Solar Heating & Cooling Programme

International Energy Agency

IEA Task 21

Daylight in Buildings

DAYLIGHT RESPONSIVE LIGHTING CONTROL - CASES

International Energy Agency
Task 21, Subtask B
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CONTENTS

Contributors to these case studies:

Laurens Zonneveldt	**TNO-TU Eindhoven**
Heiko Belendorf	**TU Berlin**
Bjørn Brekke	**SEFAS**
Catherine Laurentin	**ENTPE**
Shauna Mallory-Hill	**TNO-TU Eindhoven**
Ferdinando Raponi	**ENEA**
Frans Taeymans	**Etap Lighting**
Ariadne Tenner	**Philips Lighting**
Martine Velds	**TU Delft**

Participating institutions, IEA Task 21, Subtask B

TNO-TUE
Centre for Building Research
P O Box 513
5600 MB Eindhoven, The Netherlands

Philips Lighting BV
P O Box 80020
5600 JM Eindhoven, The Netherlands

Etap Lighting N.V.
Antwerpsesteenweg 130
B-2390 Malle, Belgium

Technische Universität Berlin
Institut für Elektronik und Lichttechnik
FG Lichttechnik, Sekr. E6
Einsteinufer 19
10587 Berlin, Germany

Delft University of Technology
Faculty of Architecture
P O Box 5043
2600 GA Delft, The Netherlands

ENEA, SIRE
Systems and Components for Energy Savings
Casaccia
00060 S.M. di Galeria, Roma, Italy

ENTPE/DGCB
Rue Maurice Audin
69518 Vaulx-en-Velin, Cedex, France

SEFAS
7491 Trondheim, Norway

Helsinki University of Technology
Otakaari 5 A
02150 Espoo, Finland

CASE 1

PHILIPS LIGHTING, EINDHOVEN (NL), LUXSENSE

1. Control System

Name: **Luxsense**
Manufacturer: Philips Lighting
Sensors: luminance measurement below the sensor (combination daylight and artificial light)
Strategy: closed loop, proportional
Characteristics: luminaire mounted system, sensor directly connected to HF-ballast, 0-10V control

2. Test facility

Name: Philips Lighting
Address: Mathildelaan, Eindhoven, The Netherlands

3. Test room

The test office is located at the ground floor (1m above street level) of a single story building in Eindhoven, The Netherlands. The window is facing west, with a view out that is partially obstructed by a low storage building (height 3m above street level) at a distance of 5 m. A drawing and pictures of the room are shown in the figures. The building facade contains a window area reaching from 0.9m to 4m above the floor over the total width of the room. A false ceiling is installed at 2.8m above the floor. The room is 3.65 m wide and 5.4 m long. It has light walls (r = 0.8), grey carpet (r = 0.1), and a white ceiling (r = 0.8). The window contains clear double glazing.

The "standard" furniture is placed in a "standard" way, with a desk and a conference table as is shown in figure 1. When the office is used by a subject it contains office equipment, such as a telephone, a personal computer (network connection has been provided), and a printer if needed.

The office is furthermore "decorated" with posters at the walls and a small cupboard to make the office look as realistic as possible.

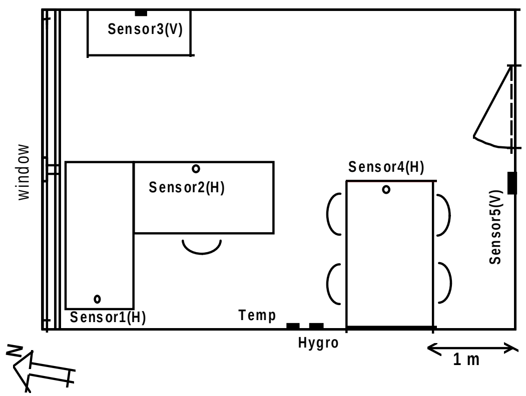


Figure 1: Layout of the room, including the position of the sensors.

*Figure 2: Photograph of the Philips test roo*m.

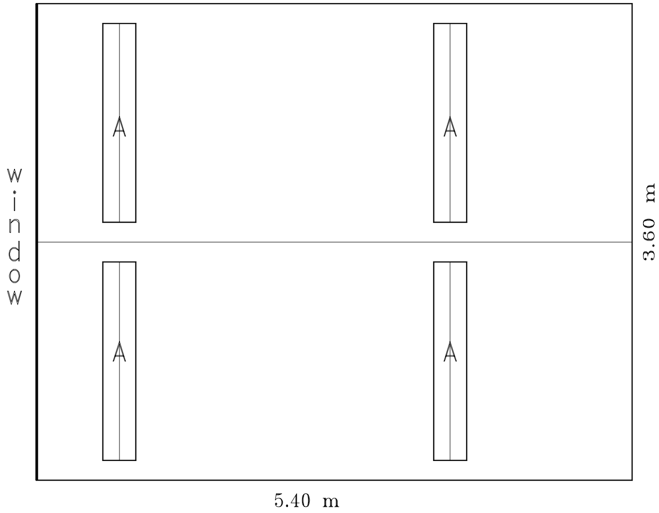


Figure 3, luminaire positions

4. Installation

For the artificial lighting a direct/recessed system has been installed (figure 3).
This system consists of four luminaires of the Philips type TBS 300/2.50 M6 (twin-lamp luminaires with mirror optics), which are recessed in the ceiling. This is considered to be a “standard Western European” lighting solution. The luminaires contain 2 fluorescent lamps, operating on high frequency ballasts, with a colour temperature of 4000K and good colour rendering (R_a= 80). The lamps are dimmable to 3% of the light output. The artificial illuminance at the desk has a maximum value of 1000 lx.

This control system has a photocell and automatic daylight linked dimming in each luminaire, the commercial type name is Luxsense. The luminance of the relevant area underneath the luminaire is controlled; the lamps are dimmed when the luminance exceeds a certain value. The system runs automatically without possibility for the user to adjust anything except for the blinds, which could be controlled manually.
Data are collected with a specially developed piece of equipment, a combination of a data logger and a control unit, which can be programmed and read out by means of a PC.
Illuminance is measured every minute at several positions in the room. Horizontal illuminance is measured at the desk, and at the conference table,

vertical illuminance is measured at the wall in front of the desk, behind the desk and at the rear wall, next to the door, all at “eye level” (1.5m above the floor).

5. Tests

The subjects were asked to work several days in the office. They brought their own PC and their own work. They were instructed to fill in the questionnaire every half-hour. Overruling of the control was not possible, only the blinds could be adjusted. The sensors were tuned to 800 lx at the working plane. This was the lowest possible value with the lighting installation because there were 4 twin lamp 58 Watt luminaires installed.
The experiment has been running during 14 days, with 3 different subjects (2 males, age 44 and 57 and 1 female, age 23). Of these 14 days 5 days had completely overcast skies, 2 had clear skies and on the remaining 7 days there was a mixture of blue sky and clouds (mixed).
The Luxsense system tries to maintain a minimum illuminance under the luminaire. The measurements in figure 4 show the illuminance at the desk during the time that the artificial lighting was on. On overcast days in this time of the year (late autumn) the daylight contribution on the desk is less than 800 lx and the artificial lighting can keep the illuminance at a constant level. On clear and mixed days, especially in the afternoon the daylight contribution is higher than 800 lx and the lamps are dimmed by the control system to the minimum light output. The total illuminance increases with the increasing daylight contribution.
Figure 5 shows the illuminance at the conference table. Here the contribution of the daylight is very low and the control system keeps the illuminance nearly always constant.
The users were in general very satisfied with the lighting and the control system. When the sun hit the window, on clear and mixed days in the afternoon, the window was rated to be too bright. And one of the subjects mentioned that the wall with the door was too dark in relation to the rest of the room.
One of the reasons that the users were so satisfied is probably the high illuminance in the room, especially on overcast days. The fact that the luminaires showed different brightnesses was mentioned by one of the subjects, but did not seem to bother him.

6. Monitored parameters

Due to the fact that the luminaire/lamp combination was slightly overdimensioned for the Luxsense system the energy savings are difficult to establish. The installation was never running at full power and therefore no energy saving percentage can be given. In figure 6 the daily averages are show for the total and artificial illuminance as a function of the average daylight contribution.
Figure 7 shows the average power per square meter used per day as a function of the daylight contribution. From this figure it can be seen that the used power drops from 13 W/m^2 to 7 W/m^2 when the average daylight contribution rises from 200 to 1300 lx.

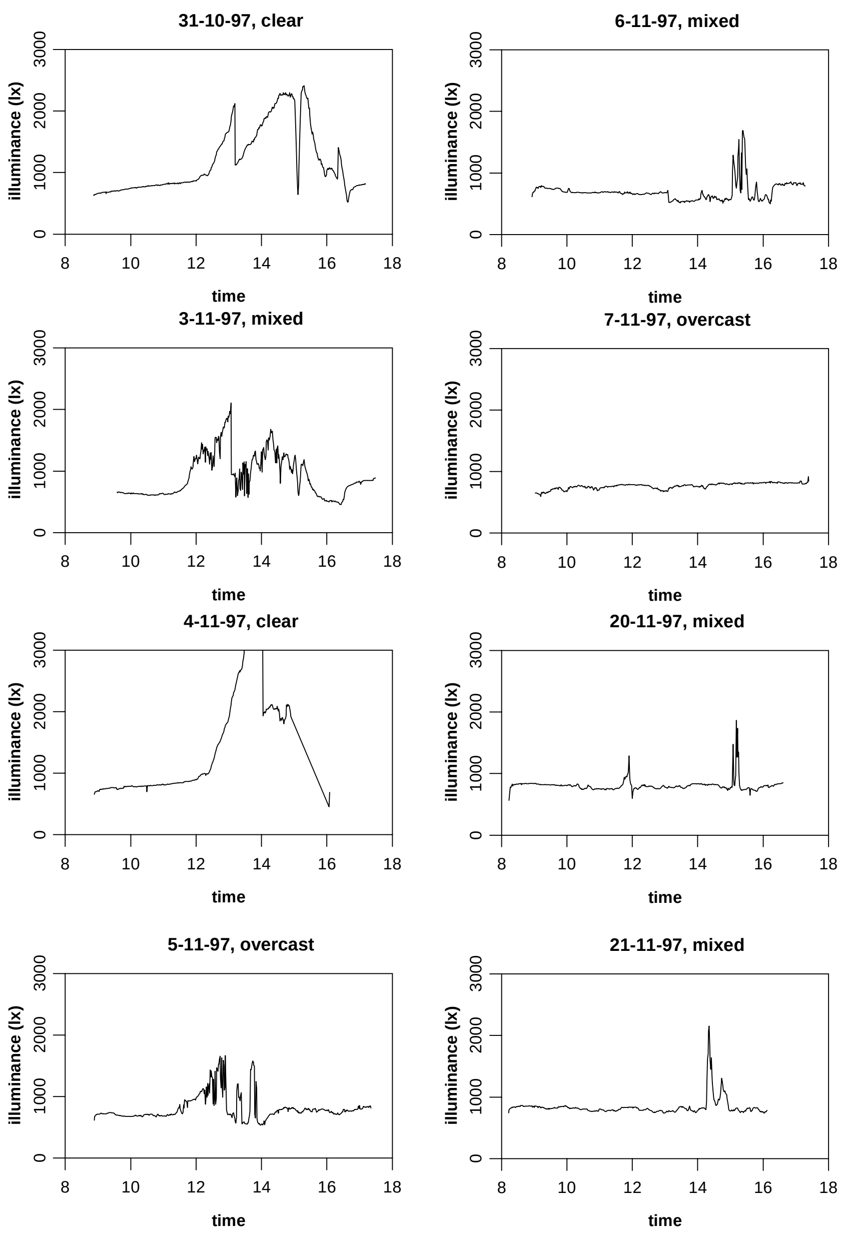
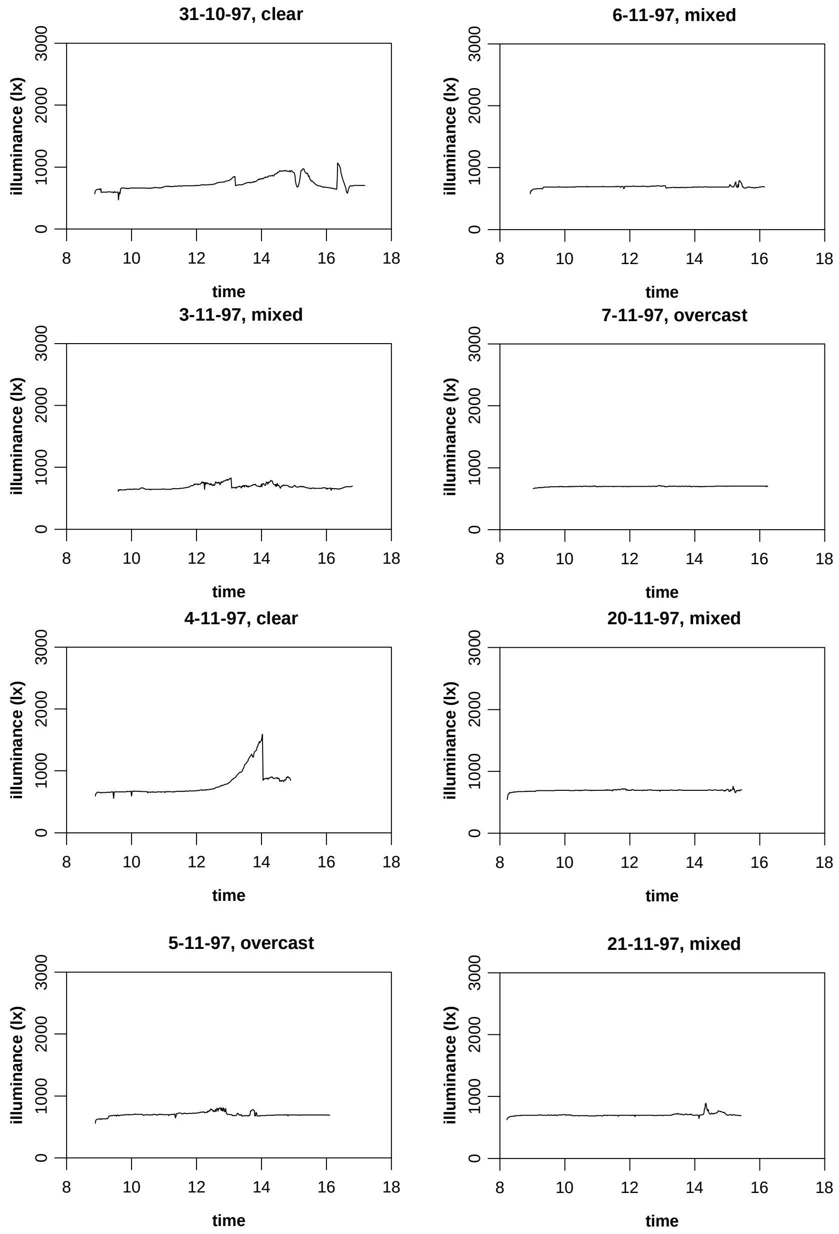


Figure 4: Measured illuminance at the desk as function of time (Luxsense).

Figure 5: Measured illuminance at the table as function of time (Luxsense).



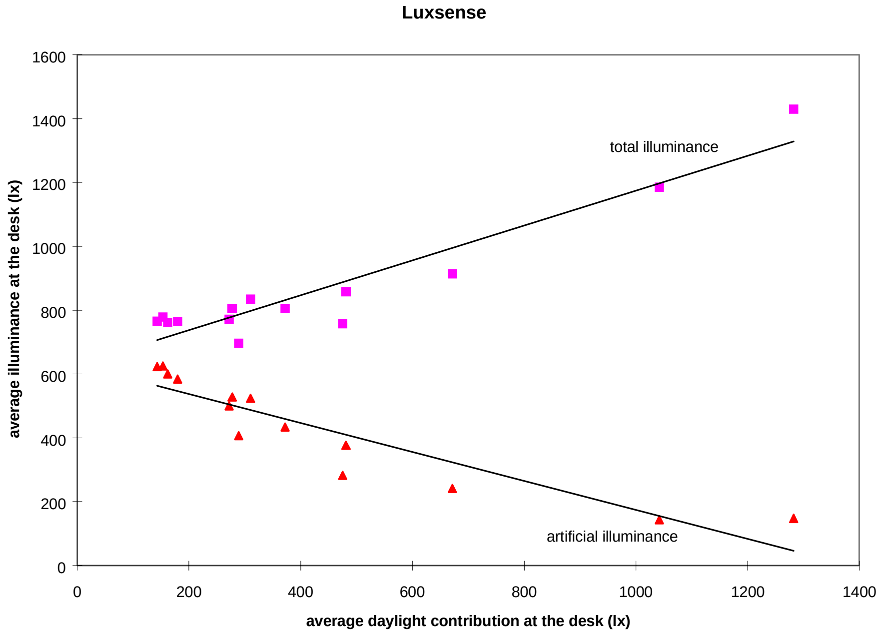


Figure 6, average total illuminance and average artificial illuminance as a function of the daylight

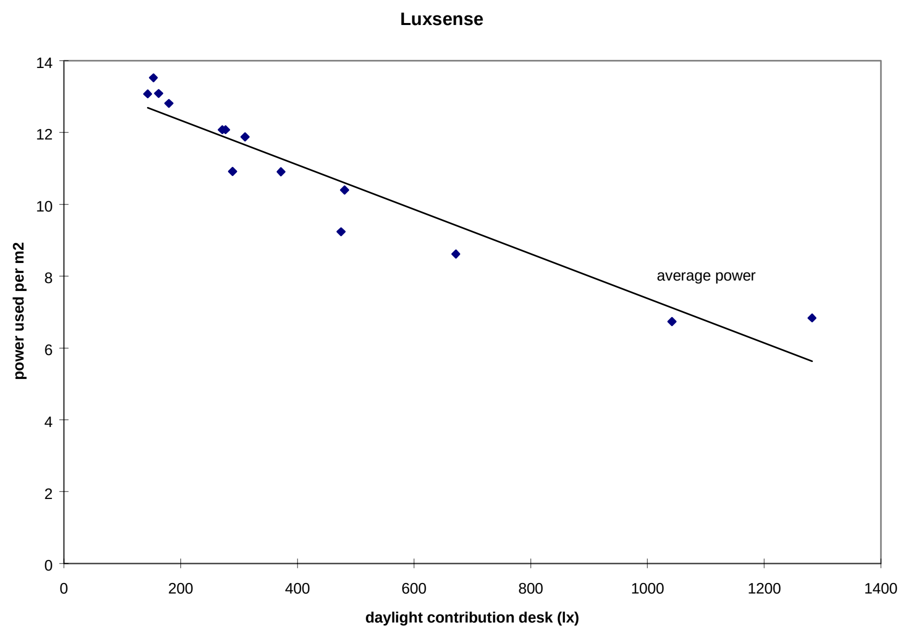


Figure 7, average used power per m² as a function of the daylight contribution

CASE 2

PHILIPS LIGHTING, EINDHOVEN (NL), TRIOS

1. Control System

Name: **Trios**
Manufacturer: Philips Lighting
Sensors: luminance measurement below the sensor (combination daylight and artificial light)
Strategy: closed loop, constant holder
Characteristics: room based system, one sensor per room, connected to luminaires, 0-10V control, hand-held infrared remote control

2. Test facility

Name: Philips Lighting
Address: Mathildelaan, Eindhoven, The Netherlands

3. Test room

The test office is located at the ground floor (1m above street level) of a single story building in Eindhoven, The Netherlands. The window is facing west, with a view out that is partially obstructed by a low storage building (height 3m above street level) at a distance of 5 m. A drawing and pictures of the room are shown in the figures. The building facade contains a window area reaching from 0.9m to 4m above the floor over the total width of the room. A false ceiling is installed at 2.8m above the floor. The room is 3.65 m wide and 5.4 m long. It has light walls (??= 0.8), grey carpet (? = 0.1), and a white ceiling (? = 0.8). The window contains clear double glazing.
The "standard" furniture is placed in a "standard" way, with a desk and a conference table as is shown in figure 1. When the office is used by a subject it contains office equipment, such as a telephone, a personal computer (network connection has been provided), and a printer if needed.
The office is furthermore "decorated" with posters at the walls and a small cupboard to make the office look as realistic as possible.

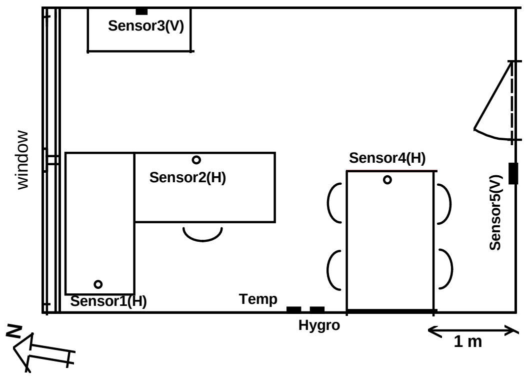


Figure 1: Layout of the room, including the position of the sensors

Figure 2: Photographs of the Philips test room

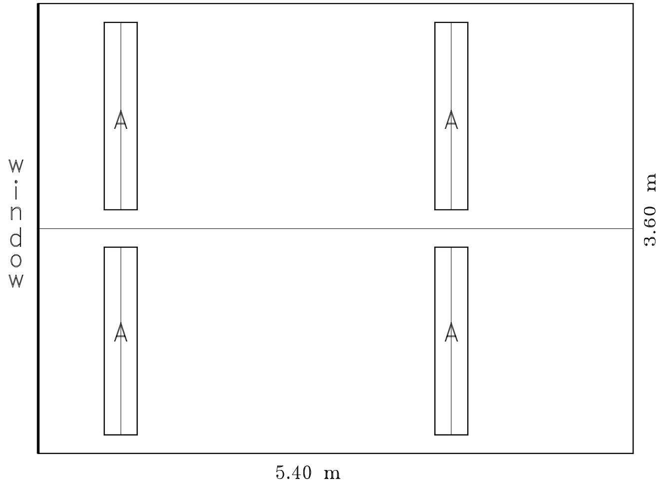


Figure 3, luminaire positions

4. Installation

For the artificial lighting a direct/recessed system has been installed (figure 3).
This system consists of four luminaires of the Philips type TBS 300/2.50 M6 (twin-lamp luminaires with mirror optics), which are recessed in the ceiling. This is considered to be a “standard Western European” lighting solution. The luminaires contain 2 fluorescent lamps, operating on high frequency ballasts, with a colour temperature of 4000K and good colour rendering (R_a= 80). The lamps are dimmable to 3% of the light output. The artificial illuminance at the desk has a maximum value of 1000 lx.

The control system is a room-based system. There is one sensor mounted at the ceiling above the desk. The light output of all the lamps is regulated according to the luminance measured. The user of the room cannot adjust the lighting, but can adjust the venetian blinds. It turned out that it was necessary to allow the users to adjust the blinds, because when the sun shines into the office during the afternoon it is impossible to do any work without closing the blinds.
Data are collected with a specially developed piece of equipment, a combination of a data logger and a control unit, which can be programmed and read out by means of a PC.
Illuminance is measured every minute at several positions in the room. Horizontal illuminance is

measured at the desk, and at the conference table, vertical illuminance is measured at the wall in front of the desk, behind the desk and at the rear wall, next to the door, all at "eye level" (1.5m above the floor).

5. Tests

The subjects were asked to work several days in the office. They brought their own PC and their own work. They were instructed to fill in a questionnaire every hour. Overruling of the control was not possible, only the blinds could be adjusted.
The sensor was tuned to 1200 lx at the working plane. This was the lowest possible value with this installation. There are 4 twin lamp 58 Watt luminaires installed.
The experiment has been running during 16 days, with 3 different subjects (2 males, age 44 and 54 and 1 female, age 23). Of these 16 days 6 days had completely overcast skies, 1 had clear skies and on the remaining 9 days there was a mixture of blue sky and clouds (mixed).
The Trios system tries to maintain a minimum illuminance at the desk. The measurements in figure 4 show the illuminance at the desk during the time that the artificial lighting was on. On overcast days in this time of the year (spring) the daylight contribution on the desk is less than 1200 lx and the artificial lighting can keep the illuminance more or less at a constant level. On clear and mixed days, the contribution of the daylight exceeds 1200 lx and the lamps are dimmed by the control system to the minimum light output. The total illuminance increases with the increasing daylight contribution. On mixed days when the daylight illuminance changes frequently the system does not keep the illuminance at a constant level.
Figure 5 shows the illuminance at the conference table. Here the contribution of the daylight is very low. Because the control system has its sensor above the desk the illuminance on the conference table is changing and lower than the illuminance at the desk.
The users were in general satisfied with the lighting and the control system. When the sun hit the window, on clear and mixed days in the afternoon, the window was rated to be too bright. In the afternoon the desk illuminance and the wall illuminance (especially near the door) is rated as too low.

6. Monitored parameters

One of the reasons that the users were satisfied is probably the high illuminance in the room. The Trios system sometimes overestimates the amount of daylight, which results in a too low total level, which is rated too low by the users.
Because of the higher than normal illuminance the energy savings of the daylight-linked control cannot be calculated.
In figure 6 the daily averages are show for the total and artificial illuminance as a function of the average daylight contribution.
Figure 7 shows the average power per square meter used per day as a function of the daylight contribution.

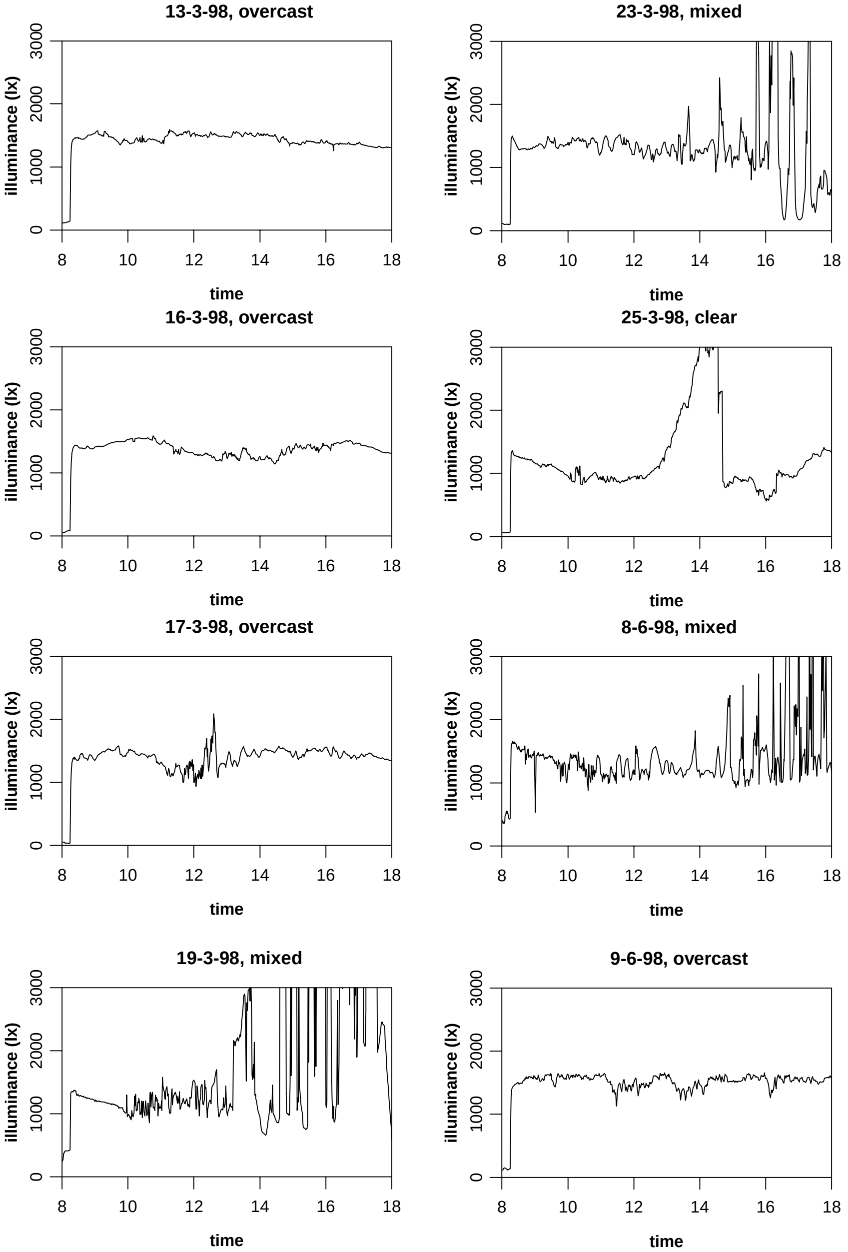
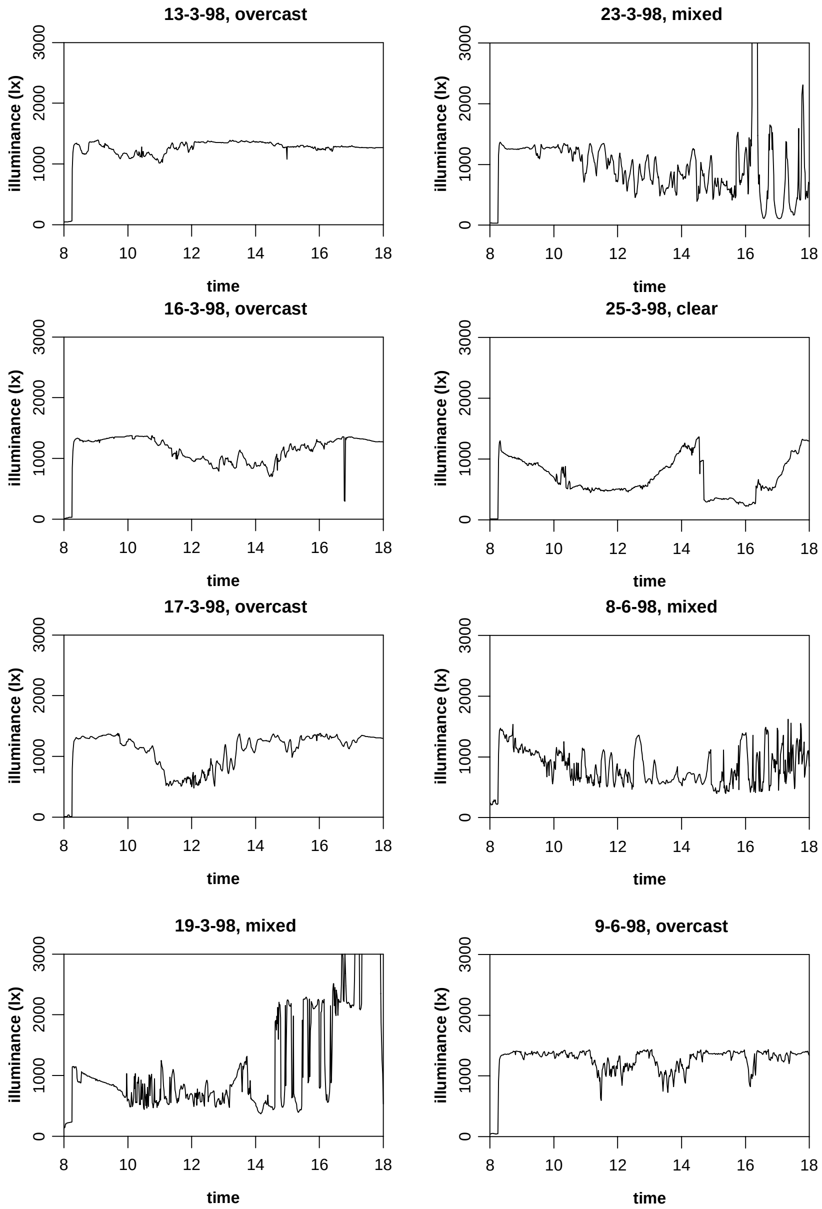


Figure 4: Measured illuminance at the desk as function of time (Trios).

Figure 5: Measured illuminance at the table as function of time (Trios).



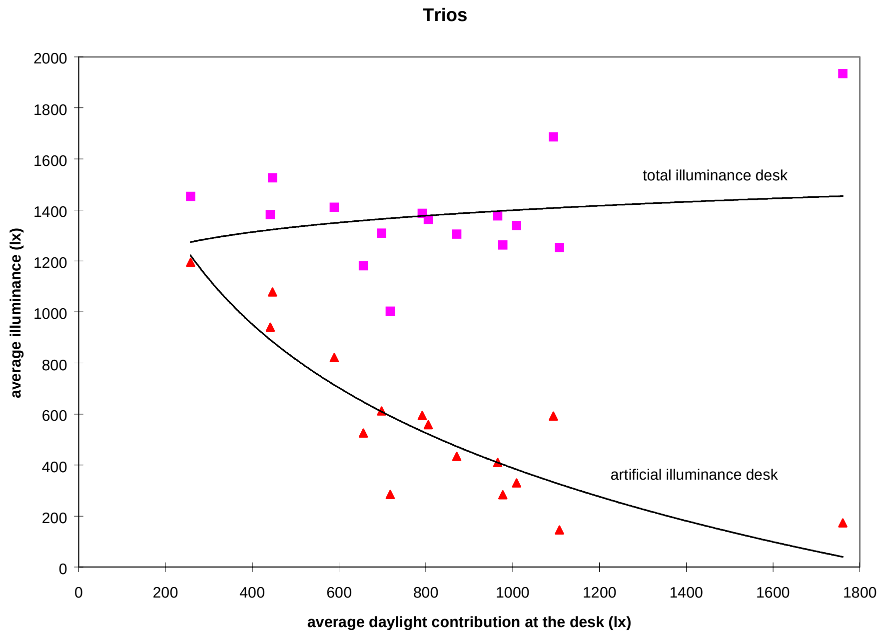


Figure 6, average total illuminance and average artificial illuminance as a function of the daylight contribution

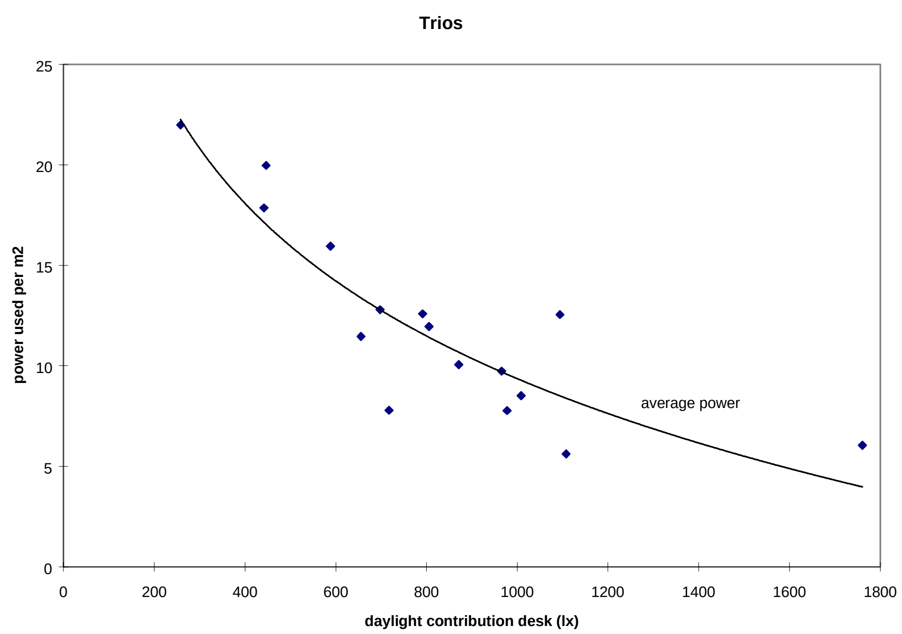


Figure 7, average used power per m² as a function of the daylight contribution

CASE 3

OFFICE ROOM ON THE CORNER OF A BUILDING IN MALLE (BELGIUM)

1. Control system

Name ELS
Manufacturer ETAP
Functions: daylight responsive lighting control
Sensors: daylight/artificial light/~~occupancy~~
Strategy: evaluate aspects of monitoring protocol

2. Test lab

Company: ETAP NV, Antwerpsesteenweg 130, B-2390 MALLE, Begium
Test person: Dhr. F. Taeymans

3. Test room

The office room used for this test is a corner room with windows in the West and South facade. The plan is shown in figure 1.

The room dimensions are:

Width (along the South facade)	5.3 m
Depth (along the West façade)	5.3 m
Ceiling height	2.7 m
Sill height	0.6 m
Window height	2.0 m

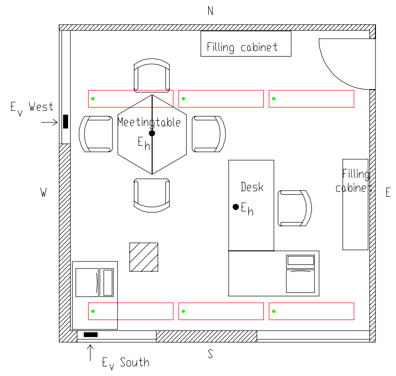


Figure 1: Test room in Malle.

Table and desk height	0.75 m
Cabinet height	0.95 m

The (diffuse) reflectivity factors of room surfaces are:

Walls (without paintings etc.)	80 %
Ceiling	80 %
Floor	20 %

5. Test periods

The measurements started in week 7 on 13th of February . 1997. The end of the measurements was in week 11 on 24th of March 1997.

Figure 2 Radiance rendering of the test room.

Table 1 Overview of the weather conditions during the measurements.

Week	7 - 97	8 - 97	9 - 97	10 - 97	11 - 97
Mon		overcast	overcast, rain	sunny	sunny
Tue		overcast some breaks	overcast,	overcast	morning misty, afternoon clear
Wed		overcast, showers	overcast, some breaks	changing	morning misty afternoon clear
Thu	changing	clear	overcast	overcast, afternoon some sun	clear, later overcast
Fri	changing	changing	sunny	sunny	clear, later overcast
Sat	fair, light overcast	sunny, clear	sunny, daylight only	sunny	
Sun	fair, light	sunny, clear	sunny,		

6. Monitored parameters

6.1 Light distribution of the test room

Overcast day
The following graphs show the typical behavior of the used control system for ‘typical’ sky conditions. The first one shows what happens on an overcast day. The vertical illuminance on the windows (top lines) is relatively low and strongly varying. The illuminance on the table and the desk (due to daylight in combination with electric light) is kept constant by the controls at the desired level of 500 lux.

Partly cloudy sky
Graphs 5 and 6 show the typical behavior of the used control system for an partly overcast day. The vertical illuminance on the windows (top lines) is high and strongly varying. The illuminance on the table and the desk is kept constant for most of the time at the desired level of 500 lux.

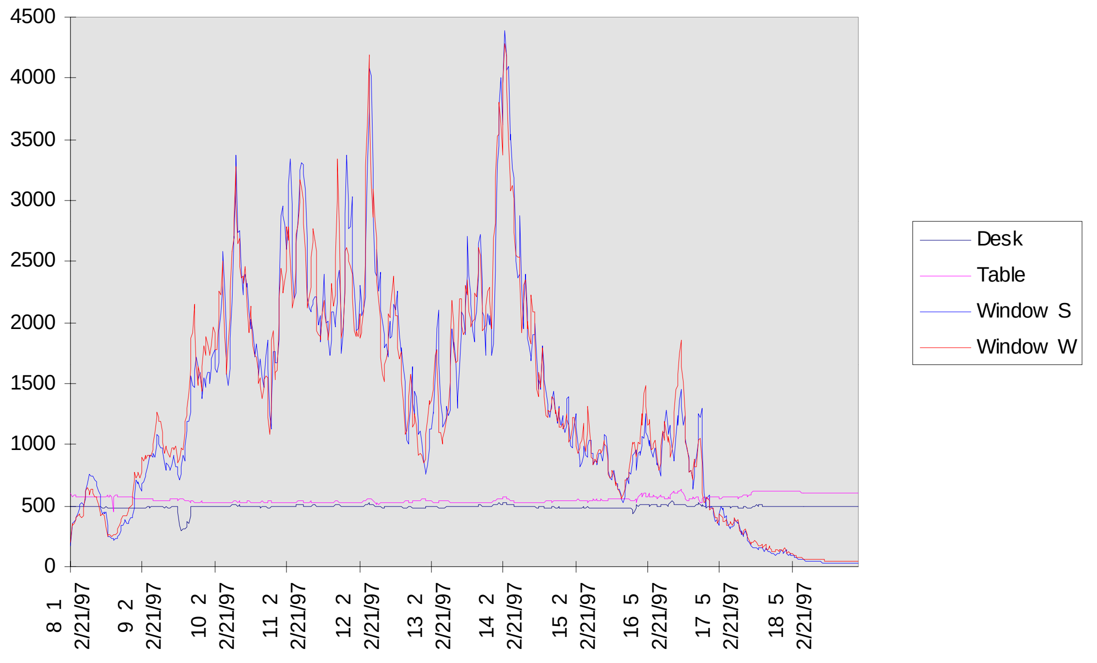


Figure 3 Behavior of the lighting on an overcast day.

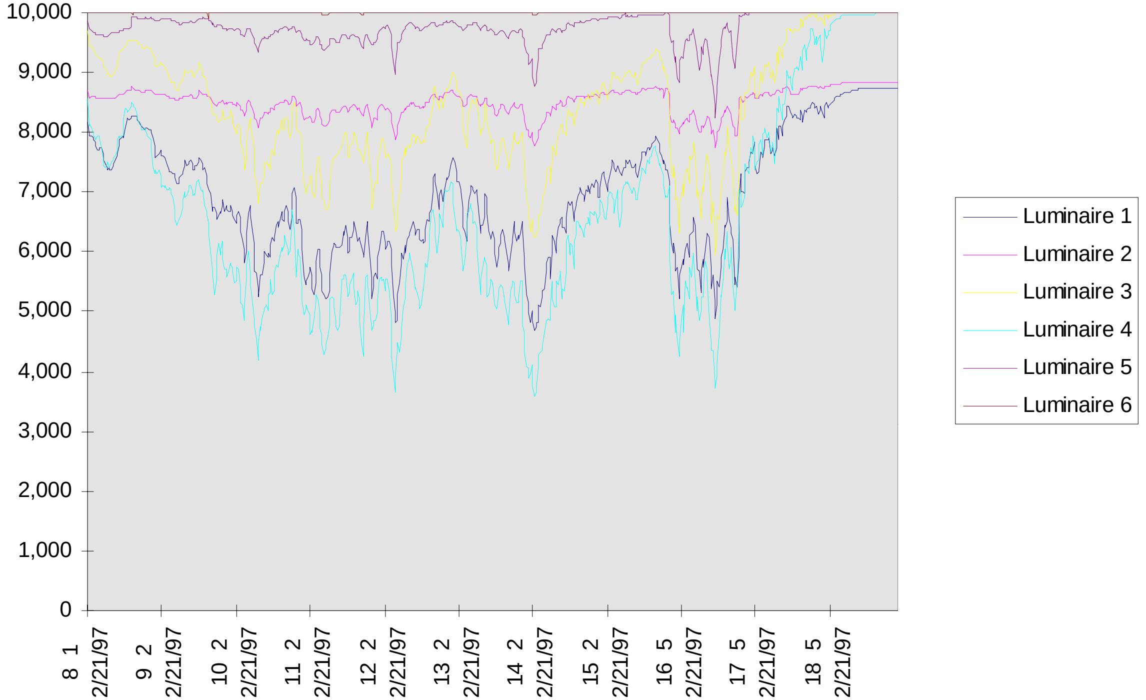


Figure 4 Voltage over regulator for six luminaires

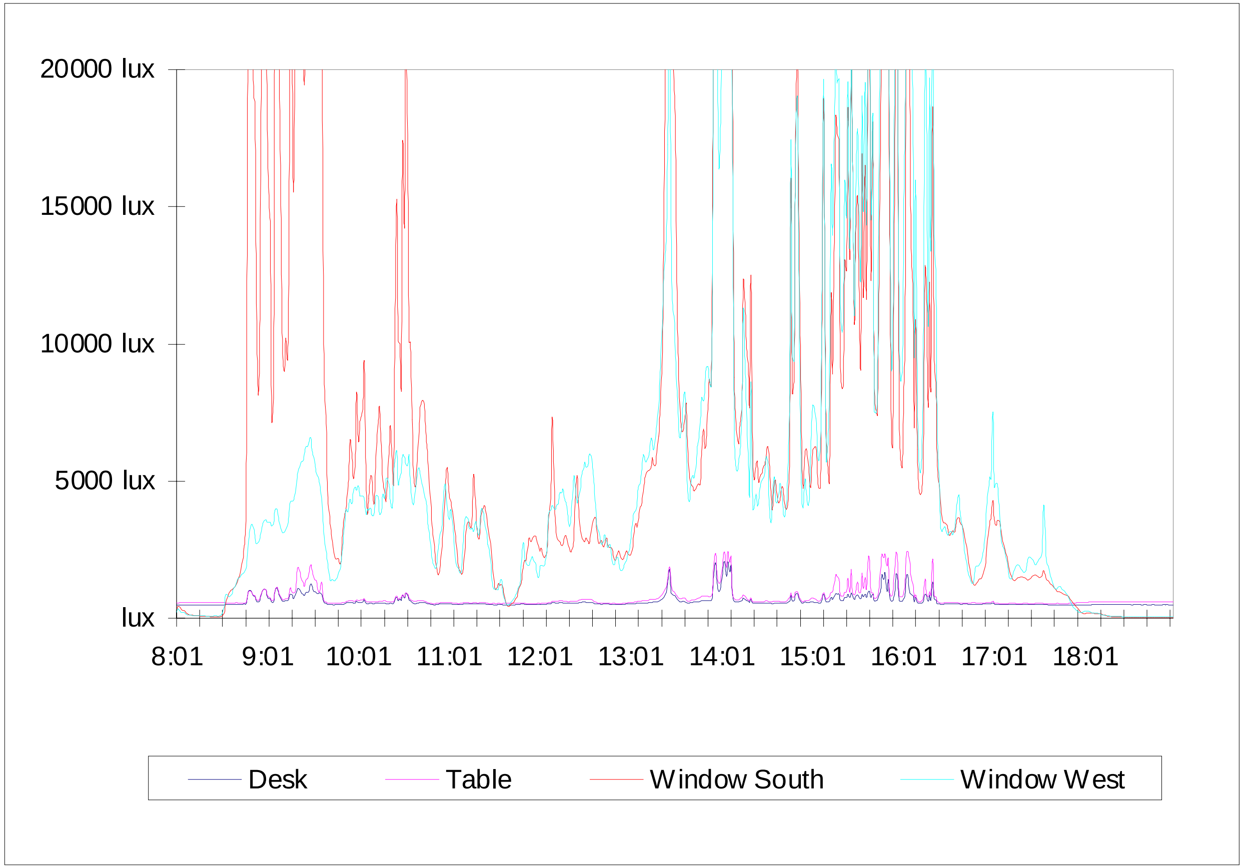


Figure 5 Lighting behavior on a partly overcast day.

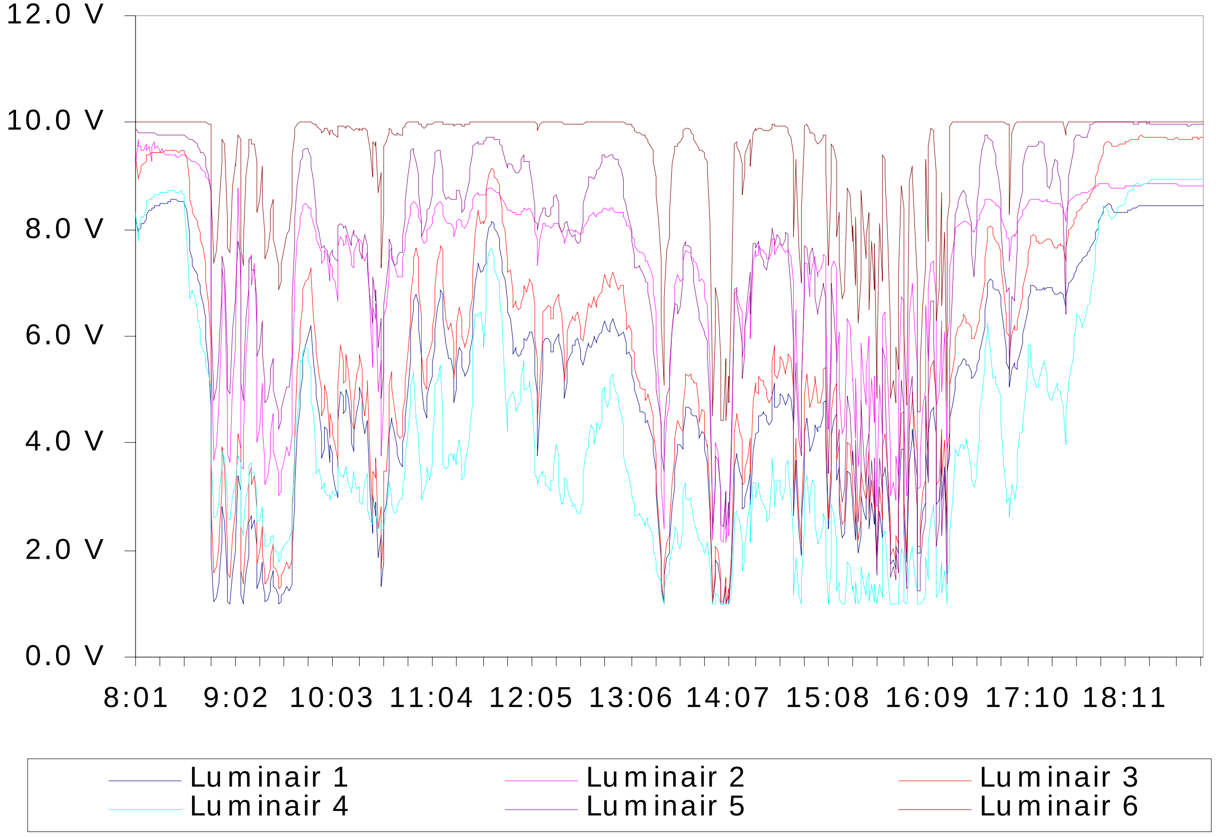


Figure 6 Voltage over regulator for six luminaires

CASE 4

LONG-TERM ENERGY MEASUREMENTS IN AN OFFICE ROOM IN BREDA (NL)

1. Control system

Name ELS
Manufacturer ETAP
Functions: daylight responsive lighting control
Sensors : daylight/artificial light~~/occupancy~~

2. Test lab

Company: ETAP B.V., Tinstraat 7,
NL-4823 AA BREDA, The Netherlands
Test person: Mr. W. Sliepenbeek

3. Test room

The room is located on the first floor of a free standing office building in industrial area on the west side of Breda. The plan of the room (including furniture and luminaire positions) is shown in figure 1.

The room dimensions are:
Width (along the South facade) m
Depth (along the West façade) m

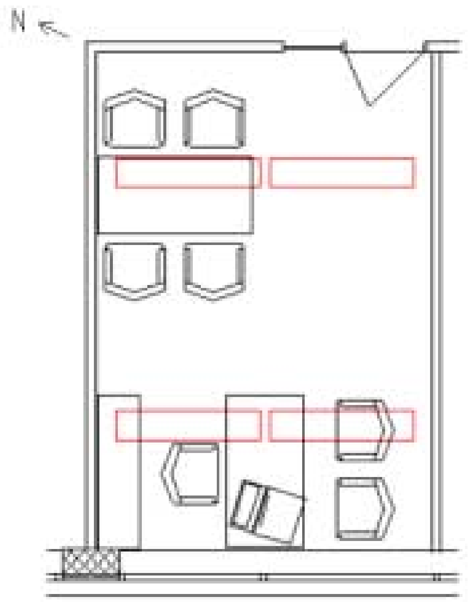


Figure 1: Plan of the office in Breda.

Ceiling height m
Sill height m
Window height m
Table and desk height m
Cabinet height m

The (diffuse) reflectivity factors of room surfaces are:
Walls (without paintings etc.) %
Ceiling %
Floor %

Figure 2: Photograph of the testroom in Breda.

A photo of the room is shown in figure 2. It is a standard office room with a standard layout: a desk near the window and a table for meetings in the back of the room.

5. Test periods

This case is an example of a long-term evaluation of a daylight responsive lighting control system. The results show the variations in weekly energy use for the lighting system, divided in two zones.

6. Monitored parameters

6.1 Light distribution of the test room

Monitoring is done using two kilowatt-hour meters and a timer measuring the total number of hour of use. To avoid an uneven or unrepresentative distribution of the use over the day or year, o clock is used to switch the lighting on at 8:00 am and off at 6:00 pm.. The data are read once a week and recorded in a logbook for further processing.
The results of the measurements show that the

savings can differ from week to week. This type of measurement is very easily performed but gives a lot of useful information. In this case is shows that the overall energy savings are considerable. There is as may be expected quite a difference between the results for the window zone and the second zone in the back of the room. But also in the inner zone the results show that the control system will save a considerable amount of energy.

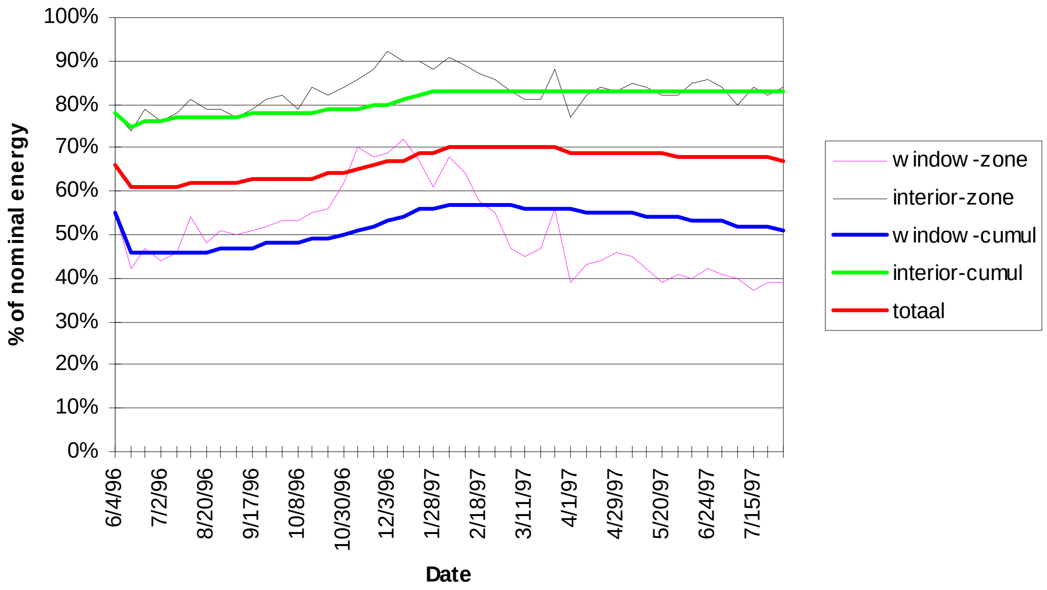


Figure 3: The results of the energy monitoring over more than one year.

CASE 5

OFFICE ROOM ON THE WEST FAÇADE OF A BUILDING IN EINDHOVEN (NL)

1. Control system

Name Luxsense
Manufacturer: Philips
Sensors: luminance measurement below the sensor(combination daylight and artificial light)
Strategy: closed loop, proportional
Characteristics: luminaire mounted system, sensor directly connected to HF-ballast, 0-10V control

2. Test lab

Company: CBO-TNO-TUE, Den Dolech 2
NL-5612 AZ EINDHOVEN, The Netherlands
Test person: Mr. L. Zonneveldt

3. Test room

The room has light colored matte finishes on the walls and ceiling with dark blue carpeting on the floor. Electric lighting in the test room utilizes the new energy efficient Philips T5 lamp.

Figure 1: Building and façade of the testroom

The room dimensions are:

Width	3.6 m
Depth	4.9 m
Ceiling height	2.6 m
Sill height	0.9 m
Window height (not continuous)	1.7 m
Table and desk height	0.75 m

The (diffuse) reflectivity factors of room surfaces are:

Walls (without paintings etc.)	70 %
Ceiling	70 %
Floor	30 %

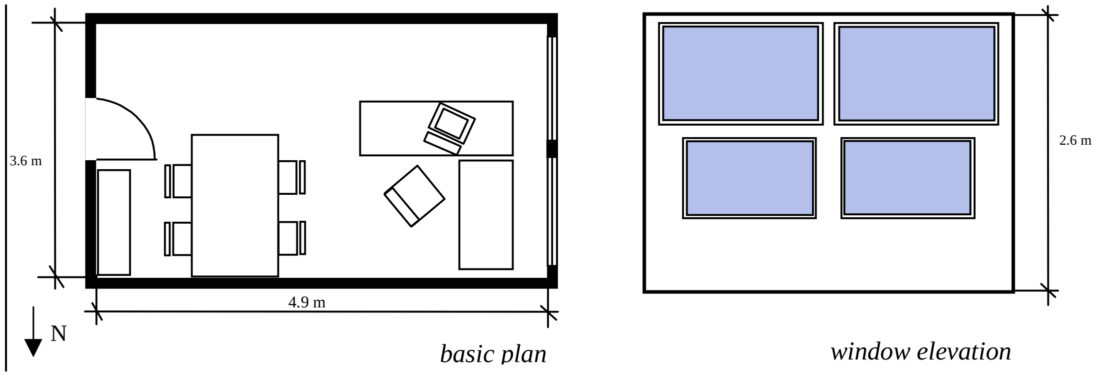


Figure 2: Basic plan and window elevation of both test rooms.

4. Installation

The test room contains a system developed by the CBO-TNO-TUE. It uses a combination of direct and indirect sources for both daylight and electric light. Daylight is directed towards the ceiling by standard light-coloured horizontal venetians. Electric lighting is provided by four pendant direct-indirect luminaires. All four luminaires have a light sensor pointed at the work surface automatically adjusting the illuminance at the work surface to approximately 500 lux.

6. Monitored parameters

6.1 Light distribution of the test room

To collect data about the two different systems an identical configuration of six sensors according the IEA Task 21 Monitoring Procedures is used. Two sensors are placed at eye level on the walls, (one on the back wall and the other near the window). Three sensors are placed on work surface height (one in the daylight zone, one in the inner zone, and one in the intermediate zone). One sensor is placed vertically on the window to measure the exterior light level.

6.4 Energy savings

See fig ure 4.

Figure 3 Photograph showing the test room.

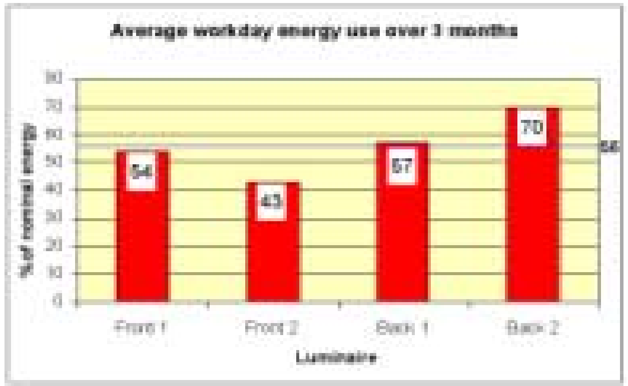


Figure 4.

CASE 6

HUT LIGHTING LABORATORY

Objective

The objective of this experiment is to measure the capability of daylight responsive lighting control systems and to establish the energy savings provided by the systems. The test of both control systems was carried out in July-August 1999.

1. Control systems

ETAP
Name of the system: ELS
Description of lighting applications: artificial light control
Wiring: twisted pair
Control strategy: closed loop
Electrical characteristics: the system is directly connected with each luminaire and send a signal 0-10V to the HF ballast.

Helvar
Name of the system: MIMO 2
Description of lighting applications: artificial light control
Wiring: twisted pair
Control strategy: closed loop
Electrical characteristics: the system is directly connected with each luminaire and send a signal 0-10V to the HF ballast.

2. Test lab

HUT Lighting Laboratory
P.O. Box 3000, FIN-02015 HUT, Finland

3. Test room

The test room was a typical small office room (fig. 1) situating on the ground floor of a 4 floor office building. The dimensions of the room were; length 4,0m; width 2,4m and height 2,7m. The vertical window with double glazings faced to west. Window size; h 1,33m;w 1,53m.

Figure 1, View of the test room

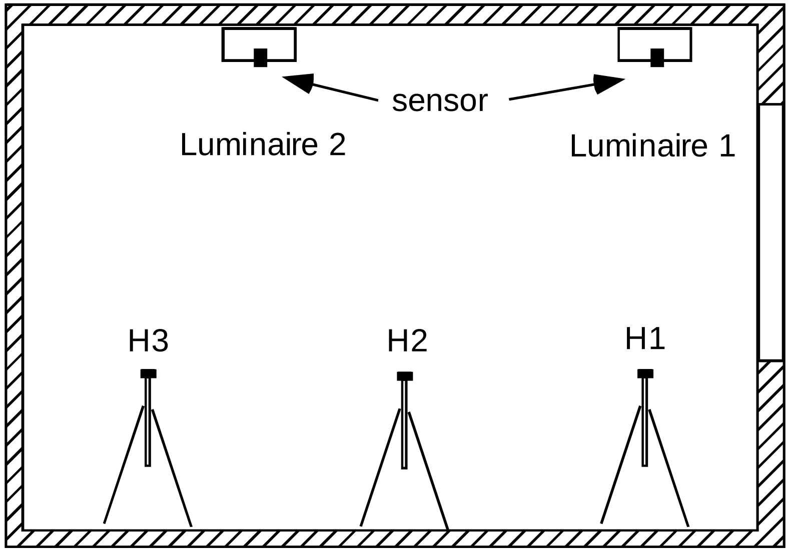


Fig. 1. Test room layout

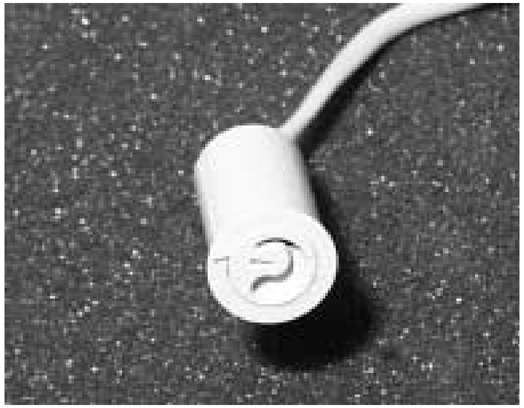
No venetian blinds were used under the test, because the room was unoccupied.
Luminaires: Idman 1x58W with white painted lamels
Number of luminaires: 2
Lamps: Philips TLD 58W/84, CCT 4000 K
Ballasts: Philips HF dimmable 0-10V
The objectives of this experiment are to measure the capability of daylight responsive lighting control systems, and to establish the energy savings provided by the systems. The performance of the system tested is established by experiment in one room without any reference room

4. Installations

a) Els, manufactured by Etap

The system controls the power and light output of the fluorescent lamp(s) per luminaire in accordance with the luminance (brightness) of the surface area illuminated by the luminaire. The system controls the light level with no delay.
Positioning of components: The system is made up of one LDR (Light Depending Resistor) sensor fixed directly on the lamp, facing downwards, and connected to the terminals of the HF ballast.
Calibration: The calibration of the system is very easy.

ETAP ELS



Helvar MIMO 2

It consists on turning the adjusting ring of the sensor. Turning to the left results in a higher lighting level, turning to the right in a lower lighting level.

b) Mimo 2, manufactured by Helvar

The new Helvar MIMO 2 system controls the power and light output of the fluorescent lamp(s) per luminaire in accordance with the luminance (brightness) of the surface area illuminated by the luminaire. The system electronics controls the light level with a delay of few minutes
Positioning of components: The system is made up of one tubular shape sensor and electronics package installed in a luminaire, sensor side facing downwards, and connected to the terminals of the HF ballast.

Calibration: The calibration of the system is very easy. It consists on turning the aperture ring of the sensor. Turning to the left decreases the aperture area and results in a higher lighting level, turning to the right in a lower lighting level.

5. Test periods

Mimo 2 and Els:
Measurements and calibration began in June 99. The outdoor horizontal and vertical (west) illuminances were recorded every day during the four weeks. Summer 99 in Finland was very sunny and clear, so unfortunately no totally overcast day occurred during the test period. The measurements began on 22nd July and stopped on 20th August. For every six minute period, an average was taken from 9 o'clock in the morning to 5 o'clock in the evening to give 80 measurements per day.

6. Monitored parameters

6.1 Light distribution of the test room under overcast sky is presented in fig. 2.

Daylight Factor:

$DF(\%) = 100 * I_{int} / I_{ext}$

I_{int}: Horizontal illuminance level, inside without artificial light
I_{ext}: Horizontal illuminance level, outside on the roof of the building

The measurements and calculations have been done under overcast sky.

6.2 Operational status of the control system

We calculated the illuminance maintenance of the system tested. The illuminance maintenance is the percentage of time when the luminaires never dim under the desired illuminance level.

6.3 Energy savings

The power consumed by the luminaires, for the evaluation of energy savings, was calculated from the recorded control signal values and measurements carried out in the integrating sphere. In the integrating sphere the lumen output and the power consumption over the whole control signal range (0…10V) was

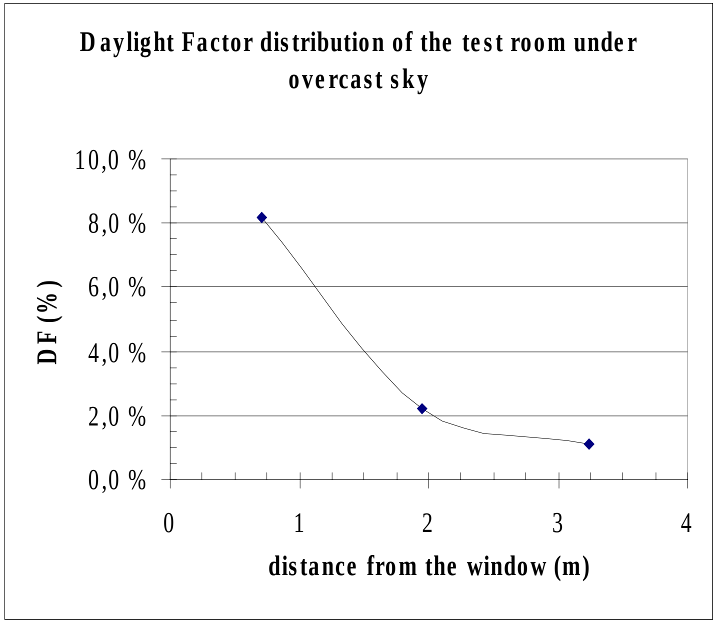


Fig.2. Measured daylight distribution in the test room

measured. From the results functions between measured units and control signal level were determined by using curve fittings. Fitted curves and the calculation formulas are presented in fig. 3.

The energy savings were calculated between 9 a.m. to 5 p.m. The reference power was calculated by using the control signal readings recorded without daylight.

6.4 Measuring instruments

The room was fitted out with three photocells located on the workstations. The locations of the photocells had been chosen according to the IEA monitoring protocol.

The distances (H1, H2, H3) of the photocells from the window are:

H1 = 0,71 m

H2 = 1,95 m

H3 = 3,24 m

Outdoor horizontal and vertical west photocells were located on the roof of building.

A calibration of all the photocells available in the test room and outdoors was made before the experiments.

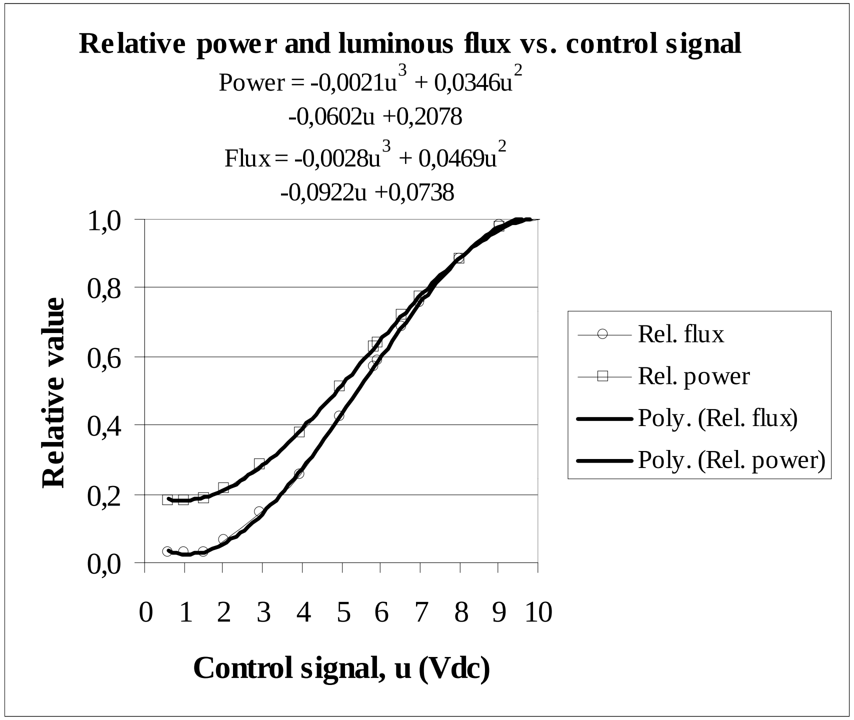


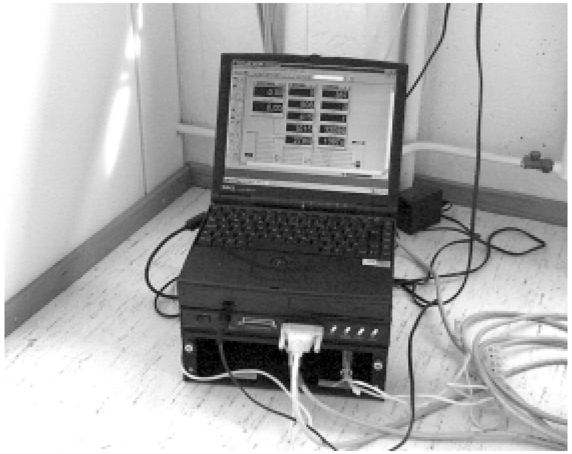
Fig. 3. Light output and power consumption of a 58W fluorescent lamp as a function of the control signal.

The signal sent by the photocells under a constant level of illuminance was measured and verified the coefficient of calibration for each photocell.

Data acquisition system: Iotech Daqbook 200
Photocells: PRC Krochmann

7. TEST RESULTS

With the results of measurements, the artificial light outputs of each luminaires were calculated. Beacause no reference room was used and each luminaire was controlled separately, spatial and temporal distributions of daylight and artificial light in the room is difficult to calculate. In figures 4 and 5 are presented two examples of the relative light outputs under clear sky conditions. Reference level (relative value =1,0) is the measured individual output level of each luminaire with no daylight.



Data acquisition system

8. Power consumption

We determined the energy savings by the comparison between the use of the system tested and the use of same luminaires, lit at the constant output level all the day.
The reference level was the level recorded during night-time without daylight.
With the ETAP system the reference illuminance level in the middle of the room (H2) was just 400 lx although the sensitivity of the control sensors was turned to the minimum. One reason may be the relative light color of the floor. The corresponding control signals were only about 6 Vdc.
With Helvar system it was easy to adjust the control sensors so that the desired 500lx illuminance level was gained. The corresponding control signals were about 7 Vdc

Resuming of energy savings and illuminance maintenance for the all system tested

In table 1 are presented the calculated the average energy savings during the test period, daily between 9 a.m. to 5 p.m. The room is divided only to two areas, daylight and mixed light area, because it was impossible to calculate savings for three areas without reference room measurements and the number of luminaires was only two.

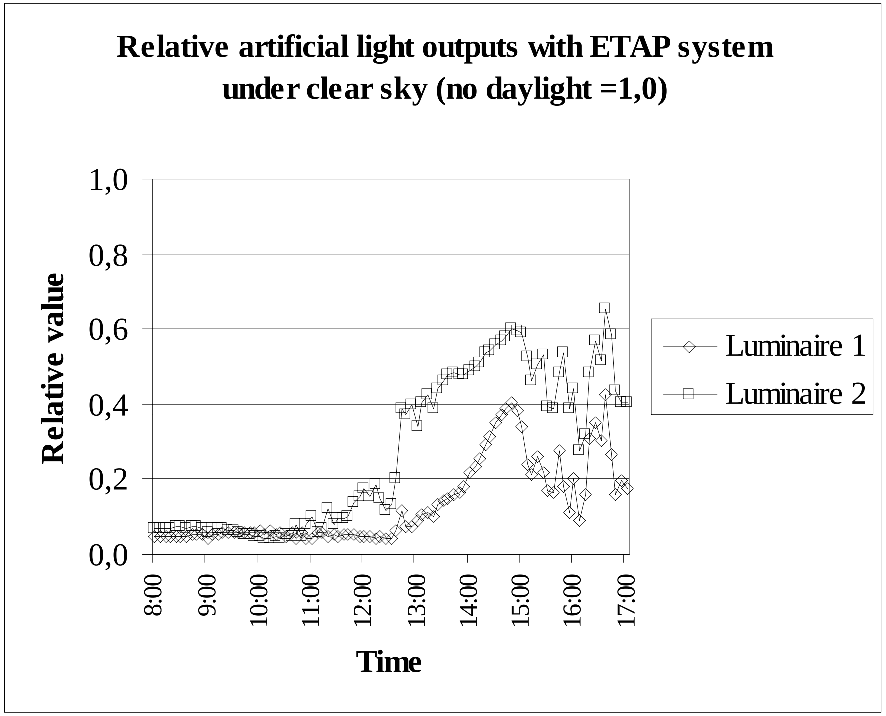


Fig. 4 Relative artificial need per luminaire with Etap ELS system. Reference levels (individual to each luminaire) are measured at night without daylight.

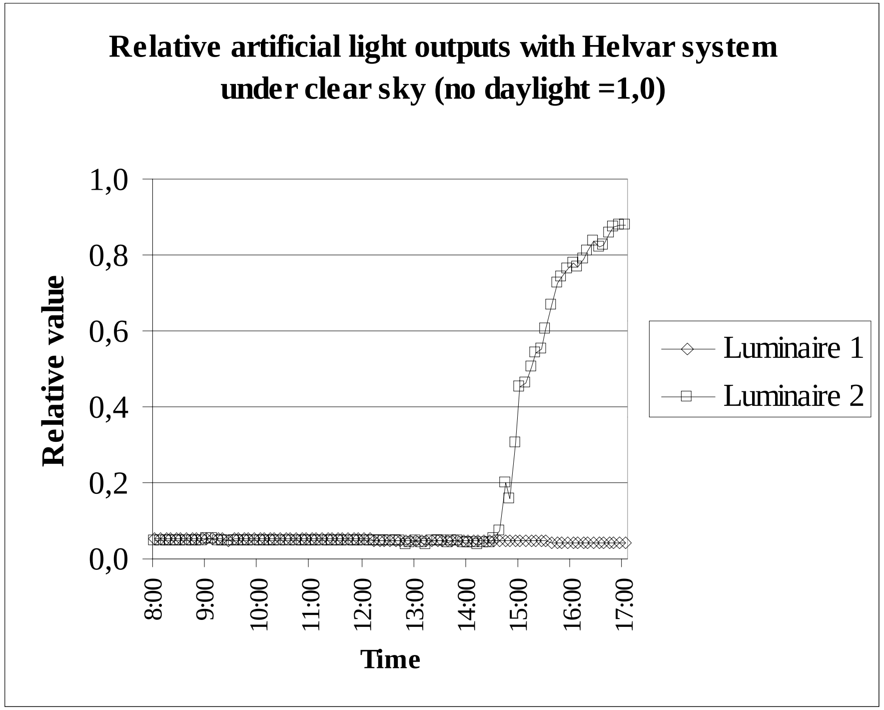


Fig. 5. Relative artificial need per luminaire with Helvar Mimo 2 system. Reference levels (individual to each luminaire) are measured at night without daylight.

Table 1. Calculated average energy savings.

		"Mimo" HELVAR	"Els" ETAP
System		Closed	Closed
Sensor		On the luminaire, facing down	On the luminaire, facing down
Type of ballast		HF ballast	HF ballast
Areas controlled		2	2
Energy savings (%)	Daylight area	74	59
	Mixed light area	60	48
Illuminance maintenance (%)	Daylight area	100	100
	Mixed light area	100	100
Others		No switch off	No switch off

IEA 21

CASE 7

DAYLIGHT PLUS ARTIFICIAL LIGHT RESPONSIVE LIGHTING CONTROL SYSTEM DEVELOPED BY ENEA

Introduction

Italy's primary interest is principally oriented to reduce overheating and glare inside the spaces, while a secondary goal is to use daylight as much as possible.

This choice arises both from the typology of the investigated test room, but above all, from the local climate situation with high values of solar irradiation and because of the absence of external obstructions.

Particularly test room architecture shows aspects typically oriented to the overheating control, i.e.very adsorbent glasses, external fixed shades, internal movable curtains, no reflecting strips along the windows, long and not very high windows.

Because of this very peculiar situation, it is necessary to test a control system which can be integrated with devices, which are normally used to control sun direct irradiation .

This means to control internal vertical louvers and two levels of fluorescent artificial light (at the beginning), then a dimming control of fluorescent lamps will be used to reduce energy consumption.

A survey of daylight responsive control systems made in Italian market (also extended to countries with the same overheating problems, like Spain and Greece) showed that there were no commercial systems.

The abovementioned reasons result in a very rigid framework inside which the participation of Italy can be realized; from a practical point of view the idea of Italy is to follow these main steps, which can be in some aspects not so different from the choices made by the subtask B:

- to develop and build up a non commercial control system mainly orientated to control room overheating, which may be easily implemented with internal louvers and artificial light, see figure2;
- to test the abovementioned non commercial control system with reference to illumination requirements and ability to control artificial lighting in a test room (normally occupied office room), following the task protocol (when it is possible and not in contrast with the room characteristics);
- to compare the test room results with the measurements performed in another room (control room) identical to the test room.

7.1. Control system

Name: EBES (Eight Bit ENEA Control System)
Manufacturer: ENEA
Sensors: daylight/artificial light
Characteristics:
Daylight control: open / closed vertical strips blinds by a "step by step" electric motor- safe guard for left/right

rotation by two optoelectronic sensors (infra-red led transmitter + receiver)

Artificial light control:

stepped systems proportional dimming system controlled by digital signals.

Flexibility : Possibility to change the responsive and to adapt the system to particular requirements by replacing the eprom inside with a new one, supporting the specific software.

Possibility to talk with the system by a serial port, in order to develop a new software on the ram of the system and to test it before ransferring it into the eprom.

Possibility to read the date, time, illuminance (lux), set point (xxx lux) etc. on a liquid crystal display.

This control system developed and built up in ENEA has a significant opportunity to be used for improving energy saving in many offices where an interior vertical-strips-louver is generally installed.

The idea of this self made prototype was originated by the absence of commercial control systems built by the Italian manufacturers and the great diffusion of the above-mentioned louver, used mainly to reduce glare and overheating.

Primary effort has been to build the hardware.

A microprocessor (MC) Intel 8032 was used to build (on a printed circuit with all electronic components) a general-purpose device that can be programmed by a PC connected to a serial port.

This type of microprocessor has three bi-directional (I/O) ports of 8 bits.

In our system we use port 1 to connect the MC 8032 with the other devices.

As we can see by the block diagram in figure 1, a shielded light sensor is on the ceiling of the room; it has a field of view sufficient to give a good correlation with the work plane illumination without noise of direct light.

A little amplifier fitted in this sensor gives an output signal of good level (max 5 volts) for an analogic/ digital converter, so that the MC 8032 can see this level and the algorithm can send the measurement value to the external display.

Since the sensor signal may be not quite linear, the program runs for a loop of measurement (about 50) before displaying the value (lux) that is also used to compare the illuminance with a set point value (i.e.450 lux).

The algorithm handles this data to give the input to the electrical motor to find a good position of the louver in order to control daylight; if the illuminance of daylight is not sufficient, than the artificial light is switched on and the system starts to control the illuminance.

Looking at the block diagram, we find the electronic interface driver; this device communicates with the MC by the port n°1 (bits 0,1,2). Bit 0 controls “cw/ ccw” rotation left/right, bit1 enables, bit2 generates a frequency of square waves.

The interface gives the signal power that the motor needs to rotate step by step.

There is a safety device that controls the end of rotation of the strips on the left and on the right; this device made with infra red led (two couples transm.+ receiv.) uses bit 6 and bit 7 to talk with MC .

The artificial light control device uses bit3, bit4, bit5 to adjust the illuminance level of four fluorescent lamps.

It is obvious that in the following this prototype needs a better testing, in order to improve its performance mainly to decrease energy consumption and to satisfy occupant comfort needs.

7.2. Test lab

Company : ENEA
Test person : F. Raponi

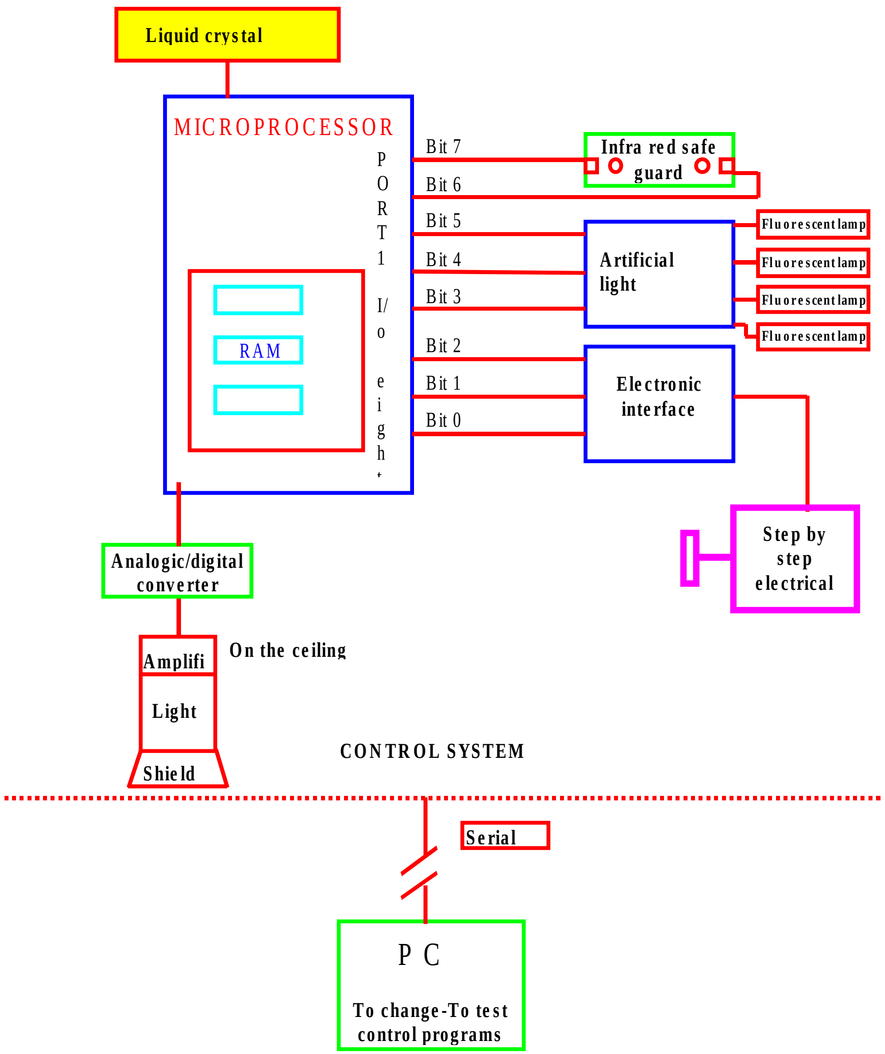


fig 1. block diagram of the control system

7.3. Test room

Figure 2. Photographs showing the window of the test room with the vertical blinds

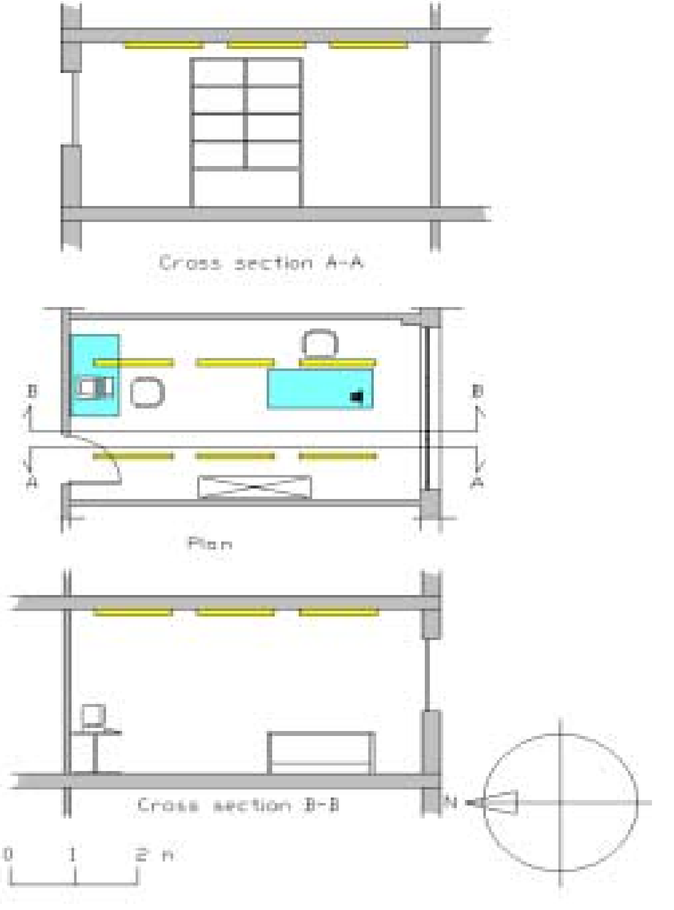


Figure 3. Plan and sections of the test room

7.6. Monitored parameters

7.6.1 Energy savings

Further to the preliminary tests we verified if the control system was reliable enough and if it satisfied the occupants.

The test room, in which we located this system, is a typical office-room, inside there are six fluorescent lamps fitted on the ceiling (four normally used + two for emergency) see Figure3. The control is connected with the group of the four lamps by a presence sensor; each lamp is a Philips PH TLD 36w/83 and the measured power consumption is 45Watt with the ballast. We have collected some data with an average work plane illuminance value of 450 +/-40 lux (set point) in a cloudy day so that only daylight contribution was not sufficient to maintain the illuminance value.

The system, in this case, fixed the louver in open position in order to receive all the contribution of daylight and switched on the four lamps to begin the control sequence of dimming artificial light.

The lighting power consumption was measured using a power transducer and a kWh-meter POWER/ENERGY monitor LAEL Mod.8122.

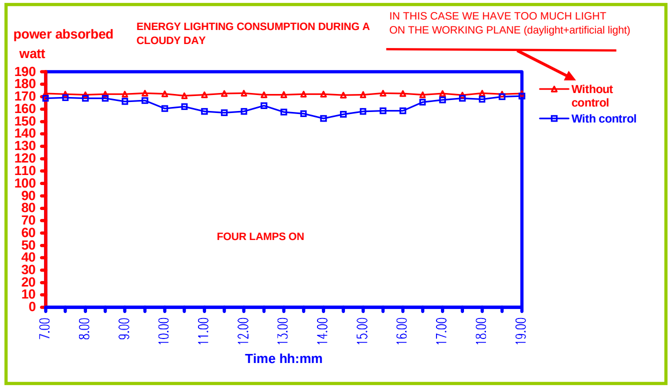
The diagram (Figure4) shows the energy consumption in the two situations: with and without control and in two different situations of daylight illuminance.

The artificial lighting system (ballast etc), which we used at the beginning, had a minimum power reduction of 50%; but it showed, about this value, a no good response to reduce fluorescent light level.

It probably depends by the used dimmable ballast that we will change with a different type.

A next report will describe the results of tests and measurements with the system EBES.

The test will be made using the Task protocol, with some limitations concerning the position of the sensors; these limitations are mainly caused by



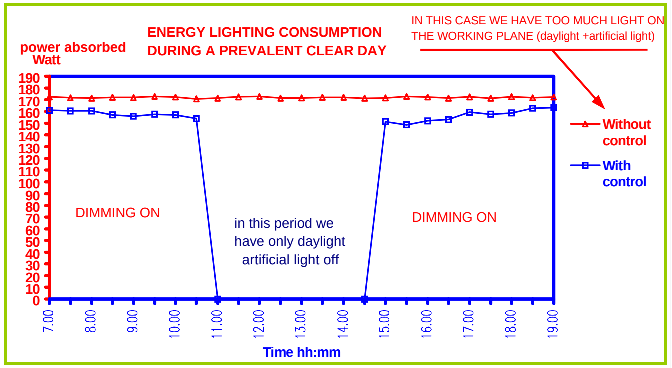


Figure 4. Electric lighting energy consumption.

different effective height of the windows.
The measurements are in progress in the already described test room in the final report of the project B3.

7.7 Conclusions

At first we have to remark that this device is not an industrial product, but a self made control system, that surely may be improved by changing control program (software), or by building it with better and smaller electronic devices (Hardware).
This control system moves internal vertical louvers and two levels of fluorescent artificial light (in a first phase), then in the second step was included a dimming control of fluorescent lamps to reduce energy consumption.
For this reasons and for the particularly test room architecture, showing aspects typically oriented to the overheating control, -i.e. very adsorbent glasses, internal movable curtains, no reflecting strips along the windows, long and no very high windows, we have tested the system following the task protocol as much as possible.
The testing of control system is performed according the following guidelines:

Installation.
For the prototype EBES it is necessary to place the box as much as possible near the window and connect with:
1-the cable from the electric motor
2-the cable from the safe guard
3-the cable from the illuminance sensor placed on the ceiling
4-the cable for dimming control of fluorescent lights
5-the cable of power supply controlled by a presence sensor.
The set point for the chosen illuminance on the work plane is fixed in the algorithm before the installation.

Test period
Unfortunately the test was performed only in three periods: two solstices and one equinox for a week each, because of the long time spent in assembling and in checking the system.

Weather recording
The general weather conditions on Casaccia are recorded manually during the test period.
The following two simplifications are applied:
1-the cloudness of the sky is divided only in three classes: quasiclear (QC), cloudy (C), overcast (O) corresponding respectively (for the classification into octaves of World Meteorological Organization) QC=0-3 oct. C=4-6 oct, O=7-8 oct.
2- the cloudness is never constant all the day, thus the cloudness observed at twelve ‘o clock is considered valid for all the day.

Monitoring parameters
Energy consumption of control system and luminaires.
General wheather conditions manually recorded.
Lighting condition outside and inside the test room according to the subtask b procedure, described above.Temperature and humidity in the room.

Lighting conditions
The monitoring of the test-room illuminance is performed with a minimun of seven sensors (Skye) placed with the geometry before described.

Energy consumption
The energy consumption is measured with a kWh-meter POWER/ENERGY monitor LAEL Mod.8122.
The power absorbed by the luminaires is 45 Watt for each fluorescent lamp.
The power absorbed by the control system is 11 Watt in stand-by and 35 Watt when the actuator is working.

Characteristics of Control system (self made)
Name……………… EBES
Manufacturer ………ENEA
Function…………… daylight and atificial light control
Integration………… stand alone one in each room
Control strategy …… closed loop
CPU.................. …. microprocessor Intel 8032 AH-
Language..........……MCS BASIC-52-
Sensor sensibility.. ….0-1000 lux-Daylight
control.......…………......open / closed vertical strips blinds by a step to step electric motor- -- safe guard for left/right rotation by twooptoelectronic sensors (infra-red led transmitter + receiver)
Artificial light control....................stepped systems proportional dimming system controlled by digital signals.-

Flexibility
- Possibility to change the responsive and to adapt the system to particular requirements by replacing the eprom inside with a new one, supporting the specific software.-
- Possibility to talk with the system by a serial port, in order to develop a new software on the ram of the system and to test it before of the transfer on the eprom.-
-Possibility to read on a liquid crystal display the date, time, illuminance (lux), set point (xxx lux) etc.-

CASE 8

PRESENTATION OF ENTPE RESULTS

The objectives of this experiment are to measure the capability of daylight responsive lighting control systems and to establish the energy savings provided by the systems. The test of two control systems in December 99 completed the experiment of two other control systems tested in February 98, under the same experimental procedure, in the same test rooms.
The four systems belong to two different families of control systems, two are open loop systems and the two others are closed loop systems.

8.1 Control systems

Servodan
Name of the system: **Luxstat**
Description of lighting applications: artificial light control
Wiring: twisted pair
Programming tool: programmes with the National Instrument labview® environment
Control strategy: open loop
Electrical characteristics: the Luxstat Control is supplied with 230V and can be directly connected to the 0-10 V output of three HF Ballasts. It is made up of one sensor per room and a light controller.

Etap
Name of the system: **Els**
Description of lighting applications: artificial light control
Wiring: twisted pair
Control strategy: closed loop
Electrical characteristics: This system is directly connected with one luminaire and send a signal 0-10 V to the HF Ballasts.

Zumtobel
Name of the system: **Luxmate Daylight**
Description of lighting applications: artificial light control
Wiring: twisted pair
Control strategy: open loop
Electrical characteristics: The system is supplied with 230V. It is made up of one sensor per room. The sensor is connected to a controller which send three signals to three numerical Ballasts. The system can also be used with HF dimming Ballasts.

Philips
Name of the system: **Trios**
Description of lighting applications: artificial light control
Wiring: twisted pair
Control strategy: closed loop
Electrical characteristics: This system is made up of one sensor per luminaire, directly connected with one luminaire and send a signal to a controller which send then a signal 0-10 V to the HF Ballasts.

8.2 Test lab

ENTPE - LASH, URA CNRS 1652, 2 rue Maurice Audin
69518 Vaulx-en-Velin Cedex FRANCE
Catherine Laurentin

8.3 Test room

The performance of the system tested is established by experiment in two identical test rooms. The two rooms are standard offices with a vertical window and three workstations (see figure 1). Each workplace is illuminated by two adjoining parabolic troffers which are well-equiped with one 55 W compact fluorescent lamp (CCT 4000 K, CRI 85) that can be individually dimmed from 1% to 100% by means of an electronic ballast.

8.4 Installation

a) Luxstat, manufactured by Servodan
Positioning of components: The system is made up of a light sensor located outside the room, on the window. This sensor measures the vertical daylight illuminance. According to this level, it controls three daylight zones and regulates the artificial lighting to ensure the desired level of illuminance in the room.

Calibration: For the adjustment of the control, we

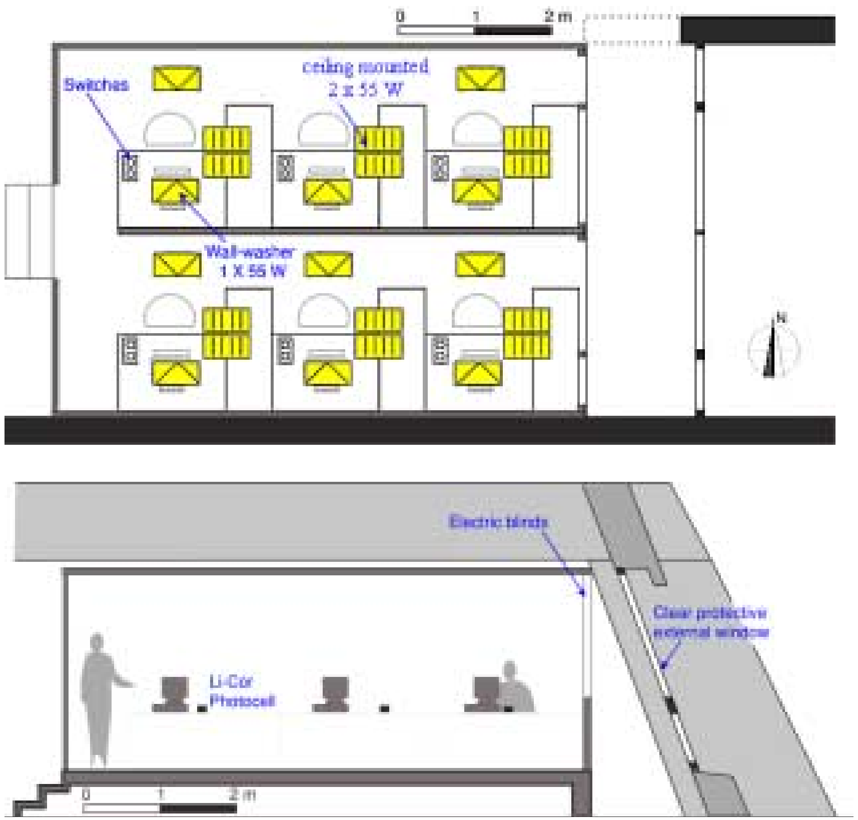


__Figure 1__: plan and elevation of the test rooms (the twin cells)

measured the indoor lux level, on the three workstations. We also measured the sensor lux level, outside, on the window. Then, we could calculate the Luxstat Control's adjustment angle per channel with the help of a graph provided by the company. The main problem that could change the results is the ratio between vertical and horizontal illuminance measured, because it is considered as a constant ratio.

b) Els, manufactured by Etap

Positioning of components: The system is made up of one sensor connected directly on one ballast, facing down the desk.
Calibration: The calibration of the system is very easy. It consists on turning the head of the sensor. Turn on the right, to increase the illuminance level on the table down, and on the left to dim it.

c) Luxmate Daylight, manufactured by Zumtobel

Positioning of components: The system is made up of a light sensor located on the ceiling, looking at the window. This sensor was installed following the instructions and recommendations sent by the company. It controls three daylight zones and regulates the electrical light to ensure the desired level of illuminance in the room. The system is also made up of light controllers. Luxmate Daylight is optimized for numerical ballasts.
Calibration: For the adjustment of the controller, we measured the indoor lux level, for the three workstations. A calibration has to be done on the «Luxmate» controller with the adjustement of the buttons which control the three areas. The calibration consists in two period of time:

- during the day, when daylight illuminance level exceed 500 lux on the workplace near the window, and under overcast sky
- in the evening, when the area at a remote distance from the window does not perceive natural light.

a) Trios, manufactured by Philips

Positioning of components: The system is made up of one multi-sensor, located on the ceiling, looking at the workstation down. It is connected to a controller that send a signal to the ballast. This system is connected with a multi-function light controller. This controller send a signal (1-10 V) to a luminaire or a group of luminaires. The luminaire dim (or increase) its intensity in response to the signal, then the sensor measure the illuminance level on the workstation, send a signal to the luminaires, and so on. Trios is optimised for HF Philips ballasts.
Calibration: The calibration of the three sensors consists on an adjustement on the remote control, wich is in fact a programming tools. It allows the programmer or the user to choose between four configurations, one that induce 25% of intensity on the luminaires, the second 50%, the third 75% and the last 100%. It is also possible to regulate more precisely the intensity of the luminaires by a pression on buttons located on the remote control.
User interfaces: unoccupied rooms

8.5 Test periods

Luxstat and Els:
Measurements and calibration began in January 98. The sky's conditions were recorded every day during the tests i.e. Two weeks, so we have measurements under overcast skies and clear skies. The measurements began on 1st February and stopped on 18th February, at 6 o'clock in the morning to 8 o'clock in the evening. For every six minute period, an average is taken to give 140 measurements per day.

Luxmate Daylight and Trios:
Installation and calibration began in November 98. The sky conditions were recorded every day during the tests i.e. four weeks, so we have measurements under overcast and clear skies. The measurements began on November 15th and stopped on December 15th, at 6 o'clock in the morning to 8 o'clock in the evening.

8.6 Monitored parameters

8.6.1 Light distribution in the test rooms

The daylight distribution in our test rooms is represented in figure 2.
Daylight Factor:
$DF\ (\%) = 100 * I_{int} / I_{ext}$

$I_{int:}$ Horizontal illuminance level on the desk
$I_{ext:}$ Horizontal illuminance level, outside on the roof of the building

8.6.2 Operational status of the control system

We calculated the illuminance maintenance of the system tested. The illuminance maintenance is the percentage of time when the luminaires never dim under the desired illuminance level.

8.6.3 Energy savings

Using the set up of the cells rooms, we could measure the power consumed by the luminaires, for the

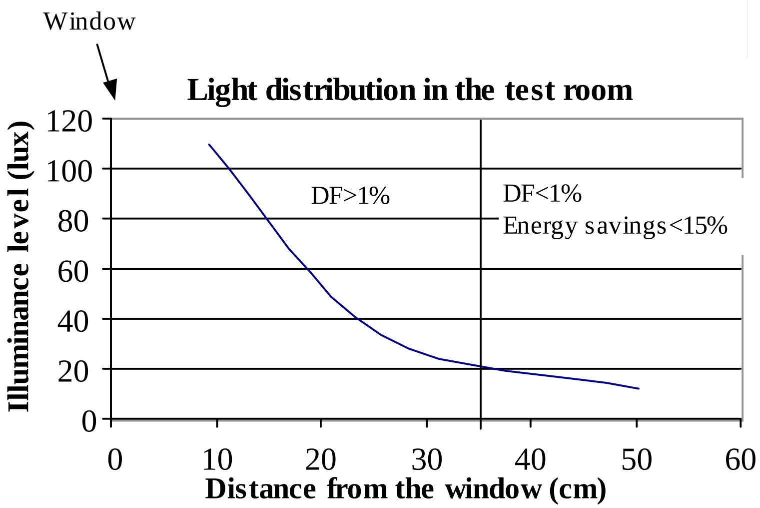


***Figure 2**: daylight distribution in the test room (the measurements and calculations have been done under overcast sky)*

evaluation of energy savings. The energy savings were calculated between 8 a.m to 5 p.m. We determined the energy savings by the comparison between the use of the system tested and the use of Philips luminaires, lit at the same illuminance level all the day and at each location.

8.6.4 Measuring instruments

The room was fitted out with three photocells located on the three workstations. The locations of the photocells had been chosen according to sensor configuration tests submitted by V. Berrutto[1] (configuration 2).
The distances (H1, H2, H3) of the sensors from the window are :
H1 = 94 cm
H2 = 258 cm
H3 = 502 cm

A calibration of the twelve photocells available in the test rooms was made before the experiment. As the calibration occured in January 98 before the first testing control systems, we measured the signal sent by the photocells under a constant level of illuminance and verified the coefficient of calibration for each photocell.

8.7 Test Results

With the results of measurements, we calculated the contribution of artificial light and daylight on each workstation. We could then deduce the evolution, during a day, of artificial light and daylight (see figures 3 and 4). The graphs, presented below, lead us to conclude on the capability of the control systems and their capacity to maintain a minimum illuminance level of 500 lux.

Power consumption

We determined the energy savings by the comparison between the use of the system tested and the use of Philips luminaires, lit at the same illuminance level all the day and at each location (see table 1).

8.8 User Preferences

We know that daylight responsive lighting control systems can save energy and maintain an illuminance level on the workplane, but how confident are we that this satisfies user expectations ? The objective of this survey is to observe user preferences, under a mixing of artificial and natural light and monitor their way to control artificial light, the illuminance level they tend to prefer, etc…
The tests took place in two identical test rooms, named Twin Cells, with a window on the side and containing three workstations each. Each workplace has an artificial lighting, with wall-washers and one ceiling mounted, luminaire which can be manually controlled by the user. The shading of natural light can be adjusted with venitian blinds, installed in the double glazing.
During all the tests, we recorded the global illuminance level on each working plane with Li-COR® photocells and the user settings on the potmeters. Each workplace was equipped with computers, all identicals (all the brightness computer screens were adjusted at

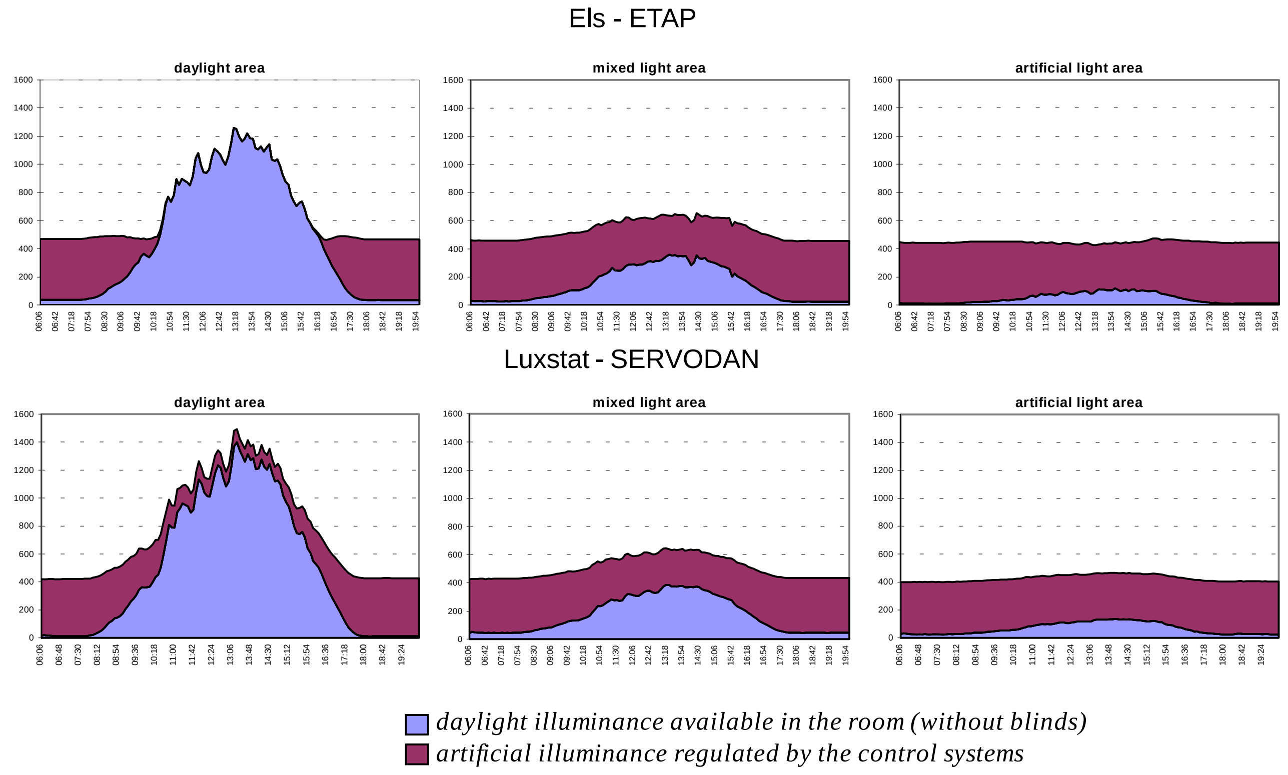


Figure 3: ***evolution of artificial light and daylight, during one day (6th of february 98)***

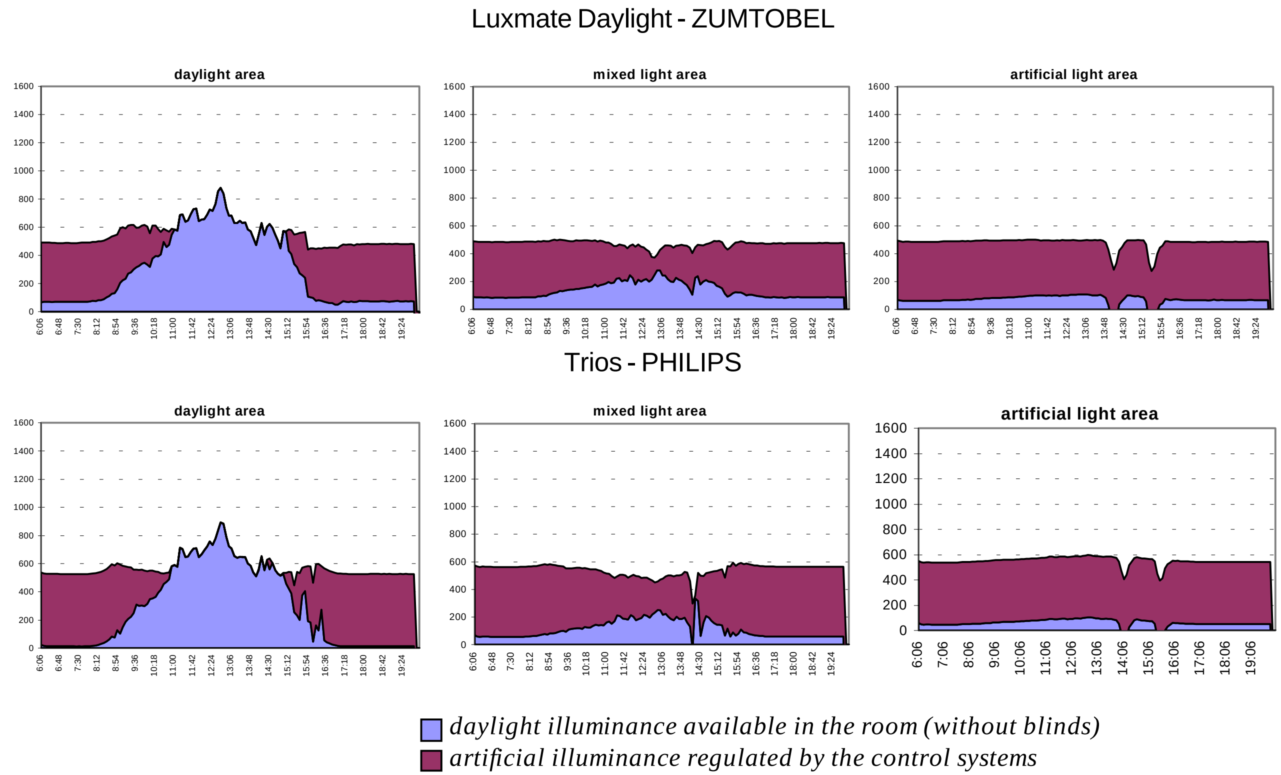


Figure 4: evolution of artificial light and daylight, during one day(15th of december 98)

		"Luxstat" SERVODAN	"Els" ETAP	"Luxmate" ZUMTOBEL	"Trios" PHILIPS
Open or closed loop system ?		Open	Closed	Open	Closed
Sensor		Verticaly, on the window	On the luminaire, facing down	On the ceiling, looking at the window	On the ceiling, facing down
Type of ballast		HF ballasts	HF ballasts	Digital ballasts	HF ballasts
Areas controlled		3	1	3	1
Energy savings (%)	Daylight area	75	45	60	60
	Mixed light area	45	30	30	30
	Artificial light area	10	20	10	5
Illuminance maintenance (%)	Daylight area	94	100	100	100
	Mixed light area	96	100	85	95
	Artificial light area	100	100	100	100
Others			luminaires never switch off		

Table 1, Energy savings and illuminance maintenance for all the systems tested

the same level : 82-84 cd/m^2 and verified before every test). Because the two rooms are turned towards the east, all the periods of test occured in the afternoon, to avoid the direct solar radiation.

8.9 Individual Procedure

8.9.1 Protocol

The test occured in the Twin Cells on 30 voluntaries, from 20 to 35 years old, in March and April 1998. Two subjects, one in each room, were tested at the same time. They had to seat successively at 3 identical adjoining workplaces (see plan and section above). Each working plane was illuminated by two ceiling mounted and by one wall-washer in front of the user, that the occupant could dim from its maximum (corresponding to 1200 lx on the table) down to 0. The occupant could also control daylight, only when they are at a close distance from the window, by adjusting the height and the tilt angle.
For each subject, the test lasted 30 minutes. All was timed and controlled by a programming using the LabView (© National Instrument) environment.

During the 30 minutes, the user had a 5 minutes period of «pre-conditionning» : he had to play a computer game named hangman, realised on a white screen to accustom the user to the screen brightness. After this period, the voluntary had to make a manual input and fill gaps in a text on the computer and handle natural and artificial light to make his visual environment more comfortable. After 3 minutes, a message on the computer told the subject to stop the manual input and fill the questionnaire (on the computer). When he was finished, he had to go on the next workstation and follow the same procedure. Another voluntary, in the other room, made the same test, in same conditions, in the same order. The surveys occured during the same period of time : between 3 to 5 o'clock in the afternoon (no direct solar radiation and user sensitivity increased).

8.9.2 Instrumentation

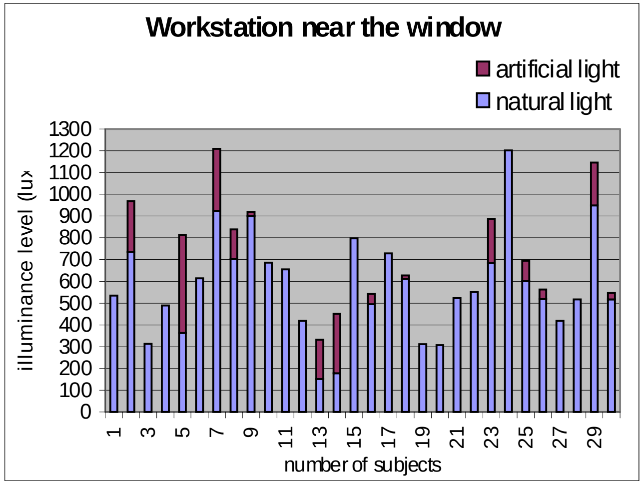
During all the surveys, we measured the horizontal illuminance level on each workplane, with photocells located near the computer and the vertical illuminance level, outside, on the window. These measurements were recorded through a data acquisition unit, every 3 minutes (30 secondes to wait between two measures and 6 measurements to average before saving). The choices of the occupants on the potmeters and the contribution of each luminaire were also recorded every minute. We took into account the sky conditions for every day, with the global horizontal illuminance, the global vertical illuminance for each orientation, recorded every 5 minutes, on the roof of the laboratory [Dumortier, 1998].

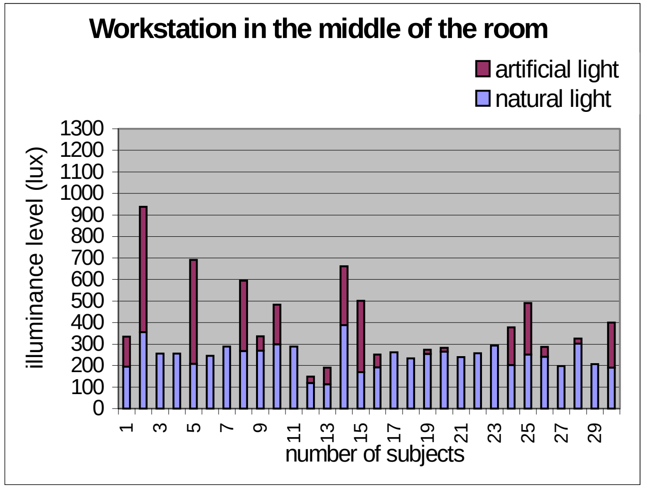
8.9.3 Results

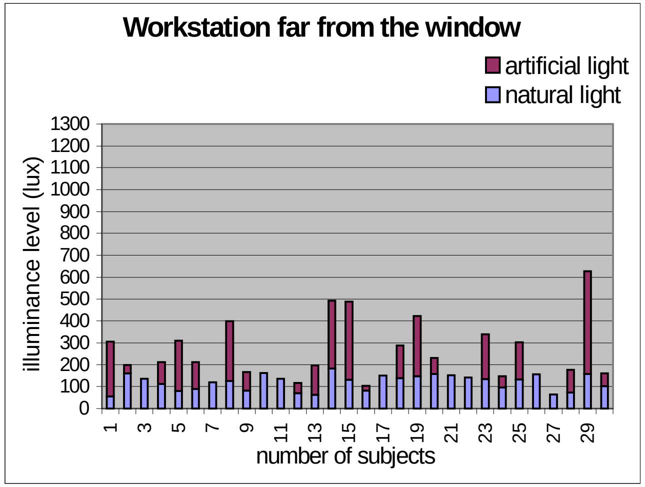
With the help of global illuminance level measured on each workstation and contribution of each luminaire, we have been able to deduce the share of artificial light and daylight. The data analysis helped us to conclude on the preferences of users according to the position in the room, the amount of artificial light added on each workplace according to the amount of daylight.

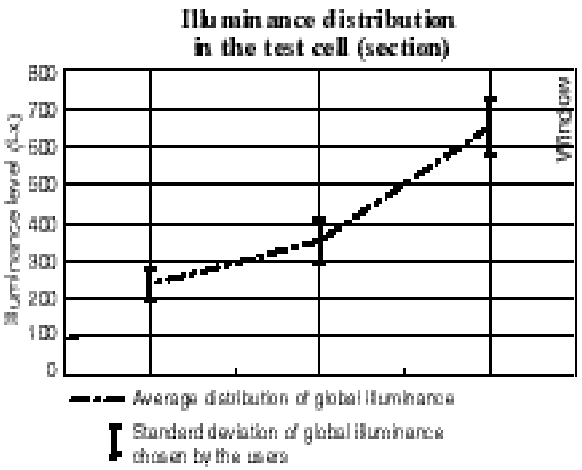
Levels of illuminance due to artificial light only
The first observation we can make is that the users never switch on the luminaires to the maximum. They have the possibility to add around 1200 lx of artificial light on the table, but, whoever it was and whatever was their position, they never added more than 500 lx of artificial light, even when daylight provided less than 100 lx. This remark could have an influence during the choice of the luminaires in offices and its capacity.
We observed the amount of artificial light and daylight, chosen by the voluntaries. We can see some results on the graphs followed, showed the part of daylight and artificial light for each subject, sitting at the 3 workstations.
From these graphs, we can separate three different occupant reactions according to the three workstations:

Near the window
It is the only one of the thee location where occupants were given the possibility to adjust the venitian blinds. It is probably why the awares of artificial light added


Workstation near the window
artificial light
natural light
illuminance level (lux)
number of subjects


Workstation in the middle of the room
artificial light
natural light
illuminance level (lux)
number of subjects


Workstation far from the window
artificial light
natural light
illuminance level (lux)
number of subjects


Illuminance distribution
in the test cell (section)
Window
Average distribution of global illuminance
Standard deviation of global illuminance
chosen by the users

are so different. 17 out of 30 users did not regulate artificial light and controlled (or not) only the blinds. For the persons who added artificial light, the extra amount was between 20 to 450 lx, 168 lx in average. The global illuminances chosen, in this case, are very different according to each voluntary and the responses inhomogeneous.

In the middle of the room

The number of subjects who didn't add artificial light is 12, a little less than in the location near the window. The selected level of illuminance due to artificial light only chosen by the users was between 30 to 580 lux and 192 lx in average, higher than the average levels in the location near the window. The global illuminance levels chosen here are more homogeneous.

Far from the window

In this situation, the level of daylight is very low, but we can observe that 9 subjects did not choose to adjust artificial light; that induced very low level of global illuminance (around 120 lx) on the table. Besides, the level of artificial light chosen was between 20 to 350 lx on the table, corresponding to an average of 167 lx, levels lower than the values recommended (350 lx [AFE, 1997]). The responses in this workplace are particularly homogeneous and stable.

Global level of illuminance

It is clear that the levels of illuminance prefered by the users on the workplane depend on their position in relation to the window. If we look at the maximum level of global illuminance chosen; we notice that, near the window, the maximum is 1200 lx for the two rooms (minimum : 300 lx), in the middle of the room, the maximum is 900 lx and far from the window, the maximum is 500 lux. A same subject accepts to work under very different levels in relation to his position.

Which workplace is the most comfortable ?

According to the respons writed in the questionnaire, it seems that no workplace is especially unpleasant (10 positions out of 90 are unpleasant), otherwise the reactions on visual comfort are quite neutral. Yet, the most pleasant seems to be the workplane near the window.

8.9.4 Discussion

We must discuss here on the measurements and the calculations. We came up against some difficulties during the result analysis. It is right that the photocells measure the global illuminance level on the table and the potmeters give us the contribution of artificial light (in volt), but we calculated the part of daylight and the contribution of artificial light in lux. This calculation induce an error of 5%, which is very acceptable. Besides, the main problem is about the measurements of the photocells averaged every 3 minutes. For the location near the window, because of the blinds, we needed to compare the amount of daylight and artificial light with the vertical illuminance on the window, to verify the precision of the results. But, we noticed that the time between 2 averages, for the photocells, was too long, knowing that the time for the user to choose his lighting was around 5 minutes. We evaluated that the vertical illuminance didn't change during 3 minutes more than 10%. This induce an error more important near the window, of around 10%, only for the sky conditions not stable (intermediate sky). To avoid this error, we should measure the position of the blinds and, with a calibration, conclude on the exactely amount of daylight.

8.10 Collective procedure

Sometimes, the Twin Cells are occupied by students for lessons. We took advantage of this, and explained to them, at the beginning of the session, that they could choose their visual environment, by regulating artificial light and daylight. At the end of the session, they had to fill a questionnaire on their perception of the environment (visual and thermal). We finally had 45 answers, 4 groups, one of whom cames three different times. They were 2 or 3 by workstation. In comparison with the individual procedure, each working plane was occupied by 2 or 3 students, they chose their visual environment simultaneously and only the group near the window could control the venitian blinds.

8.10.1 Results

For the group which came three different times, we could observe if the answers were reproduced. Near the window, the levels chosen by the groups are very differents (from 425 lx to 1033 lx). In the middle of the room, the choices are more homogeneous (from 278 lx to 523 lx). And then, far from the window, the levels are quite identicals (from 130 lx to 195 lx and 3 same levels). These results confirm the fact that the presence of the window has a determining role in user choices.

Can we compare these results with the results obtained by the individual procedure ? We can first notice the homogeneous average of global illuminance level for the workstation near the window (653 lx for the individual procedure and 689 lx for the collective, even if the answers were inhomogeneous), a very high level, especially for a work on computer. The level, in the middle of the room was more important for the collective procedure (418 lx instead of 353 lx for the individual). We perhaps can explain this because of the shade made by the group near the window or because of a working environment more in exchange with the neighbour or the teacher. Finally, the level chosen by the group located far from the window, was lower than for the individual answers (145 lx instead of 237 lx), they rarely dimmed artificial light.

However, from the table follows, we can observe the same phenomenon as the test before. In other words, the levels chosen by all the groups located in a remote distance from the window, are very homogeneous; in the middle of the room, the answers are intermediates, and close from the window, the answers are very differents. The results of this test confirmed the hypothesis made in the individual procedure.

		Average of global illuminance level, for each group, according to the location from the window (in lx)		
Group	Date	close	intermediate	remote
1	02/26/98	425	278	195
2	03/02/98	479	293	110
2	03/09/98	458	559	178
2	03/23/98	963	346	103
3	03/27/98	775	523	139
4	04/01/98	1033	507	
Average of global illuminance		**688**	**417**	**145**
relative difference of choices (%)		**– 17**	**– 13**	**– 11**

8.11 Conclusion

The most relevant from these tests is about the differences of illuminance level chosen by the users between the position near the window and the others. The response for people sitting far from the window are more homogeneous than close to the window, we could suppose that this position is probably felt like the most comfortable; but according to the answers of the questionnaire, we discovered that the most comfortable is the position near the window. People accept to work under very high level if they are close to the window, even for a work on computer. This finding is probably due to the diffusion of daylight, and of course we can't talk about daylight without taking into account the significance of the window and the outside view, which induces a more important adaptability faced with the illuminance levels. Besides, in this test, we didn't measure the corelated color temperature, which may had an effect on the user preferences. This parameter will be introduced in the next survey.

This test was a first of a serie of other tests, which allowed the improvement of procedure

8.12 References

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CASE 9

TU-BERLIN, CONTROL SYSTEM TESTS

Dipl.-Ing. Heiko Belendorf
Dr.-Ing. Sirri Aydinli
Prof. Dr. rer. nat. Heinrich Kaase

1. Control Systems

Case I:
Name: EIB Open Loop Control N342.
Manufacturer: Siemens AG, Germany
Strategy: Open Loop Control
Case II:
Name: Siemens Closed Loop Control
Manufacturer: Siemens AG, Germany
Strategy: Proportional Closed Loop
Case III:
Name: ETAP ELS light control system
Manufacturer: ETAP Belgium
Functions: daylight responsive lighting control
Sensor:daylight and artificial light sensing
Strategy: Closed loop control
Case IV:
Name: Luxmate Daylight (TLS)
Manufacturer: Zumtobel Staff
Strategy: Open loop control

2. Test facility

Name: TU-Berlin
Address: Technical University of Berlin, Institute for Energy- and Automation Technology, Department of Lighting Technology, Einsteinufer 19, 10587 Berlin, Germany

3. Test room

The test-room are localised in the building of the Electrical Engineering faculty of the TU-Berlin. An overview of one of the test rooms including the measuring system gives *figure 1*.

The geographical orientation of the window façade is 186^0 (with north 0^0, east 90^0, south 180^0 and west 270^0). The dimensions of the test rooms are: length 4,7m, width 3,5m, height: 3m with a room area of 16,45 m^2. The glazed area of the window is variable (shading

Figure 1a, Test room in Berlin

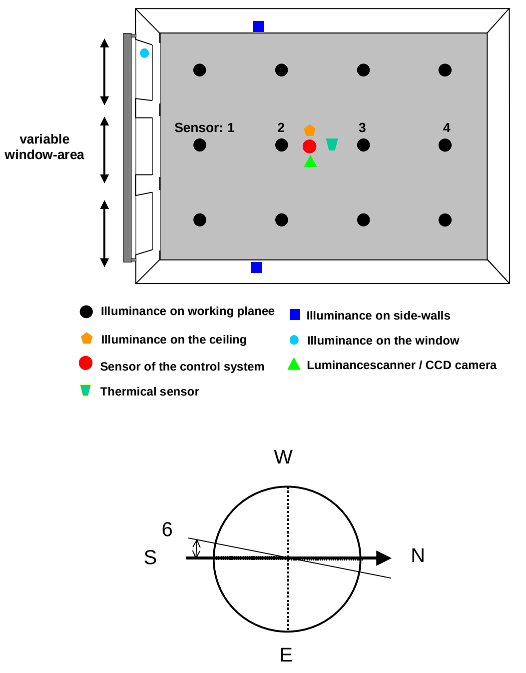

Figure 1b: Layout of the sensors and orientation of the test room

elements are used to modify the window size). In the following “large window” means 5,2m^2 and “small window” 3,3m^2 glazed area. Small window-size is according to the minimum size mentioned in the German guidelines for working places. Reflection factors (diffuse light) of the rooms are standard values: wall r_w=0,55, ceiling r_d=0,85, ground r_b=0,25. Test rooms during testing were unoccupied and empty (no furniture).

The exact sensor positions can be seen in *table 1* (sensors numbered 1 to 12 in the working plane of 0,85m) with **d** – distance from wall (west) side, **b** – distance from window side

WINDOW-SIDE			
b/d	*0,6 m*	*1,76 m*	*2,90 m*
0,88 m	1	2	3
2,04 m	4	5	6
3,2 m	7	8	9
4,36 m	10	11	12

Table 1: Sensor positions in the test-room related to the distance to a reference point

Monitored parameters

The parameters monitored in the testing were: illuminance distribution in the working plane, energy consumption, general weather conditions, daylight illuminances and luminance distribution of the sky. Calculation of energy savings, daylight and artificial light contribution was performed using the collected data. Energy savings are calculated with:

$$\text{Energy-saving} = ((W_{max}-W_{actual})/W_{max}).100\%$$

W_{max}: Energy consumption of the artificial lighting in 100% dimming state for the working day without control system.

W_{acutal}: The monitored energy consumption with control system over the monitored time.

Measuring instruments

The measuring system equipment in the test-rooms consists of the following components: voltage multiplexer (multi-channel), photo-current / voltage converter, 15 photometer-heads (V(l)- and cosine-corrected per test room, power-meter (or the power is calculated out of the control voltage at the voltage interface of the dimmable electronic ballast). The accuracy of the measured illuminances is about 10% and the measurement range is from 30 to 100klx.

The reference distribution of the illuminance on the working plane in the test-room depends on the (100% dimming) night time state of the used artificial lighting installation. The requirements of the German norm DIN5035 are fulfilled.

Test periods

The testing period for each system was from 8-18^{00} TST (true solar time), i.e. a standard 10 h office day. Measurements were carried out for several days representing the different sky conditions.

For further and more detailed information on the test facilities see Task 21 document: "Subtask A and B – Descriptive document on test rooms".

4. The cases

The following gives a description of some case studies carried out at TU-Berlin on daylight-responsive control systems.

Case I

EIB open loop control, system N342, Siemens AG, Germany

Control System

Name: EIB Open Loop Control N342.

Manufacturer: Siemens AG, Germany

Strategy: Open Loop Control

System description: The controller (type N342) is able to control various different luminaire rows dependent to ten different EIB daylight sensors (type GE253), which means one system consisting of a controller and a sensor can control different room zones, i.e. ten independent control functions can be programmed. The system is based on the EIB bus system *(figure 2)*.

The sensor has to be installed on the window inside; looking outside and detecting daylight. The system was calibrated referring to the night time illuminance distribution with 100% light-output of the lamps. The lighting installation consists of two luminaire rows whose lamps are dimmed with dimmable electronic ballasts via the commands of the switching- / dimming unit of the EIB who receives the dimming signals from the light controller. The ballast receives the dimming commands through its 1-10 V interface.

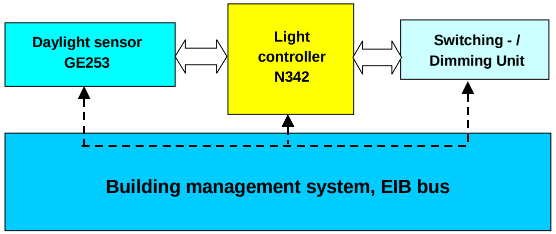

Figure 2: EIB Communication between sensor, controller and switching- /dimming-unit

The following EIB components are necessary for the control system: switching-/dimming unit for every luminaire-row, light controller and brightness-sensor and two dimmable electronic ballasts with 1-10V interface. Control sensor and luminaire row location are shown in *figure 3*.

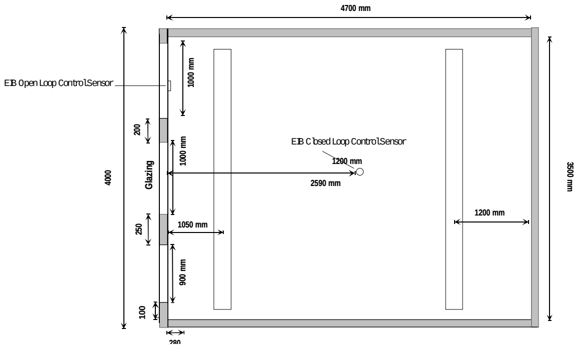

Figure 3

Installation

Positioning of components: The EIB-controller N342 has to be connected to the bus system EIB. The sensor system GE 253 is located inside the window plane and has to be connected to the EIB bus.

Cabling corresponds to the bus system, no extra cabling is necessary (only sensor connection to the bus).

User interfaces: Offers all the various bus system user interfaces, especially necessary ETS software for programming.

General evaluation of the system's installation „friendliness": The system can be described as user friendly. Its handling corresponds to the general programming of the bus system. Only the calibration procedure needs some time. The sensor and the controller are easy to install.

Test

The illuminance distribution in the test room in the working plane with (height 0,85m) is given in *table 2*. The twelve Illuminances in Lux on the working plane are measured at night in the absence of daylight (night time state) and are used for the test as reference. The illuminances in *table 2* are presented according to their local positions, see *figure 4* for the graphical representation of the distribution. The following figures for practical reasons will only refer to the four values of the measured illuminances in the middle line of the room (sensor no. 2, 5, 8 and 11: 1-4, see figure of the measurement facilities above). The average illuminance is 745lx.

The Siemens light controller N342 has to be tested

709	880	715
665	801	669
729	880	756
635	804	696

Table 2: Reference illuminance distribution in lx for the open loop system (N342) test (see table 1)

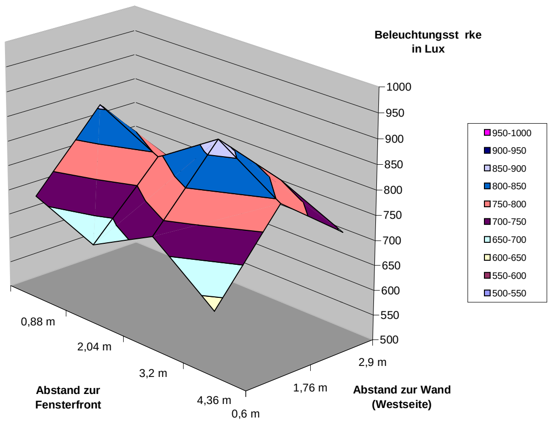

Figure 4: Reference illuminance distribution

in combination with the sensor GE 253 (quantifying the incoming light in the window-plane). The tests were performed for two different window-sizes under different sky conditions. Each window-size testing had its own control function pair, i.e. four functions are describing the control relation between sensor signal and dimming state (expressed through 1 byte values) in order to take into account the different amount of incoming daylight.

The method of calibrating the open loop control system has a relevant influence on the system's behaviour and the quality of the control. For the tests the system was calibrated as follows: Night-time distribution was the reference state and the illuminances of each luminaire on the working plane forms the base for the calibration. During calibration (setpoints for daytime) the artificial light for each luminaire row was dimmed in a way that the illuminance-requirements referring the German norm were fulfilled.

Besides that the calibration-procedure can be afflicted with some uncertainties referring to the exact dimming state and the corresponding stable illuminance behaviour of the daylight. The system adjustment has to be done through programming of the light-controller module N342 with the EIB bus system software ETS (EIB tool software), An extra calibration of the sensor itself is not necessary. The application software for the controller offers the opportunity to define eight different points to set one of the ten control functions.

The time course of two luminaire row's power consumption as well as the 16 different illuminances are registered over the test duration of 10h. *Table 3* and *table 4* gives an overview about some of the test results containing all relevant parameters inclusive the performed relative energy saving, the relative usable light exposure ("room-potential") calculated for the specific day and the lacking light exposure.

Test- day	*Sky condition*	Energy saving [%]	Relative lacking light exposure [%]	Room-potential at test-day [%]
28.01.99	*Overcast*	*17*	*1,3*	*15*
02.02.99	*Overcast*	*22*	*2*	*20*
03.02.99	*Overcast*	*12*	*1*	*8*
04.02.99	*Overcast*	*11*	*0,8*	*7*
26.01.99	*Varying / cloudy*	*59*	*0,5*	*63*
29.01.99	*Varying*	*57*	*1*	*61*
30.01.99	*Cloudy / overcast*	*42,5*	*2,8*	*41*
01.01.99	*Clear sky*	*52*	*0,79*	*54*
03.01.99	*Clear / partly cloudy*	*51*	*1,3*	*53*
31.01.99	*Clear*	*60*	*1*	*61*

Table 3: Compilation of test-results for the open loop control system N342 for small window size

The following gives more detailed illustration to one of the tested days.
Test-day: 28.01.1999
Window-size: small,
Sky condition: overcast

Test-day	*Sky condition*	Energy saving [%]	Relative lacking light exposure [%]	Room-potential at test-day [%]
08.01.99	*Overcast / cloudy*	*22,5*	*2,1*	*19*
09.01.99	*Cloudy*	*26*	*1,4*	*24*
16.01.99	*Overcast / cloudy*	*31*	*1,3*	*31*
06.01.99	*Clear*	*67*	*1,2*	*68*
10.01.99	*Clear*	*65*	*1,8*	*66*
17.01.99	*Clear*	*51*	*0,8*	*55*

Table 4: Compilation of test-results for the open loop control system N342 for large window size

Average of relative lacking light exposure: H_{LLE}=1,35%
Maximum power of luminaire row at window (LB1) at night: $P_{max,LB\,1}$=220,4 W
Maximum power Luminaire row wall-side (LB2) at night: $P_{max,LB\,2}$=223,6W
Theoretical energy consumption:
(100% light output during the whole day)
$W_{theor,LB1}$=2204,2 Wh
$W_{theor,LB2}$=2236,4 Wh
$W_{theor,total}$ = 4440,7 Wh
Real energy consumption of system:
W_{LB1}=1500,2Wh
W_{LB2} = 2170,2Wh
W_{ges} = 3670,4Wh

Energy-savings:
ES_{LB1}=31,9%
ES_{LB2}=2,96%
ES_{ges}=17,35%
Absolute energy-saving:
ES_{LB1}=703,99 Wh
ES_{LB2} = 66,25 Wh
ES_{ges} = 770,25 Wh

Figure 5 to *figure 10* shows the course of the interesting illuminances, the power of the luminaires, the cumulative frequency of short coming and exceeding of the reference illuminaces and the daylight illuminances.

Conclusion

The system was efficiently able to use the offered usable light exposure. The calibration procedure needs some time and the system's performance depends on the correct programming of the control function (dimming value as function of the sensor value). Also the sky type during the calibration can influence the system's behaviour.

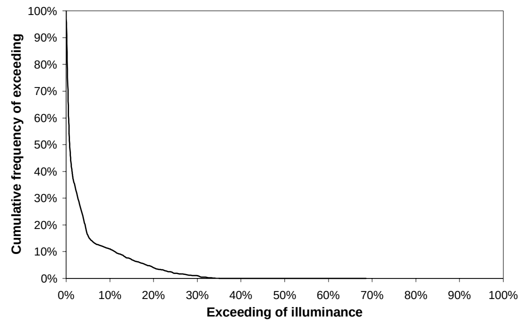

Figure 5 Cumulative frequency of exceeding referring to reference-illuminance, 28.01.99

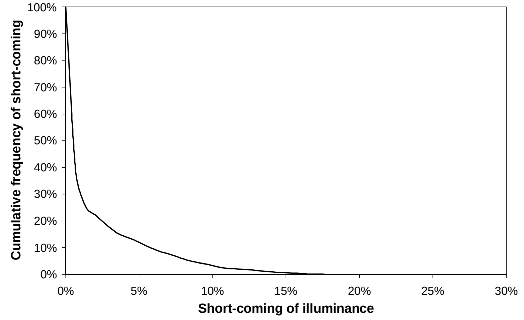

Figure 6 Cumulative frequency of short-coming of illuminance, 28.01.99

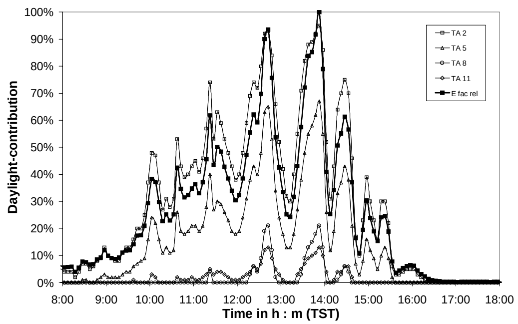

Figure 7: Daylight-contribution of the illuminances of the sensor row EIB 2 to EIB 11 and relative daylight illuminance at facade, 28.01.99

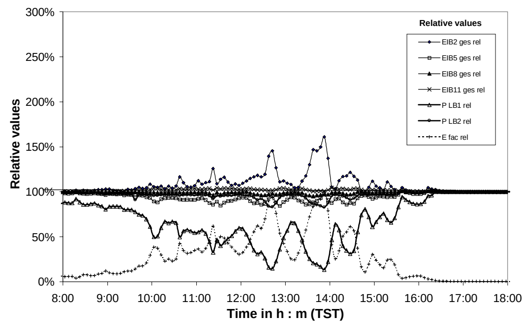

Figure 9: Relative Illuminance at the sensors in comparison to the power of luminaire row LB1 and LB2 and relative illuminance of facade, 28.01.99

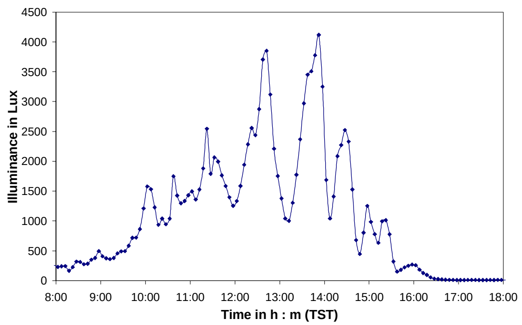

Figure 8: Absolute illuminance on facade, 28.01.99

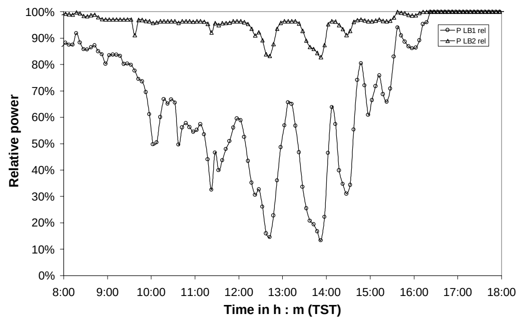

Figure 10: Power of the luminaire rows, 28.01.99

Case II
EIB Closed loop control system, Siemens AG, Germany

Control system
Name: Siemens Closed Loop Control
Manufacturer: Siemens AG, Germany
Strategy: Proportional Closed Loop

One Controller is able to control ten different luminaire rows dependent to different interior brightness sensors (type GE252), which means one system consisting of a controller and a sensor can control different luminaires i.e. the controller can be programmed with the ETS Software with ten independent control functions.

Installation and Test
Electrical characteristics: The system is based on the European Installation Bus (EIB). Its integration in the building management system offers all the advantages of a decentralised bus system. For the sensor position see *figure 3.* Positioning of components: The EIB controller has to be connected to the bus system EIB. The sensor is mounted on the ceiling of the room detecting the working plane. It has to be connected to the EIB bus. Cabling: Corresponding to the bus system. No extra cabling necessary, only sensor connection to the bus. User interfaces: Offers all the various bus system user interfaces, especially necessary ETS software for programming. General evaluation of the system's installation „friendliness“: The system can be described as user friendly. Its handling corresponds to the general programming of the bus system. Only the calibration procedure needs some time. The sensor and the controller are easy to install. See table 4 for some test results.

Test-day	*Sky condition*	Energy saving [%]	Relative lacking light exposure [%]	Room-potential at test-day [%]
10.05.99	*mostly clear sky / then later cloudy*	*91,59*	*0,18*	*94*
15.05.99	*Overcast / cloudy, rain*	*67,54*	*0,44*	*70*
16.05.99	*Clear, later cloudy/ overcast (varying)*	*93,68*	*0,2*	*96*

Table 4 :Compilation of test-results for the open loop control system for large window size

Detailed information for one test-day:
Test-day: 15.05.1999
Window-size: large
Sky condition: overcast / cloudy and rainy
Average lacking light exposure H_{LLE}=0,44 %
Maximum power of luminaire row (window-side, LB1): $P_{max\ LB\ 1}$ = 220,4 W
Maximum power of luminaire row (wall-side, LB2): $P_{max\ LB\ 2}$ = 223,5 W
Theoretical energy consumption:
(100 % light output during whole office day)
$W_{theor.LB1}$ = 2203,7 Wh
$W_{theor.LB2}$ = 2235,1 Wh
$W_{theor.ges}$ = 4438,7 Wh
Real energy consumption of system:
W_{LB1} = 278,8 Wh
W_{LB2} = 1162 Wh
W_{ges} = 1440,8 Wh
Energy-savings:
ES_{LB1} = 87,4 %
ES_{LB2} = 48 %
ES_{ges} = 67,5 %
Absolute energy-savings:
ES_{LB1} = 1924,9 Wh
ES_{LB2} = 1073 Wh
ES_{ges} = 2997,9 Wh
Relative usable light exposure for the day (roompotential) RP = 70%

Reference illuminance distribution

650	772	649	E_n=670 lx
596	721	598	
655	801	683	
570	727	621	

See figure 11 to *figure 17* for the course of the interesting quantities.

Conclusion

In the testing the system made use energy efficient use of the available daylight. Generally, the closed loop proportional control strategy is suited to control energy efficient with good maintenance of the reference illuminance (small lacking light exposure). The calibration of the control can be done through a two points setting of the control function (night time calibration and switch off point with daylight).

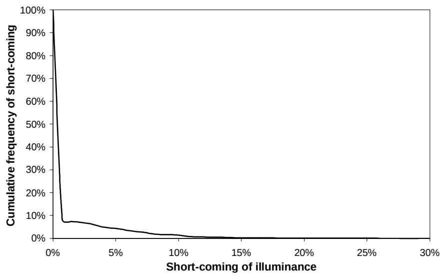

Figure 11: Cumulative frequency of short-coming of illuminance, test day 15.05.1999

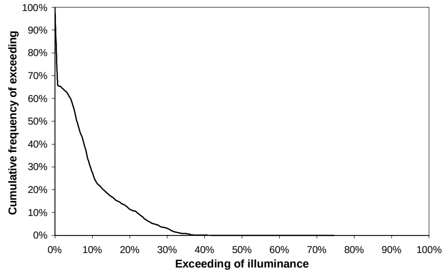

Figure 12a Cumulative frequency of exceeding of illuminance, 15.05.99

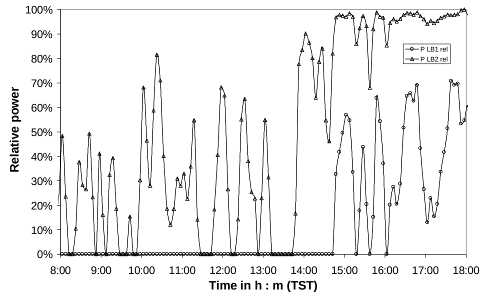

Figure 14 Relative power of luminaire rows, 15.05.99

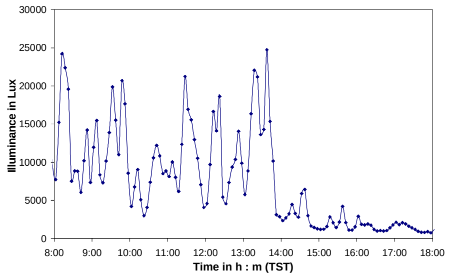

Figure 12b Illuminance on facade, 15.05.99

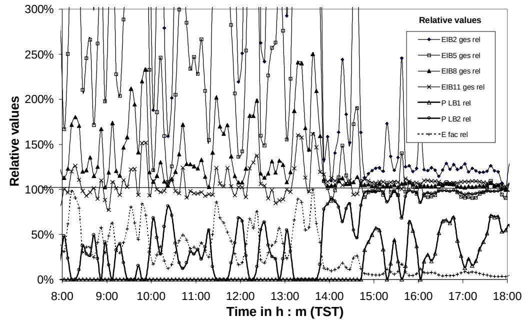

Figure 15 Relative values: power of luminaires, illuminances on working plane and facade illuminance, 15.05.99

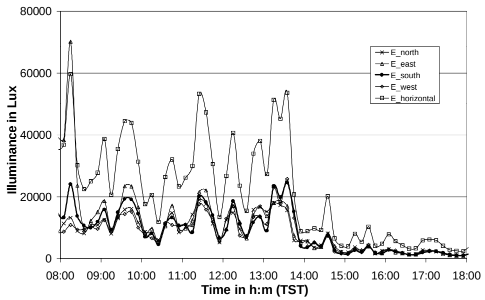

Figure 13 Daylight illuminances

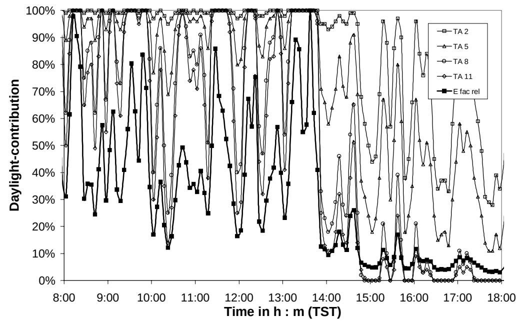

Figure 16 Daylight contribution and facade illuminance, 15.05.1999

Case III

ELS Closed loop control system, ETAP NV, Belgium

Control System

Name: ETAP ELS light control system

Manufacturer: ETAP Belgium

Functions: daylight responsive lighting control

Sensor:daylight and artificial light sensing

Strategy: Closed loop control

Capacity: One sensor is able to control the 1-10 V interface of an electronic ballast with one or two lamps (luminaire based system) depending to the amount of incoming light.

Electrical characteristics: The ELS has to be connected to the voltage interface of the electronic dimmable ballast. The system is a stand alone (luminaire based) system and do not need an extra voltage supply. The two luminaire rows (containing each two luminaires) were entirely equipped with four ELS sensors. For position of the sensors see *figure 17*

Installation

The sensor cabling has to be connected to the analogue 1-10 V interface of the ballast. The sensor itself is directly plugged / mounted on the lamps (with a metal clip). No extra cabling is necessary, only the sensor system needs to be connected to the ballast. Normally the luminaires are pre-equipped with

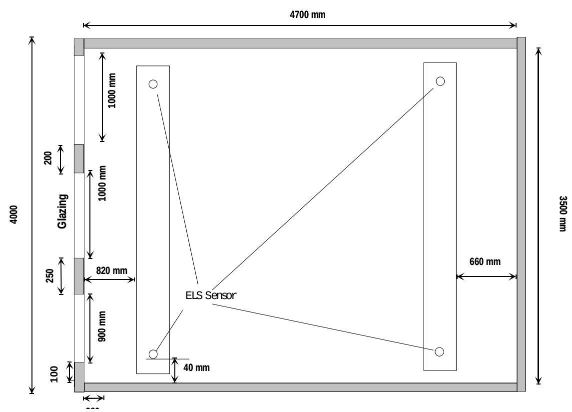

Figure 17 Luminaire and sensor position

that system by the manufacturer.
User interfaces: The adjustment (turning) of the sensor tube can be used to calibrate the system and at the same time change its detection area.
General evaluation of the system's installation „friendliness": Very user friendly through its facile installation.

Test
The installation consists of two luminaire rows (LB1 and LB2) whose lamps are dimmed with dimmable EVGs via the ELS sensor system.
The reference distribution of the illuminance on the working plane in the test-room depends on the adjustment of the tubus-ring of the control sensor mechanism. The illuminance distribution in on the working plane was measured by night in the absence of daylight is used as reference, *table 5* (illuminances are presented in a table according to their position in the room).
The different power levels of the two luminaire rows under night time condition can be explained by the control mechanism of the sensor system, i.e. the adjustment of the sensor-tubus for the different rows were different. The night time state is used as reference situation.

540	641	519
514	619	509
490	608	518
433	529	464

Table 5 Reference illuminance distribution for the ELS test in lx

Power of the luminaire rows:
Window side LB1: $P_{max\ LB1}$=208W
Wall side LB 2: $P_{max\ LB2}$=181W
$P_{max\ LB1} + P_{max\ LB2}$ = $P_{ges\ theor.}$ = 389W
Theoretical energy consumption:
LB1: $W_{LB1,theor.}$=2078 Wh, LB2: $W_{LB2,theor.}$=1807 Wh.
Daily maximal energy: $W_{ges.,theor.}$ = 3885 Wh
See *table 6* for a compilation of some test results.

Detailed information for one test-day, 26.08.1998:
Sky condition: varying cloudy sky
Window size: small
Absolute energy saving: 1825 Wh
Relative energy saving:47%
See *figure 18* to *figure 25* for the detailed system behaviour.

Conclusion
The system is very easy to install. It can be used to save energy for lighting in buildings. The possibility to change the calibration is coupled with influencing the detection area of the sensor. Normally the system is pre calibrated by the manufacturer. The system was able to maintain the reference illuminance level in the room during the test interval. The system in the testing tended to deliver more artificial light than absolutely necessary (depending on the sky type), i.e. the room potential tends exceeds the energy savings.

Date	Sky Conditi on	Room poten-tial at the test day [%]	Window Size	Relative Energy-saving in [%]
26.08.98	Varying cloudy		small	47
23.09.98	Over-cast		large	46
12.04.99	Varying	91	large	62,5
29.04.99	Partly clear, then cloudy	94	small	64
17.05.99	Clear	90	large	59,26

Table 6 Some test results for the ELS system

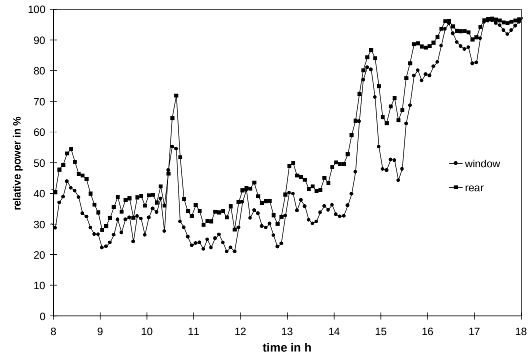

Figure 19 Relative power of luminaire rows, 26.08.98

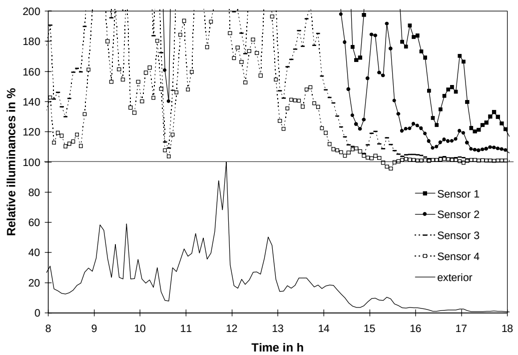

Figure 18 Relative illuminances on working plane, 26.08.98

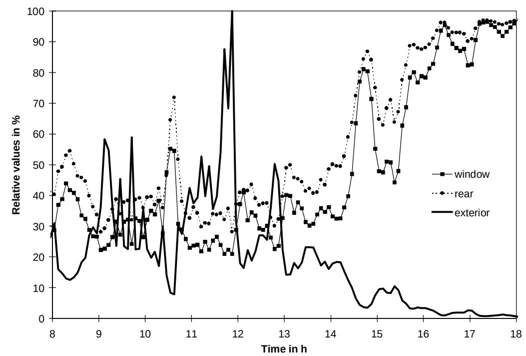

Figure 20 Relative values of power and exterior illuminance on window facade, 26.08.98

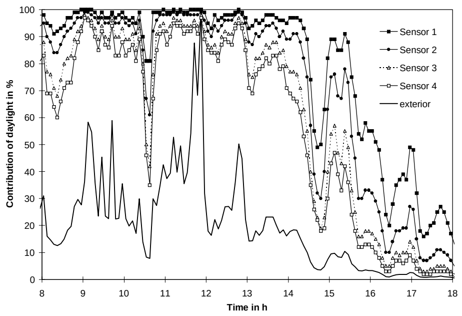

Figure 21 Daylight contribution of illuminances, 26.08.98

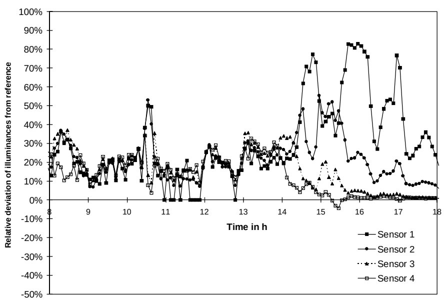

Figure 22 Relative deviation of illuminances from desired reference illuminances, 26.08.98

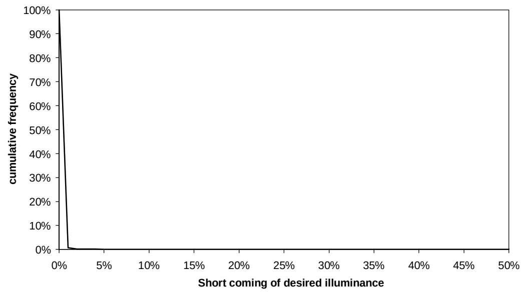

Figure 23 Cumulative frequency of short coming of reference illuminance, 26.08.98

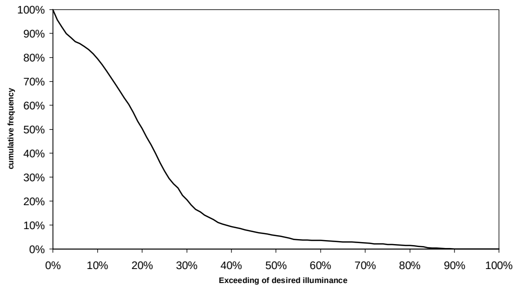

Figure 24 Cumulative frequency of exceeding of referemce illuminance, 26.08.98

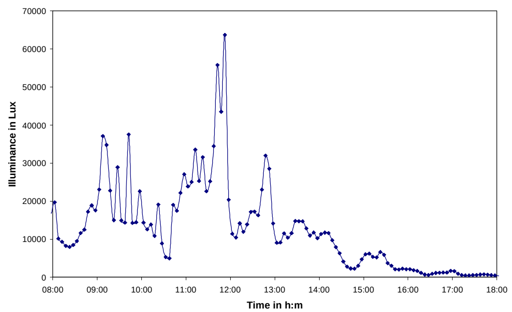

Figure 25 Absolute external illuminance on facade, 26.08.98

Case IV

Open loop control system Luxmate Daylight, Zumtobel Staff

Control System

Name: Luxmate Daylight (TLS)

Manufacturer: Zumtobel Staff

Strategy: Open loop control

Capacity: One daylight controller can control up to 3 different luminaire rows.

The system is based on the Luxmate bus system. The interior sensor (LM-LSD) is ceiling mounted and directed to the window (should detect only daylight from window plane).

Installation

Positioning of components: The Luxmate Daylight Controller has to be connected to the bus system Luxmate.

Cabling: The daylight sensor and the controller have to be connected to the bus system.

User interfaces: The system offers all the user interactions the bus system offers, e.g. programming of the control directly through the controller connected to the Luxmate bus. See *figure 26* for the position of the sensor.

General evaluation of the system's installation „friendliness": The calibration and the adjustment of the system can be considered as user friendly.

Test

See table 7 *for a compilation of the results of some selected test-days.*

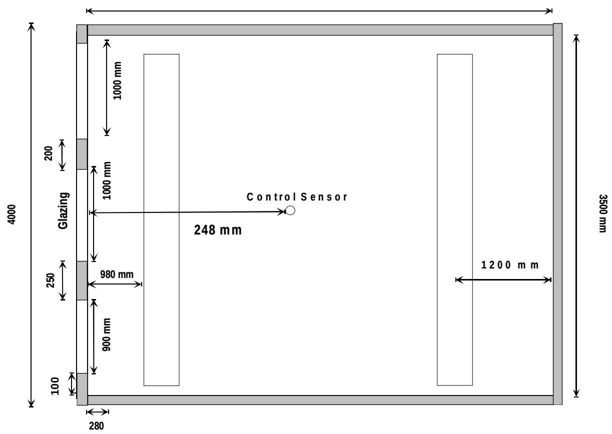

Figure 26 Drawing of the test room with Luminaire and sensor position

Date	Sky condition	Relative Energy-savings [%]	Room-potential for test day[%]	Lacking light exposure [%]
23.11.98	overcast	41,94	42	3,28
05.12.98	overcast	32,4	28	4,35
06.12.98	overcast	31,67	28	3,39
22.11.98	varying	61,92	58	6,18
07.01.99	varying	11,17	21	0,06
11.02.99	clear	75,87	81	0,42
13.02.99	varying	50,41	63	0,51
31.01.99	clear	59,72	69	0,17
06.01.99	clear (mostly)	57,86	70	0,27

Table 7 Compilation of some test results from the TLS system for large window size

Detailed information for one test-day:
Test-day: 07.01.1999 with large window
Sky condition: varying sky
Average lacking light exposure H_{LLE}=0,06%
Maximum power of luminaire row (window-side, LB1) $P_{max\,LB\,1}$=217,57 W
Maximum power of luminaire row (wall-side, LB2, 100%) $P_{max\,LB\,2}$=218,60 W

Theoretical energy consumption
(100% light output during whole office day)
$W_{theor.LB1}$=2175,70 Wh
$W_{theor.LB2}$=2186,00 Wh
$W_{theor.total}$=4361,70 Wh

Real energy consumption of system:
W_{LB1} = 1754,71 Wh
W_{LB2} = 2119,98 Wh
Wges= 3874,69 Wh

Energy-saving:
ES_{LB1} = 19,35 %
ES_{LB2} = 3,02 %
ES_{ges} = 11,17 %

Absolute Energy-saving
ES_{LB1} = 420,99 Wh
ES_{LB2} = 66,02 Wh
ES_{Tota} = 487,01 Wh

Relative usable light exposure for test-day ("roompotential") RP=21%

See *figure 27* to *figure 33* for the courses of the interesting values.

Conclusion

The system used the offered room potential with efficiently. The calibration procedure is practical

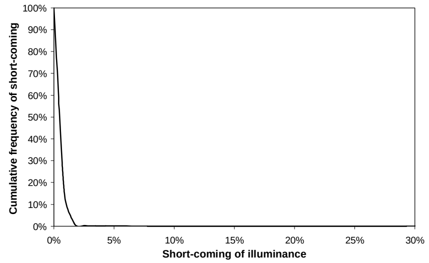

Figure 27 Cumulative frequency of short-coming of illuminance, 07.01.99

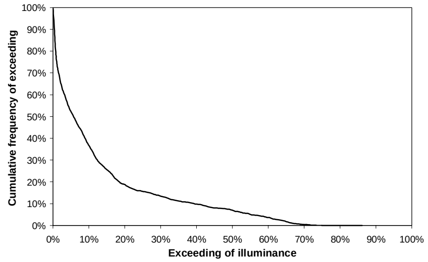

Figure 28 Cumulative frequency of exceeding of illuminance, 07.01.99

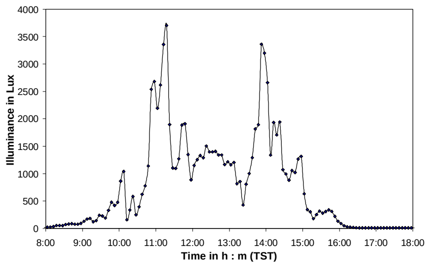

Figure 29 Illuminance on facade, 07.01.99

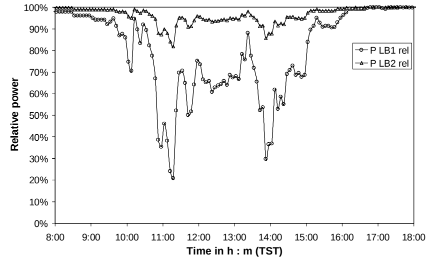

Figure 30 Relative power of luminaire rows, 07.01.99

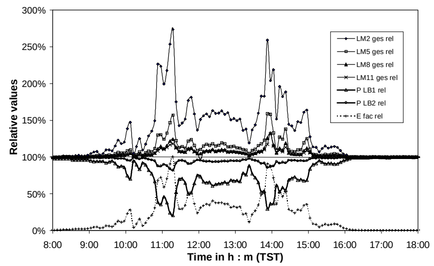

Figure 31 Relative power of luminaires, illuminances on working plane and facade 07.01.99

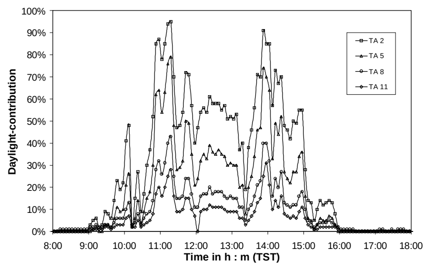

Figure 32 Daylight contribution on illuminances, 07.01.99

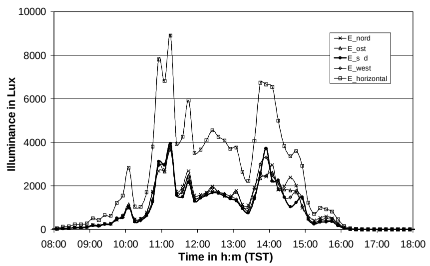

Figure 33 Daylight illuminances on test-day, 07.01.99