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DISSERTATION

LIGHTING, SHADING AND VENTILATION CONTROLS: A STUDY OF USER BEHAVIOR IN OFFICE BUILDINGS

ausgeführt zum Zwecke der Erlangung des akademischen Grades eines Doktors der technischen Wissenschaften unter der Leitung von

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Abstract

This work presents results of a study of user interactions with building systems (lighting, shading and ventilation) in office buildings. The focus of the project is to observe and analyze the control-oriented occupants' behavior toward lighting, shading and natural ventilation systems based on a long-term study in two office buildings in Austria. Discovering possible relationships between behavior of occupants and internal/external environment parameters increase knowledge about building performance. The first building is a governmental organization located in Hartberg, Austria. The occupants regularly receive clientele with administrative questions and requests. The second object is a high-rise office complex that is a seat of international organizations in Vienna, Austria.

Internal and external parameters; state of occupancy (Presence/absence), state of lights (on/off), indoor and outdoor illuminance, temperature, relative humidity, state of shades and windows (open/close) were continuously observed and recorded every five minutes (shades and windows every 10 minutes) over the period of nine months (from November 2005 to July 2006) in case of the first object and one year (from January 2005 to December 2005) in case of the second object. Subjective impressions and attitudes of observed building occupants were documented with questionnaires and interviews. Three software applications involving image processing and databases were developed.

Collected data was analyzed through visualization and statistical analysis to explore the hypothesized correlation between occupants' actions and environmental parameters. The main objectives of the analysis were to uncover "objective" factors of control-oriented occupant behavior in buildings and to quantify the impact of occupant behavior on building performance (indoor climate conditions).

Based on the results from this research, operation of the building systems partly depends on indoor/outdoor conditions. Therefore, it is necessary to have accurate information about user control behavior in office buildings in order to predict building performance and energy consumption. These behavioral patterns can be used to develop empirically supported predictive models for control oriented occupant actions in buildings, building simulation programs, building automation systems, energy management and energy contracting to improve energy effectiveness and occupant comfort and innovation of user interfaces products.

Keywords: User control actions, occupant behavioral models, manual control of lighting, shading and windows, building modeling, building environment, natural ventilation, building simulation

Kurzfassung

Diese Arbeit umfasst Ergebnisse einer Langzeitfeldstudie über die Interaktion von Gebäudenutzern und dem Gebäude an Hand von zwei Bürogebäuden in Österreich. Besonderes Interesse galt der empirischen Beobachtung von steuerungsorientiertem Nutzerverhalten bezüglich Beleuchtung, Beschattung und natürlicher Belüftung. Die Erkenntnis von möglichen Zusammenhängen zwischen dem Verhalten von Gebäudenutzern einerseits und inneren bzw. äußeren Parametern andererseits ist die Grundlage für die Optimierung der Gebäudeperformance. Bei einem Gebäude handelt es sich um ein Verwaltungsgebäude der Bezirksverwaltung mit regelmäßigem Parteienverkehr in Hartberg, Steiermark. Das zweite Gebäude, ein Hochhauskomplex, befindet sich in Wien und ist Sitz einer internationalen Organisation. In diesem Gebäude gibt es keinen Parteienverkehr.

Objektive Daten, wie die Präsenz der Nutzer, der Zustand der Beleuchtung (ein/aus), Innen- und Außenparameter wie etwa Beleuchtungsstärke, relative Feuchtigkeit und Temperatur, sowie der Öffnungsgrad der Beschattungseinrichtungen und Fenster (offen/geschlossen), wurden in fünfminütigen Intervallen gemessen. Der Messzeitraum betrug beim ersten Gebäude neun Monate (November 2005 bis Juli 2006) und beim zweiten Gebäude ein Jahr (Jänner bis Dezember 2005). Subjektive Daten wurden mit Fragebögen und Interviews erhoben.

Um die Hypothese eines Zusammenhangs zwischen Nutzerverhalten und Umgebungsparametern zu überprüfen wurden die gesammelten Daten analysiert. Zur Datenanalyse wurden diesbezüglich drei Applikationen entwickelt. Das primäre Ziel der Analyse bestand darin den prädizierten Zusammenhang objektiv darzulegen und den Einfluss von Nutzerverhalten auf die Gebäudeperformance zu quantifizieren.

Die Arbeit zeigt, dass steuerungsorientiertes Nutzerverhalten zum Teil mit Innen- und Außenparametern korreliert. Je genauer das Verhalten von Nutzern bekannt ist umso präziser kann die Performance des Gebäudes und der Energieverbrauch prognostiziert werden. Die Ergebnisse dieser Arbeit tragen dazu bei robuste Modelle für Nutzerverhalten für die Verwendung in der Gebäudesimulation und Gebäudeautomation, sowie für das Energiemanagement und Energie-Contracting zu generieren, um Energieeffizienz und Nutzerkomfort sowie die Entwicklung von Bedienelementen der Haustechnik zu fördern.

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Vienna, Austria, November , 2007

Dedicated to my parents and Majid

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1 Introduction

Office users do influence their working environment by operating the artificial lighting system, the shading and glare protection devices, the windows and heating/cooling devices. The aim of monitoring user behavior is to have an expressible quantity of data, based on when and how users manipulate building systems (lights, shades and windows) and also identify interdependency of external parameters to user behavior. The relationship between user manipulations and changeable internal/external's parameters investigated to understand in which conditions people do operate their lighting systems, shading devices or open/close the windows to achieve the desired working environment.

This thesis presents the results of a long-term empirically study that conducted in 6 offices in a governmental organization in Hartberg (referred here as HB), and 29 offices in a large high-rise office complex in Vienna (referred here as VC), Austria. The main goal of this study was to discover possible relationships between behavior of occupants and internal/external environmental factor.

Internal and external parameters were observed over the period of nine months in case of HB from November 2005 to July 2006 and one year in case of VC from January 2005 to December 2005. Two weather stations mounted on top of each building, a number of indoor data loggers, and three digital cameras were used to continuously monitor and record every five minutes such events and states; occupancy, indoor and outdoor temperature and relative humidity, internal illuminance, external wind speed and horizontal global irradiance, status of electrical light fixtures, position of shades and windows. Vertical global irradiance was derived based on recorded horizontal global irradiance values, using geometry of the buildings by simulation programs. Three software applications involving image processing and databases were developed. The results reveal clear patterns in user behavior and its dependency with indoor and outdoor environmental parameters. The result of modeling user-building interactions may significantly influence thermal and visual comfort conditions as well as cooling and heating loads.

Chapter 1 includes Introduction, motivation of choosing the topic and a summary on previous studies in area of occupants' behavior. Chapter 2 gives details about the case studies, describes research methodology, measuring equipments, computer programs, data collection and processing the data. Chapter 3 is dedicated to the results of the analyzed data and interviews. Chapter 4 compares the results, discusses and gives comments on the results from the previous chapter and provides some input models for simulation applications and chapter 5 is conclusion of the study and future research perspectives.

1.1 Motivation

About 75 % of energy consumed for/in buildings is in operation of them over their lifetime. Identifying opportunities to reduce the energy like using better and more reliable construction materials, improving building systems and developing simulation applications for better understanding and prediction of building performance has become a priority in the global efforts to reduce climate change (United Nations environment program 2007). Accurate prediction of building performance (energy consumption, indoor environment) requires, among the others, information on user control behavior, as in most buildings, windows, shades, luminaires, radiators, fans, and other control devices can be operated by building occupants. Energy performance of buildings can be significantly influenced with occupants' presence, activity and control over the building systems and devices (Mahdavi 2006b).

Thus, multiple studies have been and are being conducted internationally to collect data on building users' interactions with building control systems and devices. Such empirically based data can bring about a better understanding of the nature, type and frequency of control-oriented user behavior in buildings and support the development of corresponding behavioral models for integration in building performance simulation applications.

Our experiences show that there are differences between the modeled and the real building energy performance. One explanation for the discrepancy is the ignorance of an important factor significantly affecting the energy processes; the presence and activity of users. The behavior of occupants should be distinguished as a separate environmental factor with specific parameters. Proper monitoring strategy needs to be created and patterns systematically defined as a base for models. While we know that people's attitudes and particularly occupants' behavior have significant effects on the performance of various energy systems, the exact influence of these effects is insufficiently explored. In addition, the nature of the multi-fold human-system interactions and their consequences for the performance of energy-consuming environmental systems are not well understood. Moreover, most researches on energy systems concentrate on energy generation and distribution systems and technologies and they are typically "hardware"-oriented.

In the domain of energy systems of the built environment, considering user-interfaces in office buildings and their influence on user behavioral patterns can increase the accuracy of the energy performance predictions.

Hence, the present research study investigates a better understanding of occupants control behavior in two office buildings, the modeling users' patterns can be used to:

- Improve existing building simulation tools
- Predict the performance of building systems
- Improve occupants comfort and satisfaction
- Innovate advanced building systems
- Control building systems for facility managers to save energy

1.2 Background

A review of past experimental studies on manual control strategies for artificial lighting systems, shading operation and natural ventilation in office buildings is presented. In these studies, the patterns of switching on or off the lights, operating the shades, opening and closing the windows were explored.

1.2.1 Artificial lighting system

One of the first studies about behavior of occupants regarding light on/off actions carried out by Hunt in 1979. Hunt's findings state that all luminaires in one room are switched on or off usually at the same time. Hunt, Love (1998) and Pigg (1998) also observed that the switching lights on/off actions either happen on arrival of the occupant to the room or while leaving.

Love divided the users upon their behavior regarding light use into two groups: those who turn on the lights and leave them on even when they are away from the room for intermediate absences and those who turn on the lights only when the illuminance is less than a threshold.

Hunt (1979), Love (1998) and Reinhart (2001) observations agree that there is a strong relationship between illuminance on the working area on arrival and switching the lights on by the occupants (see Figure 1.2-1).

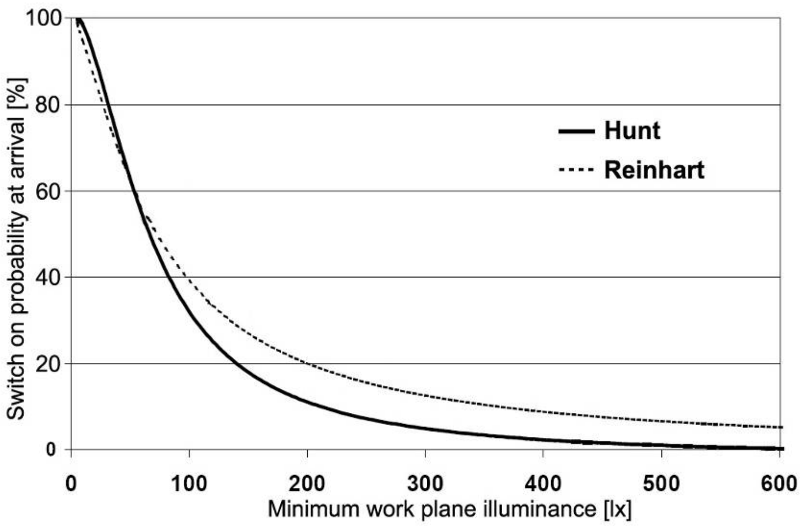

Figure 1.2-1 Switch on probabilities upon arrival found by Hunt and Reinhart

Pigg and Reinhart found a close relationship between switching lights off and the period that elapses before the occupant comes back to the room (see Figure 1.2-2).

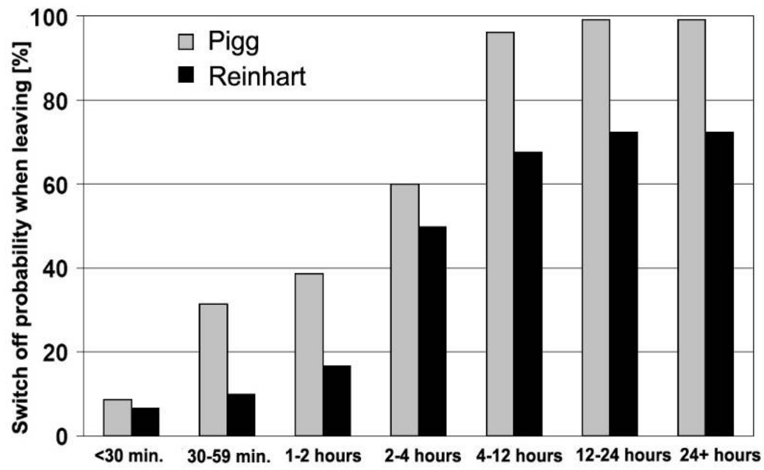

Figure 1.2-2 Probability of switching the lights off when leaving the office

Newsham and Veitch (2002) reported that the chosen illuminance level in cubicle offices with out daylight is between 400 and 600 lx, although the illuminance level could be chosen between 83- 725 lx.

Reinhart (2002) monitored blinds and manual control of electric lighting. He tried to find whether manually controlled electrical lighting system and automatically controlled blinds with manual override are operated in relation or independently from each other. He verified increasing in probability of switching the lights on in illuminances less than 100 lx.

1.2.2 Manual control of shades

A limited number of studies about manual operation of shading devices have been carried out so far. In the following, a summary of the major findings is presented.

Inoue et al. (1988) investigated manual control of venetian blinds of four high-rises in Tokyo, Japan. He took photos of each facade simultaneously and the direct and defuse irradiance were collected every one hour. The measurement period was for one to three weeks for each façade. The major findings of Inoue's research are:

Shades occlusion is proportional to the depth of sunlight penetration into the offices (see Figure 1.2-3). Threshold of direct solar radiation onto the façade for closing shades is 50 W.m^{-2}. When irradiance decreases, apparently, the shades are not completely reopened. It can be because of the visual connection to outside conditions that is lost due to closed shades.

Figure 1.2-4 shows the correlation between the percentage of closed shades and the amount of incident solar radiation on the façade. It reveals that the relation between shades operation and incident illuminance on the façade follows an arc, shows that even the times when incoming solar irradiance decreases, the number of closed shades can rise.

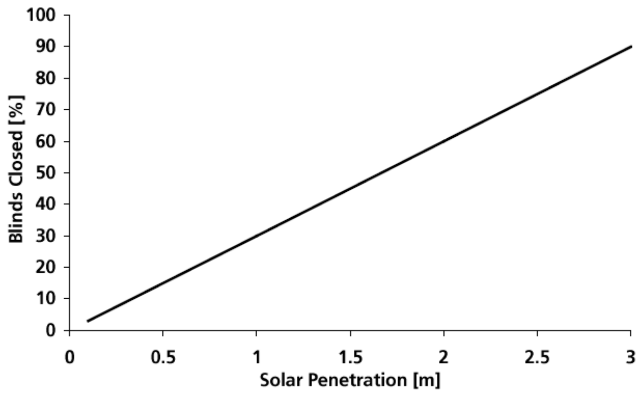

Figure 1.2-3 *Percentage of closed blinds in relation to direct solar penetration in an office on SSW façade*

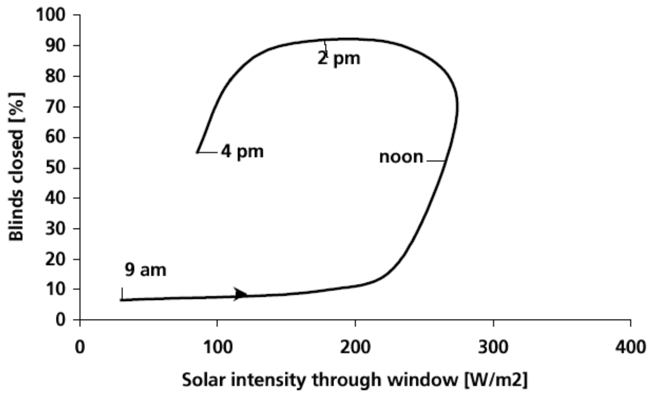

Figure 1.2-4 *Percentage of closed blinds in relation to the vertical solar irradiance on a SSW façade*

The result of Farber et al. (1992) investigation in buildings in UK indicated that a threshold of 300W/m^2 would cause a change in the shade position.

Newsham (1994) investigation on single offices in UK revealed that when solar radiation is above a threshold of 233 W/m^2, occupants close the shades and the shades will be remained closed until the following morning.

Rubin (1978) investigated manual controlling patterns in offices in north and south facades in USA. He used photography method to register the state of 700 windows' shades. The focus of his research was on the influence of window orientation, quality of view and seasonal changes. He wanted to test if different blind positions are the result of an awareness decision by the occupants or they just represent the effect of irrelevant changeable like the maintenance personnel. However, he could not establish that how shades are set in relation to the sky conditions, time of the day and seasons. Robin's results are summed up in the following:

- Closing the shades in southern offices is higher than northern ones. Occupants want to use their shades to block direct sunlight.
- Occupants intentionally set the shades in a certain position. Only 50 shades out of 700 were adjusted more than once after the manipulation.
- The daily manipulation of the shades is very rare, it could happen over a period of weeks or months.
- Occupants apparently accept that their shades are extraneously opened than closed.

Lindsay et al. (1993) studied on five office buildings in England. His method for recording data in one building was based on time-lapse photography, twice a day over a period of 4 months and using video camera together with user occupancy in 2-hour-time-steps for the second building. Temperature, direct and diffuse irradiance, type of the sky conditions (clear/overcast) and the state of the other buildings' shades were collected in one-hour time-steps.

The number of investigated window blinds was 54 on a southern façade, 100 windows on a southwestern façade, and 105 windows on northern façade. His findings are:

- The average rate of shade manipulations for different windows in the same façade is around 40% and it is usually does not change daily from 0% to 100 %.
- Operation of the shades was in response to the amount of solar radiation and position of the sun with respect to the façade.

- Occupants tend to close the shades during the day according to the incident direct sunlight to the facade whereas they mainly open them at the end of the working day or early in the morning.
- In all buildings, there was a significant correlation between hours of direct sunlight onto a façade and rising of overall shades closing in the façade.
- The rate by which shade occlusion rises with direct sunlight is different for buildings.

For example in a building that had lowest correlation, the average of shades occlusion was 70%. His speculation for the reason of permanently high shade occlusion was that the building tended to be overheated.

In the other study later, he suggested that the general motivation for occupants to manipulate their shades is to avoid glare rather than to prevent overheating.

Inoue's result also supports the assumption that states direct sunlight as low as 50 $W.m^{-2}$, which corresponds to relatively low solar gains, does trigger increased shades operations.

Pigg et al. (1996) investigated the usage of the shades in 63 offices. The results are:

- 36% of the occupants never operated the shades.
- Shades operation in north façade is significantly lower than south façade.
- 37% of his subject's study stated that in order to reduce glare on their computer screen, they operate the shades.

Rea (1984) investigated shade operation in a high-rise office building in Ottawa, Canada. He observed three façade orientations on a cloudy and sunny day by taking external photos in the morning, at midday and in the afternoon. The main concentration of the study was interactions between shades operations and external variables parameters like sky conditions, time of the day, and orientation of facade. The results reveal that:

- There is a high correlation between state of the shades and façade (windows) orientation and sky conditions.
- Closing the shades was correlated positively with incident irradiance on the façade.

His findings also support Rubin's result that occupants operate their shades in order to reduce penetration of solar radiation. However, the force of solar heat or daylight reduction for manipulation of the shades did not realize from the results.

In the case of occupants' prevention in changing the shades every day, Rea concluded in agreement with Rubin's results that users have a long-term feeling of solar irradiances. This inertia of occupants to react towards changing sky conditions might be similar to the tendency of people to operate their electric lighting only once or twice a day upon arrival or departure.

Bülow-Hübe (2000) studied on 50 subjects in two test offices in Sweden. The results indicated that the shades were frequently used throughout the day to control glare. She did not establish correlation between degree of closing shades and illuminance or sky luminance. Although she found that the existence of sunlight patches in the offices stimulate occupants to operate the shades.

1.2.3 Natural ventilation

Very few studies on the manual operation of windows were conducted worldwide. Nevertheless, some consistent patterns were established concerning the percentage of open windows, opening hours and frequency of opening/closing actions as related to occupancy, season, outdoor/indoor temperature and time of the day.

Nicol (2001) studied on some naturally ventilated office buildings in Europe, UK and Pakistan. According to the result of this study, it is noticeable that in all three surveys, the proportion of opened windows tends to increase significantly as the outdoor temperature rises above 10 ºC. At 22 ºC, 50% of windows in European offices were open and it rises to 80% when the outdoor temperature rises to 33ºC. He concluded that the outdoor temperature at which occupants start to open their windows for ventilation in all climates is similar.

The observation on user behaviour in 21 south-facing offices in Freiburg in Germany, by Herkel et al. (2005) reveals a strong correlation between percentage of open windows and the time of the year, outdoor temperature and occupancy patterns. In this study parameters like window status, occupancy, indoor and outdoor temperature as well as solar radiation were measured every minute from July 2002 to July 2003. The summary of the Henkel's results are:

- Seasonal dependency

The operation of windows (percentage of open windows, frequency of opening/closing) strongly correlates with the season. In summer the percentage of opened windows is higher than in winter (60-80% of the small windows are opened in summer, in winter 10%). Highest frequency of opening/closing is observed in the transition seasons spring and autumn, because of the changing weather conditions.

- Outdoor temperature dependency

There is a strong correlation between the outdoor temperature and the percentage of open windows. Above 20 °C, 80% of the small windows are completely opened whereas 60% of the large windows are tilted /opened.

Above a certain outdoor temperature, the frequency of opening windows increases strongly.

- Time of the day dependency

As related to the time of the day, the windows are more frequently opened /closed in the morning (9:00) and in the afternoon (15:00).

- Occupancy

Opening/closing the windows occurs mostly when occupants arrive or leave their workspace. At the end of the working day, open windows are mainly closed.

Bourgeois (2005) monitored the manual operation of windows in 211 mechanically ventilated offices in a university building in Quebec, Canada. Simultaneously status of windows, lights and blinds, together with outside climatic conditions (air temperature, direct solar radiation) were recorded. He explored if established occupancy patterns for manual operation of electrical lights are applicable for opening/closing windows.

However, results of the past studies support each other in some cases but there are discrepancies between them. The main reason could be applying different methodology for analysis, building types, shading devises, or different monitoring procedures.

Future research in the area of people's behavior in buildings should consider more building types in different climatic and cultural settings, as well as long-term monitoring and collection of high-resolution data. Another recommendation would be unifying the research design and methods (length of monitoring, logging intervals, building control systems, number of monitored offices, experimental equipment setup, methods of analysis), which would allow consistent comparison of the results.

2 Research design

2.1 Objects description

The objects of the study contains of two office buildings in Austria with different characteristics concerning occupancy and building systems' operations. The first one is a governmental office building that, in this study, is referred to as "HB" and the second one is an international office complex in Vienna that is referred to, in this study as "VC" divided in two office groups directed to north as "VN" and south-west as "VS".

2.1.1 HB

The office building "HB" is located in Hartberg, (Styria, Austria). It consists of two connected blocks (old and new constructed) with 3643m^2 ground area on 4 floors. The observation block is the old one, which has a conventional façade consists of concrete and glass. The new block has a glass façade supported by aluminum frames. The orientation of the building and offices is northeast.

Figure 2.1-1 shows a general view of the building and the observed offices.

Figure 2.1-1 General view of HB

A characteristic feature of this building is its use as a governmental service unit. The occupants arrive rather early in their offices and regularly receive clientele with administrative questions and requests.

2.1.1.1 The offices and occupants

The measurements were carried out on six offices over a period of nine months from November 2005 to July 2006. Three offices situated on first floor and three on second floor. They contain of two single occupancy offices with about 20m^2 floor areas each and four double occupancy offices that have about 28m^2 areas each. All the 10 monitored workstations face northeast direction. They are equipped with desktop computers and in some cases printers and task lights. The occupants perform both screen-based and paper-based tasks. The furniture in the offices, except chairs, is made of light brown wood (cupboards and bookshelves). The walls and ceilings have white color and parquets cover the floor. The offices have two or three window units. Figure 2.1-2 shows interior views of two offices on the first and second floor.

Figure 2.1-2 Left: Interior view of a double occupancy office on the first floor, right: Interior view of a single occupancy office on the second floor

A schematic layout of three offices on the second floor is given in Figure 2.1-3.

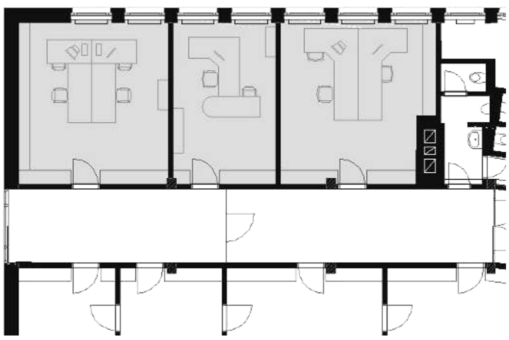

Figure 2.1-3 Schematic plan of sample offices in HB

2.1.1.2 Building system

The offices are equipped with the followings systems: Two rows of luminaries with four or six fluorescent (58 W) lamps divided into two circuits and manually controlled by two switches near the entrance door. The electrical lighting is manually controlled and there is no schedule to control the lighting use during the different time of the day and year. The heating system is based on radiators units located under each window and users can change the setting for fine adjustment of temperature. There is no cooling and air conditioning system in the offices; the occupants can have natural ventilation by opening the windows. Shading elements are contains of two manually operable parts: external shades and internal curtains to control daylight. The windows are double-glass in two or three modules that are manually operable in two positions (turn open and tilt open).

2.1.2 VC

The building is a high-rise International office complex in Vienna consists of six tower blocks with 92 floors. The observed offices are located in tower D, situated on 12th and 13th floors and face to two directions, north (VN) and south-west (VS). Figure 2.1-4 shows a general view of the building.

Figure 2.1-4 General view of north façade of tower D (building VC)

2.1.2.1 The offices and occupants

29 offices were observed over a period of one year from January 2005 to December 2005. 15 offices are facing north (eight rooms on 12th and seven rooms on 13th floor, referred as VN). 14 offices are facing to south-west (eight rooms on 12th and six rooms on 13th floor, referred as VS). The type of the offices is single occupancy with about 13-17m^2 areas. All 29 workstations are equipped with desktop computers and in some cases with printers. The offices are furnished with chairs, tables and shelves. Each office has 3 or 4 window units which are not operable. The walls are metal panels with isolation layer, ceilings are expose-concrete and the floors are covered by carpet.

Figure 2.1-5 shows interior views of two offices on 12th floor in north and south-west façade.

Figure 2.1-5 Left: interior view of an office on 12th floor in south-west facade, right: an interior view of an office on 12th floor in north façade

In Figure 2.1-6 the layout of offices is presented.

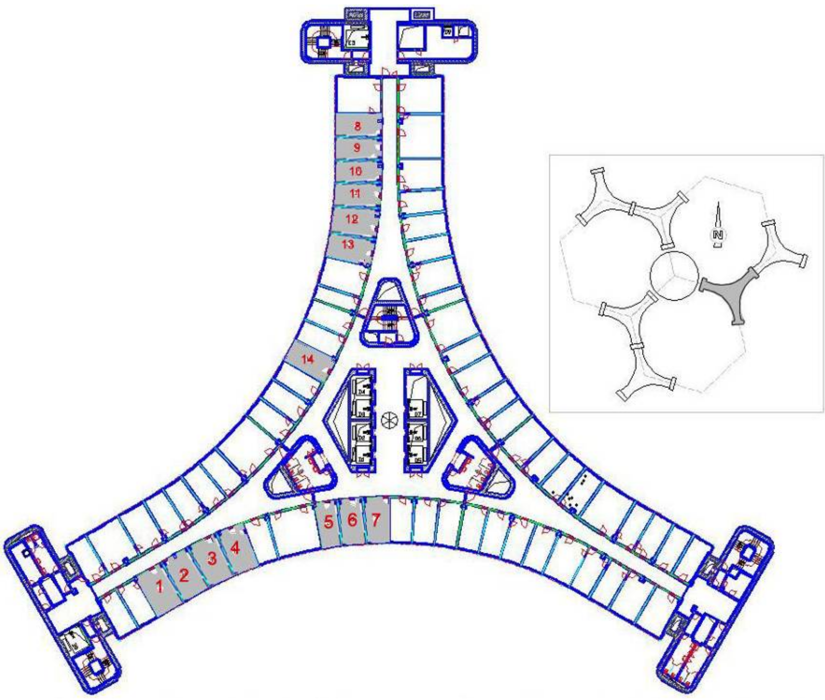

Figure 2.1-6 Layout of the offices on floor thirteen

2.1.2.2 Building system

The offices are equipped with the following systems of environmental control: 3 rows of luminaries, 9 or 12 lamps of 36W each, divided into two circuits manually controlled by two switches near the entrance door. Luminaires are divided in two groups; the middle row switched on/off independently and can be used anytime. The row close to the windows and the row close to entrance are switched on/off by a controller and can be used only if illuminance outside is less than a threshold and only between 7:00 and 21:00 on working days. Internal shading system can be manually operated by occupants (Mohammadi 2007).

There are three or four fan-coil units under each window for fine adjustment of temperature. The heating, ventilation and air-conditioning (HVAC) systems are being operated only during working days and hours. Operation time of the systems is between 7:00 and 18:30, except June, July and August, when it is between 7:00 and 18:00. On Monday mornings, the operation starts at 6:00 and on Friday evenings, turns off half an hour earlier than the mentioned schedule. Cooling system works from May to September and heating system from September to May. In May and September both heating and cooling are available. The ventilation inside the offices is based on fresh air supply through air ducts installed at the lower floor. The fresh air, after being filtered, humidified and slightly heated/chilled, enters inside every air-conditioning unit and blows in the offices. This air is heated in winter or chilled in summer by passing through warm/cold radiators that are installed in every air-conditioning unit (Der-Petrosian 2006).

The radiators are heated/cooled by the supply of warm/cold water; the pipes are likewise running alongside the air ducts in the façade-side ceilings (at the lower floor). The ducts and the water pipes are insulated to prevent loss of thermal energy.

2.2 Data collection

The intention was to observe user control actions pertaining to lighting, shading and windows as well as to monitor the respective prevailing indoor and outdoor conditions under which such actions occur. The Internal and external parameters were measured simultaneously. The collected data was analyzed to explore hypothesized relationships between the nature and frequency of the control actions on one side and the magnitude and dynamism of indoor and outdoor environmental changes on the other side.

The data collection in HB was done nine months starting from November 2005 to July 2006, and in VC 12 months from January 2005 to December 2005. The interval for logging all internal/external environment parameters was 5 minutes except the image photography that was every 10 minutes. The data was downloaded regularly every 30 to 40 days.

2.2.1 External environment

Outdoor climate parameters such as temperature (°C), wind speed (m/s), global horizontal irradiance ($W.m^{-2}$) and relative humidity (%), were monitored using weather station, mounted on the top of the two buildings (Figure 2.2-1). The local weather data structured in 5 minutes intervals. The weather station consists of sensors and data logger, fixed on a vertical mast. Figure 2.2-1 shows the weather station mounted on HB building.

The accuracy of the sensors is summarized in Table 2-1.

Table 2-1 Specification of the Weather Station sensors

Sensor	Measurement range	Accuracy
Solar radiation	0 to 1280 $W.m^{-2}$	±10 $W.m^{-2}$ (± 5%)
Wind speed	0 to 45 $m.s^{-1}$	± 1.1$m.s^{-1}$ (± 4%)
Temperature	-40°C to 75°C	± 0.7°C at 25°C
Relative humidity	0 to 100% between 0°C and 50°C	± 3%; ± 4% in condensing environments

Figure 2.2-1 *Left) Weather station mounted on the roof of HB building, right) 1: data logger, 2: temperature/RH sensor, 3: Solar radiation sensor, 4: Wind speed sensor*

Each sensor has a microprocessor with its own signal converter for taking a specific measurement. The measurements are recorded and stored by data logger and can be downloaded to a PC using connection cable and BoxCar Pro software. The weather stations have been read out every 2 months in order to avoid loss of data resulting from malfunction of components.

2.2.2 Internal environment

Indoor climate parameters (Temperature, Light intensity, relative humidity, presence of the users and state of artificial light) were measured using two different types of data loggers mounted under light fixtures and across working stations.

2.2.2.1 Indoor temperature/ relative humidity/ light intensity

Temperature, relative humidity and light intensity were measured by Hobo logger (Hobo U12-012 sensors manufactured by Onset Inc.) placed approximately near to the workstations. The Hobo sensors were set to log every 5 minutes state of the three parameters. The data were downloaded every 30-40 days by connecting to a computer and using the specific software. The software was used to read out data, launching sensors for the next measurements and see the status of the logger.

The measured parameters by the sensor are:

- Room temperature [θ_i in °C]
- Relative humidity [RH_i in %]
- Light intensity [E in lx]

Figure 2.2-2 shows the sensor/logger and its components.

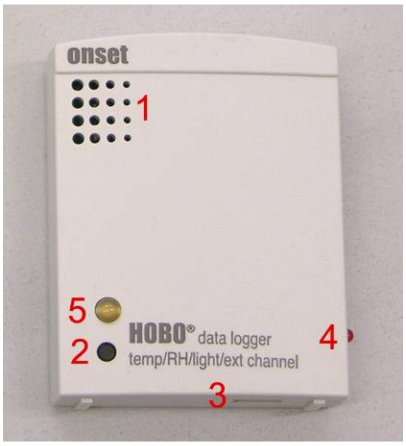

Figure 2.2-2 Hobo sensor/logger

1. Relative humidity/temperature sensor
2. Reset button
3. USB port
4. LED operation indicator
5. Illuminance sensor

Key specifications of the sensor/logger are presented in Table 2-2 (Onset 2007).

Table 2-2 Key specifications of the Hobo sensor/logger

Internal sensor	Measurement range	Accuracy
Temperature	-20°C to 70°C	± 0.35°C from 0° to 50°C
Relative humidity	5% to 95%	± 2.5% from 10% to 90%
Light intensity	12 to 32,000 lx	

In building VC, the sensors were installed on the wall near the workplace with a removable stick. The horizontal position was not considered in most of offices of

VC as proper because it could be easily covered by objects and could bother the occupants.

Figure 2.2-3 shows indoor sensor positions in VC offices.

▲ Horizontally mounted hobo sensor in VC

◄ Vertically mounted Hobo sensor in VC

Figure 2.2-3 Typical indoor Hobo sensor positions in VC

The sensors were named with: "room number_sensor ID_installation date". For example "623_201_051029" means the sensor is in room 623, it is the first internal hobo sensor in the room and installed on 29.10.2005 (see appendix 9.3).

In building HB, hobo sensors were installed horizontally on the workstations. Figure 2.2-4 shows view of installed HOBO sensors in first and second floor offices in HB.

Figure 2.2-4 Position of the Hobo sensors in the offices in HB left): a single occupancy office, right): a double occupancy office

2.2.2.2 Occupancy/ state of light

IT-200 loggers manufactured by Wattstopper Inc. were used to log occupancy and state of artificial light (on/off), (see Figure 2.2-5).

Figure 2.2-5 IT-200, occupancy/state of light (on/off) sensor

1. Red LED blinks during occupancy detection
2. Green LED blinks when lighting is detected
3. Test button activates LEDs for 60 seconds during which sensitivity is set and proper location for occupancy detection is verified
4. Button adjusts the sensitivity of the light sensor
5. Infrared sensor detects movement of people
6. Adjustable light pipe observes lighting level
7. Reset switch
8. Serial port connects to PC

Key specifications:

- Lithium battery operated, average battery life ~10 years, battery life indicator
- Coverage up to 45 m^2
- Stores a maximum of 4096 entries
- Connects to computer (PC) for data retrieval via serial connector cable

The IT-200 records a log entry whenever there is a change in either occupancy or lighting status and stores a detailed history of these events for retrieval by PC. It utilizes passive infrared technology to detect occupancy. It observes the luminance through a plastic pipe to determine if lights are on or off (Wattstoper 2006). The loggers were installed so that the lens had a clear view of the workspace and the light-pipe aimed towards the nearest light fixture (see Figure 2.2-6).

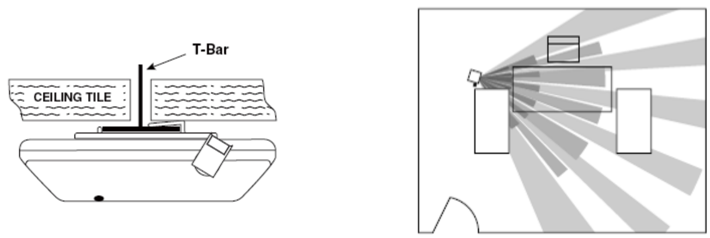

Figure 2.2-6 Installation of occupancy and state of light (on/off) sensor

The occupancy sensor monitors an area of up to 45 m² using passive infrared technology (PIR).

To set an interval for the sensors, we considered two types of limitations; storage and accuracy. Finally, it was decided to accept five-minute intervals. The sensor ID for IT-200 loggers was starting with "1" (e.g. "622_101_051119" refers to the first occupancy sensor in room number 622 and the date of installation which was 19.11.2005), (see appendix 9.3).

The light sensor is necessary not to be exposed to direct sun light, because it produces unreliable results. Limitation of the indoor data logger is the memory capacity, which stores measurements with logging interval of 5 min. up to 50 days. Thus, the logged data was downloaded in intervals of 30 to 40 days.

2.2.3 Façade

To monitor the shading operation in buildings VC (VN, VS) and HB, three high-resolution digital cameras (Nikon Coolpix 8700 with a resolution of eight mega pixels) and 2 GB compact flash memory cards were used to take the pictures in preset time intervals (see Figure 2.2-7).

Figure 2.2-7 Example of contrasts in the images of HB

The cameras, facing the buildings, were mounted inside metal boxes for protection against environmental damages (see Figure 2.2-8). Each camera was able to take maximum of 1800 pictures in one session. To cover a 10-days period, the interval for taking pictures was set to be 10 minutes.

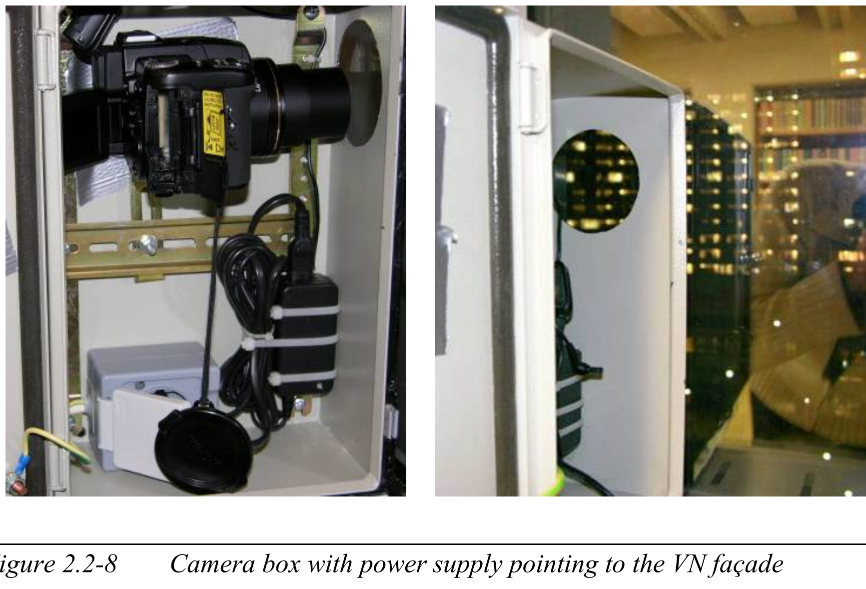

Figure 2.2-8 Camera box with power supply pointing to the VN façade

2.2.4 Natural ventilation

In building HB, occupants have the possibility to open or tilt the windows to ventilate their offices naturally. Each office has two or three of window units (see Figure 2.2-9 and Figure 2.2-10).

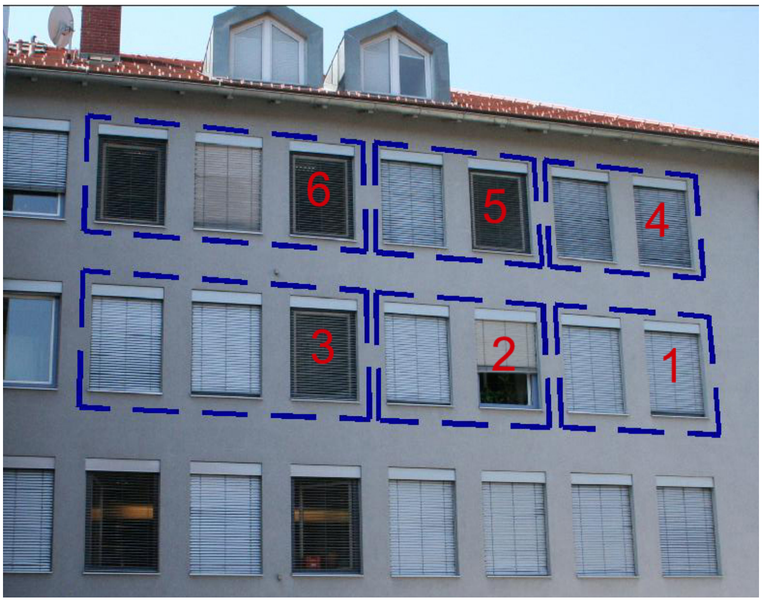

Figure 2.2-9 HB ofiices

Figure 2.2-10 Opened and tilted windows

In order to register the state of the windows, the same method of registering the shading position was applied (regularly taking digital photographs of the façade every 10 minutes).

In VC, the windows cannot be opened and the offices are centrally ventilated. The ventilation system is based on air-conditioning units that provide fresh air via fan-coils in the offices. Each office has three or four air-conditioning units under the windows.

2.2.5 Interviews

The occupants observed in this study were interviewed at the end of the measurements. The number of interviewed occupants in HB was 7 out of 10 occupants and 24 out of 29 occupants in VC. The questionnaires were structured in several sections. The first section is related to occupants' personal and employment circumstances (gender, age etc.), this being important in order to check for and control non-environmental issues that may possibly affect behavior.

The second section is related to user perceptions of indoor climate parameters and control systems (temperature, day/artificial light, heating and cooling, air conditioning, etc.).

The third section, investigates operational and accessibility of the systems and systems control.

In the forth section, consciousness of functionality of the building control systems were investigated.

The last section pertains to personal preferences of organizing the current or ideal working places and health complaints. The summary of the questionnaire results are presented in section 3.4.

2.3 Data processing

2.3.1 Overview

Indoor and outdoor parameters were logged in five-minute intervals for a period of nine months in HB and twelve months in VC. State of artificial light on/off, illuminance, temperature, relative humidity and occupancy as indoor parameters were logged for 10 workstations in 6 offices in HB and 29 offices in VC. Simultaneously outdoor parameters (temperature, relative humidity, wind speed, global solar irradiance) were logged too. Position of the shades and state of the windows were derived from captured digital images in ten-minute intervals parallel to the environmental parameters.

All measured data were structured in excel sheets for each office. Figure 2.3-1 shows a sample of excel sheet for an office in building HB.

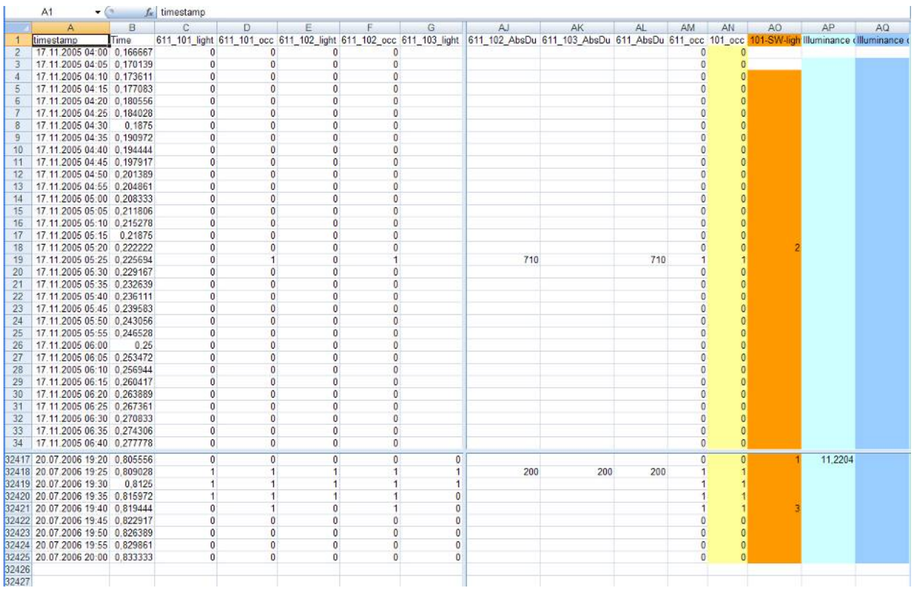

Figure 2.3-1 Sample of a structured Excel sheet for building HB

In order to synchronize all parameters, the following applications were used.

2.3.2 SenSelect

The sensor data selection tool application, SenSelect, based on Perl and MatLab processes the data in order to synchronize data in terms of time and five-minute intervals. A special method to name the stored data files of each sensor for using this application is necessary; the name of the stored excel files and folders should consist of building code, sensor code, number of floor, number of room, workstation and date. In appendix 9.3, method of naming sensors, files and folders is presented. The folders and files are selected in main menu and in the right part, the exact date and time that data have to be synchronized are selected. The next step is to define a path for saving the result. In addition, a window shows the CPU usage while processing data (see Figure 2.3-2).

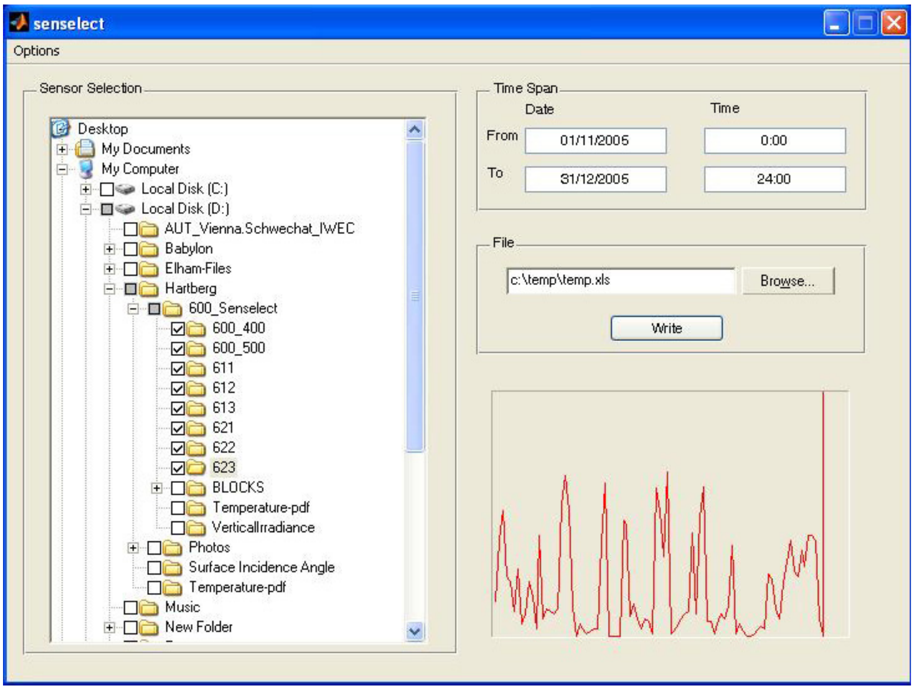

Figure 2.3-2 Graphical user interface of SenSelect

2.3.3 SenSat

SenSat is an application based on MySQL to collect and export data of different files/sensors (e.g. hobo, IT, images, and weather station) according to the specific date and time in a file for the analysis. This program has two interfaces: Excel-importer for importing data and data query for exporting the data.

2.3.3.1 Excel Importer

Excel-importer application imports data of excel files which are already processed by SenSelect in order to save data in a database for analysis. The imported data to database, in each part, can be completely or partly edited by right click on the name and selecting the options. The possible options are deleting data before, after or at a certain date/time and deleting values that are less/greater than or equal to a certain value. Figure 2.3-3 shows the interface of SenSat Importer.

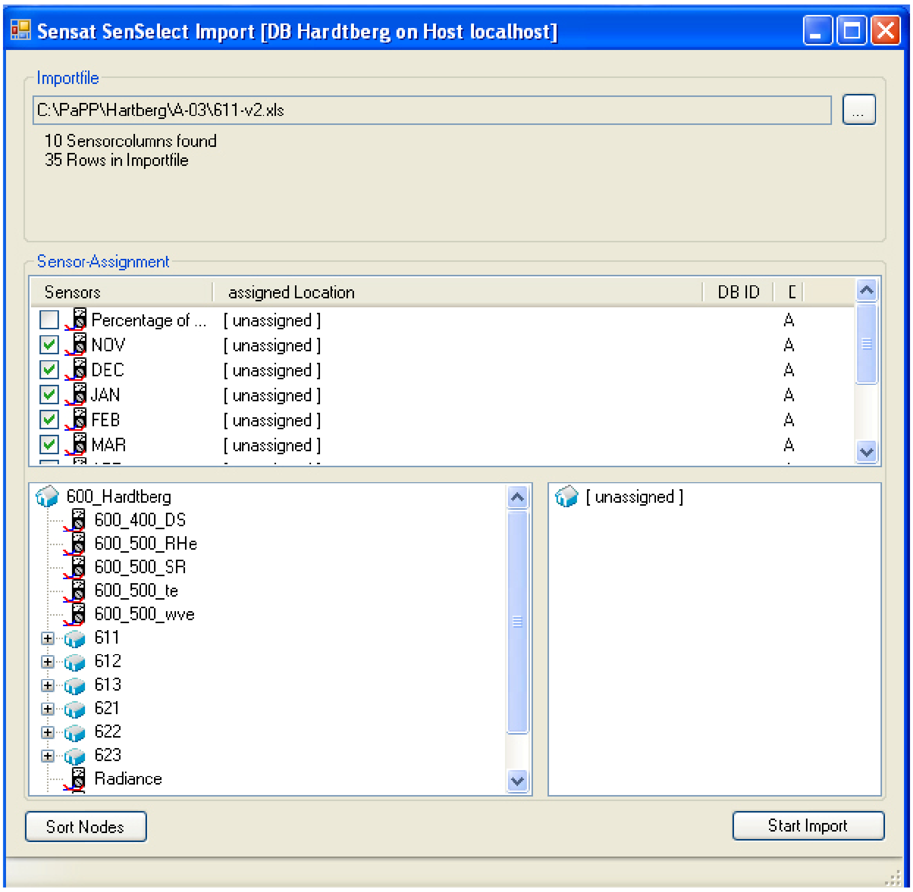

Figure 2.3-3 *User interface of the Excel importer application*

2.3.3.2 Data Query Application

Data query reads the data of selected sensors in a specified duration of time and exports the data. For the analysis, the data in working days and hours between 6:00h and 18:00h in building HB and 8:00h to 20:00h in building VC was considered. In the time part, the information for each building is specified and can be saved for loading again. According to this date/time, the selected data will be exported and saved in a CSV file that can be converted later to Excel files. The main window of data query application is shown in Figure 2.3-4.

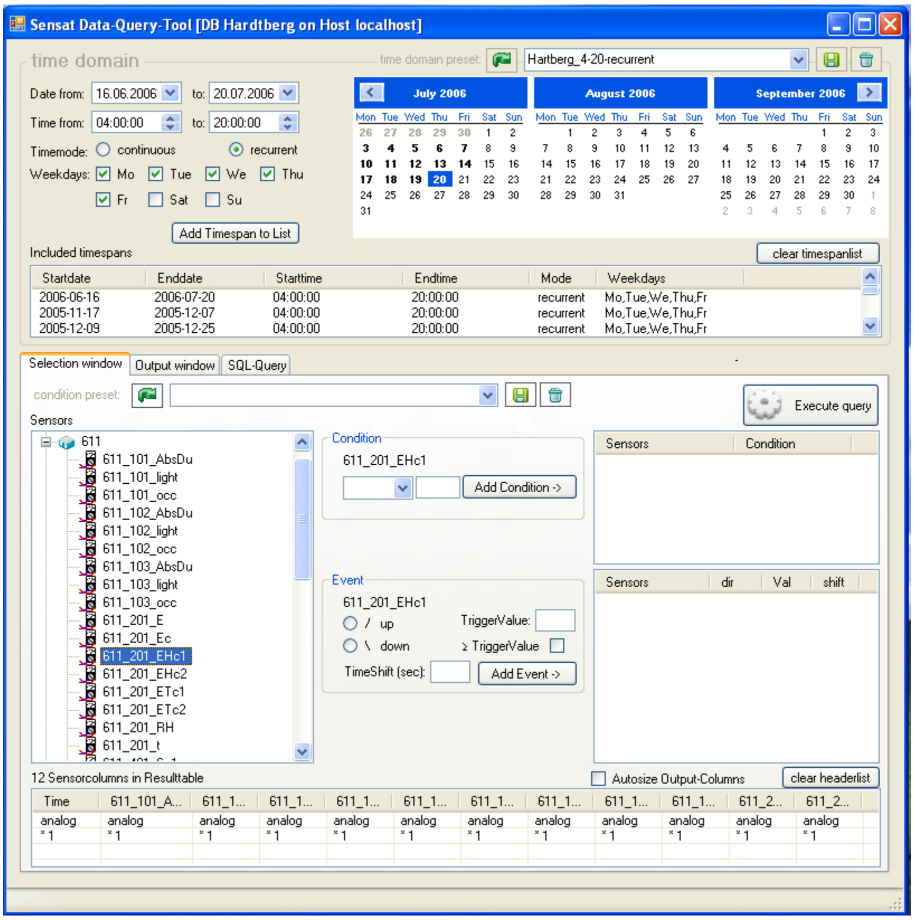

Figure 2.3-4 User interface of the data query application

2.3.4 Image processing

34,500 digital images for building HB and 105,000 digital images for building VC were taken during nine/twelve months of observation. The cameras registered the state of windows and shades every ten minutes.

In order to process the images and define the position of the shades and state of the windows, a Semi-Automated application was designed and developed based on LabVIEW. The program compares contrast in pixels in sequential images and if there is a change (more than 10%), it shows the image so that the user can specify the position of the shades and windows. The accuracy of comparing two pictures in the program could be defined; for example, 900 means if the similarity between the two sequential pictures is less than 90%, the subsequent picture will be shown to the user. Figure 2.3-5 and Figure 2.3-6 show snapshots of the graphical user interface of the LabVIEW application for building VC and HB.

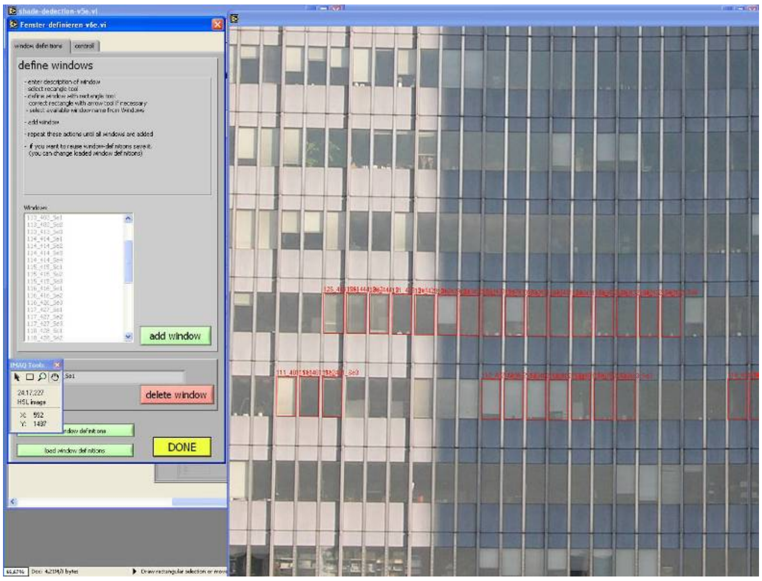

Figure 2.3-5 Interface of the shades detection program for building VC

Levels of the shades were defined to be 100% when they are fully closed and 0% when they are fully opened. Intermediate levels were defined in 20% steps between fully opened and closed. Internal shades (curtains) were defined to be 0% when they are not applied and 100% when they are applied. States of the windows were defined to be 100% when they are opened and 20% for tilt open and 0% when they are closed.

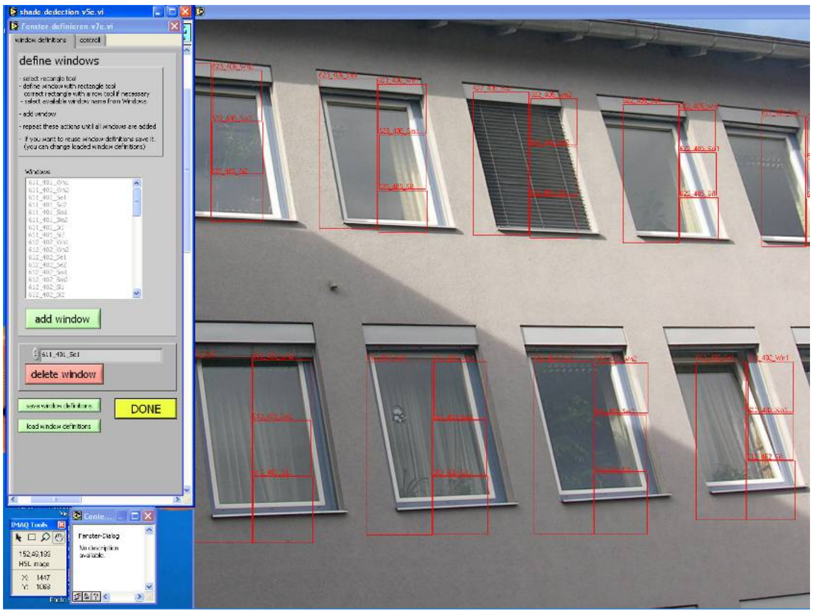

Figure 2.3-6 Interface of the shades/windows detection program for HB

Figure 2.3-7 shows the levels of the shades in two offices in building VC.

The results of the processed images were structured in Excel files with header, picture name, date of capture and name of windows and shades. As the time step interval for the other measurements was 5 minutes and images were taken every 10 minutes, the out put files were processed by SenSelect in order to unify them for the analysis.

Figure 2.3-7 Shade position steps

2.3.5 Calibration of HOBO illuminance sensors

Calibration of Hobo sensors was crucial according to the technical specifications. Each sensor was calibrated individually. They were calibrated with high accurate Minolta T-10 illuminance meters in two different conditions; first under artificial light and then under daylight situations. The measurements of artificial light were done at 0, 40, 75, 225, 450 and 680 lx. To derive the correlations, the Hobo values were plotted versus mean Minolta values and then the artificial and daylight correlation functions were merged for a new correlation factor to calibrate the Hobos (see Figure 2.3-8).

Figure 2.3-8 Calibration of the light sensors

2.3.6 Calibration of IT-200 sensors

For the purpose of IT calibration, a set of experiments was done by installing four IT sensors pointing towards a test workstation. The occupant wrote the time when he was present at his workstation. The IT recorded data were downloaded and processed by SenSelect. According to the comparing data, by filing five-minute gaps the accuracy of the sensor data increases to 95%.

The experiment for calibration of IT sensors is presented in Figure 2.3-9 .

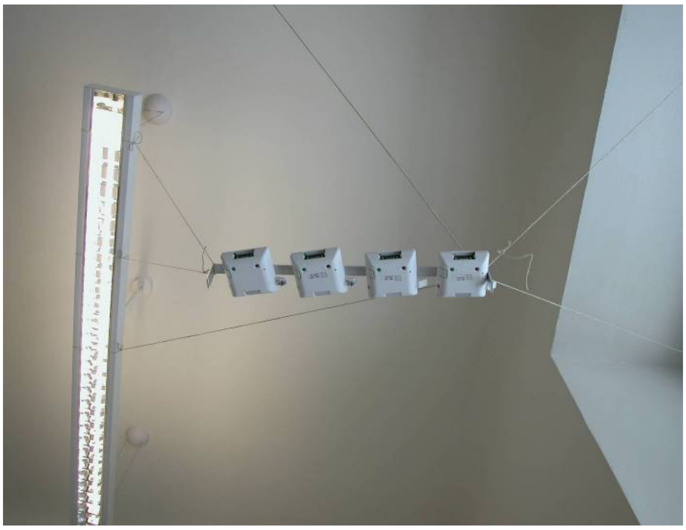

Figure 2.3-9 Calibration of IT-200 sensors

2.3.7 Derivation of horizontal illuminance from measured vertical illuminance

As in many cases in building VC, horizontally installation of HOBO sensors on the workstations was not possible, vertical illuminance on the wall was measured. Therefore, it was necessary to convert vertical illuminance levels on the wall to horizontal illuminance levels on the table and also on head position of the occupants. A set of measurements was conducted for each workstation using three HOBO sensors, one mounted on the table, one on the head position that was about 50 cm above the table and the last, on the original position of the sensor. Figure 2.3-10 shows the view of installed HOBO sensors for the conversion.

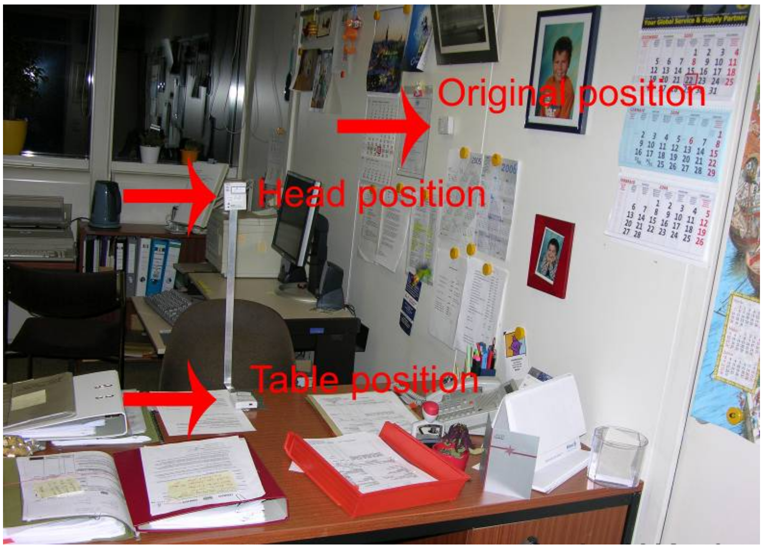

Figure 2.3-10 *A set of sensors installed in a room in VC for derivation of horizontal illuminance from vertical illuminance*

Figure 2.3-11 shows, as an example, the correlation between the two sets of data in a room in VC.

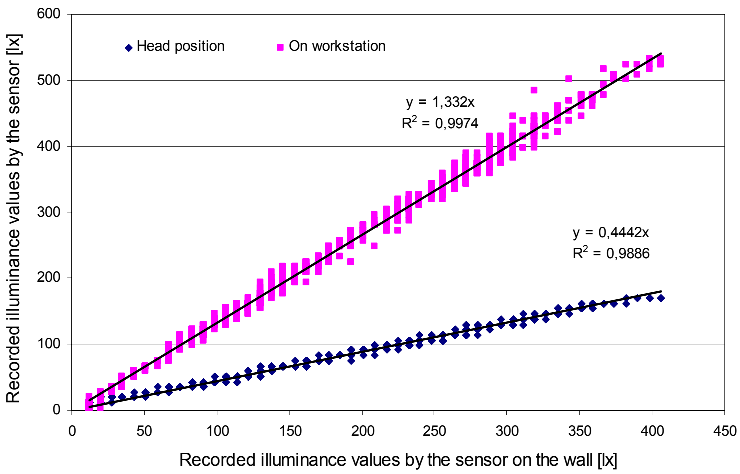

Figure 2.3-11 *Converting vertical illuminance into horizontal illuminance on the workstation for a room in VC*

2.3.8 Computational derivation of vertical irradiance (façade)

Our weather stations provided horizontal global illuminance measurements. Thus, it was necessary to computationally derive incident irradiance values on vertical (or inclined) building surfaces from measured global irradiance values. The derivation was performed using the RAD method, which was found to be suitable method compared to H&K and MET methods (Mahdavi et al. 2006).

This method involves the use of RADIANCE lighting simulation system (Ward et al. 2003) which uses backward ray-tracing methodology. Perez All-weather sky (Perez et al. 1993) was used as the underlying sky model. Perez All-weather sky model requires the input of both diffuse horizontal and direct normal irradiance. As the measurements for these parameters were not available during this experiment, the diffuse horizontal component is derived from the measured global horizontal irradiance. In order to derive the diffuse fractions from the measured global horizontal irradiance, the algorithm suggested by Reindl et al. (1990) was used. This algorithm considers following parameters: clearness index (k_t), sun altitude (a) (Solar altitude of year 2005), outdoor air temperature (T_a) and the relative humidity (ϕ). The measurements of global horizontal irradiance, outdoor air temperature and the relative humidity were obtained from the weather stations. The details are presented in appendix 9.1.

2.4 Data analysis

2.4.1 General data structure

Collected data were structured with date/time stamp for each parameter in excel files and stored in database. The data analysis was considered through two categories: states (S) and events (E). States indicate the status of the systems (S_S); (lights on/off, status of shades/windows), indoor environmental parameters (S_i); (air temperature, illuminance level), Outdoor environmental parameters (S_e); (outdoor temperature, global irradiance) and state of occupancy (S_O); (occupied/vacant). Events show the actions that can be related to system (E_S); (switch lights on/off, pull shades up/down or open/close the windows) or occupancy (E_O); (entering into/leave the office). The general data structure is presented in Table 2-3 (Mahdavi et al. 2007b).

Table 2-3 The structure of the collected data

Data	Type	Instances
Events (E)	System-related (Es)	Switch lights on/off
		Pull shades up/down
	Occupancy-Related (Eo)	Entering into / leaving an office
States (S)	System-related (Ss)	Lights on /off
		Position of shades/windows
	Indoor environ. (Si)	Air temperature [°C]
		Illuminance level [lx]
	Outdoor environ. (Se)	Outdoor temperature [°C]
		Global irradiance [W/m^2]
	Occupancy-Related (So)	Office/workstation occupied/vacant

For the purpose of analysis, the range of data considered was limited to working days and hours 6:00 to 18:00 in HB and 8:00 to 20:00 in VC.

The hypothesis of this study assumes that there are relationships between nature and frequency of user's actions (events), state of systems in buildings and state of environmental parameters. In order to define these correlations, data analysis was done based on events and states in particular conditions.

For example, the light intensity on workstations could be a reason that occupants switch on/off the lights, or the solar radiation on the façade is a reason that they change the position of the shades (pull up/down), or the outdoor/indoor temperature could trigger users to open or close the windows. In these cases, the states of environmental parameters, immediately before the events' occurrence, are the main factors to analyze the frequency and probability of control actions (E_s versus S_i / S_e).

In order to know when occupants switch on/off the lights, the state of environmental parameters, immediately before the events' occurrence, was considered. To analyze the frequency/probability of switching on the lights upon arrival to the offices or switching on/off the lights while being in the office (intermediate switching on/off events), the state of illuminance on the workstations, immediately before the action occurrence, was considered.

To calculate usage of artificial lights in the offices, state of system (S_s) versus state of occupancy (S_o) was considered. Moreover, these two states were applied to find the probability of switching off the lights when the occupants leave their offices in relation to the duration of absence before the next entering.

3 Results

The results are divided into 5 main topics: occupancy related analysis, operation of artificial lighting, shade system related, ventilation, and interviews. The results of each building are presented in separate sections.

3.1 HB

3.1.1 Occupancy

Figure 3.1-1 shows the mean occupancy level over the course of a reference day (averaged over the entire observation period). Note that this Figure represents the presence at the user's workstation and not the building. Moreover, as Figure 3.1-2 demonstrates, the occupancy patterns in individual workstations can vary considerably.

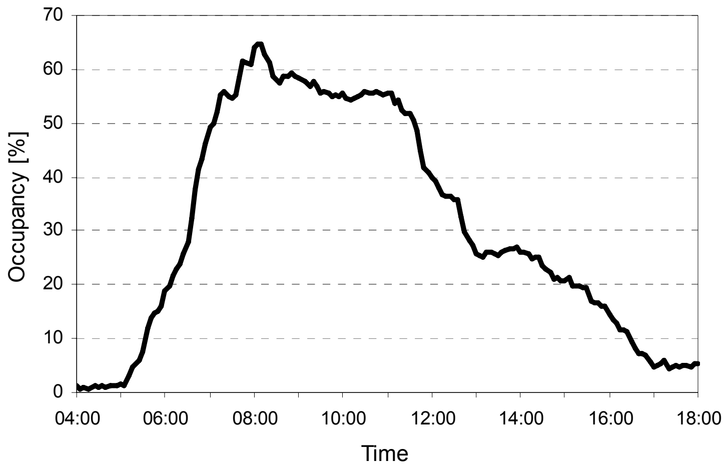

Figure 3.1-1 *Mean occupancy level over the course of a reference day in HB, averaged over all observed workstations*

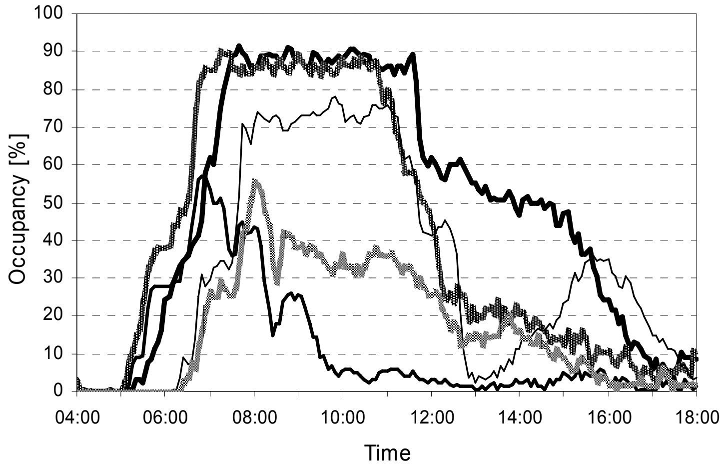

Figure 3.1-2 *Observed occupancy levels in 5 workstations in HB, over the course of a reference day*

Figure 3.1-3 illustrates the state of occupancy levels in the observed months of measurement.

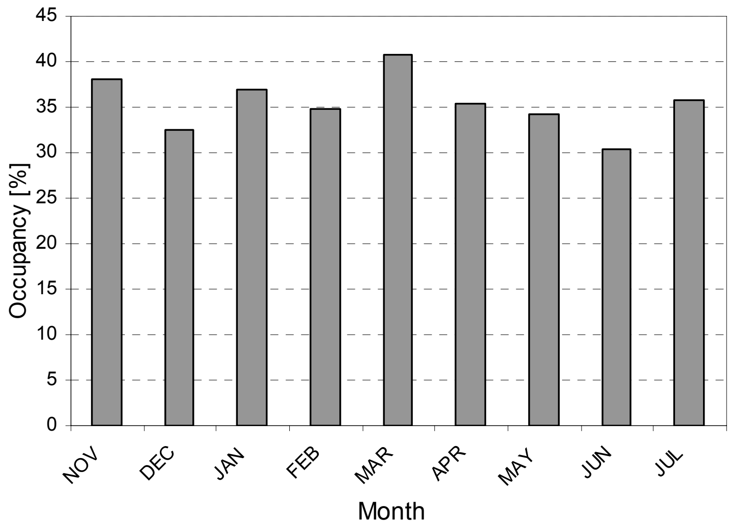

Figure 3.1-3 *Monthly occupancy levels in the measurement period in HB*

3.1.2 Lighting

Figure 3.1-4 and Figure 3.1-5 show the mean lighting operation over all offices and in occupied offices over the course of a reference day.

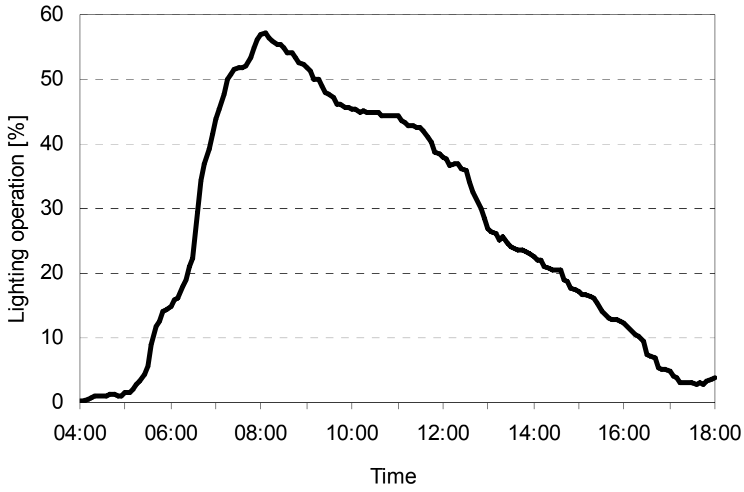

Figure 3.1-4 Mean lighting operation in HB offices over the course of a reference day

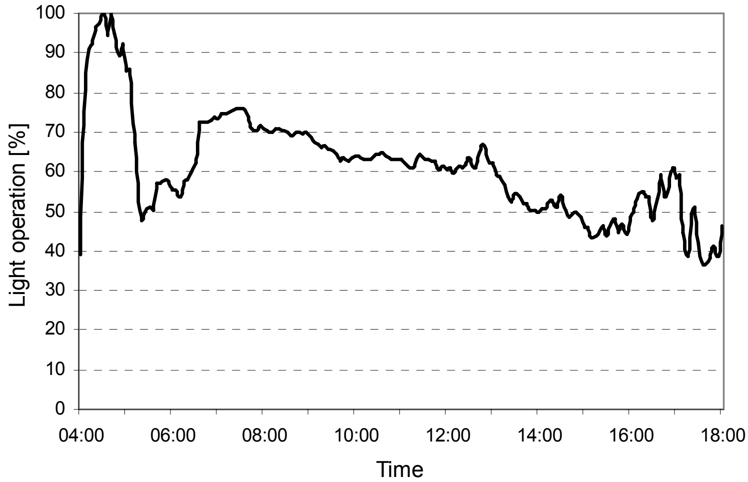

Figure 3.1-5 Mean lighting operation in occupied offices of HB over the course of a reference day

To provide an impression of the differences amongst individual light usage profiles, Figure 3.1-6 shows the lighting operation in each observed office for the entire monitoring period in the working hours. Figure 3.1-7 shows the observed effective lighting load in the course of a reference day.

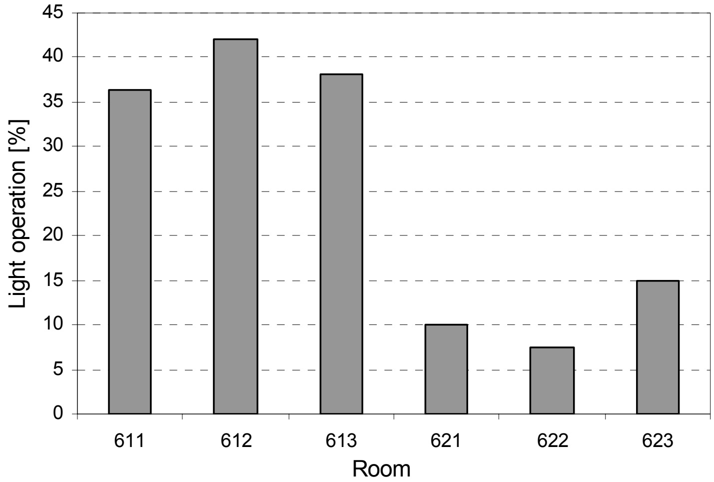

Figure 3.1-6 *Duration of lighting operation (in percentage of respective overall occupied hours) in HB offices*

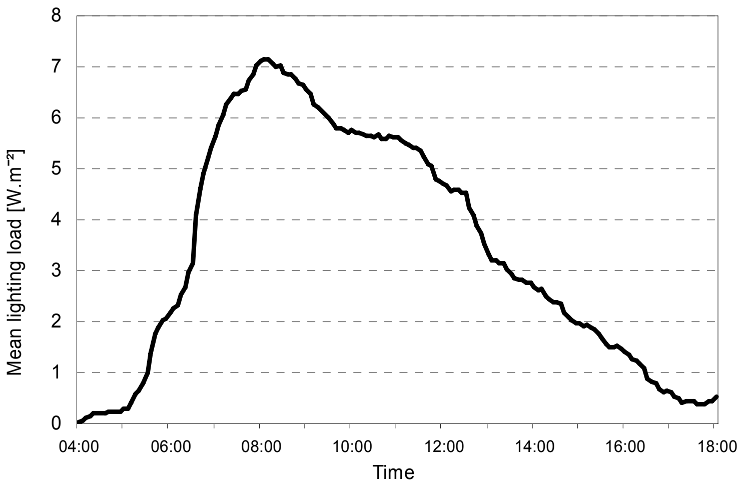

Figure 3.1-7 *Mean lighting electricity load in HB offices over the course of a reference day*

Figure 3.1-8 shows the probability that an occupant would switch the lights on upon arrival in his/her office as a function of the prevailing task illuminance level immediately before the arrival.

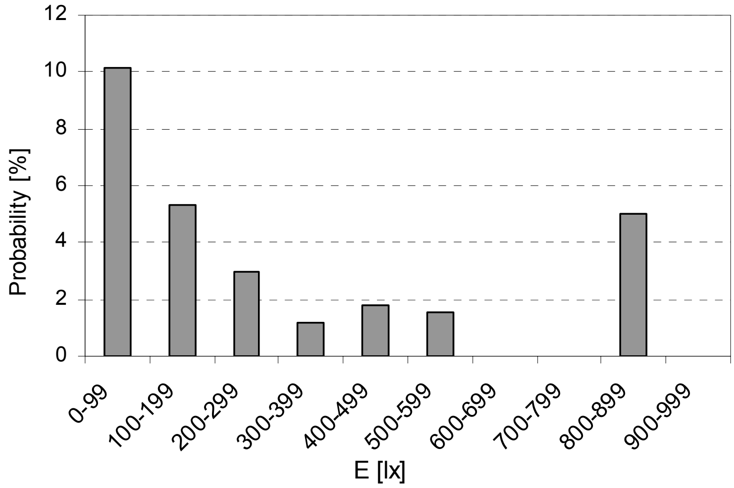

Figure 3.1-8 Probability of switching the lights on upon arrival as a function of the prevailing task illuminance level in the office in HB

Figure 3.1-9 shows the normalized relative frequency of (intermediate) actions "switching the lights on" by occupants who have been in their offices for at least 15 minutes before and after the occurrence of the action as a function of the prevailing task illuminance level immediately prior to the action's occurrence. Normalization denotes in this context that the actions are related to both occupancy and the duration of the time in which the relevant illuminance ranges (bins) applied.

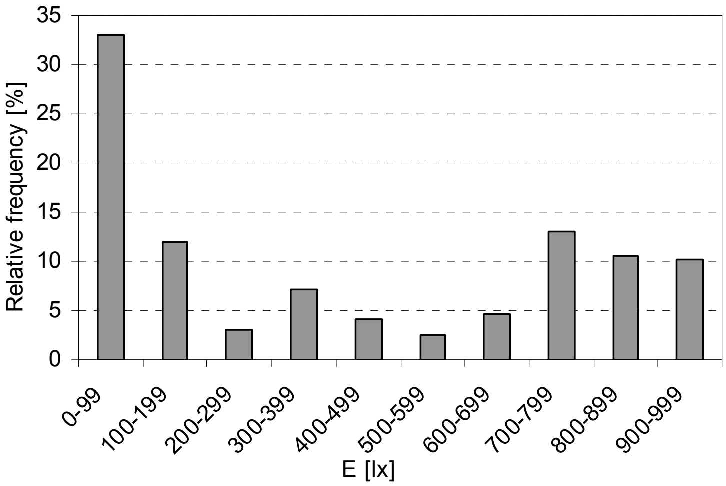

Figure 3.1-9 *Normalized relative frequency of intermediate light "switching on" actions as a function of the prevailing task illuminance level in HB offices*

Figure 3.1-10 shows the normalized relative frequency of all "switching the lights on" actions (upon arrival and intermediate) as a function of the time of the day with mean global horizontal irradiance. In this case too, actions are normalized with regard to occupancy.

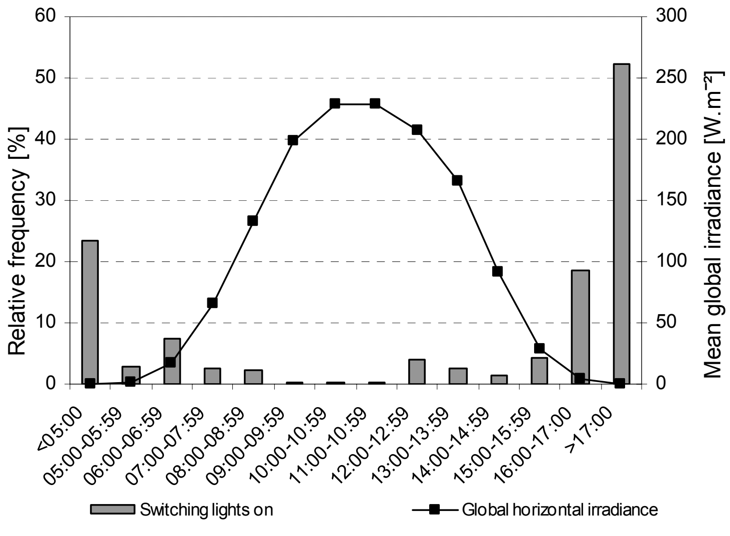

Figure 3.1-10 *Normalized relative frequency of "switching on" actions with mean global horizontal irradiance for a reference day in HB offices*

Figure 3.1-11 shows the probability that an occupant would switch off the lights upon leaving his/her office as a function of the time that passes before he/she returns to the office.

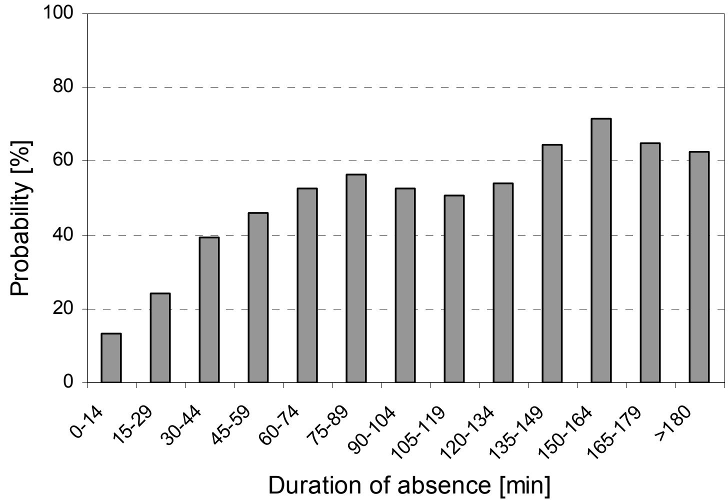

Figure 3.1-11 Probability of switching the lights off in HB as a function of the duration of absence from the offices

Figure 3.1-13 shows normalized relative frequency of (intermediate) "switching the lights off" actions as a function of the prevailing illuminance level, immediately prior to the action's occurrence. Intermediate in this context means more than 15 minutes after arrival and 15 minutes before leaving the office. Normalization denotes in this case the consideration of occupancy and the applicable durations of the respective illuminance bins while deriving the actions' frequency.

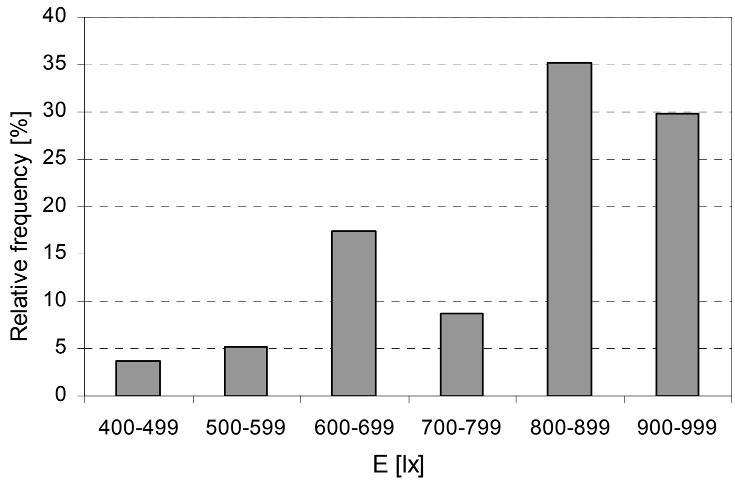

Figure 3.1-12 *Normalized relative frequency of switching the lights off in HB offices as a function of the prevailing illuminance level, immediately prior to the action's occurrence*

3.1.3 Shading

As offices in HB have curtains and external shades (Venetian blinds), for the purpose of the shade analysis both types were considered. Figure 3.1-13 and Figure 3.1-14 show mean monthly shade deployment degree together with mean global horizontal irradiance in the observed months and over the course of a reference day.

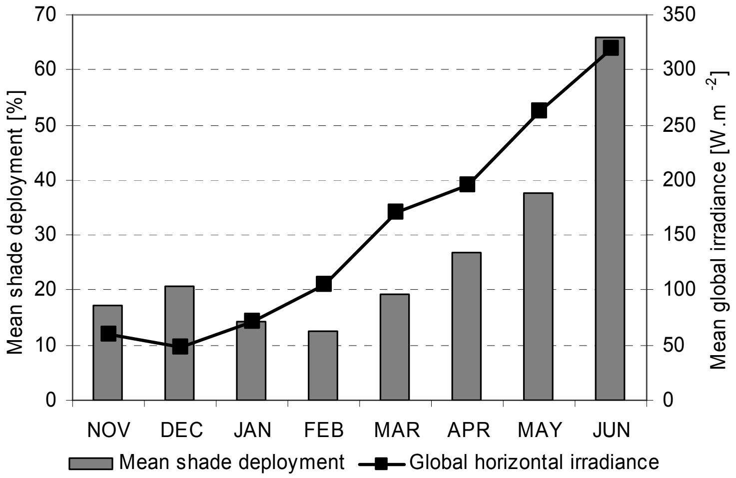

Figure 3.1-13 Mean monthly shade deployment degree together with mean global horizontal irradiance in HB offices

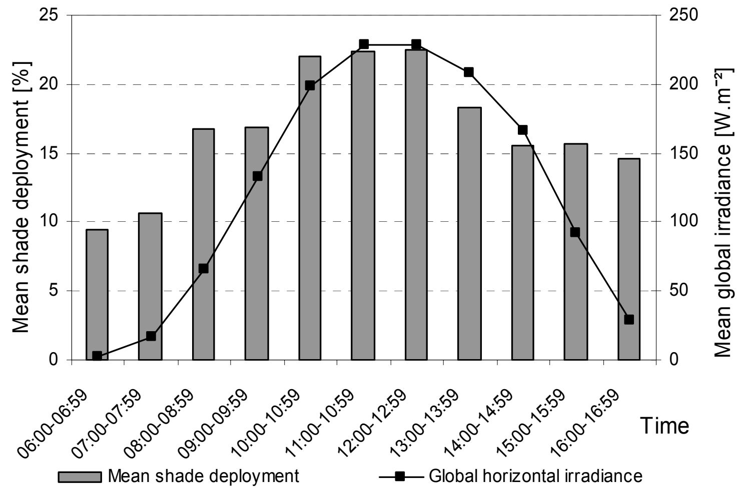

Figure 3.1-14 Mean shade deployment degree together with mean global horizontal irradiance over the course of a reference day in HB offices

Figure 3.1-15 and Figure 3.1-16 show normalized relative frequency of "opening shades" and "closing shades" as a function of the global horizontal irradiance in HB. The number of actions is normalized with regard to occupancy and the time during which the respective irradiance bins applied.

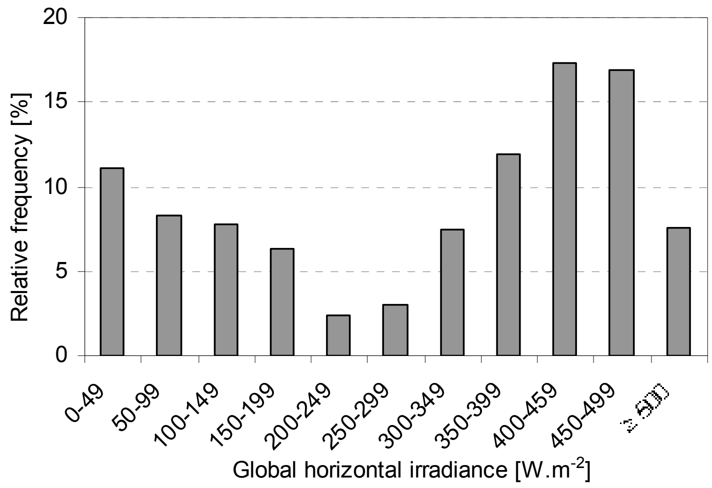

Figure 3.1-15 Normalized relative frequency of opening shades as a function of global horizontal irradiance in HB offices

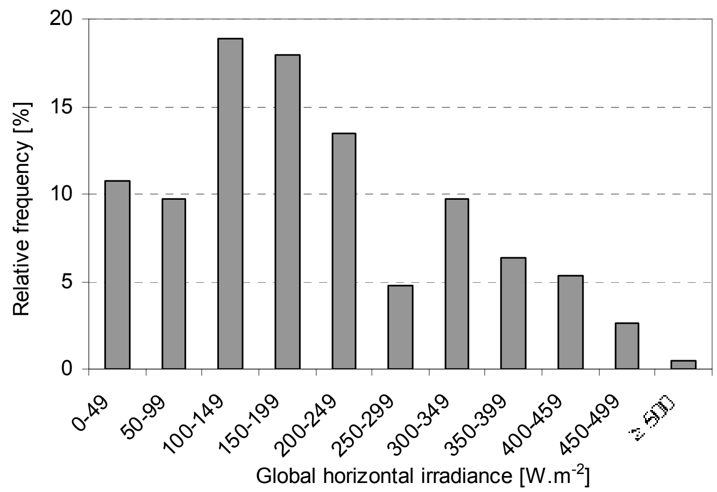

Figure 3.1-16 Normalized relative frequency of closing shades as a function of global horizontal irradiance in HB offices

Figure 3.1-17 and Figure 3.1-18, show normalized relative frequency of "opening shade" and "closing shade" actions with mean global vertical irradiance over the course of a reference day.

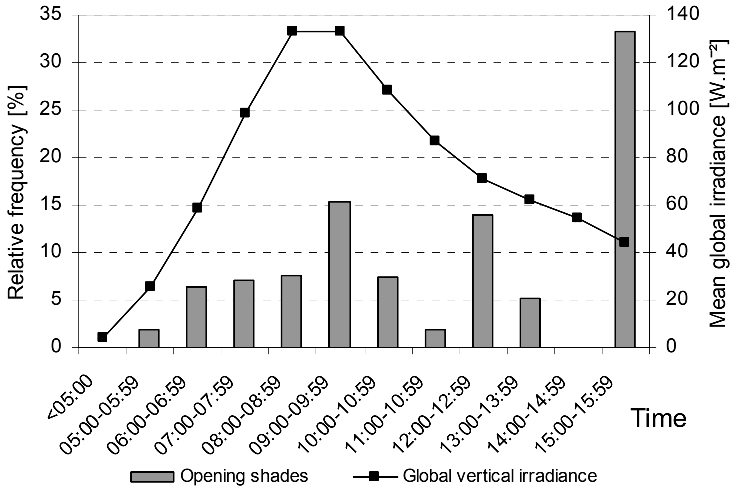

Figure 3.1-17 Normalized relative frequency of "opening shade" actions with mean global vertical irradiance over the course of a reference day in HB offices

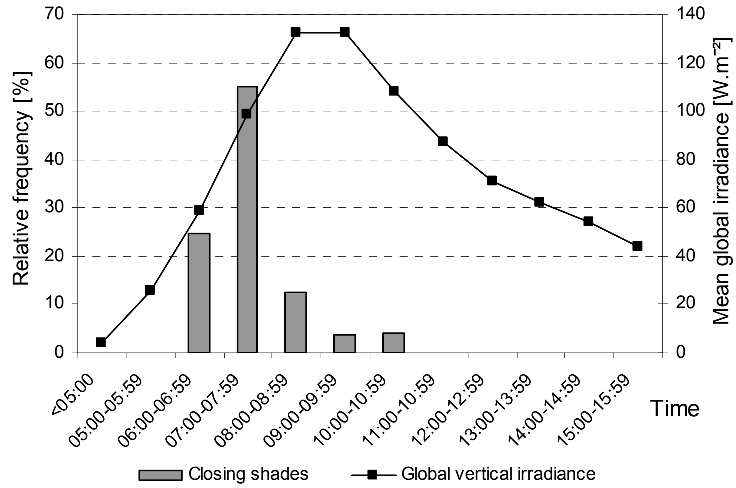

Figure 3.1-18 Normalized relative frequency of "closing shade" actions with mean global vertical irradiance over the course of a reference day in HB offices

Figure 3.1-19 and Figure 3.1-20 illustrate mean shade deployment degree as a function of global horizontal irradiance and global vertical irradiance averaged over all observed offices.

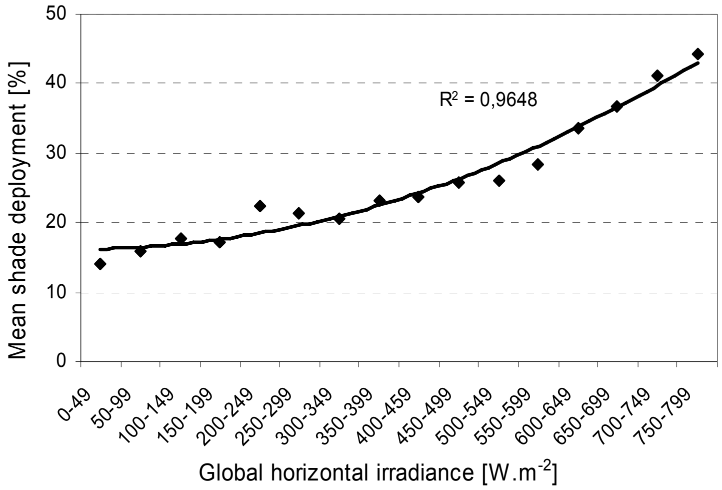

Figure 3.1-19 *Mean shade deployment degree as a function of global horizontal irradiance averaged over all observed offices in HB offices*

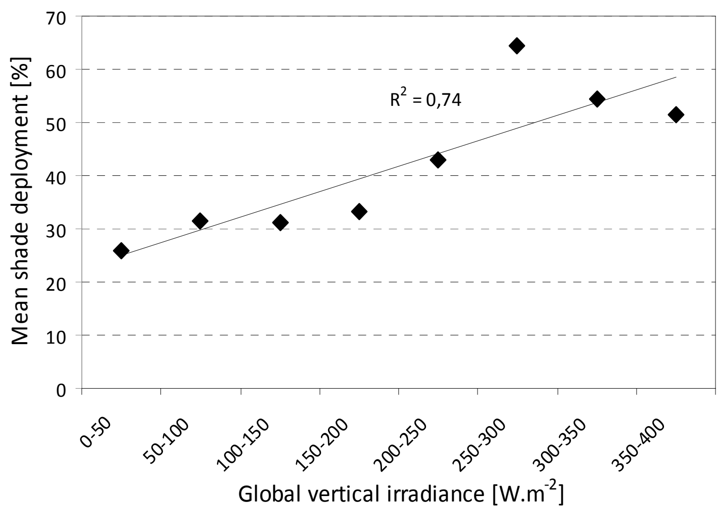

Figure 3.1-20 *Mean shade deployment degree as a function of global vertical irradiance averaged over all observed offices in HB offices*

3.1.4 Natural ventilation

The results included in this section reveal the relationship between user behavior concerning opening and closing windows and indoor and outdoor temperature, time of the day, and month of the year. To analyze opening actions, both "tilt" and "turned open" actions were considered as opening actions.

Figure 3.1-21 and Figure 3.1-22 show normalized relative frequency of actions "opening" and "closing" windows over the course of a reference day (between 5:00 and 18:00) during the observation period.

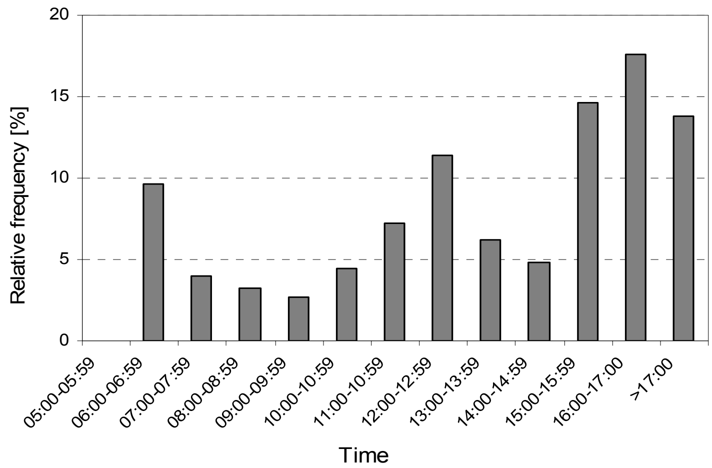

Figure 3.1-21 Normalized relative frequency of "opening window" actions over the course a reference day in HB offices

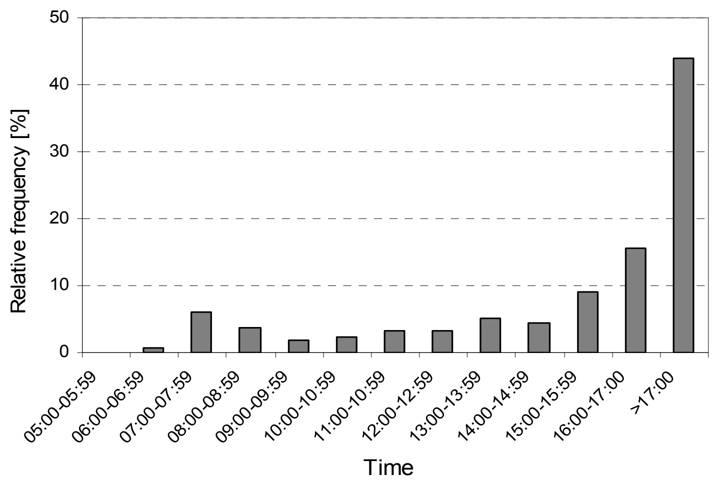

Figure 3.1-22 Normalized relative frequency of "closing window" actions over the course a reference day in HB offices

Figure 3.1-23 and Figure 3.1-24 show normalized relative frequency of opening and closing window actions in the observed months (November 2005 to June 2006).

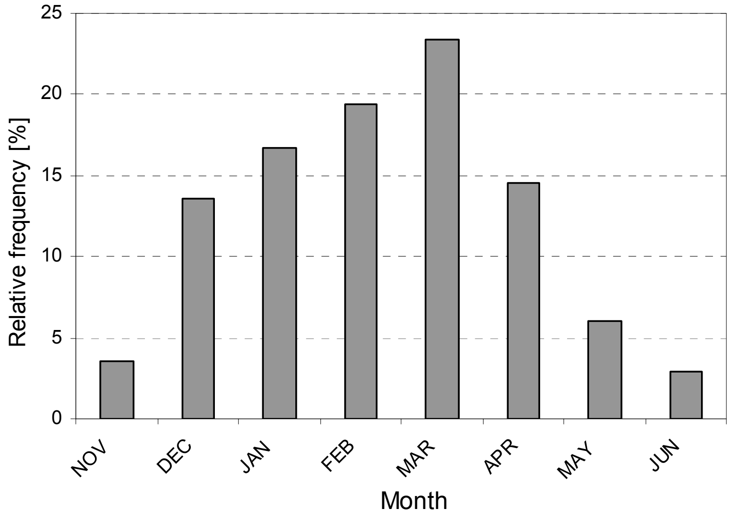

Figure 3.1-23 Normalized relative frequency of "opening window" actions in the observed months in HB offices

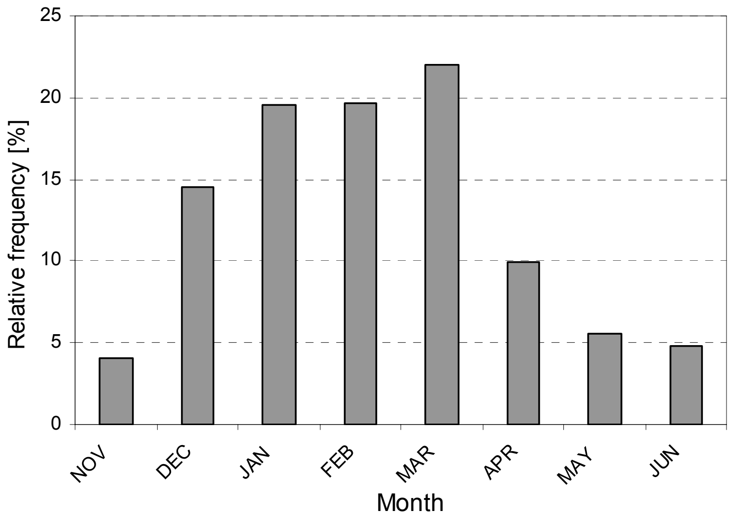

Figure 3.1-24 Normalized relative frequency of "closing window" actions in the observed months in HB offices

Figure 3.1-25 and Figure 3.1-27 illustrate normalized relative frequency of opening and closing windows as a function of the indoor temperature immediately before the action occurs.

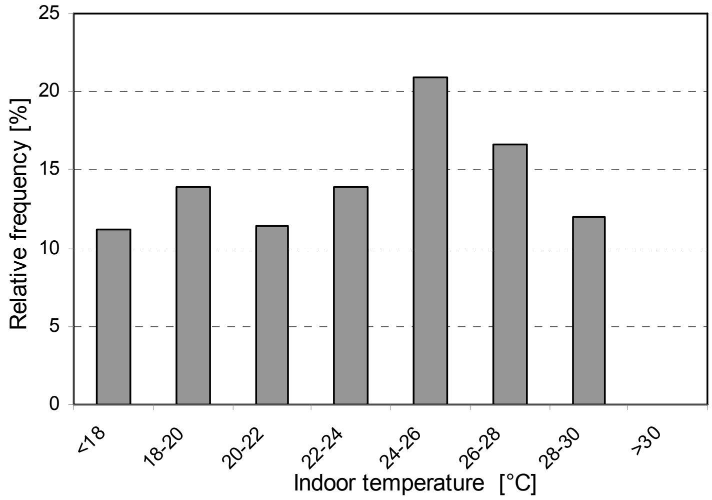

Figure 3.1-25 Normalized relative frequency of "opening window" as a function of indoor temperature in HB offices

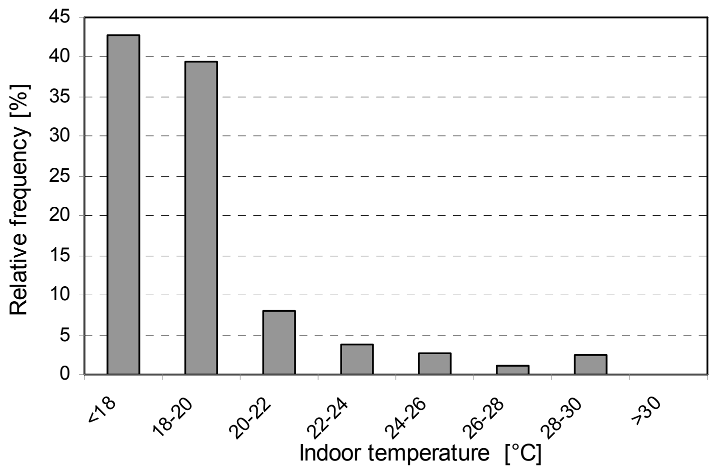

Figure 3.1-26 Normalized relative frequency of "closing window" as a function of indoor temperature in HB offices

Figure 3.1-27 and Figure 3.1-28 present normalized relative frequency of opening and closing windows as a function of outdoor temperature immediately before the action occurs.

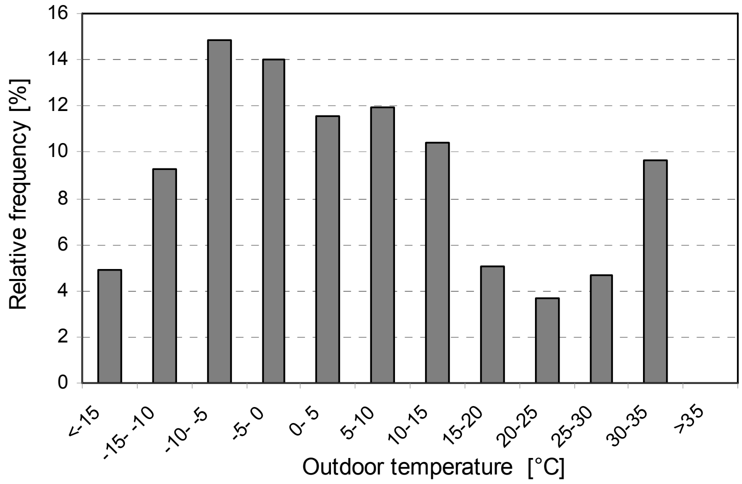

Figure 3.1-27 Normalized relative frequency of "opening window" as a function of outdoor temperature in HB offices

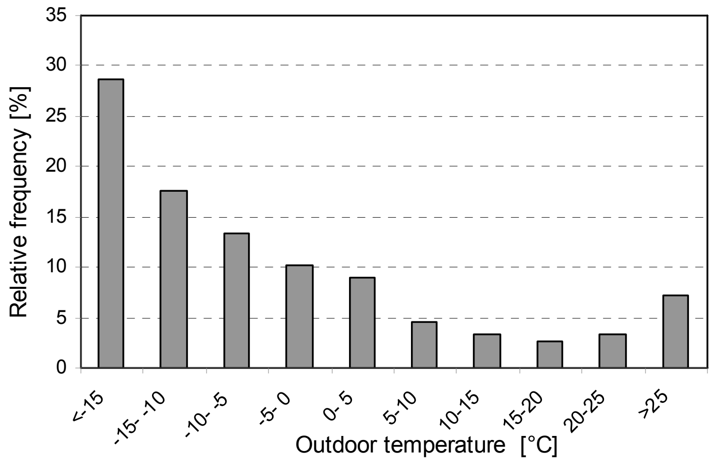

Figure 3.1-28 Normalized relative frequency of "closing window" as a function of outdoor temperature in HB offices

Figure 3.1-29 and Figure 3.1-30 show the probability that an occupant would open the windows upon arrival in his/her office as a function of indoor and outdoor temperature immediately before arrival.

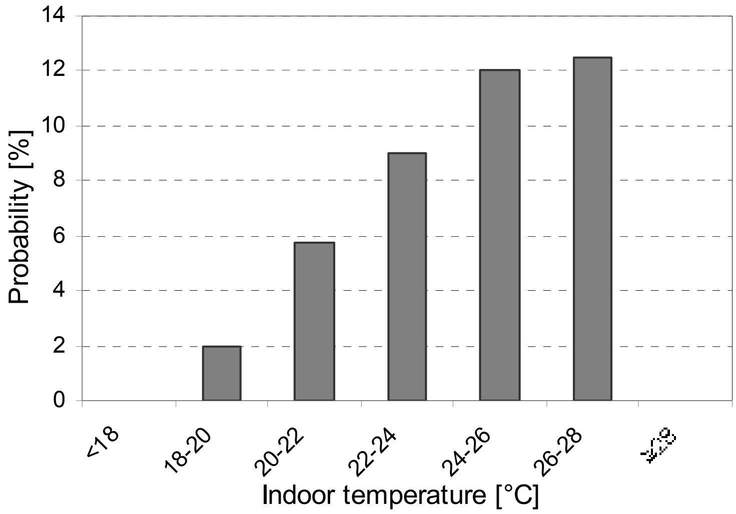

Figure 3.1-29 *Probability of "opening window" upon arrival as a function of indoor temperature in HB offices*

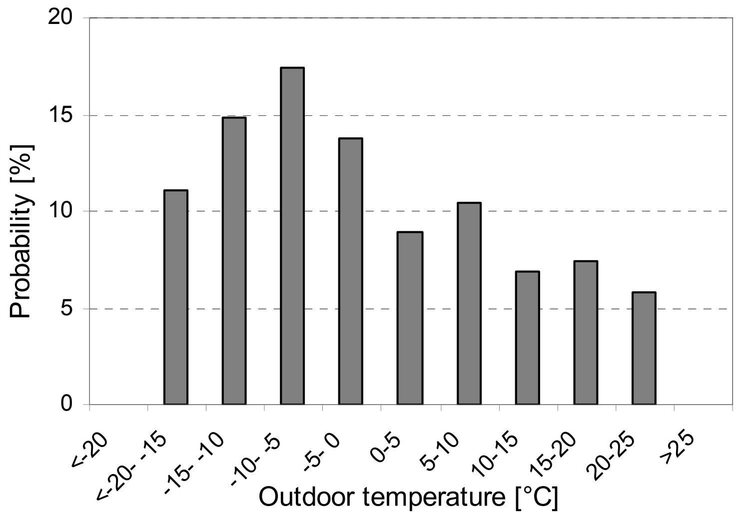

Figure 3.1-30 *Probability of "opening window" upon arrival as a function of outdoor temperature in HB offices*

Figure 3.1-31 and Figure 3.1-32 present the probability that an occupant would close the windows, when leaving his/her office for more than three hours as a function of the indoor and the outdoor temperature immediately before the action occurs.

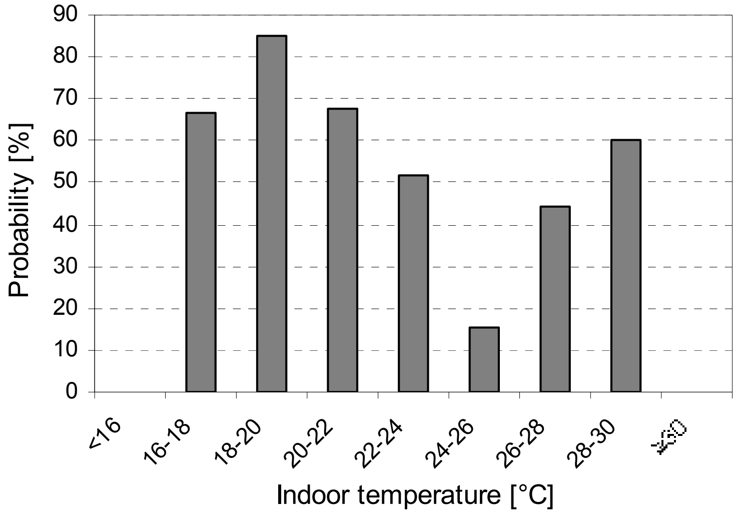

Figure 3.1-31 Probability of "closing window" upon leaving as a function of indoor temperature in HB offices

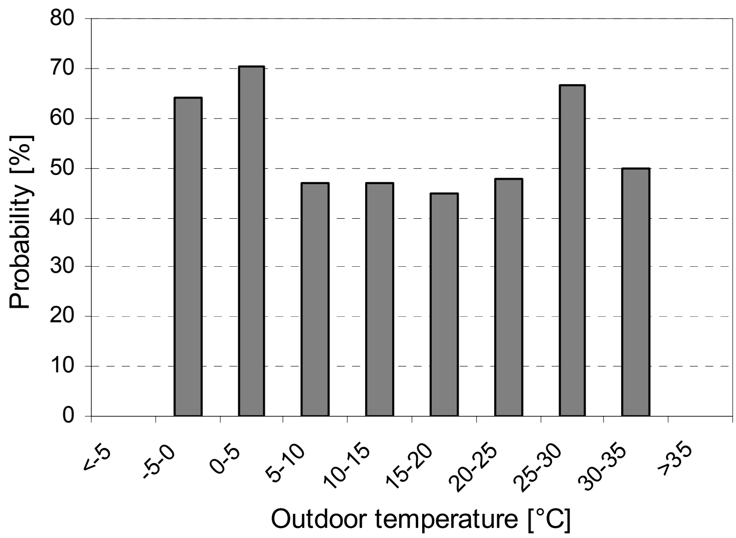

Figure 3.1-32 Probability of "closing window" upon leaving as a function of outdoor temperature in HB offices

Figure 3.1-33 and Figure 3.1-34 illustrate mean window opening degree over the course of a reference day in the observed months.

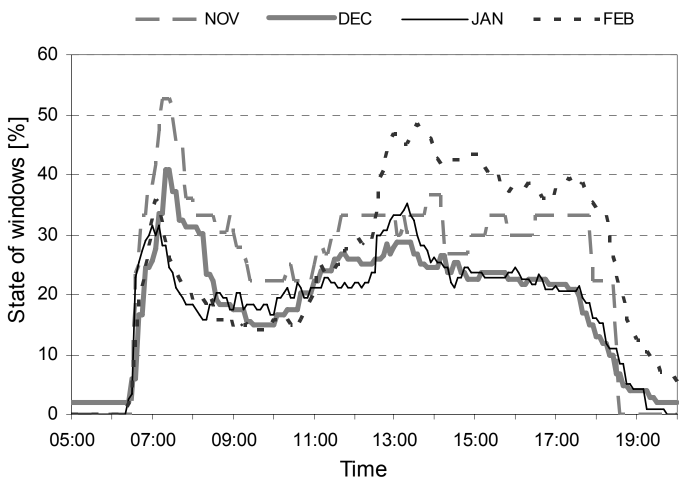

Figure 3.1-33 Mean window opening degree over the course of a reference day in HB offices in November, December, January and February

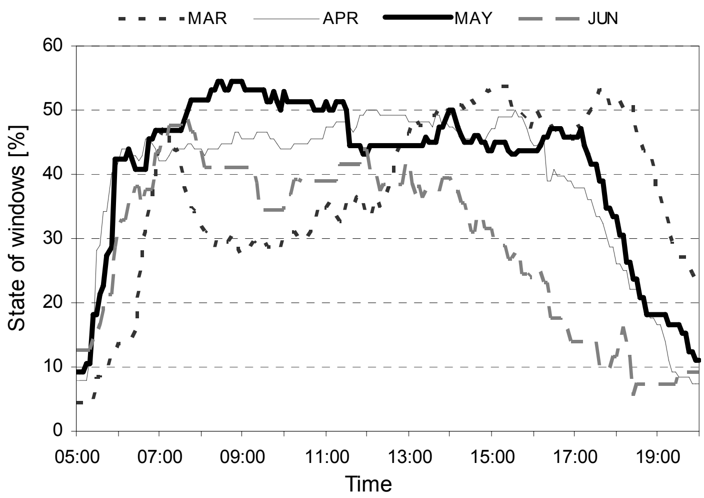

Figure 3.1-34 Mean window opening degree over the course of a reference day in HB offices in March, April, May and June

Figure 3.1-35 and Figure 3.1-36 show mean window-opening degree together with the mean indoor and outdoor temperature in working hours and the observed months.

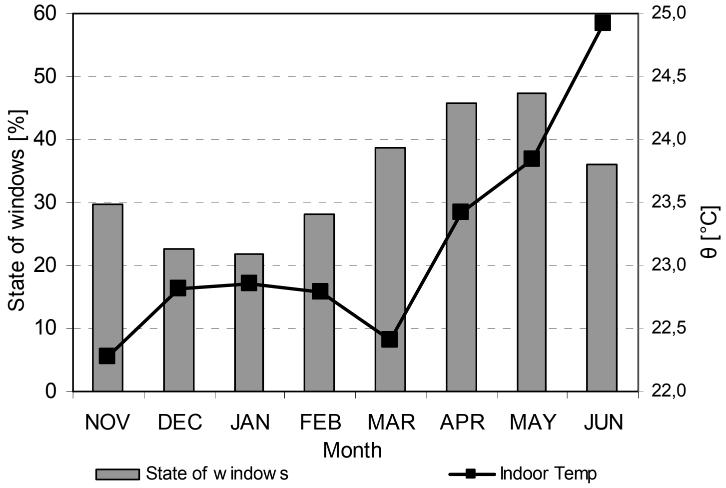

Figure 3.1-35 Mean window opening degree together with mean indoor temperature in the observed months in HB offices

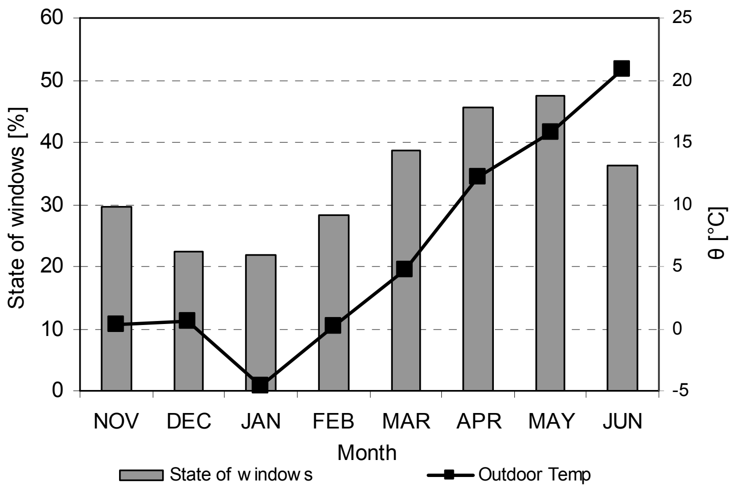

Figure 3.1-36 Mean window opening degree together with mean outdoor temperature in the observed months in HB offices

Figure 3.1-37 and Figure 3.1-38 illustrate normalized relative frequency of opening and closing windows as a function of difference of indoor temperature and neutrality temperature. Neutrality temperature is calculated as follows:

$T_n = 17.6 + 0.31*T_{e.av.}$ (Szokolay 2004)

When T_n is neutrality temperature and T_{eav} is monthly average of outdoor temperature (0:00 – 24:00).

In Table 3-1, the mean outdoor temperature and calculated neutrality temperature from November 2005 to July 2006 is presented.

Table 3-1 Calculated neutrality temperature for HB

Month	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
$T_{e.av}$ (ºC)	0.32	0.11	-4.24	-0.40	3.54	10.77	14.34	18.76	21.35
T_n (ºC)	17.70	17.64	16.28	17.47	18.70	20.94	22.04	23.41	24.22

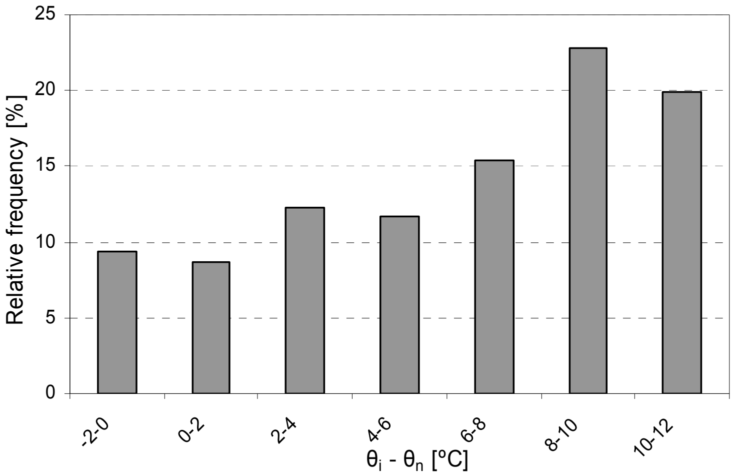

Figure 3.1-37 Normalized relative frequency of "opening window" as a function of difference of indoor temperature and neutrality temperature in HB offices

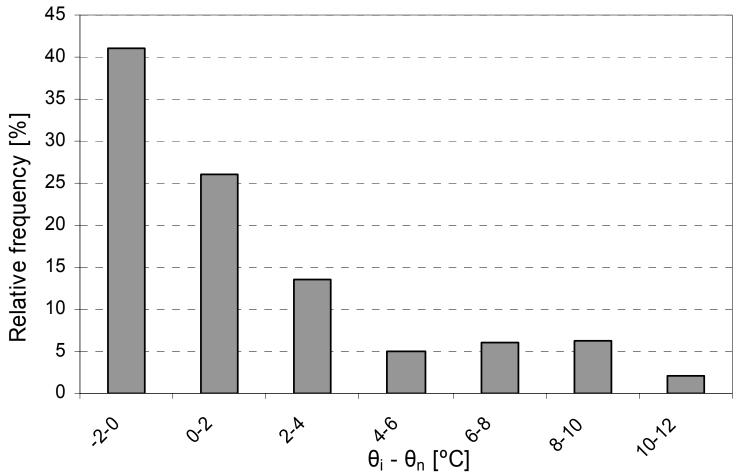

Figure 3.1-38 Normalized relative frequency of "closing window" as a function of difference of indoor temperature and neutrality temperature in HB offices

3.2 VN

3.2.1 Occupancy

Figure 3.2-1 and Figure 3.2-2 illustrate mean occupancy level in VN averaged over the observed period (January to December 2005) and over the course of a reference day. Note that these figures represent the presence in the user's office and not the complex. The data in this and the following occupancy figures is for working days and hours from 8:00 to 20:00.

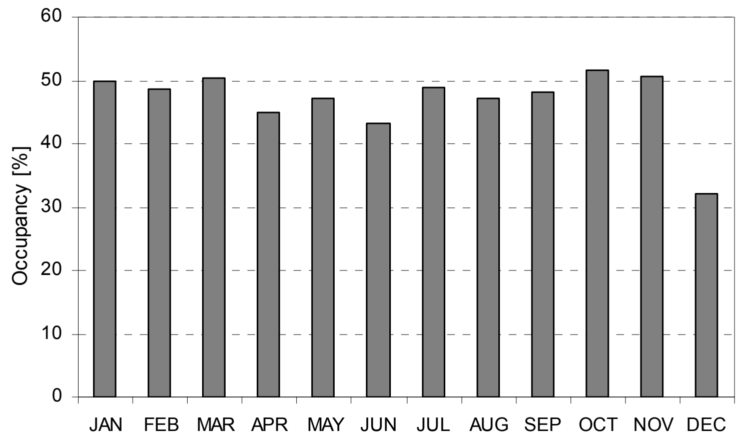

Figure 3.2-1 *Mean monthly occupancy level in VN, averaged over all the observed offices*

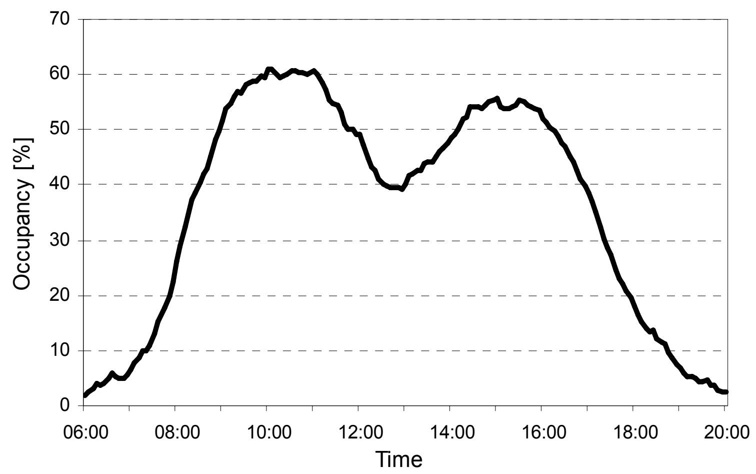

Figure 3.2-2 *Mean occupancy level over the course of a reference day, averaged over all observed offices of VN*

3.2.2 Lighting

Figure 3.2-3 and Figure 3.2-4 show the mean lighting operation over all offices and in occupied offices over the course of a reference day. Obviously, the information in these figures is about the general light usage tendency in all observed offices.

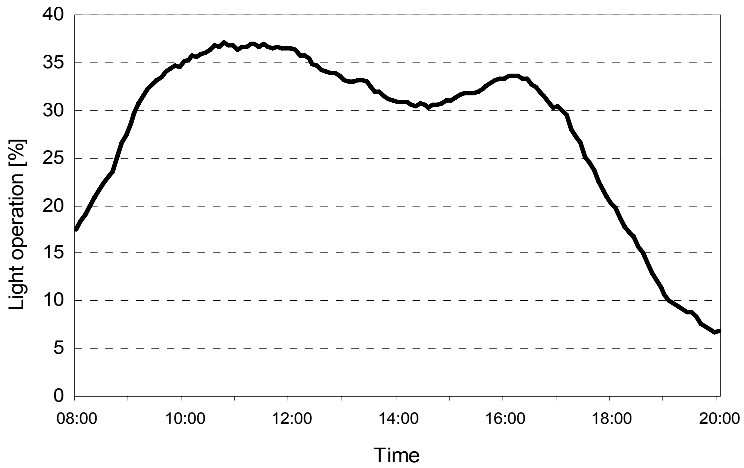

Figure 3.2-3 Lighting operation in VN offices over the course of a reference day

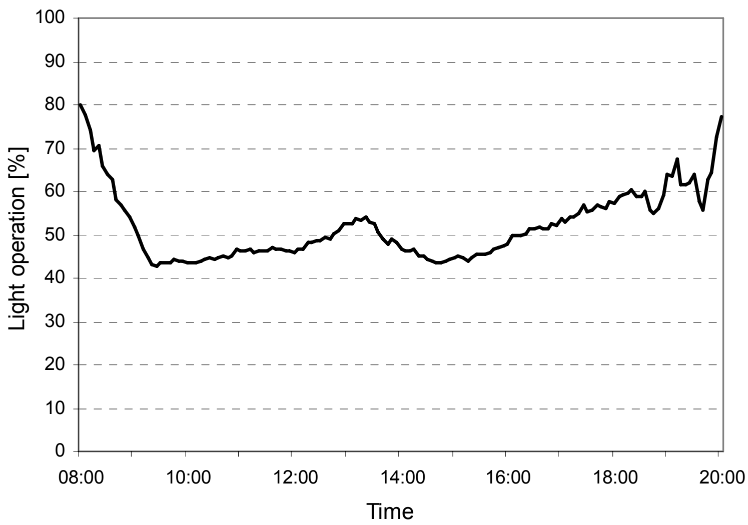

Figure 3.2-4 Mean lighting operation in occupied offices of VN over the course of a reference day

To provide an impression of the differences amongst individual light usage profiles, Figure 3.2-5 shows the lighting operation in each observed office for the entire monitoring period in the working hours. Figure 3.2-6 illustrates mean lighting electricity load over the course of a reference day averaged over the observed offices in VN.

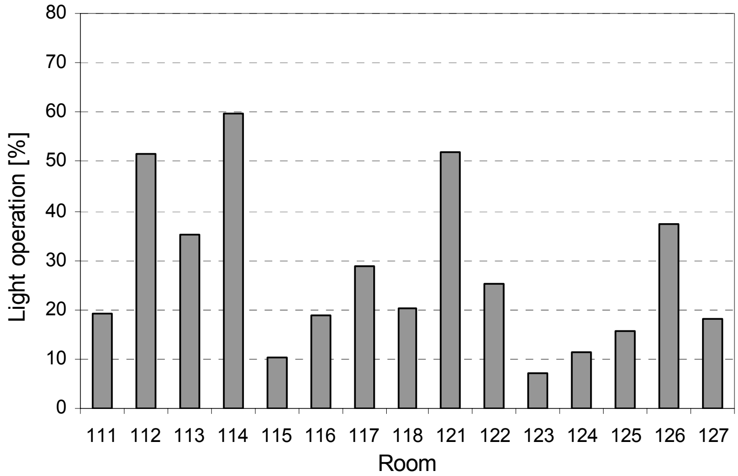

Figure 3.2-5 Duration of lighting operation (in percentage of respective overall working hours) in VN offices

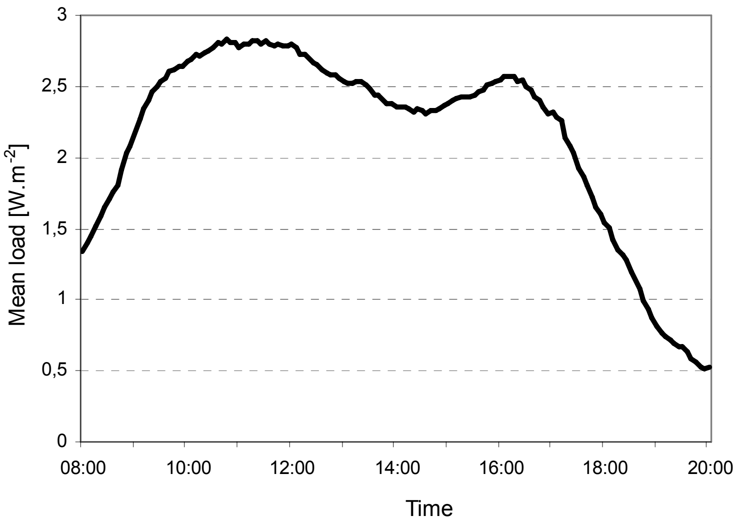

Figure 3.2-6 Mean lighting electricity load over the course of a reference day averaged over the observed offices in VN

Figure 3.2-7 shows the probability of switching the lights on upon arrival in the office as a function of the prevailing task illuminance level immediately before the arrival.

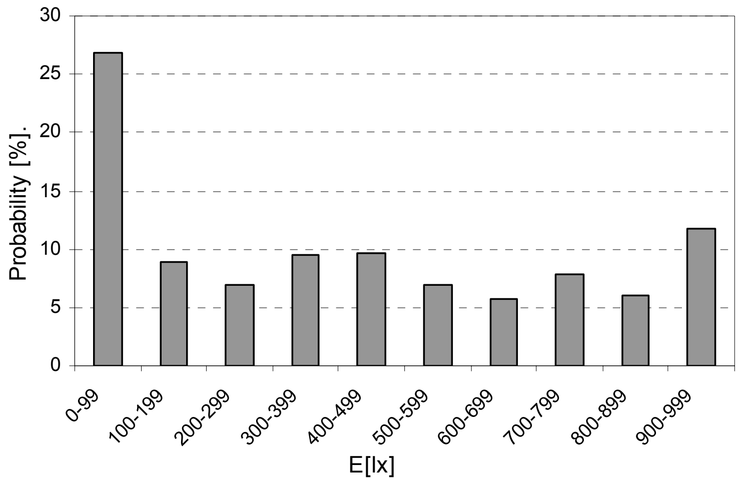

Figure 3.2-7 *Probability of switching the lights on upon arrival in the office as a function of the prevailing task illuminance level immediately before the arrival in VN offices*

Figure 3.2-8 shows normalized relative frequency of intermediate actions "switching light on" by the occupants who have been in their offices for more than 15 minutes before and after the occurrence of the action as a function of the prevailing task illuminance level immediately prior to the action's occurrence. Intermediate in this context means at least 15 minutes after arrival and 15 minutes before leaving the office. Normalization denotes in this context that the actions are related to both occupancy and the duration of the time in which the relevant illuminance ranges (bins) applied.

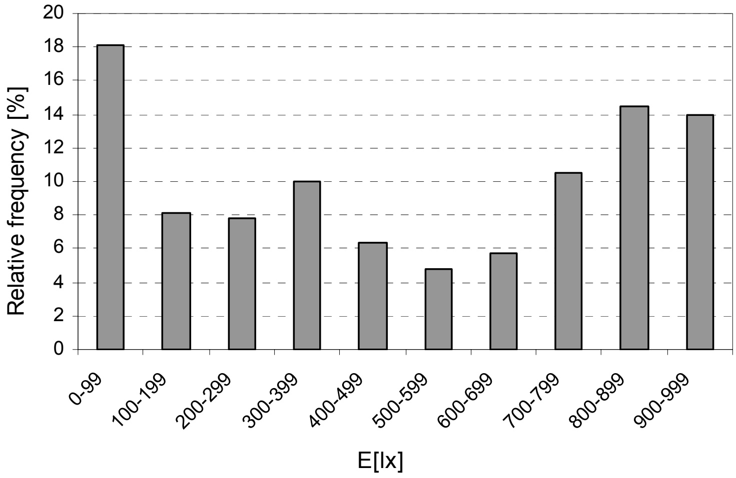

Figure 3.2-8 *Normalized relative frequency of intermediate light "switching on" actions as a function of the prevailing task illuminance level in VN offices*

Figure 3.2-9 shows normalized relative frequency of all "switching on" actions (arrival and intermediate) by occupants as a function of time of the day. Normalization denotes in this context that the actions are related to occupancy. Note that this figure also includes corresponding data concerning mean global irradiance.

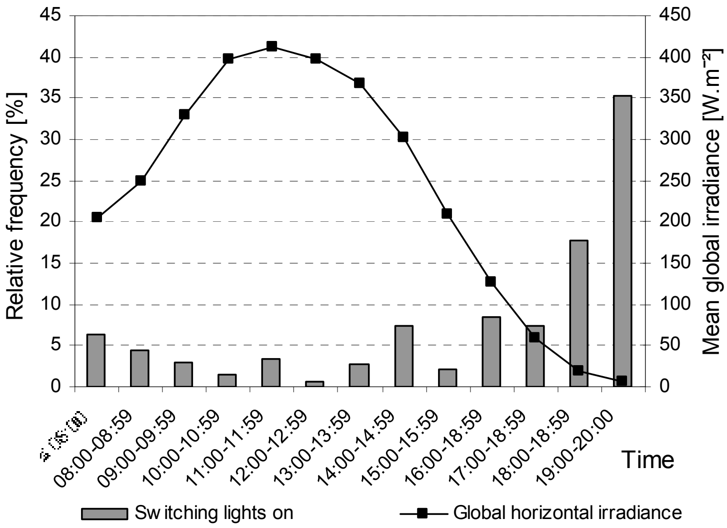

Figure 3.2-9 *Normalized relative frequency of all light "switching on" actions by occupants as a function of time of the day in VN*

Figure 3.2-10 shows the probability that an occupant would switch off the lights upon leaving his/her office as a function of the time that passes before he/she returns to the office.

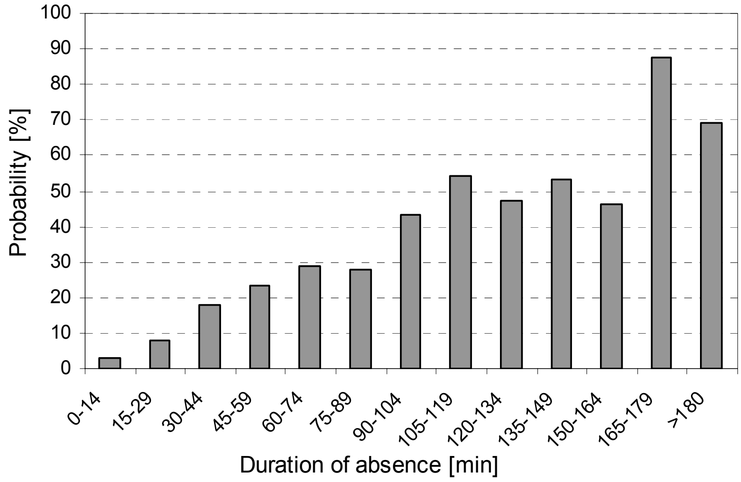

Figure 3.2-10 Probability of switching the lights off as a function of the duration of absence from the offices in VN

Figure 3.2-11 shows normalized relative frequency of the intermediate "switching the lights off" actions as a function of the prevailing illuminance level, immediately prior to the action's occurrence. Normalization denotes in this case, the consideration of occupancy and the applicable durations of the respective illuminance bins while deriving the actions' frequency.

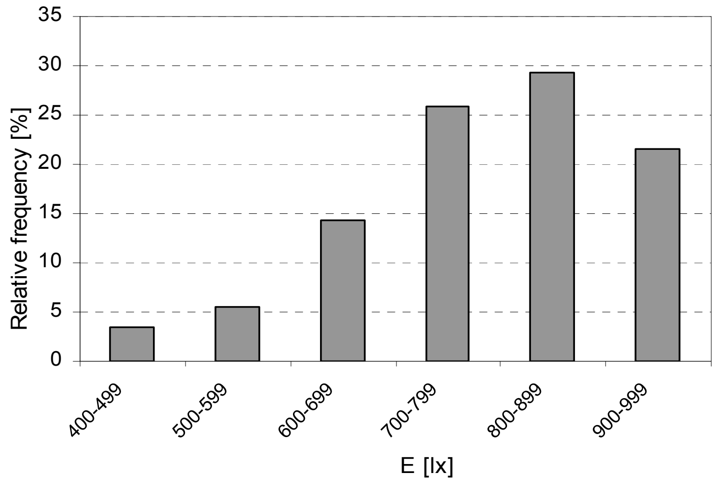

Figure 3.2-11 Normalized relative frequency of "switching off" actions in VN offices as a function of the prevailing illuminance level

3.2.3 Shading

Figure 3.2-12 represents mean monthly shade deployment degree in VN, averaged over the observed offices in year 2005.

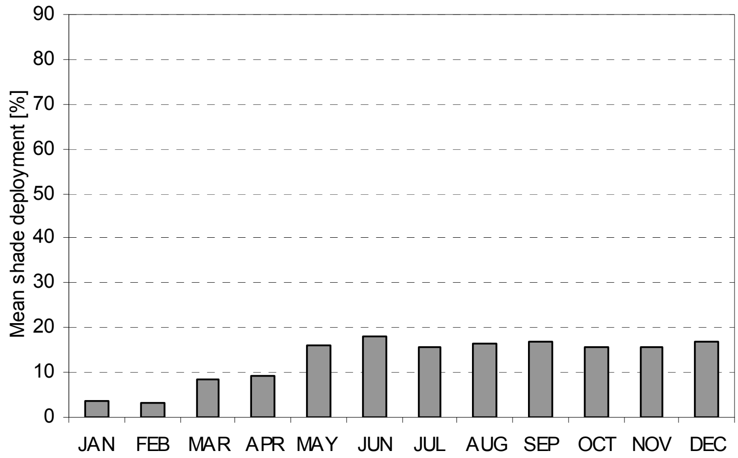

Figure 3.2-12 Mean monthly shade deployment degree in VN averaged over the observed offices in year 2005

Figure 3.2-13 shows mean shade deployment degree in VN as a function of global vertical irradiance. In appendix 9.5, mean shade deployment degree in VN as a function of global horizontal irradiance is presented (Figure 9.5-1).

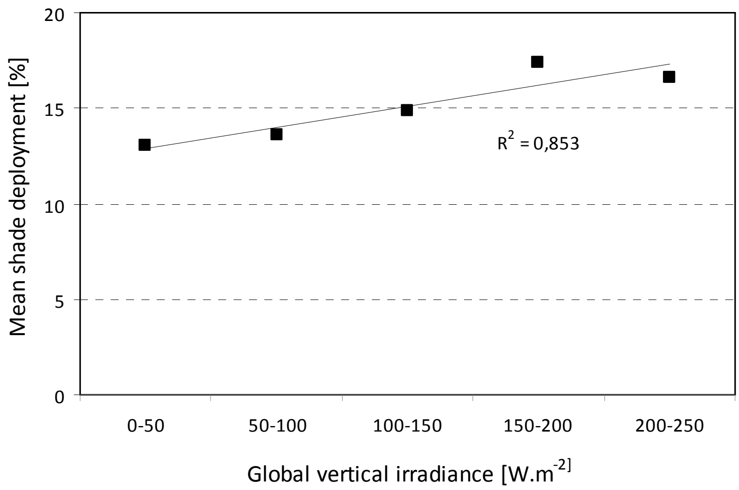

Figure 3.2-13 Mean shade deployment degree in VN as a function of global vertical irradiance

Figure 3.2-14 shows normalized relative frequency of "opening shades" and "closing shades" as a function of the global horizontal irradiance in VN.

Figure 3.2-15 shows normalized relative frequency of the same actions as a function of the global vertical irradiance. The number of actions is normalized with regard to occupancy and the time during which the respective irradiance ranges (bins) applied.

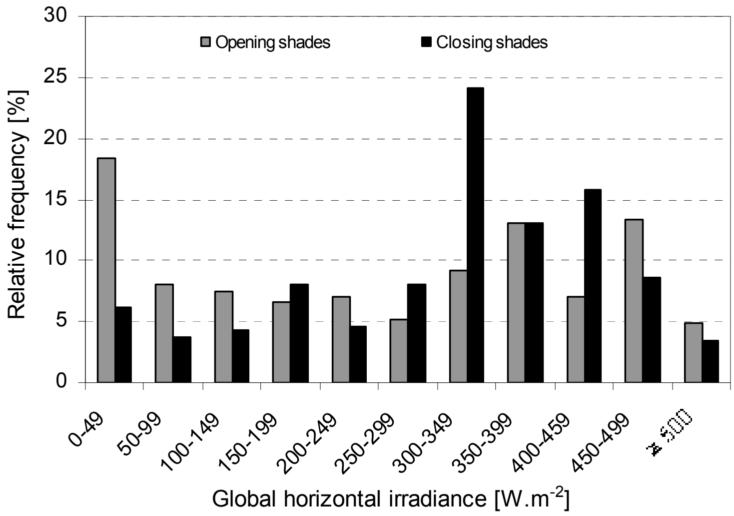

Figure 3.2-14 *Normalized relative frequency of opening and closing shades in relation to global horizontal irradiance in VN*

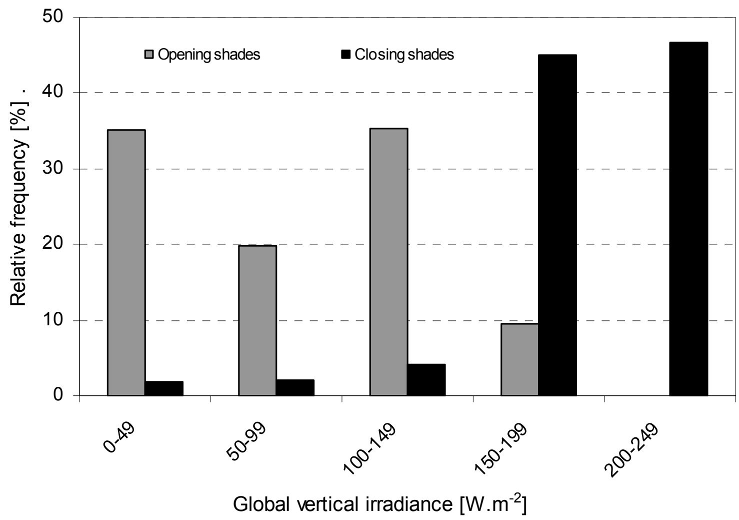

Figure 3.2-15 *Normalized relative frequency of opening and closing shades in relation to the global vertical irradiance in VN*

Figure 3.2-16 and Figure 3.2-17 show normalized relative frequency of "opening shade" and "closing shade" actions together with mean global vertical irradiance over the course of a reference day in VN.

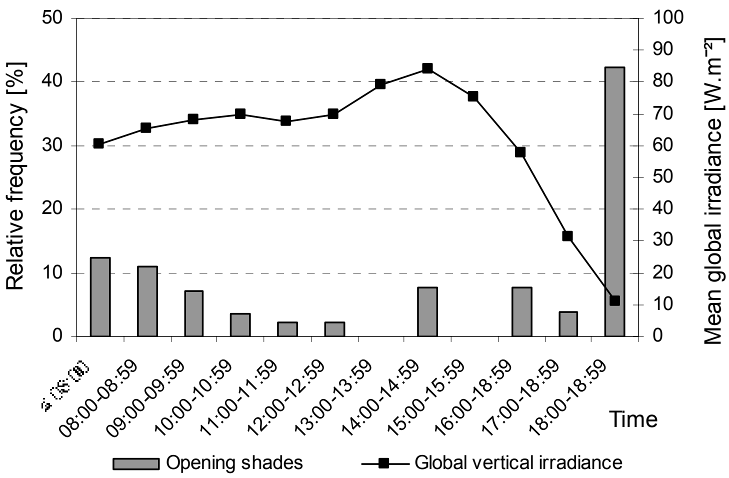

Figure 3.2-16 Normalized relative frequency of "opening shade" actions together with mean global vertical irradiance over the course of a reference day in VN

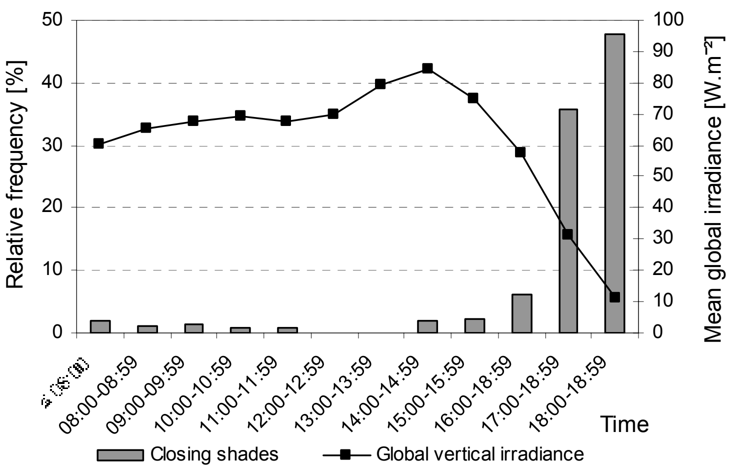

Figure 3.2-17 Normalized relative frequency of "closing shade" actions together with mean global vertical irradiance over the course of a reference day in VN

3.3 VS

3.3.1 Occupancy

Figure 3.3-1 and Figure 3.3-2 illustrate mean occupancy level in VS averaged over the observed period (January to December 2005) and over the course of a reference day. Note that these figures represent the presence in the user's office and not the complex. The data in this and the following occupancy figures is for working days and hours from 8:00 to 20:00.

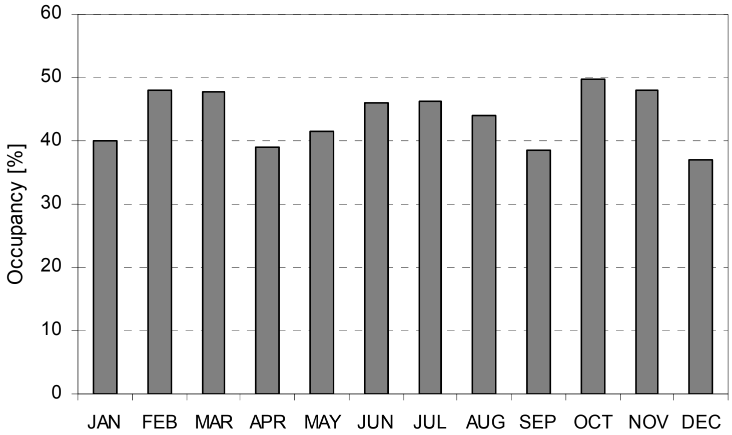

Figure 3.3-1 Mean monthly occupancy level in VS, averaged over all observed offices

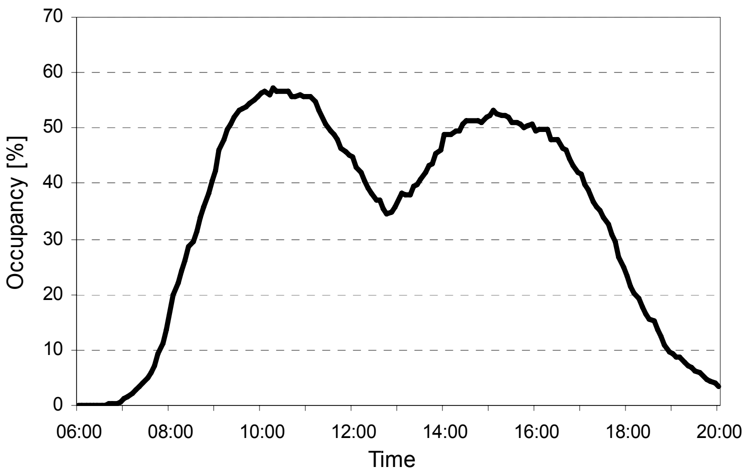

Figure 3.3-2 Mean occupancy level in VS over the course of a reference day

3.3.2 Lighting

Figure 3.3-3 and Figure 3.3-4 show the mean lighting operation over all offices and in occupied offices over the course of a reference day. Obviously, the information in these figures is about the general light usage tendency in all observed offices.

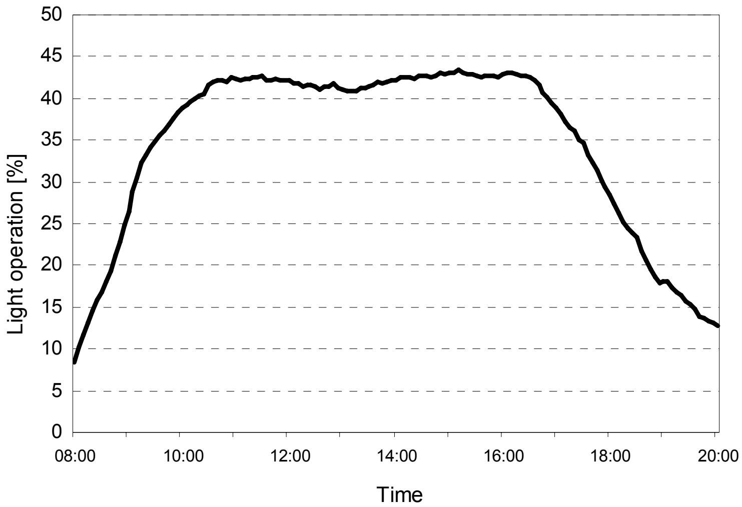

Figure 3.3-3 Lighting operation in VS offices over the course of a reference day

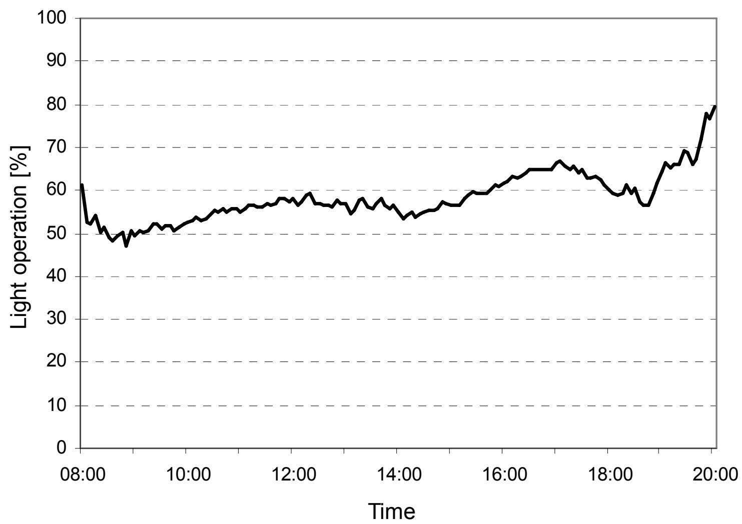

Figure 3.3-4 Mean lighting operation in occupied offices of VS over the course of a reference day

To provide an impression of the differences amongst individual light usage profiles, Figure 3.3-5 shows the lighting operation in each observed office for the entire monitoring period in the working hours. Figure 3.3-6 illustrates mean lighting electricity load over the course of a reference day averaged over the observed offices in VS.

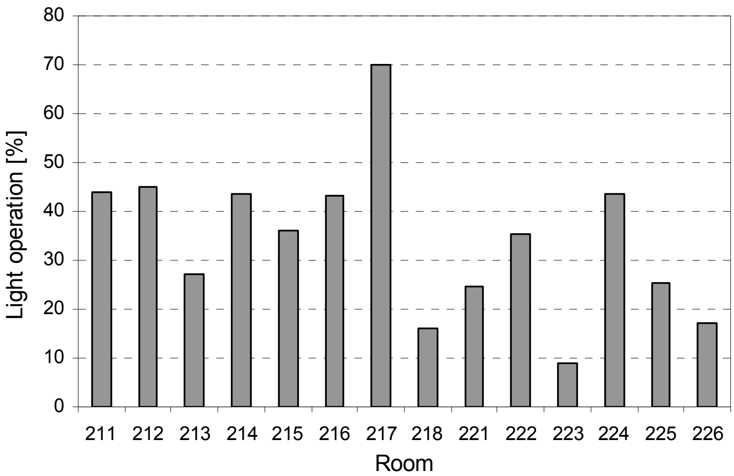

Figure 3.3-5 *Duration of lighting operation (in percentage of respective overall working hours) in VS offices*

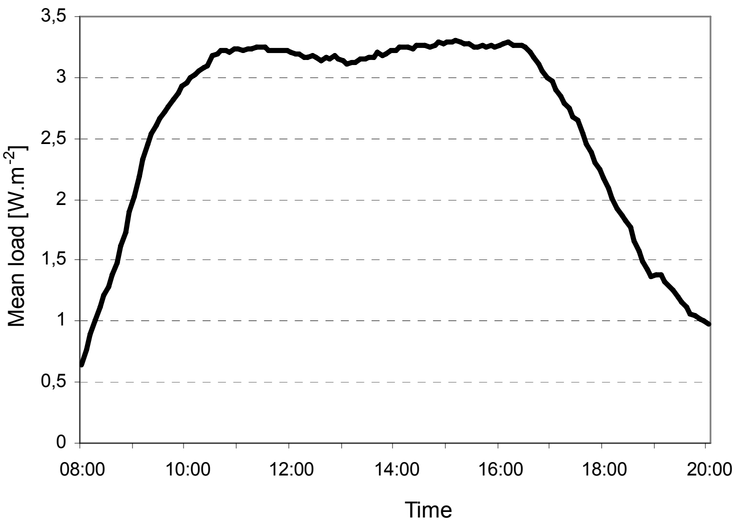

Figure 3.3-6 *Mean lighting electricity load over the course of a reference day averaged over the observed offices in VS*

Figure 3.3-7 shows the probability of switching the lights on upon arrival in the office as a function of the prevailing task illuminance level immediately before the arrival.

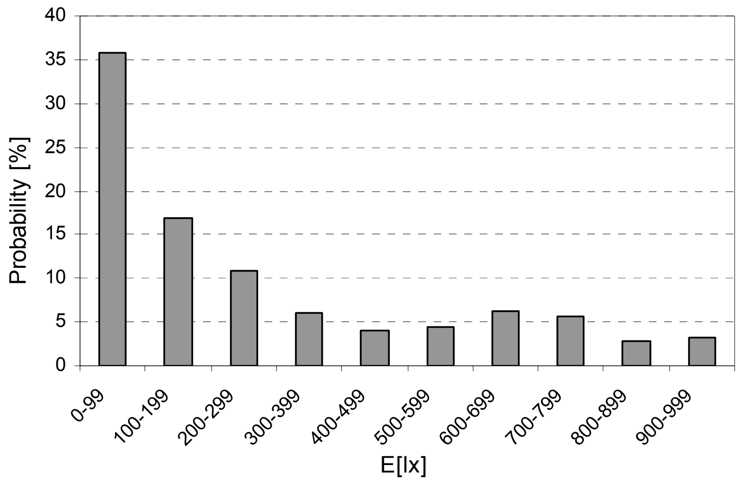

Figure 3.3-7 *Probability of "switching the lights on" upon arrival in the office as a function of the prevailing task illuminance level immediately before the arrival in VS*

Figure 3.3-8 shows normalized relative frequency of intermediate actions switching the lights on by occupants who have been in their offices for more than 15 minutes before and after the occurrence of the action as a function of the prevailing task illuminance level immediately prior to the action's occurrence. Normalization denotes in this context that the actions are related to both occupancy and the duration of the time in which the relevant illuminance ranges (bins) applied.

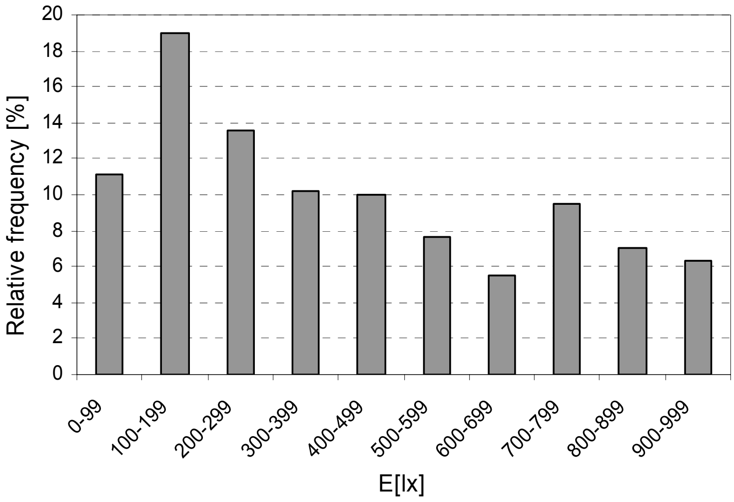

Figure 3.3-8 *Normalized relative frequency of intermediate light "switching on" actions as a function of the prevailing task illuminance level in VS*

Figure 3.3-9 shows normalized relative frequency of intermediate actions "switching the lights on" by occupants as a function of time of the day. Intermediate in this context means more than 15 minutes after arrival and 15 minutes before leaving the office. Normalization denotes in this context that the actions are related to occupancy. Note that this figure also includes corresponding data concerning mean global irradiance.

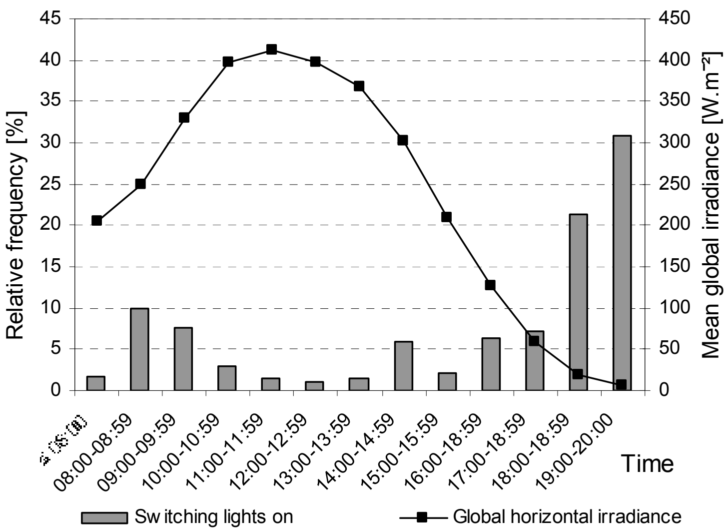

Figure 3.3-9 *Normalized relative frequency of intermediate light "switching on" actions by occupants as a function of time of the day in VS*

Figure 3.3-10 shows the probability that an occupant would switch off the lights upon leaving his/her office as a function of the time that passes before he/she returns to the office.

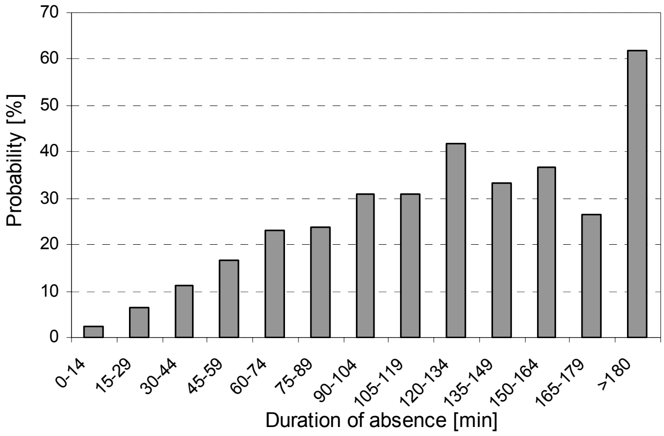

Figure 3.3-10 Probability of switching the lights off as a function of the duration of absence from the offices in VS

Figure 3.3-11 shows normalized frequency of the (intermediate) "switching the lights off" actions as a function of the prevailing illuminance level, immediately prior to the action's occurrence. Intermediate in this context means more than 15 minutes after arrival and 15 minutes before leaving the office. Normalization denotes in this case, the consideration of occupancy and the applicable durations of the respective illuminance bins while deriving the actions' frequency.

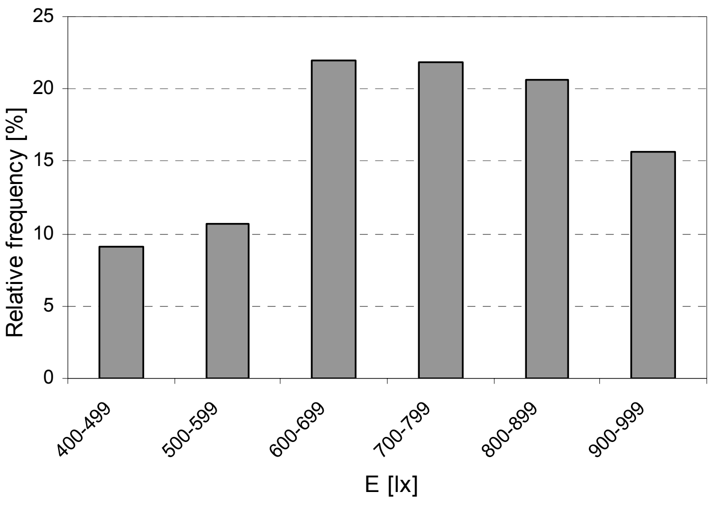

Figure 3.3-11 Normalized relative frequency of light "switching off" actions in VS offices as a function of the prevailing illuminance level

3.3.3 Shading

Figure 3.3-12 represents mean monthly shade deployment degree in VS, averaged over the observed offices in year 2005.

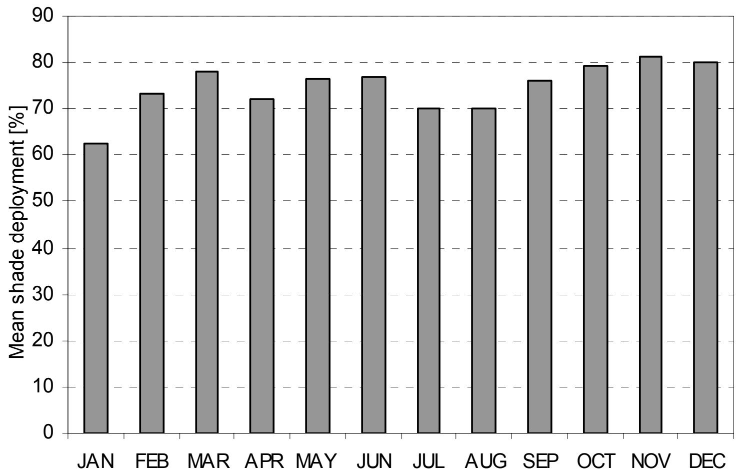

Figure 3.3-12 Mean monthly shade deployment degree in VS averaged over the observed offices in year 2005

Figure 3.3-13 shows mean shade deployment degree in VS as a function of global vertical irradiance.

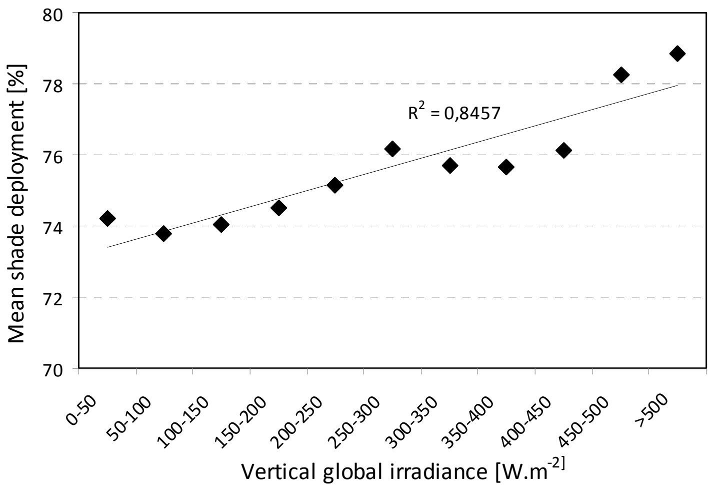

Figure 3.3-13 Mean shade deployment degree in VS as a function of global vertical irradiance

Figure 3.3-14 shows normalized relative frequency of "opening shades" and "closing shades" as a function of the global horizontal irradiance in VS.

Figure 3.3-15 shows normalized relative frequency of the same actions as a function of the global vertical irradiance. The number of actions is normalized with regard to occupancy and the time during which the respective irradiance ranges (bins) applied.

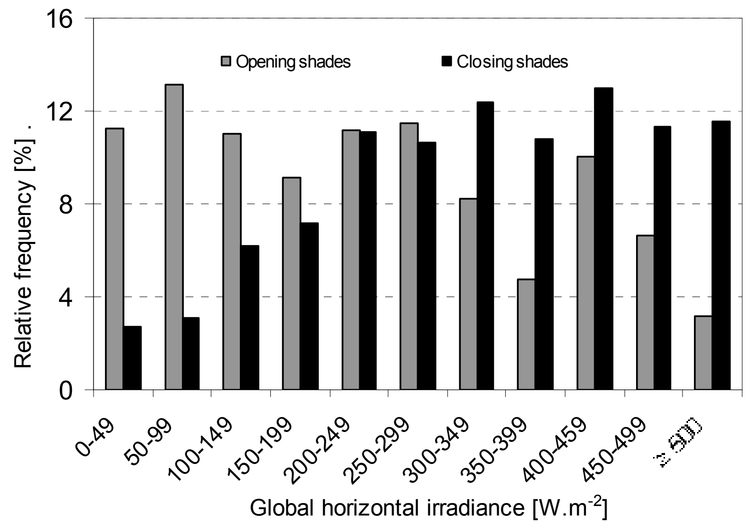

Figure 3.3-14 *Normalized relative frequency of opening and closing shades in relation to global horizontal irradiance in VS*

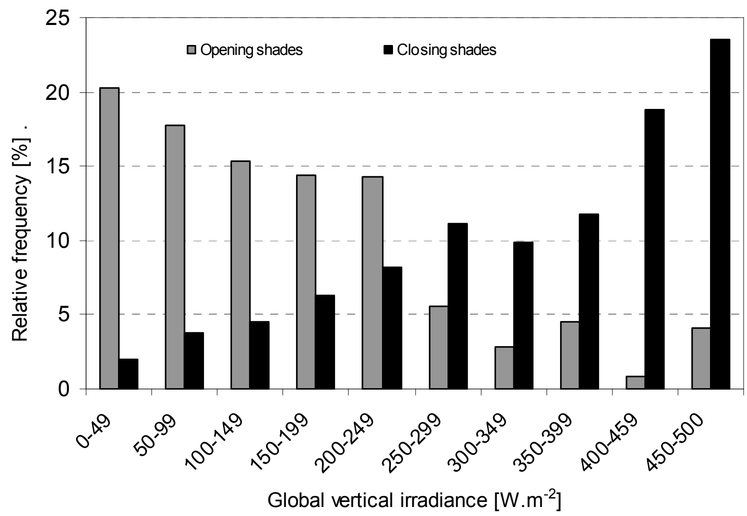

Figure 3.3-15 *Normalized relative frequency of opening and closing shades in relation to the global vertical irradiance in VS*

Figure 3.3-16 and Figure 3.3-17 show normalized relative frequency of "opening shade" and "closing shade" actions together with mean global vertical irradiance over the course of a reference day in VS.

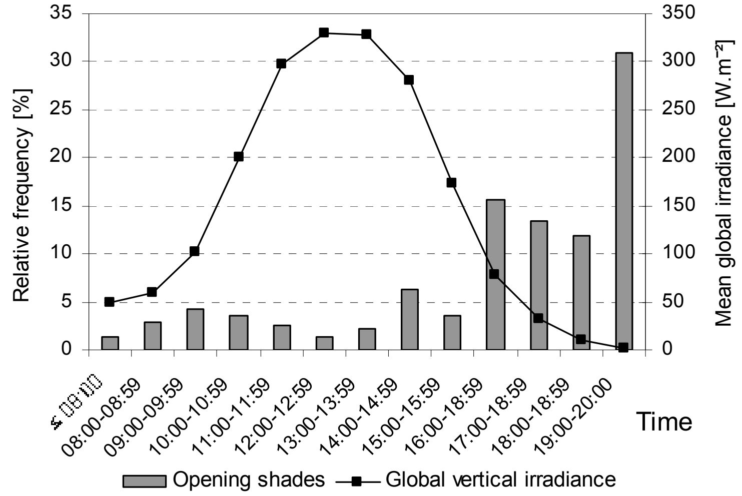

Figure 3.3-16 Normalized relative frequency of "opening shade" actions together with mean global vertical irradiance over the course of a reference day in VS

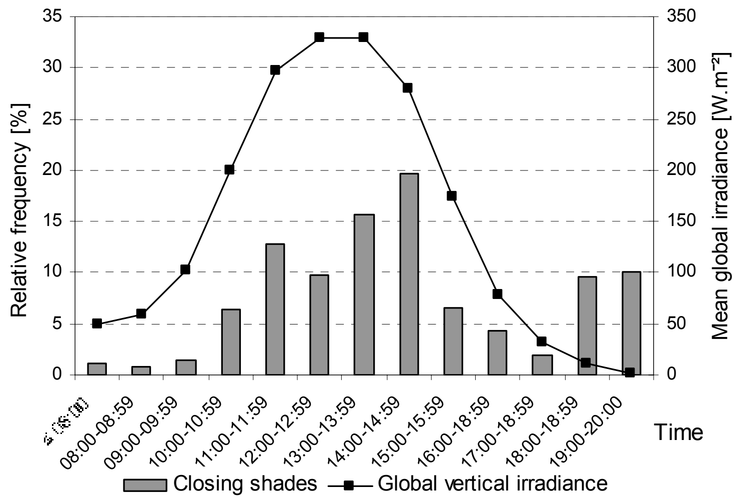

Figure 3.3-17 Normalized relative frequency of "closing shade" actions together with mean global vertical irradiance over the course of a reference day in VS

3.4 Interviews

Out of ten people in HB, seven persons were interviewed, three males and four females. The age of people was between 36-55 years old and only one person was under 25 years old. They were all clerks and had been working there for more than 6 months.

Twelve people (out of 15) in VN were interviewed. 70% are women, 40% of the occupants are between 36 and 45 years old and 50% more than 45, while 30% are older than 55 years.

Twelve people (out of 14) in VS were interviewed. 58% are women, 50% of the occupants are between 36 and 45 years old, while 33% are older than 45 years. The participants are from all over the world.

The interview results are summarized in appendix 9.4.

The following graphs present some results of the three buildings.

Figure 3.4-1 shows the percentage of occupants' work performing on computer.

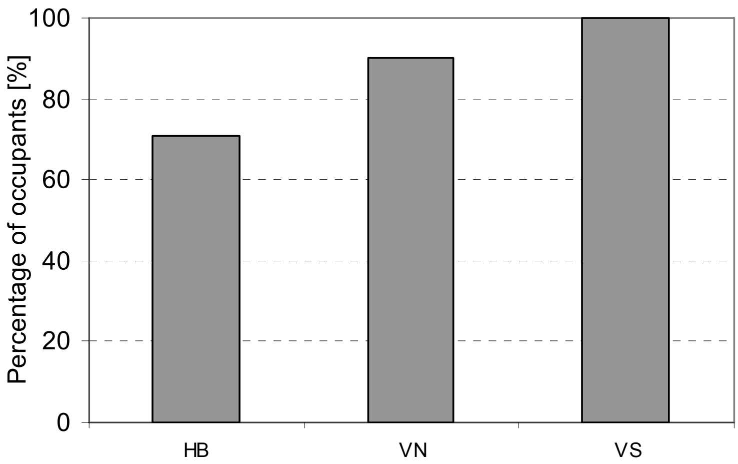

Figure 3.4-1 Percentage of work performing on computer in HB, VN and VS offices

Figure 3.4-2 and Figure 3.4-3 reveal occupants evaluations of average temperature in their offices in winter and summer in building HB, VN and VS with average of measured indoor temperature in working hours in winter and summer in the offices.

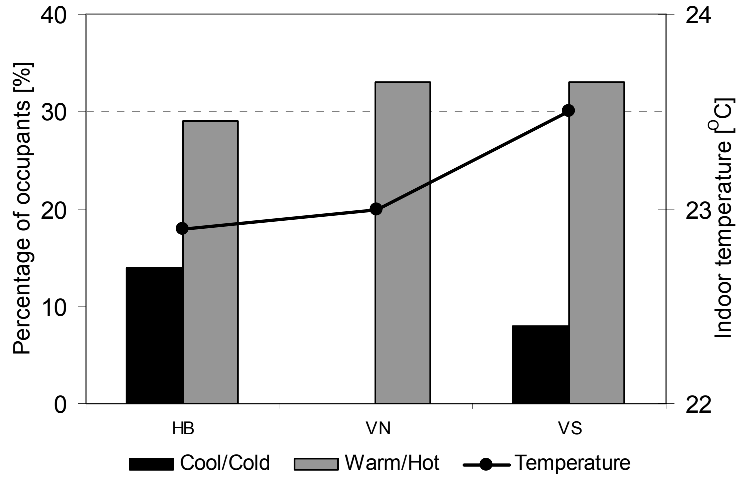

Figure 3.4-2 *Evaluation of average temperature in winter in HB, VN and VS offices*

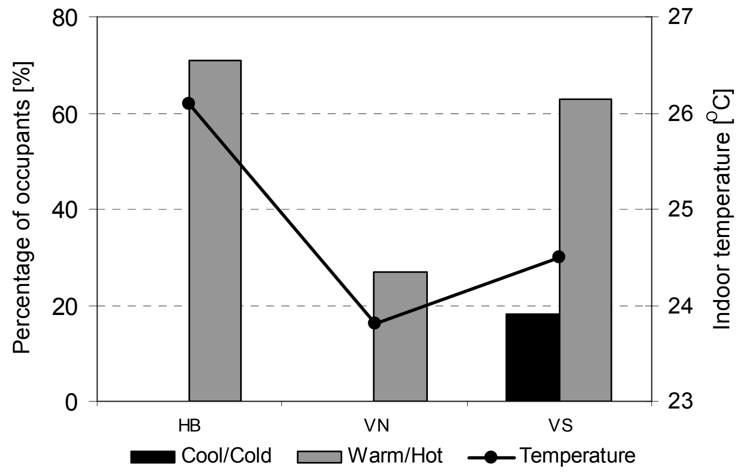

Figure 3.4-3 *Evaluation of average temperature in summer in HB, VN and VS offices*

Figure 3.4-4 and Figure 3.4-5 present the people evaluation of air quality and heating system in their offices.

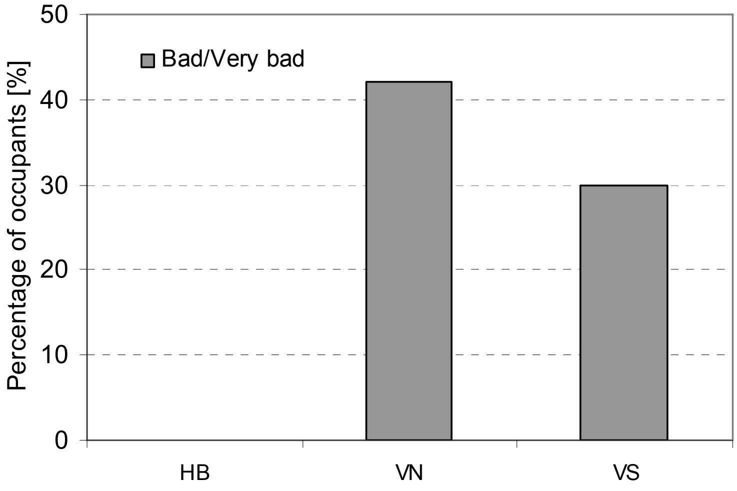

Figure 3.4-4 Evaluation of air quality in the HB, VN and VS offices

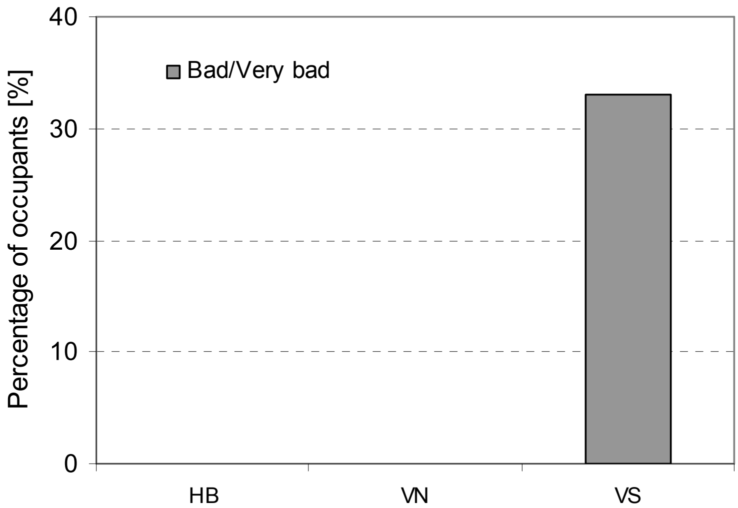

Figure 3.4-5 Evaluation of heating system in the HB, VN and VS offices

Figure 3.4-6 illustrates the occupants' dissatisfaction with the possibilities to ventilate the offices.

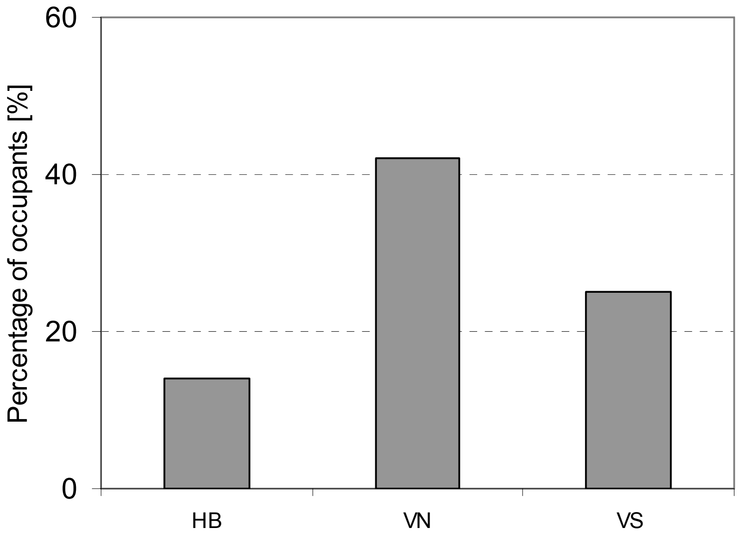

Figure 3.4-6 *Dissatisfaction with ventilation possibilities in HB, VN and VS offices*

Figure 3.4-7 illustrates the percentage of people who annoyed by reflections on their computer screen and direct sunlight on the workstations.

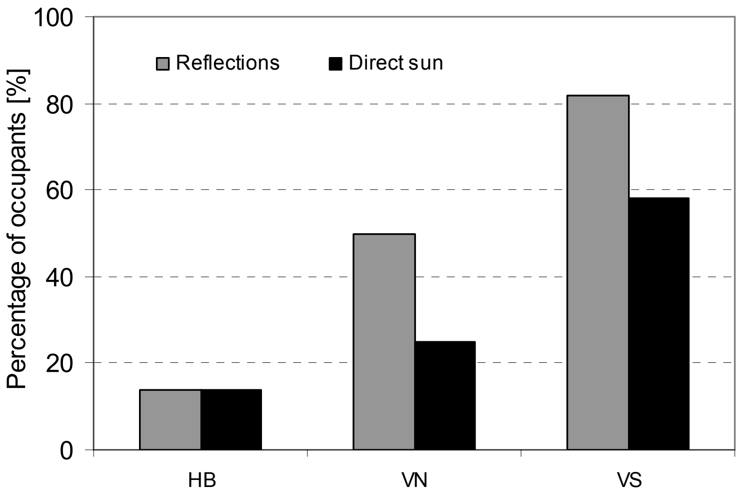

Figure 3.4-7 *Percentage of people in HB, VN and VS annoyed by reflection/Direct sunlight*

Figure 3.4-8 presents the percentage of people who insufficiently informed about how the building systems like heating, cooling, ventilation and shades work in their offices.

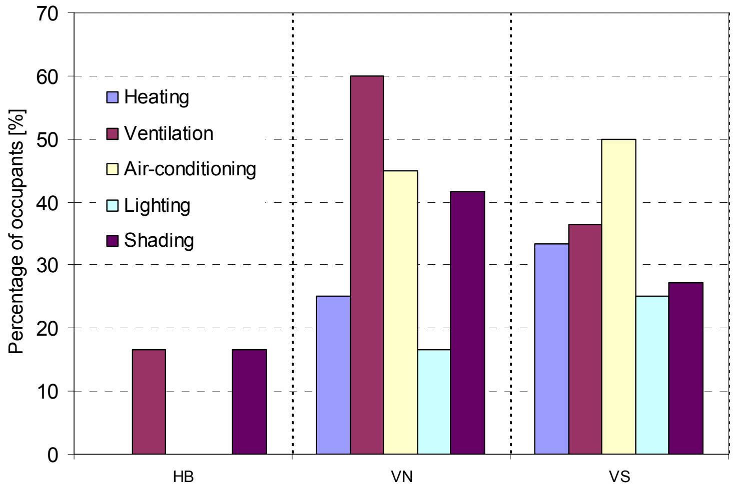

Figure 3.4-8 insufficient information on building systems in HB, VN and VS

Figure 3.4-9 illustrates the availability of occupants' interest in training concerning building systems in the offices.

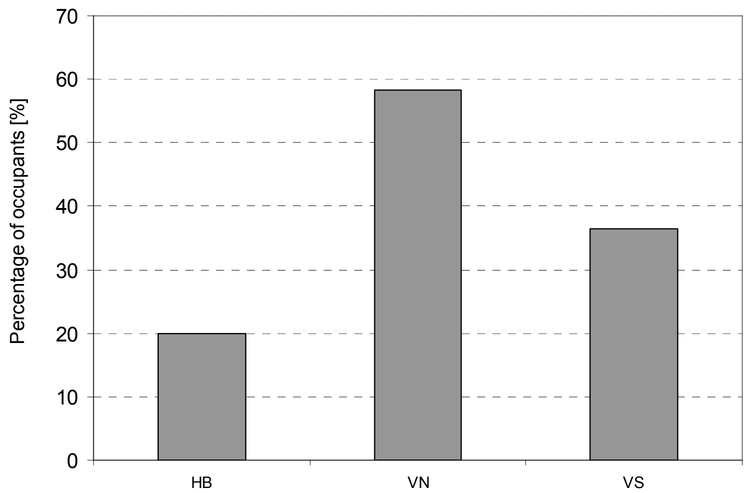

Figure 3.4-9 Availability of interest in training about the building systems for occupants in HB, VN and VS offices

Figure 3.4-10 reveals the percentage of people who think that they can influence on building energy consumption in the way they operate building systems in the offices.

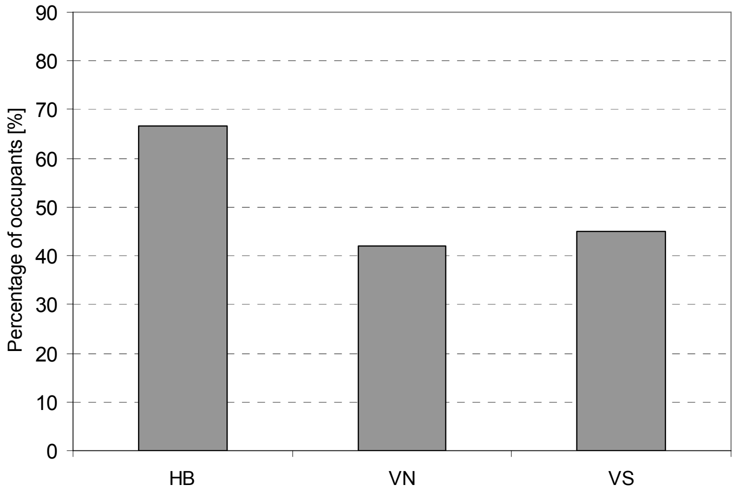

Figure 3.4-10 Occupants' consciousness about energy in HB, VN and VS offices

Figure 3.4-11 presents the percentage of occupants who think about energy conservation when they operate building systems.

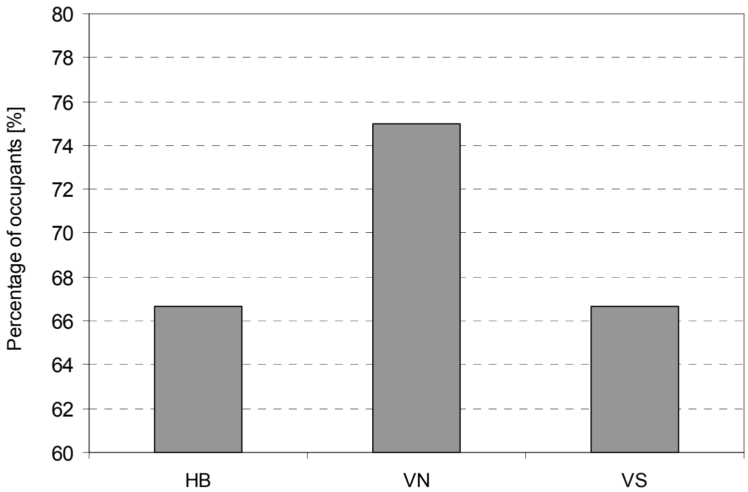

Figure 3.4-11 Occupants consideration of energy conservation in HB, VN and VS offices

Figure 3.4-12 illustrates relative frequency of the most urgent improvement measures in the offices that occupants wanted to be considered.

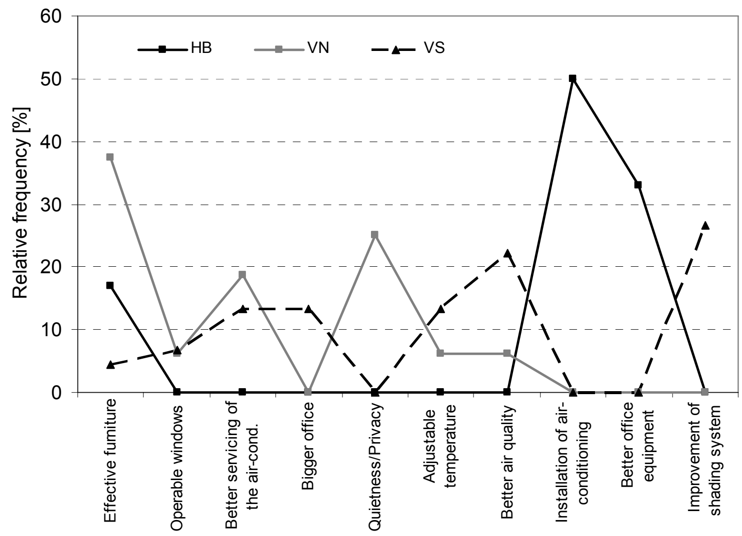

Figure 3.4-12 Urgent improvement in the offices in HB, VN and VS

Figure 3.4-13 and Figure 3.4-14 present information about the health of observed occupants in three buildings.

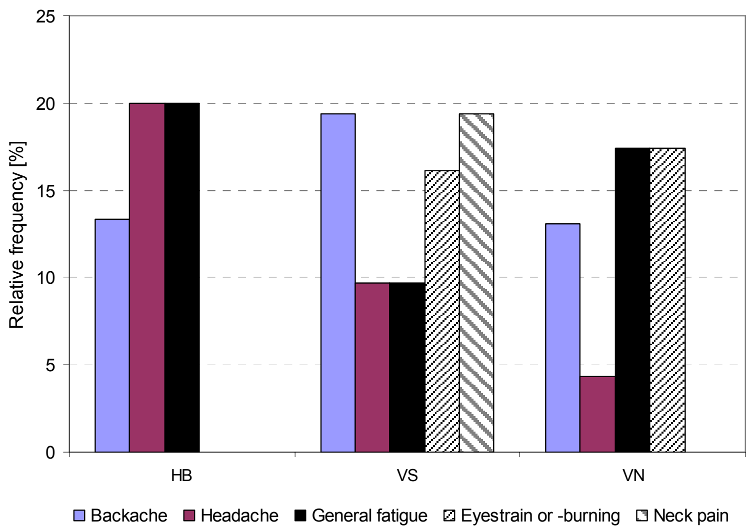

Figure 3.4-13 information about the health of occupants in HB, VN and VS

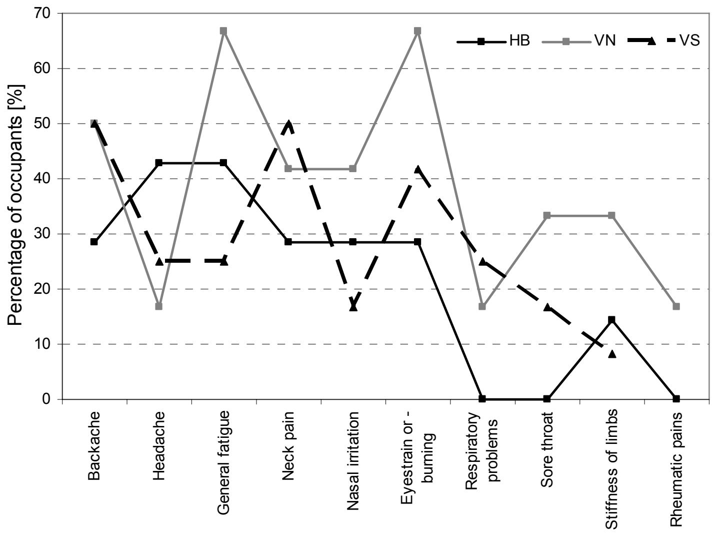

Figure 3.4-14 percentage of occupants' health complaints in HB, VN and VS

4 Discussion

In this section, the dependency of occupants' control actions with building systems (lighting, shading, natural ventilation) on indoor and outdoor environmental parameters will be discussed.

4.1 Behavior

4.1.1 Occupancy

From the occupancy model of the observed office buildings, a corresponding people load model is derived. The mean occupancy levels in HB, VN, VS and corresponding people loads (Figure 3.1-1, Figure 3.2-2, Figure 3.3-2 and Figure 4.1-1) show differences amongst the monitored buildings. The Occupancy pattern of HB is different from the more general trend observed in VN, VS and other more typical office buildings (Mahdavi 2007c). This is probably due to the special nature of the work performed in this building, which is a governmental office building with public service hours.

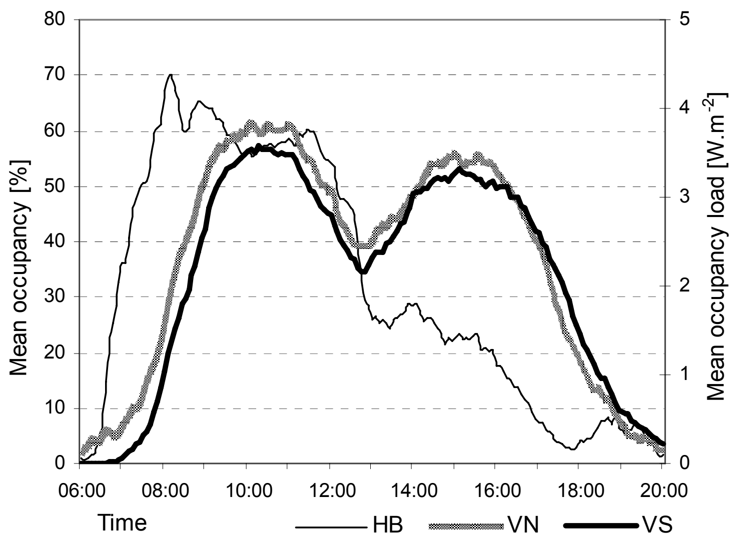

Figure 4.1-1 Mean occupancy and occupancy load over the course of a reference day for HB, VN, and VS

In order to arrive at generally valid occupancy patterns (applicable to different types of buildings with different functions) for use in simulation programs, it is necessary to have a larger number of empirically derived occupancy patterns.

The mean occupied hours by the users in all offices is rather low. The average percentage of occupied hours in HB offices is about 49% and the average for building VC (VN+VS) is about 47% over the working hours. It shows that if we consider all working hours in the observed offices, the offices are not occupied at least half of the working hours. Hence, the environmental systems in the observed offices (and in other offices where full-occupancy is assumed) may be over-designed.

In order to have an initial illustrative model of occupancy and occupancy loads, data from VN and VS were synthesized (see Figure 4.1-2). Such data can be used temporarily for simulation purposes until additional and more generalized data become available.

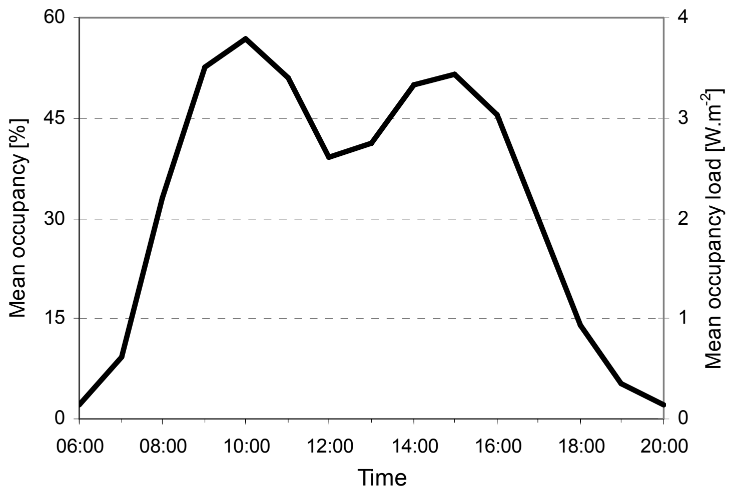

Figure 4.1-2 Generic model of occupancy and occupancy load, averaged over VN and VS

4.1.2 Artificial light

Lighting operation:

Similar to occupancy patterns, the patterns of lighting loads and lighting operation in occupied offices in HB, VN and VS are also different in individual buildings (see Figure 4.1-3 and Figure 4.1-4). Figure 4.1-5 illustrates the correlation between occupancy and lighting operation in HB, VN and VS. Thereby, a high correlation between occupancy and lighting operation in each observed office building is evident.

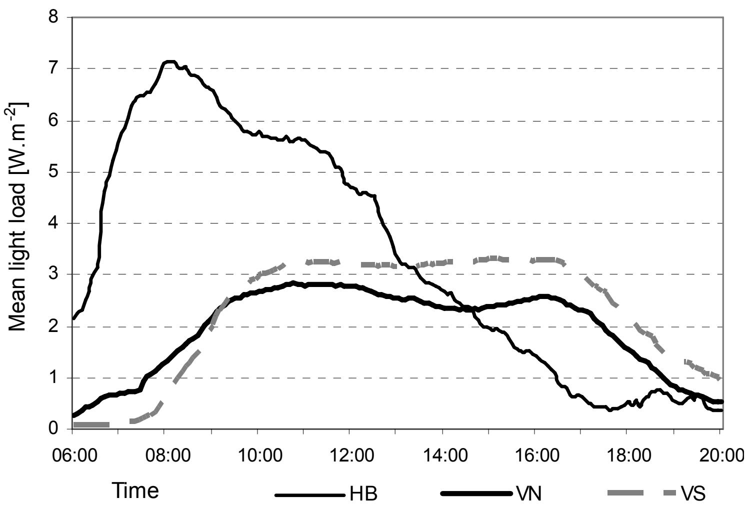

Figure 4.1-3 Mean lighting load in HB, VN and VS

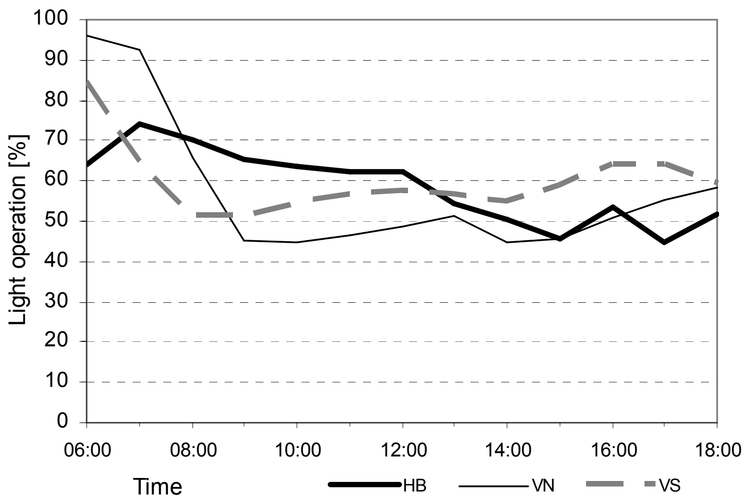

Figure 4.1-4 Lighting operation in occupied offices over the course of a reference day in HB, VN and VS

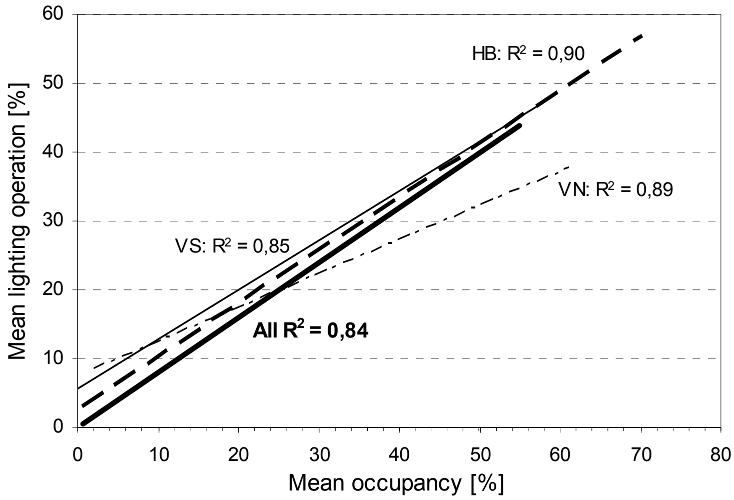

Figure 4.1-5 Lighting operation in relation to occupancy, averaged over HB, VN, VS and all

Similar to the previously discussed occupancy patterns of VN and VS with other studies, a generic model of mean lighting load for using in simulation programs is derived based on the data form these two offices (Figure 4.1-6).

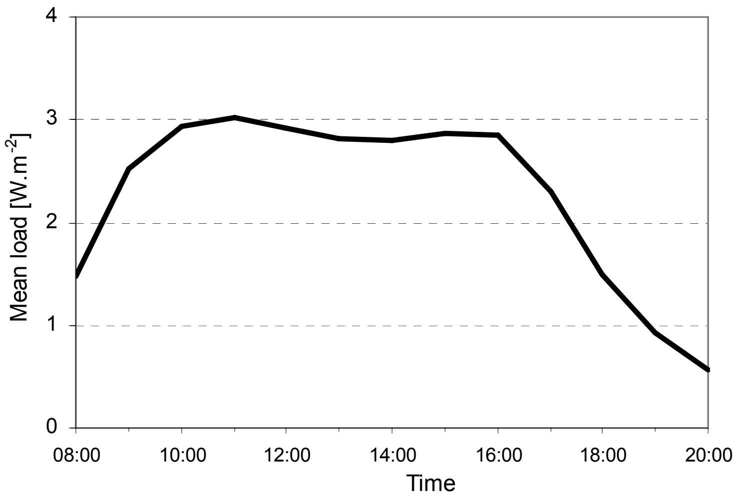

Figure 4.1-6 Generic model of the mean lighting load, averaged over VN and VS

The use of electrical lighting in the observed offices in HB (see Figure 3.1-6) shows a significant difference between offices located on the first floor (611, 612, and 613) versus those located on the second floor (621, 622, and 623). Using more electrical lights in the offices on the first floor than the second floor may be due to the presence of trees or obstacles in the close proximity of the building, resulting in longer periods of shading on the first floor.

Figure 4.1-7 illustrates the percentage of lighting operation over the course of a reference day in VN and VS respectively. The figure points that less electrical energy for lighting is used in the north oriented offices (VN) as compared to Southwest offices (VS), even though the latter orientation receives more daylight. This increased usage in VS can be explained by considering mean shade deployment degree in VS (approximately 75%) as compared to VN offices, where mean shade deployment amounts to merely 15% (see Figure 4.1-15).

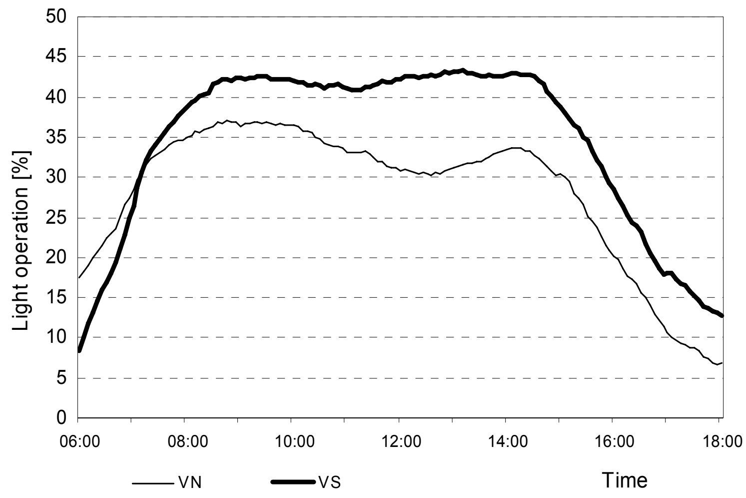

Figure 4.1-7 Light operation level in VN and VS

Switching lights on upon arrival:

Concerning the dependency of the action "switching on the lights upon arrival" on prevailing illuminance levels on the work stations, Figure 3.1-8, Figure 3.2-7 and Figure 3.3-7 suggest that only illuminance levels below 100 lx are likely to trigger actions at a non-random rate.

Figure 4.1-8 shows the probability of switching the lights on upon arrival in the office based on data from HB, VN and VS.

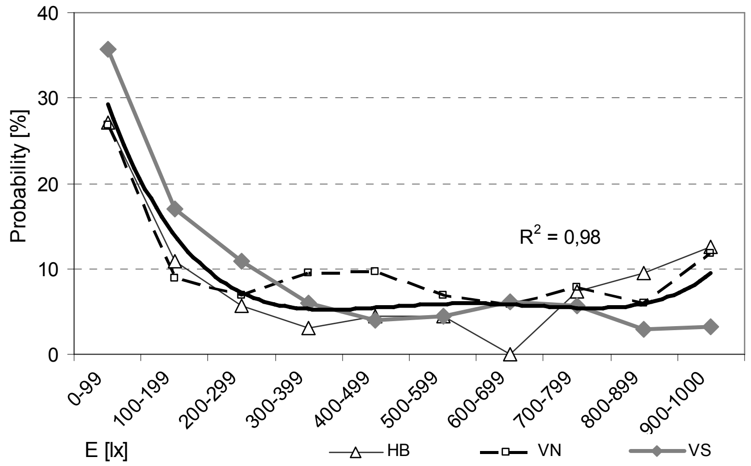

Figure 4.1-8 Probability of switching on the lights at arrival in the office, averaged over HB, VN and VS

This data suggests that the probability of switching on actions is significantly higher when the illuminance is less than 100 lx. However, the switching on probability also seems to slightly rise for illuminance levels beyond 700 lx. A reason for this circumstance may be a previous shade deployment action leading to a reduction of illuminance level at the workstation. This possibility could not be tested within the the present work. Another possibility may be a very bright window that would cause high visual contrast in the room, triggering thus a switching the lights on action to reduce the contrast. Future work must test this possibility as well.

Dependency of intermediate "switching the lights on" actions on prevailing task illuminance:

Figure 4.1-9 shows the normalized relative frequency of intermediate "switching on" actions (in HB, VN and VS) as a function of the prevailing workstation illuminance levels. The patterns here are comparable to Figure 4.1-8 and can be explained based on a similar reasoning.

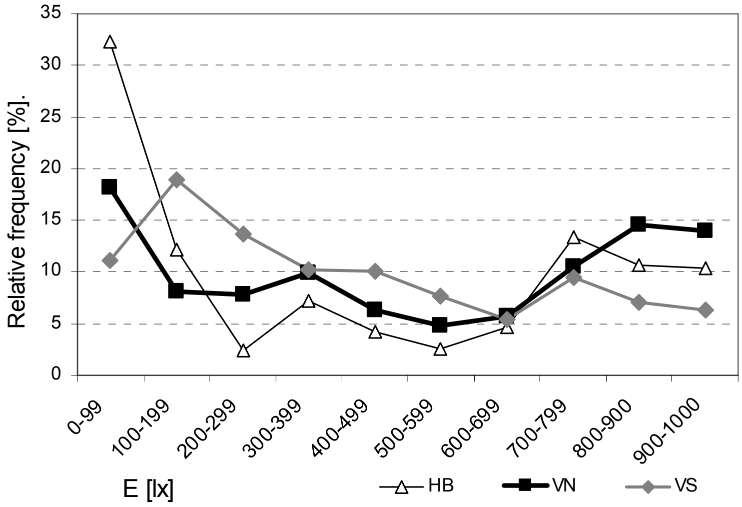

Figure 4.1-9 *Normalized relative frequency of intermediate light "switching on" actions in HB, VN and VS*

Dependency of "switching the lights on" actions on time of the day:

If the frequency of the "switching on" actions is viewed in terms of the time of the day (Figure 3.1-10, Figure 3.2-9 and Figure 3.3-9), a higher frequency of the "switching on" actions in case of HB, VN and VS can be observed after 16:00. This can be expected, because daylight-based illuminance levels in the offices decrease significantly in the afternoon hours.

In Figure 4.1-10, the frequency of switching on actions for all observed offices is shown together with the mean global irradiance.

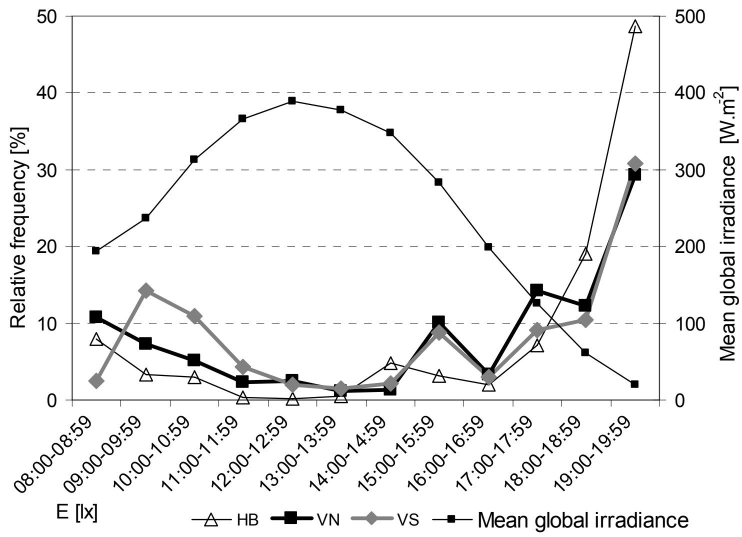

Figure 4.1-10 *Normalized relative frequency of light "switching on" actions in a reference day in HB, VN and VS*

Dependency of "switching the lights off" actions on prevailing task illuminance:

Figure 4.1-11 presents the normalized relative frequency of intermediate "switching off" actions (in HB, VN and NS) as a function of the prevailing workstation illuminance levels. Despite minor deviations, this data generally confirms the expected tendency to switch off the lights with higher illuminance level.

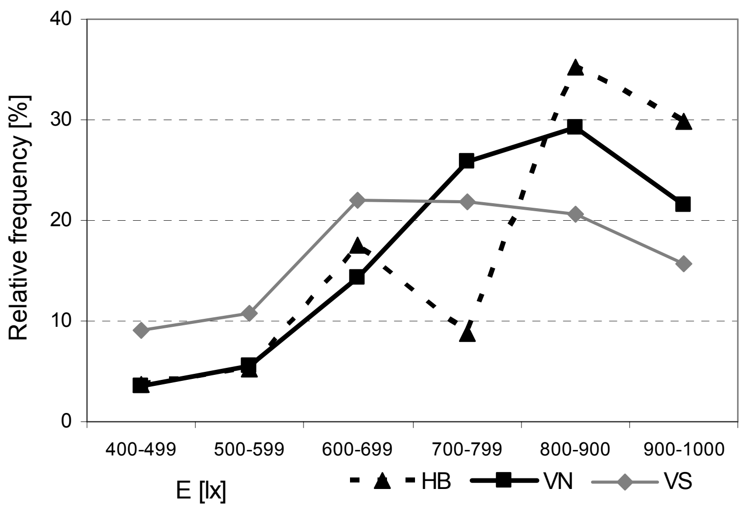

Figure 4.1-11 *Normalized relative frequency of intermediate light "switching off" actions in HB, VN and VS*

"Switching off" actions as a function of duration of absence:

A clear relationship between duration of absence and switching off actions is illustrated in the Figure 3.1-11, Figure 3.2-10 and Figure 3.3-10. Figure 4.1-12 and Figure 4.1-13 illustrate this correlation based on the data from HB, VN and VS. This information can be used as the basis for behavioral models in simulation applications and for energy saving calculations.

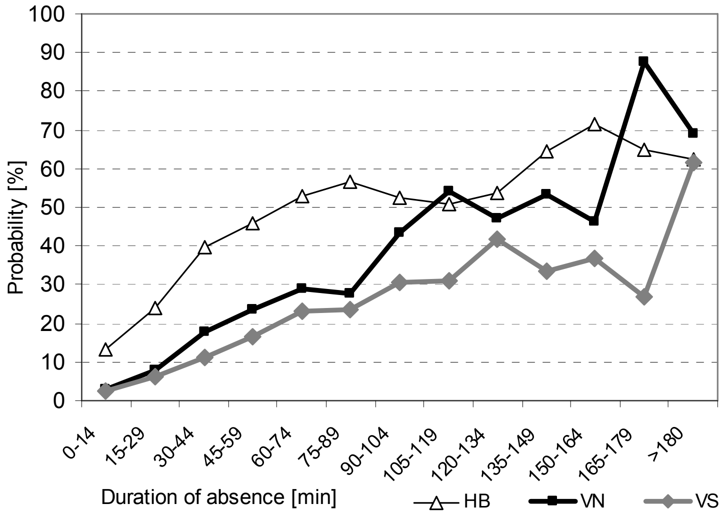

Figure 4.1-12 Probability of switching off the lights in relation to the duration of absence from the office, averaged over HB, VN and VS

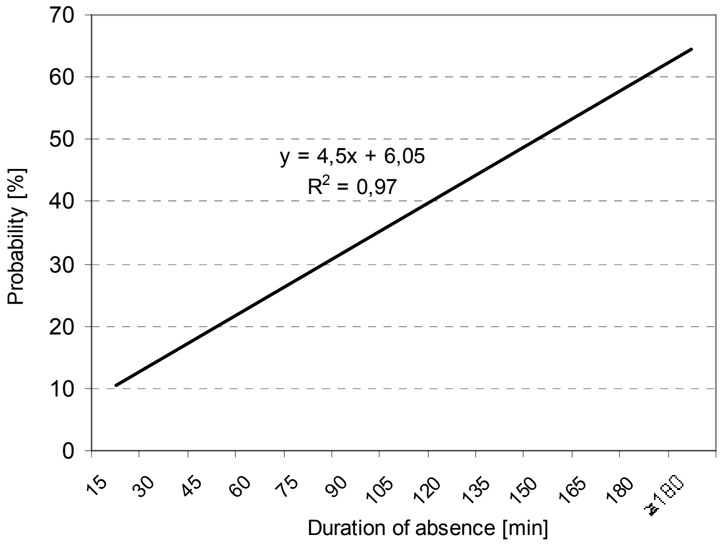

Figure 4.1-13 Probability model for "switching the lights off" as a function of the duration of absence based on data collected in HB, VN and VS

The figures show that the lights were still on in 35% of the offices, which have been vacated for more that 3 hours. This points to a high saving potential regarding electrical energy use for office illumination. In appendix 9.5, three scenarios for energy saving (for electrical lighting) are considered and the associated achievable benchmarks are derived.

4.1.3 Shades

Relationship between shade deployment degree and irradiance:

In case of HB offices, there is an evident relationship between shade deployment and the magnitude of solar radiation (Figure 3.1-14, Figure 3.1-19 and Figure 3.1-20). In case of VN and VS, as Figure 4.1-14 reveals, the shades deployment level does not vary too much as related to irradiance, but there is a significant difference in the overall shade deployment level between these two facades (approximately 75% in the case of south-west-facing façade VS and some 15% in the case of the north-facing façade VN).

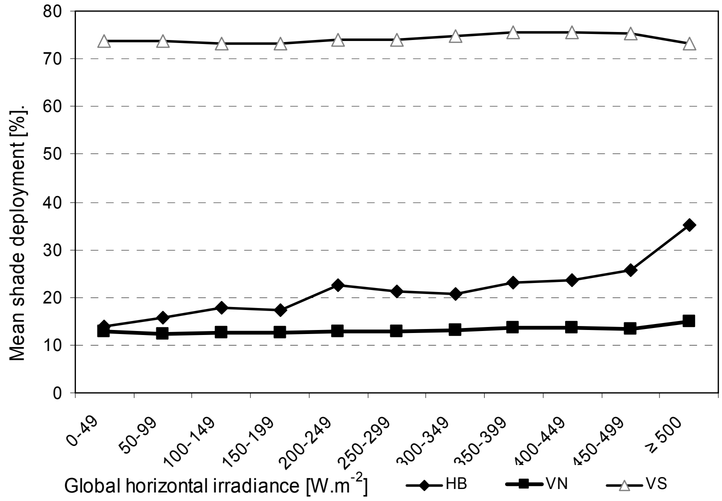

Figure 4.1-14 Mean shade deployment in relation to the global horizontal irradiance in HB, VN and VS

The dependency of the mean shade deployment levels on the incident global irradiance differs from building to building and façade to façade. Figure 4.1-15 reveals mean monthly shade deployment degree for the offices in HB, VN and VS. HB offices face northeast and have direct solar irradiation in the morning hours. VN, which has north orientation, rarely experiences direct solar exposure. On the other hand, VS offices facing southwest direction have solar radiation for a long period. Moreover, HB offices have interior curtains, which, can partly control the glare and reduce the need for manipulating the external shades.

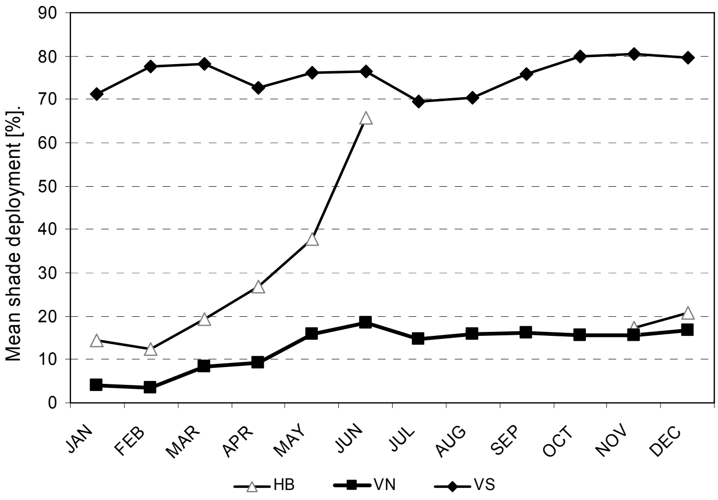

Figure 4.1-15 Mean monthly shade deployment degree in HB, VN and VS

In case of applying the shades, the arrangement of the workstations in the offices may influence the need of shades manipulations. Occupants in VS sit rather close to the window, thus they have frequently problem with glare and daylight reflection on their computer screens. Occupants in HB in comparison with the others are less exposed.

Closing shade actions as a function of time of the day:

Figure 4.1-16 combines data from HB, VN and VS regarding the normalized relative frequency of the closing shades actions as a function of time of the (reference) day.

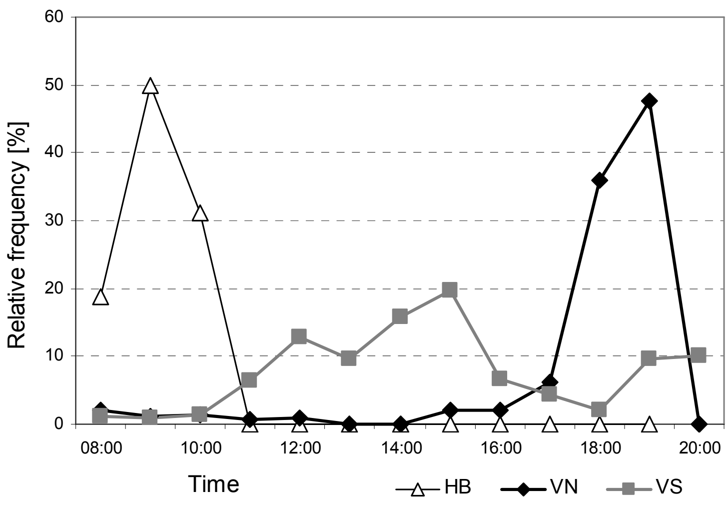

Figure 4.1-16 Normalized relative frequency of "closing shade" in relation to time of the day in HB, VN and VS

This data matches the expectation well and can be adapted for a generic behavioral model. Due to orientation of the façade in HB (north-east) and the resulting direct insolation of the windows during the early morning, the shades are more frequently closed in the morning hours (from 6 to 9 am), where as in case of VN (north-facing), shades are more frequently closed in the afternoon. In case of VS, (south-west-facing) higher frequencies occur during midday.

Dependency of opening/closing shade actions on global irradiance:

The observations in HB did not reveal a clear relationship between the frequency of "opening shade" and "closing shade" actions and global horizontal irradiance (Figure 3.1-15 and Figure 3.1-16), but there is a clear relationship between the frequency of "closing shades" actions and incident radiation on the façade for buildings VN and VS (see Figure 4.1-17). The corresponding analysis of the "closing shades" actions shows a significantly higher action frequency once the incident radiation rises above 200 $W.m^{-2}$ (Figure 3.2-14, Figure 3.2-15, Figure 3.3-14 and Figure 3.3-15).

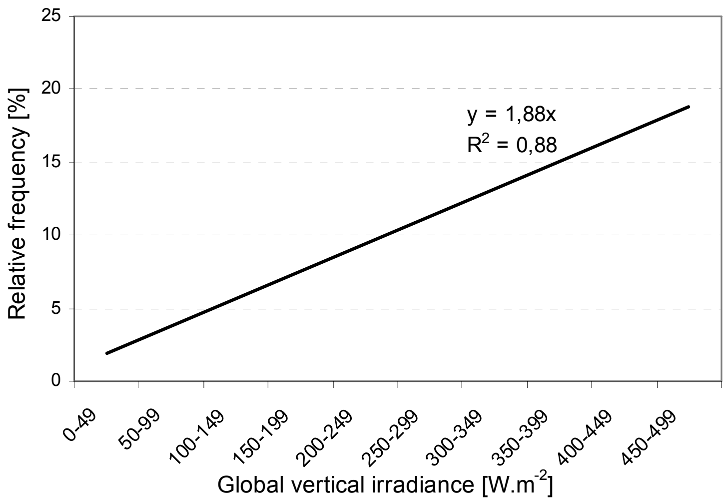

Figure 4.1-17 Normalized relative frequency model for "closing shade" in relation to the global vertical irradiance in VN and VS

Appendix 9.6 presents a summary of action rates (hourly switching lights on/off, opening/closing shades) and shade deployment degree for all the observed offices in buildings HB, VN and VS.

4.1.4 Ventilation

Dependency of opening/closing windows on time of the day:

The office building HB offered the natural ventilation option. The observations suggest that windows are opened early in the day, after the lunch hour and towards the end of the working hours (see Figure 4.1-18). Closing actions observed at a higher rate before the occupants leave their offices for the day.

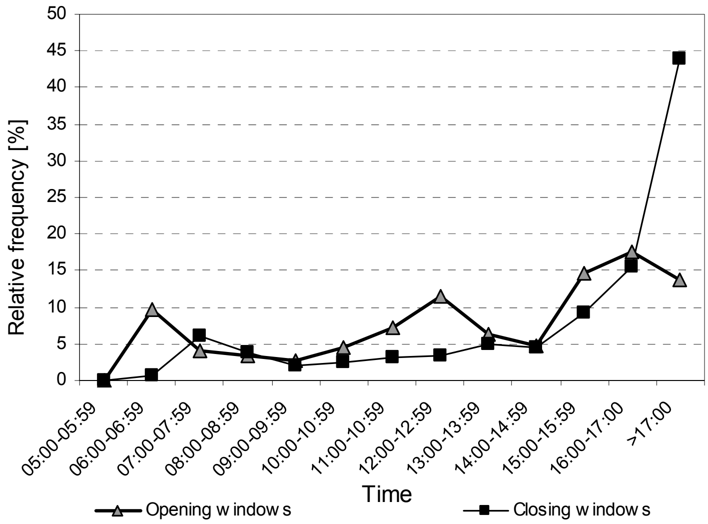

Figure 4.1-18 *Normalized relative frequency of "opening and closing window" actions over the course of a reference day in HB*

Dependency of opening/closing windows on indoor/outdoor temperature:

As Figure 3.1-23 and Figure 3.1-24 illustrate, the frequency of the windows operations during the cold months of the year from December to March is high. The highest frequency of window opening and closing actions occurs when the outdoor temperatures are rather low (see Figure 3.1-27 and Figure 3.1-28). The probability of opening the windows at lower outdoor temperature is higher too (see Figure 3.1-30). It might be because of the heating system, which tends to overheat the offices. As Figure 3.1-29 presents, the occupants open the windows of their offices more frequently when the indoor temperature rises.

Figure 3.1-32 illustrates that the probability of closing the windows is higher when the occupants leave their offices at the end of the day and the outdoor temperature is low. It shows that they are less likely to leave their windows open at very low or high outdoor temperature. In general, windows are more open during the warmer months than the cooler months (see Figure 3.1-33 and Figure 3.1-34).

In Figure 4.1-19 state of opened windows averaged over the cooler months (November, December, January, February and March) and warmer months (April, May and June) is presented.

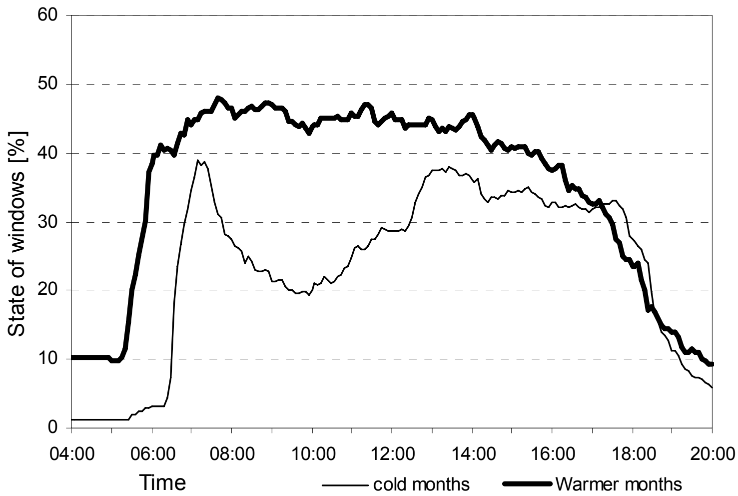

Figure 4.1-19 State of opened windows averaged over cooler/warmer months over the course of a reference day in HB

State of windows in relation to indoor/outdoor temperature:

As Figure 3.1-35 and Figure 3.1-36 illustrate, there is a certain correlation between indoor/outdoor temperature and monthly state of windows. This dependency might be used as the base information for a general model to predict the opening state of windows in this building.

Dependency of opening/closing windows' actions on neutrality temperature

Figure 4.1-20 shows normalized relative frequency of opening and closing windows as a function of difference between indoor temperature and neutrality temperature. As it can be seen in this figure, closing actions rise rapidly as indoor temperature decrease below neutrality temperature. Opening actions rise slightly as indoor temperature rise above neutrality temperature.

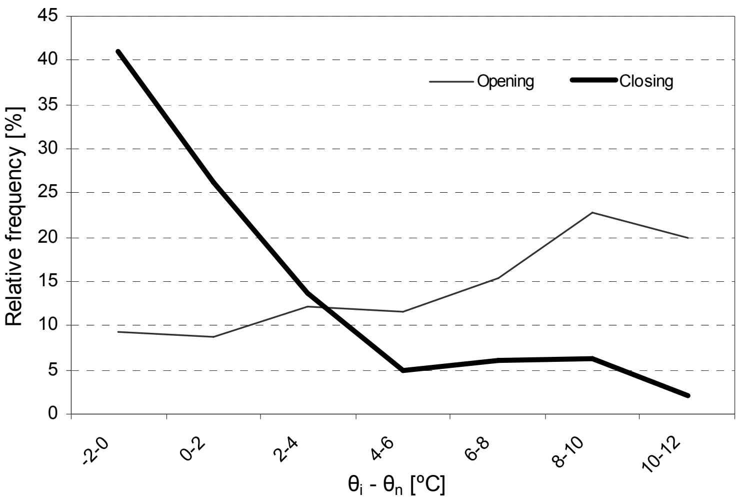

Figure 4.1-20 Normalized relative frequency of opening and closing windows as a function of deference between indoor temperature and neutrality temperature in HB

4.2 Interviews

According to interview results in HB, VN and VS, occupants in building HB, which is naturally ventilated, have better perception of air quality (see Figure 3.4-4). Additionally the occupants' satisfaction in HB in comparison to VN and VS offices that have air-conditioning system is higher (see Figure 3.4-6).

The majority of the interviewees (65% to 100%) in all observed offices considered that it is important to be able to have control on opening/closing the windows and shades (see Figure 4.2-1).

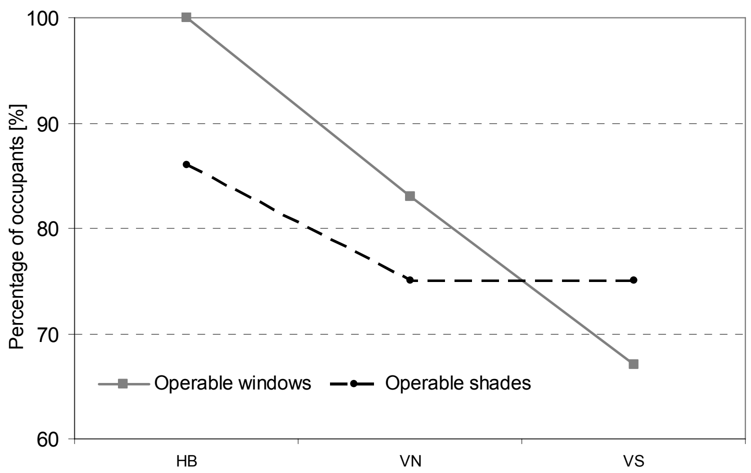

Figure 4.2-1 Importance (Important/Very important) of having the possibility to operate windows and shades

Even though, building HB is naturally ventilated, occupants expressed that they would like to have air-conditioning system in their offices (Figure 3.4-12). As Figure 3.4-3 illustrates, the highest measured mean daily indoor temperatures occurred in summer in HB. This is perhaps reflected in the occupants' evaluation of the thermal conditions and their desire to have air-conditioning system.

Figure 3.4-8 shows that occupants in air-conditioned offices feel less informed about environmental control systems. This may be due to higher complexity of air-conditioning systems as compared to natural ventilation systems. Accordingly, these occupants are more interested in training and information concerning the operation of systems than the others (Figure 3.4-9).

As Figure 3.4-1 reveals, a high percentage of the observed occupants work with computer, the frequency of expressed health complaints and disorders (Figure 3.4-14) seems to reflect this circumstance (backache, headache, general fatigue, etc.).

5 Conclusion

The thesis presented the results of an empirical study of user interactions with building systems in two different types of office buildings in Austria. The results, which are the outcome of a long-term collected data with high-resolution measurements, imply the possibility of deriving general patterns of user control behavior as a function of indoor and outdoor environmental parameters. These findings are expected to improve existing databases of occupants' behavioral patterns in buildings. Better and high-resolution information in this regard can provide a solid basis to evaluate the impact of occupancy behavior on building energy consumption and to develop strategies for better building systems operation. Moreover, the implementation of empirically based behavioral patterns into simulation programs can lead to more accurate simulation results. Such dependable simulation results can support the evaluation of different lighting, ventilation and shading strategies and products already during the design phase of a building.

5.1 Future research

Future research in this area must address a number of important issues:

A larger number of buildings must be studied to increase the statistical significance of the results.

Buildings from different cultural and geographical backgrounds must be considered by selection of the sample.

Where possible, more accurate sensing devices would be beneficial. Likewise, a larger number of sensors in each room could improve the spatial resolution of the results.

The reproduction of the results via simulation (lighting and energy) could allow for an extended hypothesis testing opportunity. For example, more sophisticated indicators of visual comfort (beyond illuminance) could be considered (e.g. daylight glare indices).

Further studies should be designed to explore the effect of building design and systems configuration of users' behavioral patterns.

Ongoing work on stochastic reproduction of user behavior patterns should be further pursued and refined (validated) on the basis of accumulating empirical data.

List of publications

Author of:

How Do People Interact With Buildings Environmental Systems? An Empirical Case Study Of An Office Building. BS2007 Proceedings of the 10th International Building Performance Simulation Association Conference and Exhibition. Beijing, China, 2007, ISBN: 0-9771706-2-4, 7P.

Co-Author of:

User control actions in buildings: Patterns and impact. WellBeing Indoors - Clima 2007 10-14 June - Helsinki – Finland. Seppänen O, Säteri J, (Hrg.). ISBN: 978-952-99898-2-9; Paper-Nr. C03.

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9 Appendix

9.1 Computational derivation of vertical irradiance (façade)

Reindl et al. identified three characteristic intervals for clearness index, defined as the ratio of global horizontal to extraterrestrial radiation. Depending on clearness index value, the diffuse fractions (I_d/I) are calculated as per equations 16-18 (Reindl et al. 1990):

i) $0 \leq k_t \leq 0.3$ Constraint: $I_d / I \leq 1.0$

$$I_d / I = 1.00 - 0.232 k_t + 0.0239 \sin(\alpha) - 0.000682 T_a + 0.0195 \phi$$

(1)

ii) $0.3 \leq k_t \leq 0.78$ Constraint: $I_d / I \geq 0.1$ & $I_d / I \leq 0.97$

$$I_d / I = 1.329 - 1.716 k_t + 0.267 \sin(\alpha) - 0.00357 T_a + 0.106 \phi$$

(2)

iii) $0.78 \leq k_t$ Constraint: $I_d / I \geq 0.1$

$$I_d / I = 0.426 k_t - 0.256 \sin(\alpha) - 0.00349 T_a + 0.0734 \phi$$

(3)

Where

I	global horizontal irradiance
Id	diffuse horizontal irradiance
kt	clearness index
a	sun altitude
Ta	outdoor air temperature
□	relative humidity

After having calculated diffuse fractions, diffuse horizontal irradiance and normal direct irradiance, are calculated as follows:

$$k_{diff} = I_d / I$$

(4)

$$I_d = I \cdot k_{diff}$$

(5)

$$I_{bh} = I - I_d$$

(6)

$$I_{bn} = I_{bh} / \sin(\alpha)$$

Where

kdiff global horizontal irradiance
Ibh direct horizontal irradiance
Ibn direct normal (beam) irradiance
Ta outdoor air temperature

Diffuse horizontal irradiance and direct normal irradiance provide the input data for Perez All-weather model for sky luminance distribution, used as the underlying sky model for simulations performed with RADIANCE lighting simulation system. Besides, RADIANCE lighting simulation program requires also some other information such as the reflectance, modeling the environment, obstruction, materials. Based on the inputs, the vertical irradiance (or any inclined surfaces) levels are calculated in a 5-minute step. The overall schematic diagram of the RAD method is shown in Figure 9.1-1.

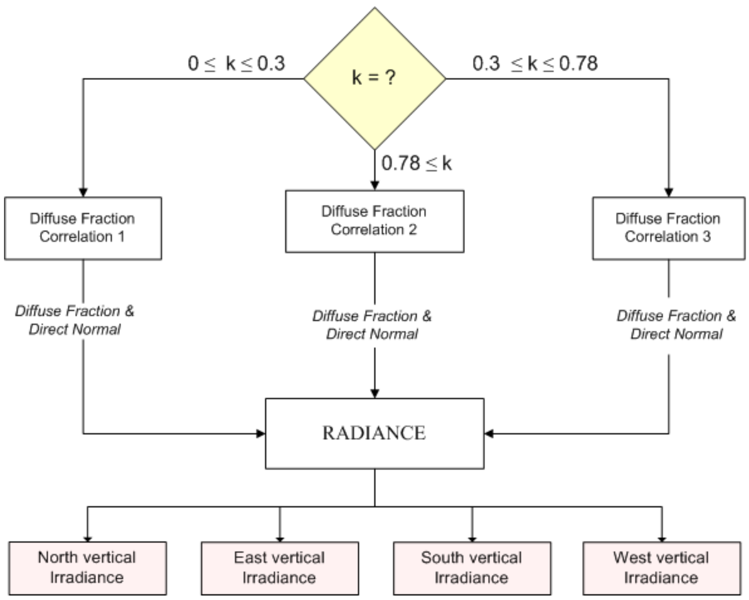

Figure 9.1-1 Schematic diagram of RAD method

9.2 System settings

```
Systemsettings in the Control Panel:

Regional and Lanquage Options:

Regional Options:
      Standard format                     "English (UK)"

      Location                      "Austria"

Customize:
      Numbers:
            Decimal Symbol                ","   [Comma]

            No. of digits after decimal   "2"

            Digit grouping symbol         "."

            Digit grouping                "123.456.789"

            Negative sign symbol          "-"   [Minus]

            Negative number format        "-1,1"

            Display leading zeros         "0,7"

            List separator                ";"   [Semicolumn]

            Measurement system            "Metric"


      Currency:
            Currency symbol               "$"

            Positive currency format      "$1,1"

            Negative currency format      "-$1,1"

            Decimal symbol                ","   [Comma]

            No. of digits after decimal   "2"

            Digit grouping symbol         "."

            Digit grouping                "123.456.789"

      Time:
            Time sample             "13:03:08"

            Time format             "HH:mm:ss"

            Time separator                ":"   [Column]

            AM symbol                     [left empty]

            PM symbol                     [left empty]

      Date
            Calendar                "2029"

            Short date sample       "28.04.2005"

            Short date format       "dd.MM.yyyy"

            Date separator                "."   [Point]

            Long date sample        "Donnerstag, 28.04.2005"

            Long date format        "dddd, dd.MM.yyyy"
```

9.3 Sensor naming

The following code-system shows how to name sensors and files.

Example: **602_112_041126**

1. Digit: Project Number

1: VIC North Facade	3: E-Tel / Eisenstadt	5: UNIQA / Vienna
2: VIC West Facade	4: TU - Freihaus	6: HB Hartberg

2.-3. Digit: Room Number

Start with 01, 02, 03, …

4. Digit: Sensor Type

1: IT-200	3:Hobo Temperature	5:Weather Station	7:AP Logs	9 : SolRad
2: Hobo	4: Camera Files	6:Log for heating control	8:MIKS	v :photos, plans, questionnaire, etc.

5.-6. Digit: Sensor Number

Start with 01, 02, 03, … in each room. (For the Weather Station: 11 v med (WSM), 12 v max (WSS), 20 te, 30 RH, 40 SR), underscore "_" as Separator

7.-12. Digit: Date

YYMMDD (every time you reset the sensor, you will have to change the date)

This means that the example above is the HB building:	**6**02_112_051126
Room number two:	6**02**_112_051126
It is an IT-200 sensor:	602_**1**12_051126
And it is the sensor number twelve:	602_1**12**_051126
The measurement start is on 26th November 2005:	602_112_**051126**

9.4 Questionnaire (interviews)

The results for the different buildings are expressed in terms of percentage of people.

Table 9-1 Summary of the interviews

	Question	Category	HB	VN	VS
1.	Personal information				
1.1	Gender	M	43	30	42
		F	57	70	58
1.2	Age	<25	14	0	0
		25-35 years	0	10	16
		36-45 years	43	40	50
		46-55 years	43	20	17
		>55 years	0	30	17
1.5	How many hours in average do you work per week?	0-10 hours	0	0	0
		11-20 hours	0	0	0
		21-30 hours	14	0	0
		31-40 hours	58	64	8
		41-50 hours	14	26	33
		51-60 hours	0	0	59
		>60 hours	14	0	0
1.6	Of these, how many hours do you spend at your workstation?	0-10 hours	0	10	8
		11-20 hours	29	0	0
		21-30 hours	14	10	17
		31-40 hours	43	50	42
		41-50 hours	14	30	33
		51-60 hours	0	0	0
		>60 hours	0	0	0
1.7	What percentage of your work do you perform on computer?	0-10%	14	0	0
		11-20%	0	0	0
		21-30%	0	0	0
		31-40%	14	0	0
		41-50%	0	10	0
		51-60%	0	30	0
		>60%	72	60	100
1.8	How long have you been working in your current office	0-6 months	14	10	0
		7-12 months	14	10	0
		13-24 months	29	30	25
		25-36 months	0	10	8
		37-60 months	29	10	42
		61-120 months	14	20	17
		121-180 months	0	10	8
		>180 months	0	0	0
2.	Evaluation of the indoor climate and environ. control systems				
2.1	How do you find the air quality in your office?	Very bad	0	0	10

		Bad	0	42	20
		It's OK	43	42	40
		Good	57	16	20
		Very good	0	0	10
2.1a	What do you mean by 'bad' air quality?	Polluted ventilation system	0	0	
		Poor ventilation	100	100	
		Lack of plants	0	0	
2.2	Are you satisfied with the possibility to ventilate your office?	Not at all	0	0	25
		Less satisfied	14	42	0
		It's OK	0	42	25
		Satisfied	72	16	50
		Very satisfied	14	0	0
2.2a	Why are you not satisfied with the possibility to ventilate your office?	Not operable windows/Lack of fresh air			
		External glass layer not operable			
		Difficult to open the windows			
2.3	How is the average temperature in your office in winter?	Cold	0	0	0
		Cool	14	0	8
		Neutral	57	67	58
		Warm	29	33	34
		Hot	0	0	0
2.4	How is the average temperature in your office in summer?	Cold	0	0	0
		Cool	0	0	18
		Neutral	29	73	18
		Warm	57	27	27
		Hot	14	0	37
2.5	How satisfied are you with the heating system in your office?	Not at all	0	0	8
		Less satisfied	0	0	25
		It's OK	0	75	50
		Satisfied	100	25	0
		Very satisfied	0	0	17
2.6	How satisfied are you with the air-conditioning in your office?	Not at all		16	25
		Less satisfied	25	17	
		It's OK		42	50
		Satisfied		17	0
		Very satisfied	0	8	
2.7	Do you have sufficient daylight in your office?	Not sufficient	14	9	8
		Could be more	0	8	0
		It's OK	86	83	67
		A bit too much	0	0	17
		Too much	0	0	8
2.8	Are you annoyed by direct sunlight at your workstation?	Frequently	14	8	25
		Occasionally	0	17	33
		Rarely	29	17	25
		Never	57	58	17

2.9	Are you annoyed by reflections or too bright surfaces on your computer screen?	Frequently	0	8	27
		Occasionally	14	42	55
		Rarely	14	33	18
		Never	72	17	0
2.10	Do you have sufficient artificial light in your office?	Not sufficient	0	0	8
		Could be more	0	8	17
		It's OK	100	92	75
		A bit too much	0	0	0
		Too much	0	0	0
2.11	Are you annoyed by noise in your office?	Frequently	0	8	0
		Occasionally	29	25	17
		Rarely	14	25	50
		Never	0	42	33
2.11a	In case of 'Frequently' and 'Occasionally', specify the source of noise!	From the corridor	25	50	
		Air-conditioning	0	0	
		Colleagues in the room	0	0	
		Equipment	0	0	
		Street noise	14	0	0
		Elevators		0	50
		From neighbor rooms	75	0	
2.12	Evaluate the distance of your workstation from the window.	Too close	0	0	25
		It's OK	100	100	75
		Too far	0	0	0
2.13	Evaluate the outdoor view from your office window.	Very good	0	33	25
		Good	43	67	33
		Satisfactory	57	0	33
		Not satisfactory	0	0	9
2.14	Do you have enough privacy in your office to work undisturbed?	Yes	57	42	50
		It's OK	43	58	33
		No	0	0	17
3.	Operation and accessibility of the systems and system controls				
3.1	Can you open the windows of your office if required?	Impossible	0	100	100
		Difficult	0	0	0
		It's OK	29	0	0
		Easy	57	0	0
		Very easy	14	0	0
3.2	How important is it for you to have the possibility to open the windows?				
		Unimportant	0	8	0
		Not so important	0	8	17
		Don't know	0	0	17
		Important	29	25	25
		Very important	71	58	40
3.3	Can you decide independently when to open/close the windows in your office	No	43	-	-

	or do you have to negotiate with other people?				
		Yes	57	-	-
3.4	Do you have easy access to the internal shades in your office?	Impossible		0	0
		Difficult		0	25
		It's OK		82	25
		Easy		18	42
		Very easy		0	8
3.5	How important is it for you to have the possibility to operate the internal shades?	Unimportant	17	0	
		Not so important	8	17	
		Don't know	0	8	
		Important	58	25	
		Very important	17	50	
3.6	Can you decide independently when to operate the internal shades in your office or do you have to negotiate with other people?	No		0	0
		Yes		100	100
3.7	Do you have easy access to the external shades in your office?	Impossible	0	-	-
		Difficult	0	-	-
		It's OK	29	-	-
		Easy	57	-	-
		Very easy	14	-	-
3.8	How important is it for you to have the possibility to operate the external shades?	Unimportant	0	-	-
		Not so important	0	-	-
		Don't know	14	-	-
		Important	29	-	-
		Very important	57	-	-
3.9	Can you decide independently when to operate the external shades in your office or do you have to negotiate with other people?	No	29	-	-
		Yes	71	-	-
3.10	Is the light switch easily accessible to you?	Impossible	0	0	0
		Difficult	0	0	0
		It's OK	0	17	25
		Easy	57	58	50
		Very easy	43	25	25
3.11	Can you decide independently when to switch on/off the light in your office or do you have to negotiate with other people?	No	43	0	0
		Yes	57	100	100
3.12	Is the thermostat easily accessible to you?	Impossible	43	0	0
		Difficult	29	8	8
		It's OK	14	42	58
		Easy	0	42	17
		Very easy	14	8	17
3.13	Can you regulate the temperature on	No	34	0	0

	your own or do you have to negotiate with other people?				
		Yes	66	100	100
4.	Awareness of the functionality of the building control systems and energy conscious behavior				
4.1	Are you sufficiently informed about how the following systems (heating, ventilation, cooling, lighting, blind protection) work in your office?				
	Heating	Not sufficient	0	25	33
		It's OK	33	50	50
		Very good	67	25	17
	Ventilation	Not sufficient	17	60	36
		It's OK	33	20	55
		Very good	50	20	9
	Air-conditioning	Not sufficient	46	50	
		It's OK		54	42
		Very good		0	8
	Lighting	Not sufficient	0	17	25
		It's OK	33	66	67
		Very good	67	17	8
	Shading	Not sufficient	17	42	27
		It's OK	17	33	73
		Very good	66	25	0
4.2	Have you ever had a training concerning the systems in your office?	No	100	100	100
		Yes	0	0	0
	If 'no', would you be interested in such training?				
	No	60	33	18	
		Don't know	20	8	46
		Yes	20	59	36
4.3	To whom do you refer in case of a problem with the building systems (heating, lighting, etc.)?	Secretary	0	0	0
		Build. Services	100	75	67
		Colleague	0	0	0
		Tech. assistant	0	0	0
		Don't know	0	25	33
4.4	Are you satisfied with the system services and support in your office?	No	0	0	0
		Don't know	50	50	64
		Yes	50	50	36
4.5	Do you think that you can influence building energy consumption in the way you operate building systems?	No	0	8	0
		Don't know	33	50	55
		Yes	67	42	45
4.6	Do you think about energy conservation, when you operate building systems?	No	17	25	17
		Don't know	17	0	17
		Yes	67	75	66
5.	Personal preferences of organizing the current / ideal working space; health complaints				
5.1	Are you satisfied with the possibilities	Not at all	0	0	0

	you have to personalize your working place (furniture, plants, photos…)?				
		Less satisfied	0	0	25
		It's OK	14	17	42
		Satisfied	72	58	25
		Very satisfied	14	25	8
5.2	Generally, do you feel fine in your office?	Not at all	0	0	0
		Less	0	17	17
		It's OK	14	33	58
		Good	43	50	17
		Very good	43	0	8
5.3	What are the most important features of the ideal working place from your point of view?	Quietness/Privacy			
		Furniture	20		
		Good working 'atmosphere"	20		
		Good indoor climate			
		Single occupancy office	20		
		Adequate lighting	10		
		Better office electrical equipment	10		
		Controllable systems	20		
		Personal organization of the workplace			
5.4	Which improvement measures in your office would you consider as most urgent?	Effective furniture	17	38	5
		Operable windows	0	6	7
		Better servicing of the air-conditioning system	0	19	13
		Installation air conditioning system	50	0	0
		Improvement of shading system	0	0	27
		Better office equipment	33	0	0
		Bigger office	0	0	13
		Quietness/Privacy	0	25	0
		Adjustable temperature	0	6	13
		Better air quality	0	6	22
5.5	Do you have any health complaints?	Backache	28	50	50
		Headache	43	17	25
		General fatigue	43	67	25
		Neck pain	28	42	50
		Nasal irritation	28	42	17
		Eyestrain or -burning	28	67	42
		Respiratory problems	0	17	25
		Sore throat	0	33	17
		Stiffness of limbs	14	33	8
		Rheumatic pains	0	17	0

9.5 Mean shade deployment in relation to global horizontal irradiance

Figure 9.5-1 and Figure 9.5-2 show mean shade deployment degree in VN and VS as a function of global horizontal irradiance.

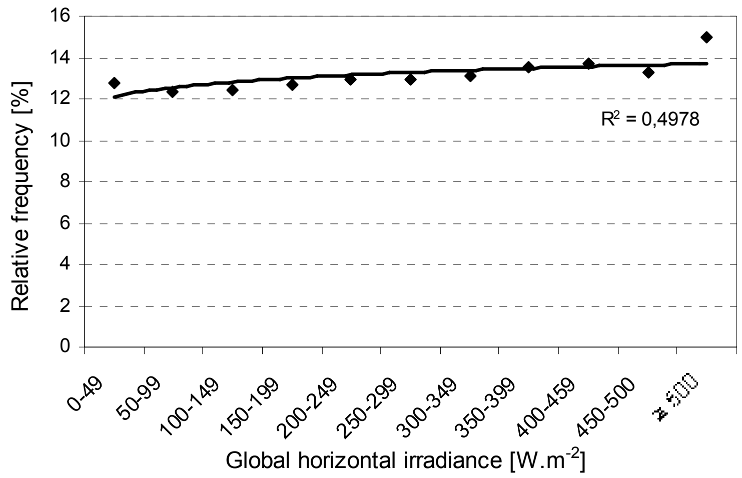

Figure 9.5-1 *Mean shade deployment degree in VN as a function of global horizontal irradiance*

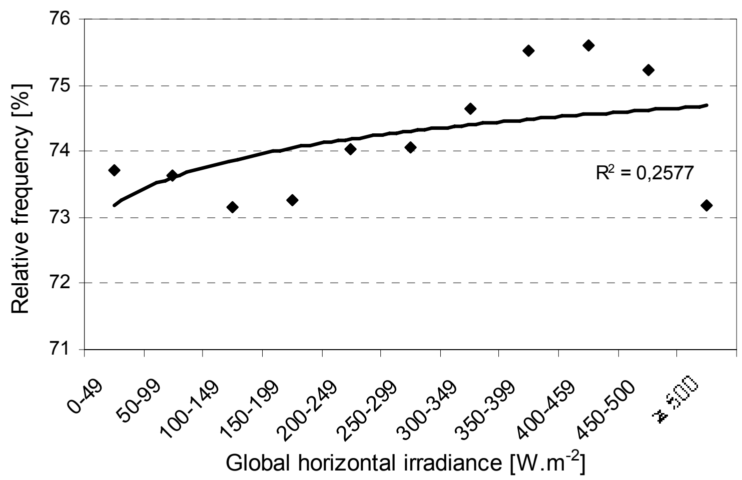

Figure 9.5-2 *Mean shade deployment degree in VS as a function of global horizontal irradiance*

9.6 Action rates

The following tables present occupancy percentage in working hours, light operation in occupied duration, action rates (number of actions per hour) in the monitored offices in HB, VN and VS.

Table 9-2 occupancy percentage in working hours, action rates (number of actions per hour) in the double occupancy offices of HB

Room	Occupancy [%]	Switching light off	Switching light on	Closing shades	Opening shades	Mean shade deployment [%]
611	87	1,234	1,216	0,005	0,007	2
613	80	0,336	0,345	0,001	0,001	51
621	16	2,118	2,041	0,003	0,003	7
623	35	2,360	2,332	0,005	0,007	8
Average	54	1,512	1,484	0,003	0,004	17

Table 9-3 occupancy percentage in working hours, action rates (number of actions per hour) in the single occupancy offices of HB

Room	Occupancy [%]	Switching light off	Switching light on	Closing shades	Opening shades	Mean shade deployment [%]
612	43	0,08	0,38	0,003	0,000	35
622	38	0,20	0,71	0,008	0,000	50
Average	40	0,14	0,54	0,005	0,000	43

Table 9-4 occupancy percentage in working hours, light operation in occupied duration, action rates (number of actions per hour) in the monitored offices of VN

Room	Occupancy [%]	Light operation in occupied hours	Switching light off	Switching light on	Closing shades	Opening shades	Mean shade deployment [%]
111	58	29	0,19	0,16	0,005	0,003	36
112	45	89	0,20	0,20	0,033	0,031	48
113	43	89	0,36	0,36	0	0	0
114	59	98	0,14	0,14	0	0	0
115	54	17	0,32	0,32	0	0	0
116	46	31	0,65	0,65	0	0	0
117	44	48	0,18	0,18	0	0	0
118	55	29	0,13	0,13	0	0	0
121	57	72	0,20	0,2	0,002	0,002	24
122	61	33	0,14	0,14	0,001	0,001	1
123	55	8	0,11	0,10	0,001	0,001	0
124	23	31	0,96	0,96	0	0	0
125	46	29	0,42	0,42	0	0	0
126	46	64	0,20	0,20	0,005	0,005	77
127	34	43	0,26	0,26	0	0	0
Average	48	47	0,30	0,30	0,003	0,003	12

Figure 9.6-1 shows the offices on north façade (VN) which receive direct sunlight in sunny days of summer (111, 112, 121, 122 and 126).

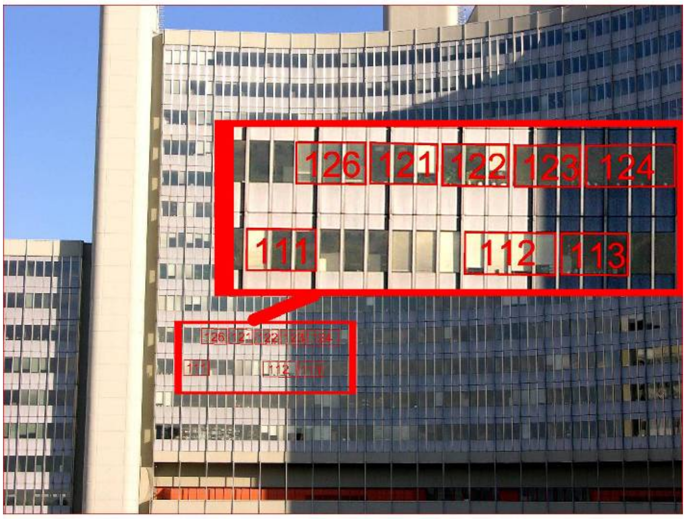

Figure 9.6-1 Direct sunlight on VN offices

Table 9-5 occupancy percentage in working hours, light operation in occupied duration, action rates (number of actions per hour) in the monitored offices of VS

Room	Occupancy [%]	Light operation in occupied hours	Switching light off	Switching light on	Closing shades	Opening shades	Mean shade deployment [%]
211	39	83	0,20	0,20	0,04	0,04	82
212	57	65	0,21	0,21	0,04	0,03	83
213	58	40	0,15	0,15	0,01	0,00	92
214	50	71	0,28	0,28	0,02	0,02	65
215	44	67	0,16	0,16	0,00	0,00	94
216	33	73	0,22	0,22	0,02	0,02	90
217	45	97	0,21	0,22	0,01	0,01	89
218	38	29	0,19	0,19	0,16	0,17	43
221	46	37	0,41	0,41	0,03	0,02	76
222	41	75	0,22	0,22	0,01	0,01	97
223	48	15	0,22	0,22	0,06	0,05	22
224	40	73	0,20	0,20	0,05	0,05	85
225	38	47	0,18	0,18	0,05	0,05	68
226	35	28	0,16	0,16	0,11	0,09	53
Average	44	57	0,22	0,22	0,04	0,04	74

Electrical lights in the monitored office buildings are switched on (and switched off) approximately 1 to 2 times in a working day. Shades, on the other hand, are opened (and closed) much less frequently, i.e., once every week on average. Hence, shades are generally operated less often than lights. The explanations for the still lower shade deployment rates in VN and HB may be as follows: VN offices face north and only some rooms in summer receive direct sunlight (see Figure 9.6-1) and the shade actions only happen in these offices (see Table 9-4). Interior curtains in HB allow for a certain level of glare control, thus reduce the need for frequent deployment of external shades.

9.7 Electrical energy saving potential in lights

Figure 9.7-1 and Figure 9.7-2 illustrate the potential for reduction of electrical energy use for lighting in HB. Thereby, three (cumulative) energy saving scenarios are computationally derived.

- The first scenario requires that the lights are automatically switched off after 10 minutes if the office is not occupied.
- The second scenario implies, in addition, that lights are switched off, if the daylight-based task illuminance level equals or exceeds 500 lx.
- Finally, the third scenario assumes furthermore an automated dimming regime, whereby luminaires are dimmed down so as to maintain a task illuminance level of 500 lx while minimizing the electrical energy use for lighting.

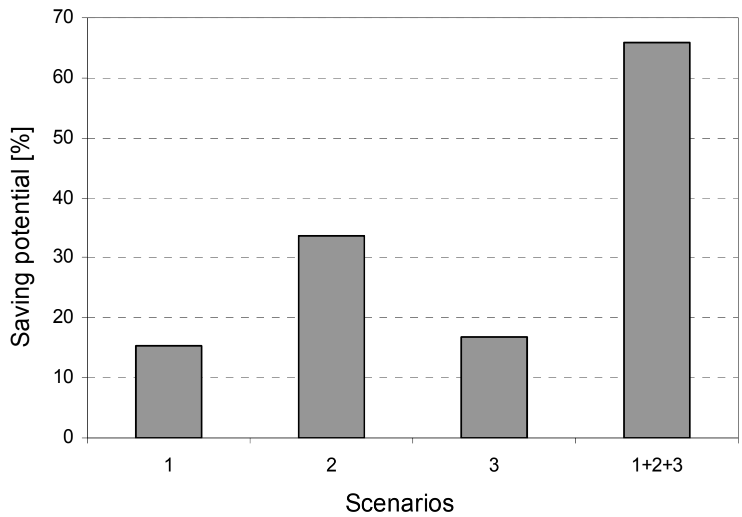

Figure 9.7-1 Estimated saving potential (in % of status quo) in electrical energy use for lighting in HB for the operation scenarios

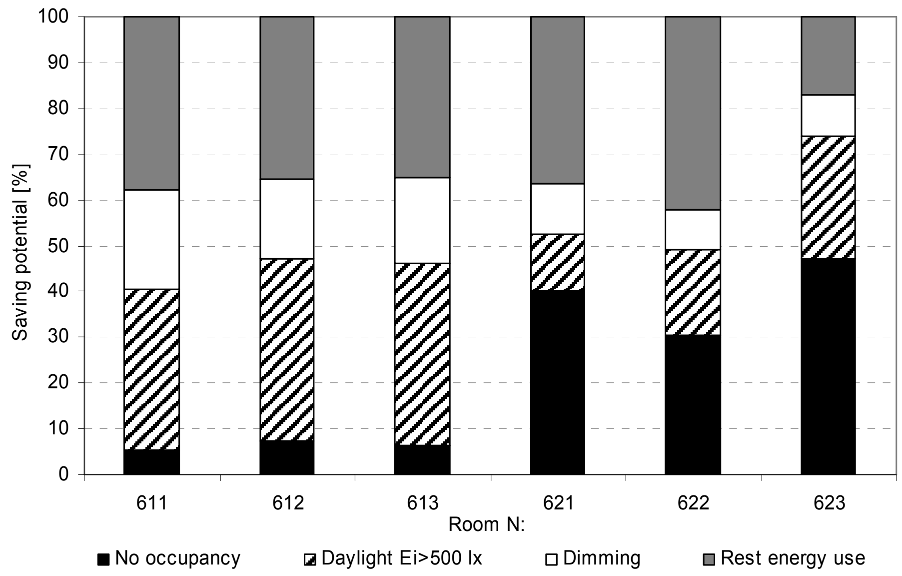

Figure 9.7-2 Estimated saving potential (in % of status quo) in electrical energy use for lighting in the 6 offices of HB for the operation scenarios

EUROPEAN CURRICULUM VITAE FORMAT

PERSONAL INFORMATION

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Date of birth	08.03.1977

SUMMARY

• Current position/Job	Research assistant, Vienna University of Technology
• Certificate	Architect, MSc. in Architecture
• Architectural design & Detailing	Been working on design of Residential & Commercial buildings, For 5 years
• Software that I know	AutoCAD, Photoshop, MS Office(Excel, PowerPoint, Word): Professional Lab View, Architectural Desktop, Adobe (After Effects, Premiere, Image Ready), Macromedia Dream Weaver (Web design), Ecotect, Odeon, Voltra (Building performance simulation software): Good ArchiCAD, Allplan: Familiar

EDUCATION AND TRAINING

• Dates	2004- Present
• Name and type of university providing education	Department of Building Physics and Building Ecology, Institute of Architecture Science, Vienna University of Technology (Karlsplatz 13 / 2703, A-1040 Vienna)
• Principal subject	Building Physics
• Title of qualification awarded	Doctor of Technology (to be)
• Dates	1996-2003
• Name and type of university providing education	School of Architecture and Urban Design, Shahid Beheshti University (Evin, Tehran)
• Principal subject	Architecture
• Title of qualification awarded	Master of Science

WORK EXPERIENCE (ACADEMIC)

• Dates	2004-Present
• Name and address of university	Department of Building Physics and Building Ecology, Vienna University of Technology (Karlsplatz 13/259.3, Vienna)
• Position held	Research assistant, Student assistant, Tutor
• Type of work	Research, Tutor of some lectures

WORK EXPERIENCE (ENGINEERING)

• Dates	2003-2004
• Name and address of company	Mabna Consulting Engineers (Tehran, 14717-53616)
• Type of business	Building Design, Interior Design, Consulting, Construction Supervisor
• Position held	Director of Design Studio
• Projects	Renovation: Pirnia Hotel, Shiraz Interior design & Construction: Tehran, Governorship's conference hall

• Dates	2000-2003
• Name and address of company	Hamid-Reza Nouri & Associates (No. 1185/6, Valiasr Ave, Tehran)
• Type of business	Building Design (Phase 1- 4), Consulting, Construction Supervisor
• Position held	Member of Design Team
• Projects	Renovation of Place Marie commercial & residential complex, PA, Lancaster, USA Construction: Gheshm Island, South Beach Park Hotel & Restaurant Complex Design: Gheshm Island, Physician & Staff Residential Complex, Persian Gulf Hospital Design: Gheshm Island, V.I.P Visitors Residential & Conference Center, South Beach
• Dates	1999-2000
• Name and address of company	Hezardastan Mobtaker (Iranian branch of Millbach, Germany), (No. 35/2, Gandi Ave, Tehran)
• Type of business	Digitalization of old German's buildings maps
• Position held	Drafter
• Projects	Digitalization of old German's buildings maps by Auto Cad
• Dates	1998-1999
• Name and address of company	1998-99 Raniz Consultant Engineers (No. 36/24, Alvand Ave, Tehran)
• Type of business	Interior Design
• Position held	Member of Interior Design team
• Projects	Interior Details of new International Airport of Tehran

PERSONAL SKILLS AND COMPETENCES

LANGUAGES	Persian / English / German
• Reading, Writing, Verbal skills	Mother Tongue / Good / Good
ORGANIZATIONAL SKILLS	I have worked closely with groups of building engineers (Civil, Mechanical and Electrical) in some projects and companies. I was director of a design studio with two design projects.
TECHNICAL SKILLS AND COMPETENCES	I know many types of software related to Architecture and building physics: AutoCAD, 3DS MAX, Photoshop, MS Office(Excel, PowerPoint, Word): Professional Lab View, Architectural Desktop, Adobe (After Effects, Premiere, Image Ready), Macromedia Dream Weaver (Web Design), Ecotect, Odeon, Voltra (Building performance simulation software), hardware and assembling: Good ArchiCAD, Allplan: Familiar Measuring Techniques, Data processing, Data analysis, Image processing
ADDITIONAL INFORMATION	I am married and my husband is an Architect, MSc. Dr. Techn. He is my special teammate.
DRIVING LICENCE(S)	European "B" (Austrian)
INTERESTS	Swimming, Climbing, Cycling - Non-smoker.

LIST OF PUBLICATIONS

• Author of:

How Do People Interact With Buildings Environmental Systems? An Empirical Case Study Of An Office Building. BS2007 Proceedings of the 10th International Building Performance Simulation Association Conference and Exhibition. Beijing, China, 2007, ISBN: 0-9771706-2-4, 7P.

• Co-Author of:

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