The psychrometric charts plotted for the indoor climate conditions during winter are presented in Figures 3-89 until 3-94.

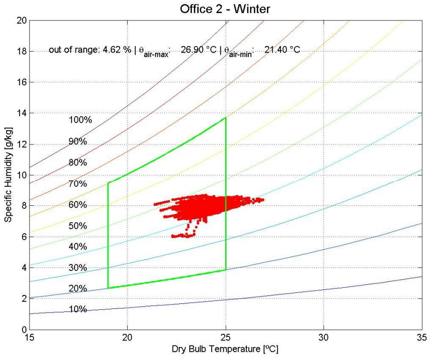


Figure 3-89 Indoor temperature and relative humidity for Office 2 in Winter

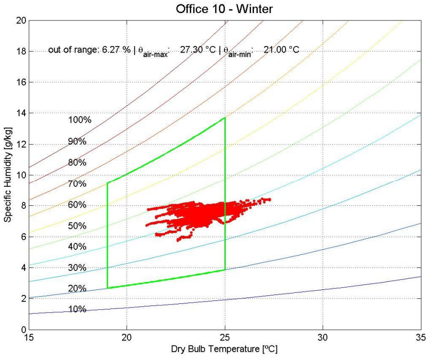


Figure 3-90 Indoor temperature and relative humidity for Office 10 in Winter

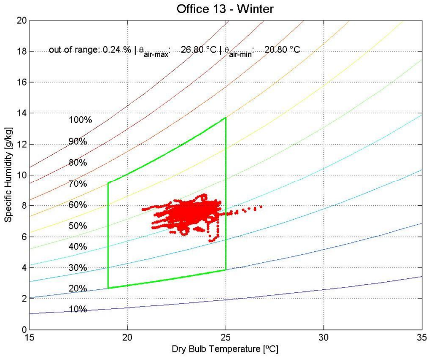


Figure 3-91 Indoor temperature and relative humidity for Office 13 in Winter

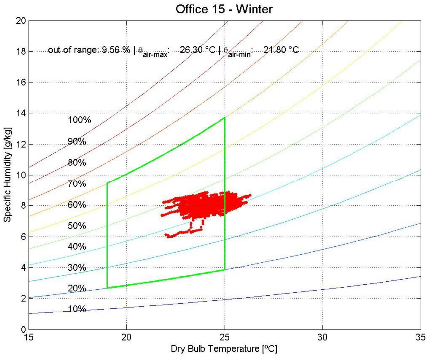


Figure 3-92 Indoor temperature and relative humidity for Office 15 in Winter

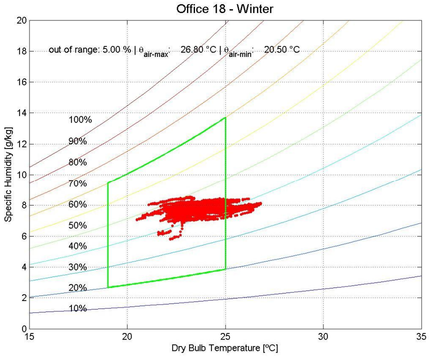


Figure 3-93 Indoor temperature and relative humidity for Office 18 in Winter

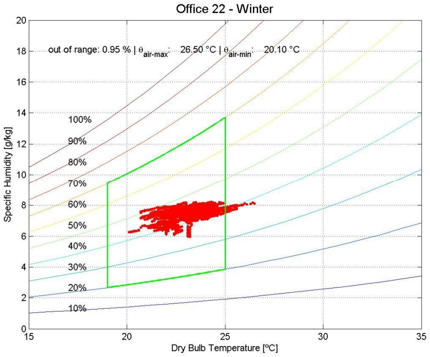


Figure 3-94 Indoor temperature and relative humidity for Office 22 in Winter

4 Discussion

4.1 Occupancy

The mean occupancy level in the monitored offices of SV building observed over the period between June and November 2013 is 31 % (Figure 3-1) and the related mean occupancy heating load is 6 $W\cdot m^{-2}$ (Figure 3-2). This reveals the fact that the offices were not fully used during the working hours, which could be explained by the nature of work performed by the occupants: 34% of the users are project managers, 17% engineers, 9% directors (Figure 3-37). These people are often traveling for business meetings and delegations to sites within Austria and other countries. Another reason for the low occupancy level could be that the working time frame chosen for this study is too large (08:00 - 19:00). Most of the occupants have an 8 hour daily schedule, while some of them have even shorter daily schedules (Figure 3-38). However, the observed occupancy result is lower than the one calculated from the users' assertion regarding the average number of hours spent working at the workstation, which is 51% (Figure 3-39).

4.2 Heating/Cooling Units

The status of the heating/cooling units was very seldom changed during the observation period between June and November 2013. Although the system was initially designed to be readjusted manually in order to achieve the desired temperature individually in separate offices, beside the basic functions which are centrally controlled, in reality many users complain that the change of units' status doesn't really make any difference in temperature and it cannot be adjusted according to personal preferences. This could explain the low frequency in adjusting the heating/cooling units. The status of 15 units was actually never changed in the entire observation period, while only 2 were adjusted more than 10 times (Figure 3-5). The users never changed the status of the thermostat in 7 offices, 5 closed and 2 open space offices (Figure 3-6).

The monthly frequency of the attempts to increase/decrease the indoor temperature was calculated and the only visible aspect resulting from it is that the most attempts to increase/decrease the temperature occurred during October, which can be explained by the fact that in this month the change from cooling to heating mode was made (Figures 3-7 and 3-8).

Regarding the relation of the attempts to adjust the temperature and the indoor temperature, the results show that the attempts to increase the temperature occurred for indoor temperature between 20°C and 24°C (Figure 3-9) and the attempts to decrease the temperature occurred for indoor temperature between 23°C and 28°C (Figure 3-10), without revealing any clear pattern. Likewise, no pattern could be determined according to outdoor temperature (Figures 3-11 and 3-12).

Based on the results of the interviews, an average of 48% of the users are unsatisfied with the HVAC building system (Figures 3-43, 3-46 and 3-47), due to the fact that it is centrally controlled and they cannot adjust the indoor climate conditions according to their own preferences, the windows are not operable, permanent strong air flow comes out of the units, the air is too dry and it smells bad from the cantina or like stale air (Figure 3-44). Some of the users are disturbed by the noise made of these units (Figure 3-52) and the air coming out, so they covered them with paper, books or plastic plates. 54% of the occupants consider as one of the urgent improvement measures in their office the improvement of the heating/cooling and air-conditioning system (Figure 3-69).

This system was built together with the building in 1963 and it was very well thought and designed at that time. Nowadays, it seems that the building's users are not so satisfied with its operation, although it is constantly checked and updated.

4.3 Artificial Lighting

4.3.1 Status of Lighting

The mean lighting load over the course of a reference day for the observation period between June and November 2013 is 32% (Figure 3-13), corresponding to 3 $W \cdot m^{-2}$ (Figure 3-14). The mean lighting load profile is not similar to the mean occupancy profile. The pattern of the lighting operation in the monitored offices of SV building reveals the fact that the users switched the lights on upon arrival, mainly in the morning, and they switched the lights off at the end of the working day. This behavior could explain the difference in lighting load for the two orientations: 27% for east side and 39% for west side (Figure 3-16). In the morning, the lighting load is much higher for the offices facing the west side than the offices facing the east side, due to lack of sunlight that triggers more actions of switching on the lights, while in the evening the lighting load tends to be similar for both sides and it is significantly reduced starting with 17:00, which is the normal end of the working day for most of the occupants.

The seasonal dependency of the lighting load is presented in Figure 3-15. There are differences between the summer months and the autumn months: the lighting load during June-August (23%) is lower than the one during September-November (43%). The artificial light demand in autumn months is approximately double than the one in summer months.

The lighting status in percentage of time for the observation period shows that the lights were on during 56% of the occupied period and during 15% of the unoccupied period (Figure 3-17). Out of the total lighting load 79% was during occupied period and 21% during unoccupied period (Figure 3-18).

4.3.2 Operation of Lighting

The probability of switching on the lights upon arrival is 73% for values below 100 lx and it decreases as the illuminance values increase until the value of 600 lx is reached, after which the users don’t switch on the lights anymore (Figure 3-19). This reveals an obvious dependency of switching on the lights actions on the internal illuminance level.

The pattern emerging from the frequency of switching on the lights as a function of the time of the day reveals the fact that occupants switch on the lights mostly in the morning with a frequency of 74% (Figure 3-20). Concerning the frequency of switching off the lights as a function of the time of the day, the actions of switching off occur mainly in the evening, when users leave their offices at the end of the working day (Figure 3-21).

The probability of switching the lights off upon leaving the office as a function of the duration of absence from the offices is very low for an absence under 180 minutes (~6%) and 71% for leaving the office at the end of the working day (Figure 3-22).

4.4 Internal Shades

4.4.1 Position of Shades

The position of the shades is definitely related to the two orientations (east and west) of the observed offices (Figure 3-23). In the morning hours, the east façade presents a higher shade deployment level, while the west façade present a lower shade deployment level. As the sun changes position, the deployment level of the shades for each orientation is accordingly adjusted. Also seasonal dependencies can be observed in Figures 3-24 and 3-25. The effective shade deployment is higher in the summer months then in the autumn months for both orientations. Moreover, the mean monthly shade deployment levels over the course of the observation period show a discernible relation with the corresponding mean global irradiance (Figure 3-26).

It was explored also the relation between the effective shade deployment and the external environment factors such as global irradiance and outdoor temperature. It can be observed that the shade deployment level has a direct dependency on these factors, as it tends to increase together with the increase of the global irradiance level (Figure 3-27) and the increase of the outdoor temperature value (Figure 3-28).

The mean shade deployment for the monitored offices of SV building is 68%, which is rather high, but could be explained by the users' answers regarding their perception of daylight (Figure 3-48) and frequency of annoyance with direct sunlight and too bright surfaces on the computer screen (Figure 3-49): 49% of the users consider they have a bit too much daylight in their office, 86% of the users are annoyed by direct sunlight and 74% of the users are annoyed with too bright surfaces on their computer screen. Therefore, 89% of the users consider important to have the possibility to adjust the shades (Figure 3-55).

4.4.2 Operation of Shades

The patterns revealed by the analysis of the actions of opening and closing the shades in relation to the time of the day are completely distinct for the two orientations of the observed offices (Figures 3-29 and 3-30). On the east side, the shades are closed by the users in the morning due to direct sunlight incident on the façade and the opening frequency is low, but it starts to rise around noon time reaching the peak between 12:00 and 13:00, after which is gradually getting lower. For the west side, the opening of the shades is done mainly in the morning due to lack of sunlight and reduced daylight availability and then it stops completely at around noon time when the sun moves on the west side of the building and the occupants start to gradually close their shades until the sunset.

The analysis of the actions of opening and closing the shades as a function of the illuminance level in the office shows that opening actions occur for illuminance levels lower than 500 lx, whit the highest frequency for values under 100 lx (Figure 3-31), while closing actions occur for illuminace levels higher than 400 lx, with a frequency that increases as the illuminance level increases, until reaching 100% for values higher than 1000 lx (Figure 3-32).

The frequency of the steps of opening/closing the shades (Figure 3-33) shows that the users generally open and close the shades with 20% or 40%. The rate of opening with 60% and 80% is higher than the one for closing, thus the users tend to change the shading position more significantly when opening the shades then when closing, which could be due to the fact that they try to keep the shades as open as possible when they are not annoyed by direct sunlight or too bright surfaces. The actions of fully opening/closing the shades occur very seldom and they represent only 2% of the total amount of actions.

Although the mean shade deployment in the observed offices is quite high, the mean illuminance level is between approximately 260 lx and 450 lx, while the offices are occupied and the lights are completely switched off (Figure 3-34).

4.5 Interviews

The content of the interviews and the results expressed in percentage of people can be found in Appendix C. A total of 35 users have been interviewed. Regarding their gender, they are basically half male and half female (Figure 3-35). A uniform distribution can be seen also regarding their age (Figure 3-36). The job positions of the users are the following: directors, project managers, engineers, accountants, technicians/designers and secretaries/assistants (Figure 3-37). Most of the persons are working 36-40 hours per week (Figure 3-38), from which most of them spend 26-37 hours at the workstation (Figure 3-39). The percentage of work performed on the computer is 70-80% for most of the occupants (Figure 3-40). The 5th floor of the building with the monitored offices has been renovated in 2012, therefore approximately half of the users are working in the current office since October 2012, while the other half since February 2013 (Figure 3-41).

Regarding the perception of the indoor climate and control systems, 43% of the users perceive the air quality in their offices as bad (Figure 3-42) and 48% are unsatisfied with the HVAC system of the building (Figures 3-43, 3-46 and 3-47), due to the fact that they cannot adjust the indoor conditions according to their personal preferences, the windows are not operable, the indoor temperature is either too cold or too warm, the air-conditioning units release a permanent strong air flow, the air is too dry and it smells bad from the cantina or like stale air (Figure 3-44).

The users assessments regarding the average temperature in winter and summer reveals the fact that during winter many users perceive the indoor temperature as cool, while during summer most of them perceive it as neutral (Figure 3-45). Many of them are complaining that the difference between morning and afternoon is very big and the indoor temperature is either too cool or too warm.

Many users consider that the daylight in their office is a bit too much (Figure 3-48) and they are annoyed by direct sunlight and too bright surfaces on their computer screen (Figure 3-49).

Most of the occupants are disturbed by noises (Figure 3-50), especially the ones working in open space offices, due to telephone conversations of their colleagues, people walking through the office, people chatting in the kitchen, coffee machine, copy machine and printer, construction works done in the building and also the air-conditioning unit (Figure 3-52). However, most of them consider they have enough privacy in the office to work undisturbed (Figure 3-51).

When the occupants were asked if they are satisfied with the fact that they cannot open the windows in their offices, 80% of them were unsatisfied with this and they would prefer to have fresh air in their offices (Figure 3-53).

Regarding the accessibility of the building's system, most of the users find it easy to operate the internal shades, the lights and the thermostat (Figures 3-54, 3-56 and 3-57) and 89% consider important to have the possibility to operate the shades (Figure 3-55).

The answers to the questions regarding the awareness of the functionality of the building control systems and energy conscious behavior reveal the fact that the users are sufficiently informed about the installed building systems (Figure 3-59). Some of them had already participated to a training regarding this (Figure 3-60) and all of them evaluated it as a good one (Figure 3-61). On the other hand, the ones that didn't receive a training regarding the building's system didn't show a too high interest in having one (Figure 3-62). In case of a problem with the building's systems, most of the persons interviewed refer directly to the building service department (Figure 3-63) and they are mainly satisfied with their services and support (Figure 3-64). When the occupants were asked if they think they can influence the building’s energy consumption in the way they operate the building’s systems, 17% answered with no, 26% didn’t know and 57% answered with yes (Figure 3-65). Likewise, when they were asked if they think about energy conservation when operating the building systems, 34% answered with no, 29% didn’t know and 37% answered with yes (Figure 3-66).

Many users are satisfied with the possibility to personalize their working place (Figure 3-67) and most of them had a positive view on the general office climate (Figure 3-68). The most urgent improvement measure in the office was for 66% of the users a better air quality, followed by having operable windows (57%), improvement of the heating/cooling system (54%) and more privacy and less noise (54%) (Figure 3-69).

4.6 Thermal Comfort

Psychrometric charts were plotted for 4 different seasons in order to analyze the thermal conditions in the offices. Most of the points are within the limits of the comfort zone. For spring time (24.05-21.06.2013) the minimum indoor temperature is 21,9°C and the maximum indoor temperature is 29°C, with 8,13% of the points being out of range due to higher temperature values than 27°C (Figures 3-71 to 3-76). For summer time (21.06-21.09.2013) the minimum indoor temperature is 17,8°C and the maximum indoor temperature is 28,4°C, with 3,13% of the points being out of range due to higher temperature values than 27°C and in the same time due to lower temperatures than 22°C (even lower temperatures than 20°C have been registered in office 22) (Figures 3-77 to 3-82). For autumn time (21.09-21.12.2013) the minimum indoor temperature is 21,2°C and the maximum indoor temperature is 28,7°C, with 9,7% of the points being out of range due to higher temperature values than 25°C (Figures 3-83 to 3-88). For winter time (21.12.2013-15.03.2014) the minimum indoor temperature is 20,1°C and the maximum indoor temperature is 27,3°C, with 4,44% of the points being out of range due to higher temperature values than 25°C (Figures 3-89 to 3-94).

The users' evaluation of the average indoor temperature in winter is cold for 6%, cool for 37%, neutral for 37%, warm for 14% and hot for 6%, while in summer is cold for 6%, cool for 14%, neutral for 57%, warm for 20% and hot for 3% (Figure 3-45).

From the interviewed users, 43% perceive the air quality in their offices as bad (Figure 3-42), due to not operable windows (60%), big differences in temperature (60%), too dry air (47%) and bad smelling air (27%) (Figure 3-44). 80% of them were unsatisfied with the fact that they cannot open the windows in their offices in order to get fresh air inside (Figure 3-53). The most urgent improvement measure in the office was for 66% of the users a better air quality, while for 57% was having operable windows. Regarding the dryness of the air, this complaint is unfounded because the relative humidity measured in the offices is within the limits of the comfort zone (20-70%).

5 Conclusion

A study on the users behavior and interaction with building systems for heating/cooling, lighting and shading in 22 offices of an office building located in the south of Vienna, Austria, has been presented. The nature, typology and frequency of user control actions have been explored and patterns of control-orientated behavior have been extracted.

The collected data through measurements of the indoor parameters by sensors over a period of ten months, hourly observations of the occupancy and the building's systems status over a period of six months and received data for outdoor parameters have been processed and analyzed in order to explore possible relations between the frequency of control actions and the indoor and outdoor parameters.

The results reveal distinctive patterns. The mean lighting load profile over the course of a reference day is not similar to the mean occupancy profile over the course of a reference day. The users don't portray an energy conscious behavior, due to the fact that they mainly switch the lights on upon arrival and switched them off at the end of the working day. The lighting load in the west part of the building is higher than the one in the east part, due to lack of sunlight in the morning. Likewise, the lighting load during autumn months is higher than the one during summer months. The shade deployment level presents a clear dependency on the façade orientation, the time of the day, the daylight availability and as well on the weather conditions. During summer months, the shade deployment degree is higher than during autumn months.

The indoor climate conditions in the monitored offices are mostly within the limits of the thermal comfort zone, but the users show a big dissatisfaction with the air quality, the not operable windows and the HVAC system.

The results of this case study are expected to increase the knowledge about the users’ behavior in office buildings and to contribute to the development of users’ bahavioural models, which can be integrated in building performance simulation programs, can provide quantitative basis for finding better and more sustainable designs, for the evaluation of the impact of occupancy behavior on building’s energy consumption, for improving the building management performance and automation systems and for initiating educational campaigns for users regarding the implications of their actions.

Future research in the field of users’ behavior should focus on different types of buildings with different geographical and cultural background, which will contribute to a better understanding of control-orientated behavior and improve the knowledge about the human factor in buildings.

The results of the multitude of studies conducted on human bahaviour could be unified and compared based on the research methodology, in terms of building’s type, monitoring period, monitoring equipment, logging intervals, building’s systems and controls, methods of analysis.

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9 Appendix

Appendix A Layout of the Monitored Offices

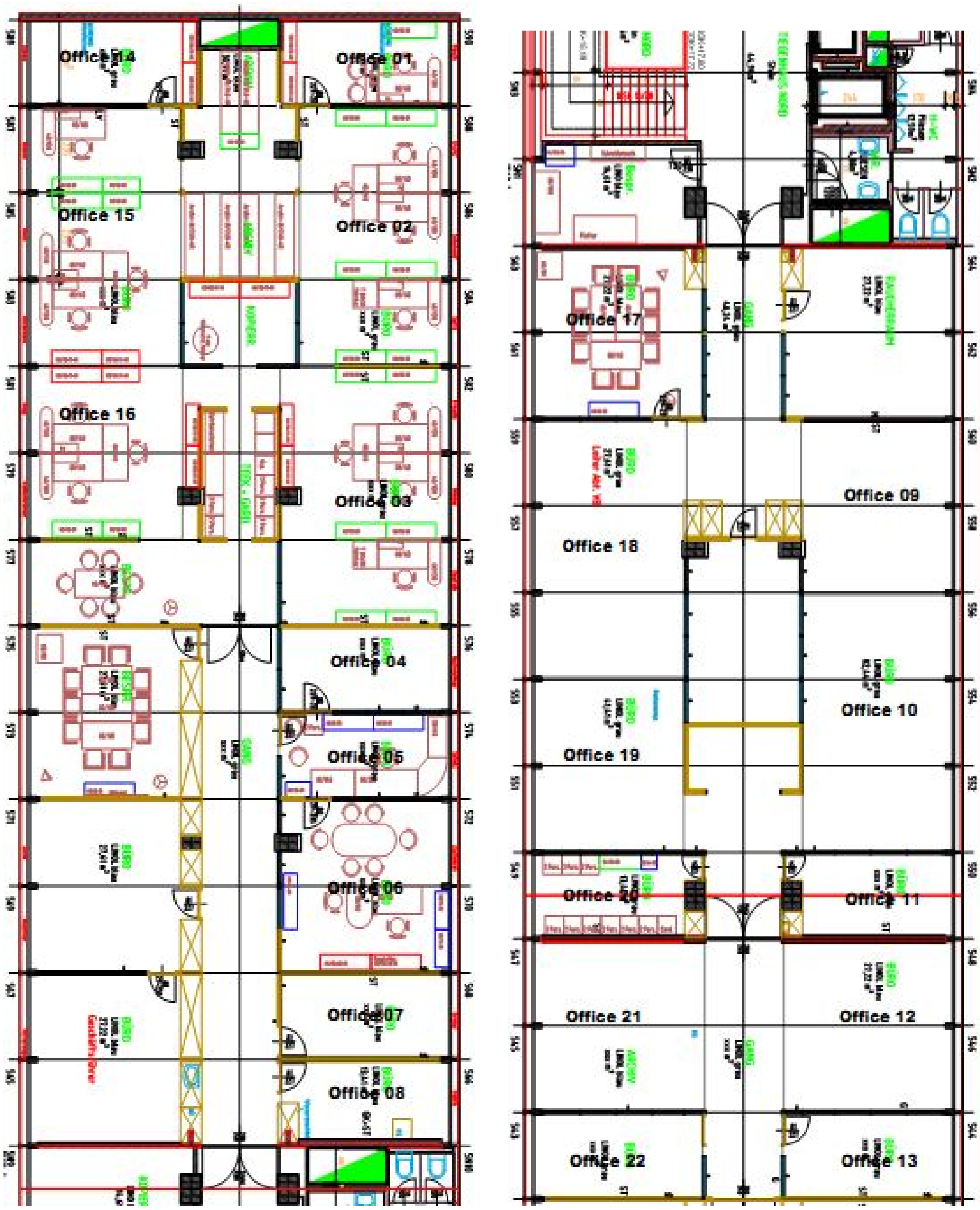


Figure A-1 Layout of the monitored offices

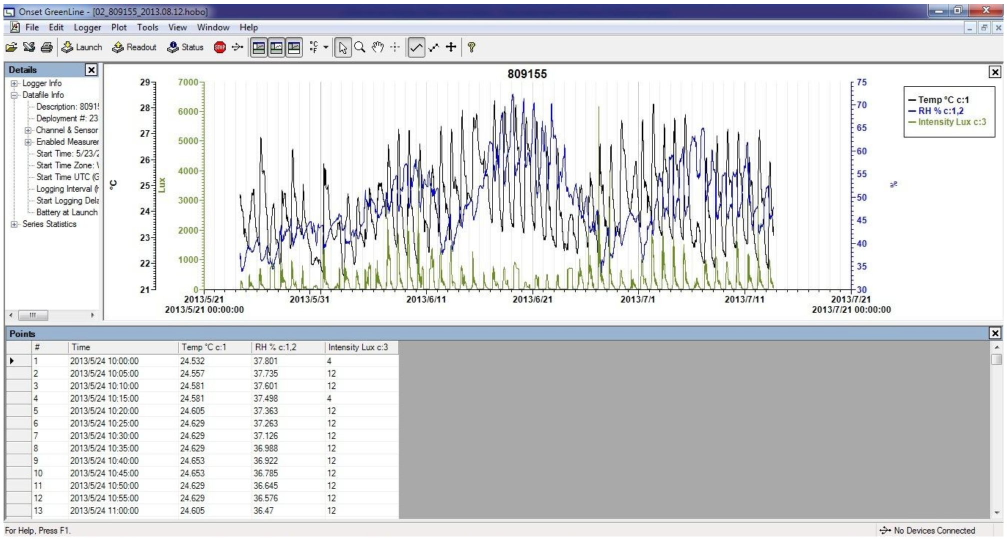
Appendix B Data Loggers and Software Application

The view of HOBO U12 data logger is presented in Figure B-1 and its technical specifications are described in Table B-1. The software application designed to support this device is GreenLine, by Onset Computer Corporation. The graphical interface of the program is shown in figure B-2.

Figure B-1 View of HOBO U12

Table B-1 Technical specifications of HOBO U12 loggers

Parameter	Range	Accuracy
Temperature	T: -20°C to 70°C	T: ±0.35 K from 0°C to 50°C
Relative humidity	RH: 5 to 95%	RH: ±2.5% from 10% to 90%
Illuminance	2 to 3000 fc (lumen·f^{t-2}) (1 fc ~ 10.764 lx)	±20 lx or ±20% of reading maximum value varies from 1500 to 4500 footcandles
	Operating Range: -20°C to 70°C	Time Accuracy: ±1 minute per month at 25°C



#	Time	Temp °C c:1	RH % c:1,2	Intensity Lux c:3
1	2013/5/24 10:00:00	24.532	37.801	4
2	2013/5/24 10:05:00	24.557	37.735	12
3	2013/5/24 10:10:00	24.581	37.601	12
4	2013/5/24 10:15:00	24.581	37.498	4
5	2013/5/24 10:20:00	24.605	37.363	12
6	2013/5/24 10:25:00	24.629	37.263	12
7	2013/5/24 10:30:00	24.629	37.126	12
8	2013/5/24 10:35:00	24.629	36.988	12
9	2013/5/24 10:40:00	24.653	36.922	12
10	2013/5/24 10:45:00	24.653	36.785	12
11	2013/5/24 10:50:00	24.629	36.645	12
12	2013/5/24 10:55:00	24.629	36.576	12
13	2013/5/24 11:00:00	24.605	36.47	12

Figure B-2 Graphical interface of GreenLine

Appendix C Summary of the Interviews Results

Table C-1 Summary of the interviews results

	Question	Category	Percentage
I Personal information			
1	Gender	Male	54
		Female	46
2	Age	< 25years	3
		25-35 years	29
		36-45 years	40
		46-55 years	26
		>55 years	3
3	Occupation	project manager	34
		engineer	17
		secretary / assistant	17
		technician / designer	14
		accountant / bookkeeper	9
		director	9
4	Average number of hours spent working per week	16 - 20 h	3
		21 - 25 h	6
		26 - 30 h	3
		31 - 35 h	0
		36 - 40 h	57
		41 - 45 h	26
		46 - 50 h	6
5	Average number of hours spent working at the workstation per week	6 - 15 h	9
		16 - 25 h	20
		26 - 35 h	51
		36 - 45 h	20
6	Percentage of work performed on computer	30 - 50 %	3
		50 - 60 %	9
		70 - 80 %	46
		85 - 90 %	31
		95 - 100 %	11
7	Time period since you are working at the present workstation	5 months	3
		12 months	54
		16 months	43

II Perception of the indoor climate and control systems			
8	How do you find the air quality of your office?	very bad	0
		bad	43
		it’s ok	40
		good	17
		very good	0
	Reasons for dissatisfaction with the air quality	not operable windows / no fresh air	60
		either too cold or too warm air	60
		too dry air	47
		air smells bad (from cantina or like stale air)	27
9	Are you satisfied with the ventilation of the office?	not satisfied at all	0
		less satisfied	43
		it’s ok	37
		satisfied	20
		very satisfied	0
	Reasons for dissatisfaction with the ventilation	centrally controlled	80
		not operable windows / no fresh air	60
		permanent strong and cold air flow from the AC unit	53
		too dry air	47
		air smells bad (from cantina or like stale air)	27
10	How is the average temperature of your office in winter?	cold	6
		cool	37
		neutral	37
		warm	14
		hot	6
11	How is the average temperature of your office in summer?	cold	6
		cool	14
		neutral	57
		warm	20
		hot	3
12	How satisfied are you with the heating/cooling system in your office?	not satisfied at all	6
		less satisfied	43
		it’s ok	40
		satisfied	11
		very satisfied	0
13	How satisfied are you with the air-conditioning system in your office?	not satisfied at all	0
		less satisfied	51
		it’s ok	37
		satisfied	11
		very satisfied	0
14	Do you have sufficient daylight in your office?	not sufficient	0
		could be more	6
		it’s ok	46
		a bit too much	49
		too much	0
15	Are you annoyed by direct sunlight at your workstation?	frequently	9
		occasionally	51
		rarely	26
		never	14

16	Are you annoyed by reflections or too bright surfaces on your computer screen?	frequently	9
		occasionally	34
		rarely	31
		never	26
17	Do you have sufficient artificial light in your office?	not sufficient	0
		could be more	6
		it’s ok	94
		a bit too much	0
		too much	0
18	Are you annoyed by noise in your office?	frequently	20
		occasionally	37
		rarely	34
		never	9
19	Do you have enough privacy in your office to work undisturbed?	never	9
		sometimes	23
		it’s ok	43
		most of the time	14
		always	11
	The sources of noise and disturbance	open space office	84
		colleagues having telephone conversations	84
		people walking through the office	52
		coffee machine	48
		people chatting in the kitchen	35
		colleagues talking in the room	29
		telephone ringing	23
		meetings in the meeting room	23
		construction works in the building	19
		air-conditioning unit	19
		copy machine, printer	26

III Operation and accessibility of the control systems			
20	Are you satisfied with the fact that you cannot open the windows in your office?	not satisfied at all	40
		less satisfied	40
		it's ok	17
		satisfied	3
		very satisfied	0
21	Can you open/close the shades easily?	not at all	0
		it's complicated	0
		it's ok	37
		easily	49
		very easy	14
22	How important is it for you to have the possibility to operate the internal shades?	unimportant	0
		not so important	3
		don't know	9
		important	40
		very important	49
23	Can you decide independently when to operate the internal shades in your office or do you have to negotiate with other people?	never	0
		sometimes	29
		most of the time	29
		always	43
	For other than always, describe the process- who, when and how.	colleagues working beside or opposite me	100
24	Is the light switch easily accessible to you?	not at all	0
		it's complicated	0
		it's ok	34
		easily	20
		very easy	46
25	Can you decide independently when to switch on/off the light in your office or do you have to negotiate with other people?	never	3
		sometimes	23
		most of the time	31
		always	43
	For other than always, describe the process- who, when and how.	colleagues working beside or opposite me	100
26	Is the thermostat easily accessible to you?	not at all	0
		it's complicated	9
		it's ok	29
		easily	29
		very easy	34
27	Can you adjust the thermostat on your own in your office or do you have to negotiate with other people?	never	3
		sometimes	26
		most of the time	9
		always	63
	For other than always, describe the process- who, when and how.	colleagues working beside or opposite me	100

IV Awareness of the functionality of the building control systems and energy conscious behavior			
28	Are you sufficiently informed about how the following systems work in your office?		
	Heating / Cooling System	not sufficient	23
		sufficient	60
		very well	17
	Air conditioning System	not sufficient	26
		sufficient	60
		very well	14
	Lighting System	not sufficient	6
		sufficient	63
		very well	31
29	Have you ever had a training concerning the systems in your office?	yes	29
		no	71
	If yes, how would you evaluate this training?	not so good	0
		good	100
		very good	0
	If not, would you be interested in such training?	no	32
		don't know	40
		yes	28
30	To whom do you refer in case of a problem with the building systems?	building's service department	74
		secretary / assistant	20
		don't know	6
31	Are you satisfied with the system services and support in your office?	no	9
		it's ok	63
		yes	29
32	Do you think that you can influence building energy consumption in the way you operate building systems?	no	17
		don't know	26
		yes	57
33	Do you think about energy conservation when you operate building systems?	no	34
		don't know	29
		yes	37

V Personal preferences of organizing the current/ideal working space; health complains			
34	Are you satisfied with the possibilities you have to personalize your working space (furniture, plants, photos, etc.)?	not satisfied at all	3
		less satisfied	11
		it’s ok	46
		satisfied	37
		very satisfied	3
35	Generally, how do you find your office climate?	bad	0
		not so good	3
		it’s ok	54
		good	31
		very good	11
36	Which improving measures would you consider the most urgent in your office?	better air quality	66
		operable windows	57
		new Heating/Cooling system	54
		more privacy and less noise	54
		more archive space	17
		bigger office	11
		more ergonomic seating	3
		everything it's ok	3
37	Do you have any health complains?	headache	26
		backache	23
		neck pain	23
		eyestrain or burning	20
		general fatigue	14
		nasal irritation	14
		sore throat	11
		stiffness of limbs	9
		respiratory problems	6
		rheumatic pains	6
		none	37