Dissertation

ON PATTERNS OF CONTROL-ORIENTED HUMAN BEHAVIOR IN OFFICE ENVIRONMENTS

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259.3

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Dedicated to my parents, my love Margit and my children Maurus and Theodora

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Unser Wissen ist ein kritisches Raten,

ein Netz von Hypothesen,

ein Gewebe von Vermutungen.

(Karl Popper)

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Kurzfassung

In dieser Arbeit über kontrollorientierte menschliche Verhaltensmuster werden Ergebnisse, welche im Rahmen des Forschungsprojekts 'People as Power Plant' gewonnen wurden, präsentiert. Im Ganzen wurden sechs Bürogebäude in Österreich beobachtet. Nachdem die Beweggründe und ein Überblick der bisherigen wissenschaftlichen Anstrengungen in diesem Feld dargelegt wurden, folgt eine Beschreibung der sechs Bürogebäude. Um die Vielfältigkeit von Bürogebäuden ansatzweise zu erfassen, wurden bewußt unterschiedliche Beispiele ausgewählt und betrachtet. Diese unterscheiden sich durch die beherbergte Branche, Raumgröße und Belegungszahl, Gebäudesysteme und den 'Freiheitsgrad der Nutzer' diese Gebäudesysteme zu beeinflussen etc.. Das bedingt, daß Analysen und die Art der Ergebnisse von Gebäude zu Gebäude variieren. Einige Ergebnisse wurden schon von meinen Kollegen in deren Arbeiten oder aber im Endbericht des Forschungsprojektes publiziert. In dieser Arbeit werden hauptsächlich Ergebnisse eines modernen Bürohochhauses (UT) sowie manche, die anderen Gebäude betreffende, Analysen gezeigt. Die Güte der Messdaten ist exzeptionell, handelt es sich doch um empirische Daten einer Feldstudie (mit uneingeschränktem Bürobetrieb) über den Zeitraum von vierzehn Monaten mit einer sehr hohen zeitlichen Auflösung von fünf Minuten. Die Messdaten von mehr als der Hälfte der beobachteten Personen des gesamten Forschungsprojektes werden in dieser Arbeit dargestellt und diskutiert. Die Ergebnisse zeigen die Möglichkeit umweltbeeinflußtes, kontrollorientiertes, menschliches Verhalten in Abhängigkeiten und Mustern zu beschreiben. Auf diesen Abhängigkeiten aufbauend wurden generelle Modelle für Anwesenheit, anwesenheitsbezogene Wärmelast, Lichteinschaltwahrscheinlichkeit bei Ankunft, Lichtausschaltwahrscheinlichkeit bei Verlassen, mittlere Lichtlast, mittleren Beschattungsgrad erstellt. Diese Modelle können im Bereich der Gebäudesimulation, der Gebäudeautomation, des Energie-Managements und Contracting Eingang finden.

Abstract

In this thesis concerning patterns of control-oriented human behavior results of the research project 'People as Power Plant' are presented. Six office buildings in Austria were investigated in toto. After describing the motivation and a brief literature review, the six observed buildings are described. To investigate a variety of office buildings, differentiated instances were chosen to be monitored. They differ in harbored branch, room size and occupant number, building systems, the degree of freedom of users to adjust these systems, etc.. Consequently, analyses and manner of results differ building by building. A number of the results of this research project have been analysed and published by my colleagues in their theses or in the Final report of the research project. Especially results of one high rise office building (UT) are presented and set into context with previous published results of this research project. The quality of the observed data is very exceptional: Empirical data collection was done in the field (in offices while they were in use), over a long period (about fourteen month) and in high resolution (using five minute intervals). Results of more than half of the people observed in the whole research project are presented and discussed in this thesis. The results describe the possibility of identifying general patterns of environmentally based control-oriented human behavior. Based on these patterns generic models could be developed for occupancy, people load, lights switch on upon arrival probability, lights switch off when leaving probability, mean lighting load and mean shade deployment. Their essence can be applied in building performance simulation, building automation, energy management and contracting.

Keywords: data collection, long-term study, control-oriented human behavior, user interaction, occupancy, occupancy models, lighting control, generic models

1 Introduction

1.1 Motivation

Talking about the energy performance of buildings and their environmental impact, most people think about building geometry, building materials or boundary conditions like weather. Although it is common knowledge that control actions can significantly affect the indoor climate, the impact of people on building performance is hardly considered even though the mere presence of occupants has an influence. However, relatively few longitudinal studies have investigated such actions in real office environments and in detail. In most buildings, occupants operate control devices such as windows, shades, luminaries, radiators, and fans to bring about desirable indoor environmental conditions. Knowledge of such user actions is crucial towards understanding, accurate prediction of building performance (energy use, indoor climate) and effective operation of building service systems.

The added value on this kind of knowledge can:

- bring about a better understanding of the nature, logic, types, and frequency of control-oriented user behavior in buildings;
- help architects and other planners to find better and more sustainable designs
- support the development of reliable, empirically-based behavioral models (of user-systems interactions in buildings);
- improve the accuracy of building performance simulation applications by integration of high-fidelity user behavior models (either in terms of general tendency patterns of statistical nature, or in terms of stochastically firing agent elements);
- improve the performance of building management and automation systems via integration of proactive and user-responsive control algorithms and methods;
- improve the informational basis of energy and performance contracting practices and processes;
- support the initiation of user information campaigns to educate and inform users regarding the implications of their control actions concerning indoor environment and energy performance of buildings;

- support facility managers in their communications and interactions with building users and in effectively addressing users' problems with buildings' environmental control systems;
- provide ideas and suggestions toward the improvement of design, operations, and – above all – user-interfaces of buildings' environmental control systems.

The present thesis provides an overview regarding an effort to observe control-oriented occupant behavior in working places in six office buildings in Austria over a period of one year. The thesis specifically addresses such behavioural pattern for one of these buildings in great detail. In particular, states and events pertaining to occupancy, systems, indoor environment, and external environment were monitored. Weather stations, a number of indoor data loggers, and 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 air velocity and global irradiance, status of electrical light fixtures, position of shades). The results reveal distinct patterns in the collected data. Specifically, control behavior tendencies show dependencies both on indoor and outdoor environmental parameters. A summary of these tendencies is presented and their principal potential as the basis of empirically grounded user action models is explored. Implications for indoor climate and energy performance are considered (Mahdavi et al. 2007).

1.2 Background

Various studies of occupants' behavior toward building systems for environmental control in office buildings have been done. They investigate the existence of patterns (regularities) of switching on/off lights, opening/closing shades and windows, and their relationships with internal/external climatic conditions. The main objective is to achieve better understanding of peoples' control behavior, in terms of patterns and energetic consequences, to be able to predict more accurately the performance of building systems as well as to improve user satisfaction. Therefore studies have been performed in real or test spaces, where information is gathered on: occupancy; status of systems; frequency of control actions for switching lights, operating shades and opening/closing windows; indoor environment (temperature, humidity, illuminance, etc.); and outdoor environment (temperature, humidity, solar radiation, illuminance, etc.); Other factors like orientation, sun position are also taken into consideration.

The next sections describe the major findings of previous studies regarding the manual operation of electrical lighting, shading, and windows.

1.2.1 Manual operation of electrical lighting

The studies in this area began in the late 70's with the intention to observe how people operate their electrical lighting, in relation to daylight levels and occupancy. The major findings can be summarized as follows:

<u>The probability of switching the lights on at arrival depends on the working plane illuminance</u>

Hunt (1979) monitored via time-lapse photography 3 medium-sized, multi-person offices, 2 school classrooms and 2 open-space teaching spaces and derived a 'switch on at arrival' probability function in relation to the illuminance on the work plane. Hunt's function has been validated by Reinhart (2001) and other researchers (Love 1998). Both functions state that illuminance levels under 100 lx cause significant increase of the 'switching on' probability (see Figure 1-1).

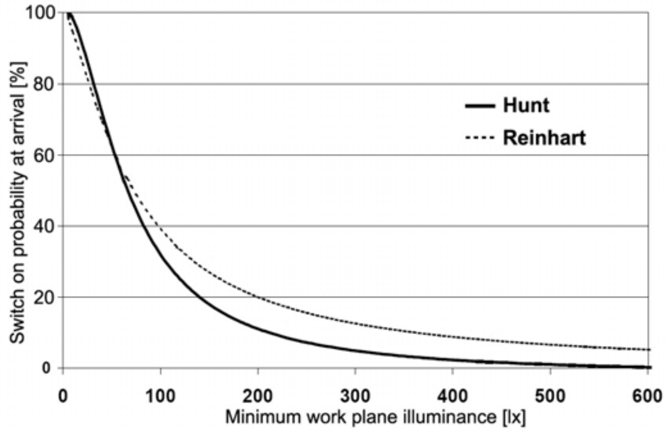

Figure 1-1 Probability of switching the lights on at arrival in the office

<u>The probability of switching the lights off depends on the period of absence from the office</u>

Pigg et al. (1996) found a strong relationship between the propensity of switching the lights off and the length of absence from the room, stating that people are more likely to switch off the light when leaving the office for longer periods. This relationship is verified in other studies (Boyce 1980, Reinhart 2001, see Figure 1-2).

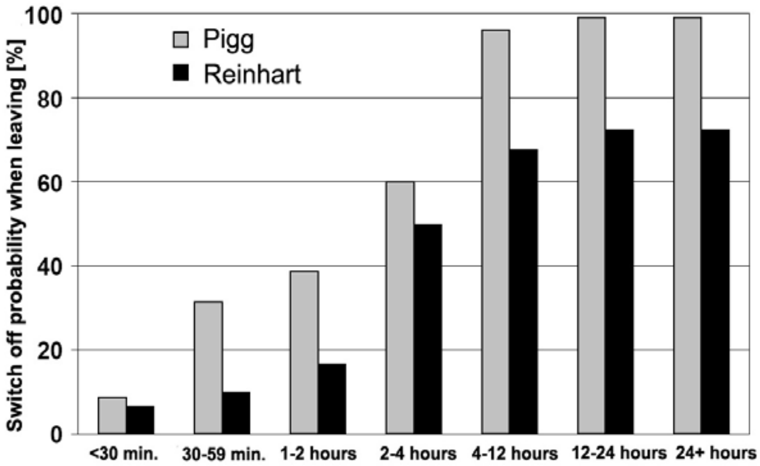

Figure 1-2 Probability of switching the lights off when leaving the office

Pigg also observed that in the presence of occupancy sensors people modify their behavior and are "about half as likely to turn out the lights when they left compared to those without occupancy sensor control" (Pigg et al. 1996). Being conscious about the energy implication of this behavioral tendency, Pigg calculated that the saving potential from the occupancy sensors is reduced by about 30%.

Intermediate switching is related to the daylight availability

'Intermediate' switching the lights is an action occurring during the period of occupation. Boyce (1980) observed intermediate switching in two open-plan offices and found that people tend to switch the lights more often in relation to the daylight availability if the lighting covers zones that are smaller. Reinhart & Voss (2003) discovered that the intermediate 'switching on' events are more common at lower than at higher illuminances. He defined an intermediate 'switching on' probability function according to which, the probability is 2% if the minimum work plane illuminance is between 0 and 200 lx; at illuminance level above 200 lx the probability drops to 0.002% for higher illuminances. Lindelöf & Morel (2006) conducted a study in a small office building in Lausanne to verify Reinhart's intermediate 'switch on' probability function. The results determined an illuminance threshold of 100 lx under which the probability raised significantly, and above that threshold the probability was very low.

Several studies could establish seasonal dependency in lighting operation. In a study about the manual switching of electrical lighting Boyce (1980) discovered that the total number of luminaires switched on was less in summer than in winter, corresponding to the considerable differences in daylight availability for the two seasons. In another study Carter et al. (1999) established seasonal dependency in the average lighting load. The researchers registered 53% lighting load in January and 43% in April and May.

1.2.2 Manual operation of shades

A limited number of studies concerning shade operation have been conducted till now, exploring how the occupants manipulate their shading devices and if they depend on external environmental factors, orientation, time of the day, etc.. The major findings in this area can be summarized as follows:

The operation of shading depends on the façade orientation

Rubin et al. (1978) investigated the operation of Venetian blinds in offices in Maryland USA and discovered that the blind occlusion was higher on the south façade (80%) than on the north façade (50%). A pilot study in one office building in Ottawa (Canada) carried out by Rea (1984) showed that on a clear day about 60% of each façade was occluded by blinds, while on a cloudy day the east façade was occluded 40%. After conducting a study in 4 high-rise office buildings in Tokyo, Japan, Inoue (1988) concluded that 'the changes in the rate of blind operation varied greatly with orientation of buildings' and the blinds on the eastern façade were mostly closed in the morning and opened in the afternoon. Lindsay & Littlefair (1992) conducted a study of 5 office buildings in UK and found a strong correlation between the Venetian blind use and the amount of solar radiation and sun position. Another finding was that the blinds had been adjusted more frequently on the south façade than on any other.

<u>Occupants manipulate their shades mainly to avoid direct sun light and overheating</u>

This dependency was found by Rubin et al. (1978). Rea (1984) confirmed Rubin's statement that people used blinds mostly when direct sun light reached the working area. Bülow-Hübe (2000) conducted an experiment in 2 south-facing single occupancy offices and observed that the shades were closed as protection from sun glare. The author couldn't establish correlation between indoor/outdoor illuminance and the shade deployment. Nevertheless a slightly better relation could be determined between the action closing shades and the existence of sun patches in the room.

<u>Above a certain threshold of vertical solar radiation the position of shades is proportional to the solar penetration depth into a room</u>

Inoue et al. (1988) derived a threshold of 50 $W \cdot m^{-2}$ vertical irradiance, above which the blind position was strongly related to the solar penetration depth into the room. The same hypothesis was confirmed by Reinhart (2001) (see Figure 1-3).

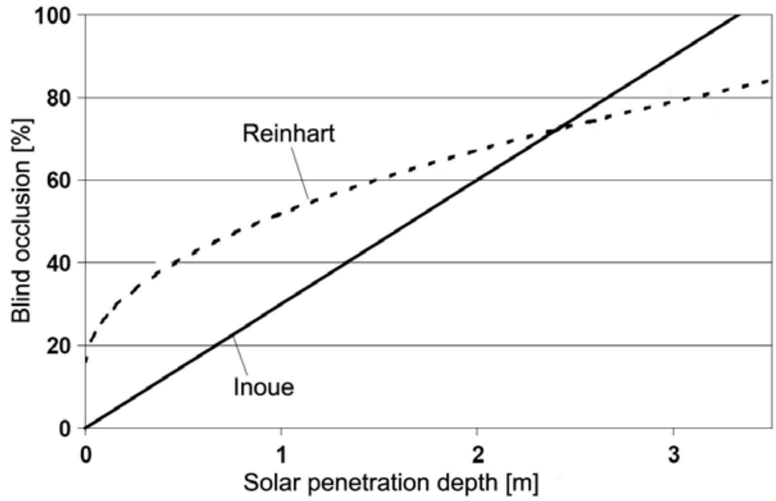

Figure 1-3 Mean blind occlusion in relation to the solar penetration depth on SSW façade, when the vertical solar irradiance is above 50 $W \cdot m^{-2}$

Farber Associates (1992) found that a threshold of 300 $W \cdot m^{-2}$ would trigger a change in the blind position by occupants in buildings in UK. Newsham (1994) modeled with the help of the computer-based thermal model FENESTRA a typical single, south facing office-room in Toronto, Canada, and compared 4 blind control strategies: always closed; always open; closed April-October and open November-March; and manual. Newsham fixed a threshold value of 233 $W \cdot m^{-2}$ for solar radiation, above which the blinds were closed and remained so until the following morning.

<u>Once being closed the shades remain closed till the end of the working day or till visual conditions become intolerable</u>

Rea (1984) observed that throughout the day people rarely changed the blinds. Rea concluded in agreement with Rubin that people have a long term perception of solar irradiances. Inoue et al. (1988) observed that the relation between blind operation and incident illumination on the façade followed a curve (see Figure 1-4). Inoue concluded that people considered long-term irradiance values, while short-time-step dynamics were largely ignored.

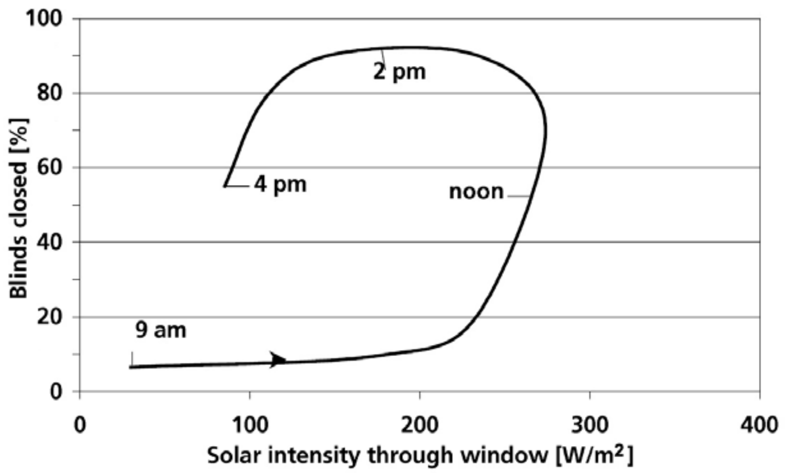

Figure 1-4 Percentage of blinds closed for SSW façade in relation to the vertical solar irradiance

Generally, there is a need for further investigation of the manual operation of shading covering more building types and shading systems. One requirement for future studies would be the consideration of occupancy in the monitored spaces, which would eliminate the uncertainty whether small number of opening/closing actions is due to daylight conditions or due to user absence from the investigated offices.

1.2.3 Manual operation of windows

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.

Herkel et al. (2005) observed the window operation in 21 south-facing individual offices in Freiburg, Germany. Parameters like window status, occupancy, indoor and outdoor temperature as well as solar radiation were recorded in one minute steps. The analysis reveals a strong correlation between the percentage of open windows and the time of the year, outdoor temperature and occupancy patterns. Most window openings happen at arrival of the person in the room. Herkel's results show four types of dependencies: 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 or 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 dependency - 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.

Humphreys & Nicol (1998) introduced an adaptive approach to human thermal comfort stating that 'people react in ways which tend to restore their comfort, if a change occurs such as to produce discomfort. Conducting a field survey, Rijal et al. (2007) concentrated on window opening behavior in naturally ventilated buildings with regard to indoor (globe) temperature and outdoor air temperature as trigger parameters. The resulting "adaptive algorithm" (Humphreys & Nicol 1998) was implemented in ESP-r toward a more realistic thermal comfort and building performance assessment. 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.

The preliminary analysis results suggest that population clustering into active/passive user regarding operable window use is observed, while arrivals and departures appear to be marked by systematic personal adjustments to operable windows (Mahdavi et al. 2007).

2 Approach

The main effort of this study concentrates on the UT building. The other buildings monitored in the research project 'People as Power Plant' were basically addressed in previous studies (Heiss & Leitner 2006, Mohammadi 2007, Lambeva 2007, and Kabir 2007). To draw a complete picture of the research approach all monitored objects and used methods are presented. The description of the buildings VC, FH, ET and HB is collaborative work and in shortened form broadly taken over from the final report of the research project "People as Power Plant" (Mahdavi et al. 2007).

2.1 Buildings

A total number of five office buildings in Austria have been monitored. Table 2-1 gives an overview of the observed buildings. More detailed information concerning the buildings is given in the following sections.

Table 2-1 Summary information on selected buildings

Code	VC	FH	ET	UT	HB
Name & location	Vienna International Center	Freihaus; Vienna University of Technology	eTel; Technologie-zentrum Eisenstadt	UNIQA-Tower; Vienna	BH-Hartberg; Bezirks-hauptmann-schaft
Function	International Organization	University	Telecom. services	Insurance	State government
Data collection	12 month	12 month	9 month	14 month	9 month
Work places observed	29	17	18	89	10
Orientation	N and SW	E	E	All	NW
Glazing to façade ratio	52 %	34 %	54 %	89 %	34 %
Glazing to floor ratio	26 %	18 %	20 %	51-80 %	18 %
Glazing transmittance	79 %	65 %	60 %	65 %	75 %
External Shades	-	Blinds (motorized)	Blinds (motorized)	Blinds (automated)	Blinds
Internal Shades	Blinds	-	Vertical louvers	Indoor screens (motorized)	curtains
Windows	Not operable	Not operable	Operable	Operable	Operable
HVAC	Air-conditioned	Air-conditioned	Mix mode	Mix mode	Naturally ventilated

2.1.1 Vienna International Centre (VC)

2.1.1.1 Geometry / Layout

The Vienna International Centre is located in Vienna and was constructed in 1970's. It covers an area of 180,000m^2 and has extraterritorial status. The complex comprises about 4,500 offices, 9 conference rooms and accommodates about 3,600 international civil servants from about 100 countries on a net floor area of about 230,000m^2. The towers of the complex (Figure 2-1 and Figure 2-2) are named from A to G and contain 92 floors (out of which 26 are technical floors). The office floors contain about 55-70 offices or staff on 61,000m^2 net office area. The Y-shaped office towers are between 48m and 120m high (UNOV 2009).

Were VC is one complex of buildings, the observed offices are all situated in tower D on the 12th and 13th floor. Two different orientations of the facades have been monitored (N and SW), that is why they are treated independent in some analyses and referred to as VC-S and VC-N. The façade of VC-N is oriented to the north-northwest and 15 rooms on two floors (8 rooms in 12th floor and 7 rooms in 13th floor) were observed. The façade of VC-S is oriented to the south and 14 rooms (8 rooms in 12th floor and 6 rooms in 13th floor) were monitored. Figure 2-3 illustrates the 13th floor and the monitored offices, which are painted gray.

Figure 2-1 Aerial view of VC; tower D

Figure 2-2 View from SSW; VC-S marked

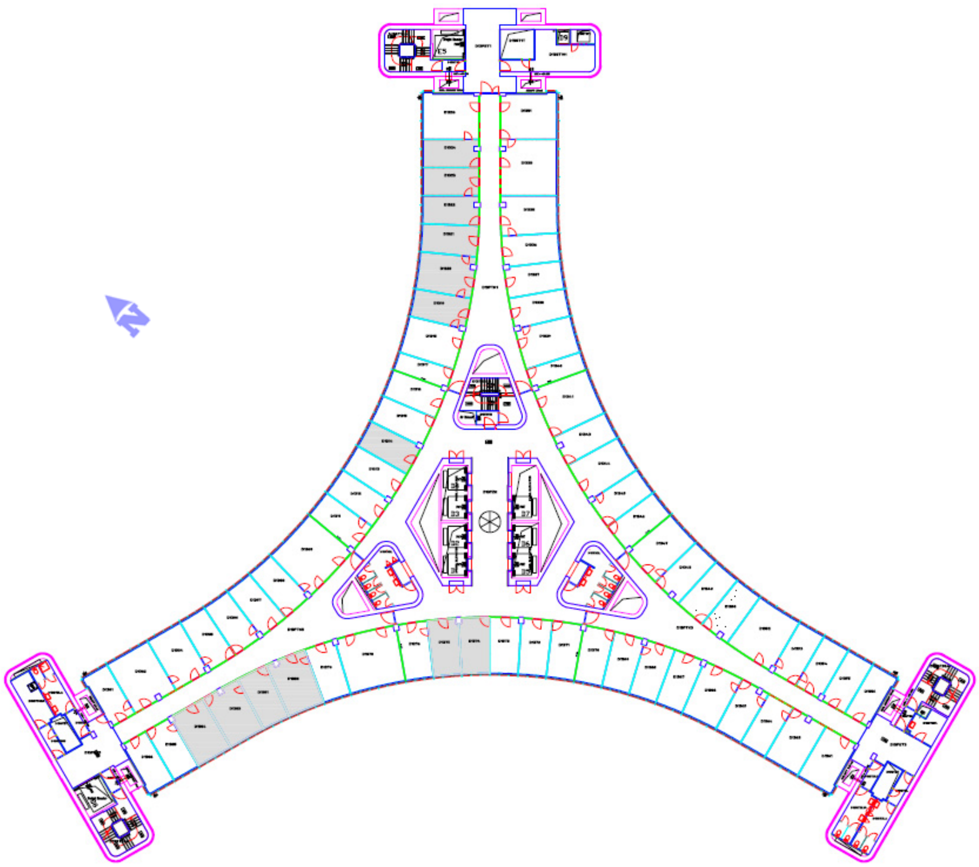

Figure 2-3 Floor plan, 13th floor

2.1.1.2 Materials and Systems

Each room is equipped with two or three tables, one computer, a telephone, one or two bookshelves, and two to four chairs. The floor surface is covered by carpet, the ceiling is made out of concrete and the wall surfaces are white metal (Aluminum). Figure 2-4 shows examples of rooms' furniture, windows, blinds, lights and surfaces. About 70% of the occupants keep plants in the room.

The complex was constructed with codes and standards of 1970's. Each room has three or four 88 cm width modules. Each module has a not operable window, one manually operable internal venetian blind, one air-conditioning unit, and one row of fluorescent luminaires that contains three bulbs of 36 W. Luminaires are divided in two groups, where the middle row can be switched on/off by the user 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. About 60% of the external wall is glass.

Figure 2-4   Two examples of rooms' furniture, windows, blinds, lights and surfaces

The fresh air is brought into the room through the air-conditioning units (fan coils below the windows), where the air is heated in winter or chilled in summer. The exhaust air is collected through special channels on top of the lighting fixtures at every window module inside the offices and through openings on the ceilings of the corridors.

The HVAC systems are being operated only during working hours on workdays. 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 evening's turns off half an hour earlier than the mentioned schedule. Cooling for the spaces is available from May until September (five months) and heating from September until May (nine months). In May and September both heating and cooling are available. Additionally there are thermostats installed in every room for occupants to lower or increase the ambient air temperature.

2.1.2 eTel (ET)

2.1.2.1 Geometry/Layout

Data collection was conducted in one open-plan office and one single occupancy office in a 3-storey building, which is part of Techno Park building complex near Eisenstadt, Austria. We refer to this building in this report as ET. The building has been constructed in 1999, hosting offices of a telecom-provider company (eTel Austria). The building consists of 3 blocks and has around 17,000m^2 floor area. The selected open-plan and single occupancy offices face east and are situated on the 1st floor. In total 18 work stations were monitored - 17 in the open-plan office and 1 in the single occupancy office. The work stations are typically equipped with desktop computers and in some cases with task lights. Figure 2-5 and Figure 2-6 show a plan of the selected office area (marked) and an interior view of the open-plan office. The room occupants perform VDT as well as paper tasks.

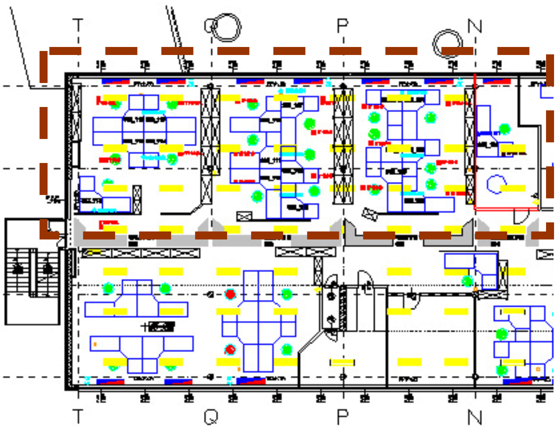

Figure 2-5 Schematic plan of the monitored area

Figure 2-6 View of the open-plan office

2.1.2.2 Materials/Systems

The façade of ET building consists of reinforced concrete, thermal insulation and aluminum cladding. The windows are conventional double glazing with aluminum frames and operable elements. External and internal shading is used for daylighting control. The external shading consists of motorized venetian blinds and can be operated centrally (via sensors for illuminance and temperature) or manually via switches mounted under the window sill. The internal blinds consist of vertical lamellas which are manually operated section wise.

The building is air-conditioned with two independent systems: an air-based system located in the ceiling plenum, and a hydronic system with fan coils below the windows. The environmental systems for heating, cooling and shading are centrally controlled by the building services. Two operation schedules for day and night are applied for system control. The fan coils are subdivided into heating and cooling cycles with operation temperature specified by the building services. The central ventilation is subdivided into floors and zones. The ventilation system supports not only the office air change, but also heating and cooling.

The open-plan office is equipped with the followings environmental control systems: 21 luminaires (3 rows x 7 light fixtures) each containing 2 neon tubes (T8) 36 W, manually controlled via switches located at both ends of the space; 9 external motorized screen shades, combined in 3 groups, operated by a switch mounted under the window sill; 3 internal shading devices, covering the entire window front; 7 fan coils under the windows for fine adjustment of temperature, controlled via 3 thermostats distributed around the space. The window front is divided into 10 fields, each with 30% operable area.

Likewise, the single occupancy office is equipped with the following systems for environmental control: 2 luminaires, each consisting of 2 neon tubes 36 W manually controlled via switch near the entrance door; external and internal shading with controls near the window; 1 fan coil, controlled via thermostat near the entrance door; and window with 30% operable area. Figure 2-7 shows the monitored area of the façade (stitched out of the two webcam positions).

Figure 2-7 Observed area of ET façade, View from East

2.1.3 Freihaus (FH)

2.1.3.1 Geometry/Layout

Data collection has been conducted in 13 scientific staff offices in Freihaus, which is one of the buildings of Vienna University of Technology (Vienna, Austria). The building has been constructed in the early 1980's, hosting scientific staff and administrative offices, canteen, as well as auditoriums and classrooms. The building has around 63,400m^2 floor area, in three tower-blocks (8, 9 and 12 floors). Figure 2-8 displays a general view of the building and the observed area of the facade (marked).

Figure 2-8 General view of FH

The 13 selected rooms face east and are situated on the 4th, 5th and 6th floor. Ten offices are single-occupancy, two are double-occupancy, and one is triple-occupancy. In total 17 work stations have been monitored. The work stations are typically equipped with desktop computers and in some cases with task lights. Figure 2-9 and Figure 2-10 show examples of office plans and interior view of one selected single-occupancy room in the 6th floor.

The room occupants are university professors, scientific and administrative staff, who perform screen-based as well as paper tasks.

2.1.3.2 Materials/Systems

The FH building has a double-skin facade. The inner layer consists of a conventional envelope (concrete and thermal insulation) with manually operable windows. The outer layer consists of fire proof enamel glass, supported by aluminum raster frame. The peripheral columns have aluminum cladding and divide the façade into fields. On each floor the field between two columns consists of 5 rectangular transparent glass elements, one of which is always operable (20% of the field).

The building is air-conditioned using two independent systems: an air-based system with both supply and return air ducts located in the ceiling plenum and a hydronic system with fan coils below the windows.

The offices in FH are typically equipped with the followings environmental control systems: 3, 4 or 6 luminaires 58 W each, divided into two circuits manually controlled via switches near the office door; external motorized screen shades operated by a switch mounted on a panel under the window; fan coil under the window for fine adjustment of temperature.

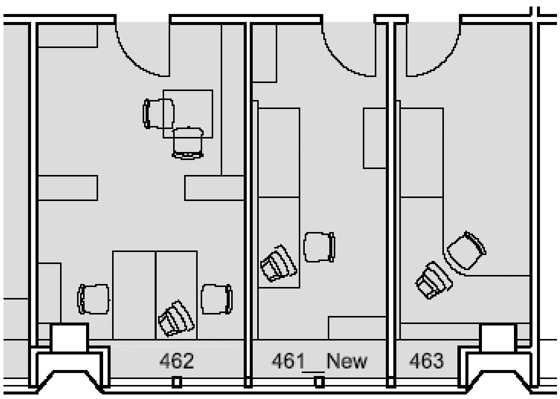

Figure 2-9 Schematic plan of sample offices in the 6th floor

Figure 2-10 View of a single-occupancy room in the 6th floor

2.1.4 UNIQA-Tower (UT)

2.1.4.1 Geometry/Layout

The UNIQA-Tower is headquarter of one of Austria's largest insurance companies (Figure 2-11). In addition there is a bank, a fitness centre and a restaurant accommodated in this complex. The competition to design the building was won by Architect Heinz Neumann. The building was constructed from May 2000 till June 2004. We refer to this building in this report as UT.

For the measurement we concentrated on the standard floors which are open-plan offices, hosting up to 94 employees. The shape of the floors is ellipse like and all workplaces are situated next to the façade (Figure 2-12 and Figure 9-1).

Figure 2-11 General view of UT from South

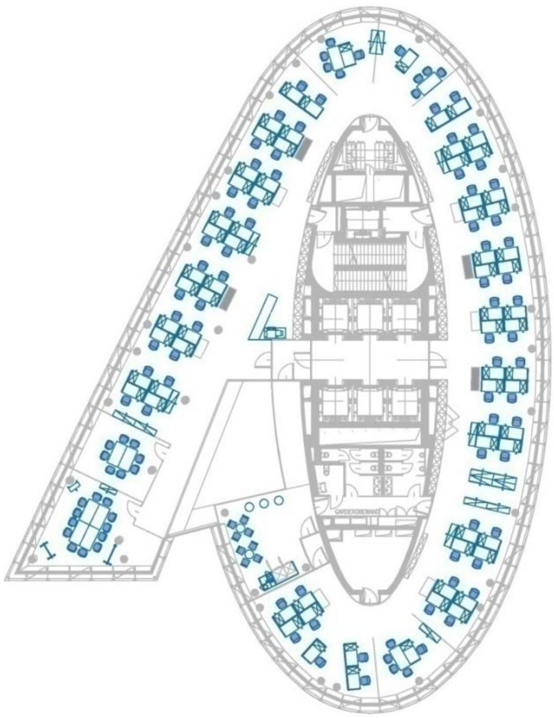

Figure 2-12 Plan of standard floor

The basic structure of the standard floor is given by the window axes. In these about 1.3m wide fields the installation for ventilation, heating, cooling and lighting is included and can be controlled individually field by field. To simplify their control the fields are grouped into zones. Therefore a zone is a defined area, where all occupants of one zone control the same artificial lights and indoor shading. The heating and cooling devices are combined. Zones can be reconfigured by the software only, that no hardware change is necessary. In most cases there is no boundary between the zones in the open-plan office. Some zones are separated by a frameless glass wall (Figure 2-13).

Figure 2-13 View of two zones divided by a frameless glass wall

Data has been collected in 10 floors, out of 21 above ground, for a period of 14 months. More than 1,000 people work in this building. More than 300 people were observed, but due to data inconsistencies data of 89 people in 26 zones has been analyzed for the project. Out of the 26 zones seven were located on the 5th floor, four on the 11th, four on the 14th, one on the 16th, ten on the 17th floor. Seven of the observed zones were single occupancy, three zones were double occupancy and the remaining zones were occupied with up to eight people. Every user performed VDT and paper based tasks.

2.1.4.2 Materials/Systems

The building is made of ferro concrete with a double-skin façade out of glass and aluminum (Figure 2-14). The outer layer of the double-skin façade is built as a structural glazing façade partly mounted with point fittings in the floor levels and intercepted by aluminum panels at the level of the floor panels for permanent ventilation of the façade's interspaces. The inner layer is made of an aluminum post and mullion construction filled with insulation glazing. Venetian blinds are mounted in the space of the double-skin façade. The Venetian blinds are operated automatically by the building management system. Roller blinds are mounted inside the second façade layer. Cooling ceilings as well as ventilation outlets are integrated in the suspended ceiling.

The raised floor contains the ventilation inlets as well as convectors for heating. Ceiling and floor are being used for electrical, HVAC, and building system bus installation. Out of the five observed buildings in this research project UT is the only building where a building management system is installed (see section 2.2.3).

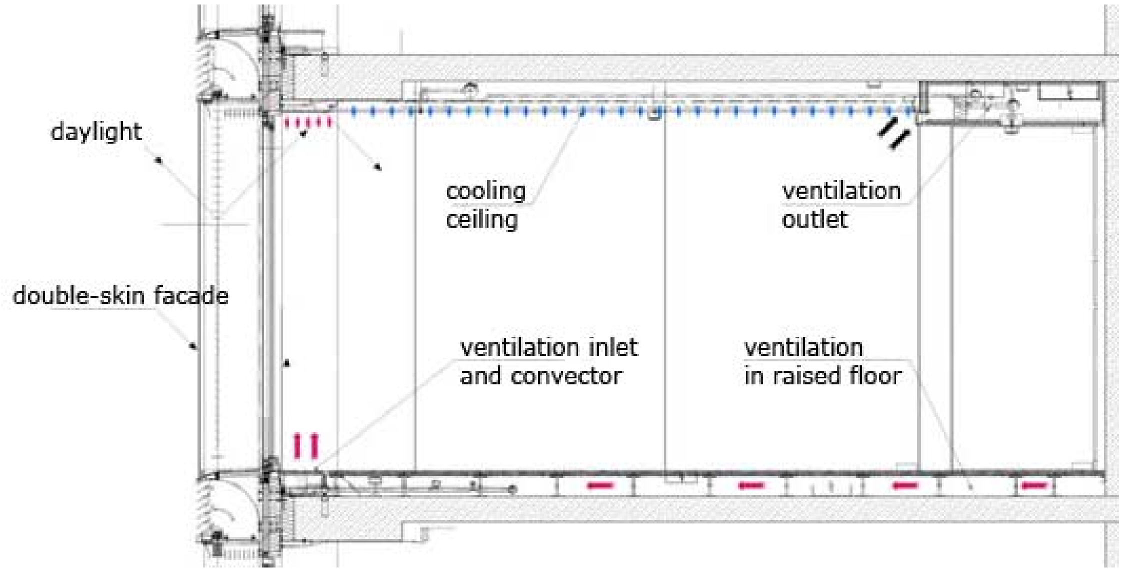

Figure 2-14   Sectional drawing of standard floor

The user has control over glare (roller blinds 0%, 25%, 80% or 100% closed) and artificial lighting (no artificial light, 300 or 500 lx) via a graphical user interface shown in Figure 2-15. In every field there are two recessed luminaires (T16, 35 W each, one dimmable) mounted in the suspended ceiling. Furthermore the user can open the windows of the inner layer of the façade in every second field (Figure 2-16).

Figure 2-15   Graphical user interface installed on every workplace

Figure 2-16   Detail of the double-skin façade: View of an open window

2.1.5 BH-Hartberg (HB)

2.1.5.1 Geometry/Layout

The measurements were conducted in 6 offices (10 workstations) of an office building in Hartberg, Austria. We refer to this office building in this report as HB. Two offices are single occupancy office and 4 offices double occupancy. The work stations are equipped with desktop computers and (in some cases) printers. Both screen-based and paper-based tasks are performed by the occupants. A characteristic feature of this building is its use as a governmental service unit: the workers arrive rather early in their offices and regularly receive clientele with administrative questions and requests. All monitored offices face the northeast direction. Half of workstations are located on the 1st and the other half on 2nd floor of the building. A general view of the observed offices and schematic layout of three offices in the 2nd floor are given in Figure 2-17 and Figure 2-18.

Figure 2-17 General view of observed offices

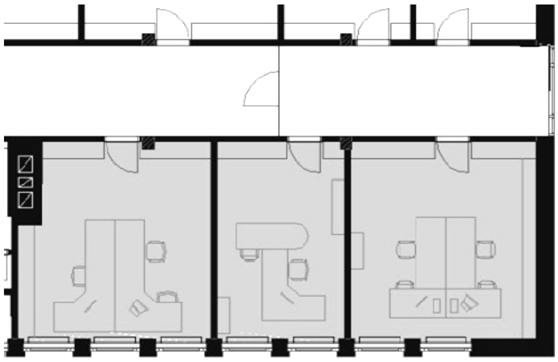

Figure 2-18 Schematic plan of sample offices in HB

2.1.5.2 Materials/Systems

The offices are equipped with the followings systems: two rows of luminaries with 4 or 6 (58 W) fluorescent lamps divided into two circuits and manually controlled by two switches, near the entrance door; external manually operated venetian blinds and internal curtains; and two or three operable tilt/turn windows. Figure 2-19 shows an interior view of a double occupancy office.

Figure 2-19 Interior view of a double occupancy office on 1st floor

The heating system of the building is based on radiators units located below each window. The setting of the radiators can be changed by users. There is no cooling and air conditioning system in the offices. Users can have natural air ventilation by opening windows.

2.2 Data collection

Before the start of the measurements it was clear that certain standards have to be established to deal with the data generated in this study. To face the fact that many people would work on this project with many different computers, all using Windows XP SP2 as operation system as well as MS Office 2003 with different languages (English, German) and later MS Office 2007, it was agreed to use the same system settings (Appendix 9.3).

To systematize the whole project and especially the generated data, a code was introduced how to name sensors, folders and files and how to store data (Appendix 9.6). According to this code all saved data files could be distinguished by building, room, sensor and date. For the data of each individual sensor one separate folder was used, named according to the above mentioned code-system. All such folders represented the sum of original data, building a tree structure. In order to guarantee accurate and uniformly stored data files, the download and reset procedures were described for each sensor. To avoid synchronization problems, UTC+1 was set as reference time (no change between winter- and summertime). The integrated internet time server synchronization of windows XP did not work on all machines, therefore Atomic Clock Sync v2.7.0.3 by WorldTimeServer.com was used to synchronize all computer clocks. The certainty in the time comparison is specified as ±2 seconds. The logging interval for all measurements was 5 minutes.

In the following sections we describe the data collection procedures pertaining to external and internal environment, occupancy, state of systems, and energy consumption.

2.2.1 External environment

To measure outdoor climatic parameters like temperature [°C], relative humidity [%], global solar radiation [$W \cdot m^{-2}$], and wind speed [$m \cdot s^{-1}$] weather stations were used, mounted either on the roof top or in near proximity of the monitored buildings.

In case of the UT building, this building is equipped with external sensors mounted on the roof. The values of 8 illuminance sensors [lx] which are mounted vertically on the roof were used. They are oriented every 45° starting from north and their data is the basis for the control of the external shades of UT. Other parameters like outdoor temperature and relative humidity values measured both on the north and on the south side of UT, as well as wind speed and wind direction could not be used due to a lack of accuracy. Solar radiation is not measured at all at the site. For that reason data from the existing weather station (manufactured by Adolf Thies GmbH & Co.KG) of the Department of Building Physics and Building Ecology, at a distance of 1.9 km, were used (see Figure 2-20). Henceforth this weather station is referred to as WSBPI. Additionally to the above mentioned parameters, the weather station measures atmospheric pressure [Pa], outdoor illuminance [lx], precipitation [mm] and wind direction [°]. This weather station is mounted on the roof and is connected to the local network. The sensors deliver analog signals to a data logger, which generates ASCII output files. A LabVIEW application transfers the log files to a data socket server. The software generates <*.txt> files, which are finally stored. The logging interval is approximately one second, which requires additional processing for structuring the data in 5 min intervals. This is achieved with a Perl script named <dezero.pl> in MatLab and the SenSelect application (see Appendix 9.7).

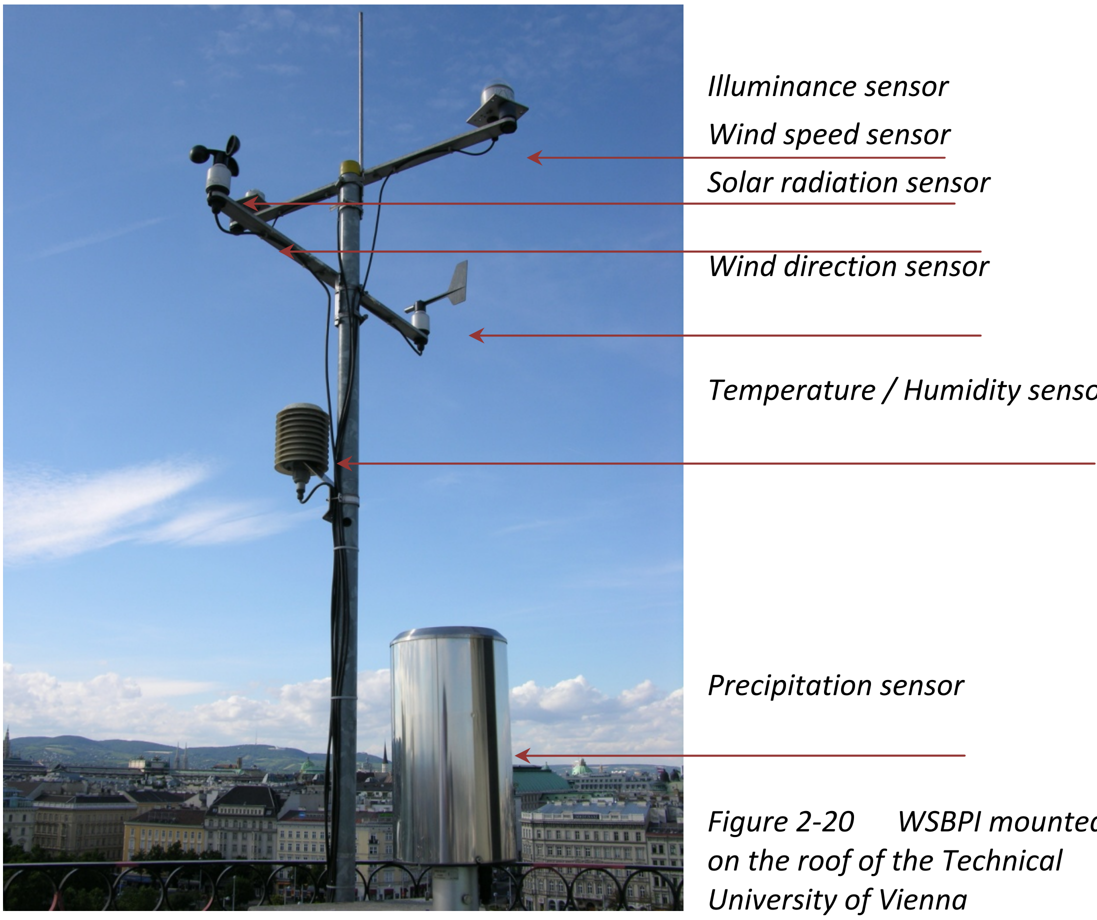

Figure 2-20 WSBPI mounted on the roof of the Technical University of Vienna

While the existing WSBPI was used for UT and FH (distance of 0.1 km) additional HOBO weather stations (manufactured by Onset Computer Corporation) were mounted on the roofs of the other monitored buildings (VC, ET, HB; see Figure 2-21). The weather station is an autarkic standalone device logging temperature [°C], relative humidity [%], global solar radiation [$W \cdot m^{-2}$], wind speed [$m \cdot s^{-1}$], and gust speed [$m \cdot s^{-1}$]. The measurements are recorded and stored by a data logger and can be downloaded to a Laptop using a serial connection cable and Onset's BoxCar Pro software. With a logging interval of 5 minutes the data logger is capable to store almost one year of measurements. Due to data security the HOBO weather stations were read out every two month to avoid data losses. The software stores the downloaded original data in a file with extension <*.dtf>. The data can be exported in several formats for use in other applications. For our project we exported the data as <*.txt> file for further structuring and analysis.

The specifications of the WSBPI and the HOBO weather stations and their components are summarized in Appendix 9.8 and Appendix 0.

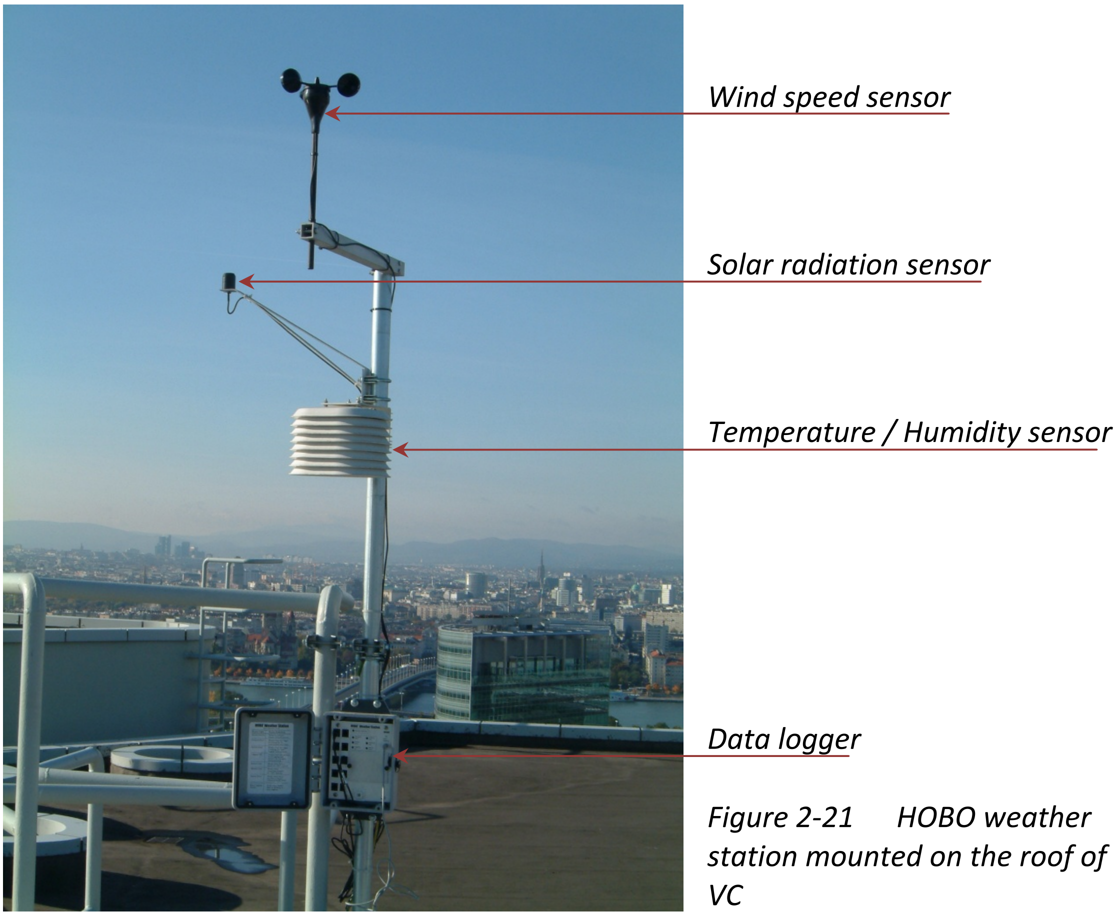

Figure 2-21 HOBO weather station mounted on the roof of VC

2.2.2 Internal environment

To keep track on the internal situation a variety of sensors and methods were used to monitor different parameters.

2.2.2.1 Indoor climatic parameters

Parameters like temperature [°C], relative humidity [%], and illuminance [lx] on workstations were measured in almost all buildings with small autarkic Hobo U12-012 loggers (manufactured by Onset Computer Corporation, see Figure 2-22).

Figure 2-22 HOBO U12-012 logger, mounted at a workplace in ET and close-up

We tried to install all sensors after consulting the occupants in order to reach high user acceptance. The sensors were installed near the workplaces on walls or mounted on aluminum bars in order not to be covered by objects like books, papers etc... Furthermore we tried to avoid possible influences like thermal radiation of computers or monitors or direct sunlight.

The storage capacity of the Hobo U12-012 loggers is capable to store the measurement data of the measured three parameters with a sample rate of 5 minutes for a measurement period up to 50 days, but due to data security the loggers were read out ideally every 3 to 4 weeks. To launch and download the logger a software application named Greenline v.1.1 (by Onset Computer Corporation) was used. The software stores the downloaded original data in a file with extension <*.hobo>. The data can be exported as <*.txt> file for further structuring and analysis. To find more about how Hobo loggers were read out see Appendix 9.10.

We also used a logger named Hobo U12-001 which is similar to the above described sensor, but can only measure temperature [°C]. You can find the specifications of the Hobo U12-012 and Hobo U12-001 sensors in Appendix 9.11.

In UT we used the opportunity to measure far more workplaces as intended. Due to limited resources it was not possible to use our sensors in all zones. In the 5th, 11th and 17th floor two HOBO U12-012 were used to measure temperature, relative humidity and illuminance. They were placed at eye level horizontally, one in a southward and one in a northward oriented zone.

To monitor the indoor climatic parameters in UT the existing building automation system described in section 2.2.3 was used. Each zone is equipped with a Johnson Controls temperature sensor. This device is mounted under the desktop about 50cm above the floor (see Figure 2-23).

Figure 2-23 Temperature logger, mounted at a workplace in UT

Relative humidity is not measured in the zones or floors of the UT by the building automation system. The average relative humidity values measured by the six installed HOBO U12-012 was 40.7 % with a standard deviation of σ = 5.59. However relative humidity was not used in the further analyses.

Internal illuminance was measured in UT by building own sensors, mounted on the ceiling facing downwards (see Figure 2-24). These sensors are used to control the artificial lighting. We hoped to find a correlation between the illuminance on the workplace (measured by the six installed HOBO U12-012) and the illuminance measured on the ceiling. Again the huge amount of measured zones forced us to use these existing sensors although they were not placed ideally for our purposes.

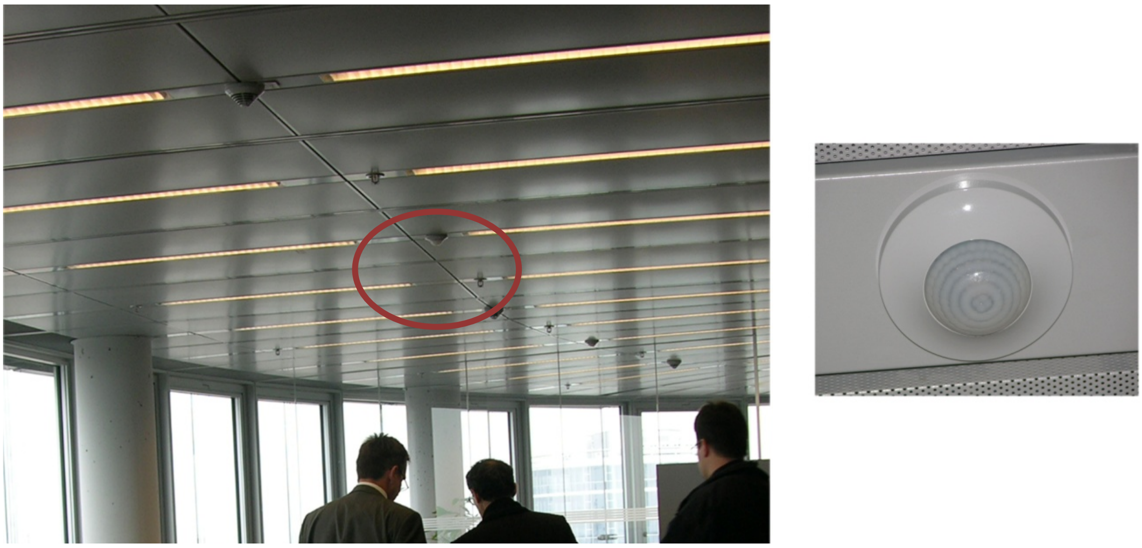

Figure 2-24 Illuminance sensor, mounted on the ceiling in UT and close-up

2.2.2.2 Occupancy

To measure the occupancy at a workplace InteliTimer Pro occupancy and light loggers (manufactured by The Watt Stopper Inc.) were used. Henceforth this sensor is referred to as IT-200 (see Figure 2-25).

Figure 2-25 IT-200 loggers mounted on the ceiling in ET and close-up

Utilizing passive infrared technology to detect occupancy, this sensor recognizes every change in occupancy status and stores a detailed history of these events in files with extension <*.itr>. Using ITProSoft 2.10 by The Watt Stopper Inc., the data can be exported as <*.xls> file. The sensor records any detected motion as <occupied>. When no motion is detected for a certain time period (α), the sensor records <not occupied>. In our measurements this delay was set for α=5 Minutes. To find more about how the IT-200 loggers were read out see Appendix 9.12. The specifications of the IT-200 logger can be found in Appendix 9.13.

In case of UT no IT-200 occupancy sensors were allowed at the workplace by the management. We were forced to get the information concerning occupancy using the building automation system which records occupancy related data two times:

In the floors the above mentioned ceiling mounted illuminance sensor (section 2.2.2.1) which is a combined illuminance and occupancy sensor, but it gives no information about the number of occupants on one hand and because it covers a range of 360°, the sensor measures <occupied> even if somebody just passes by at the corridor and nobody is in the zone. This sensor is used by the building automation system to turn off the light automated 25 minutes after the last detected motion. Not least because of this relatively long time period the data of these sensors could not be used in further analyses.

PKE Electronics AG installed and maintains the access control system. When passing the turnstile the users are registered with a card reader and the information is transferred to the security management system (server) who passes the data to SAP for payroll accounting. The occupancy data for UT used in this study was stored with the security management system and exported as <.csv> file for every user. We received this data in <.xls> format after the names of the users were deleted for data privacy reasons. Beside entrance and exit times the files included information about the workplace position and the access card number. Over the whole measurement period each change in the allocation to a workplace was followed up. Missing or unclear data in this context was one of the bottlenecks in data collection which reduced the number of workplaces from up to 400 workplaces down to 89 workplaces in 26 zones.

Because the cafeteria and restaurant are outside the gate, coffee and lunch breaks are also covered by this data if an individual uses these facilities. Differently to the other buildings were occupancy was measured directly at the workplace, we were forced to derive the "occupancy at the workplace" data out of the "occupancy in the building" data by adding 5 minutes to the arrival times and subtracting 5 minutes from the exit times.

This is based on the assumption that the average time from the gate to the workplace and vice versa is about 5 minutes. As mentioned before this data includes those brakes when the individual crosses the gates, but times when the individual stays in the tower for meetings or small breaks are not recognized.

2.2.2.3 State of light

In all buildings except UT the IT-200 (section 2.2.2.2) was used. It recognizes changes in the light status through a plastic pipe which has to be directed to the luminaire. The sensitivity can be adjusted to avoid false “light on” entries for example due to direct sunlight or reflections.

In the UT building the state of light was monitored and stored by the building automation system in 5 minute steps.

2.2.2.4 State of shading

To reduce the effort of measuring this parameter with lots of different sensors, time lapsed photography was used.

In ET two webcams were used, each connected to a PC. The distance between the viewpoint and the façade was very small (<20m), therefore, contrary to the other buildings, the relatively low VGA resolution of 640x480 pixels was sufficient enough (see Figure 2-26). Webcams and computers could be used because they were located indoors and the room used was abandoned.

Figure 2-26 Observed area of ET façade, picture stitched out of the two webcam perspectives

Advantages of this solution are that the picture taking could be programmed in 5 minute steps from 05:00 to 22:00 and that the equipment was relatively cheap. In case of ET the information concerning external and internal shades was extracted from the pictures by hand and minuted in 25% steps.

In VC, FH and HB the distance between viewpoint and façade was up to 150m. Nikon Coolpix 8700 digital cameras with a resolution of up to eight mega pixel mounted in self-made weatherproof cases were used. This case could be locked to avoid theft and also heated in the cold periods, when mounted outdoors (FH and HB), to ensure long term function of the build in devices. The cameras needed external power supply and their 2GB compact flash card had to be read out every 10 to 12 days using an interval of 10 minutes. The Nikon Coolpix 8700 was the only suitable camera for this purpose, because of its technical specifications and the possibility to do time lapsed photography. Due to the fact that the cameras firmware is limited to take not more than 1800 pictures in one cycle, the period of 10-12 days could not be extended by using a compact flash card with more memory.

Figure 2-27 Camera case mounted indoors in VC pointing to VC-N façade and close-up of the camera case.

Contrary to ET, the information about shading was extracted from the pictures semi automated by a self developed image processing application named ENVO. The level of shades was described in VC, FH and HB in 20% steps (see section 2.3.3).

No additional façade monitoring was necessary at UT. All necessary parameters were measured and stored by the building automation system.

2.2.2.5 State of window

In VC and FH the windows were not operable. In ET and HB the above described façade photography was used to observe the windows. Three states were differentiated. The digit "0" was used for a closed, "0.5" for a tilted and "1" for an open window. In UT the window operation is minuted by the building automation system, which distinguished between open and closed.

2.2.3 Building automation

As mentioned, UT is equipped with a building automation system. It was possible to use this system to measure and store data for further analysis.

HVAC systems, artificial lighting and blinds in UT are part of a building installation bus system including N2, XT, LON, Metasys and Kat-5 (see Appendix 9.14) which connects all sensors, actuators, controllers etc. Our project partner Johnson Controls Regelungstechnik GmbH installed and maintained the systems and was able to log a large number of parameters, about 2000 every 5 minutes. We received this data as MS Access (see section 2.3.2). Collected data included:

- The building's own weather station (temperature [°C], relative humidity [%], illuminance [lx] (see section 2.2.1)
- Artificial lighting in every zone (on / off, user command [lx], percentage of dimming, actual value [lx])
- Room temperature [°C] in every zone (plus additional information for cooling and heating)
- Ventilation twice per floor (air temperature [°C], relative humidity [%])
- Venetian blinds for each window axis (position [%], angle [°])
- Roller blinds for every zone (position)
- Individual windows (open / close)

2.2.4 Interviews

Beside objective data this long term field study brought the chance to collect and analyze subjective data using interviews. The occupants have of course not been told specifically about the aim of our measurements (search for patterns of user behavior).

At the end of the data collection about eighty occupants in VC, FH, ET and HB were interviewed using a questionnaire grouped in several sections – personal information (gender, age, professional occupation etc.); assessment of the indoor climate parameters and control systems – temperature, day/artificial light, air-conditioning, heating etc.; operation and accessibility of the systems and system controls; awareness of the functionality of the building control systems and energy conscious behavior; personal preferences in organizing the current / ideal working space followed by a closing question about the type and frequency of health complaints. The full questionnaire content together with the results is summarized in Appendix 9.15.

As in all other buildings, it was planned to ask all participants in UT to fill a questionnaire at the end of the monitoring period. However, building management subsequently withdrew their approval. Consequently, user interviews could not be conducted in UT. Note that a diploma thesis done by Gregor (2006) at the Department of Building Physics and Building Ecology, Vienna University of Technology, parallel to our studies, focused on thermal comfort in UT. He concluded that there were no significant problems and the number of dissatisfied was not unusually high.

2.3 Data processing

While all original data was stored in a tree structure in different folders as described in section 2.2, it was agreed to merge all measured data for one building in a standardized Excel table where the first row contained the headers and the first column contained date and time (Figure 2-28). These tables are the starting point for all analysis. For all buildings a sampling time of 5 minutes was used. The amount of data implied to automatically generate the above mentioned Excel tables.

	A	B	C	D	E	F	G	H	I
1	Date	462_101_light	462_201_t	462_201_RH	462_201_E	Solar Irr	462_409_Se1		
2	01.01.2005 05:00	0	21,461	29,892	12	0	0,8		
3	01.01.2005 05:05	0	21,461	29,892	12	0	0,8		
4	01.01.2005 05:10	0	21,437	29,89	12	0	0,8		
5	01.01.2005 05:15	0	21,437	29,925	12	0	0,8		
6	01.01.2005 05:20	0	21,437	29,96	12	0	0,8		
7	01.01.2005 05:25	0	21,437	29,96	12	0	0,8		
8	01.01.2005 05:30	0	21,437	29,96	12	0	0,8		
9	01.01.2005 05:35	0	21,437	29,96	12	0	0,8		
10	01.01.2005 05:40	0	21,437	29,995	12	0	0,8		
11	01.01.2005 05:45	0	21,437	30,031	12	0	0,8		
12	01.01.2005 05:50	0	21,413	30,029	12	0	0,8		
13	01.01.2005 05:55	0	21,413	30,029	12	0	0,8		
14	01.01.2005 06:00	0	21,413	30,064	12	0	0,8		
15	01.01.2005 06:05	0	21,413	30,064	12	0	0,8		
16	01.01.2005 06:10	0	21,413	30,099	12	0	0,8		
17	01.01.2005 06:15	0	21,413	30,099	12	0	0,8		
18	01.01.2005 06:20	0	21,39	30,097	12	0	0,8		
19	01.01.2005 06:25	0	21,39	30,097	12	0	0,8		
20	01.01.2005 06:30	0	21,413	30,134	12	0	0,8		
21	01.01.2005 06:35	0	21,413	30,169	12	0	0,8		
22	01.01.2005 06:40	0	21,413	30,169	12	0	0,8		
23	01.01.2005 06:45	0	21,413	30,169	12	0	0,8		

Figure 2-28 Example of a standardized Excel table

2.3.1 SenSelect

The **sen**sor data **selection** tool (SenSelect) v1.3.1 is a MatLab and Perl based application which enables to process almost all data collected in this project. It was jointly developed by DI Dr. Wolfgang Hofbauer and the author to create the above mentioned standardized Excel table. The automation of this process, compared with 'cut and paste' strategies, accelerated data processing and reduced errors.

The measured and stored raw data had to be synchronized in terms of time and adjusted to the 5 minute interval. Therefore it was necessary to define calculation rules for each parameter. In some cases the values had to be shifted to the closest, in some cases to the following 5 minute step. In some cases it was appropriate to use the actual value and in some cases an average value had to be used. As there are different ways to aggregate data (mean, median, geometrical mean…), this method was also defined for each parameter.

While using SenSelect it is crucial to comply with system settings mentioned in section 2.2. The data files of each sensor need to be stored in separated folders named according to the rules on how to name sensors, folders and files and how to store data (Appendix 9.6). In this project, the data was stored in a tree structure that reflects the location of the sensor (building, floor, room or zone, and workplace).

SenSelect v1.3.1 is operated with a graphical user interface (Figure 2-29). In the left part of the main window the individual sensor parameter can be chosen (e.g. 443_201 which is the HOBO number 1 in room number 3, 4th floor, building number 4). In the right part of the main window the time interval can be selected as well as the path where the output file shall be stored. Because data processing can take several minutes a system monitor showing the CPU usage is also part of the main window. Preferences such as the sampling time (in most cases 5 minutes) or sensor parameters are selected in the 'Options' menu.

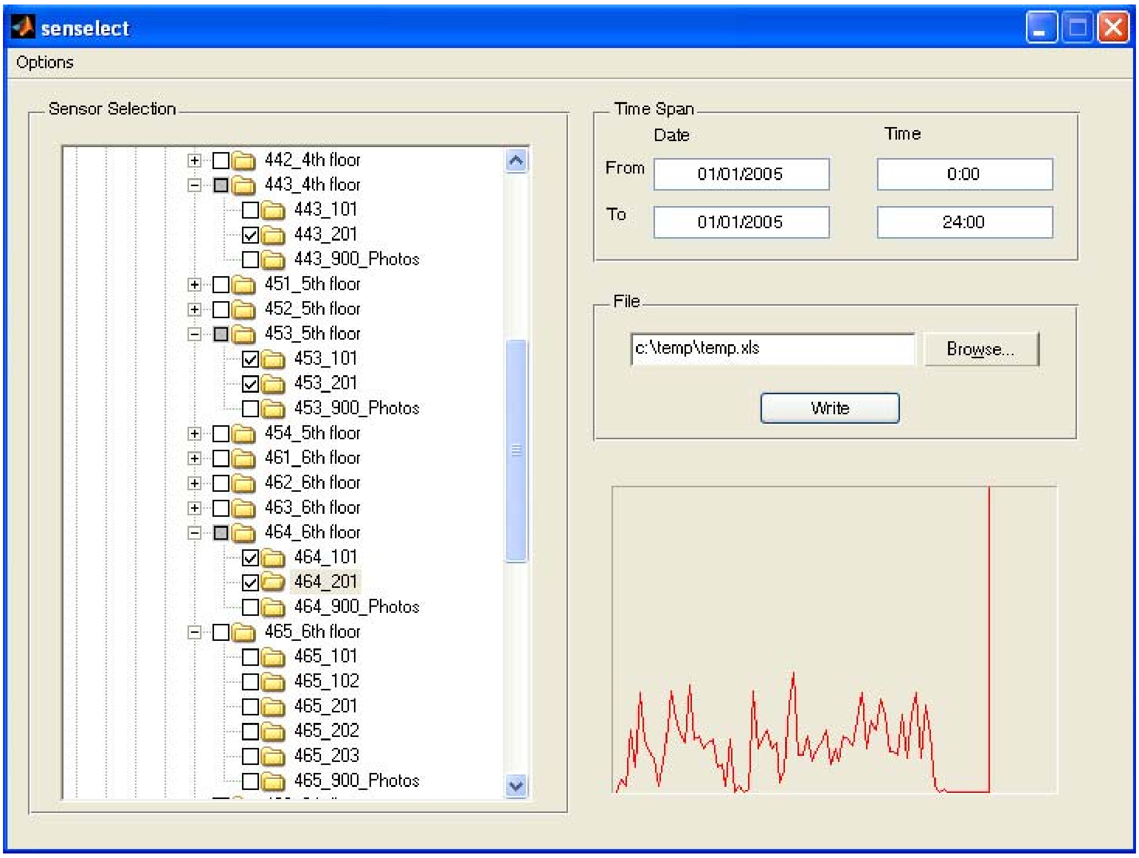

Figure 2-29   Graphical user interface (GUI) of SenSelect v1.3.1 (main window)

2.3.2 SenSat

SenSat (**sen**sor data storing and **a**nalysing **t**ool) v1.0.8 is a tool set that interacts with an SQL database. Its aim is to store data from different sources and formats in a database and provides a front end for comfortable access and analyses data (see Figure 2-30). This tool was developed jointly by Johannes Taxacher and the author primarily to handle the large amount of data delivered by the building automation system of UT. However, it is built in a way that it could be used for all buildings in our study. To optimize the runtime performance, the decision was made to write different applications and not to combine all functionalities in one application.

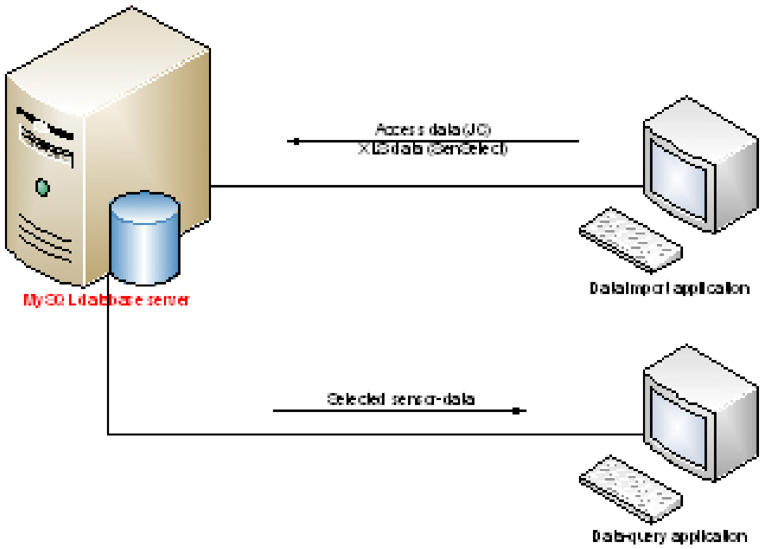

Figure 2-30 Principle functionality of SenSat

Microsoft Visual C# Express Edition was used as development tool to build a SQL database with MySQL 5.0. To save time in programming two scripts / modules were used in the source code. The DLL file AMS.Profile (Mendez 2005) was used to generate and access XML configuration files, and a class named ExcelReader (Timmerman 2004) was implemented to import <*.xls> files.

2.3.2.1 Access Importer Application

About 2000 different parameters were measured every five minutes in UT by the building automation system. Our project partner Johnson Controls managed to store these data temporary in MS Access databases for data transfer. Every week an MS Access database was generated with a size up to 1 GB. The total amount of data over the whole measurement period was more than 40 GB. Because MS Access is not built to deal with this size of data, the data was imported into one MySQL database by the Access importer application.

Inside the MS Access databases there is no information about the location of the different data points. Therefore the parameters are stored in a folder name 'unassigned' and have to be assigned manually to their location in the hierarchy of the MySQL database.

2.3.2.2 Excel Importer Application

The Excel importer application (Figure 2-31) is used to import standardized Excel tables and so called 'PKE files' as well as to maintain the database.

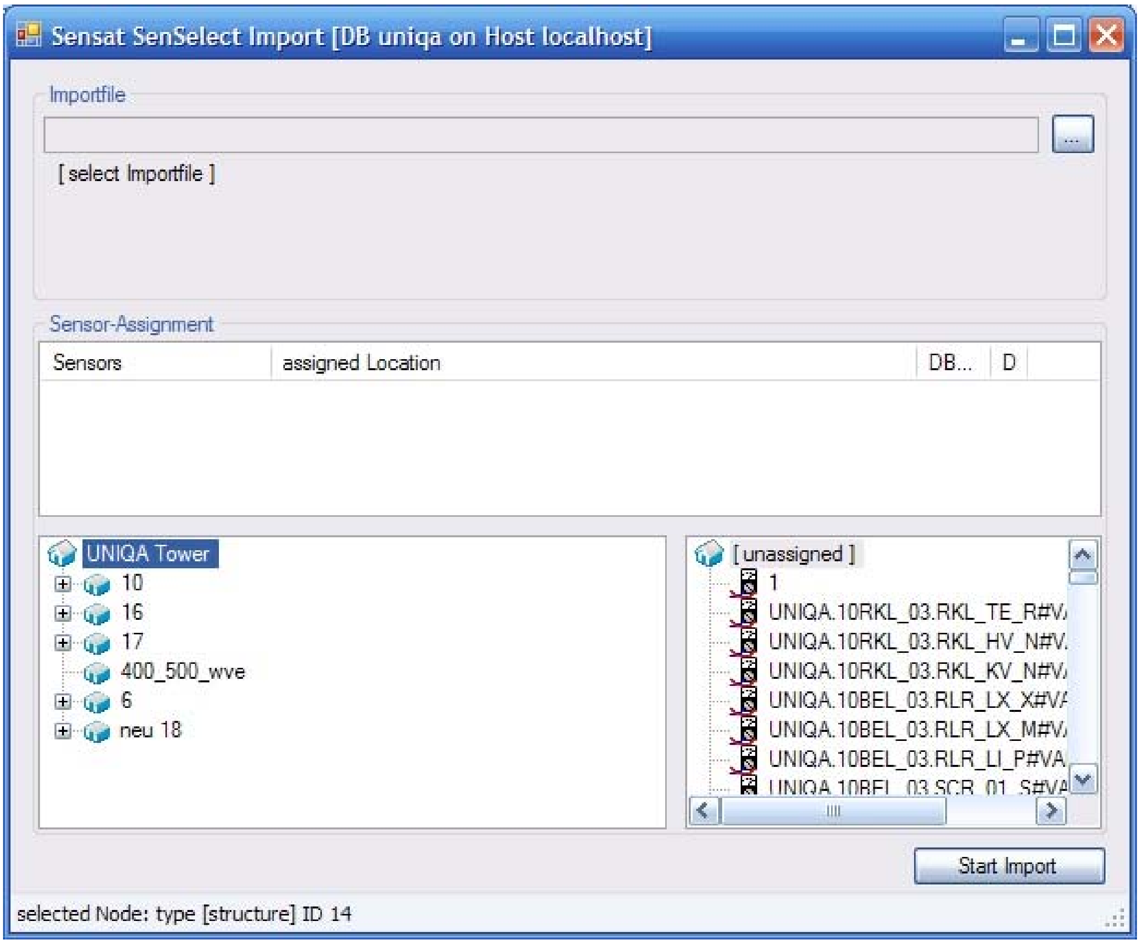

Figure 2-31 Graphical user interface (GUI) of the Excel importer application

For UT it was necessary to bring data in the format of standardized Excel tables into the database (e.g. in case of weather station or HOBO data). Because of this functionality the Excel importer application is able to import files created by SenSelect and SenSat (data query application). This is why it was possible to use SenSat not only for UT but for all other buildings as well. This was done by creating separate MySQL databases for each building. In contrast to the Access importer application, where all imported data is stored unassigned, it is possible to bring the data from the standardized Excel tables to the correct place in the data structure of the buildings database during the import process.

The presence of each individual in UT is logged by PKE (see section 2.2.2.2) in Excel format. This data was also brought into the MySQL database using the Excel Importer application.

Beside these import functions the maintenance of the database is done with the Excel importer application. With a right click at the specified node a context menu opens and the tree structure of the database (building, floor, half floor, zone or room, workplace) can be edited, structure nodes can be created, named or deleted (Figure 2-32).

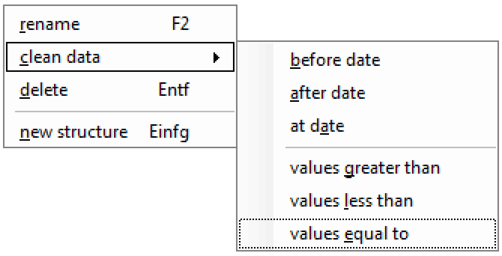

Figure 2-32 Example of the context menu of the Excel importer application

The editing of the data is only possible with the Excel importer application. The data query application which is used for data analyzing has no such function to prevent editing data by mistake. Furthermore, the termination of one structure node is only possible, if there is no data node or sub structure node assigned to this node. It is possible to delete data before, after or at a specified date/time as well as to delete values greater, less or equal than a specified value. It is also possible to merge two data nodes by drag and drop, but it is checked first if there are no entries at the same time. Because then it is not possible to merge those data nodes.

2.3.2.3 Database

A relational database is used which is implemented with MySQL-Server 5.0.18. The majority of sensor data is stored in three tables (Figure 2-33). A table named 'sensor' contains information about the sensor (name, ID …). The measurement values are stored in two tables named 'data_analog' (for floating point) and 'data_digital' (for integer). Although the naming of tables is not correct, because in the ‘data_digital’ table there are not only digital values but also all integer values, it was adopted from the MS Access databases received from our project partner Johnson Controls.

An additional table named ‘lokation’ is used to map the location referring hierarchy of the database (building, floor, half floor, zone or room, workplace). Of course it is possible to structure the database differently (e.g. according to sensor types), but for this project a structure according to the location of the sensor was chosen. For UT it was necessary to use additional tables to handle specific data types like ‘PKE files’, building server log, history of IP addresses, history of host names or history of users.

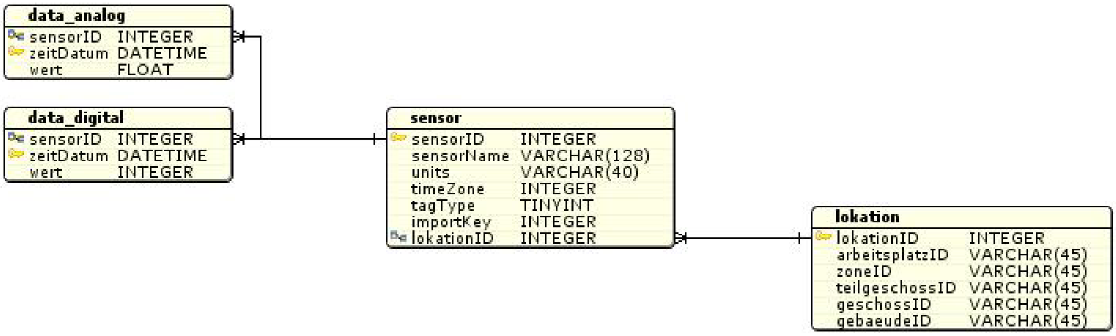

Figure 2-33 Connection between the tables in the MySQL database

2.3.2.4 Data Query Application

The data query application offers the possibility to select sensors and to read data in a chosen timeframe. The result of the query is shown on screen and can be exported as CSV file. This format was chosen because the number of rows is not limited (Excel files are limited to 65,535 rows). If the result of the query shall be imported in SenSat, the CSV file has to be converted into one or more <*.xls> files. The data query application has a graphical user interface (GUI) shown in Figure 2-34. The most important features are described below.

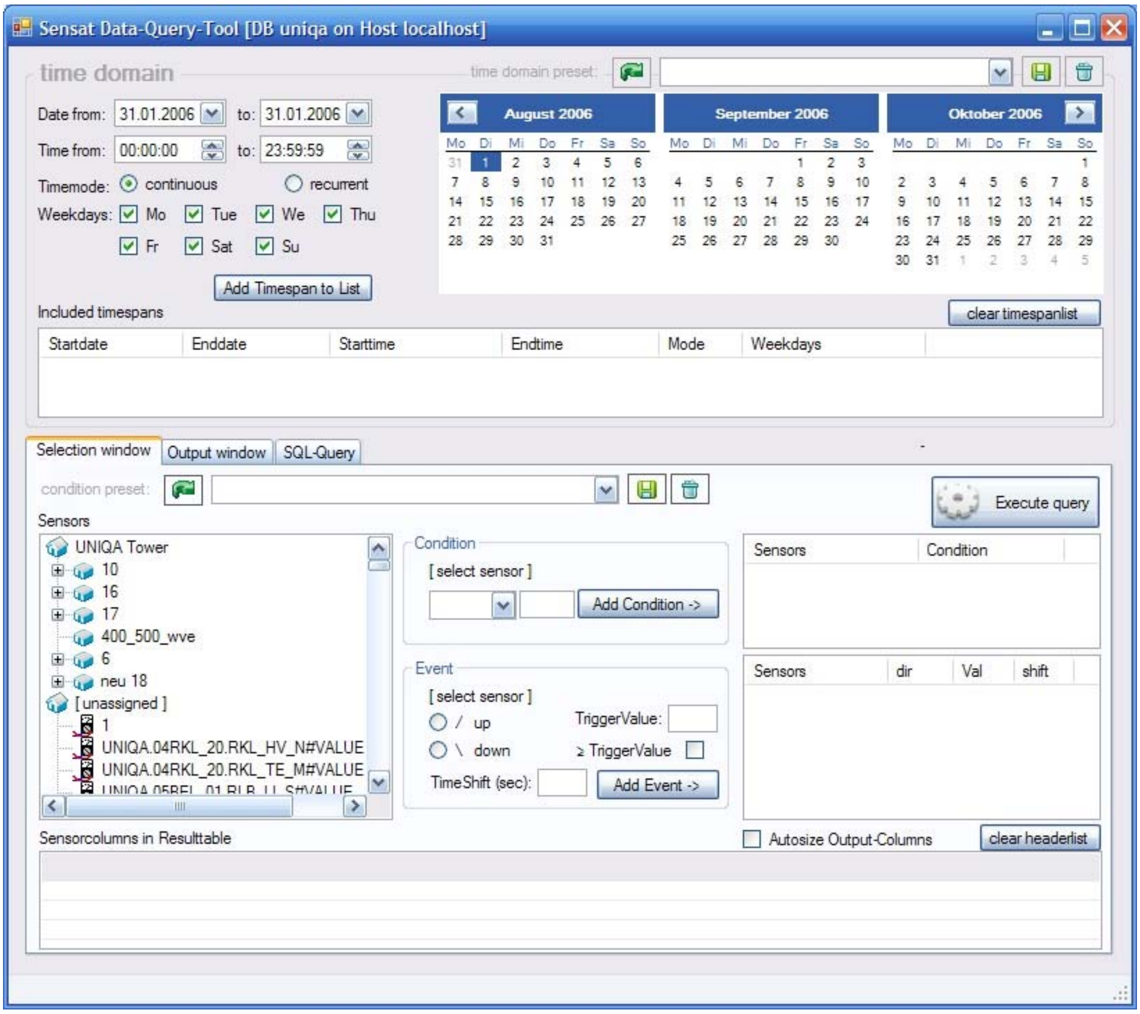

Figure 2-34 Graphical user interface (GUI) of the data query application.

The upper half ('time domain') of the graphical user interface is dedicated to date and time selection. To reach a high flexibility it is possible to select more than one time span, which will be shown in a list. It is possible to exclude weekdays and to choose between continuous or recurrent start - end time interval (Figure 2-35). The chosen timeframe can be stored as preset and therefore loaded again easily in a different session.

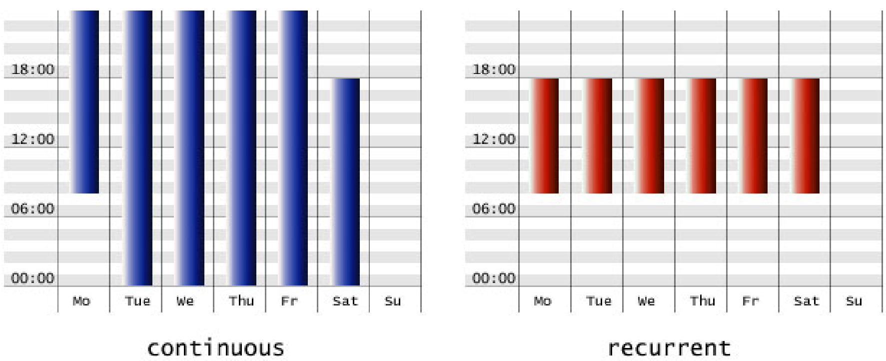

Figure 2-35 Example of different time modes

The lower half of the graphical user interface deals with selection of data. Up to 26 sensor parameters can be selected out of the database hierarchy and be shown in a table. It is possible to add correction factors to each parameter if necessary, using basic arithmetic operations. To enable more complex queries it is possible to set conditions for single parameters and to search for events ('condition' and 'event' frame).

Using the 'condition' function the output of the query will be data of the selected sensors in the selected timeframe with $\geq$, $>$, $<$, $\leq$, $=$, $\neq$, NaN ('not a number' stands for 'no value') or not NaN condition operators. If more than one condition is set, these conditions are logically connected with 'and" which means that all conditions have to be fulfilled.

The 'event' function on the contrary is logically connected with 'or' when more than one event is defined. This means that one of the events has to be found. With the 'event' function a search for step functions is indicated, where the size of the step is defined by a trigger value set by the user. In addition a time shift can be defined between the found step and the output data.

2.3.3 Image processing

A large number of digital images were taken by high resolution (8 mega pixels) cameras (about 50,000 pictures in each case) to register positions of windows in each photo (see Figure 2-36).

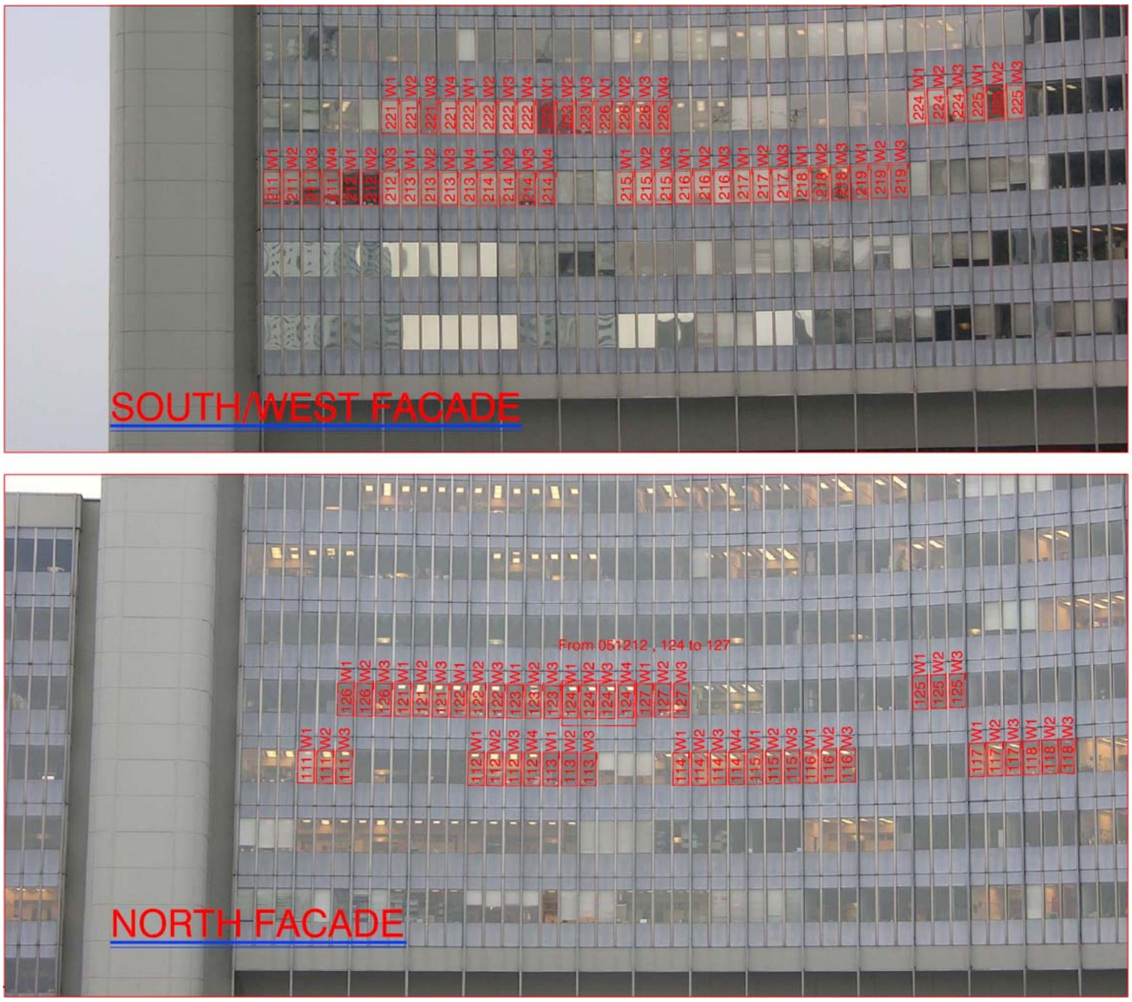

Figure 2-36 Defined position of the windows for the program

An application (ENVO) was designed and developed by the research team, to process analysis images. The program developed by Josef Lechleitner at the Department of Building Physics and Building Ecology, is based on LabVIEW and semi-automatic (see Figure 2-37).

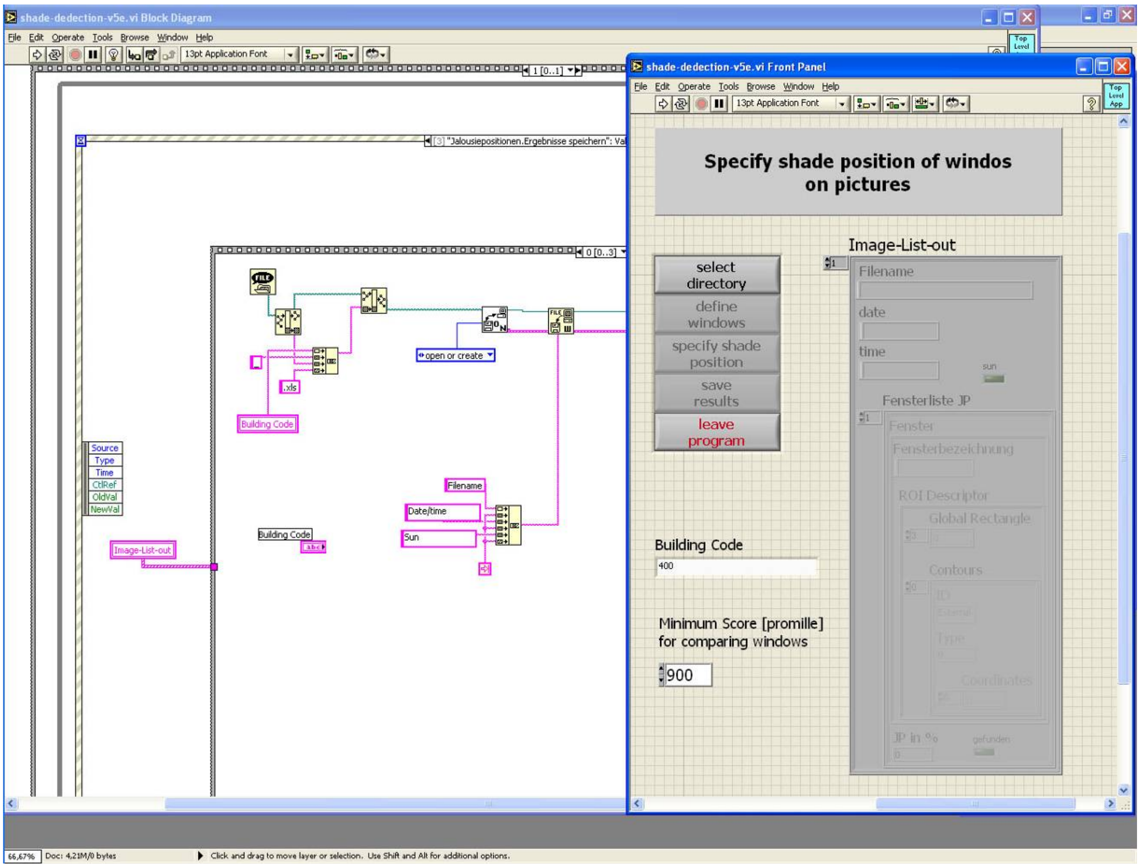

Figure 2-37 Shade detection program (ENVO)

The program compares pixels in frequent images and if there is a change, it shows the image so that the user can specify the position of the shades. Level of the shades for a completely closed shade was defined to be 100% and for an opened shade 0%. Intermediate steps of 20% between a fully closed and fully opened were used (see Figure 2-38).

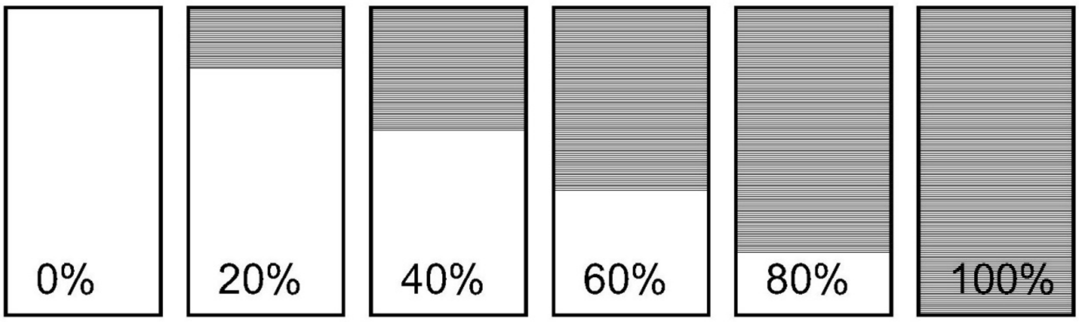

Figure 2-38 Defined positions for the shades

The accuracy of comparing two pictures in the program could be defined; for example 900 means if the similarity between the two frequent pictures is less than 90%, the subsequent picture will be shown to the user. Figure 2-39 shows snapshot of the graphical user interface of the LabVIEW application.

The program stores position of shades for future processing and all windows have to be selected before the program starts. Figure 2-39 shows selecting the windows by the program.

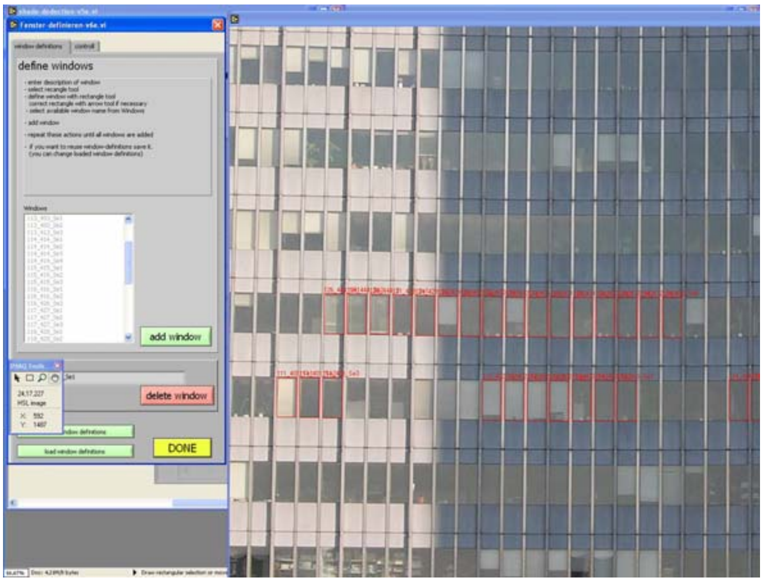

Figure 2-39 Interface of the program (ENVO)

The outputs of the program are Excel-sheets with header, picture name, the date of image capture and the names of windows. The files have ten-minute steps and are separated for each downloaded period; 'SenSelect' is necessary to combine them and adjust them to five-minute steps.

2.3.4 Calibration

2.3.4.1 Calibration of HOBO illuminance sensors

In this project 61 HOBO U12-012 units were used. The technical specification by the manufacturer (Onset 2007) declares a range of 1 to 32,280 lx, the maximum value varies from 16,140 to 48,420 lx. No further information was given for this model (in a previous model ±21.52 lx or ±20% of reading was mentioned). From this specification it was crucial to calibrate each of the used sensors individually.

The calibration measurements were done twice, first with exclusively daylight and then with exclusively artificial light. In both cases about 10 HOBO sensors were placed on a table surrounded by 3-4 Minolta T-10 illuminance meters (Figure 2-40). For artificial light the measurements (3 minutes each) were done at 0, 40, 75, 225, 450 and 680 lx. The daylight measurements lasted about 12 hours each, to cover a wide range (0 to >1,500 lx).

Out of the original data those values were excluded where the difference between the Minolta multipoint measurement values was 3% or more. The remaining data was used to plot the mean Minolta values against the values of each HOBO to derive a correlation. The correlation functions for artificial and for daylight were then merged to a new correlation which was used for calibration of each HOBO.

Among HOBO sensors there are differences but the correlation to the reference (Minolta) values was always very high (R^2>0.88). Therefore all recorded HOBO data was corrected using these individual correlation functions.

Figure 2-40 Calibration setup for HOBO illuminance sensors

2.3.4.2 Derivation of horizontal illuminance on the workstation

Due to the fact that this project measured in offices over month while people were working, it was not possible to measure horizontal illuminance levels directly on the table of the workstation. Therefore horizontal illuminance was derived from measured horizontal or vertical illuminance measured next to the workstation as described in section 2.2.2.1. For every mounted sensor and every workstation separate measurements were conducted (under different conditions) in order to derive a calibration factor for the measured data. In all buildings except UT these correlation factors could be derived.

3 Results

A number of results for VC, FH, ET and HB have been presented and discussed in previous theses as well as in the final report of the research project "People as Power Plant" (Mahdavi et al. 2007).

In the following section the results of UT are presented. Additional results for VC, FH, ET and HB, which have not been presented before are shown in the subsequent section.

3.1 UT

The analysis of UT data from 89 persons in 26 zones on 5 levels was used. Out of those zones 9 are single and 3 double occupancy zones.

3.1.1 Occupancy

The mean occupancy pattern of 89 employees over the course of a reference day (Data of the entire observation period, referring to the same time of the day was averaged and presented in one 24 hour schedule) can be seen in Figure 3-1. This graph depicts the five minute interval used for the measurements. As described in section 2.2.2.2 the 'presence in the building' has been measured. The occupancy at the workplace was estimated by adding 5 minutes to the arrival time and cutting 5 minutes from the leaving time.

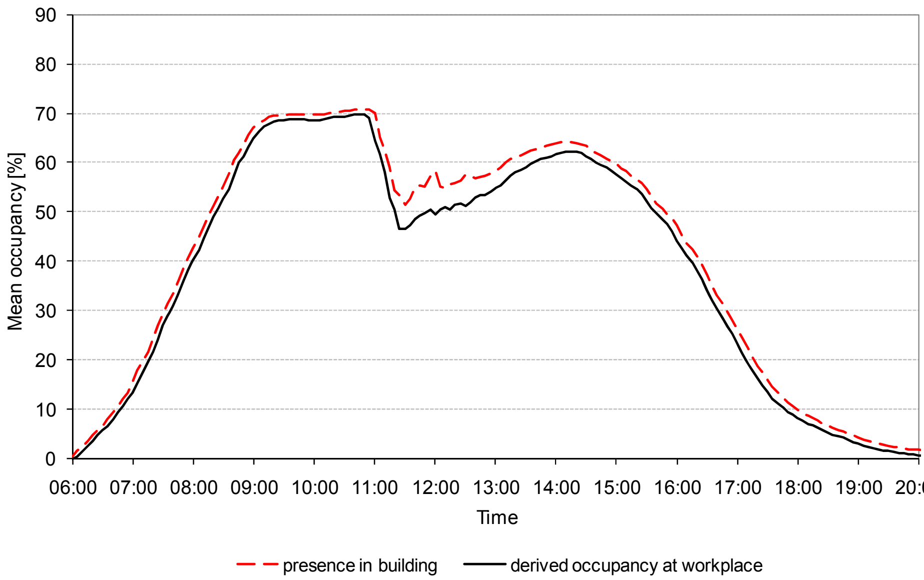

Figure 3-1 Mean occupancy level over the course of a reference day in five minute intervals, averaged over all observed workstations

Figure 3-2 shows the hourly mean occupancy level over the course of a reference day averaged over all observed workstations. These hourly values were calculated by the average of the past hour (e.g.: The value at 7:00 represents the values from 6:05 to 7:00).

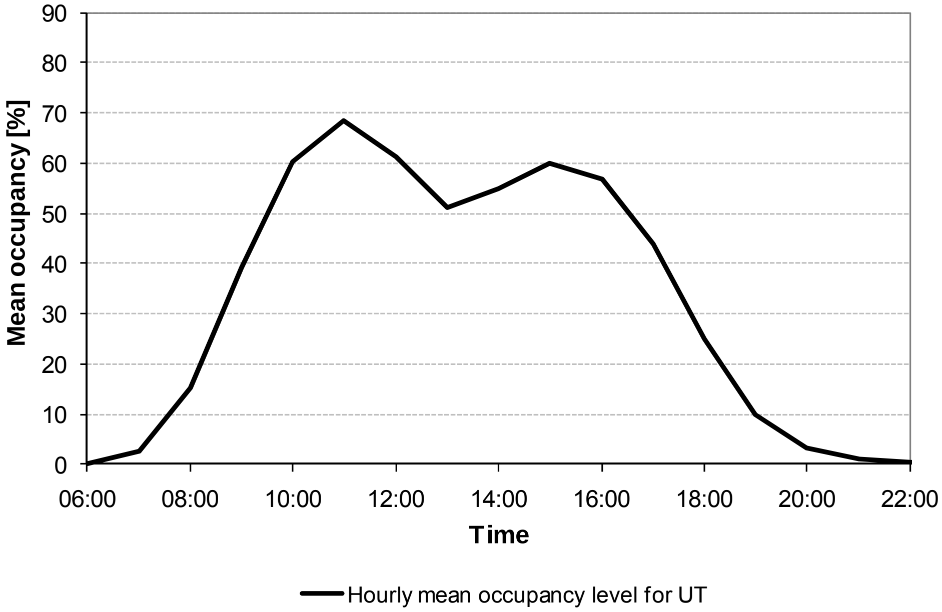

Figure 3-2 Hourly mean occupancy level over the course of a reference day, averaged over all 89 workstations

The observed 89 employees were allocated in 26 zones. Seven of those are single occupancy, three zones are double occupancy and the remaining zones are occupied with up to eight people. The hourly mean occupancy levels within one zone can vary as Figure 3-3 depicts. The graph moreover exemplarily exhibits that there are differences between the hourly mean occupancy level over the course of a reference day averaged over all 89 workstations compared with the observed pattern in zone 05_z15 and zone 14_z03. Zone 05_z15 (AP81) is a single occupancy office. This office type is normally assigned to executive personnel. Whereas zone 14_z03 (AP11-AP18) is occupied by eight people. Zones were named in the way that the first two digits ('05') indicate the level and the last three characters ('z15') indicate the number of the zone. The hourly mean was calculated as the average of twelve 5' values and refers to the past hour (e.g.: the average of the values from 06:05 to 07:00 is plotted at 07:00). This calculation rule is required by most simulation applications.

Due to the above mentioned variety of occupancy patterns, the hourly mean occupancy level over the course of a reference day averaged over all observed workstations and the corresponding standard deviations are shown in Figure 3-4.

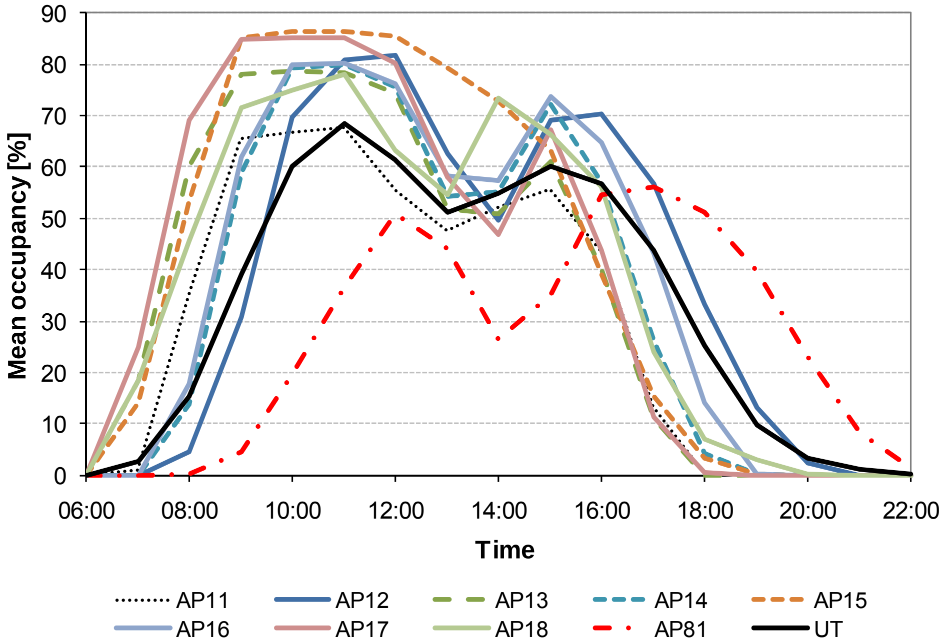

Figure 3-3 *Hourly mean occupancy level over the course of a reference day averaged over all 89 workstations compared with the observed pattern in zone 05_z15 (AP81; single occupancy) and 14_z03 (AP11-AP18; eight occupants)*

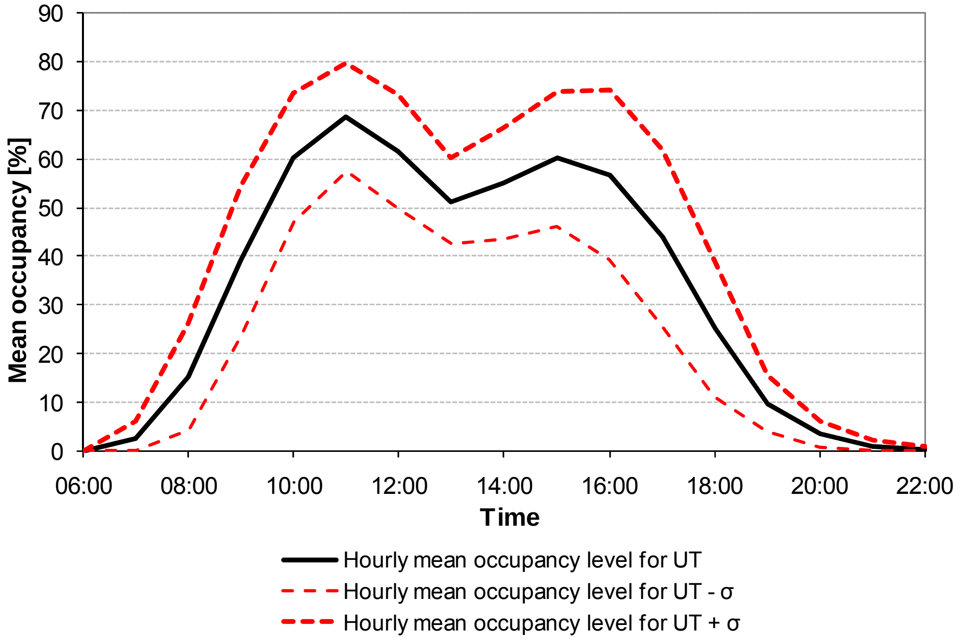

Figure 3-4 *Hourly mean occupancy level and standard deviation for a reference day averaged over all 89 workstations*

Mean occupancy as shown and described above is calculated as the average of all 89 workstations. The 89 persons observed occupied 26 zones on 5 levels. In Figure 3-5 the mean occupancy level over the course of a reference day for each observed zone is presented. As exemplarily shown in Figure 3-3 for individual people this graph shows the diversity of occupancy patterns between all observed zones.

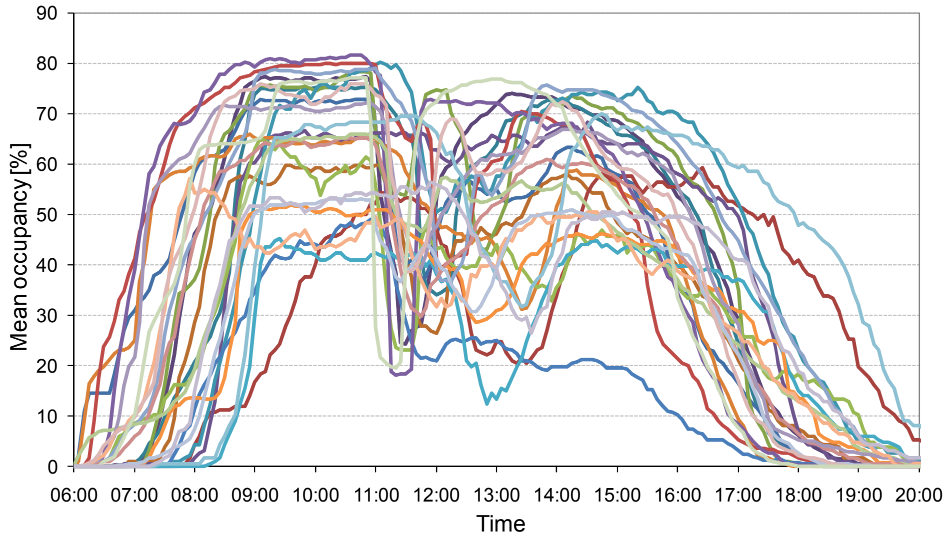

Figure 3-5 Mean occupancy level over the course of a reference day for each observed zone

The averaged patterns of the seven single -, three double - and sixteen multi occupancy zones are compared with the mean occupancy level for all workstations in Figure 3-6 over the course of a reference day.

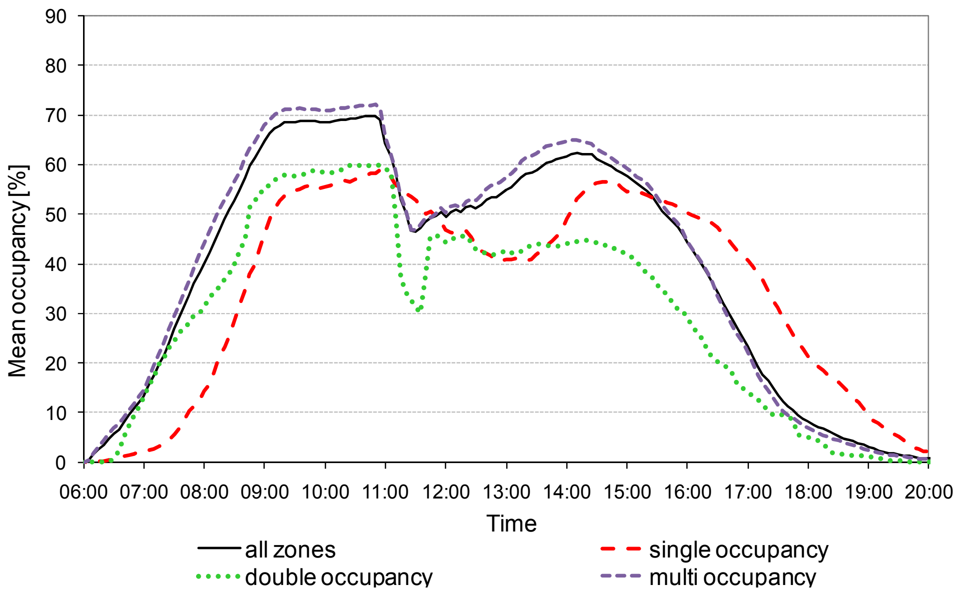

Figure 3-6 Mean occupancy level over the course of a reference day, averaged over all observed workstations, for single -, double - and multi occupancy

3.1.2 Lighting - Status

Talking about building devices in general it is necessary to distinguish between actions and status. While status gives information about the state of a device (the light is on or off) over a period of time even if this period is very short, the action gives information about a change of the status at a specific moment.

3.1.2.1 Mean lighting load

While the user can choose between three illuminance levels (see section 2.1.4.2) the building management system establishes the light level in the zone with two light circuits out of which one is dimmable (129 dimmable and 103 not dimmable illuminants in the observed zones). The total lighting load of the installed lighting devices in all 26 zones is 8120 W (232 T16 illuminants 35 W each). The mean lighting load over the course of a reference day (whole measurement period) for all intervals as well as for intervals when the zone was occupied, averaged over all zones is shown in Figure 3-7.

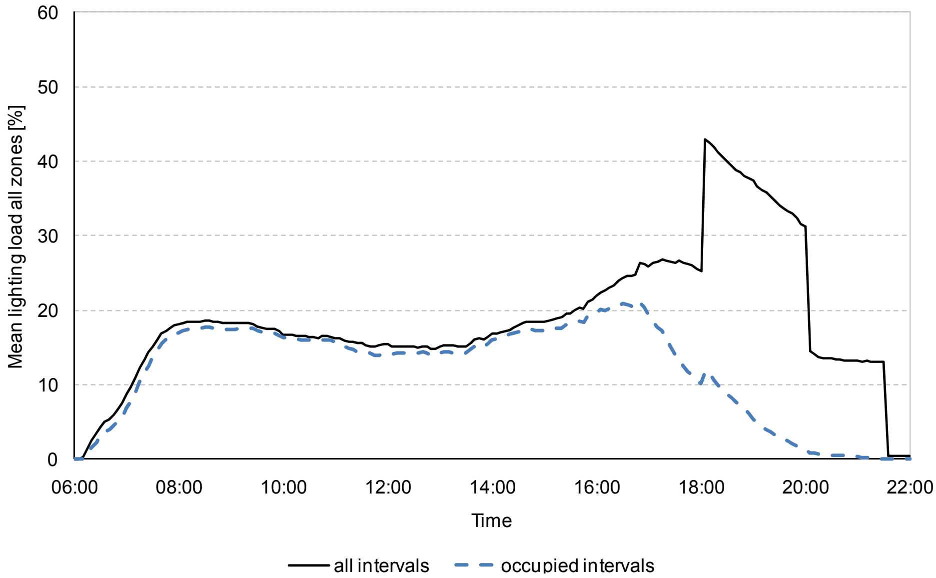

Figure 3-7 Mean lighting load over the course of a reference day for all and for only occupied intervals, averaged over all zones

The building management ran some regimes to reach a uniform external view of the façade. In winter the light in all zones was turned on 50% at 18:00, turned to 25% at 20:00 and turned off at 21:30 first (from measurement start to the 15th June 2005 and from 10th October to 22nd December 2005). Then the regime was changed in a way that the lights were turned on 50% at 18:00 and turned off at 20:00 (from 23rd December

2005 to 31st May 2006). The mean lighting load over the course of a reference day (light regime winter 2005 + 2006) for all and for only occupied intervals, averaged over all zones is visualized in Figure 3-8.

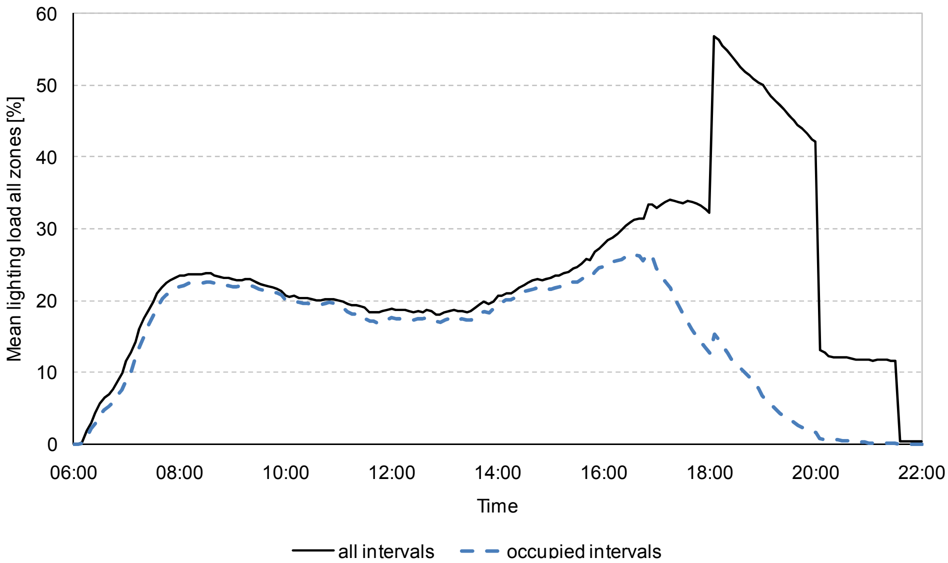

Figure 3-8 Mean lighting load over the course of a reference day (light regime winter) for all and for only occupied intervals

In summer 2005 the light in all zones was turned on 25% at 20:00 and turned off at 21:30 (from 16th June to the 9th October 2005). In summer 2006 (starting from 1st June) no automation was applied till the end of the measurement. The mean lighting load over the course of a reference day (light regime summer) for all and for only occupied intervals, averaged over all zones is displayed in Figure 3-9 (summer 2005) and Figure 3-10 (summer 2006).

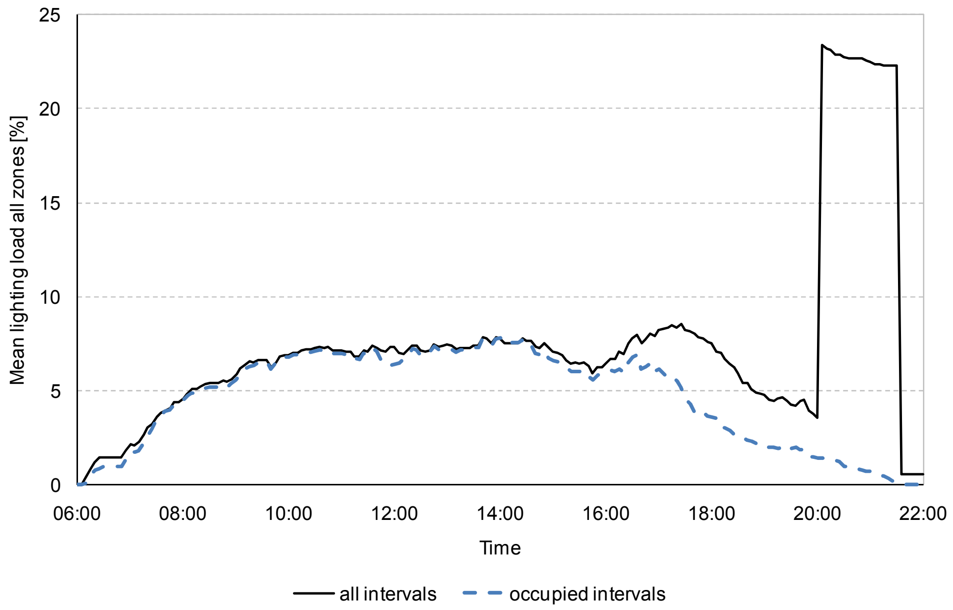

Figure 3-9 Mean lighting load over the course of a reference day (light regime summer 2005) for all and for only occupied intervals

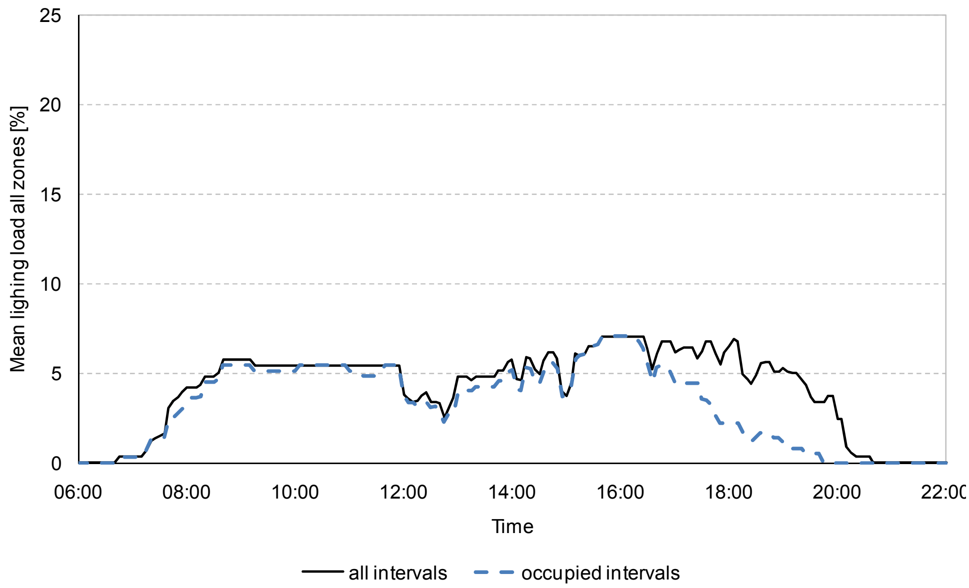

Figure 3-10 Mean lighting load over the course of a reference day (light regime summer 2006) for all and for only occupied intervals

3.1.2.2 Season dependent mean lighting load

The seasonal dependency of the mean lighting load is presented in the next graphs. Under the hypothesis that seasonal dependency is mainly connected with the length of sunshine per day, data of the two month next to summer or winter solstice respectively to vernal or autumnal equinox was used to describe the seasons. In detail following data was used:

- Winter (December and January): 01.12.2005 - 23.01.2006
- Spring (March and April): 01.04. - 29.04.2005
01.03. - 28.04.2006
- Summer (June and July) 01.06. - 28.07.2005
02.06. - 10.07.2006
- Autumn (September and October) 10.10. - 19.10.2005

Where Figure 3-11 shows the season dependent mean lighting load over the course of a reference day for all intervals, averaged over all zones, the season dependent mean lighting load over the course of a reference day for only occupied intervals, averaged over all zones is depict in Figure 3-12. Due to some data inconsistency the values for autumn in both graphs are based on an interval of only 9 days (7 workdays) and cannot be considered as representative.

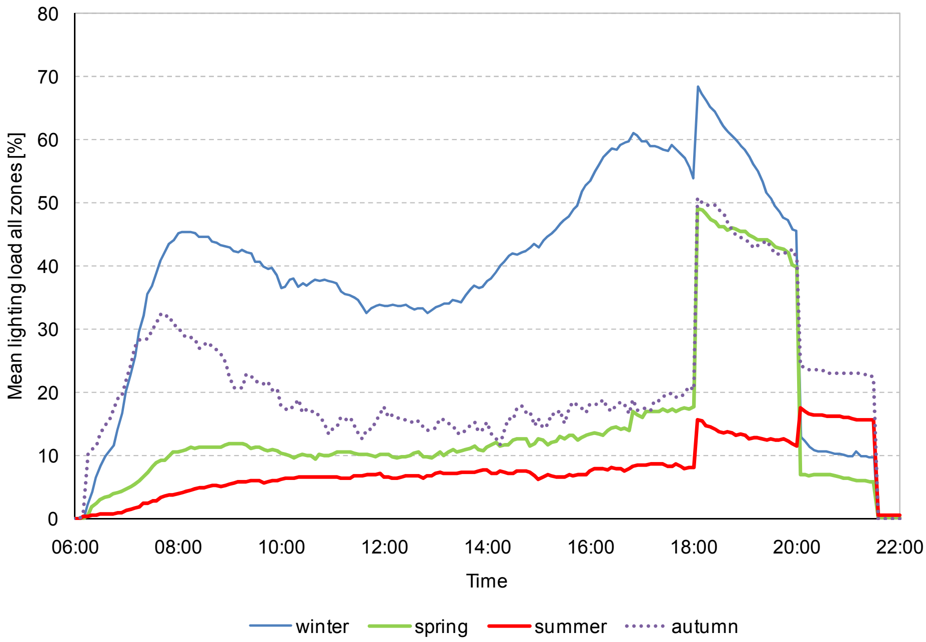

Figure 3-11 Season dependent mean lighting load over the course of a reference day for all intervals, averaged over all zones

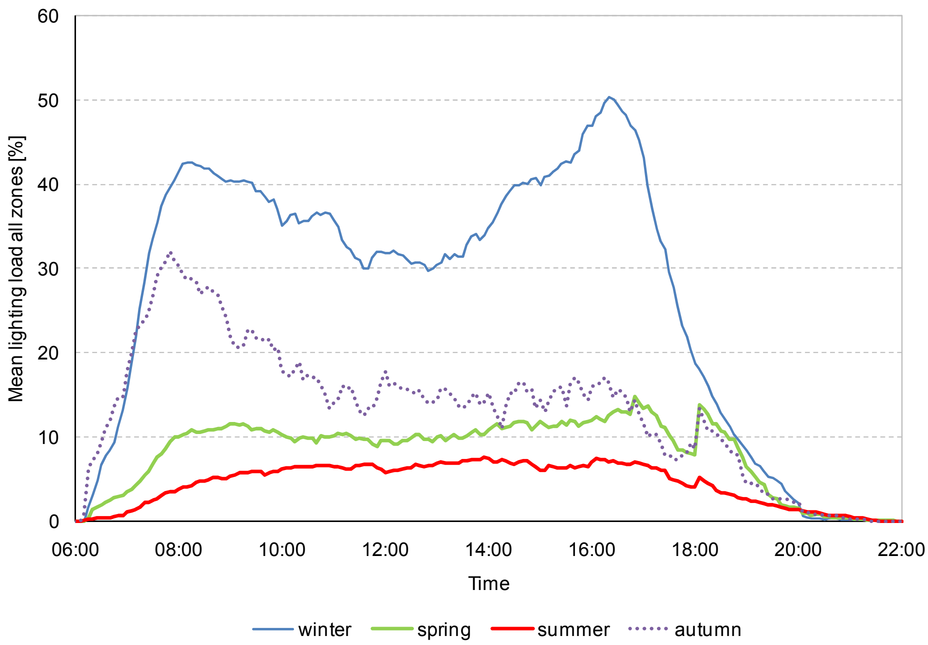

Figure 3-12 Season dependent mean lighting load over the course of a reference day for only occupied intervals, averaged over all zones

3.1.2.3 Lighting load per zone

To exclude automated actions of the building automation system the observation time interval for the next results was chosen from 06:00 to 17:55. The following graph (Figure 3-13) shows the lighting load (in percentage) for each zone for the whole measurement period under the condition that the zone was occupied. As mentioned before zones were named in the way that the first two digits ('05') indicate the level and the last three characters ('z15') indicate the number of the zone.

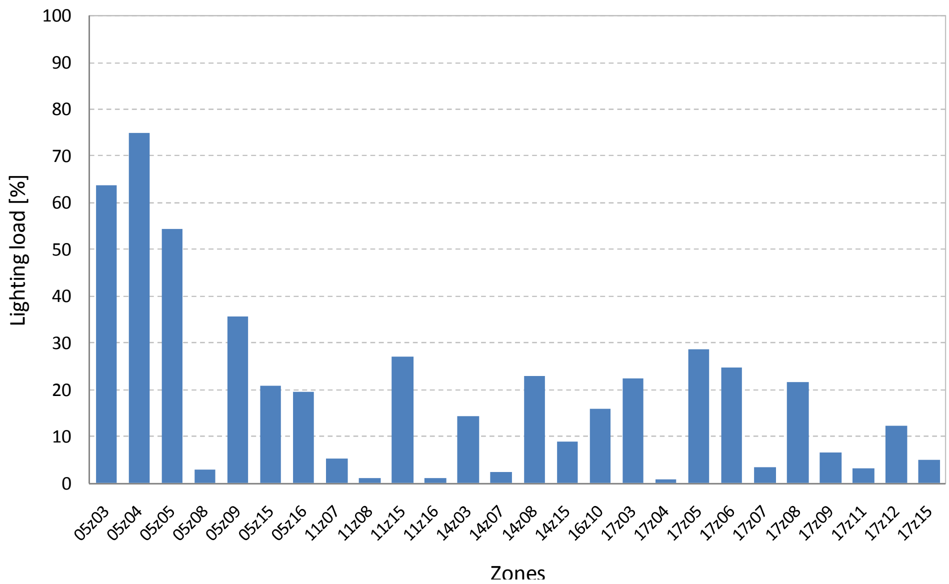

Figure 3-13 Percentage of lighting load for each zone for the whole measurement period

The difference between winter and summer months in terms of the percentage of lighting load for each zone between 06:00 and 17:55 when the zone was occupied is presented in Figure 3-14. To make the graph better readable the values for the months are connected with lines.

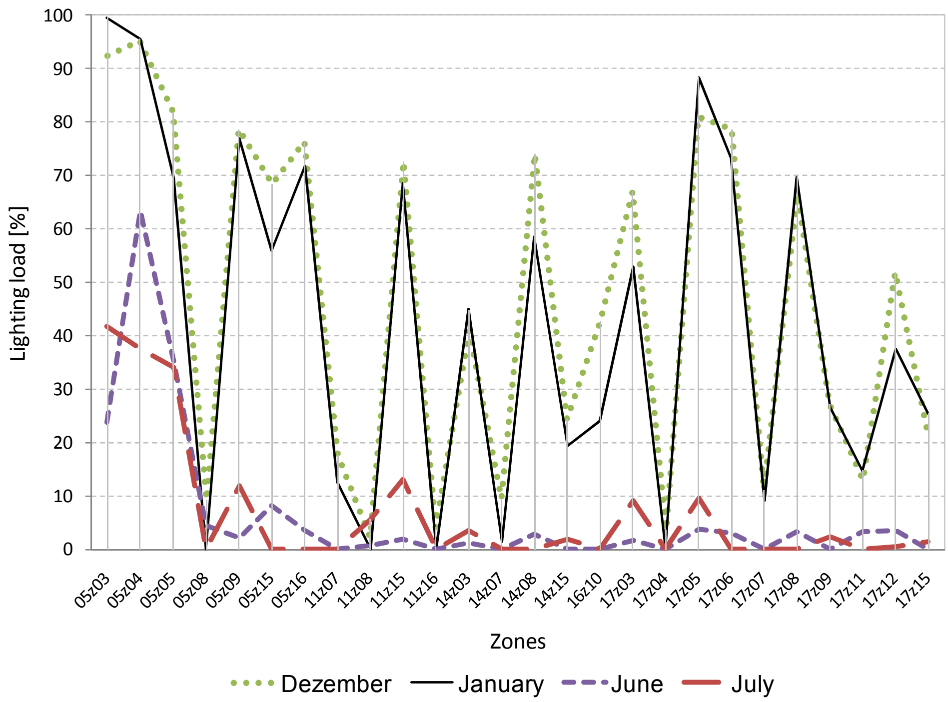

Figure 3-14 Percentage of lighting load for each zone for winter and summer month (06:00-17:55), when the zone was occupied

3.1.2.4 Lighting load per floor

Out of the 26 zones seven were located on the 5th floor, four on the 11th, four on the 14th, one on the 16th, ten on the 17th floor. The percentage of the lighting load is plotted for each floor in Figure 3-15 (06:00 -17:55; occupied).

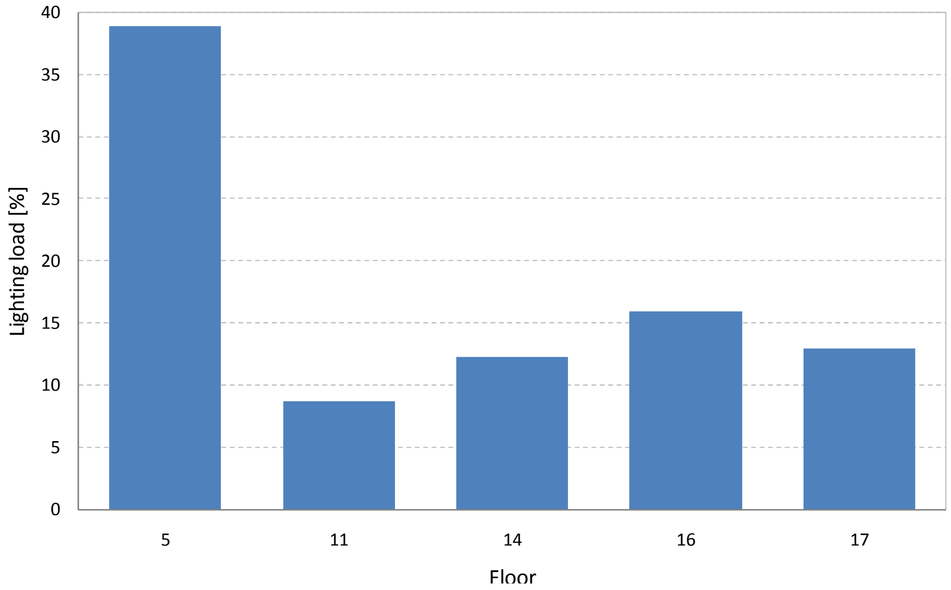

Figure 3-15 Percentage of lighting load for each floor (06:00-17:55), when the zones were occupied

3.1.2.5 Lighting load per orientation

In Figure 3-16 the lighting loads for the eight orientations of the zones is shown for the measurement period as well as winter and summer month (06:00 -17:55; occupied).

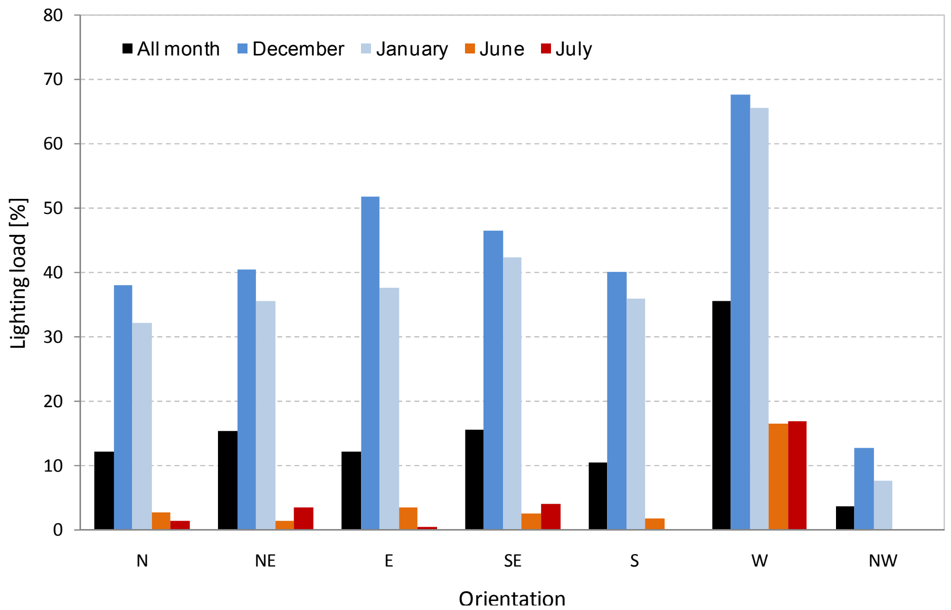

Figure 3-16 Percentage of lighting load for each orientation of the zones for the whole period and season related, when the zones were occupied

3.1.2.6 Lighting load per number of persons per zone

In this section the lighting load brought in relation to the number of persons per zone. Figure 3-17 shows the lighting load levels for each zone sorted by the number of persons per zone as well as the corresponding mean values. This information is grouped in Figure 3-18 (06:00 -17:55; occupied).

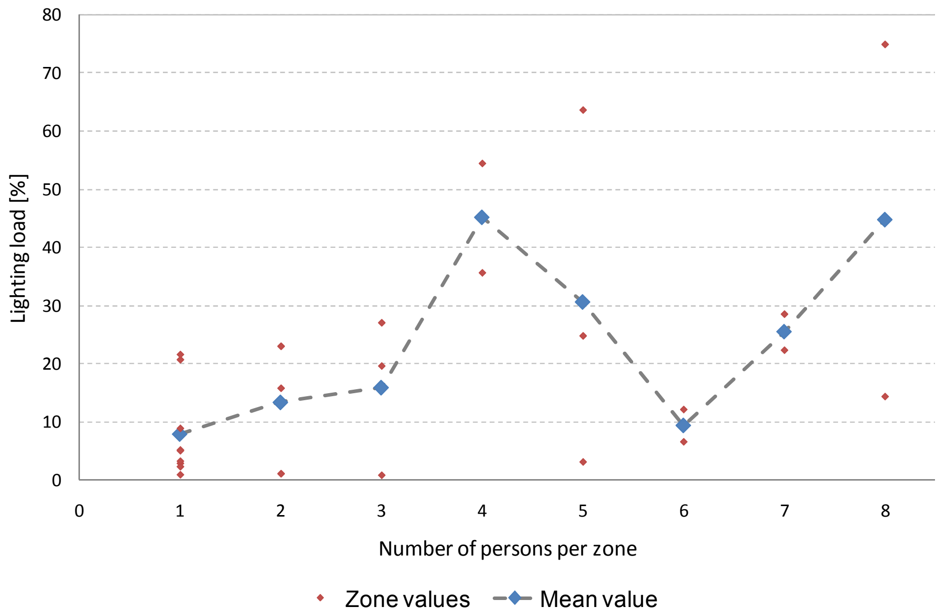

Figure 3-17 Percentage of lighting load for each zone sorted by the number of persons per zone (06:00-17:55), when the zones were occupied

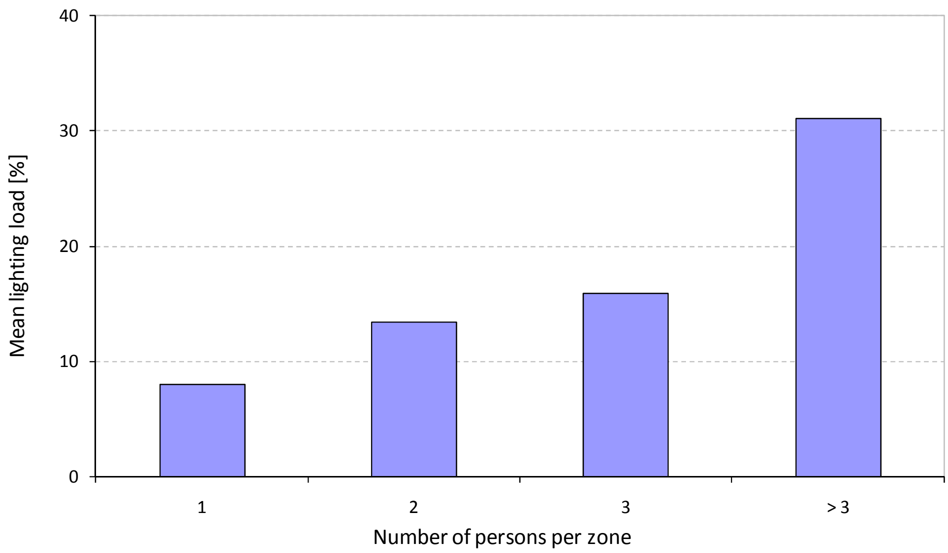

Figure 3-18 Percentage of mean lighting load against the number of persons per zone (06:00-17:55), when the zones were occupied

3.1.2.7 Shades related lighting load

In this section lighting load in the context of shade positions will be presented. Figure 3-19 shows the percentage of intervals while shades were open during working hours while occupied.

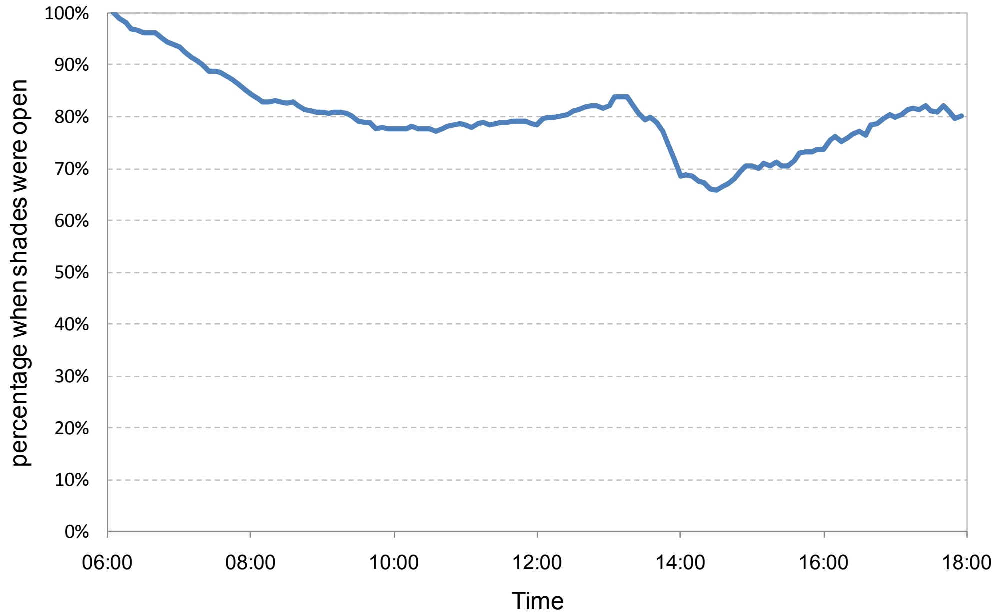

Figure 3-19 Percentage of intervals while shades were open, during working hours

In Figure 3-20 the percentage of intervals when shades were open sorted by the vertical external illuminance is presented.

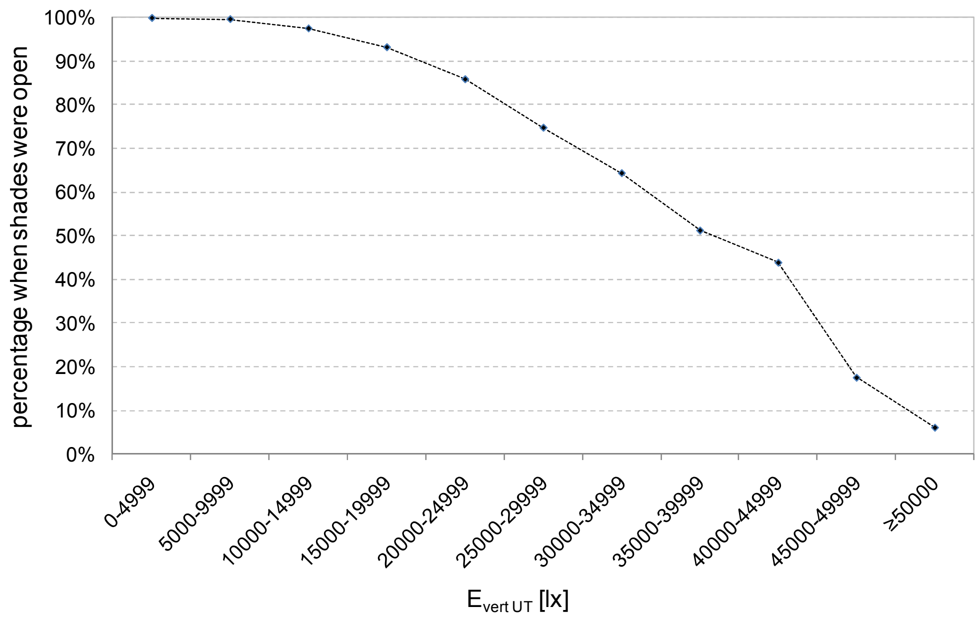

Figure 3-20 Percentage of intervals while shades were open sorted by the vertical external illuminance

Figure 3-21 then compares the percentage of mean lighting load sorted by the vertical external illuminance when shades were open or deployed.

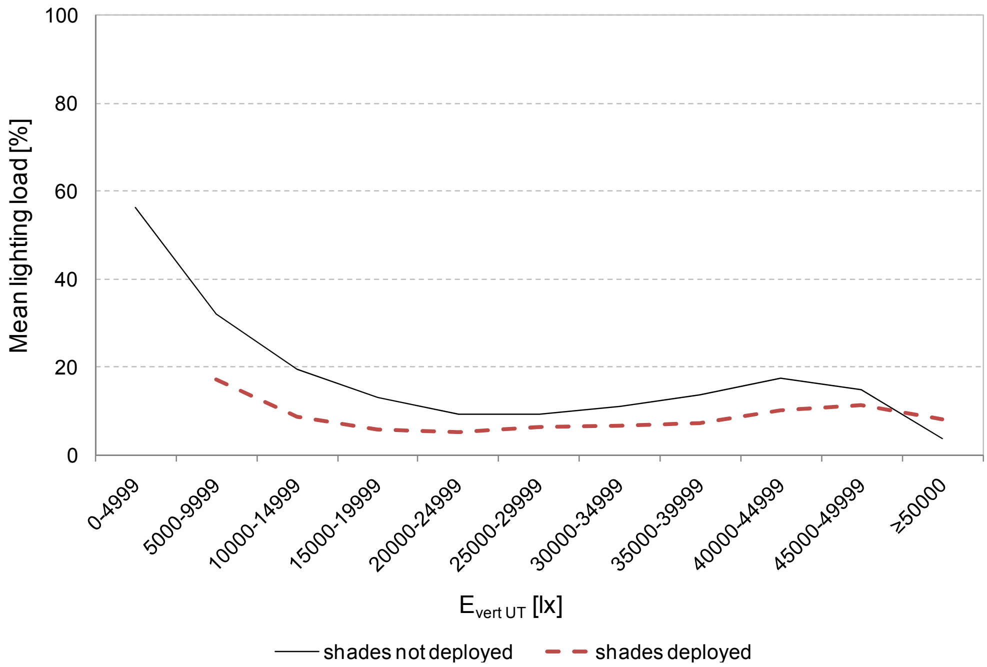

Figure 3-21 Percentage of mean lighting load while shades were open or deployed sorted by the vertical external illuminance

Consequently the same is done for horizontal external global irradiance in the next graphs. Figure 3-22 informs about the percentage of intervals when shades were open sorted by the horizontal external global irradiance. Figure 3-23 presents the mean lighting loads while shades were open or deployed sorted again by the horizontal external global irradiance.

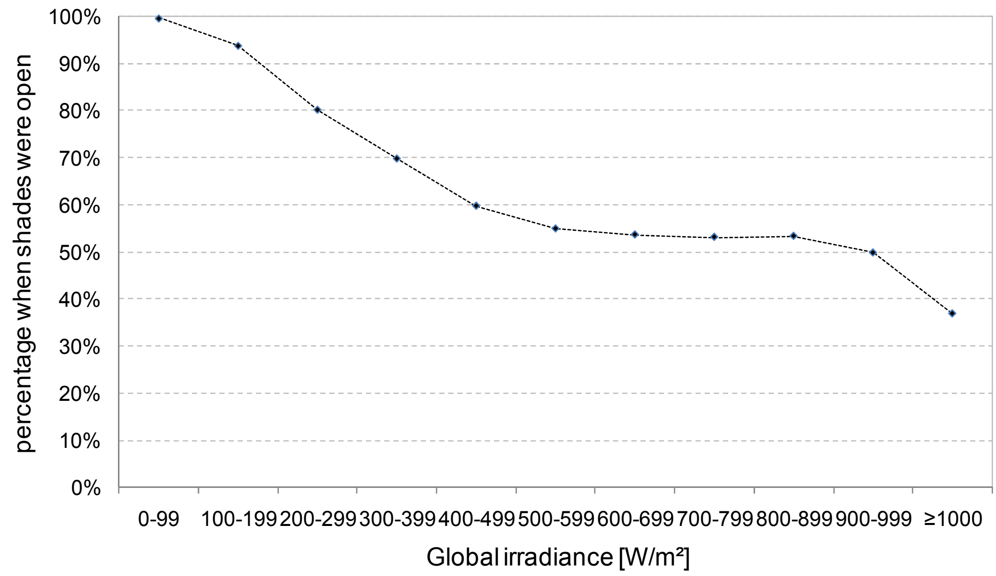

Figure 3-22 Number of intervals while shades were open or deployed sorted by the horizontal external global irradiance

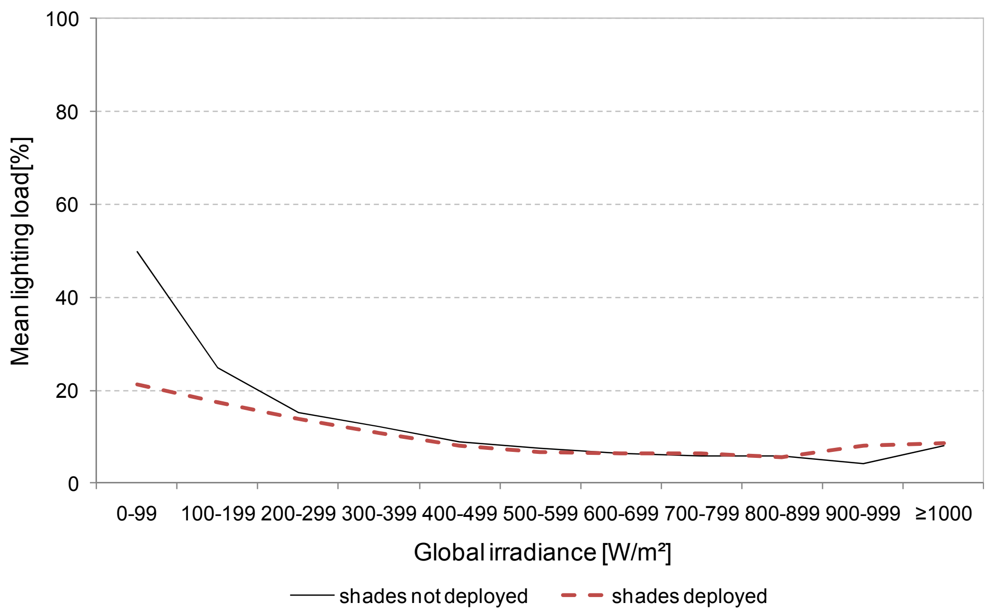

Figure 3-23 Percentage of mean lighting load while shades were open or deployed sorted by the horizontal external global irradiance

3.1.3 Lighting - Actions

3.1.3.1 Overview

In terms of actions the user in UT has the possibility to choose between 0 lx, 300 lx and 500 lx, therefore there are 3 types of 'switch on' and 3 types of 'switch off' actions. Figure 3-24 gives an overview of all 'switch on' and 'switch off' actions in the observed zones. The difference between the number of 'switch on' and 'switch off' user actions results mainly out of the fact that in most cases the building management system took over control as described. To exclude automated actions in the analysis the observation time interval for these results was chosen from 06:00 to 17:55.

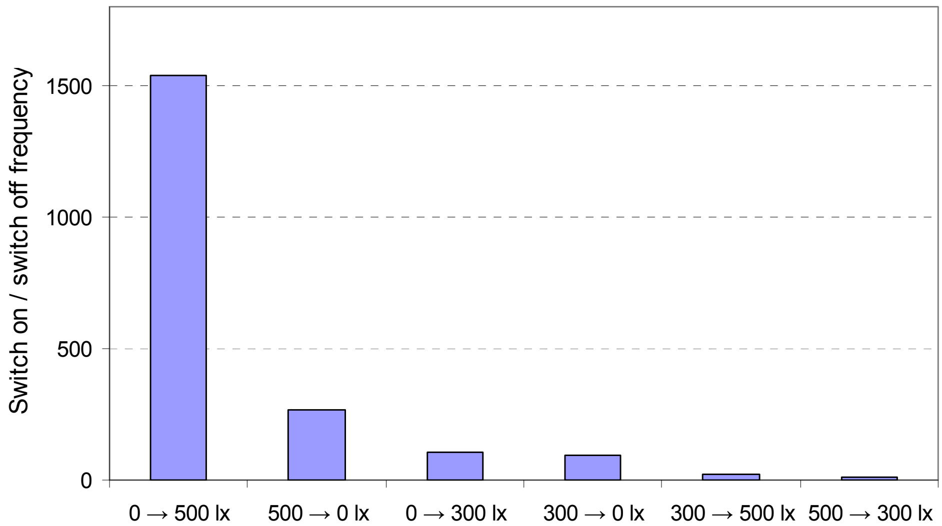

Figure 3-24 Frequency of 'switch on' and 'switch off' actions between 06:00 and 17:55

In all other buildings 'switch on at arrival' and 'switch off when leaving' were analyzed (Mahdavi et al. 2008). Because the occupancy data ("at workplace") was derived out of the "occupancy in the building" data these analyses could not be done for UT. For the analysis of 'intermediate actions' the data quality of the ceiling sensor was not appropriate.

3.1.3.2 Absolute frequencies

In the overwhelming majority of cases the light was either turned on from 0 lx to 500 lx or turned off from 500 lx to 0 lx. Therefore, the analysis was done for '0 lx to 500 lx' and '500 lx to 0 lx' switching actions. In 186 workdays the light was turned on from 0 lx to 500 lx 1540 times and turned off from 500 lx to 0 lx 264 times in all of the 26 zones in the observed period. The absolute frequencies of '0 lx to 500 lx' and '500 lx to 0 lx' switching actions between 06:00 and 17:55 are plotted against the illuminance measured on the ceiling (see section 2.2.2.1) in Figure 3-25 and Figure 3-26.

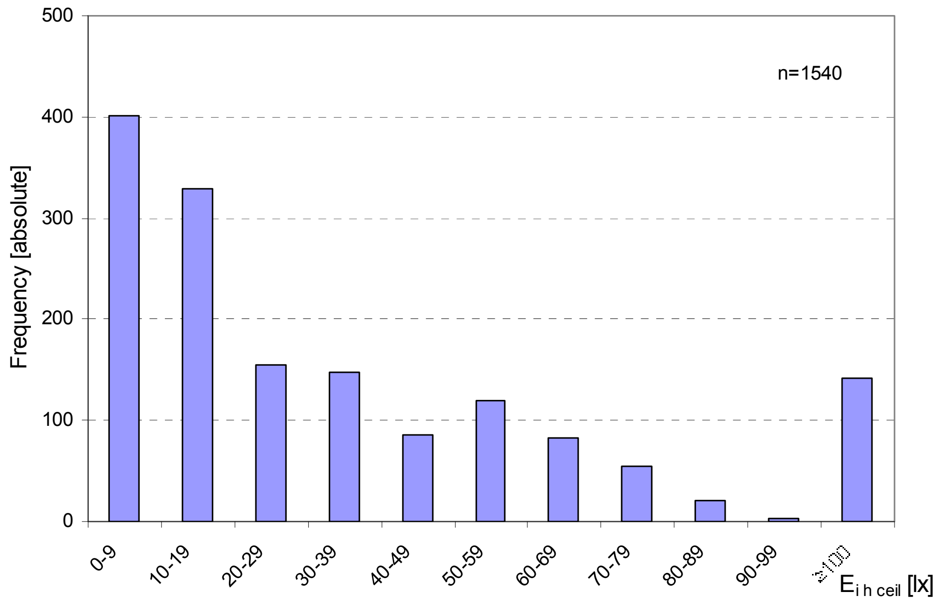

Figure 3-25 Absolute frequency of switch on actions (0-500 lx) between 06:00 and 17:55

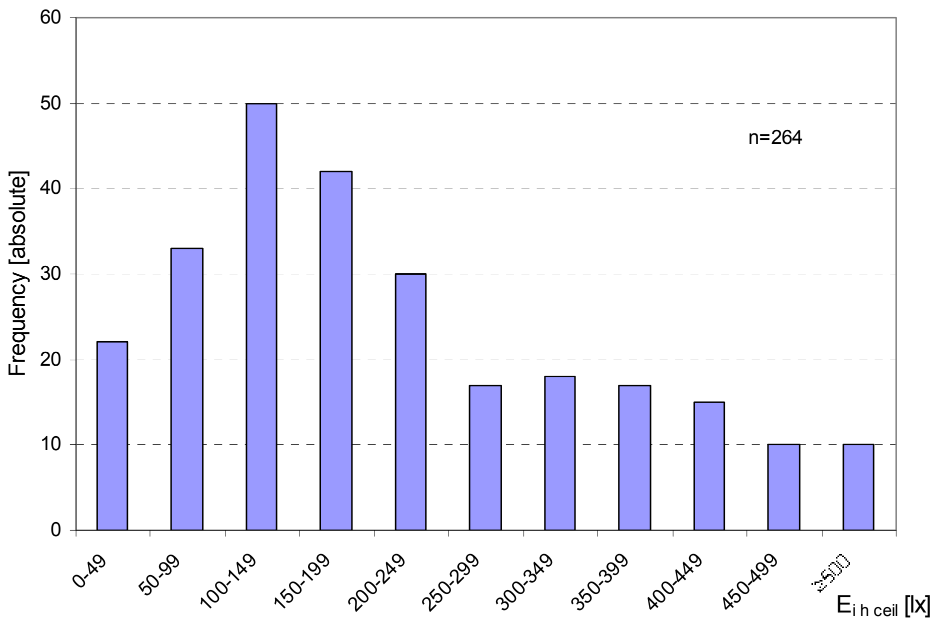

Figure 3-26 Absolute frequency of switch off actions (500-0 lx) between 06:00 and 17:55

3.1.3.3 Normalized relative frequencies

The absolute number of actions and the absolute frequencies was information used for data and result validation purposes. For the definition of patterns, the number and absolute frequencies are not applicable. The number of actions depends on the frequency of certain illuminance levels and on the number of people present at this time. We therefore introduced the 'normalized relative frequency' (Equation 1) as benchmark. The normalized relative frequency is defined by the division of the number of actions by the number of occupied intervals, for the relevant ranges or bins.

$$f_{norm.rel.} = \frac{A}{B_{occupied}}$$ *Equation 1*

where:

$f_{norm.\,rel.}$	normalized relative frequency
A	number of actions
$B_{occupied}$	number of occupied intervals

The condition that an action is counted only if the zone is occupied reduced the 'switch on' actions from 1540 to 1278 cases and the 'switch off' actions from 264 to 250. The normalized relative frequency of '0 lx to 500 lx' and '500 lx to 0 lx' switching actions between 06:00 and 17:55 are shown in Figure 3-27 ('switch on') and Figure 3-28 ('switch off').

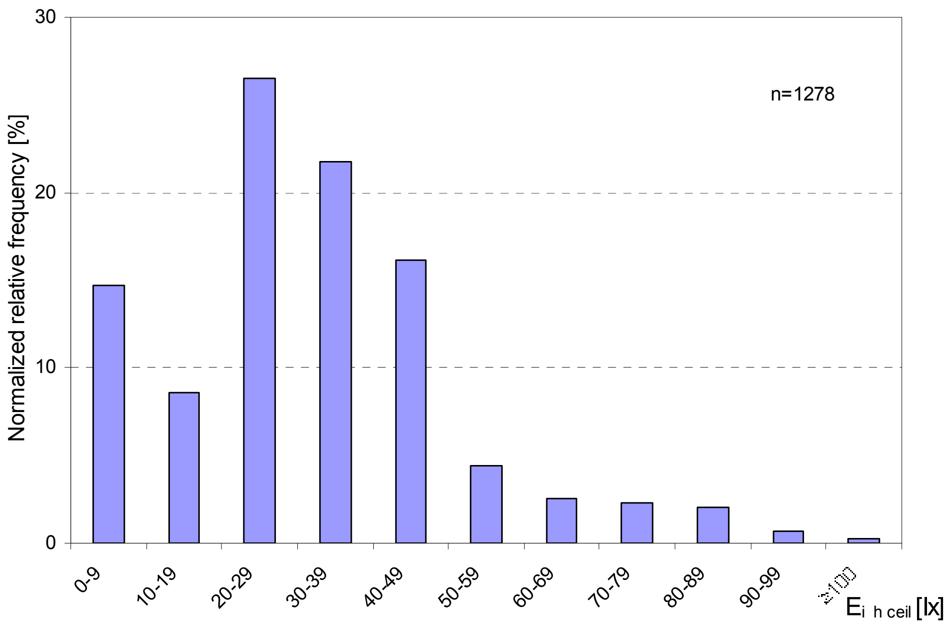

Figure 3-27 Normalized relative frequency of 'switch on' actions (0-500 lx) as a function of internal horizontal illuminance at the office ceiling, between 06:00 and 17:55

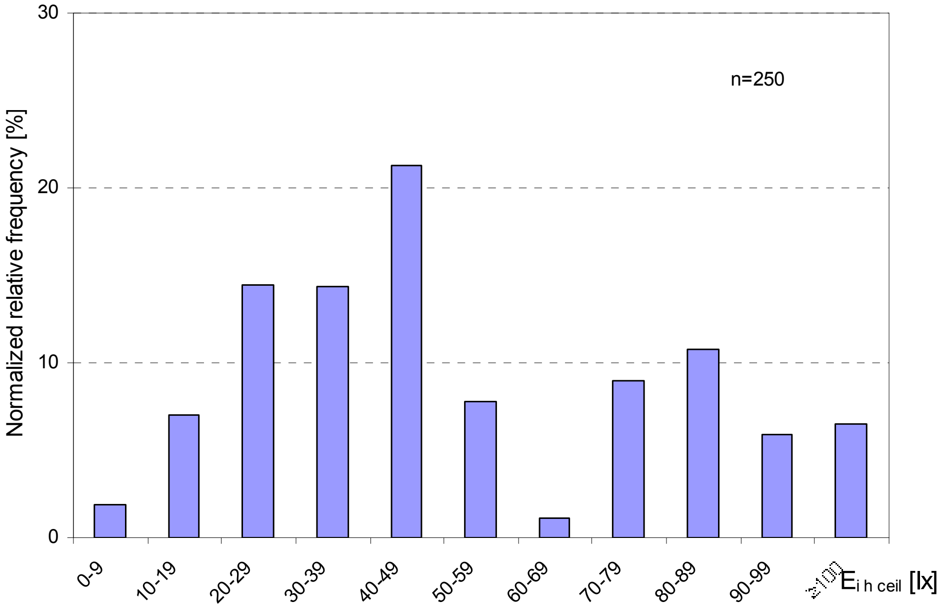

Figure 3-28 Normalized relative frequency of 'switch off' actions (500-0 lx) as a function of internal horizontal illuminance at the office ceiling, between 06:00 and 17:55

While Figure 3-27 and Figure 3-28 show results regardless the position of shades, in Figure 3-29 and Figure 3-30 only those cases are plotted where the shades are fully open. Therefore the number of 'switch on' actions was reduced from 1278 to 1214 and the 'switch off' actions from 250 to 237.

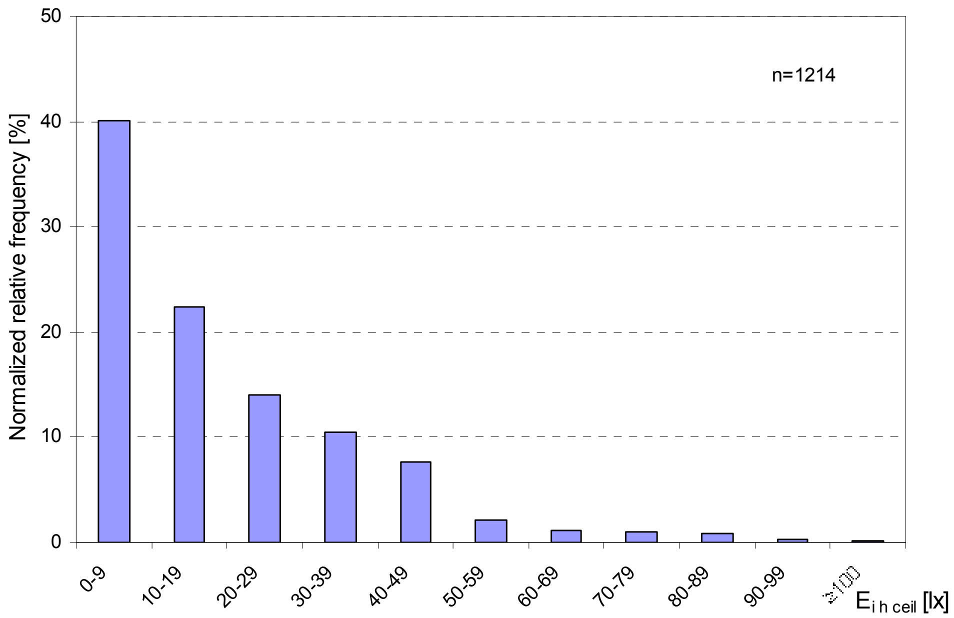

Figure 3-29 Normalized relative frequency of 'switch on' actions (0-500 lx) as a function of internal horizontal illuminance at the office ceiling, between 06:00 and 17:55 (all shades open)

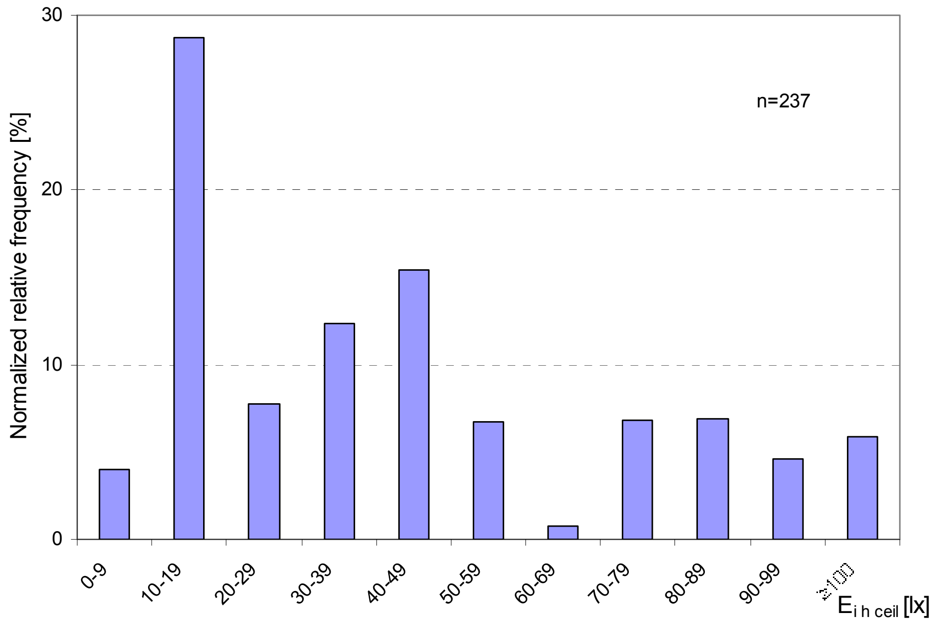

Figure 3-30 Normalized relative frequency of 'switch off' actions (500-0 lx) as a function of internal horizontal illuminance at the office ceiling, between 06:00 and 17:55 (all shades open)

Figure 3-31 exemplifies for all orientations the correlation of internal horizontal illuminance at the office ceiling ($E_{i\ h\ ceil}$) and external horizontal illuminance ($E_{h\ TU}$) for all northwest oriented zones over the measurement period.

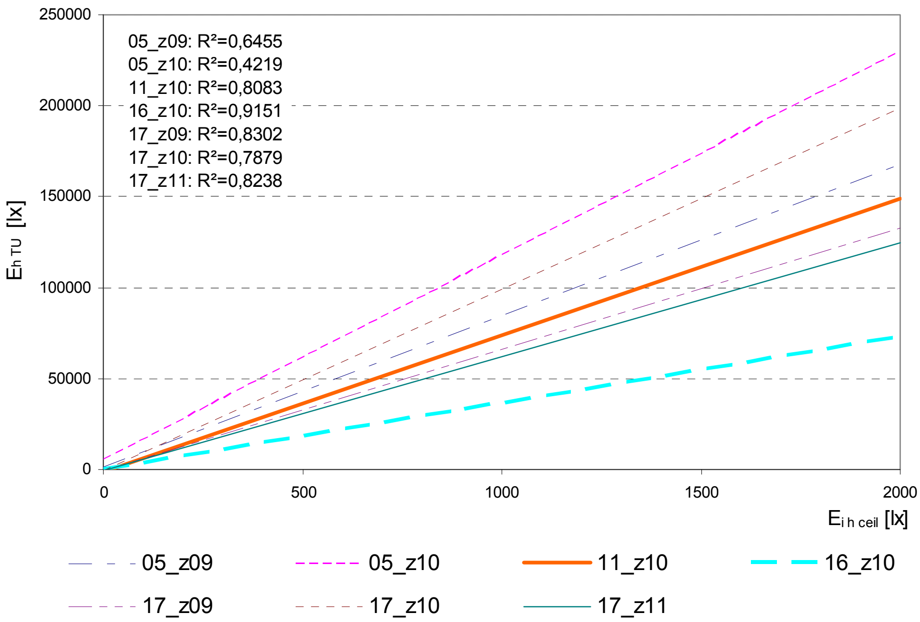

Figure 3-31 Correlation of internal horizontal illuminance at the office ceiling ($E_{i\ h\ ceil}$) and external horizontal illuminance ($E_{h\ TU}$) for all northwest oriented zones over the measurement period

To find a relation between outdoor parameters and 'switch on' actions Figure 3-32 shows the normalized relative frequency of 'switch on' actions (0-500 lx) in the observed time span (06:00 and 17:55) when the zone is occupied and all shades (internal and external) are open. $E_{v\ UT}$ is the external vertical illuminance measured on top of UT in 8 directions (see section 2.2.1).

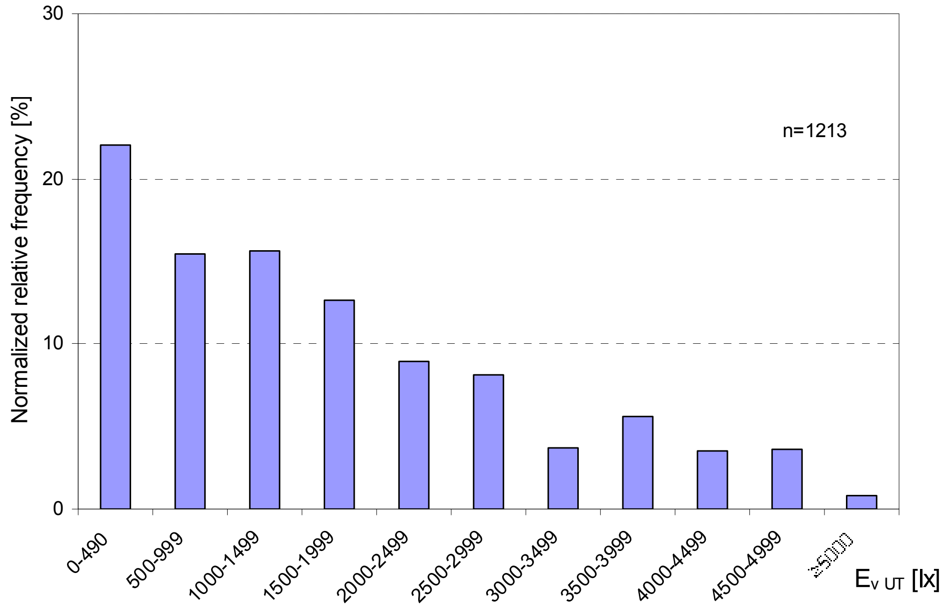

Figure 3-32 Normalized relative frequency of 'switch on' actions (0-500 lx) as a function of vertical illuminance, between 06:00 and 17:55 (all shades open)

Analogously to Figure 3-32, Figure 3-33 and Figure 3-34 show the dependency of 'switching on' actions on external horizontal illuminance ($E_{h\ TU}$) and global irradiance ($SR_{h\ TU}$), both measured with the weather station of the Department for Building Physics and Building Ecology in 1.9 km distance. The discrepancy of actions (n=1213 vs n=1160) is due to a lack of consistency in the data set.

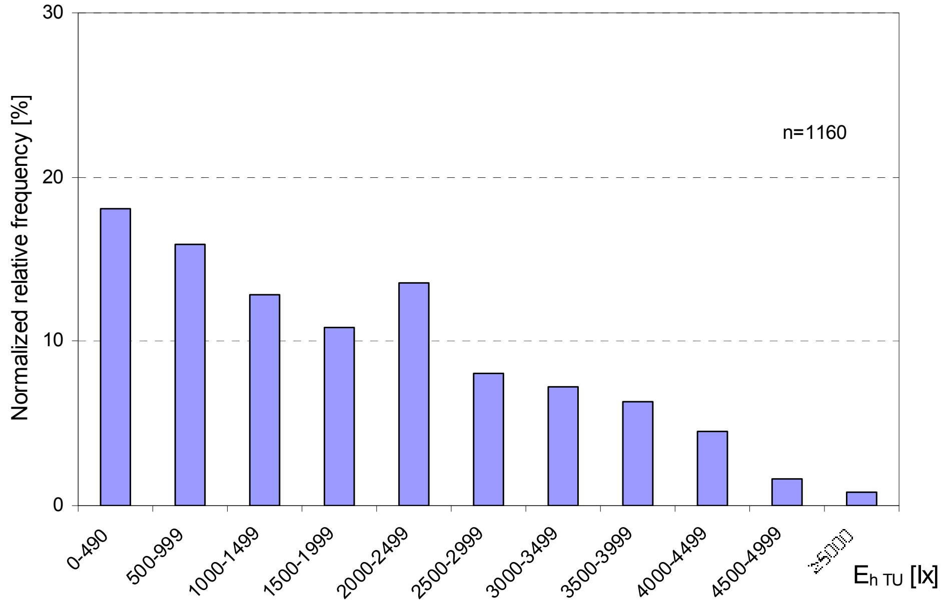

Figure 3-33 Normalized relative frequency of 'switch on' actions (0-500 lx) as a function of external horizontal illuminance, between 06:00 and 17:55 (all shades open)

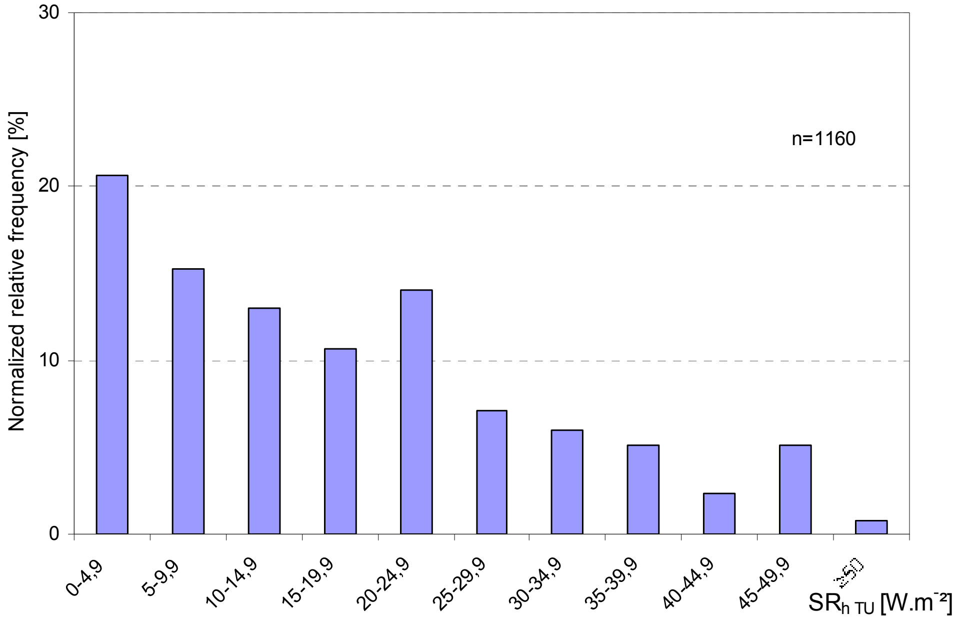

Figure 3-34 Normalized relative frequency of 'switch on' actions (0-500 lx) as a function of horizontal global irradiance, between 06:00 and 17:55 (all shades open)

The outdoor parameters were also related to the 'switch off' actions (500-0 lx). Again the condition of an occupied zone and open shades had to be met (Figure 3-35). Different zone orientation was not considered.

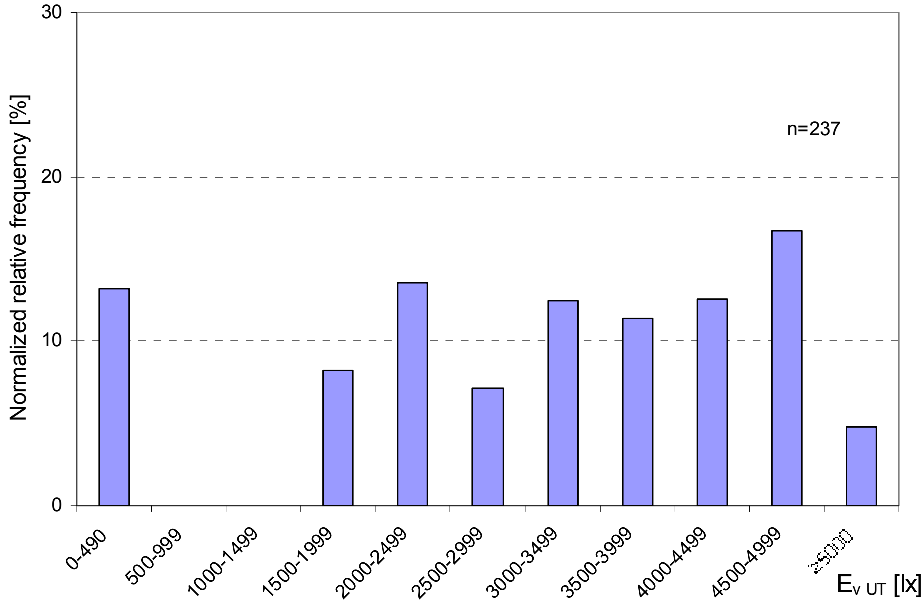

Figure 3-35   Normalized relative frequency of 'switch off' actions (500-0 lx) as a function of vertical illuminance, between 06:00 and 17:55 (all shades open)

Figure 3-36 and Figure 3-37 show the normalized relative frequency of 'switch off' actions (500-0 lx) in relation with external horizontal illuminance ($E_{h\ TU}$) and solar radiation ($SR_{h\ TU}$).

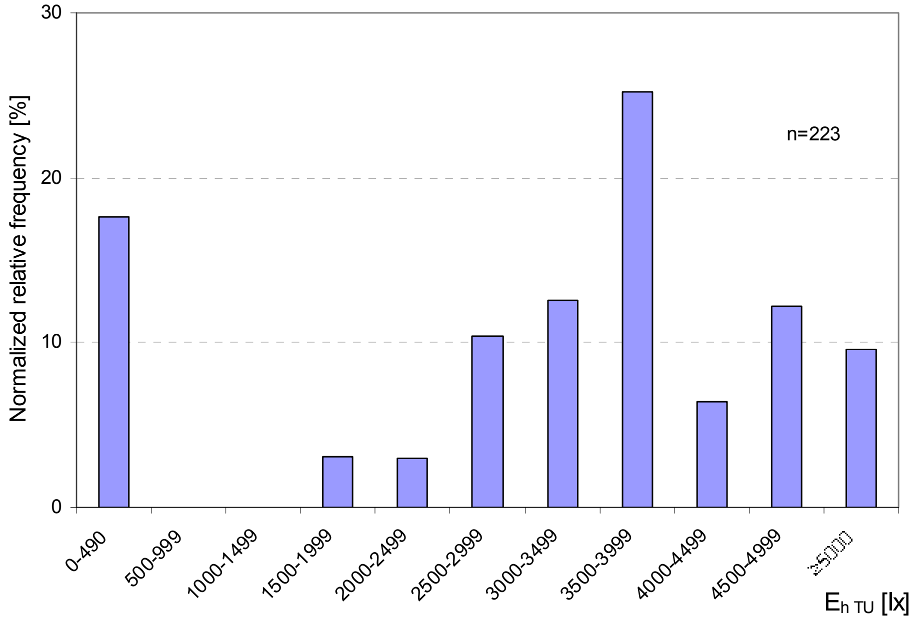

Figure 3-36 Normalized relative frequency of 'switch off' actions (500-0 lx) as a function of external horizontal illuminance, between 06:00 and 17:55 (all shades open)

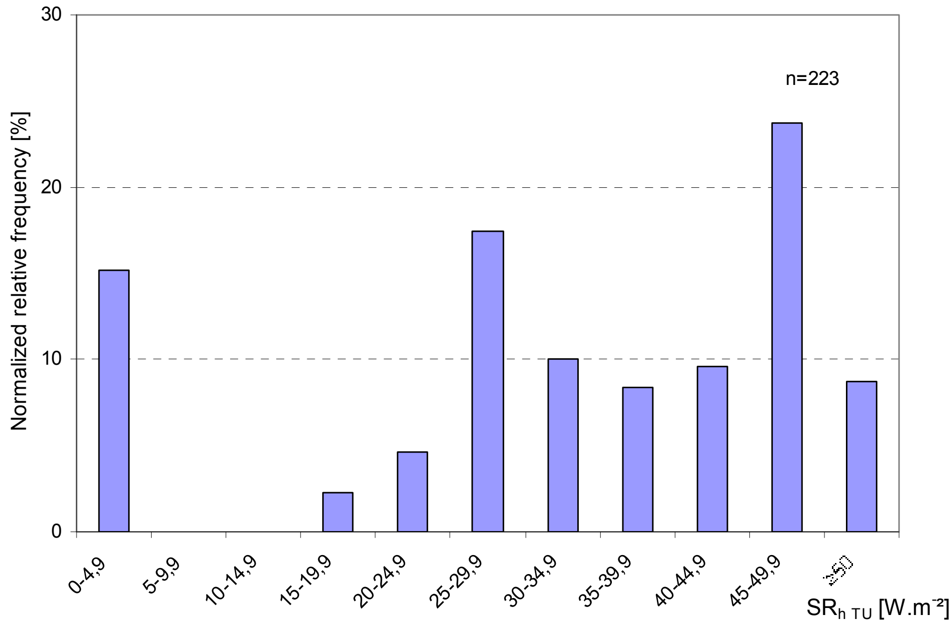

Figure 3-37 Normalized relative frequency of 'switch off' actions (500-0 lx) as a function of horizontal global irradiance, between 06:00 and 17:55 (all shades open)

3.1.4 Lighting - Energy usage

3.1.4.1 Mean lighting load

Similar to section 3.1.2.1 the mean lighting load over the course of a reference day for all intervals in the measurement period and for only occupied intervals, averaged over all observed zones is displayed in W in Figure 3-38.

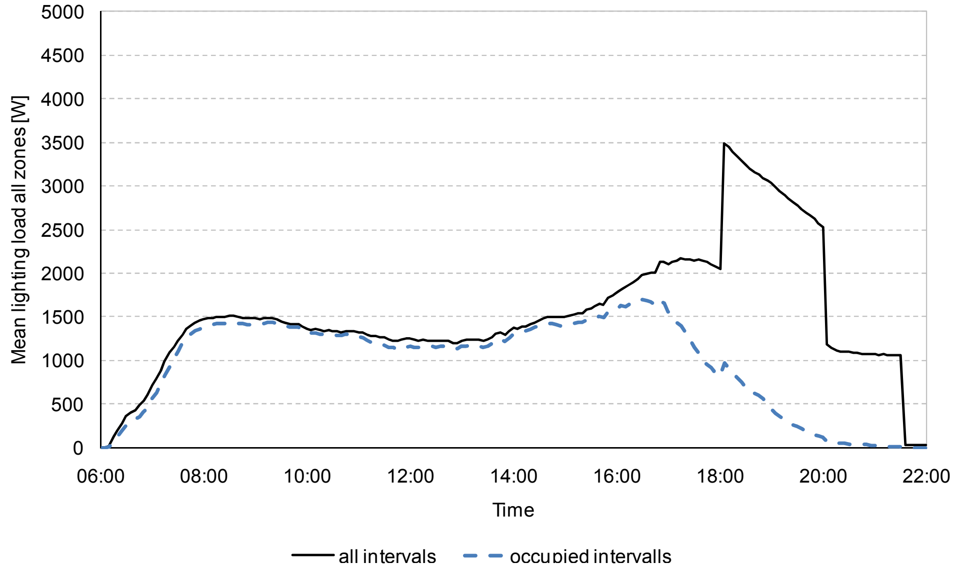

Figure 3-38 Mean lighting load [W] over the course of a reference day for all and for only occupied intervals, averaged over all zones

The energy usage is plotted as the mean lighting load over the course of a reference day for all intervals in the measurement period per m² (Figure 3-39).

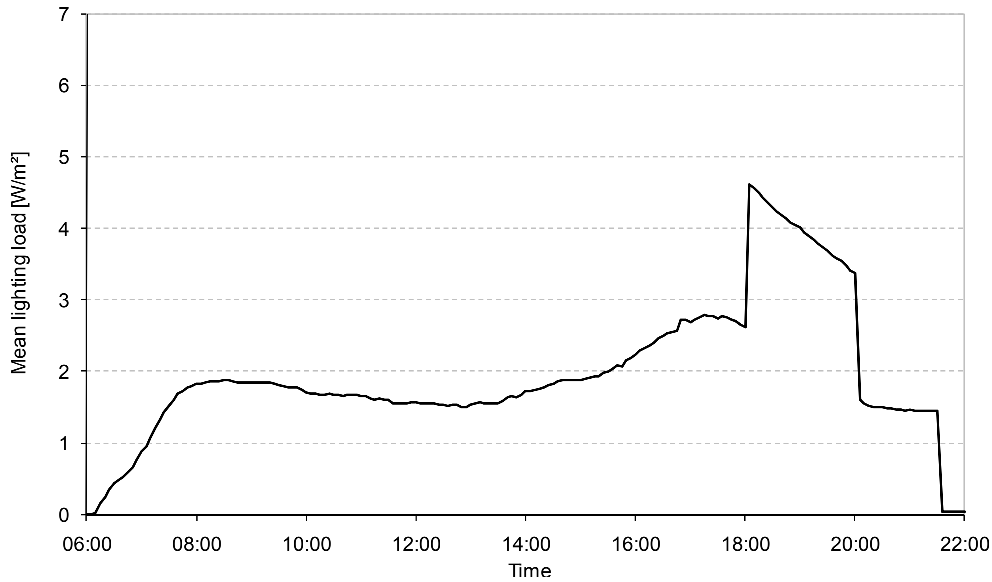

Figure 3-39 Mean lighting load per m² over the course of a reference day for all intervals, averaged over all zones

Analogously the mean lighting load per workplace (Figure 3-40) and per person (Figure 3-41) is shown over the course of a reference day for all intervals in the measurement period.

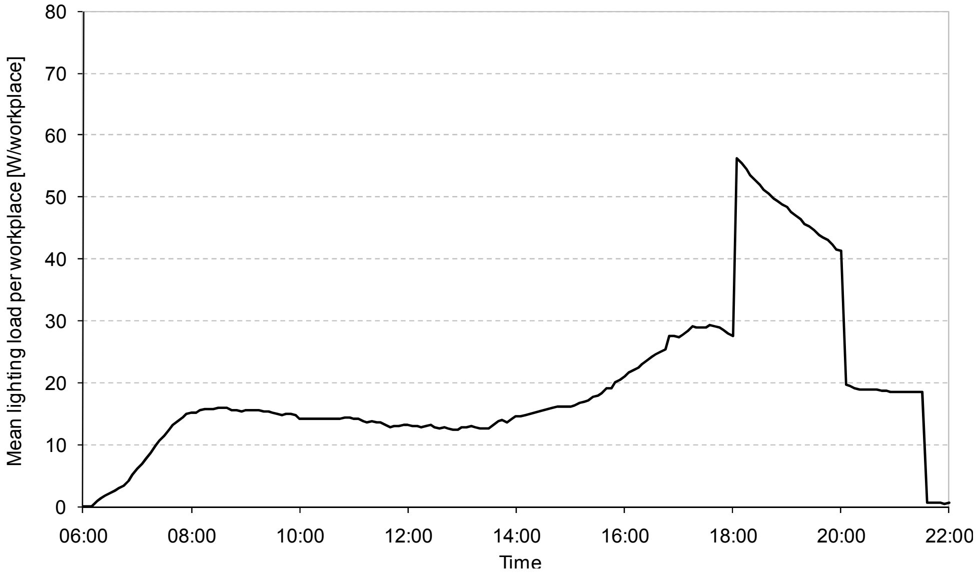

Figure 3-40 Mean lighting load per workplace over the course of a reference day for all intervals, averaged over all zones

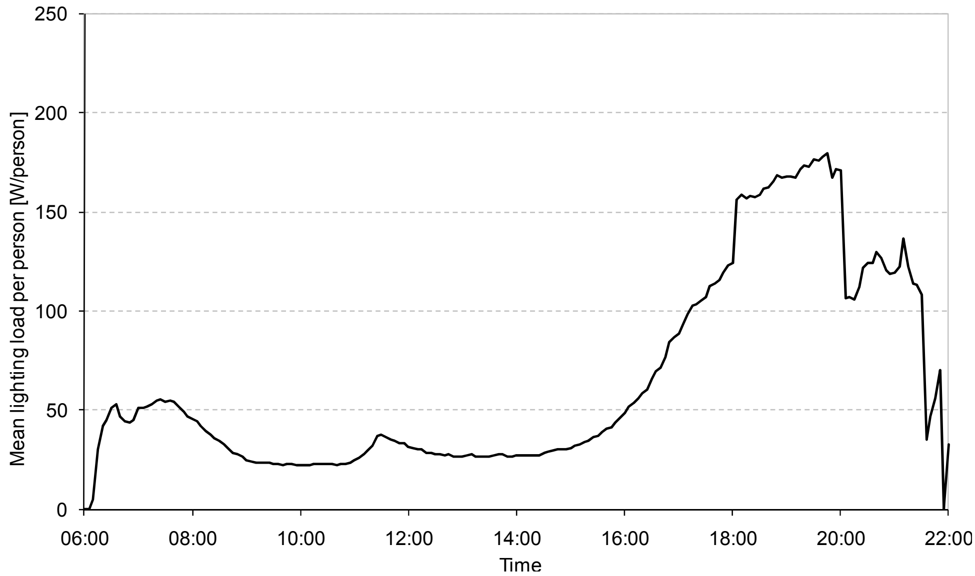

Figure 3-41 Mean lighting load per person over the course of a reference day for all intervals, averaged over all zones

3.1.4.2 Season dependent mean lighting load

The seasonal dependency of the mean lighting load in Watts, Watts per square meter, Watts per workplace and Watts per person is the subject of this section. For the seasons the same data was used as described in 3.1.2.2. Where Figure 3-42 shows the season dependent mean lighting load over the course of a reference day for all intervals, averaged over all zones, the season dependent mean lighting load over the course of a reference day for only occupied intervals, averaged over all zones is depict in Figure 3-43. The autumn values, as mentioned, are not representative (Figure 3-42 to Figure 3-46).

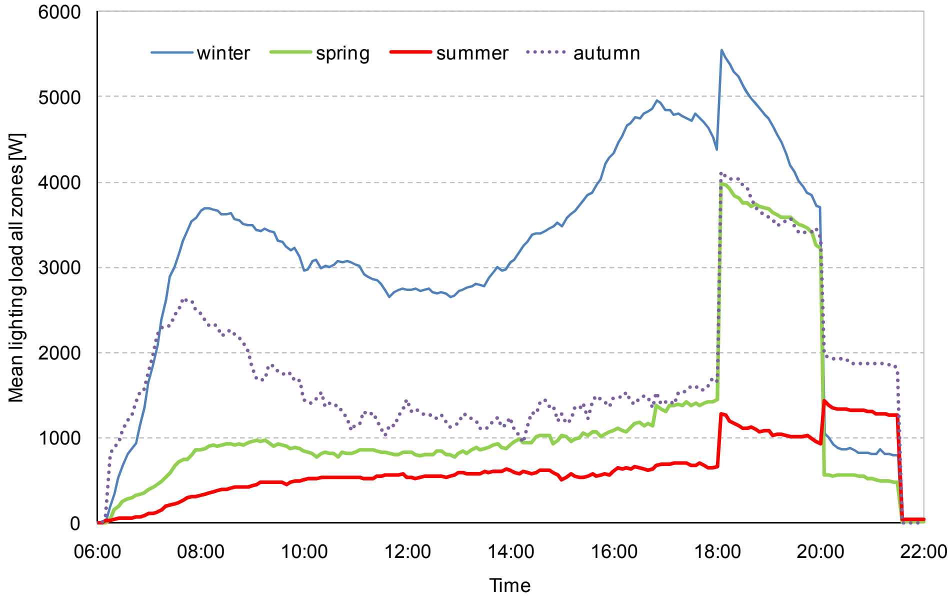

Figure 3-42 Season dependent mean lighting load [W] over the course of a reference day for all intervals, averaged over all zones

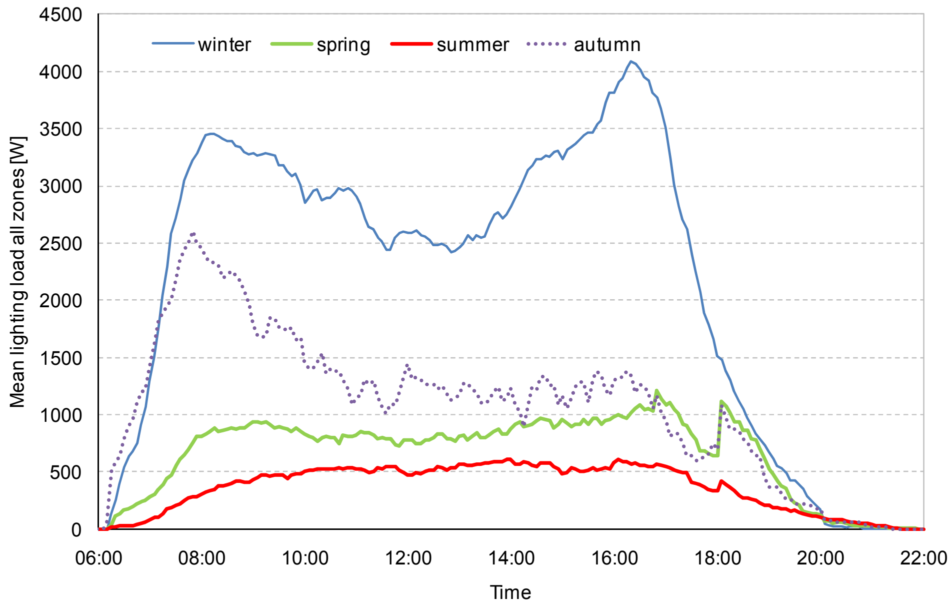

Figure 3-43 Season dependent mean lighting load [W] over the course of a reference day for occupied intervals, averaged over all zones

The energy usage is plotted as the mean lighting load over the course of a reference day for all intervals in the measurement period per m² (Figure 3-44), per workplace (Figure 3-45) and per person (Figure 3-46).

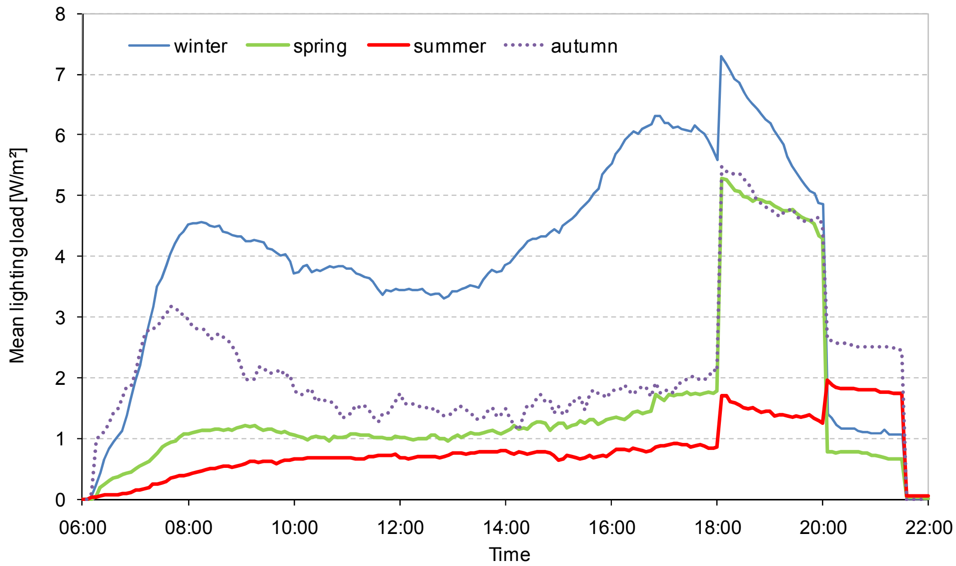

Figure 3-44 Season dependent mean lighting load per m² over the course of a reference day for all intervals, averaged over all zones

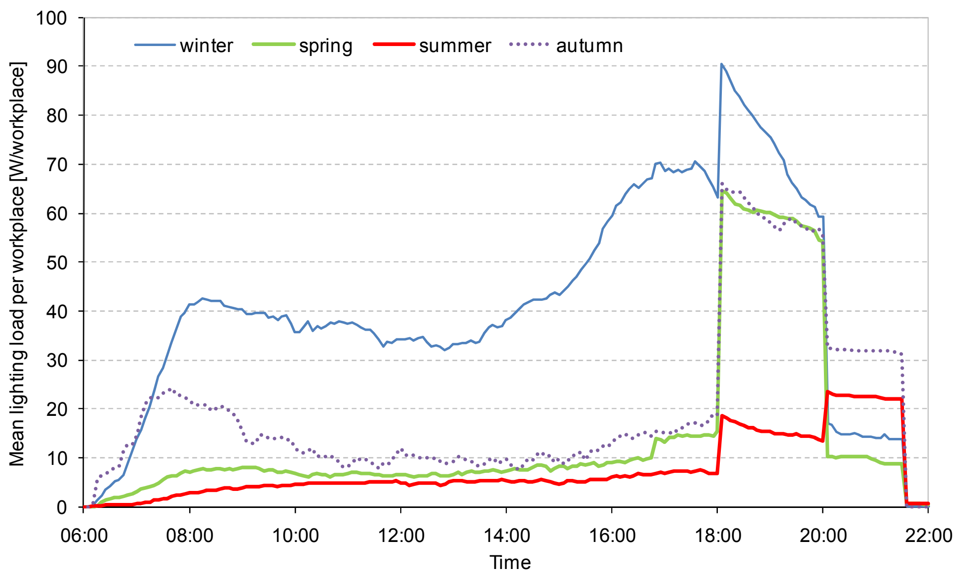

Figure 3-45 Season dependent mean lighting load per workplace over the course of a reference day for all intervals, averaged over all zones

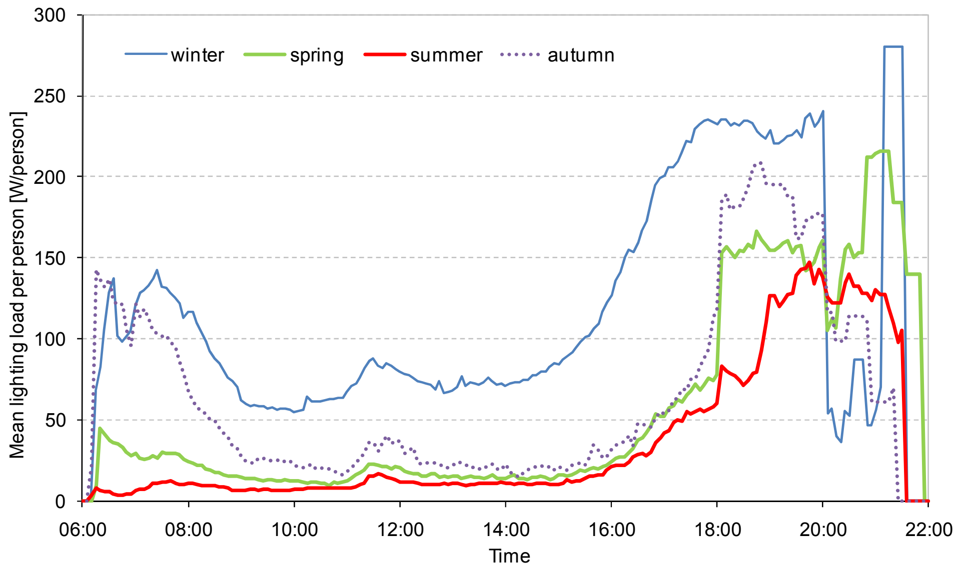

Figure 3-46 Season dependent mean lighting load per person over the course of a reference day for all intervals, averaged over all zones

3.1.4.3 Mean lighting load, occupancy and solar radiation

Over the course of a reference day the mean lighting load of all zones as well as the of single occupancy zones is plotted together with the mean occupancy and the mean solar radiation can be seen in Figure 3-47.

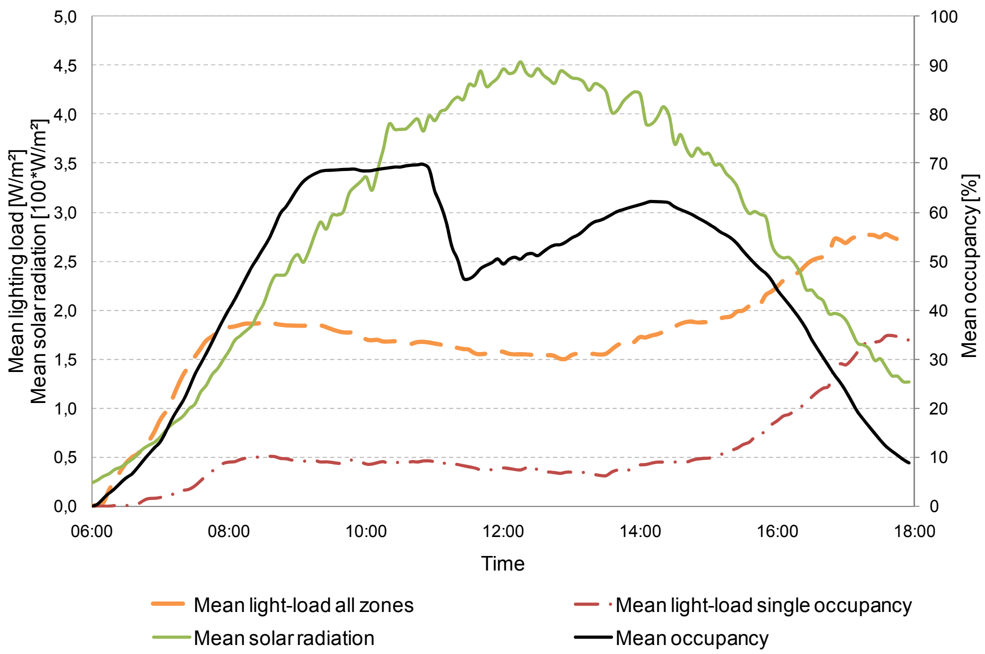

Figure 3-47 Mean lighting load of all and of single occupancy zones only over the course of a reference day for all intervals together with mean solar radiation and mean occupancy

3.1.5 Shades

3.1.5.1 External shades

External shades (venetian blinds) are controlled by the building management system not by the users themselves. They are grouped according to the orientation (8 sectors) and automated due to the external illuminance level measured on top of the building (see section 2.2.1). Shades close (100%) when E_{ext}>35,000 lx is measured for about two minutes and opened (0%) when E_{ext}<25,000 lx is measured for about ten minutes. Because these devices are automated no user patterns could be studied.

3.1.5.2 Internal shades

The user in UT has control over the internal shades (roller blinds) in order to avoid glare. The occupant can apply 0% (fully open), 25%, 80% or 100% closed blinds. There is no delay between the actions of the blinds for two back to back tasks. In Table 3-1 an overview of shading status and actions is given dependent on the deployment of the external venetian blinds. The absolute numbers for each zone are displayed and summed up for each status and action typ. All results fulfil the requirement that the zone was occupied. Because of the above mentioned external illuminance dependent regime for the external blinds, no further analysis concerning the use of internal shades was done.

Table 3-1 Overview of shading status and actions (absolute numbers and frequencies)

		zone occupied / external venitian blinds open (status 0)											zone occupied / external venitian blinds closed (status 1)										
		Status					Actions						Status					Actions					
	A2	B0	B1	B2	B3	B4	C1	C2	C3	D1	D2	D3	B0	B1	B2	B3	B4	C1	C2	C3	D1	D2	D3
	all intervals occ and vb + rb notNaN	venitian blinds open	roller blinds 0%	roller blinds 25%	roller blinds 80%	roller blinds 100%	roller blinds closed to 25%	roller blinds closed to 80%	roller blinds closed to 100%	roller blinds opened to 0%	roller blinds opened to 25%	roller blinds opened to 80%	venitian blinds closed (>90%)	roller blinds 0%	roller blinds 25%	roller blinds 80%	roller blinds 100%	roller blinds closed to 25%	roller blinds closed to 80%	roller blinds closed to 100%	roller blinds opened to 0%	roller blinds opened to 25%	roller blinds opened to 80%
05z03	14320	17988	12034	0	6	479	0	1	25	18	0	0	3889	1666	0	0	98	0	0	6	2	0	0
05z04	19709	23443	16733	0	0	417	0	0	17	14	0	0	4838	2504	0	0	6	0	0	2	0	0	0
05z05	15357	16338	12180	0	0	931	0	0	34	18	0	0	2929	1724	1	0	224	1	0	9	2	0	0
05z08	6015	9243	5450	0	0	0	0	0	0	0	0	0	86	7	0	0	0	0	0	0	1	0	0
05z09	15785	20357	14585	0	31	266	0	0	9	7	0	1	1266	688	0	0	1	0	0	0	1	0	0
05z15	7367	7219	5137	72	131	46	0	4	3	3	1	0	1881	1138	63	47	0	0	0	0	2	0	0
05z16	14545	10608	6901	0	16	1779	0	1	61	49	0	0	5636	2580	0	0	997	0	0	1	17	0	0
11z07	9062	10165	6872	0	16	54	0	3	0	3	0	0	1293	1166	0	1	3	0	0	0	0	0	0
11z08	10936	12077	8654	0	385	12	0	5	5	7	0	0	445	445	0	0	0	0	0	0	0	0	0
11z15	20459	13006	12025	1	122	737	1	11	48	26	0	3	5425	5211	0	7	143	0	0	1	18	0	0
11z16	8178	4454	4181	0	1	92	0	1	2	4	0	0	2951	2505	0	0	67	0	0	0	1	0	0
14z03	13901	19719	12467	2	12	222	1	1	12	16	0	0	3038	1142	0	0	23	0	0	3	1	0	0
14z07	4925	8242	4162	1	22	19	1	0	0	3	0	0	884	270	0	0	0	0	0	0	0	0	0
14z08	8417	14100	7329	1	23	1	1	0	0	3	0	0	1044	126	0	0	0	0	0	0	0	0	0
14z15	4031	4876	2508	0	2	235	0	0	5	6	0	0	2005	731	0	5	65	0	0	0	2	0	0
16z10	5576	7972	4768	0	0	205	0	0	1	1	0	0	630	471	0	0	124	0	0	0	0	0	0
17z03	22801	20523	18481	3	65	348	1	3	24	28	0	7	4288	3828	0	0	0	0	0	1	0	0	0
17z04	17751	16448	14336	3	20	513	1	2	24	19	0	0	3122	2795	0	3	21	0	1	1	0	0	0
17z05	22939	20158	17779	424	2	632	1	1	26	19	1	0	4162	3676	310	0	35	0	0	3	1	0	0
17z06	21305	19225	17204	3	0	538	1	0	23	22	0	0	3886	3435	0	0	56	0	0	6	0	0	0
17z07	10349	10852	7942	3	0	1	1	0	1	1	0	0	1499	1373	0	0	0	0	0	0	0	0	0
17z08	7546	8349	5773	3	0	83	1	0	0	1	0	0	524	489	0	0	0	0	0	0	0	0	0
17z09	14879	16596	11687	3	6	42	1	1	5	5	0	0	3258	3041	0	22	42	0	0	0	4	0	0
17z11	20467	15540	14307	3	63	397	1	3	27	12	0	0	3871	3593	0	0	106	0	0	1	7	0	0
17z12	19671	14595	13513	3	44	459	1	4	43	32	0	0	5783	5289	1	25	274	0	0	1	16	0	0
17z15	9314	6278	5534	3	25	56	1	3	1	3	0	0	2888	2516	0	15	50	0	0	0	0	0	0
absolute	345605	348371	**262542**	**528**	**992**	**8564**	14	44	396	320	2	11	71521	**52409**	**375**	**125**	**2335**	1	1	35	75	0	0
percentage	**100%**		**76%**	**0%**	**0%**	**2%**								**15%**	**0%**	**0%**	**1%**						

3.2 VC, ET, FH & HB

3.2.1 Occupancy

Analogue to UT (Figure 3-4) the hourly mean occupancy level over the course of a reference day averaged over all observed workstations and the corresponding standard deviations were calculated and presented in Figure 3-48, Figure 3-49, Figure 3-50 and Figure 3-51 for VC, ET, FH and HB.

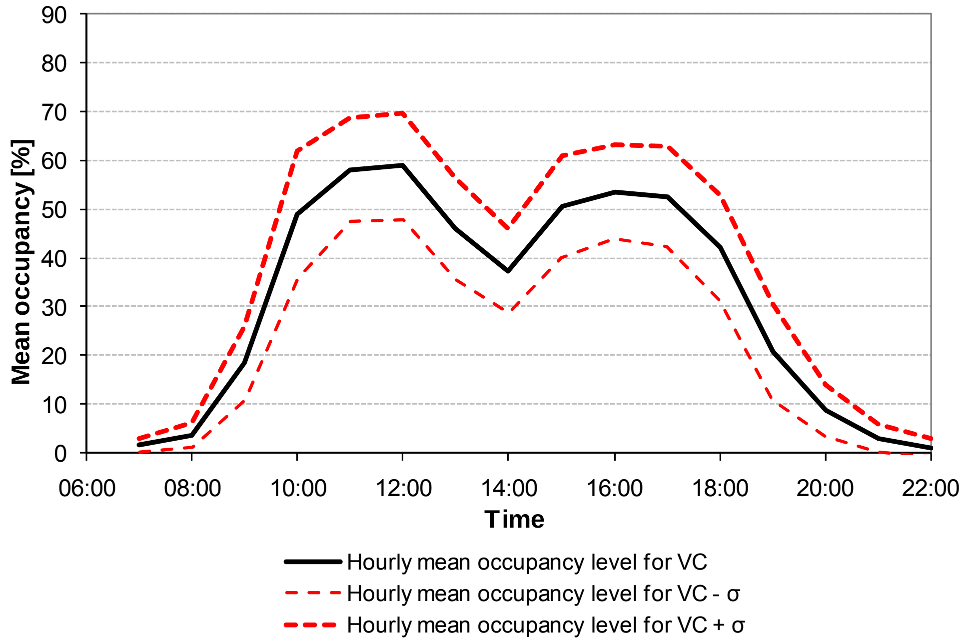

Figure 3-48 Hourly mean occupancy level and standard deviation for VC

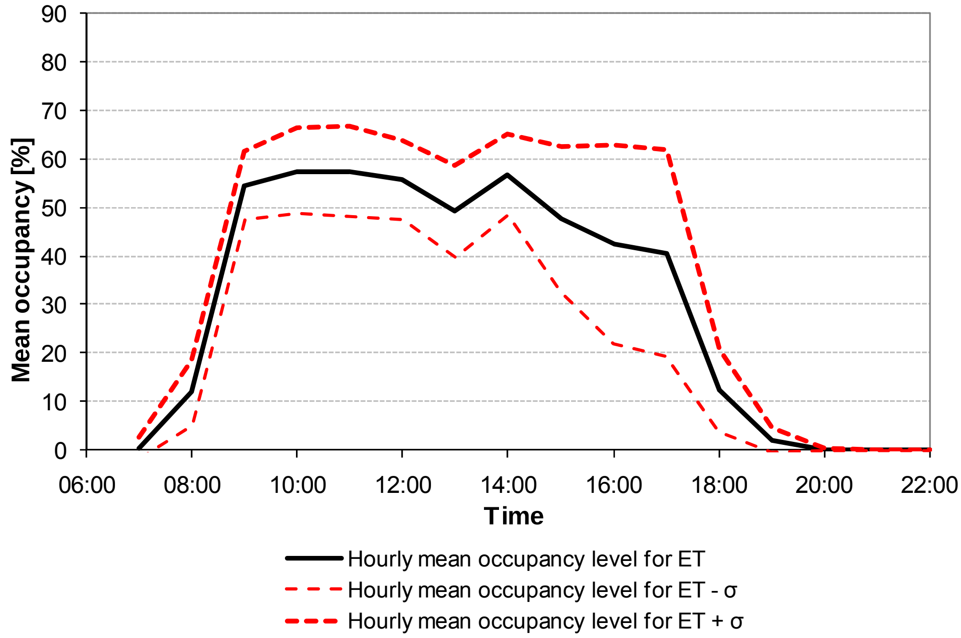

Figure 3-49 Hourly mean occupancy level and standard deviation for ET

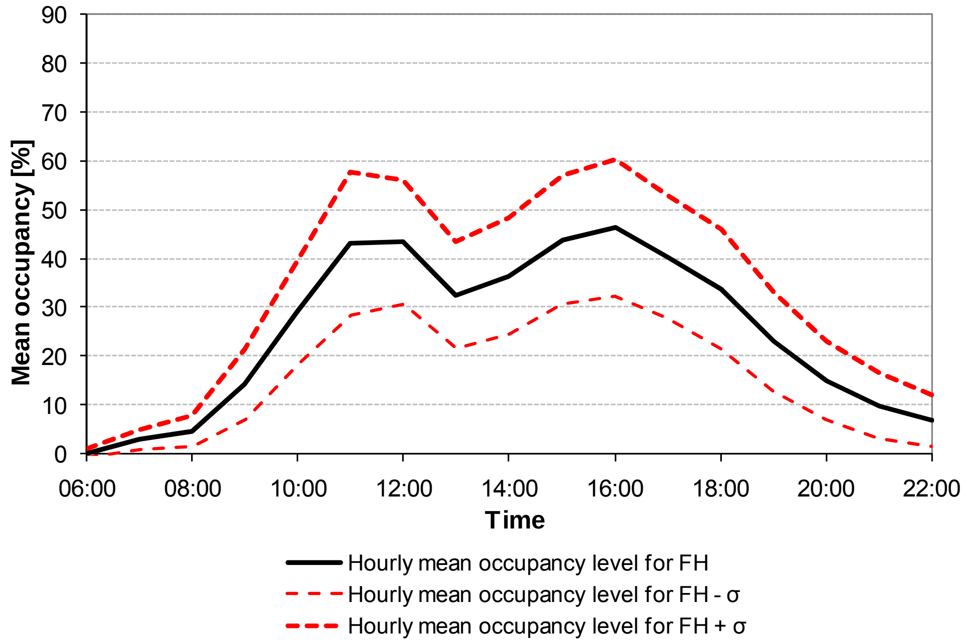

Figure 3-50 Hourly mean occupancy level and standard deviation for FH

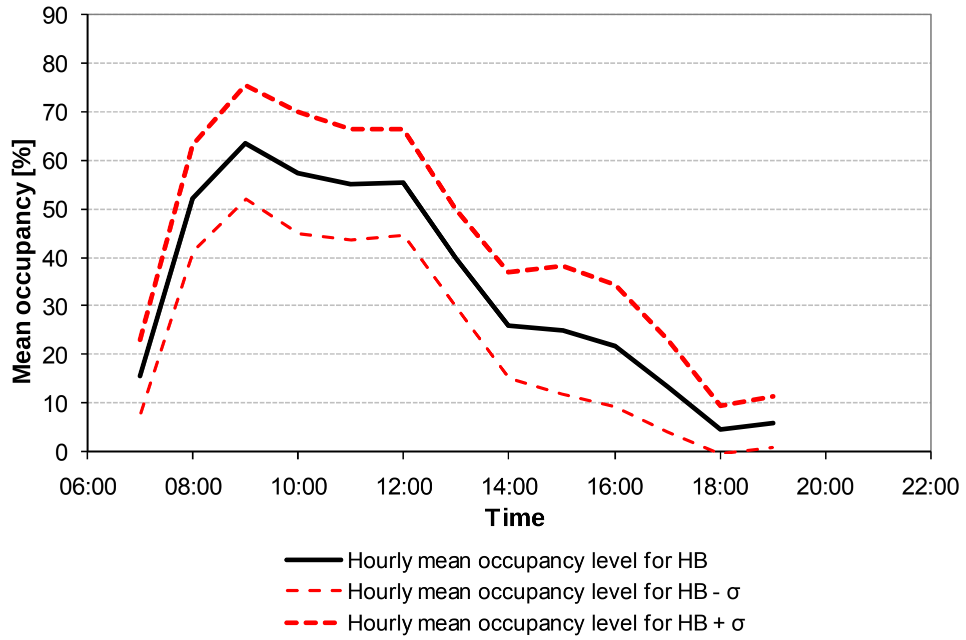

Figure 3-51 Hourly mean occupancy level and standard deviation for HB

As already mentioned the hourly mean was calculated as required by most simulation applications. The average of twelve 5' values for the hour displayed at the end of the time interval (e.g.: the average of the values from 06:05 to 07:00 is plotted at 07:00).

3.2.2 Lighting

3.2.2.1 Switch on actions

The 'switch on' at arrival probability plotted against illuminance on table in bins was already presented in previous publications. In the attempt to use probit analysis to find a function to describe this pattern, it was found that the data for VC, FH and HB had to be processed in a slightly different manner. The definitions to find these actions in the huge dataset were changed to avoid errors and misinterpretations of 'switch on' at arrival actions. In particular adoptions have been made for the HB because the raw data showed synchronisation inaccuracies. In FH the data of only three rooms (451, 454 and 465) with 7 occupants could be used due to a sensor setup failure. These changes are the main reason, why the results look different to prior publications. Figure 3-52 shows the 'switch on' at arrival probability plotted against illuminance on table (in 50 lx bins) for VC-N, VC-S, FH and HB. VCN and VC-S were considered separated in this context because of the different orientations of the façade.

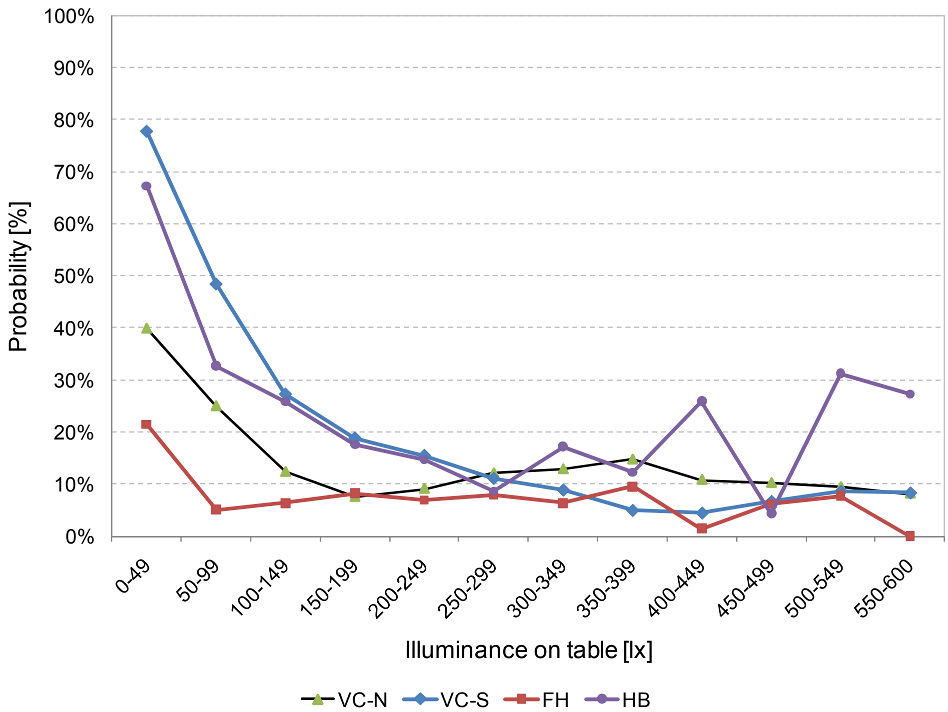

Figure 3-52 'Switch on' at arrival probability plotted against illuminance on table (in 50 lx bins) for VC-N, VC-S, FH and HB

The new derived raw dataset (action and illuminance) was then grouped for every building sorted from the smallest to the largest pertaining illuminance on table value and analogous to Hunt and Reinhart. Hunt grouped 9 events together. Reinhart used groups of 30 events. For the larger amount of data in this study, groups of 100 events fitted best. The switch on probability was calculated for each group. The resulting data were fitted to Hunt's adapted probit function (Equation 2):

$$f(x) = a + \frac{c}{(1 + exp(-b * (log_{10}(x) - m)))} \qquad \textit{Equation 2}$$

In Figure 3-53 to Figure 3-56 the 'switch on' at arrival probability plotted against illuminance on table (in groups of 100 events) and the corresponding adapted probit function for VC-N, VC-S, FH and HB is shown. In Table 3-2 the fitting parameters for the probit functions are displayed. The ranges for the parameters were set infinite. The functions were forced through *x=0* and *y=1*.

Table 3-2 Fitting parameters for VC-N, VC-S, FH and HB

	a	b	c	m
VC-N	0.08553	-3.137	0.9144	1.25
VC-S	0.04159	-4.119	0.9575	1.828
FH	0.05403	-3.5	0.9459	0.7273
HB	0.1921	-3.61	0.8086	1.38

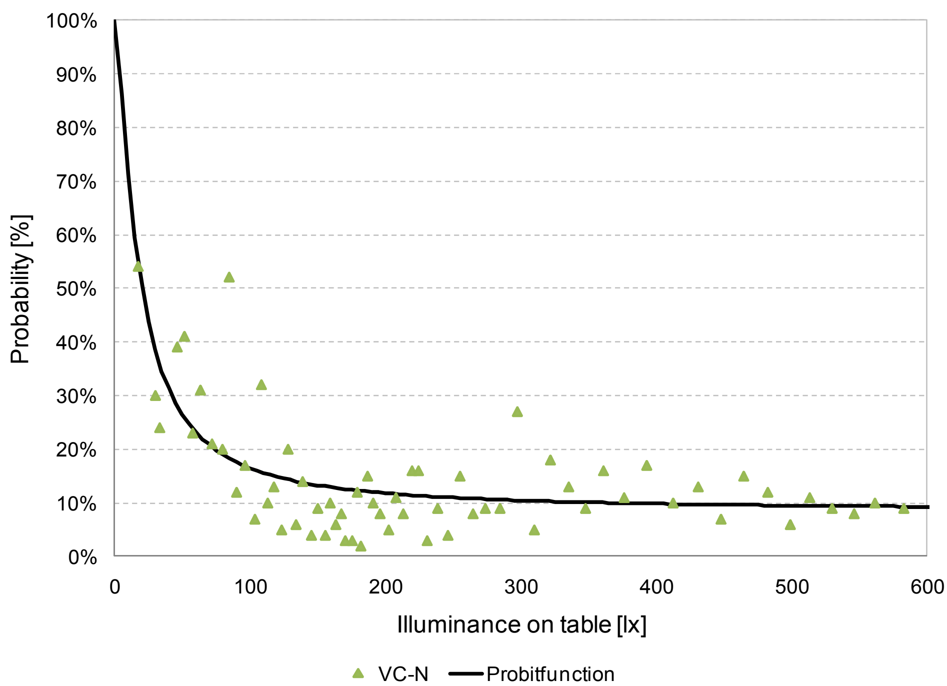

Figure 3-53 'Switch on' at arrival probability plotted against illuminance (groups of 100 events) and the corresponding adapted probit function for VC-N

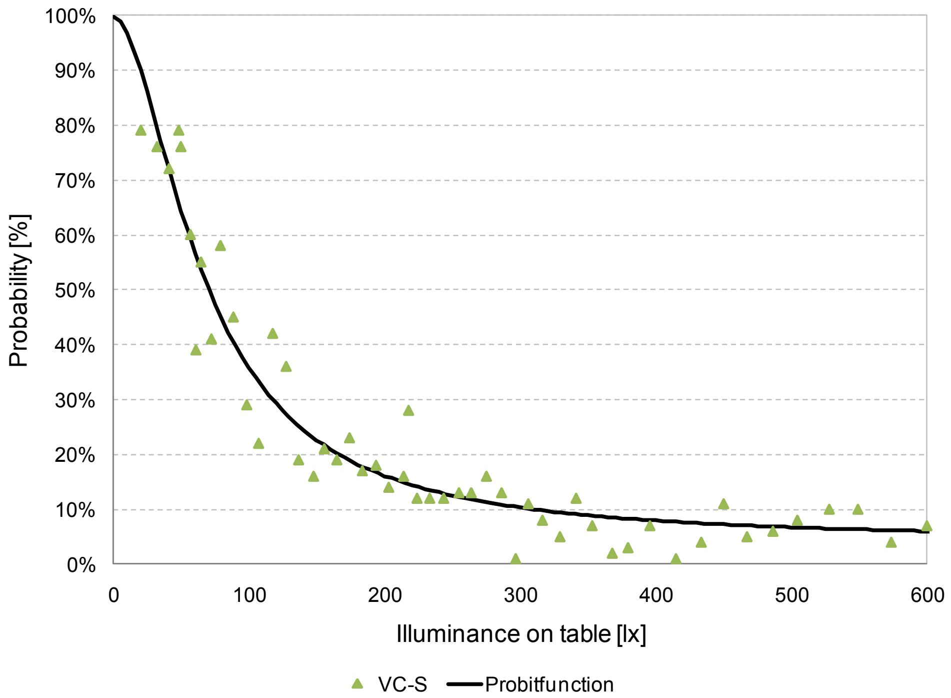

Figure 3-54 *'Switch on' at arrival probability plotted against illuminance (groups of 100 events) and the corresponding adapted probit function for VC-S*

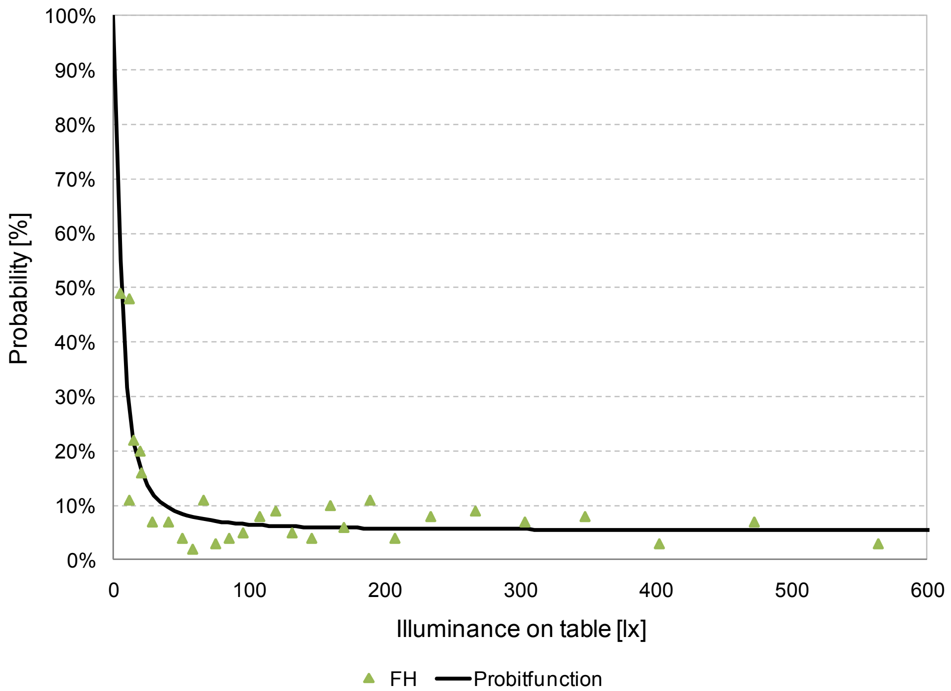

Figure 3-55 *'Switch on' at arrival probability plotted against illuminance (groups of 100 events) and the corresponding adapted probit function for FH*

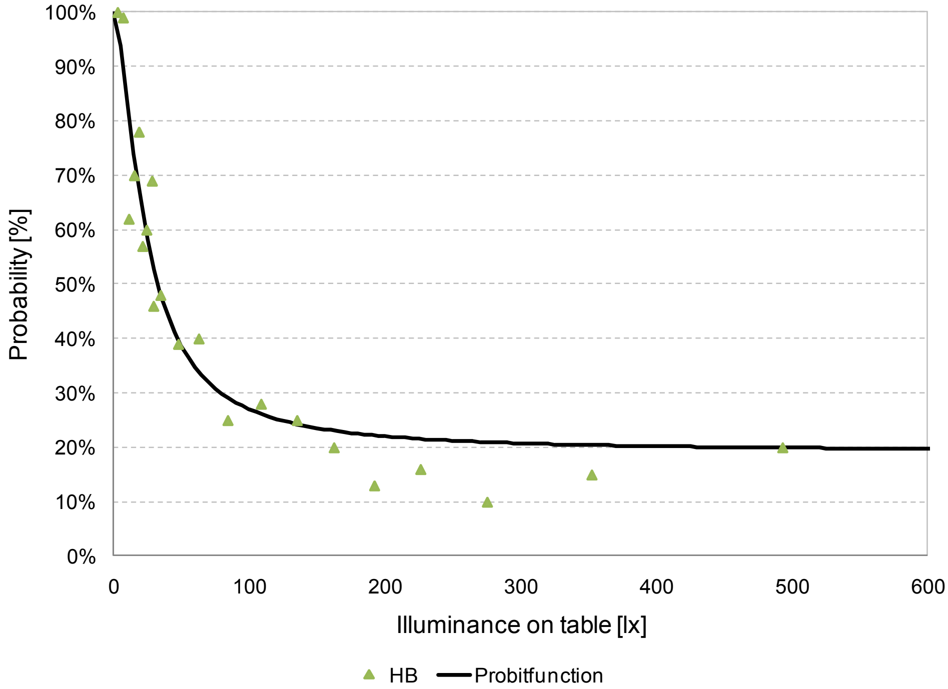

Figure 3-56 *'Switch on' at arrival probability plotted against illuminance (groups of 100 events) and the corresponding adapted probit function for HB*

In Figure 3-57 all resulting probit functions for the 'switch on' at arrival probability for VC-N, VC-S, FH and HB are plotted together in one graph.

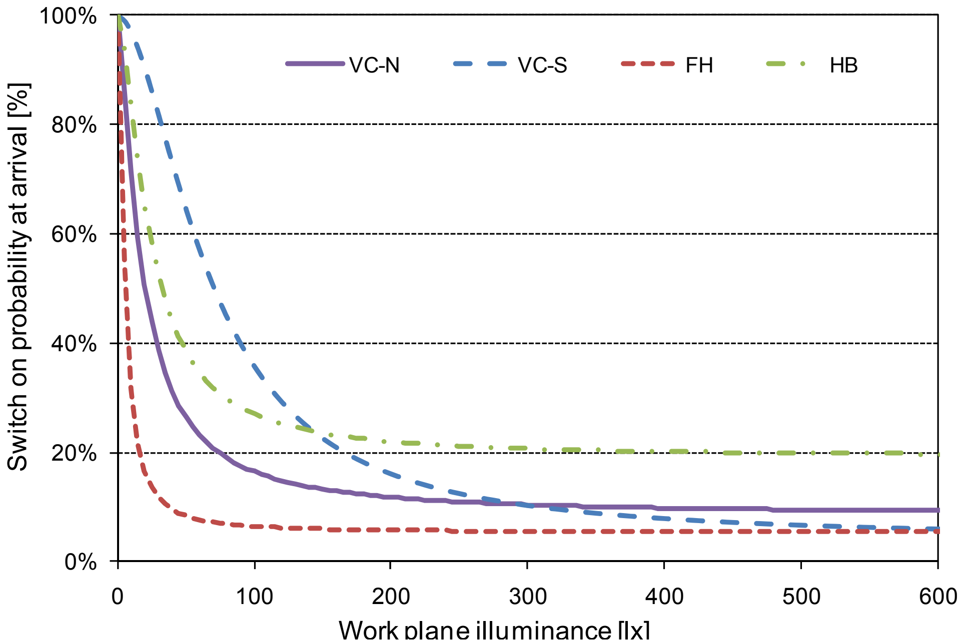

Figure 3-57 *The probit functions for the 'switch on' at arrival probability for VC-N, VC-S, FH and HB*

3.2.2.2 Switch off actions

The switch off lights probability as a function of the duration of absence was already presented in the Final Report (Mahdavi et al. 2007). Due to more strict calculation rules this probabilities slightly changed. The results are presented in Figure 3-58 for VC, FH and HB. The reason for recalculating was to avoid data inconsistencies to influence the results. In some rare cases the synchronization of the illuminance (Hobo U12-012) and the occupancy (IT-200) sensor, which measures lights on/off as well, was not correct. In changing the formulas to detect the actions this errors could be eliminated.

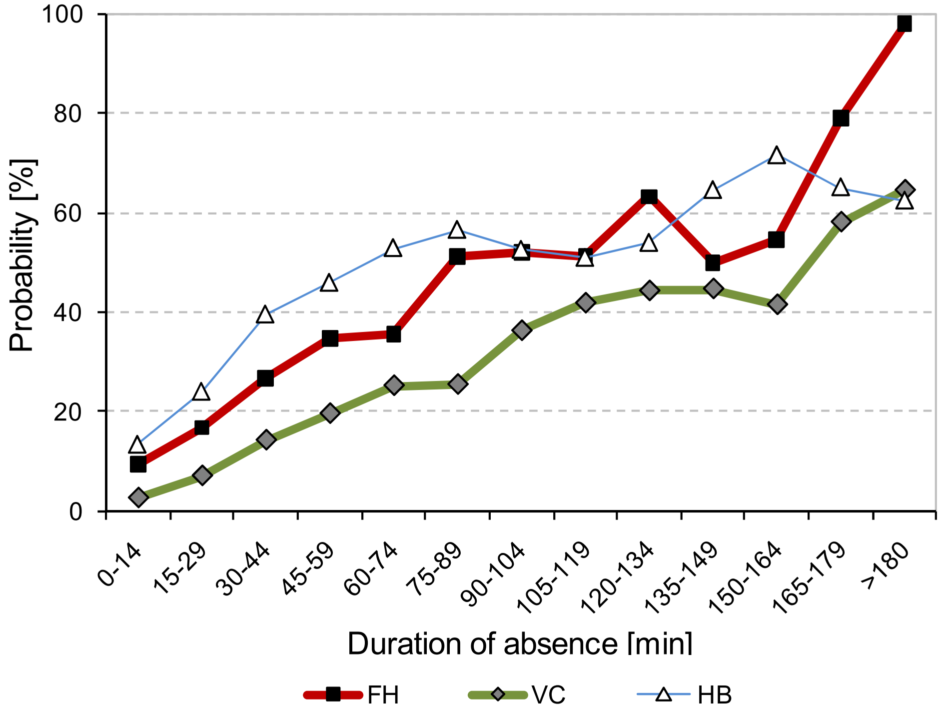

Figure 3-58 Probability of switching the lights off s a function of the duration of absence from the workstation in VC, FH and HB

4 Discussion

The research project ‘People as Power Plant’ was a long term field study and generated an extensive amount of data. Especially the data collection for UT was a challenge in it self. The goal for all five buildings was to gather objective and subjective data and to do the same analyses for each building to be able to compare and combine at the end. As mentioned not all investigations could be done everywhere because of the differences between the building. However data analysis provided a number of notable results and some of those are presented in this section.

4.1 Occupancy

Occupancy patterns of individual people can vary on a daily basis (Mahdavi et al. 2008). Of course the occupancy pattern between people varies as well as Figure 3-3 exemplarily showed for the users of two zones in UT. Zone wise again a vast difference of patterns can be found (Figure 3-5).

Grouping of the zones in terms of the number of occupants as done in Figure 3-6 for UT seams to portray patterns which can be interpreted in a way that people of multi occupancy office rooms (in most cases ‘normal employees’) compared to people in single occupancy rooms (where management is located) tend to arrive earlier in the morning. These multi occupancy zones have a higher percentage of mean occupancy (up to 70% in UT), while single or double occupancy zones have significant lower occupancy means (up to 60% in UT). A possible reason for this might be that people working on management level spend more time in meetings and are therefore not present at the workplace. The users in single occupancy zones furthermore left their workplaces later than others.

The mean occupancy levels of all buildings show remarkable differences over the course of a reference day (averaged over the entire observation period) as Figure 4-1 depicts. The mean occupancy level for HB for example is in the early morning already higher than in other buildings and declines rapidly after lunchtime because the building houses the district commission, specifically the department of planning and building inspection. In the morning there are hours open to public followed by work in the field in the afternoon. The mean occupancy levels in FH are not that high compared to others because offices of university teachers, who do not all of their work in their offices have been monitored.

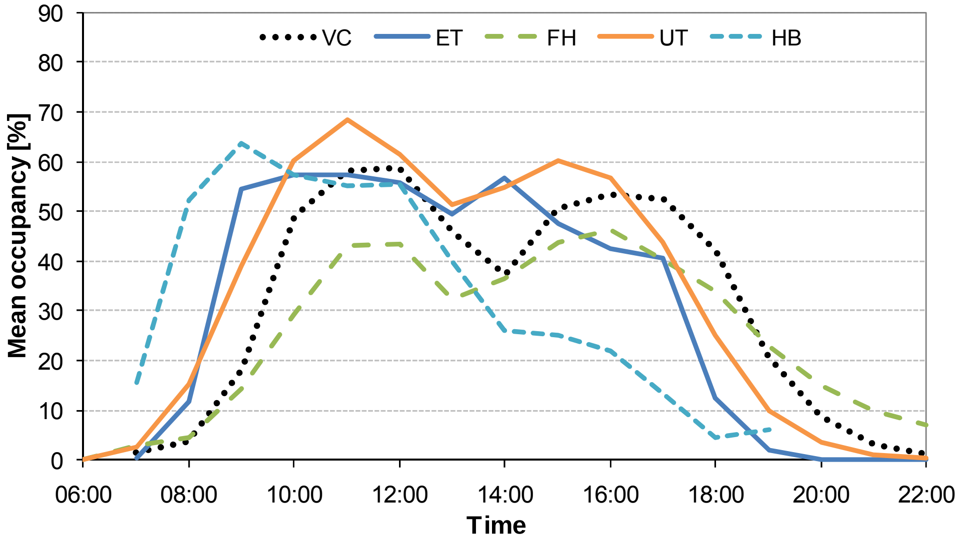

Figure 4-1 Mean occupancy over the course of a reference day for VC, FH, ET, UT and HB

The use of software agents might be one winning strategy to generate a more realistic, probabilistic scenario in simulation (Mohammadi 2007). Nonetheless out of the mean occupancy levels shown above a generic model of occupancy could be derived (Figure 4-2).

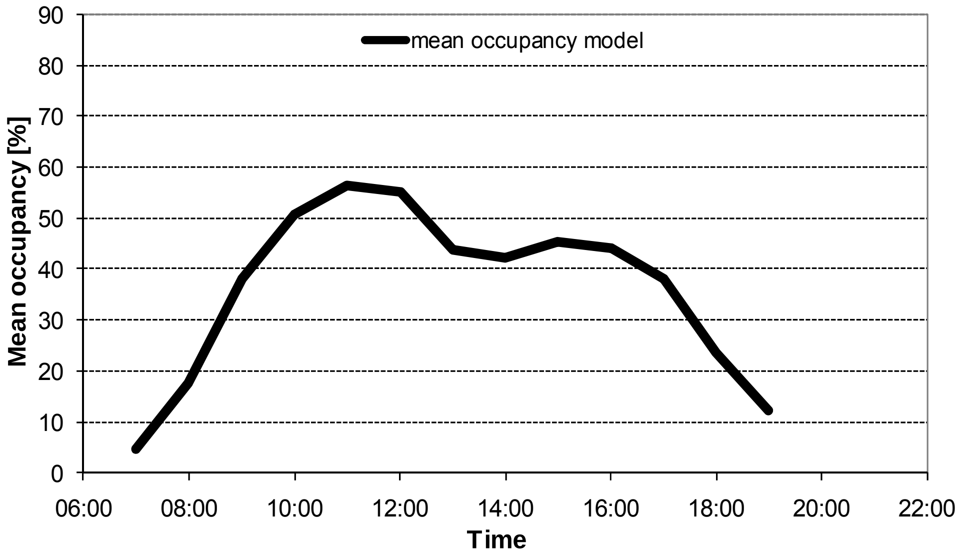

Figure 4-2 Generic model of occupancy, averaged over VC, ET, FH, UT and HB

Given the above mentioned differences it seems wise to calculate not only (hourly) mean occupancy levels (for one building) but also to derive the standard deviation range in addition, to provide a statistically relevant sense of fluctuations. This was done in Figure 3-4, Figure 3-48, Figure 3-49, Figure 3-50 and Figure 3-51 for all buildings. For UT the combination of the derived generic model and the hourly mean occupancy level and the respective standard deviation range is presented in Figure 4-3. For the other buildings this comparison can be seen in the appendix (section 9.16).

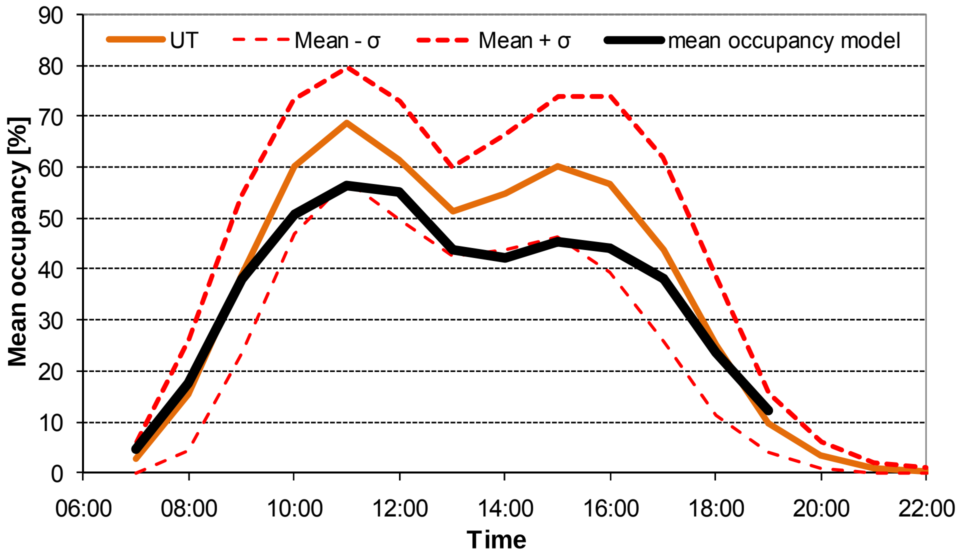

Figure 4-3 *Generic model of occupancy, averaged over all buildings compared with the hourly mean occupancy level and standard deviation for UT*

The above described existence of deviations expressly underlines the importance of a large set of empirically-derived occupancy (and light use) patterns to be able to distinguish typologically and functionally aspects while arranging simulation input data.

Although the mean occupancy levels of all buildings are slightly different from previous publications (due to different, stricter calculation rules) the following statement out of the final report of the research project "People as Power Plant" is still valid:

Such a model can be used as reference information for simulation studies of office buildings in Austria in terms of corresponding hourly schedules. Such simulations can be used, for example, to explore the impact of thermal improvement measures on the building's energy use. Note that our derived general occupancy model for offices in Austria reveals a considerable non-occupancy fraction. This implies a major energy saving potential given the availability of environmental control systems with high resolution degree (e.g. micro-zoning capability). In other words, our observations suggest that the environment systems in a considerable number of office buildings may in fact be 'over-designed', in a sense that they are dimensioned for occupancy levels that seldom occur (Mahdavi et al. 2007).

Out of the mean occupancy levels of the buildings consequently the referring people load can be derived. This can be done using the mean occupancy density (in people per square meter) multiplied with the estimated people load (heat transfer rate of human body, see Figure 4-4). Because people load is dependent on activity level (metabolic rate) and operative temperature (which can in addition be divided into sensible and latent heat transfer), it was chosen to calculate the mean occupancy density first and to analyse these patterns (Figure 4-5). Table 3-2 contains the parameters to calculate the occupancy density of the observed buildings in people per square meter.

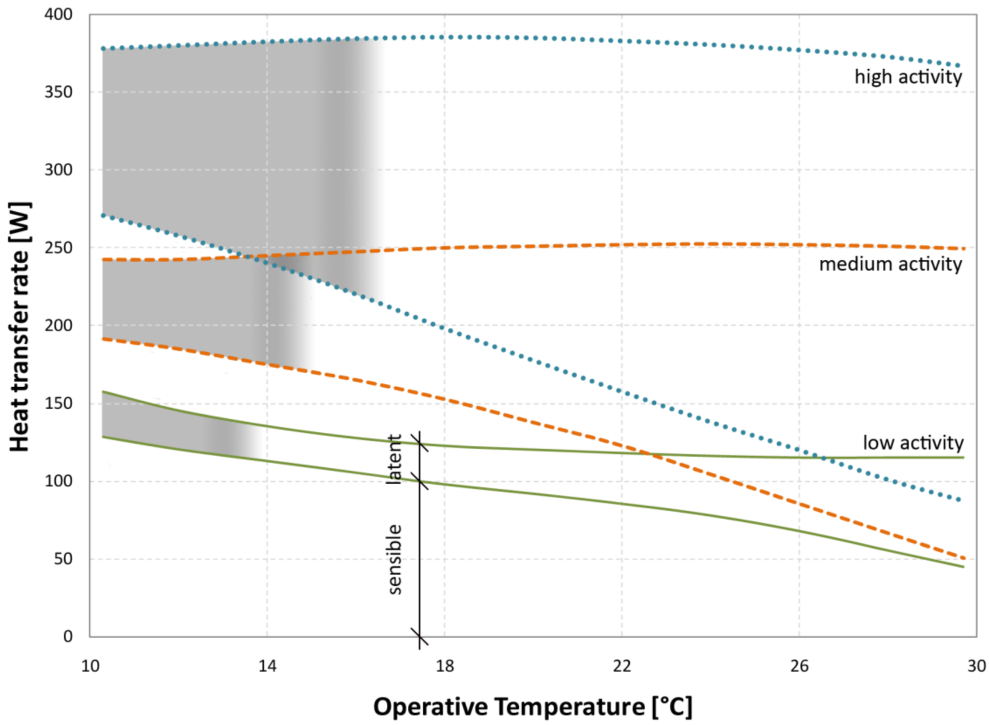

Figure 4-4 Heat transfer rate of human body as a function of activity and the ambient (operative) temperature (adapted from Rietschel & Raiß 1968)

Table 4-1 Parameters for occupancy density calculation

	people	m²	people·m⁻²
VC	29	448	0.065
ET	18	182	0.099
FH	17	236	0.072
UT	89	745	0.119
HB	10	149	0.067

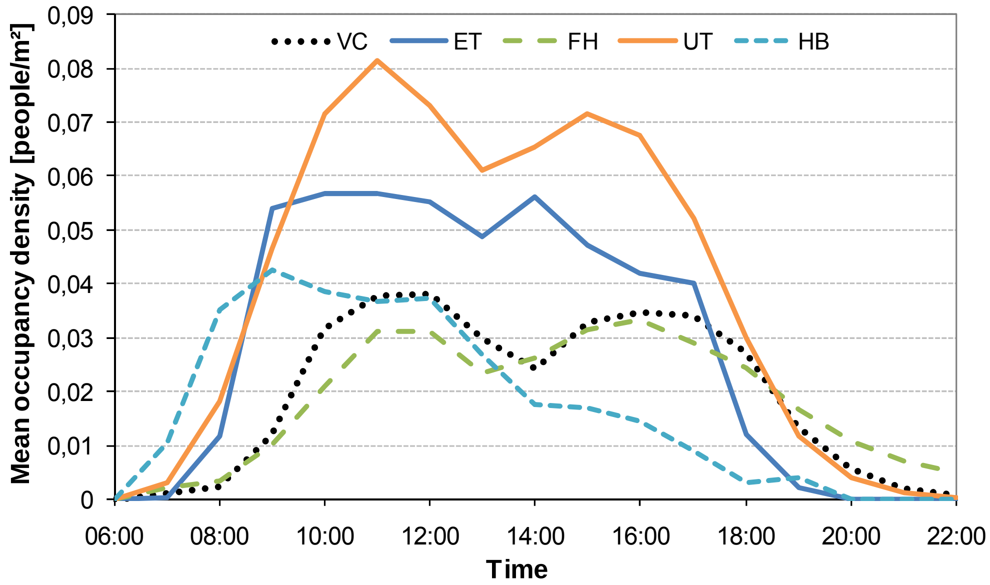

Figure 4-5 Mean occupancy density level over the course of a reference day for VC, ET, FH, UT and HB

Due to the different density the resulting graph (Figure 4-5) looks completely different compared to Figure 4-1. This fact undermines the derivation of a generic people load model. For simulation purposes it is possible to calculate the people load out of a generic occupancy model as long the density of occupancy is known.

A generic people load model over the course of a reference day for all observed buildings was generated using the mean density (0.0844 people/m^2) and 100 W as input value for the heat transfer rate.

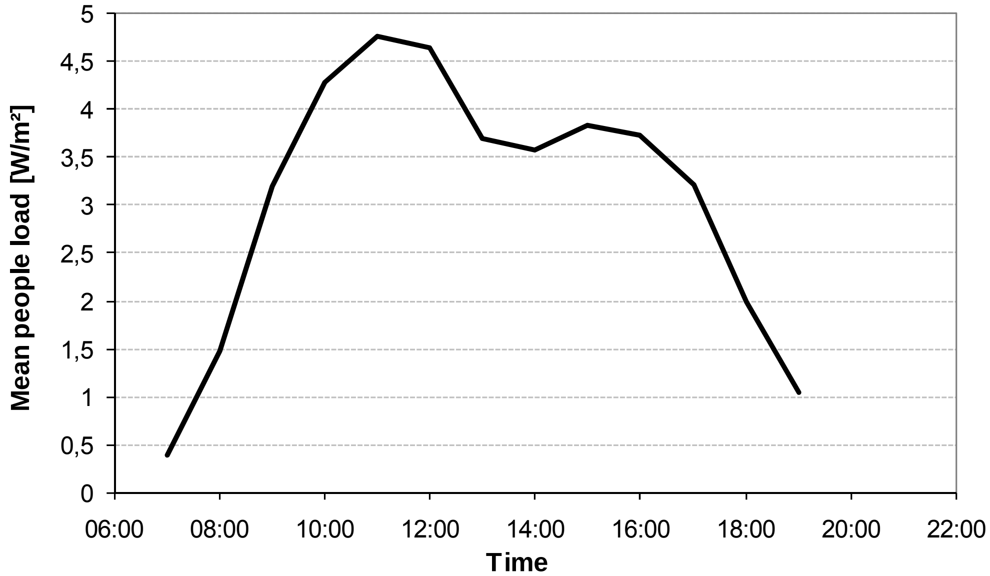

Figure 4-6 Generic people load model over the course of a reference day for all observed buildings

4.2 Lighting

4.2.1 Lighting - Status

The mean lighting load presented in Figure 3-7 for all and occupied intervals testifies that lights are turned off when the zone is not occupied in the overwhelming majority of cases till 16:00. The automated regime to turn the lights on to achieve a unified external view of the façade in the afternoon has a high effect on the energy demand for lighting as it can be seen in Figure 3-8 and Figure 3-9. Although leaving the lights on at the end of the workday (after 16:00) was observed, the energy demand due to this is small because the lights are turned off automatically after 30 minutes and minor (Figure 3-10) compared with the automated regime.

The seasonal dependencies of lighting loads are pointed out in Figure 3-11 and Figure 3-12. The light used is up to seven times higher in winter compared to the summer month. The lighting load in spring (as representative example for the changing seasons) is about three to four times lower than in winter. In both graphs again the impact of the automated regime can be seen.

The lighting loads of almost all zones are very low over the whole period (Figure 3-13 and Figure 3-14). The higher demand for zone 05z03, 05z04 and 05z05 might result out of the fact that these zones were the only monitored zones with an opposing façade. This might also explain the results in Figure 3-15 lighting load per floor.

Concerning orientation (Figure 3-16) the higher levels for the west oriented zones again this could be explained with the influence of opposing facades (zone 05z03, 05z04 and 05z05 are oriented to the West). In the summer months the values are very small for all orientations. In the winter months northwest oriented zones show far lower lighting loads compared to other orientations. The three observed zones in this orientation were all single occupancy zones. Because of this fact it is not correct to portray any orientation related correlation in UT. For such claim more zones or rooms with similar conditions would have to be observed in this building, as it was done by Mohammadi 2007 and Kabir 2007 for VC.

In Figure 3-17 and Figure 3-18 the results are again distorted by the three zones in floor number five. Therefore in Figure 4-7 the percentage of mean lighting load against the number of persons per zone is plotted for those cases when the zones were occupied, in the interval between 06:00 to 17:55 and excluding zone 05z03, 05z04 and 05z05. Still there is the tendency that the mean lighting load is increasing with the number of persons per zone.

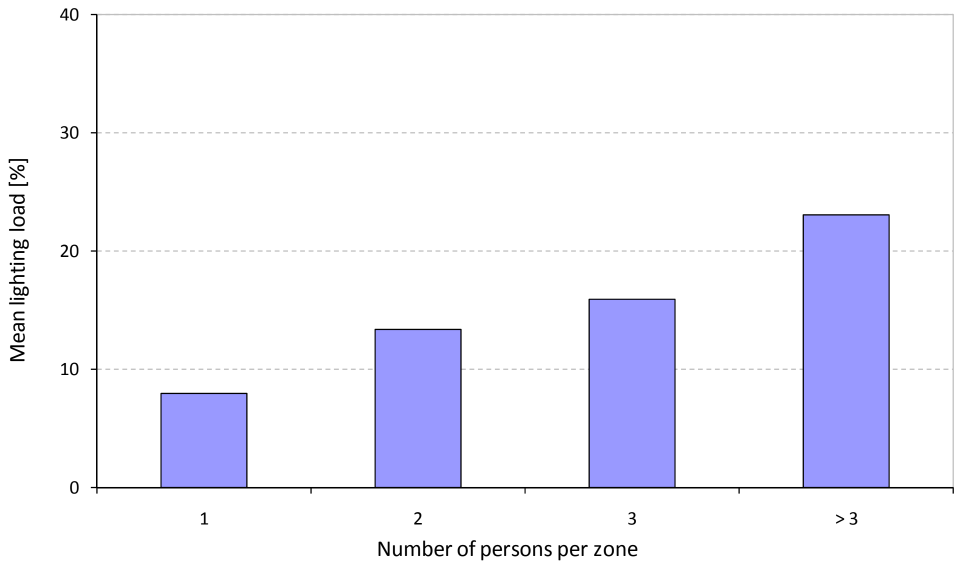

Figure 4-7 Percentage of mean lighting load against the number of persons per zone (06:00-17:55; excluding 05z03, 05z04 and 05z05), when the zones were occupied

No significant relationship between shade deployment and light operation level could be observed in UT (Figure 3-21 and Figure 3-23).

4.2.2 Lighting - Actions

In the overwhelming majority of cases people chose the 500 lx button when they wanted to turn on the light. The 300 lx button on the interface was not used very often (Figure 3-24). This shows the importance of the light control strategy (using a light level meter) not to let the people switch on the lights directly, but to let them choose the illuminance level.

Where Figure 3-25 and Figure 3-26 have just informative character because they show the absolute frequencies, the normalization of these frequencies for analysis was essential. Figure 3-29 illustrates the relationship between the normalized relative frequency of light switch on actions (0-500 lx) and indoor horizontal illuminance as measured by the building automation system's ceiling-mounted light sensors. Analogously Figure 3-32 presents the normalized relative frequency of light switch on actions compared with the external vertical illuminance as measured on top of UT. In both cases an unambiguous relationship could be discerned between switch on actions and the measured light levels. The normalized relative frequency of 'switch on' actions shows a clear dependency on internal horizontal illuminance measured on the ceiling as well as on external vertical illuminance incident on the façade measured for the orientation of the respective zones. For these analyses, only those time intervals were considered when all shades (internal roller blinds and external venetian blinds) were open. This correlation could be also found in Figure 3-33 for external horizontal illuminance and in Figure 3-34 for external (horizontal) global irradiance both measured at the weather station of the Department of Building Physics and Building Ecology, at a distance of 1.9 km.

For the switch off actions the same analyses were done (Figure 3-31, Figure 3-35, Figure 3-36 and Figure 3-37) but no correlation could be found. An explanation might be that the number of actions was small (n = 237) due to the automated light regime explained before.

As mentioned before the illuminance was not measured at the workplace in UT. In literature this value is mentioned as standard value. Attempts to establish a correlation for the measured light levels to the workplaces failed. While the attempt to find a correlation between the indoor horizontal illuminance measured on the ceiling and the external horizontal illuminance measured at the weather station of the Department of Building Physics and Building Ecology was successful (Figure 3-31).

The aggregated probability function for switching the lights on upon arrival in the office based on data from VC, FH and HB was already presented in the final report. Here illuminance on the table is depicted in 50 lx bins against the probability of switching the lights on at arrival (Figure 4-8). The raw data is calculated with more strict calculation rules, but the tenor of the graph is still the same. The fitted polynomial regression line fits even better.

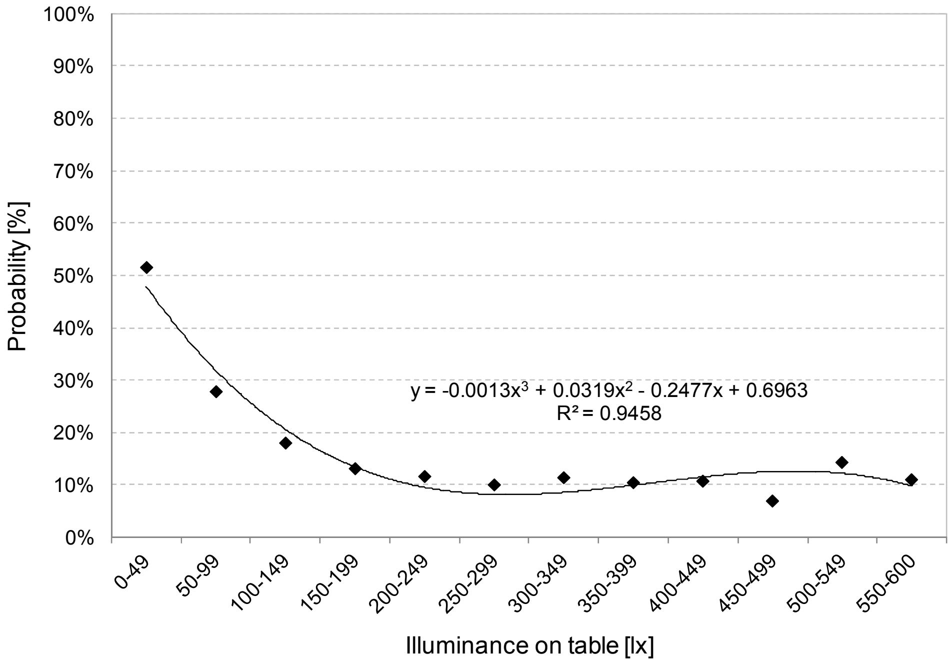

Figure 4-8 Probability of switching on the lights at arrival in the office, averaged over VC, FH and HB

However Hunt (1979) and Reinhart (2001) used an adapted probit function to describe the switching on the lights at arrival. The reason to do this was to describe the empirically measured data in a mathematical way to be able to use the achieved function. Following the hypothesis that i) all people will switch on the light (probability is 1) when it is completely dark ii) that the probability that lights will turned on at arrival will fall rapidly when there is little light and iii) that this probability will decrease gradually when the light level will rise more and more. Due to the hypothesis the probit function was chosen because it describes an S-form which should fit best. Therefore the probit function was used for VC-N, VC-S, FH and HB (Figure 3-53 to Figure 3-57) to describe best fitting regression lines. In Figure 4-9 the proposed general light switch on upon arrival probability model is presented. In Figure 4-10 this function is compared with the functions of Hunt and Reinhart. Due to the fact that we used HOBO data loggers in our research project, we were forced to exclude the majority of illuminance values below 30 lx. This data is missing in applying a regression line of course. Therefore the functions are forced to cross the y-axis at 1 (100%) following the above mentioned hypothesis.

The generic function for VC-N, VC-S, FH and HB differs to the others in being much steeper at the beginning and becoming almost parallel to the x-axis at the end. Hunt and Reinhart described with their functions that light levels below 200 lx increase the probability for switching on the lights on. The function based on the data collected in the research project 'People as Power Plant' imply that this trigger point is shifted to values below 100 lx (see Figure 4-8 and Figure 4-10). The reasons for this shift seem to remain undiscovered. The use of the HOBO data loggers should not be the reason for that shift. The sensor was calibrated and doubtful data excluded. Maybe one explanation for this low trigger point can be seen in the VDT tasks (high portion of time spend in front of computer displays) of the users.

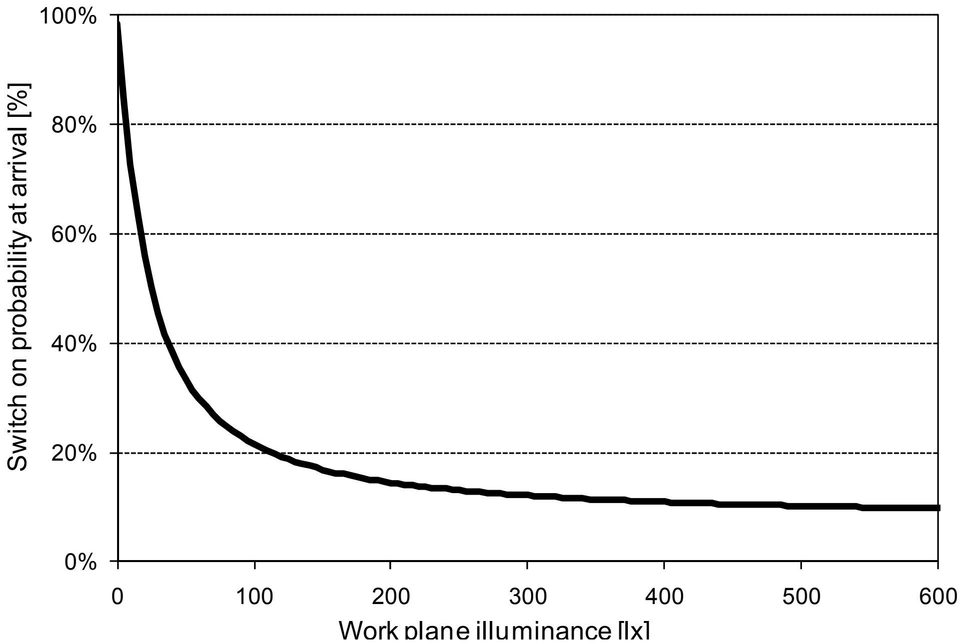

Figure 4-9 Proposed generic light switch on upon arrival probability model based on the prevailing task illuminance level prior to an action

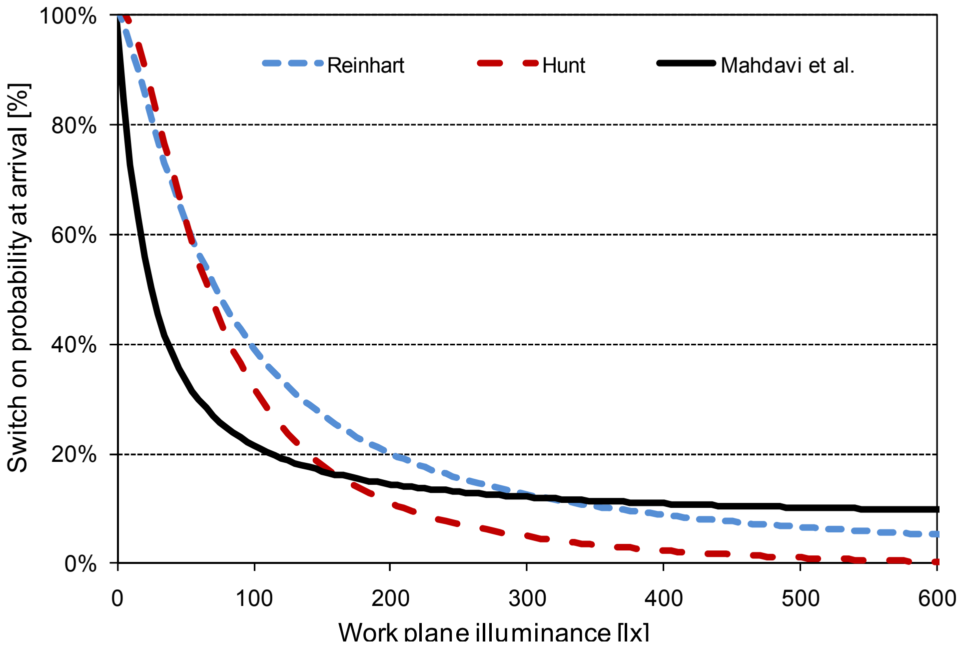

Figure 4-10 Comparison of light switch on upon arrival probability models for Hunt (1979), Reinhart (2001) and the generic function for VC-N, VC-S, FH and HB based on the prevailing task illuminance level prior to an action

The switch off lights probability as a function of the duration of absence shown in Figure 3-58 was used to derive a generic model (Figure 4-11). The use of the recalculated values improved the correlation from R^2=0.6599 to R^2=0.7312.

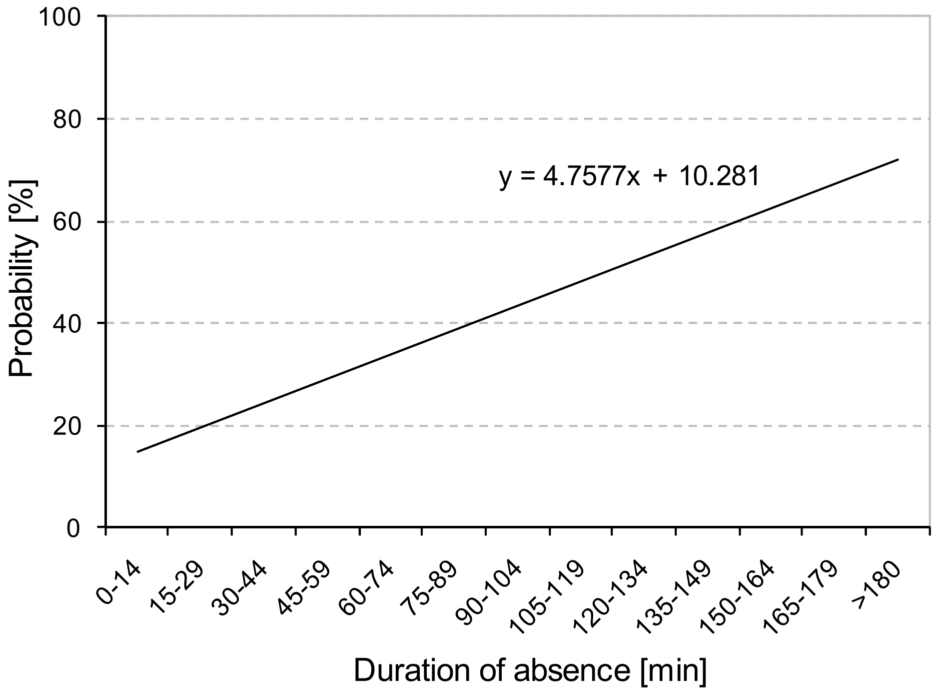

Figure 4-11 Proposed generic lights switch off probability model based on the duration of absence from the workstation

4.2.3 Lighting – Energy usage

The lighting loads in section 3.1.2 have been presented in percentage of the installed lighting power. This is useful for analyses referring to the building itself. For example zones can be compared or seasons analysed. But these relative values:

- can not be used for comparisons with other buildings
- give no information concerning the absolute energy usage

Therefore, even if the graphs look similar, the mean lighting loads were presented in Watts (Figure 3-38), Watts per square meter (Figure 3-39) and Watts per workplace (Figure 3-40) over the course of a reference day for all (and in Figure 3-38 also for occupied) intervals. Figure 3-41 portraying the mean lighting load per person over the course of a reference day for all intervals, shows clearly the possible energy saving potential at the end of the workday (after 16:00). Season wise and therefore more detailed the mean lighting load over the course of a reference day is illustrated in Figure 3-42 to Figure 3-46.

The overlay of the curves for mean occupancy, mean solar radiation and mean lighting loads for single occupancy and for all zones in Figure 3-47 shows on one hand a big difference between the mean lighting for single occupancy zones and the average for all zones. This might result not only out of the lower energy consumption of single occupancy zones for lighting, but also out of the fact that there are more square meters per person in a single occupancy office compared to others. The results rather show the match in time of mean solar radiation and mean occupancy. In terms of daylight usage this match is almost ideal. Additionally the increase of the mean lighting load in the afternoon (after 16:00) is portrayed. Although the occupancy curve declines, there is an increase of mean lighting load due to the lack of daylight.

A comparison of energy usage due to lighting between the observed buildings is done in the next graph (Figure 4-12). The mean lighting loads in VC, FH, UT and HB are compared expressed in Watts per square meter over the course of a reference day.

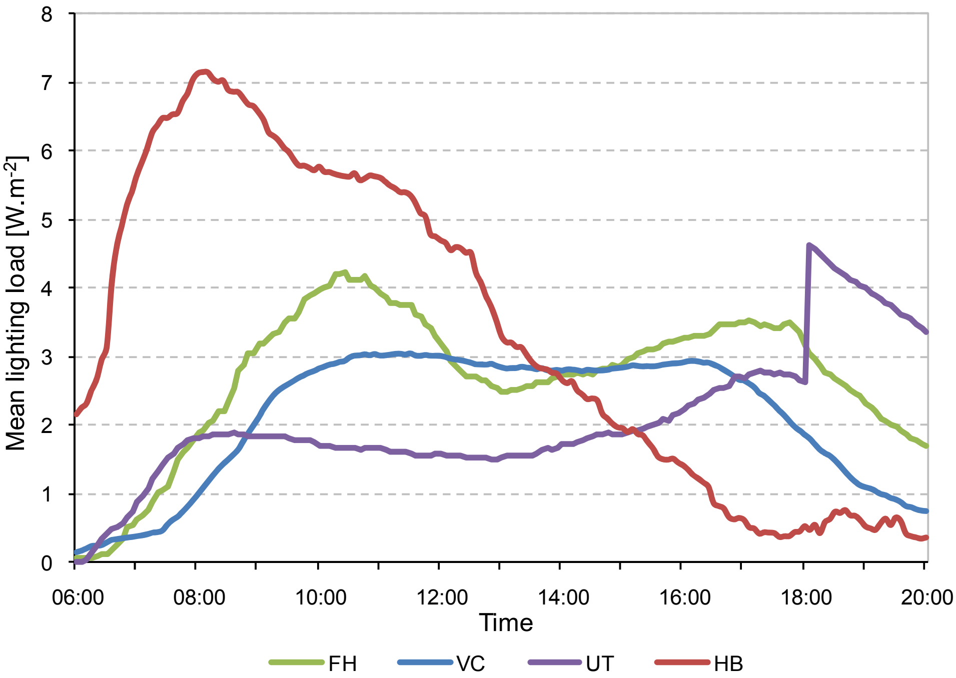

Figure 4-12 Mean lighting load in VC, FH, UT and HB

As it was the case with occupancy patterns in the observed buildings, the patterns for lighting loads showed wide difference. Nonetheless Figure 4-13 presents the derived generic model of the hourly mean lighting load based on data from VC, FH, UT and HB. The hourly values were calculated by the average of the past hour (e.g.: The value at 7:00 represents the values from 6:05 to 7:00).

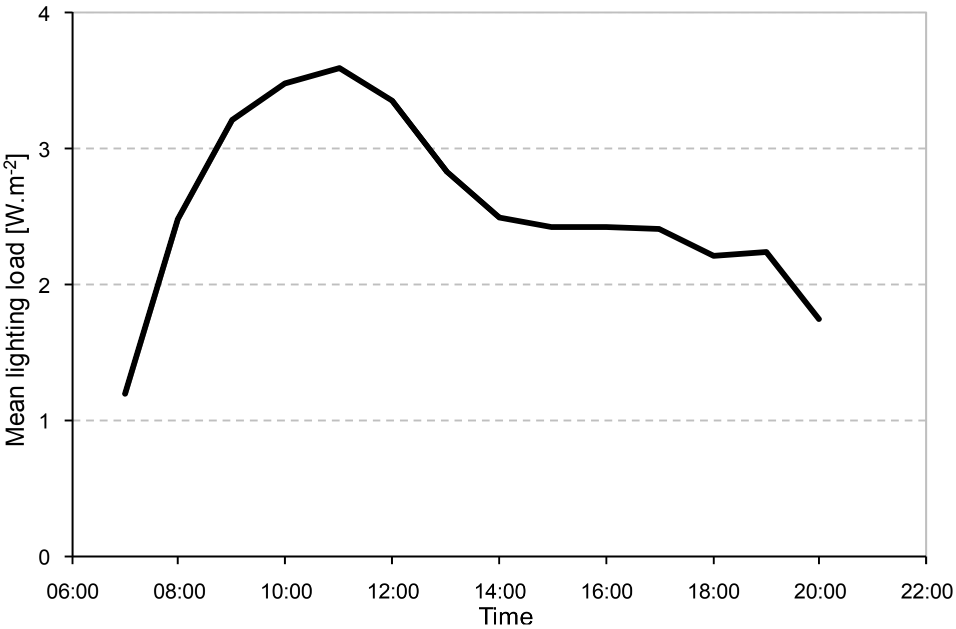

Figure 4-13 Generic model of the mean lighting load, averaged over VC, FH, UT and HB

4.3 Generic models résumé

So far five generic models have been modified or developed for this thesis and represent the latest and final results of the research project “People as Power Plant”:

- Generic model of occupancy (Figure 4-2)
- Generic people load model (Figure 4-6)
- Generic light switch on upon arrival probability model (Figure 4-9)
- Generic lights switch off probability model (Figure 4-11)
- Generic model of the mean lighting load (Figure 4-13)

To give a full overview of all general models developed in this research project one additional model developed by Mahdavi 2009 is presented (Mahdavi & Pröglhöf 2009). Based on the mean shade deployment in relation to the global horizontal irradiance (Figure 4-14) which was presented and discussed in the Final Report a latter model (Figure 4-15) based on the hypothesis that the shade deployment level (in percentage) depends on both façade orientation (N; NE+NW; E+W; SE+SW; S) and vertical irradiance intensity. A possible mathematical formulation of this dependency is expressed in Equation 3 (Mahdavi 2010). Herein *SD* denotes the shade deployment level (in percent) and E_v incident vertical irradiance (in W·m^{-2}). The constants *a*, *b*, *c*, and *d* depend on location and building features and k_1 and k_2 (Equation 4+5) are trigonometric functions of the façade normal azimuth (in degrees, whereby the corresponding values for north, east, south, and west are 0, 90, 180, and 270 degrees respectively) as per the following equations:

$$SD = a - b \cdot k_1 - c \cdot k_2 \cdot (d - E_v)$$ *Equation 3*

$$k_1 = 0.5 \cdot (1 + cos\alpha)$$ *Equation 4*

$$k_2 = 1 - cos^2 \alpha$$ *Equation 5*

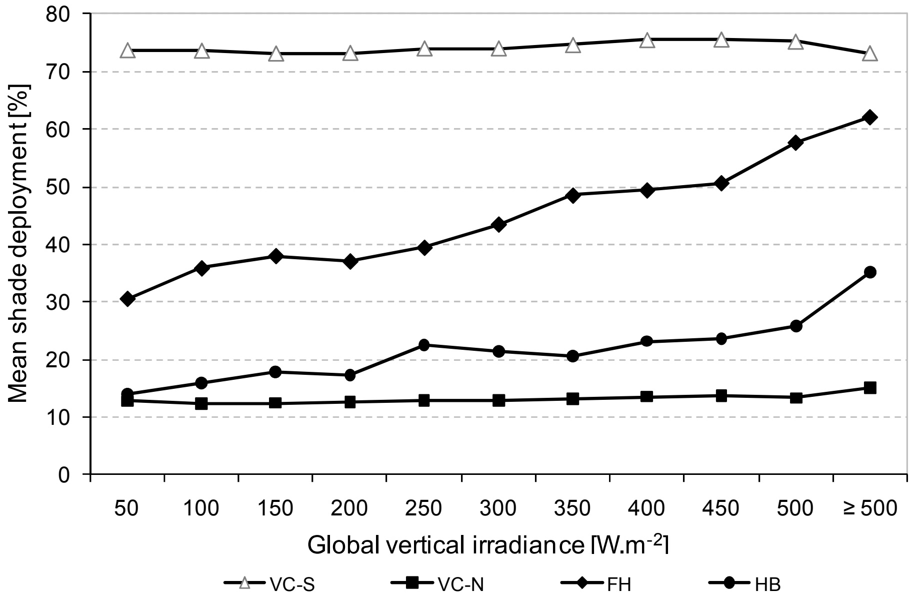

Figure 4-14 Mean shade deployment in relation to the global horizontal irradiance (Mahdavi et al. 2007)

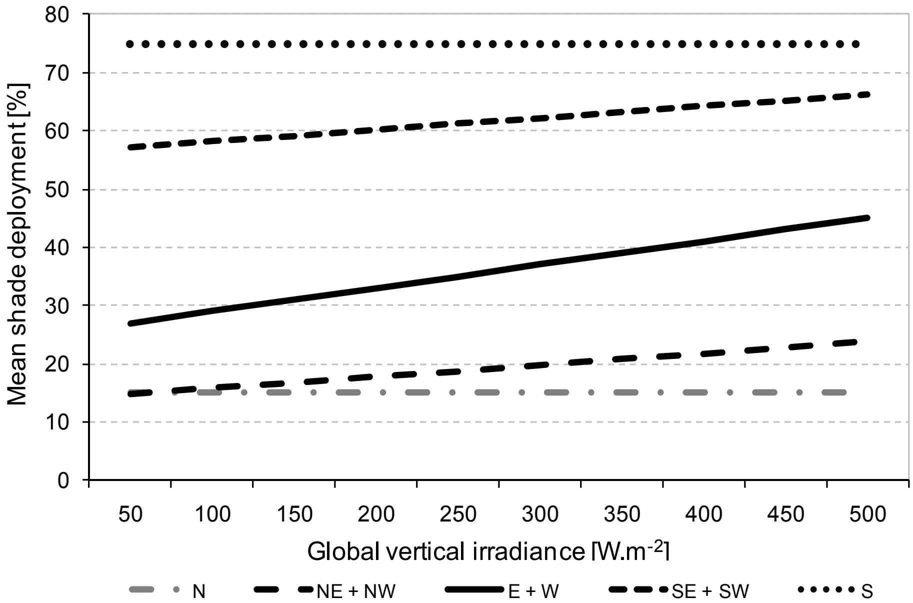

Figure 4-15 Generic dependency model of shades deployment level as a function of façade orientation and the incident global (vertical) irradiance on the façade (Mahdavi et al 2008)

Figure 4-16 compares the predictions based on Equation 3 with empirical findings documented in Figure 4-14. Thereby, the values for the constants were set as follows: *a=75*, *b=60*, *c=0.04*, and *d=500*. The actual façade normal azimuth values for the respective façades were applied for the computation and comparison with model predictions (*α=206*° for VC-S, *103*° for FH, *51*° for HB, and *326*° for VC-N).

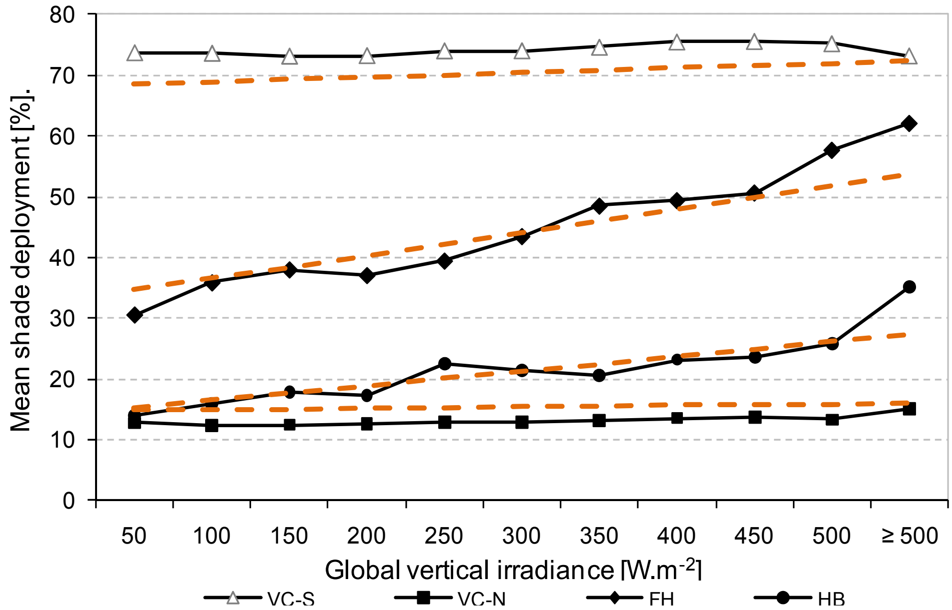

Figure 4-16 Comparison of the general shade deployment model's predictions (dashed lines) with empirical observations (Mahdavi et al 2008)

Such aggregate models represent realistic general trends and not reality in terms of predicting future states or actions conditions in buildings. The relevance of such generic models is of course limited to the context as pointed out (e.g. in section 4.1 - differences in occupancy patterns can be very large). Nonetheless those models have an important role in simulation of building performance and benchmarking. Compared, the crude models for occupancy used at the moment lead to overestimations whereas the findings of this research project illustrated that workstations are unoccupied at least half of the working day. All input parameters (geometry, material, environmental or user based, etc.) in simulation are subject to be as realistic as possible. Although there are variations in the different patterns they can be important in assessing the quality of a design or building hardware in defining best and worst case scenarios.

Given sufficient observations, statistical methods can be used to generate individual occupancy patterns that could represent the mean occupancy level associated with a building. Such models can be implemented in simulation applications in terms of autonomous agents with built-in methods (Chang & Mahdavi 2002) to generate stochastic behavior. Stochastic state and action models generate per definition different input data at each simulation run. For benchmarking or to compare different design alternatives this will be a problem. To select the right type of model for a specific performance inquiry is the basis for reliable simulation.

5 Conclusion

5.1 Contributions

In this thesis a study concerning patterns of control-oriented human behavior in office buildings in Austria was presented. Especially results of one high rise office building (UT) were investigated and set into context with previous published results of the research project ‘People as Power Plant’. The results describe the possibility of identifying general patterns of user control behavior. Different and complex correlations and patterns concerning user presence or their control-oriented actions as a function of environmental indoor and outdoor parameters such as illuminance and irradiance have been highlighted. Furthermore the observations emphasize the need to typologically differentiate when the developed models are used as simulation input values. Behavior and patterns cannot be applied to other buildings without specific calibration. However the behavioral models aggregated, are far more representative than the schedules used to this end. It is a matter of fact that the reliability and robustness of results gained out of simulation applications depends on the coherence of input assumptions. The compound results of this field study contribute to generate more robust occupant behavior models. As mentioned in the Final Report the results of this study will:

- improve the reliability and robustness of computational building performance simulation applications and simulation based benchmarking;
- provide a more dependable basis for the design and configuration of user interfaces and control algorithms for buildings' environmental control systems;
- deliver a quantitative basis for the evaluation of the impact of occupancy behavior on buildings' energy consumption;
- help develop strategies to inform building occupants regarding the energy and comfort implications of their control actions.

5.2 Future research

Occupancy 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. Another idea for future research is to investigate residential buildings as well. In combination with post occupancy evaluations (POE) this field studies should increase the knowledge of inter-individual differences and widen the scope. Furthermore the development of new interface related control strategies and algorithms might have a huge potential.

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7 List of Figures

8 List of Tables

9 Appendix

9.1 Symbols

A	[m^2]	area
E	[lx]	illuminance
ET		eTelBuildling (see section 2.1.2)
f		frequency
FH		FH Building (see section 2.1.3)
HB		HB Building (see section 2.1.5)
n		number
p	[Pa]	atmospheric pressure
RH	[%]	relative humidity
SD	[%]	Shade deployment level
SR	[$W \cdot m^{-2}$]	global solar radiation
UT		UT Building (see section 2.1.4)
v	[$m \cdot s^{-1}$]	wind speed, air velocity
V	[m^3]	volume
VC; VC-N; VC-S		VC Building (see section 2.1.1)

Indices:

cal	calculated
ceil	ceiling
dir	direction
e or ext	external
h or hor	horizontal
i or int	internal
max	maximal
min	minimal
norm	normalized
occ or occupied	occupied
rel	relative
TU	Vienna University of Technology
v or ver	vertical

9.2 Glossary

<**absolute frequency**> Absolute number of occurrences in an observed time span;

<**arrival**> The condition, that occupancy time is at least three intervals long has to be fulfilled.

<**hourly mean**> Calculated as the average of twelve 5' values and refers to the past hour (e.g.: the average of the values from 06:05 to 07:00 is plotted at 07:00). This calculation rule is required by most simulation applications.

<**intermediate**> The condition, that the occupied status has to be fulfilled in between three intervals before till three intervals after (e.g. an action occurred).

<**leaving**> There are no conditions. Every leaving action is considered.

<**lighting load**> The lighting load represents the usage of absolute installed illuminants. The mean lighting load is therefore the average over a specific time span.

<**NaN**> Not a number; Out of the terminology of MatLab; stands for no value;

<**normalized relative frequency**> Is defined by the division of the number of actions by the number of (occupied) intervals, for the relevant time span, ranges or pins.

<**reference day**> Data of the entire observation period, referring to the same time of the day was averaged and presented in one 24 hour schedule (reference day).

9.3 Own publications in the context of this thesis

"Descriptive Models of Control.oriented User Behavior in Buildings"

Mahdavi, C. Pröglhöf, presentation; Healthy Buildings 2009, Syracuse, USA; 13.09.2009 - 17.09.2009; in: "Healthy Buildings 2009", E.A. Bogucz et al. (eds.); self-published (2009), paper 115;

"Toward empirically-based models of people's presence and actions in buildings"

Mahdavi, C. Pröglhöf, presentation; Building Simulation 2009, University of Strathclyde, Glasgow; 27.07.2009 - 30.07.2009; in: "Building Simulation 2009", L.B. McElroy, J.S. Turley (eds.); (2009), 8 p.

"User Behavior and EnergyPerformance in Buildings"

Mahdavi, C. Pröglhöf, presentation; IEWT 2009 - 6.Internationale Energiewirtschaftstagung an der TU Wien - Energie, Wirtschaft und technologischer Fortschritt in Zeiten hoher Energiepreise, Vienna, Technical University Vienna; 11.02.2009 - 13.02.2009; in: "IEWT 2009 Energie, Wirtschaft und technologischer Fortschritt in Zeiten hoher Energiepreise", G. Brauner (ed.); (2009)

"Observation-based models of user control actions in buildings"

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"User-System interaction models in the context of building automation"

Mahdavi, C. Pröglhöf, presentation; ECPPM 2008 - eWork and eBusiness in architecture, Engineering and Construction, Sophia Antipolis, Frankreich; 10.09.2008 - 12.09.2008; in: "ECPPM 2008 eWork and EBusiness in Architecture, Engineering and Construction", A.S. Zarli, R. Scherer (eds.); (2008), ISBN: 978-0-415-48245-5; p. 389 – 396;

"How Do People Interact With Buildings Environmental Systems? An Empirical Case Study Of An Office Building"

E. Kabir, A. Mohammadi, A. Mahdavi, C. Pröglhöf, presentation; "BS2007 Proceedings of the 10th International Building Performance Simulation Association

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"User-based window operation in an office building"

A. Mahdavi, E. Kabir, A. Mohammadi, C. Pröglhöf, presentation; Indoor Air 2008 - The 11th International Conference on indoor Air Quality and Climate, Copenhagen; 17.08.2008 - 22.08.2008; in: "Indoor Air 2008", B. Olesen, P. Strom-Tejsen, P. Wargocki (eds.); (2008), paper 177, 8 p.

"Modeling User Control Of Lighting And Shading Devices In Office Buildings: An Empirical Case Study"

A. Mohammadi, E. Kabir, A. Mahdavi, C. Pröglhöf, presentation; "BS2007 Proceedings of the 10th International Building Performance Simulation Association Conference and Exhibition", B. Zhao, D. Yan, X. Zhou, C. Wang, C. Li, J. Wang, X. Zhou, J. Li, B. Cao, Q. Deng (eds.); self-published, Beijing, China, 2007, ISBN: 0-9771706-2-4, 7 p.

"Two case studies on user interaction with buildings' environmental systems"

A. Mahdavi, L. Lambeva, A. Mohammadi, E. Kabir, C. Pröglhöf, journal; Bauphysik, 29. Jahrgang / February 2007 / Heft 1 (2007), 1; p. 72 - 75.

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"User Interactions with Environmental Control Systems in Buildings"

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"Observing occupancy control actions in an educational building"

A. Mahdavi, L. Lambeva, C. Pröglhöf, G. Suter, A. Mohammadi, E. Kabir, J. Lechleitner, presentation; 17th Air -Conditioning and Ventilation Conference 2006 - May 17-19, 2006, Prague, Czech Republic, Prag, Tschechien; 2006; in: "17th Air - Conditioning and Ventilation Conference 2006 - May 17-19, 2006, Prague, Czech Republic", J. Schwarzer, M. Lain (eds.); Prague, Czech Republic (2006), p. 201 - 204

"User control actions in building: From observation to predictive modeling"

A. Mahdavi, L. Lambeva, C. Pröglhöf, G. Suter, A. Mohammadi, E. Kabir, J. Lechleitner, presentation; Nové Poznatky V Teórii Konstrukcii Pozemnych Stavieb A Ich Uplatnenie V Stavebnej Praxi - 2005, Kocovce; 07.11.2005 - 08.11.2005; in: "Nové Poznatky V Teórii Konstrukcii Pozemnych Stavieb A Ich Uplatnenie V Stavebnej Praxi - 2005", A Puskár et al. (ed.); self-published (2005), p. 64 - 73

9.4 UT - Horizontal section

The horizontal section (Figure 9-1) of the 17th level was chosen to give a general picture of the floors, zones and workplaces. The short red lines indicate the zone boarders. The workplaces are numbered. All observed zones look very similar. The numbering of the zones is almost identical.

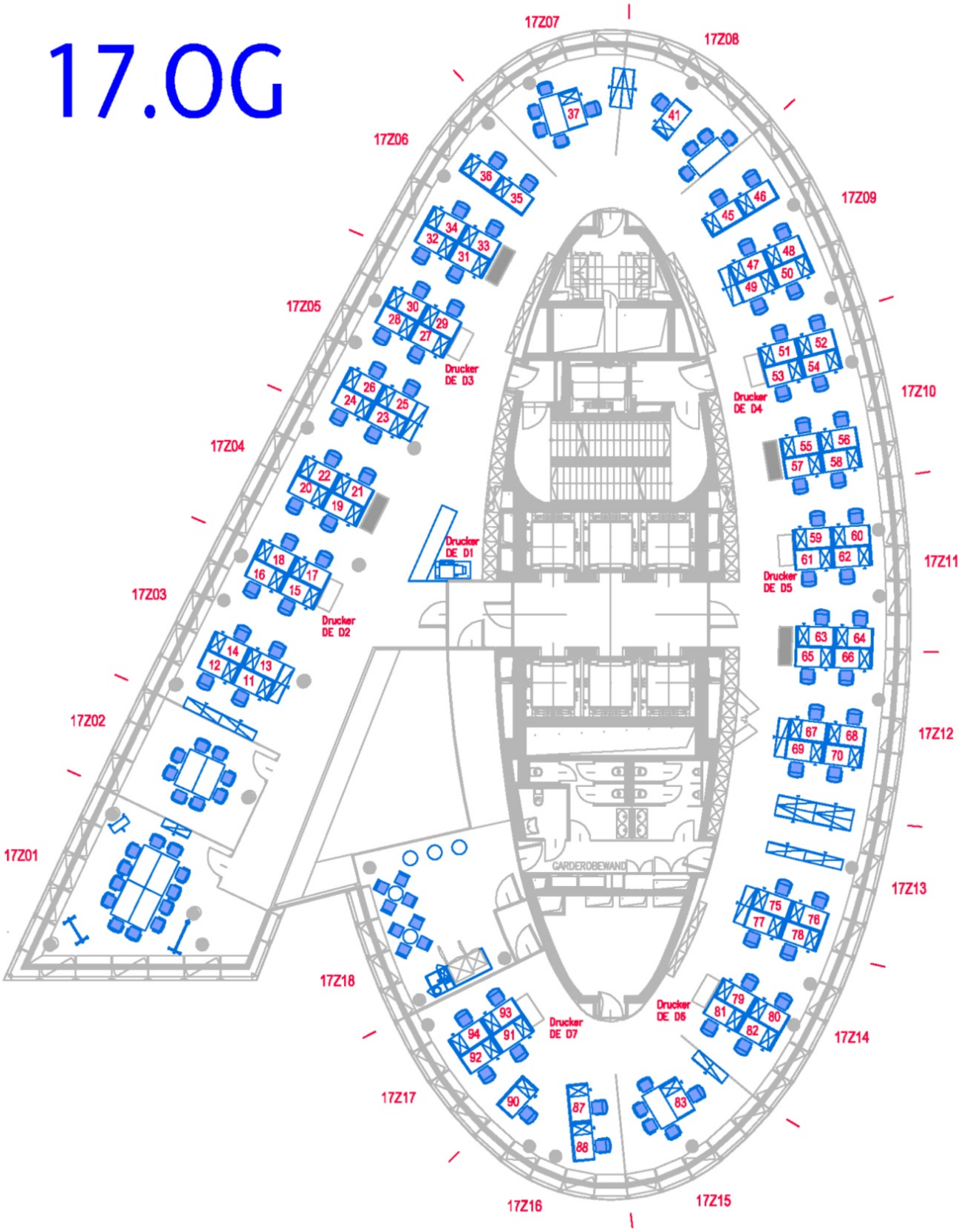

Figure 9-1 Horizontal section of the 17th floor

9.5 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"
```

9.6 Sensor naming scheme

How to name the Sensors / Files

Please use the following code-system when you install sensors or reset sensors:

302_112_041126

1. Digit = Project Number

1 = VIC D-Tower North Facade
2 = VIC D-Tower West Facade
3 = E-Tel / Eisenstadt
4 = TU - Freihaus
5 = UNIQA / Vienna
6 = BH Hartberg
7 =

2.-3. Digit = Room Number

Start with 01, 02, 03, ... (mark the number in a plan)
(If necessary: 2.Digit=floor; 3.Digit=Room number)

As Separator use underscore "_"

4. Digit = Sensor Type

1 = IT-200	2 = Hobo
3 = Hobo (Temp only)	4 = Camera Files
5 = Weather Station	6 = Log for heating control
7 = APLogs	8 = MIKS
9 = SolRad	v = photos, plans, questionnaire, etc.

5.-6. Digit = Sensor Number

Start with 01, 02, 03, ... in each room (mark the number in a plan)!
[For the Weather Station:

11	v med (WSM)
12	v max (WSS)
20	t_e
30	RH
40	SR

]

As again 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 E-Tel building:	**3**02_112_041126
Room number two:	3**02**_112_041126
It is an IT-200 sensor:	302_**1**12_041126
And it is the sensor number twelve:	302_1**12**_041126
The measurement start is on the 26th November 2004:	302_112_**041126**
If you have to add something to the filename use again "_":	302_112_041126_**testa**

Installing the sensors mark them correctly, using the same system:
302_112_041126 **including** the installation date and plot the position of the sensor in a plan.

If there is a question, please ask!

9.7 Data processing of WSBPI data

This document represents the documentation and guideline for WSBPI_data

All Files referring to the weather station mounted on top of BPI are stored in a folder named

"400_500 WSBPI"

- Inside this folder there are following folders:
  - **"alle Daten im Zeitraum (orig)"**
    where all original WS-Files are stored.
  - **" Referenzdaten BPI new"**
    where WSBPI data is stored in a .zip and .txt file
  - **" 400_500 structured datatree"**
    where all edited data is stored in different folders
  - **" 400_500 UTC+1 final results"**
    where the Senselect processed WSBPI data is stored in a .xls files
- Furthermore this document ("Protocol WSBPI_data.doc") is stored in "400_500 WSBPI"

---

1. <u>**Preprocessing the WS-files**</u>

Sorting all folders after the time zone (UTC, UTC+1, UTC+2) and if necessary dividing the files:

a. in case the time zone has changed inside the file
b. in case the year has changed inside the file
{Because the program recognizes the year just once, the files covering the changing of the year have to be split into two files [one ending with the 31.Dec. and the other starting with the 01.Jan.]}

2. <u>**Using MatLab**</u>

Then the folders are processed with a perl script named "dezero" in MatLab.

a. Therefore the path where the processed files shall be written out has to be edit in "dezero.pl" at line 20.
b. With:
">> perl('dezero.pl', 'C:..../400_500 WSBPI/400_500 structured datatree/400_500 ...')"
the command will be executed. This command will read all files out of the given folder and write each file into the folder edited in <dezero.pl>. The created files will be unified in terms of linefeed etc. and all rows in which zeroes occur due to logging error will be erased (see line 29).
c. To save time it is recommended to shift all files when processed out of
"C:..../400_500 WSBPI/400_500 structured datatree/400_500..."
into
"C:..../400_500 WSBPI\400_500 structured datatree\archiv pre_zeroless processed\archiv pre_zeroless 400_500 ..."

If you do so next time only the new not processed files will be read out and written into the folder edited in <dezero.pl>, which will safe time. The existing files in this folder will stay untouched but with the same name will be overwritten

3. <u>**Using SenSelect**</u>

The folders stored in
"C:..../400_500 WSBPI\400_500 structured datatree\ zeroless \ 400_500 ..."
can be processed by SenSelect folder by folder. It is necessary create an extension less file named "read_WSBPI" in each folder before running SenSelect. Because of the amount of data SenSelect creates and stores all data in a temporary file inside the folder to fasten up the data readout. SenSelect will check if there is a temporary file and if the temporary file is still valid:

a. If "yes" SenSelect will use the temporary file and give out the results quite fast.
b. If "no" Senselect will recreate and calculate a temporary file and then give out the results. This will take longer.

It is good practice to structure the files in separate folders in the above mentioned folder referring to a year or a quarter of a year, because they will be processed quarter by quarter due to the fact that the size of excel sheets is limited. Using this method guaranties that the time needed to process the data is reduced to a minimum.

As known the default sampling time is 5 minutes, but if a different sampling rate for the WS-data is needed this will be reached by adjusting the sampling rate in the preferences of SenSelect.

4. <u>**Results**</u>

The results are stored in the above mentioned folder as .xls files for each quarter of the year. The name shows the identity (400_500) followed by the time zone (UTC+1) and the year and quarter (e.g.: 05_2). In these Files all non measured and non valid values are represented as NaN (empty cells).
The results processed by SenSelect have to be brought together by hand inside Excel to achieve a unified time code (UTC+1).

9.8 Technical specifications of WSBPI (Thies 2007)

Sensor / Device name or number	Range	Accuracy
Temperature/Relative humidity: "Hygro-Thermogeber compact 1.1005.54.161"	Temp: -30°C to +70°C RH: 0 to 100%	Temp: +0.2 K at 20°C and wind speed >1.0 $m{\cdot}s^{-1}$ RH: ±2%
Solar radiation: „Pyranometer CM3 by Kipp & Zonen 7.1415.03.000"	0 to 1400 $W{\cdot}m^{-2}$	Sensitivity ±0.5% Applied correction +2%
Illuminance: "V-Lambda Strahlungssensor 4.3"	0 to 130 klx	
Wind speed: "Windgeber compact 4.3519.00.000 beheizt"	0.5 to 50 $m{\cdot}s^{-1}$	Accuracy ± 3% or ± 0.5 $m{\cdot}s^{-1}$ Resolution <0.1 $m{\cdot}s^{-1}$
Wind direction: "Windrichtungsgeber compact 4.3129.00.000"	0 to 360°	Accuracy ± 5 ° Resolution 11.25°
Precipitation: "Niederschlagsgeber 5.4032.30.007 ohne Heizung"	max 7 $mm{\cdot}Min^{-1}$ 0°C to +60°C	0.1 mm Precipitation
Barometer: "Barogeber PTB100A 3.1158.00.073"	800 to 1600 hPa	+20°C - ±0.3 hPa 0°C to 40°C - ±1 hPa -20°C to +45°C - ±1.5 hPa -40°C to +60°C - ±2.5 hPa
Data logger: "MeteoLOG TDL 14"	Operating Range: -30°C to +50°C	±0.2% of measurement range Time Accuracy: not decisive

9.9 Technical specifications of HOBO weather stations (Onset 2007)

Sensor / Device name or number	Range	Accuracy
Temperature/Relative humidity: “S-THA-M002”	Temp: -40 °C to 75 °C RH: 0 to 100% between 0°C and 50°C	Temp: ±0.7 K at 25 °C RH: ±3% between 0°C and 50°C ±4% in condensing environments
Solar radiation: “S-LIB-M003 Solar Radiation Sensor (Silicon Pyranometer)”	0 to 1280 $W \cdot m^{-2}$	Accuracy ± 5% or ±10 $W \cdot m^{-2}$ Additional temp. induced error ±0.38 $W \cdot m^{-2}$/°C from +25°C
Wind speed: “S-WSA-M003”	0 to 45 $m \cdot s^{-1}$	±1.1$m \cdot s^{-1}$ (± 4%)
Data logger: “H21-001”	Operating Range: -40°C to +70°C	Time Accuracy: ±5 seconds per week at 25°C

9.10 Instruction for HOBO Loggers

How to save data / 2

Please use the following guideline to save data carefully:

HOBO LOGGER (both types) using Greenline Software

You will have to save the HOBO Logger data twice:

- once as original HOBO File (*.hobo,*.hob)
- and second as Text File (*.txt).

When you readout the data the Greenline software saves the data automatically as HOBO File in a folder you choose. (Use for that purpose one folder for each sensor and name that folder using the code-system you already know, not using the date stamp (for example: 465_201)). Please save both, the original HOBO File and the Text File in that folder.

Follow this 3 Steps reading out and saving data:

1. Select in "Exporting and Display" (File Menu / Preferences Window) the following:

Export Settings:

	select	- Export Serial #, Deployment # and Description
	select	- Export Point #
as Column Separator use	**Semicolon ";"**	
	do not select	- Separate Date and Time Columns

Date Time Display and Export Format:

Date Format:	**Day Month Year**	
	select	- Show Full 4 Digit Year
Date Separator:	**Period "."**	
Time Format:	**24 Hour**	
Time Separator:	**Colon ":"**	
	do not select	- Use Asterisk (*) for Unit Degree (°) Symbol

then press OK…

2. Now you can readout the data. As mentioned before the Greenline software saves the data automatically as HOBO File (*.hobo) in a folder you choose (see above).

3. To save the data as Text File (*.txt) you can either press the "Export File" button or you choose "Export Points as Excel Text" in the "File". Again you have to choose the folder where you want to save the file and then press save.

That was it!

If there is a question, please ask!

9.11 Technical specifications of HOBO U12 loggers (Onset 2007)

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

9.12 Instruction for IT200 loggers

How to save data / 1

Please use the following guideline to save data carefully:

IT200 using ITProSoft Software

You will have to save the IT200 Logger data twice:

- once as original IT File (*.itr)
- and second as Excel File (*.xls).

1. When you want to readout the data use "Retrieve Log Entries" in the "Logger" Menu. To save as an original IT File (*.itr) press the save button and you will be able to choose a folder to save in. (Use for that purpose one folder for each sensor and name that folder using the code-system you already know, not using the date stamp (for example: 465_201)).
Please save both, the original IT File and the Excel File in that folder.

2. To save the data as Excel File (*.xls) press the "Export as" button in the "File" Menu. If the sensor has been reset correctly the name of the file should be generated automatically. You will have to choose "Excel Files". Again you have to choose the folder where you want to save the file and then press save.

That was it!

If there is a question, please ask!

9.13 Technical specifications of IT-200 loggers (Watt Stopper 2005)

OCCUPANCY SENSORS | Auditing Tools

IT-200 InteliTimer® Pro Logger

PROJECT
LOCATION/TYPE

Product Overview

Description

The InteliTimer Pro (IT-200) is a revolutionary occupancy and light logger that establishes the energy saving potential when using occupancy sensors. With this versatile tool, spaces for lighting control use can be pinpointed and savings can be verified.

Operation

The IT-200 records a log entry every time there is a change in either the occupancy status 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 light level through a clear, plastic light pipe to determine if lights are on or off. The logger distinguishes artificial lighting from natural lighting to give accurate "lights-on" readings. To log data, a user places the logger so that its lens has a clear view of the workspace and the light-pipe aims towards the nearest light fixture.

Software

Included with the IT-200 is IT-ProSoft 2.0 software. In a single keystroke or mouse click, users can retrieve, store, analyze, or print data reports. These reports can be directly exported to Microsoft Excel® for further analysis. IT-ProSoft also enables users to operate multiple units in multiple locations while ensuring that each logger's identity and logging site information will be correctly merged. Once the logged information is retrieved, the unit can be reset and used to log information at another test site. Users may group logging data from different areas and automatically receive separate reports by utilizing the IT-200's bookmarking feature.

Applications

The IT-200 offers a simple and cost-effective method of auditing any building space for wasted lighting. Since the logger is portable and battery operated, it is convenient to quickly move it from one location to download to a computer, and on to the next location for another logging session.

Features

- Reports show graphs of occupancy and lighting and projects savings and statistical information
- Users set logging parameters for more accurate savings projection
- Powered by a lithium battery, with an extended life span of approximately ten years
- Small and lightweight for ease of use and portability
- Installs quickly and conveniently and requires no wiring
- IT-ProSoft 2.0 operates in six languages (English, French, German, Spanish, Swedish, and Norwegian) with appropriate currency/ date/time formats, and energy and HVAC defaults
- Occupancy detection LED helps users confirm that logger is detecting motion in desired space
- Light level LED helps users set logger to identify the on and off lighting levels of different locations
- The LEDs work for a 60 second test period to preserve battery life

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800.879.8585

Specifications

InteliTimer Pro

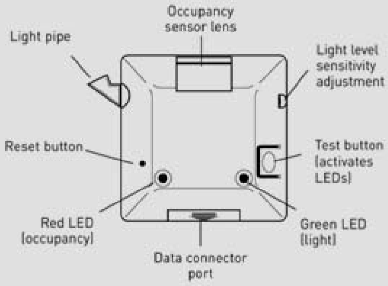
- Lithium battery operated. Average battery life ~ 10 years. Battery life indicator
- Test button activates LEDs for 60 seconds during which sensitivity is set and proper location for occupancy detection is verified
  - Red LED blinks during occupancy detection
  - Green LED blinks when lighting is detected
- Recessed reset switch
- Coverage up to 150 ft² (45.7m²)
- Stores a maximum of 4096 entries
- Stores site name to identify the area being monitored
- Connects to computer (PC) for data retrieval via serial connector cable
- Includes a serial to USB adapter for computers without serial ports

IT-ProSoft Software

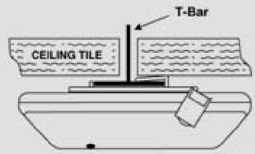
- Lists all log entries: entry number, date/time of entry, lighting status, occupancy status
- Users set logging parameters (energy cost/kWh, size of load, site name, sensor time-outs) for more accurate savings projection
- Reports show daily graphs of occupancy and lighting data, and lighting/occupancy analysis projecting savings and statistical information
- HVAC factor enables calculation of additional potential savings due to reduced HVAC load
- While connected, software can reset the logger in preparation for a new logging session
- Merge log capability combines outputs from multiple loggers monitoring a single location
- Supports Windows 95, 98, 2000, & NT platforms
- Downloadable at www.wattstopper.com

Controls & Installation

Product Controls



T-bar Ceiling Installation



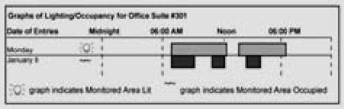
The IT-200 simply clips to a T-bar of a ceiling tile - no wiring is needed. For installation onto other surfaces, the unit comes with a flat bracket and double-stick tape.

Coverage & Software Reports

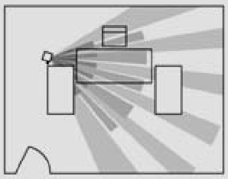
Logged Entries Report

Entries:	42	Cost/kWhr:	$0.080
From:	Sun, Aug 14, 1995 at12:00:00 PM	HVAC Adder:	15%
To:	Thu, Aug 18, 1995 at 9:32:00 PM	Load Size:	180W
1	Sun, Aug 14, 1995 at12:00:00 PM	Lights ON	Occupied
2	Sun, Aug 14, 1995 at 2:25:00 PM	Lights ON	Vacant
3	Mon, Aug 15, 1995 at7:50:00 AM	Lights ON	Occupied
4	Mon, Aug 15, 1995 at10:15:00 AM	Lights ON	Vacant
5	Mon, Aug 15, 1995 at10:50:00 AM	Lights ON	Occupied
6	Mon, Aug 15, 1995 at12:15:00 PM	Lights OFF	Vacant

Lighting & Occupancy Graph

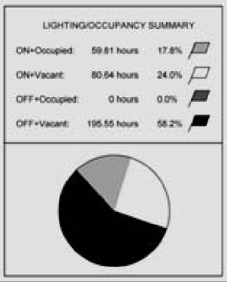


Office Placement Example



The IT-200 monitors an area of up to 150 ft² (13.9m²). The unit should be placed near the light source with the light pipe aimed at the light and the lens facing the occupant's main work area.

Lighting & Occupancy Graph



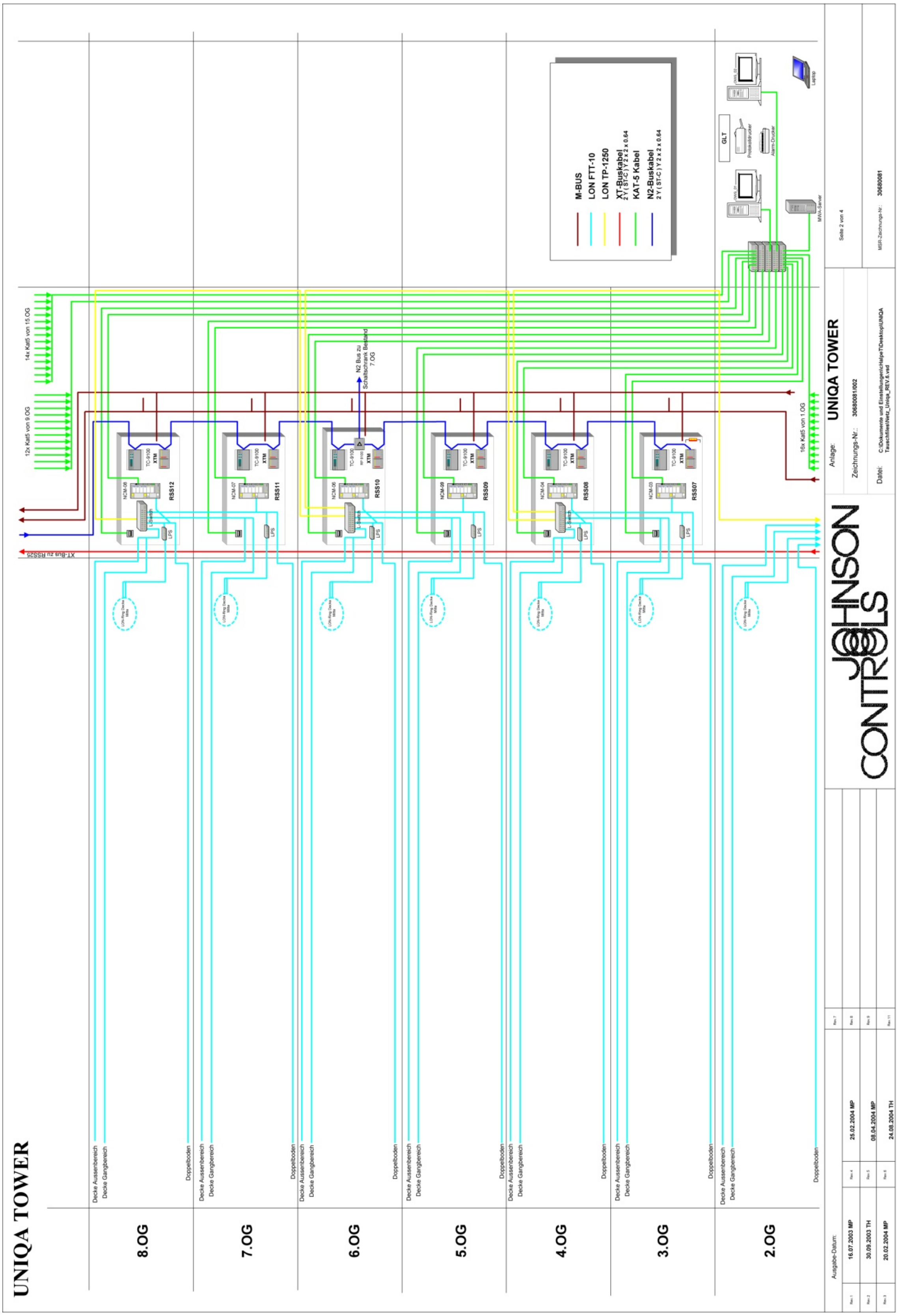
Ordering Information

Catalog No.	Description
☐ IT-200	Occupancy and light logger with software for PC

All units are white

Pub. No. 5005

9.14 Part of the control scheme for UT



9.15 Lighting - Energy usage: Additional graphs for light control regime

To show the impact of the various light control regimes described in section 3.1.2.1 the detailed results are presented in this section.

Winter regime 2005 + 2006

In Figure 9-2 the mean lighting load in W, in Figure 9-3 the mean lighting load per m², in Figure 9-4 the mean lighting load per workplace and in Figure 9-5 the mean lighting load per person is shown over the course of a reference day for all intervals (01.04. - 15.06.2005 and 10.10.2005 - 31.05.2006), averaged over all zones.

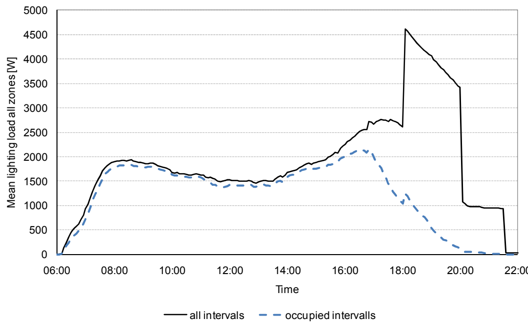


Figure 9-2 Mean lighting load [W] over the course of a reference day for all and for only occupied intervals (winter regime 2005+06), averaged over all zones

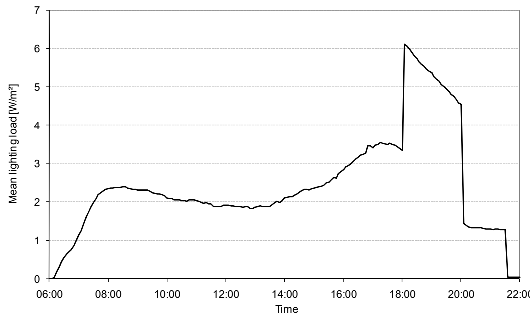


Figure 9-3 Mean lighting load per m² over the course of a reference day for all intervals (winter regime 2005+06), averaged over all zones

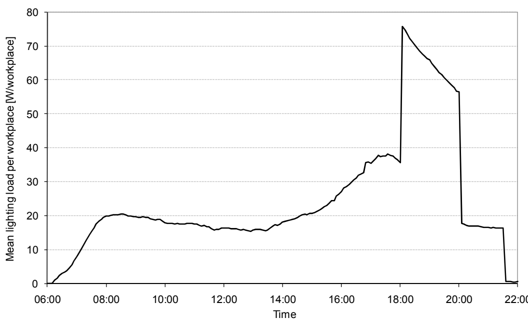


Figure 9-4 Mean lighting load per workplace over the course of a reference day for all intervals (winter regime 2005+06), averaged over all zones

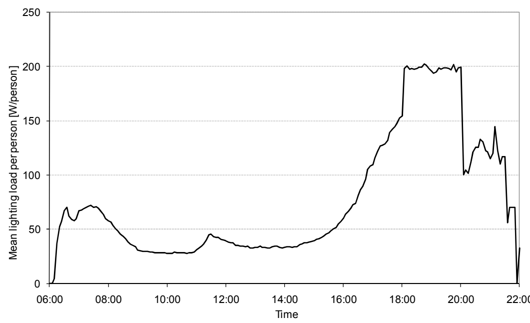


Figure 9-5 Mean lighting load per person over the course of a reference day for all intervals (winter regime 2005+06), averaged over all zones

Summer regime 2005

In Figure 9-6the mean lighting load in W, in Figure 9-7 the mean lighting load per m², in Figure 9-8 the mean lighting load per workplace and in Figure 9-9 the mean lighting load per person is shown over the course of a reference day for all intervals (16.06.2005 – 09.10.2005), averaged over all zones.

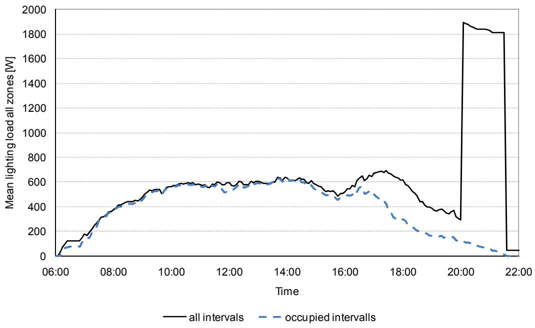


Figure 9-6 Mean lighting load [W] over the course of a reference day for all and for only occupied intervals (summer regime 2005), averaged over all zones

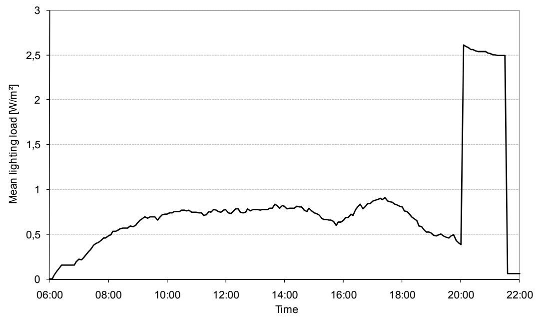


Figure 9-7 Mean lighting load per m² over the course of a reference day for all intervals (summer regime 2005), averaged over all zones

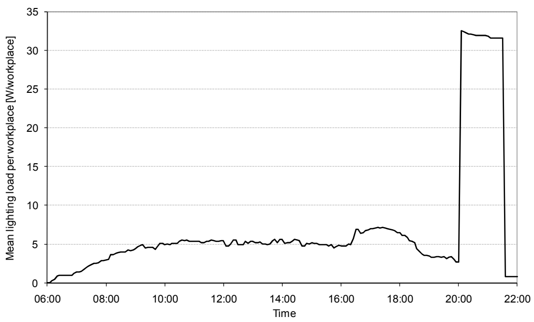


Figure 9-8 Mean lighting load per workplace over the course of a reference day for all intervals (summer regime 2005), averaged over all zones

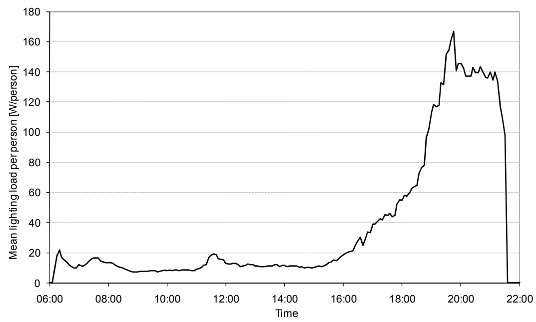


Figure 9-9 Mean lighting load per person over the course of a reference day for all intervals (summer regime 2005), averaged over all zones

Summer regime 2006

In Figure 9-10 the mean lighting load in W, in Figure 9-11 the mean lighting load per m^2, in Figure 9-12 the mean lighting load per workplace and in Figure 9-13 the mean lighting load per person is shown over the course of a reference day for all intervals (01.06. – 10.07.2006), averaged over all zones.

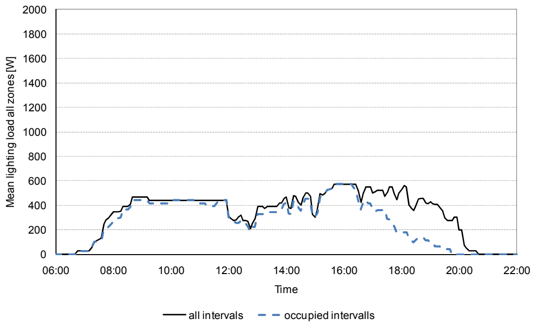


Figure 9-10 Mean lighting load [W] over the course of a reference day for all and for only occupied intervals (summer regime 2006), averaged over all zones

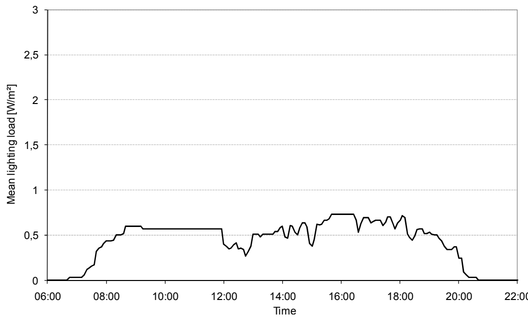


Figure 9-11 Mean lighting load per m² over the course of a reference day for all intervals (summer regime 2006), averaged over all zones

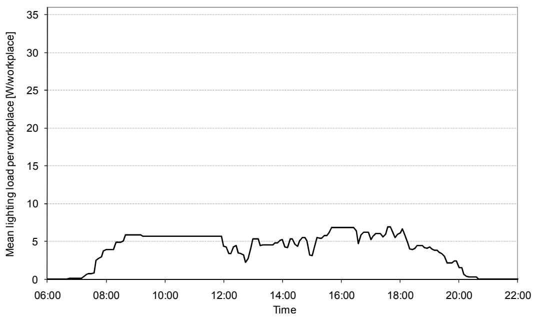


Figure 9-12 Mean lighting load per workplace over the course of a reference day for all intervals (summer regime 2006), averaged over all zones

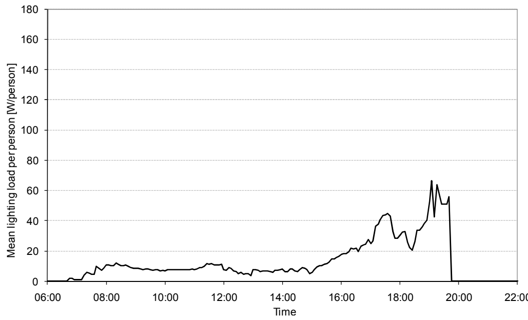


Figure 9-13 Mean lighting load per person over the course of a reference day for all intervals (summer regime 2006), averaged over all zones

9.16 Generic occupancy model and the hourly mean occupancy levels

The generic model of occupancy, averaged over all buildings is in the following graphs (Figure 9-14, Figure 9-15, Figure 9-16 and Figure 9-17) compared with the hourly mean occupancy level and standard deviation for the obversely building.

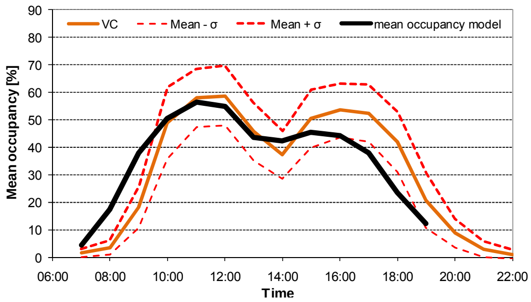


Figure 9-14 Generic model of occupancy, averaged over all buildings compared with the hourly mean occupancy level and standard deviation for VC

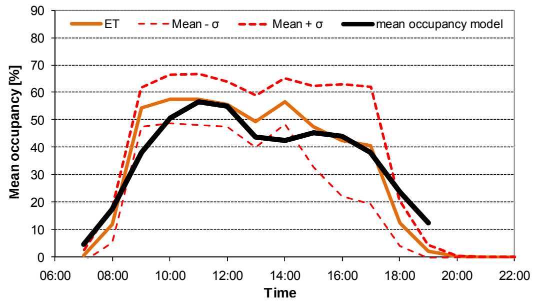


Figure 9-15 Generic model of occupancy, averaged over all buildings compared with the hourly mean occupancy level and standard deviation for ET

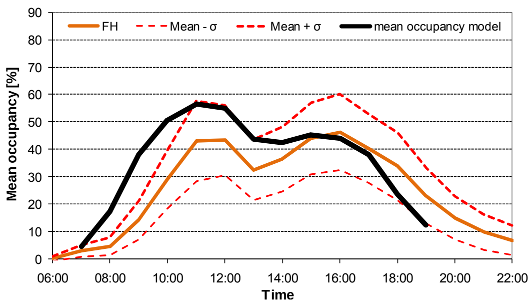


Figure 9-16 Generic model of occupancy, averaged over all buildings compared with the hourly mean occupancy level and standard deviation for FH

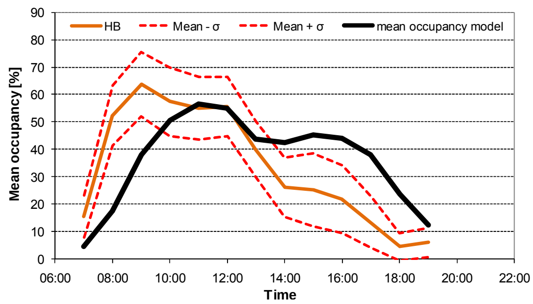


Figure 9-17 Generic model of occupancy, averaged over all buildings compared with the hourly mean occupancy level and standard deviation for HB

Curriculum vitae (CV) Claus Pröglhöf

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Personal Information

born 29.01.1974 in Lower Austria; married, 2 children;

Highlights of Qualification

- Several years of experience in scientific work and research
- Practical experience in planning and conducting architectural projects
- Excellent administrative and analytical skills
- Comprehensive software skills
- Proven to work under difficult and tense conditions
- Languages: German (native), English (very good)

Research Areas

Building physics, natural ventilation, user behavior, sustainable architecture

Professional Background

2006 -	Univ.Ass., Department of Building Physics and Building Ecology, Vienna University of Technology, Austria
2004 - 2006	Project Assistant, Department of Building Physics and Building Ecology, Vienna University of Technology, Austria
2001 -	Member of the architectural planning group "team_em"; renamed to "ertlundhenzl architektur"
1998 – 1999	European Community Monitor Mission (ECMM): Served as Observer in Bosnia and Herzegovina (BiH) from November 1998 to Mai 1999

Educational Background

2004 -	PhD Student, Department of Building Physics and Building Ecology, Vienna University of Technology, Austria
2004	Dipl.-Ing., Vienna University of Technology, Austria
1992 – 1993	National service at the Austrian Armed Forces, Officer's course
1992	BRG Rechte Kremszeile in Krems, Lower Austria, Austria