ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

DAYLIGHTING DESIGN OF EUROPEAN BUILDINGS

Scientific Report

Prof. J.-L. Scartezzini	Project leader
Dr. R. Compagnon	Physicist
S. Citherlet	Physicist
G. Courret	Physicist
L. Michel	Physicist
B. Paule	Architect
Dr. S. Simos (EIG)	Architect

Swiss contribution to UE project 93.0015, financed by OFES/BBW

Laboratoire d'Energie solaire et de Physique du bâtiment - ITB - DA DECEMBER 1997

1998 ~~REPRO~~ EPFL

LIST OF CONTENTS

SUMMARY

The EU project "Daylighting Design of European Buildings" is aimed at making daylighting design rules for buildings available to the European building industry. Its focus is placed on the use of daylighting in buildings to reduce artificial lighting needs while simultaneously improving the visual comfort of users and the architectural aspects of buildings.

Carried out by a team of about 20 individual European research institutions including Swiss participants, the overall project led to the achievement of the following objectives:

- 60 non-residential buildings in Europe were monitored regarding daylighting, energy performance and user reaction (case studies monitoring)
- a selected fraction of these buildings was simulated through computer modeling in order to generalize daylighting and energy performance rules for practicing architects and engineers (virtual case studies modeling)
- a "Sourcebook of 60 European Case Studies", which illustrates appropriate daylighting solutions through the presentation of monitored buildings, was made available
- "European Daylighting Design Guidelines" for appropriate integration of daylighting technologies in non-residential buildings were written.

The research activities of the Swiss team supported the overall goals of the EU project with the following contributions:

- *Case Studies Monitoring*

  Monitoring of 5 non-residential Swiss buildings including energy performance assessment of electric lighting systems

- *Virtual Case Studies modeling*

  Development of a detailed computer simulation methodology for the assessment of thermal and visual performance of buildings and application of this methodology to the Swiss selected case studies
- *Daylighting Design Guidelines and Sourcebook*

  Monitoring of advanced daylighting systems (anidolic systems) in new experimental test modules. Contribution of these and the other relevant Swiss research results (case studies monitoring and simulation) to the final documents of the EU project.

This report gives an overview of the activities carried out in Switzerland within the framework of the EU project. It complements the two main deliverables of the project (Daylighting Design Guidelines and Sourcebook), which targets architects and engineers.

RESUME

Le but du projet UE "Daylighting Design of European Buildings" est de mettre à disposition de l'industrie européenne du bâtiment des règles de conception et de dimensionnement en éclairage naturel. Il vise à obtenir ainsi une utilisation plus intensive de l'éclairage naturel dans les bâtiments à des fins d'économie d'énergie, tout en améliorant le confort visuel des utilisateurs et l'aspect architectural des bâtiments.

Près de 20 institutions de recherche européennes, ainsi que des équipes Suisses, ont participé à ce projet permettant ainsi d'atteindre les objectifs suivants:

- 60 bâtiments non-résidentiels, répartis dans l'ensemble de l'Europe, ont été diagnostiqués sur le plan de leurs performances en éclairage naturel, en énergie et en confort visuel.
- Une partie de ces bâtiments ont fait l'objet de simulations numériques détaillées, afin d'élaborer des règles pratiques de conception et de dimensionnement en éclairage naturel ("Virtual Case Studies modeling").
- Un "Sourcebook of 60 European Case Studies", illustrant de façon appropriée les bâtiments européens analysés a été élaboré.
- Des "European Daylighting Design Guidelines" présentant des solutions appropriées d'éclairage naturel à l'usage des praticiens ont été rédigées.

Les activités de recherche spécifiques, menées en Suisse dans le cadre du projet UE, ont contribués à la réalisation de ces objectifs, en permettant de mener à bien les tâches suivantes:

- "*Case Studies Monitoring*"
  5 bâtiments suisses non-résidentiels on fait l'objet d'un diagnostic expérimental conformément à un protocole approprié, comprenant de plus une détermination des performances énergétiques des dispositifs d'éclairage artificiel.

- "*Virtual Case Studies modeling*"

  Une méthodologie de simulation numérique appropriée (détermination des performances énergétiques et lumineuses des bâtiments) a été mise sur pied et appliquée aux bâtiments suisses sélectionnés.

- "*Daylighting Design Guidelines and Sourcebook*"

  Des dispositifs avancés d'éclairage naturel (systèmes anidoliques) ont fait l'objet d'un suivi expérimental détaillé sur des modules d'expérimentation en éclairage naturel; les résultats de ce dernier, ainsi que ceux provenant du diagnostic de bâtiments et de leur simulations numérique, ont été mis en valeur par le biais de contributions aux principaux ouvrages issus du projet UE ("Daylighting Design Guidelines and Sourcebook").

Ce document rend compte des activités spécifiques menées en Suisse dans le cadre du projet européen. Il complète ainsi les autres publications issus de ce projet, destinées aux praticiens du domaine du bâtiment.

1 INTRODUCTION

1.1 Aims of the project

The issue of 'building sustainability' has now reached a larger consensus in Europe. Daylighting received as a consequence greater attention in practice due to its capability of reducing non-renewable energy consumption in non-residential buildings (offices, schools, commercial buildings, etc.).

Several daylighting research programs were initiated in Europe during the last ten years [CEC 93]. Similar actions undertaken in Switzerland led to the development of advanced experimental and computer-based daylighting design tools at EPFL (LUMEN research program) [Sca 93] [Sca 94].

The EU project "Daylighting Design of European Buildings" is aimed at making these research results available to the building industry; its focus is placed on the use of daylighting in buildings to reduce artificial lighting needs while simultaneously improving the visual comfort of users and the architectural aspects of buildings.

In order to achieve that goal, the following specific objectives were defined for the overall project :

- to evaluate 60 selected non-residential buildings in Europe with regard to daylighting, energy performance and user reaction (monitoring of case studies)

- to perform a computer simulation of eleven of these buildings in order to generalize the daylighting and energy performance rules identified during the monitoring period (modelling of case studies)

The achievement of these objectives led to the elaboration of dissemination and information material, aiming at practicing architects and engineers and consisting of the following deliverables:

- "European Daylighting Design Guidelines" for appropriate integration of daylighting technologies in non-residential buildings [CEC 98a];

- a Sourcebook of "60 European Case Studies", illustrating through the presentation of real buildings, daylighting appropriate solutions [CEC 98b].

Other significant outcomes of the project can also be identified are:

- the elaboration of a "Monitoring package",

- the development of a daylighting and thermal performance building simulation methodology,

- the assessment of performance of advanced daylighting systems (anidolic systems).

Figure 1.1 illustrates the overall project objectives and deliverables that guided its organization.

The project started in September 1994 and was completed in August 1997.

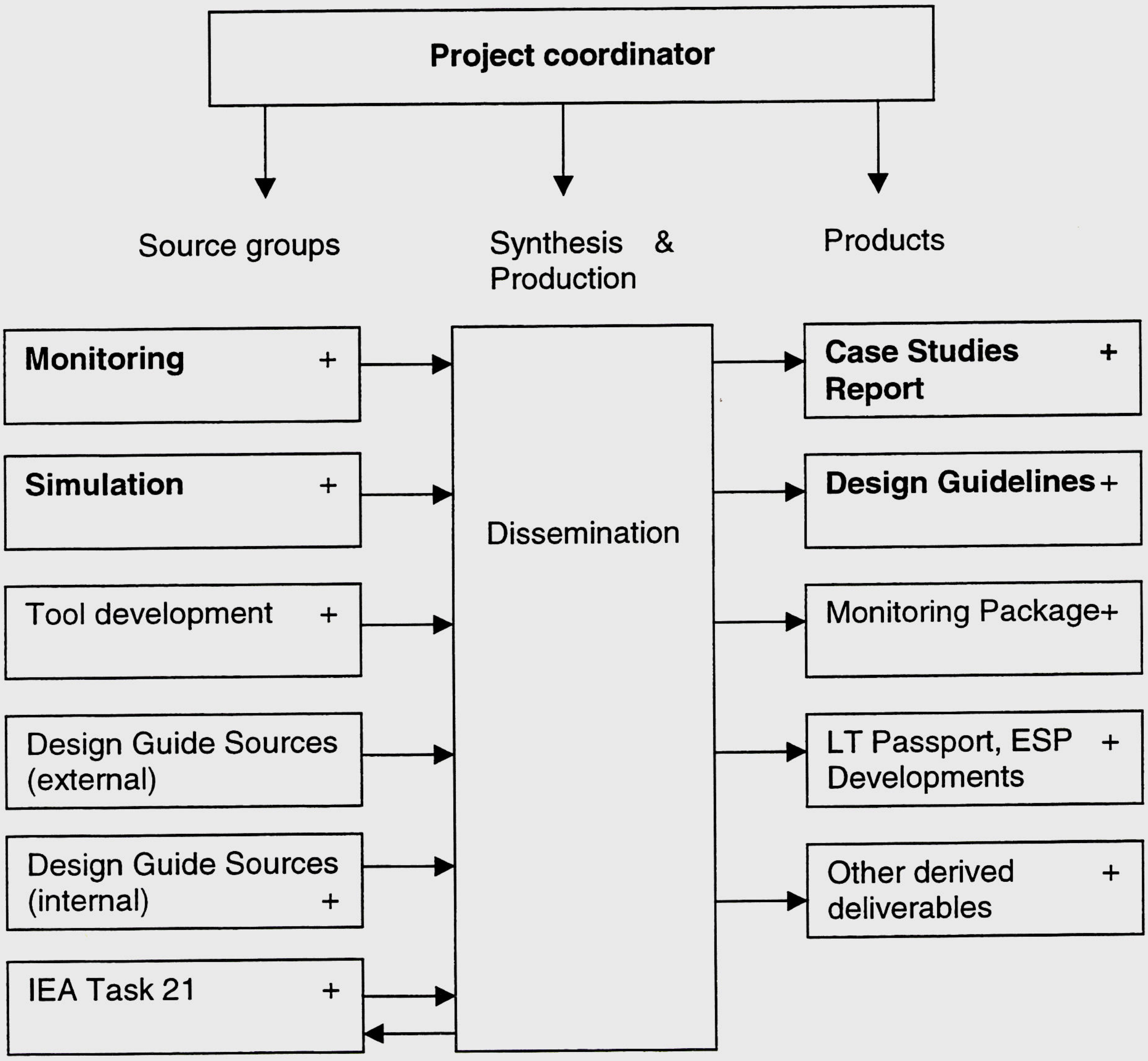


Figure 1.1: Organization of the EU project "Daylighting Design of European Buildings"
Bold : main groups and deliverables
+ : Swiss contributions

1.2 Organization of the project

The EU project was carried out by a team of about 20 individual research institutions in Europe, including the Swiss participation. Annex A gives a list of these institutions, together with the detailed organization of the project.

To carry out, in an efficient way, the different main tasks of the project, the research institutions formed several working groups, placed under the responsibility of a coordinator. As monitoring and modelling of selected case studies made up the major source of information of the project and the "Daylighting Design Guidelines" represented the main project deliverables, the following three work groups were constituted :

- a "Monitoring group", whose work was coordinated by Dr. M. Fontoynont (ENTPE/DGC, France)
- a "Simulation group" whose responsibility was assumed by Prof. J. Clarke (University of Strathclyde, Scotland)
- a "Design Guidelines group", coordinated by Prof. N. Baker (University of Cambridge, UK)

The Swiss participants were involved in the activities of all these working groups (cf. Annex A), a short description of the activities of these groups are given hereafter.

Monitoring group

The monitoring group evaluated the daylighting performance of the selected non-residential buildings (60 case-studies). This work was planned to document the principal parameters of the buildings daylighting performance, including :

- climatic data
- impact of the building environment
- characteristics of the fenestration system (window and shading device)
- visual comfort
- users reaction
- evaluation of the electric lighting system
- performance of lighting control strategy

The monitoring data was gathered in all participating countries. A common protocol was defined initially to facilitate the description and the comparison of the assessed building performance [Ber 95a, b]. Another document was elaborated by LESO-PB/EPFL to describe the evaluation procedure of the electric lighting system performance [Mic 96]; the latter was based on the experience gained in the field through important national daylighting research activities (LUMEN research project [Sca 94]). In the same way, a presentation format of building performance data, based on the investigations carried out within the framework of the same national activities [Gol 94], was successfully proposed to the project community.

Modelling group

The modelling group performed computer simulations of selected case studies (11 buildings) in order to obtain general design guidance from the monitored buildings.

The full daylighting contribution of different daylighting systems was assessed by simulation of a real building (as-built case) and the same building but without daylighting fixtures (reference case). The predictions of the computer tools were also checked against the building performances in the same while.

Novel computer simulation procedures were set up for that purpose: they imply a joint use of a dynamic thermal simulation program (ESP-r), together with an advanced daylighting simulation tool (ADELINE/Radiance).

A performance assessment method, which includes an appropriate representation format of the performance data (Integrated Performance View [Cla 95]), was defined at the beginning of the project. The Swiss team greatly contributed to this method thanks to its expertise in the field of visual comfort assessment gained during national research projects [Sca 93].

Design Guideline group

The Design Guideline Group had the responsibility of producing the "European Daylighting Design Guidelines", using the results of the two former groups, together with those coming from other expected sources (cf. Figure 1.1).

The Swiss team contributed substantially to the "Guidelines" through the specific daylighting performance monitoring of test modules carried out at EPFL (cf. paragraph 1.3) and writing of several chapters.

1.3 Description of the Swiss contribution

The Swiss specific activities in the project fitted perfectly in with its overall objectives. They benefitted from the important daylighting research activities carried out in Switzerland since the late eighties (LUMEN research program [Sca 93] [Sca 94]).

They contributed to the work progress of the three project groups and brought moreover a novel and unique contribution to the main outcomes of the project by providing another source for the "Design Guidelines" (monitoring of advanced daylighting systems).

All these activities were aimed at reaching the following specific objectives :

Case studies monitoring

- to monitor 5 Swiss case studies, using the appropriate procedure
- to complement the monitoring by undertaking an energy performance assessment of the electric lighting system

Case studies simulation

- to elaborate a computer simulation methodology to assess the thermal and visual performance of daylighting systems,
- to apply this methodology to some Swiss selected case studies.

Design guide Source

- to perform monitoring of advanced daylighting systems (anidolic systems) within new experimental test modules (DEMONA test modules [DEM 97]).

Daylighting design guidelines

- to valorize the experimental and simulation results through analysis and final appropriate sum-up,
- to prepare specific written contributions to the "Guidelines".

Figure 1.2 illustrates the organization of the specific activities carried out in Switzerland within the framework of the project.

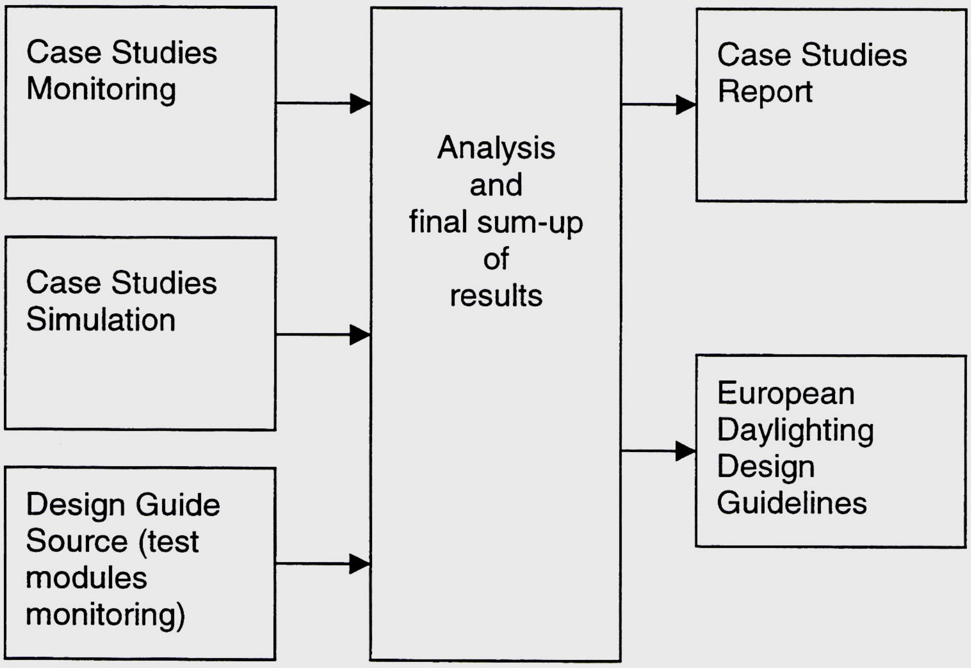


Figure 1.2: Organization of the Swiss specific contribution to the project.

This scientific report gives an overview of the activities carried out in Switzerland within the framework of the EU project. The structure of the document is based on the organization of the project and organized in the following manner :

- Chapter 2 gives an overview of the Swiss case studies monitoring and results (resp.: Simos Eclairagiste)

- Chapter 3 presents the simulation work carried out by the Swiss team (resp.: LESO-PB/EFPL)

- Chapter 4 shows the results of the monitoring campaign of advanced daylighting systems, carried out within appropriate test modules (resp.: LESO-PB/EPFL)

- Chapter 5 gives an overview of the final analysis and sum-up of the results of the project (resp.: LESO-PB/EPFL)

The main written contributions delivered to the EU project coordinator, within the framework of the activities of the 3 main project groups, are given in the Technical report [Sca 97b].

The two main deliverables of the EU project ("Daylighting Performance of Buildings: 60 European case studies" and "European Daylighting Design Guidelines") are published by the European Commission DG XII [CEC 98a] [CEC 98b].

2 MONITORING OF CASE STUDIES

The aim of monitoring the daylight performance of buildings throughout Europe was to provide background information for the preparation of the "European Daylighting Design Guidelines".

Case studies were selected for that purpose in the different EU countries (cf. Table 2.1) to cover various types of buildings, user profiles and climatic conditions. The focus was, however, placed on buildings with a high potential for electric lighting savings, such as office buildings, schools, and institutional and commercial buildings.

The Swiss contribution to this work had the following goals:

- to monitor the daylighting performance of 5 non-residential Swiss buildings
- to assess the energy efficiency of the corresponding daylight responsive electric lighting installations.

An overview of this work is given in this chapter. A detailed presentation of the outcome of the building monitoring is moreover given in the Technical Report (cf. Chapter 1 [Sca97b]).

2.1 Description of the buildings

The selection of the case study buildings throughout Europe was carried out at the beginning of the project. Much attention was given to this operation in order to benefit from an appropriate set of buildings, representative of the diversity of existing daylighting systems, building types and usage.

Sixty buildings, located in 15 different European countries [CEC 98a], were selected for that purpose.

Offices	Tractebel (Bel)
	Sukkertoppen (Dk)
	Trundholm (Dk)
	Domino Haus (Ger)
	Architects office (Gre
	Beresford (Irl)
	SAS HQ (Swe)
	EOS Office (CH)
	Reiterstrasse Building (CH)
	UAP Building (CH)
	Victoria Quay (Sco)
	NOA Building (Gre)
	Statoil (Nor)
	Kristallen Building (Nor)
	CNA Office (CH)
	Goteborg (Swe)
	LNEC (Por)
	Irish Energy Centre (Irl)
Transport	Stansted Airport (UK)
	Waterloo Station (UK)

Demo-projects	German Pavilion (Ger)
	Comphoebus (It)
	Bruntland Centre (Dk)
Museums	Staatsgalerie (Ger)
	Ludwig Museum (Ger)
	Byzantine Museum (Gre)
	Castlevecchio (It)
	MIN (Fra)
	Trapholt Art Museum (Dk)
	Waucquez Art Museum
	Modern Art Centre (Por)
Schools	Dragvold University (Nor)
	Pharmacy Faculty (Por)
	Queen's Building (UK)
	Anatomical Theatre (Swe)
	Collège Terre Sainte (CH)
	Collège La Vanoise (Fra)
	Berthold Brecht School
	Agricultural Bank (Gre)
	School of Education (Por)

Galeries	St. Huber (Bel)
	Galleria V.Emmanuele II (It)
Libraries	Stockholm Library (Swe)
	Darwin Library (UK)
	Bibiothèque de France (Fra)
	Trinity Library (UK)
	APU Centre (UK)
Houses	La Roche (Fra)
	Tombazis House (Gre)
	Serra Residence (Esp)
	Hawkes House (UK)
Churches	Monastery Benedictine (Ita)
	Cathedral St. Jean (Fra)
	Romchamp (Fra)
	Baroque Church (Fra)
	La tourette Convent (Fra)
	Pantheon (Ita)
Factories	Fagus (Ger)
Stores	Paustian House (Dk)
Other	Palm House (UK)

Table 2.1: Case study buildings selected for monitoring (60 case studies)

Table 2.1 gives a list of these buildings, together with their respective function. Most of them are office buildings (30%), which probably show the highest electricity savings potential; museums (13%), schools (15%) and other institutional buildings (libraries, churches) represent the rest of them.

A great variety of daylighting strategies are represented within the 60 case studies. Table 2.2 gives the distribution of these daylighting systems within the set of buildings: zenithal openings (22%) and atria (18%) make up the main fraction of daylighting systems, followed by glazed courtyards (13%), advanced glazing (13%) and clerestories (8%).

Type of systems	Number of systems
Zenithal openings	13
Artia	11
Glazed courtyards	8
Advanced glazing	8
Clerestories	8
Lightshelves	3
Bilateral daylighting	3
Prismatic panels	2
Combined systems	4

Table 2.2: Repartition of daylighting systems within the 60 case study buildings

Several buildings were considered as potential candidates for case study monitoring in Switzerland. Five buildings, located in four different towns of the western and eastern parts of the country were finally chosen on the basis of the following criteria:

- main architectural characteristics
- use of specific daylighting features
- type of building construction (new building, refurbishing)
- building location in the country.

Table 2.3 shows the main features of the Swiss selected case studies. Different daylighting systems are represented within this set of 5 buildings, three of which were new constructions and two refurbished.

Building name	Building use/type	Daylighting systems	Building site
Collège de la Terre Sainte	School/new	Artium, Lightshelves	Coppet
EOS Headquarters	Office/new	Lightshelves, bilateral	Lausanne
Reiterstrasse building	Office/new	Courtyards, bilateral	Bern
UAP Insurance building	Office/refurbished	Clerestories	Lausanne
CNA/SUVA building	Office/refurbished	Prismatic panels	Basel

Table 2.3: Description of the Swiss selected case studies

The five buildings were analyzed in detail in order to retrieve their main architectural features and dimensions from existing sketches and drawings. A few rooms, representative of the building's daylighting performance, were selected within the building for monitoring. A description of the buildings is given hereafter; more detailed information is given in the Technical Report [Sca 97b].

<u>*Collège de la Terre Sainte*</u>

The building is a string shaped 3-story building located on an open site (cf. Fig. 2.1).

<u>Main building data</u>

Location: Coppet (VD)

Latitude:	46.31 N
Longitude:	6.19 E
Elevation:	370 m
Construction date:	1989-1991
No of floors:	3+1 basement
Gross floor area:	9600 m^2

Figure 2.1: External view of Collège de la Terre Sainte (southwestern facade)

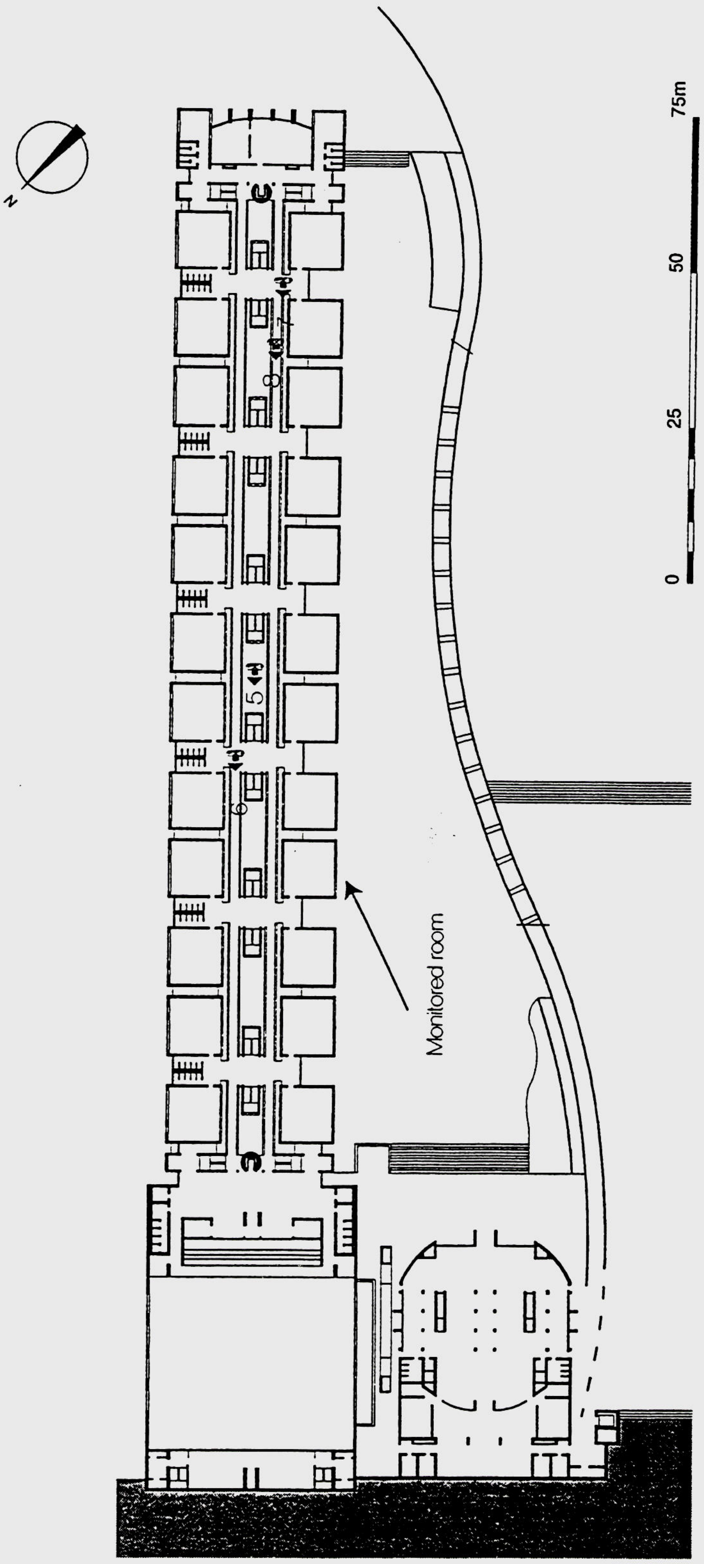


Figure 2.2: Plan of the Collège de la Terre Sainte (location of the monitored room is indicated)

The main building facades face northeast and southwest, with classrooms on both sides (cf. Fig. 2.2). A central glass-covered stair and walkway stretches along the building across regularly spaced atria (9.5 m deep). Figure 2.3 shows a view of an atrium, and Figure 2.4, a building cross section.

Figure 2.3: View of the ground floor of the central atrium: classrooms are located on both sides.

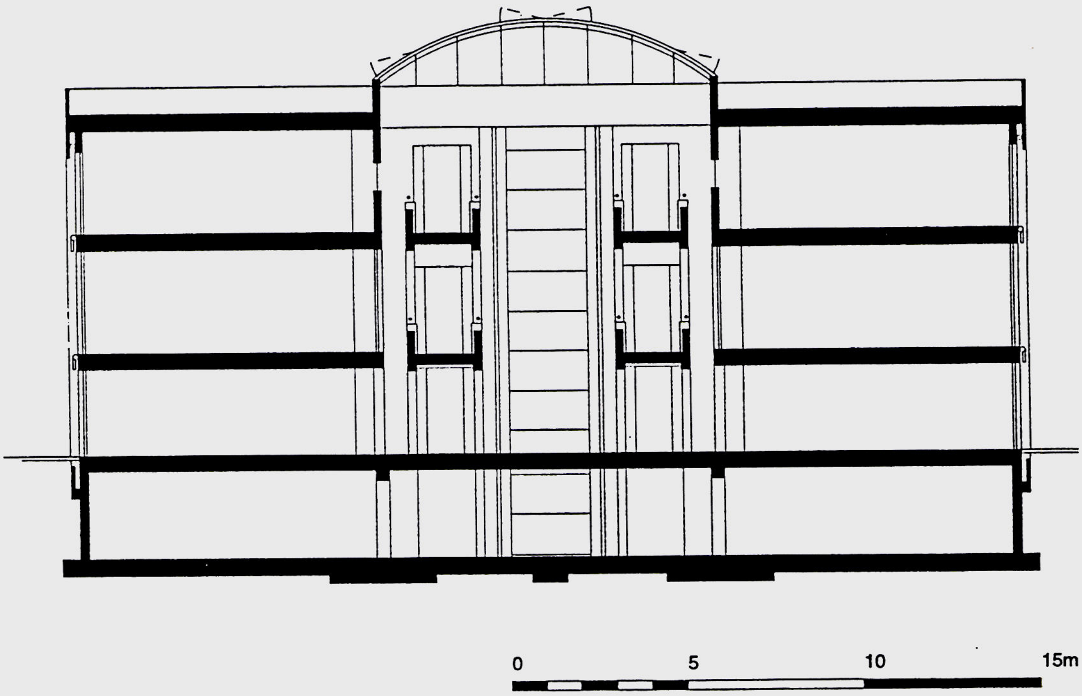
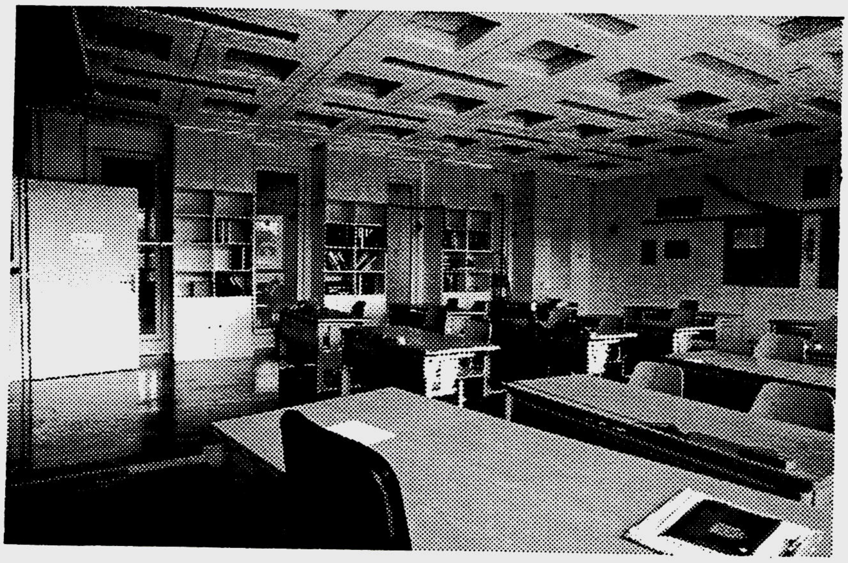


Figure 2.4: Vertical cross section of the building, showing atrium and classrooms

The building comprises 24 classrooms per floor, each one able to host between 24 and 26 children, which corresponds to a daily occupation for the whole building of 600 children (including 100 pupils for temporary activities).

A classroom, which is representative of the long row of classrooms on both sides of the building was chosen for monitoring: this classroom is located on the 1st floor of the building on the southwestern side (cf. Fig. 2.5 a and b).

a)



b)

Main classroom data

Room dimensions:
8.95 m (w) x 8.2 m (d) x 3.0 m (h)

Main facade glazing area: 11.6 m^2
Corridor wall glazing area: 6.2 m^2

Occupancy pattern: 8 am to 5 pm (except July and August)

Figure 2.5: View of a classroom a) Main window side
b) Corridor side

The classroom benefits from bilateral daylighting through the addition of the daylight flux that enters through the glazed areas of the main facade (double-glazing, τ_{hh} = 0.70) and the one from the glazing in the corridor wall (borrowed light, translucent glazing, τ_{hh}= 0.48).

The room glazing ratio equals 0.24: a glazed area of 11.6 m^2 is included in the main wall and 6.2 m^2 are glazed on the corridor side (cf. Fig. 2.2).

The walls of the classroom are painted white and show a high reflection coefficient (ρ_{hh} = 0.83). The ceiling is painted the same color; the floor is covered with a green-gray carpet and therefore darker.

The classroom is equipped with recessed fluorescent lighting fixtures fitted with conventional magnetic ballast. There are 4 rows of 4 luminaires (1 x 36 W) placed parallel to the main facade of the classroom (cf. Fig. 2.2)

EOS Headquarters

The EOS building is situated on a sloping site located in the middle of the town of Lausanne. It consists of two building blocks linked by an entrance platform on the ground floor (cf. Fig. 2.6).

Figure 2.6: External view of the EOS Headquarters (southwestern facade)

The building's main facade faces southwest and is characterized by continuous window openings fitted with high insulation glazing (U = 0.6 W/m^2k) and an aluminum lightshelf (cf. Fig. 2.7). The building incorporates a central atrium that provides daylight to the building core and the central distribution system (cf. Fig. 2.8).

Main building data

Location: Lausanne (VD)

Latitude:	46.31 N
Longitude:	6.38 E
Elevation:	500 m
Construction date:	1994-1995
No of floors:	6+2 basements
Gross floor area:	5900 m^2

Figure 2.7: View of the southwestern building facade fitted with light shelves

Figure 2.8: View of the central atrium of the largest building block (ground floor)

The majority of the office rooms are located along the main building facade: about ten office rooms benefit from the outstanding view and daylight provision of this facade (cf. Fig. 2.9). The central atrium is located behind the office rooms and provides them with daylight on their backside (cf. Fig. 2.10).

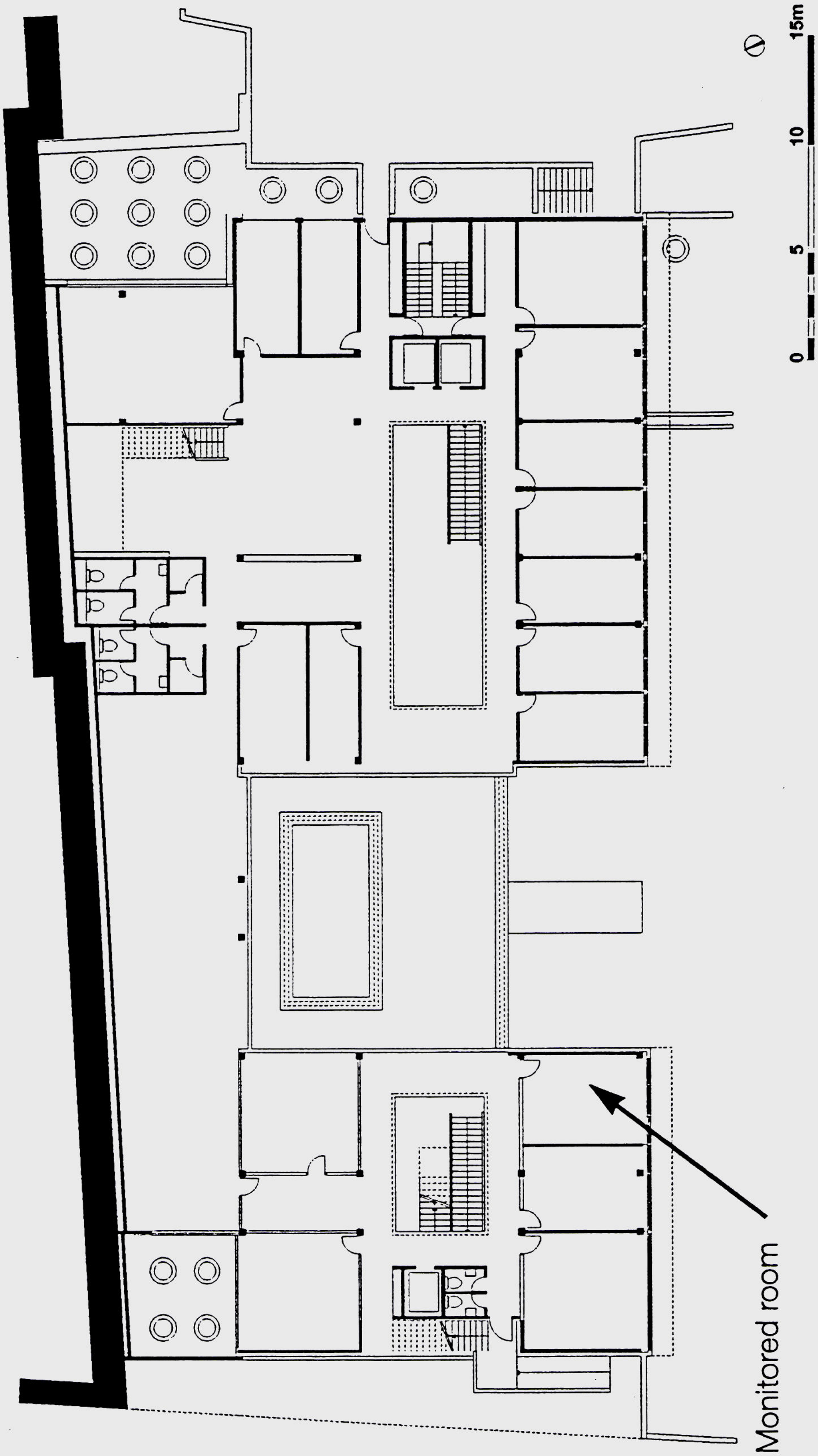


Figure 2.9: Plan of EOS Headquarters building (location of monitored room is indicated)

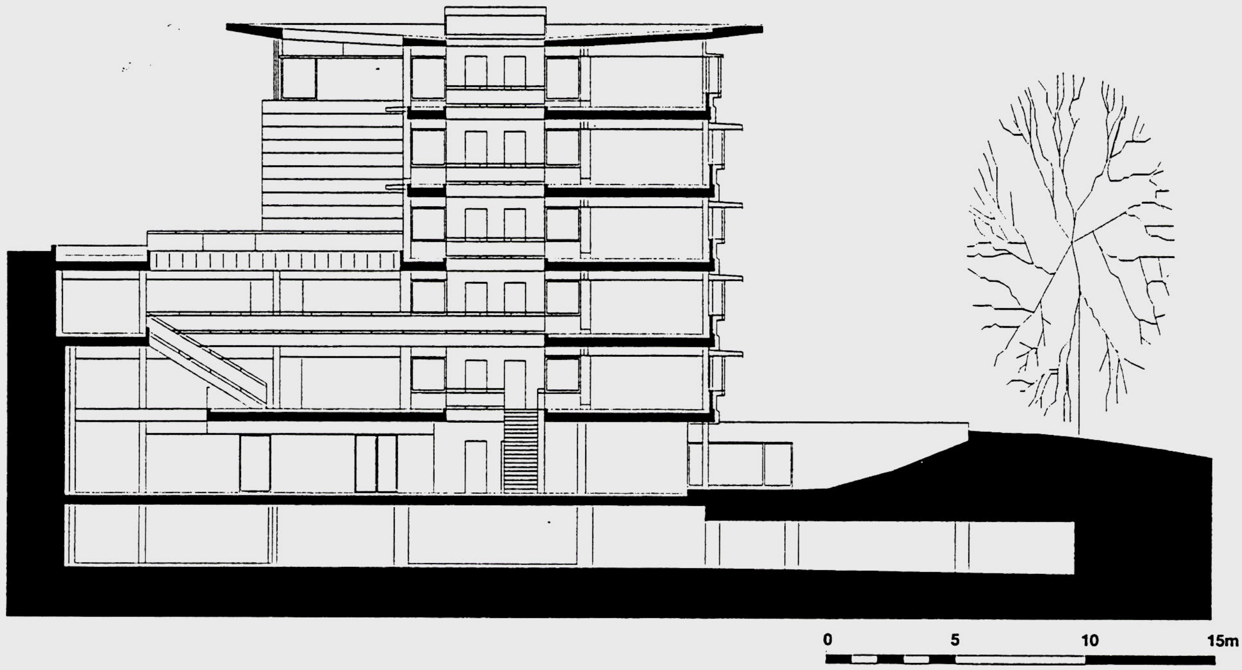
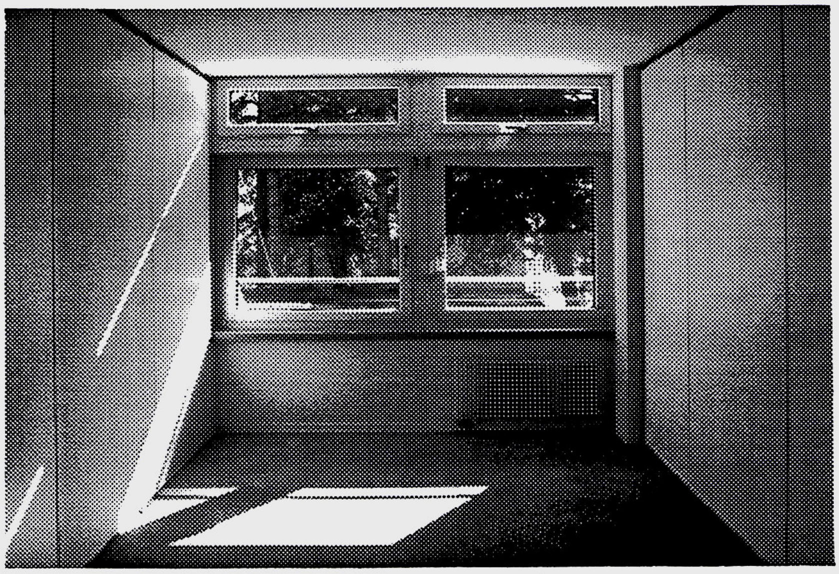


Figure 2.10: Vertical cross section of the building, which shows the office rooms on the main facade and the central atrium.

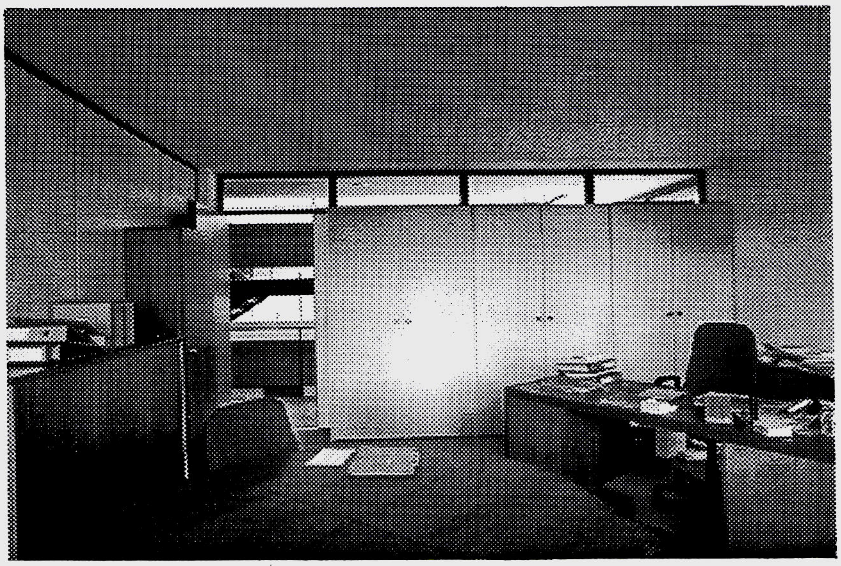
The building comprises about 10 office rooms per floor that are located along the main building facade and occupied by one person each; one situated on the third floor was chosen for the monitoring (cf. Fig. 2.9).

Each office room benefits from bilateral daylighting: borrowed light openings that provide daylight to the room through the central atrium (cf. Fig. 2.11b) complement the main facade openings (cf. Fig. 2.11a).

The glazing ratio of an office room is equal to 0.19: the main part of the glazing area is located on the main facade (4.4 m^2). It is made of super-insulated glass (double-glazing with selective coating on a plastic film) of a bi-hemispherical transmittance of 0.69. (U-value equal to 0.6 W/m^2k).



a)



b)

Main office room data

Room dimensions:
5.7 m (w) x 5.2 m (d) x 2.6 m (h)

Main facade glazing area: 4.4 m^2
Back wall glazing area: 1.2 m^2

Figure 2.11: View of an office room
a) Main window side fitted with a lightshelf
b) Secondary openings through central atrium

The glazed area of the back wall is small (1.2 m^2); it consists of clear glass with a poor window fraction (0.09) (cf. Fig. 2.11b). The room walls are clear (ρ_{hh} = 0.79) and so is the ceiling (ρ_{hh} = 0.82). The floor and furniture are dark colored (ρ_{hh} = 0.12 and 0.16 resp.).

There are no ceiling lighting fixtures in the room. Each desk is equipped with a floor luminaire in direct-indirect lighting mode. Each luminaire uses 3 compact fluorescent lamps (3 x TL55 W); switching between luminaires is possible from the entrance door and from the work desk. There is no automatic dimming on the luminaire either daylight responsive or user controlled.

Reiterstrasse Building

The building is located in urban surroundings characterized by rather low obstructions on the horizon. It shows a substantial construction volume and a high room space density (cf. Fig. 2.12).

Figure 2.12: External view of the Reiterstrasse building (northwestern and southwestern facades)

Zenithal openings placed above the walkways contribute to the lighting in the building all the way down to the lower floor (cf. Fig. 2.13). Fourteen courtyards spread over the building layout enhance the penetration of daylight into the building core and particularly the office rooms (cf. Fig. 2.14). The building cross-section (cf. Fig. 2.15) shows the close relation between the office rooms and the courtyards.

Main building data

Location: Bern (BE)

Latitude:	46.57 N
Longitude:	7.26 E
Elevation:	540 m
Construction date:	1979-1987
No of floors:	2+2 basements
Gross floor area:	11030 m^2

Figure 2.13: View of the glass covered walkway (1st floor) and adjacent courtyards

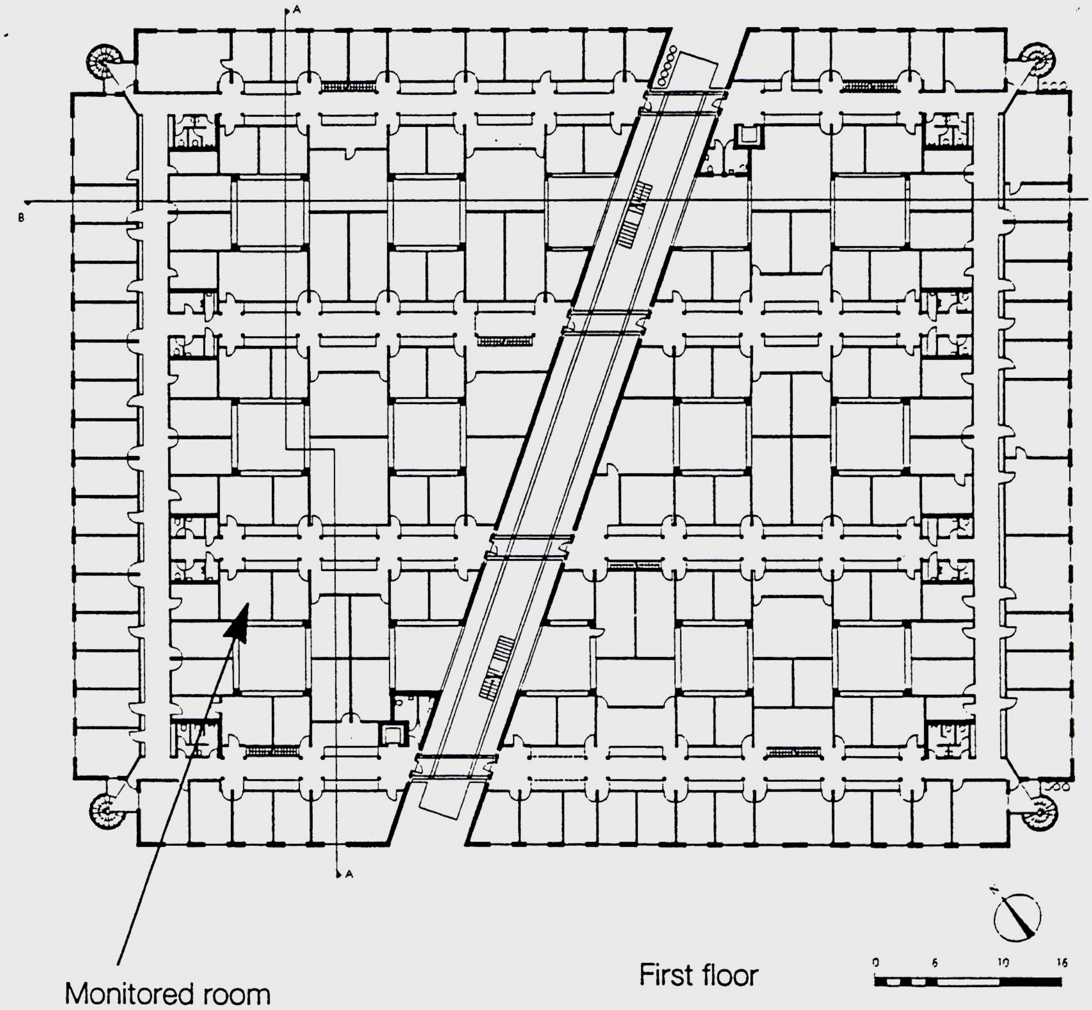


Figure 2.14: Layout of Reiterstrasse building
(the monitored office room is indicated)

The building comprises a dense configuration of office rooms on each floor. One of them located next to a courtyard and in the proximity of the southwestern facade was chosen for monitoring (cf. Fig. 2.14). Fig. 2.16a and b show internal views of the office room.

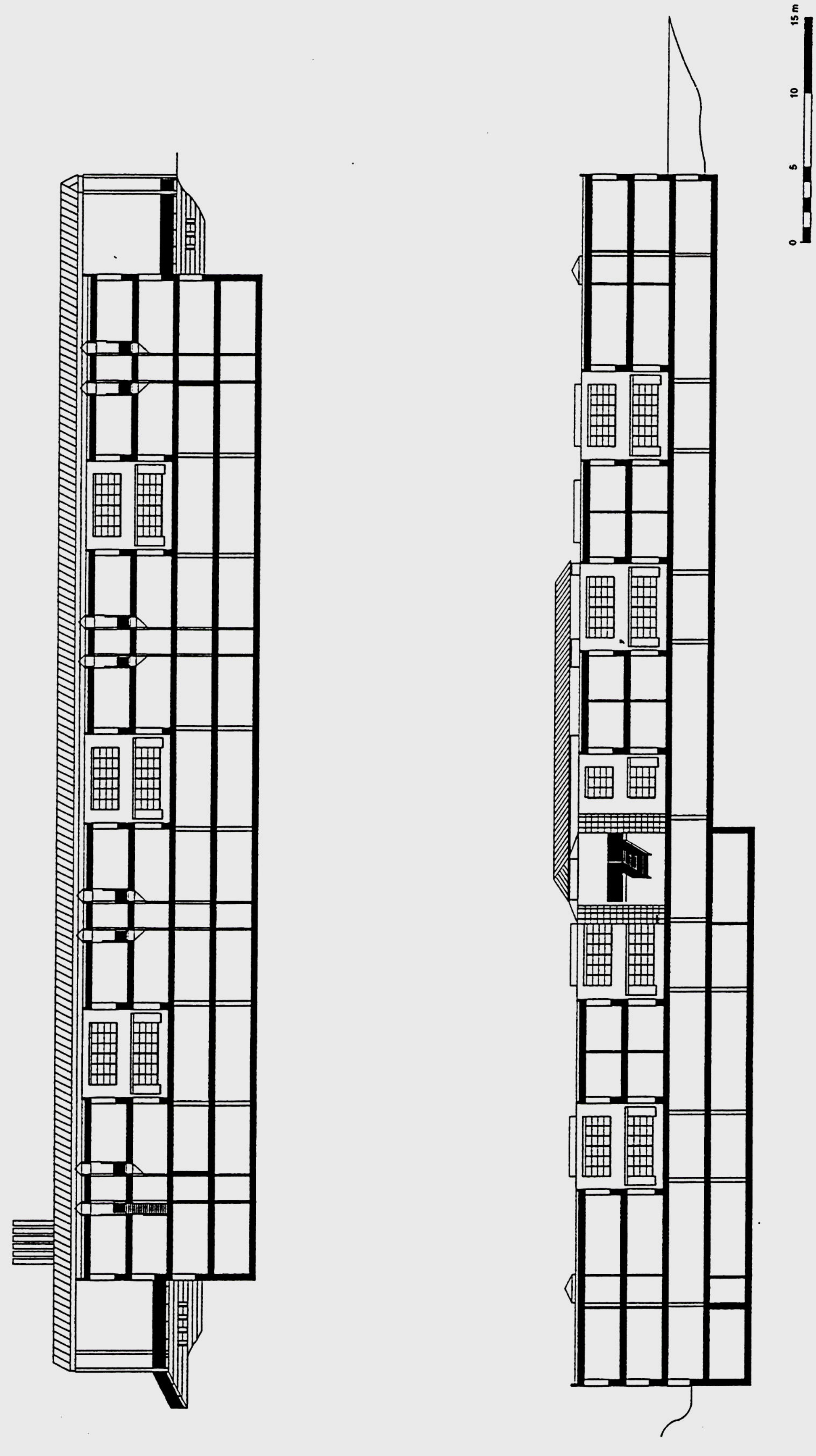
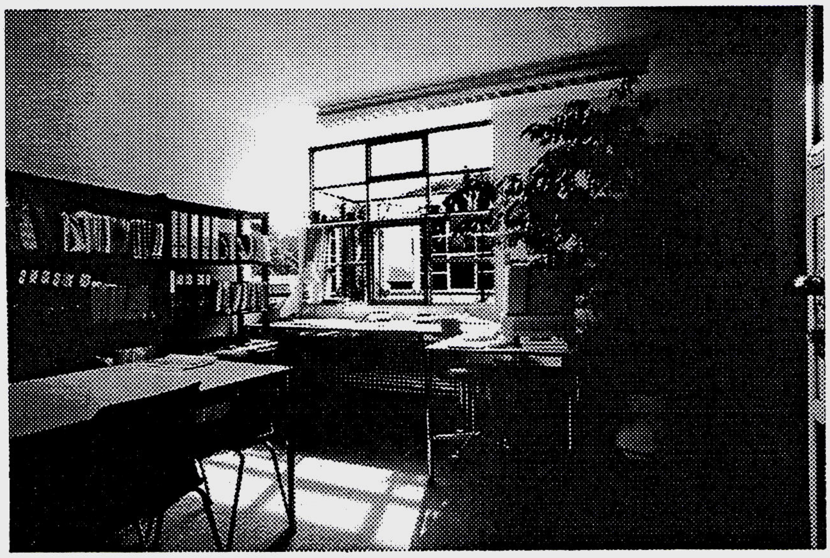
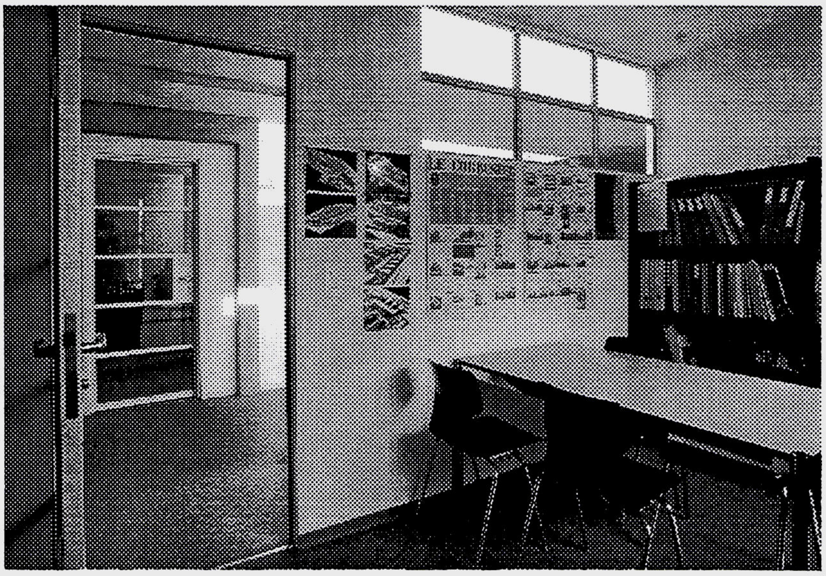


Figure 2.15: Vertical cross-section of the Reiterstrasse building



a)



b)

Main office room data

Room dimensions:
3.9 m (w) x 4.1 m (d) x 2.55 m (h)

Courtyard facade glazing area:
2.75 m^2
Corridor wall glazing area:2.8 m^2

Occupancy pattern: 8 am to 6 pm

Figure 2.16: View of an office room
a) View in direction of a courtyard b) Corridor side

The room is lit through an opening in the courtyard wall and through the openings of the corridor side. Double-glazing equips both openings: its transmittance under daylight is equal to resp. 0.65 (courtyard) and 0.73 (corridor side). The glazing ratio of the room is rather large with 0.35. Both glazing areas are similar (cf. Fig. 2.16).

The walls and the ceiling are light colored and show rather high bi-hemispherical reflectance values (ρ_{hh} = 0.74 and 0.76 resp.); the floor is very dark (ρ_{hh} = 0.66.).

The office room is equipped with two rows of two fluorescent lighting fixtures (1 x 36 W), mounted with conventional magnetic ballast and parallel to the courtyard wall. They are controlled by double hand switches located close to the entrance door; there is no automatic dimming control of the luminaires.

UAP Building

The UAP building is a 5-story administrative building located in urban surroundings (cf. Fig. 2.17). The building was constructed in 1969 and refurbished in 1991. The envelope and internal partitions were remodeled at this occasion. Daylighting penetration through the facades, wall surface paintings and electric lighting systems were improved at the same time.

Main building data

Location: Lausanne (VD)

Latitude:	46.31 N
Longitude:	6.38 E
Elevation:	410 m
Construction date:	1969, refurbished 1991
No of floors:	5+1 basement
Gross floor area:	2800 m^2

Figure 2.17: External view of the UAP building (southwestern facade)

The building has peripheral office rooms with identical southwestern and northeastern facades (cf. Fig. 2.18); a central core contains the vertical distribution system. The building layout (cf. Fig. 2.19) and vertical cross-section illustrate this (cf. fig. 2.20).

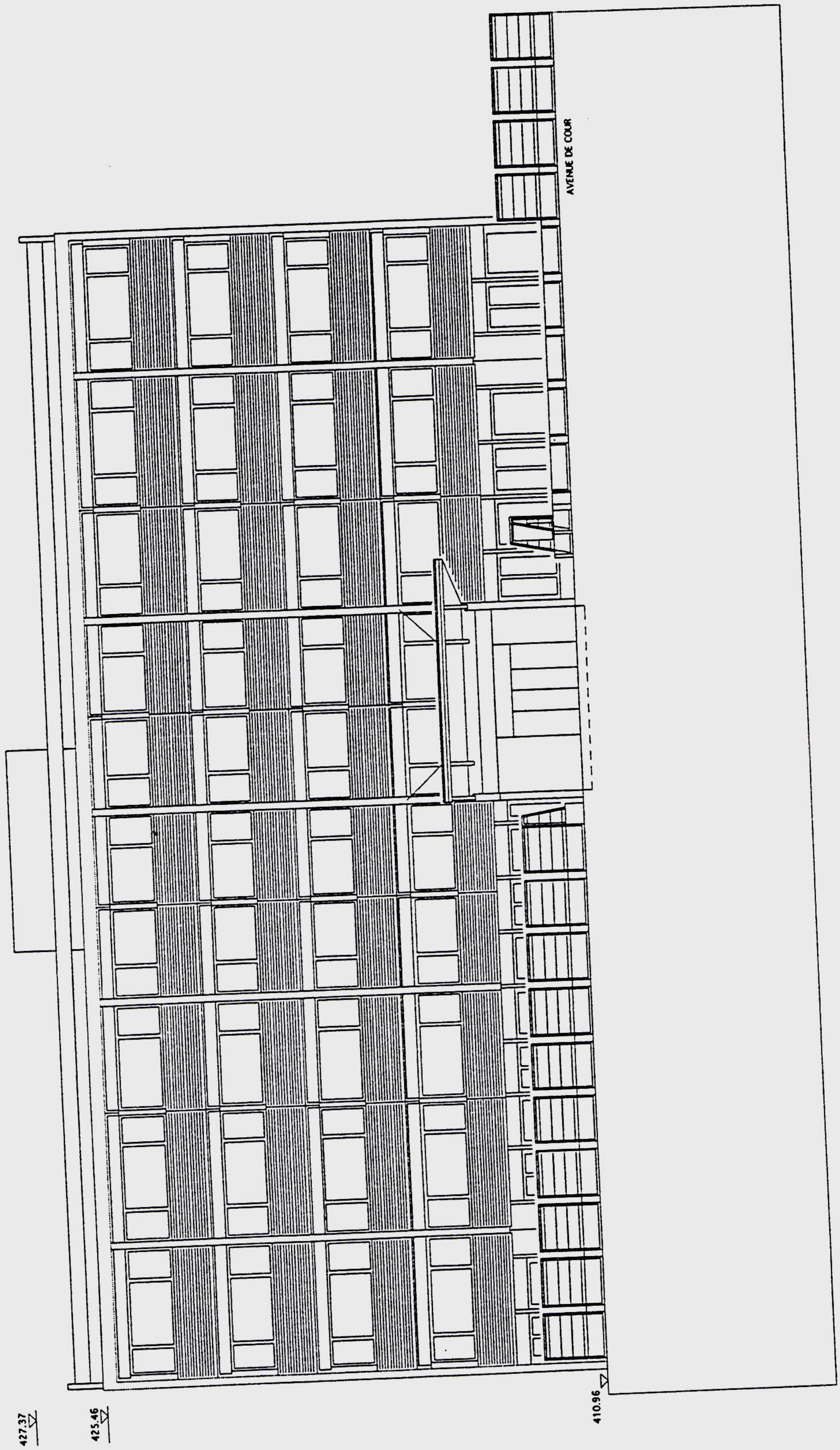


Figure 2.18: Sketch of the refurbished main building facade (southwestern facade)

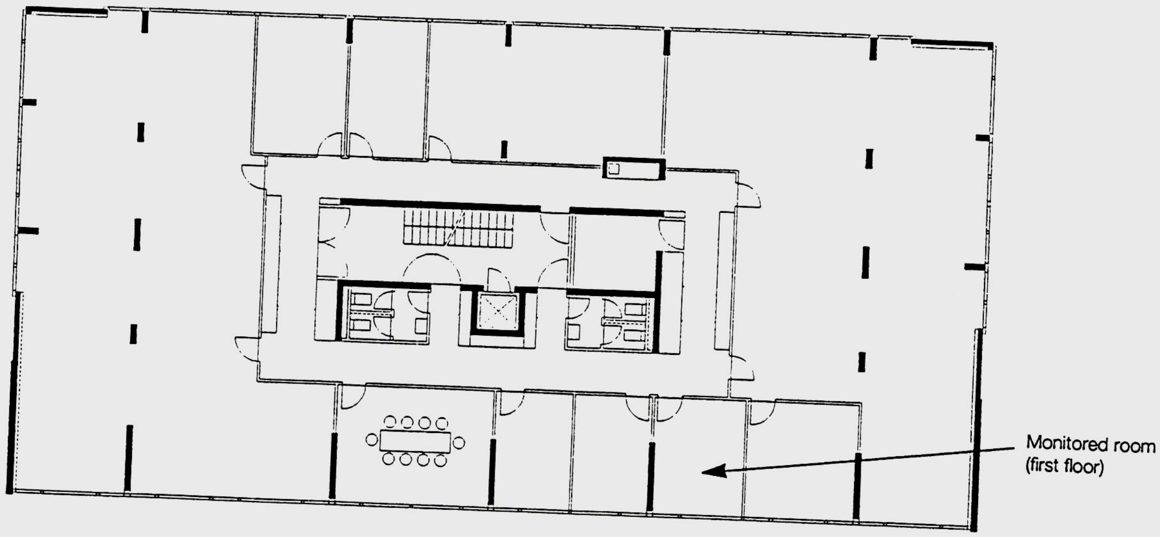


Figure 2.19: Layout of the first floor of the building (the monitored room is indicated)

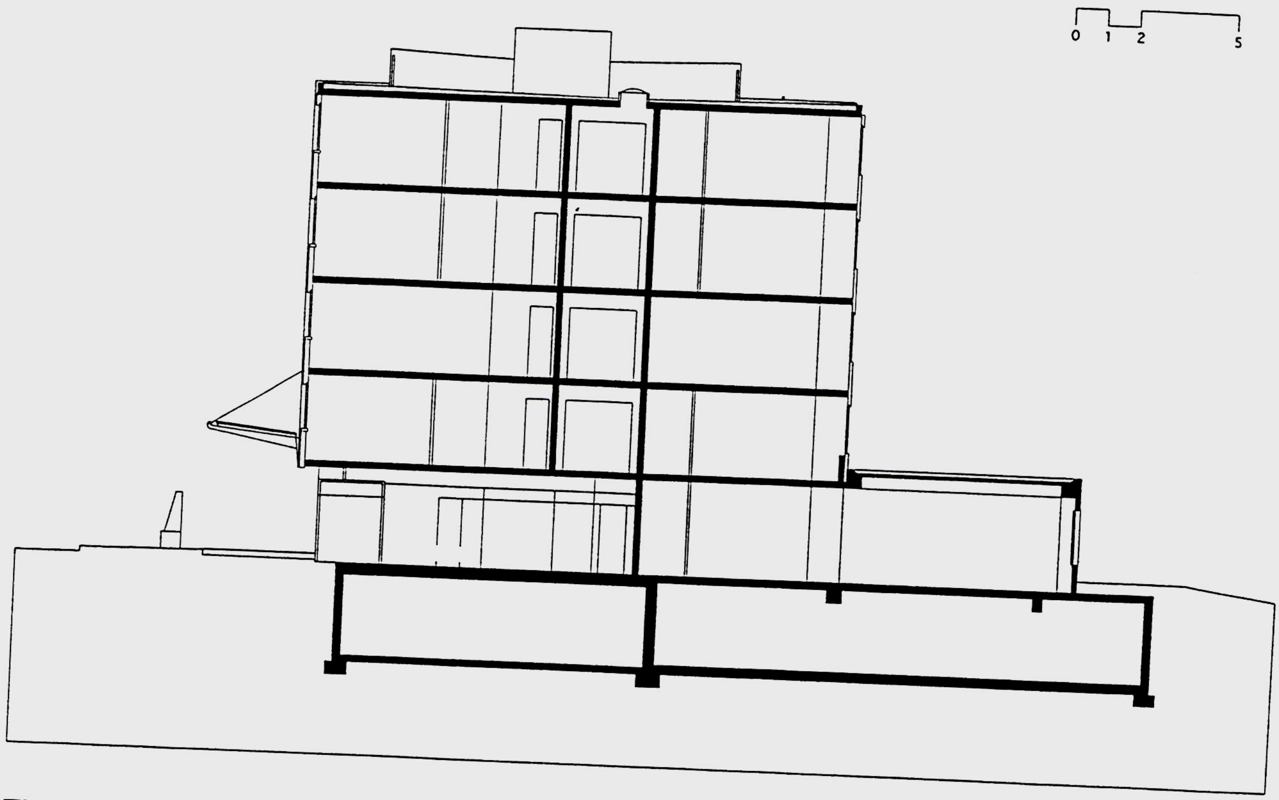
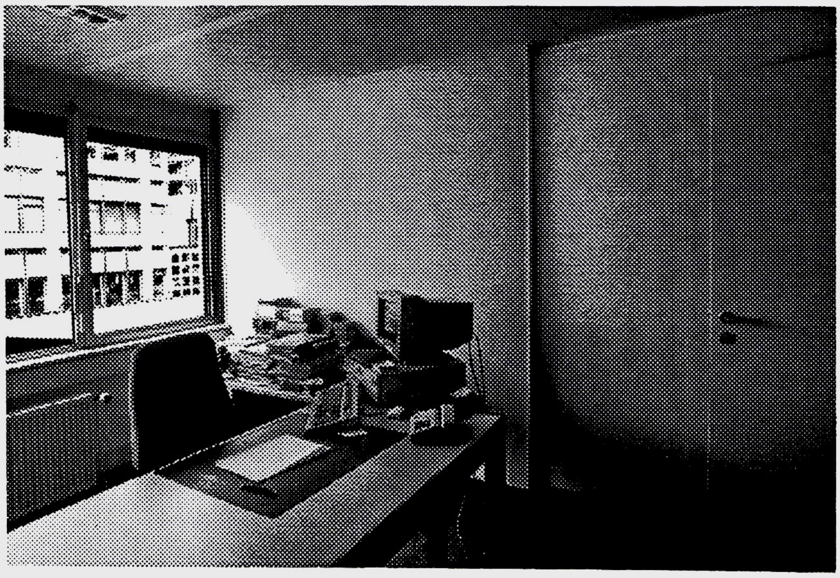
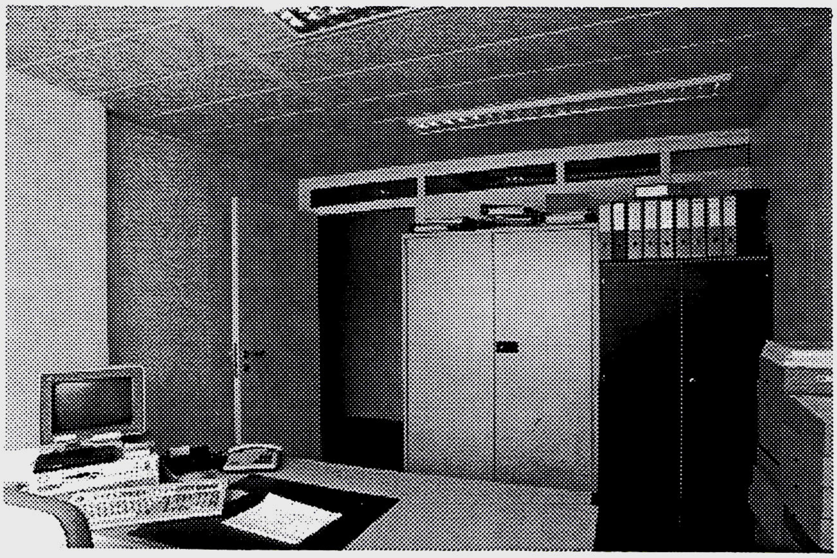


Figure 2.20: Vertical cross-section of the building with central distribution core and peripheral office rooms

The building comprises now, after refurbishment, about 12 office rooms per floor, each one occupied by one to three persons. One of the office rooms on the first floor was selected for monitoring (cf. Fig. 2.19). Figure 2.20 a and b show the room from different angles.



a)



b)

Main office room data

Room dimensions:
3.05 m (w) x 4.0 m (d) x 2.45 m (h)

Glazing area: 3.6 m^2

Occupancy pattern:
7.30 am to 7 pm (except weekend)

Figure 2.20: View of an office room
a) windows
b) corridor side

The refurbished room shows a rather high glazing ratio of 0.30: it benefits from side lighting through a usually well sunlit facade (cf. Fig. 20a). The windows are equipped with insulated double-glazing with a bi-hemispherical transmittance of 0.73.

The room walls and ceiling were painted in light colors during refurbishment; even if not optimal (values of walls and ceiling are reversed), they show reasonable bi-hemispherical reflectance values (ρ_{hh} = 0.76 for the walls and 0.56 for the ceiling). Furniture is gray with a reflectance of 0.42.

The new electric lighting system consists of three rows of recessed high optical efficiency luminaires (1 x 50 W, HF), fitted with electronic ballast and placed parallel to the window. A daylight responsive controller (Philips Trios) drives the two rows of luminaires closer to the window: they can only be switched on and off. Two hand switches located next to the door control the two groups of luminaires.

Non-refurbished electric lighting systems still exist on other floors of the same building. Their lighting fixtures consist of two rows of single-tube luminaires fitted with translucent acrylic protection. Only one hand switch, located close to the entrance door, allows a control of all the luminaires. A comparison of the efficiency of the ancient and new electric lighting system was carried out in the course of the energy performance assessment: it is reported in paragraph 2.4.

CNA/SUVA Building

The CNA/SUVA building is a retrofitted office building, to which a new extension with apartments was added. The building is located in an urban area and was refurbished: a double-skin facade was installed (cf. Fig. 2.21).

Figure 2.21: View of the CNA/SUVA building (northeastern facade)

The double-skin facade was designed to achieve different goals during the refurbishment of the building:

- to improve the penetration of daylight
- to reduce the heating energy demand
- to allow natural ventilation through the office spaces.

Figure 2.22 gives an inside view of the double-skin facade; Figure 2.23 shows a sketch of the facade that illustrates how it works.

Main building data

Location: Basel (BS)

Latitude:	47.56 N
Longitude:	7.59 E
Elevation:	270 m
Construction date:	1991-1993
No of floors:	6+1 basement
Gross floor area:	2840 m^2

Figure 2.22: Inside view of the double-skin facade

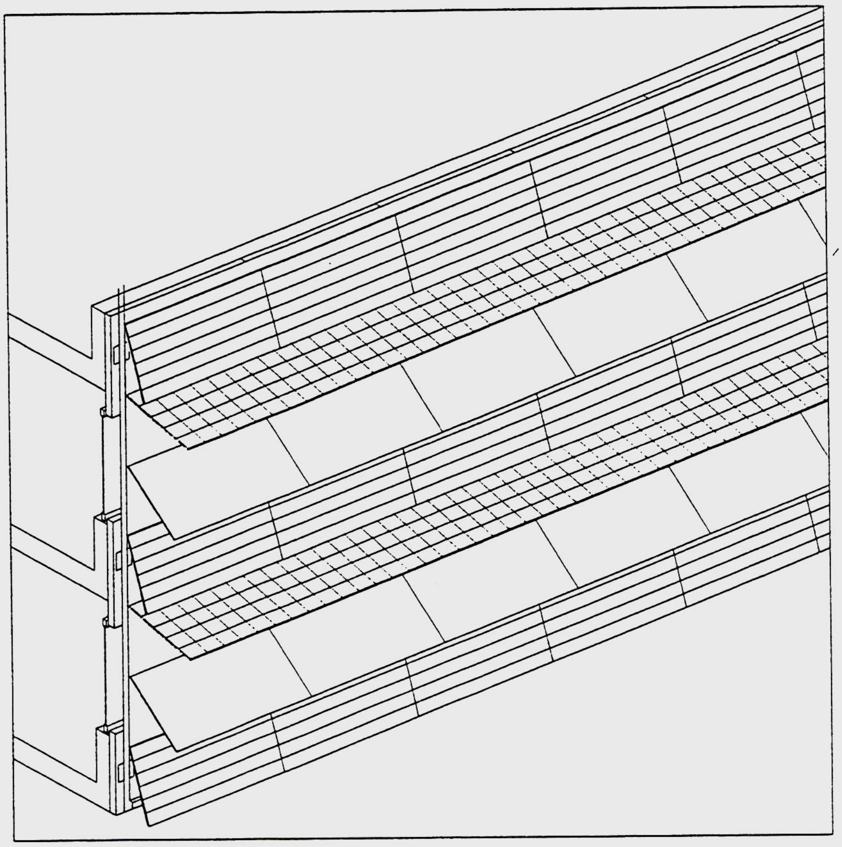


Figure 2.23: Sketch of the double-skin facade

At each floor level, the double-skin facade has a triple horizontal banding with top-hung motorized windows. Each band has a specific function:

- the upper one is made of insulated glazing with integrated prismatic panels; the glass panels move according to the sun position to direct sunlight into the interior of the building (daylighting function)

- the middle one is made of clear insulated glazing, which can be moved manually by the users during daytime (natural ventilation function)

- the lower band acts as a passive solar air collector during wintertime and creates a buffer zone in front of the old stone building wall (heating function).

Figure 2.24 shows the layout of the UAP building and indicates the monitored room situated on the third floor. The plan of the room shows the characteristics of the envelope wall, which is typical for a building of the early years of this century.

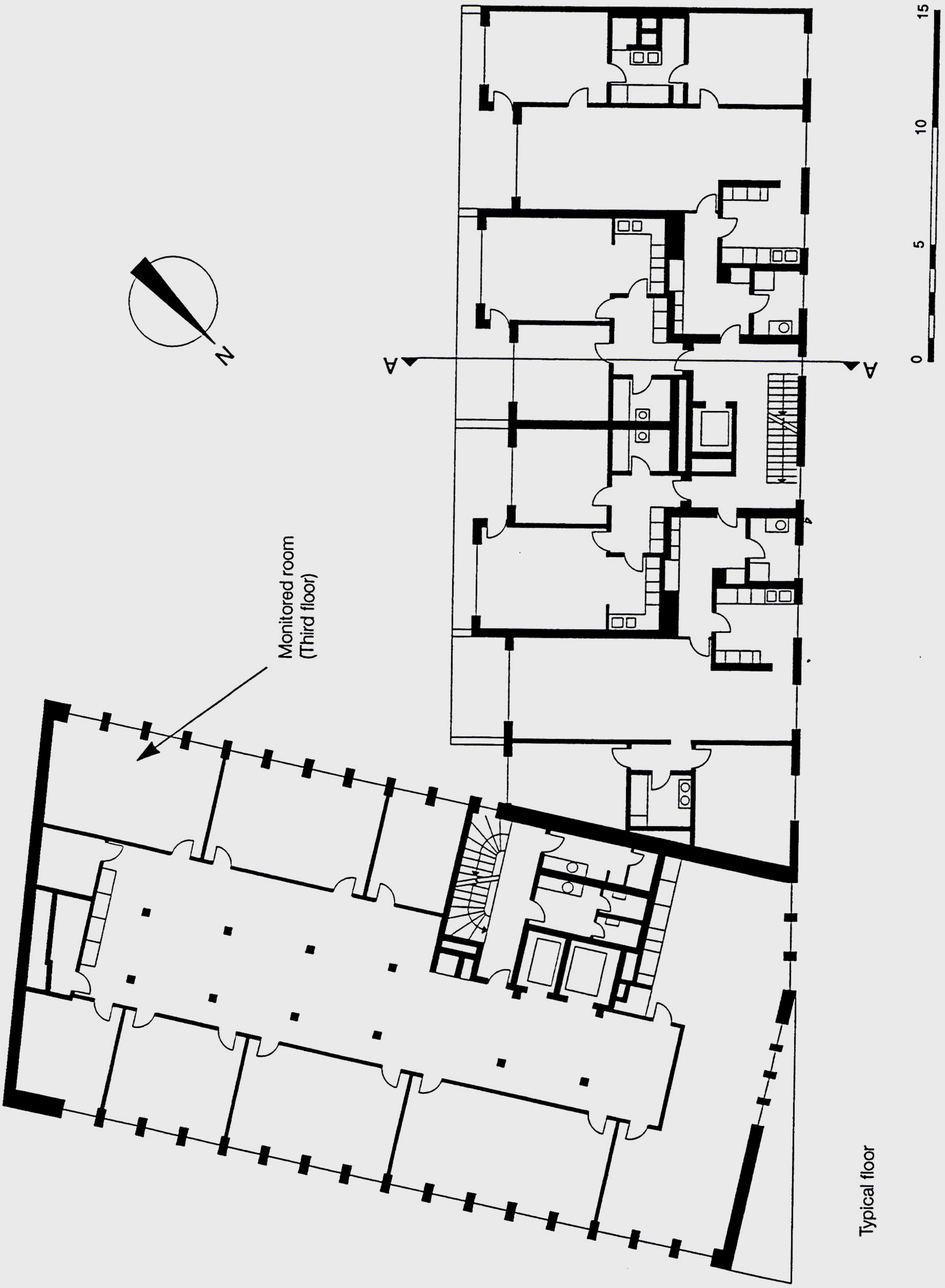


Figure 2.24: Layout of the UAP/SUVA building (monitored room indicated)

The monitored room is located on the 3rd floor and its windows are part of the southwestern backyard facade. It benefits from daylight that penetrates through the double-skin and is redirected by prismatic panels on a sunny day. Figure 2.25 gives an internal view of this office room.

a)

b)

Main office room data

Room dimensions:
4.35 m (w) x 7 m (d) x 2.6 m (h)

Double-skin facade glazing area: 3.6 m^2

Inside building glazing area: 7.4 m^2

Occupancy pattern: Flexible (42h/week)

Figure 2.25: View of the monitored office room
a) in the direction of the double-skin facade
b) in the direction of the building interior

The glazing ratio of the envelope wall is low at 0.08. The glazed area of the wall is limited to 3.6 m^2 rather high vertical openings (typical of buildings of the early years of the century).

The bi-hemispherical transmittance of the clear insulation glazing of the double-skin is 0.68. The corresponding value of the prismatic panel is 0.4. The office room is characterized by clear walls (ρ_{hh} = 0.65); the floor is dark (ρ_{hh} = 0.12); the furniture is clear (ρ_{hh} = 0.65).

The electric lighting system consists of two rows of 4 fluorescent fittings (1 x 36 W, Osram 21), placed parallel to the facade and equipped with electronic ballast. There is one hand switch per row located close to the entrance door and no automatic dimming of the luminaires.

2.2 Description of daylighting monitoring procedure

A common monitoring procedure was defined previous to the performance evaluation of the case study buildings [Ber 95a,b]. The procedure, also used for the buildings selected in Switzerland, allowed two possible levels of investigation:

- 1st level:
  Assessment of daylighting performance during 2-3 overcast days (worst-case conditions)

- 2nd level:
  Same measurements plus several visits of the building on sunny days (equinoxes, summer/winter solstices)

Both levels were considered for the Swiss buildings; an accent was, however, placed on the 1st level of monitoring, which is more representative of typical daylighting conditions in central Europe.

Besides assessing the daylighting performance of selected buildings, the monitoring procedure defined common and accurate ways to characterize both quantitative and qualitative aspects of daylighting. To reach that goal, the following specific data were gathered in each case study:

- views of buildings, inner spaces and daylighting systems,
- physical description of the building and the monitored room
- photometric properties of glazing materials and inner surfaces
- daylight factor distribution on reference plane
- daylight flux through daylighting systems and inner spaces
- luminance distribution and contrast at work place.

In the case of the Swiss buildings, the characteristics of the electric lighting system and the assessment of its energy efficiency regarding its utilization and response to daylighting provisions were added to the above data (cf. paragraph 2.4).

The monitoring procedure was demonstrated first in a pilot study carried out for the Collège de la Vanoise (Modane, France). A description of this procedure is given hereafter, with examples from the pilot study; a detailed description is given in [Ber 95 a,b]. The description of a similar procedure, applied within the framework of a Swiss national research project (LUMEN research project) is given in [Sca 94].

2.2.1 Physical description of the buildings

<u>Pictures</u>

Pictures of the building inner spaces as well as external views were taken with a wide-angle lens (20 mm focal) and high film speeds (400 ASA).

All pictures were taken without artificial lighting; date and time of day were recorded for sunny day conditions.

<u>Building plans and sections</u>

Building plans and sections were usually obtained from the building designer. They generally needed partial redrawing and corrections to match the requested symbolism. Most of them had to be translated into numerical format.

The plans described the whole building generally and, the monitored room in more detail.

2.2.2 Photometric properties of material

The photometric measurements were carried out using two different types of apparatus:

- two Brüel and Kjaer illuminance meters
- a Brüel and Kjaer luminance meter (Model 1011).

Photometric properties of glazing materials were measured first, to take into account that they directly affect the quantity of daylight that enters the building. Inner surfaces were also taken into account, due to their strong influence on daylighting propagation within buildings (absorption and reflection of daylight). The following photometric properties were measured for that purpose:

- the bi-hemispherical reflectance of inner surfaces (ρ_{hh})
- the bi-hemispherical transmittance of glazing materials (τ_{hh})
- the bi-normal transmittance of glazing materials (τ_{nn}).

A short description of the techniques used to measure these data is given hereafter.

<u>Bi-hemisperical reflectance</u>

In the absence of a perfectly diffusing light source, the bi-hemispherical reflectance of inner surfaces (ρ_{hh}) was measured in the presence of fully available daylight and using the following procedure (cf. Figure 2.27):

- 1st step:
  Standard diffusing white and gray samples are placed on the aimed surface; luminances of both standards (L_{white} and L_{gray}) are measured.

- 2nd step:
  The luminances of the surface ($L_{surface}$) is measured right after Step 1 and as close as possible to the standard samples.

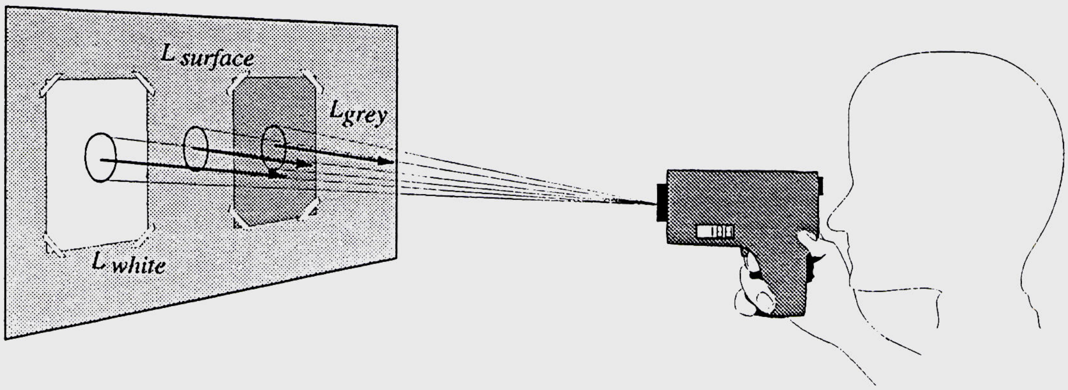


Figure 2.27: Bi-hemispherical reflectance measurement technique [Ber 95a]

The bi-hemispherical reflectance of the surface is given by the average of the two following values:

$$\rho_1 = \rho_{white} \cdot \frac{L_{surface}}{L_{white}}$$

$$\rho_2 = \rho_{gray} \cdot \frac{L_{surface}}{L_{gray}}$$

$$\rho_{hh} = \frac{\rho_1 + \rho_2}{2}$$

The procedure can be repeated to obtain sounder values of the surface reflectance and avoid the possible influence of particular daylighting situations.

Bi-hemishperical transmittance

The measurement of the bi-hemispherical transmittance (τ_{hh}) is carried out under overcast sky for glazing and shading devices. Again two steps are used (cf. Fig. 2.28):

- 1st step:
  An illuminance meter is placed on the external pane of the window facing the outside; one measurement (E_{ext}) is taken.

- 2nd step:
  A second measurement (E_{int}) is made right after the first one, with the illuminance meter placed behind the internal window pane (at 1 cm, to avoid light interreflections), facing outside.

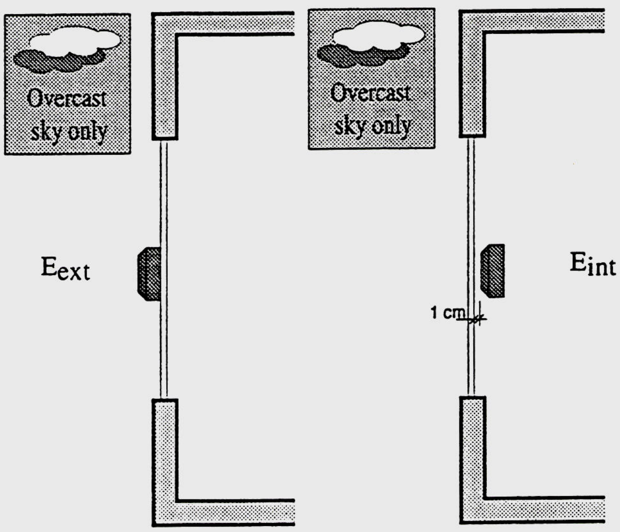


Figure 2.28: Bi-hemispherical transmittance measurement technique [Ber 95a]

The bi-hemispherical transmittance is given by the following equation:

$$\tau_{hh} = \frac{E_{int}}{E_{ext}}$$

The measurement is repeated several times to obtain sound transmittance values.

Bi-normal transmittance

The bi-normal transmittance (τ_{nn}) is a parameter that is usually provided by the glazing manufacturers.

It is measured again following a two-step procedure (cf. Fig. 2.29):

- 1st step:
  One luminance measurement ($L_{w/\ window}$) is made by pointing the luminance meter perpendicularly to the internal pane of the window, facing outside.

- 2nd step:
  A second luminance measurement ($L_{w/o\ window}$) is performed right after the first one, holding the luminance meter in the same position but without the window.

The measurement is made by pointing at a homogenous part of the sky vault or the facade of a building. The bi-normal transmittance is given by the following equation:

$$\tau_{nn} = \frac{L_{w/\ window}}{L_{w/o\ window}}$$

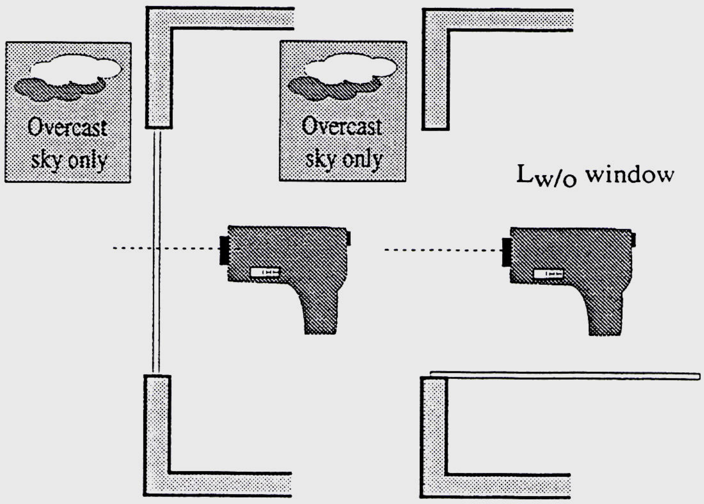


Figure 2.29: Technique of measurement of the normal-normal transmittance τ_{nn}.

2.2.3 Daylight factors

The daylight factor is a common denominator to assess a building's daylight performance. Daylight factors were measured under overcast skies according to the procedure recommended by CIE [CIE 70]. Different daylight factors were measured, however, in the building spaces to consider all the existing surfaces receiving daylight.

Horizontal daylight factors (reference plane)

Planes on which visual tasks are performed (e.g. desk, blackboard, etc.) are considered as reference planes. Illuminance measurements (E_{in}) were carried out on these planes simultaneously with measurements of the external horizontal illuminance (E_{out}) in a non-obstructed situation (usually on the roof of the building). Figure 2.30 illustrates the procedure.

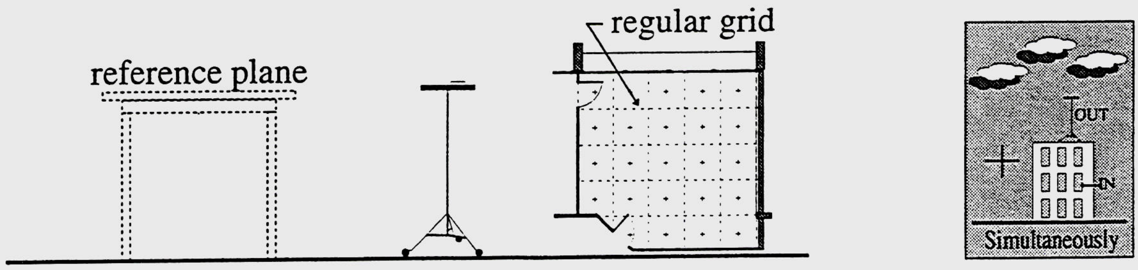


Figure 2.30: Assessment of daylight factor by simultaneous measurement of indoor illuminance on the reference plane (E_{in}) and outdoor horizontal illuminance (E_{out}) [Ber 95a].

The daylight factor at a given point P of the reference plane is simply given by the following relation:

$$D(P) = \frac{E_{in}(P)}{E_{out}}$$

Daylight factors were measured on an equally spaced grid of points; the distance between points was adapted to the room dimensions (15 points were considered at the minimum). The reference plane in office room was placed on the desk surface at 0.7 m from the floor. Daylight factor isolines were plotted with a linear interpolation on a logarithmic scale according to a blue scale convention (cf. paragraph 2.3).

Vertical daylight factors (eye level)

Besides being an important figure when vertically oriented tasks are considered, vertical illuminance assessed at eye level are key parameters in the determination of lighting environment conditions for the users: they drive their pupil size and consequently their acuity level and perceived visual comfort.

Vertical daylight factors were measured at eye level (1.2 m above the floor) in four directions at given reference locations corresponding to the user desk. The four directions were chosen parallel and perpendicular to the main viewing directions of the users (cf. Fig. 2.31).

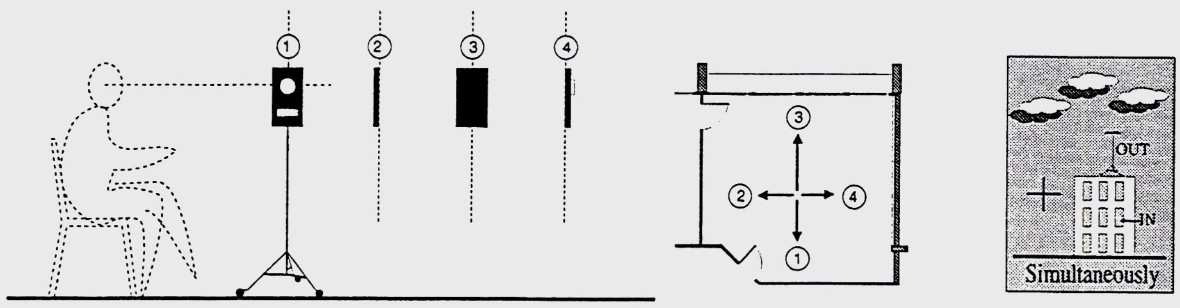


Figure 2.31: Measurement of vertical daylight factors [Ber 95a]

Daylight factors on windows and VDT screens

To assess the luminous flux that enters through the window openings, daylight factors were measured on the internal window pane, with the illuminance meter facing outside (cf. Fig. 2.32). Daylight fluxes for a 10 klux external horizontal illuminance were determined that way for all main room openings. By placing the illuminance meter at the center of VDT screens, corresponding daylight factors were determined to assess the veiling reflections produced on the screens (cf. Fig. 2.32).

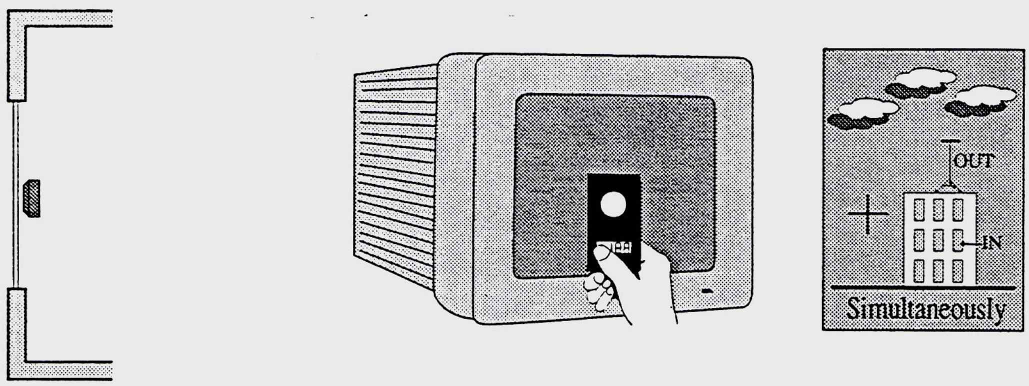


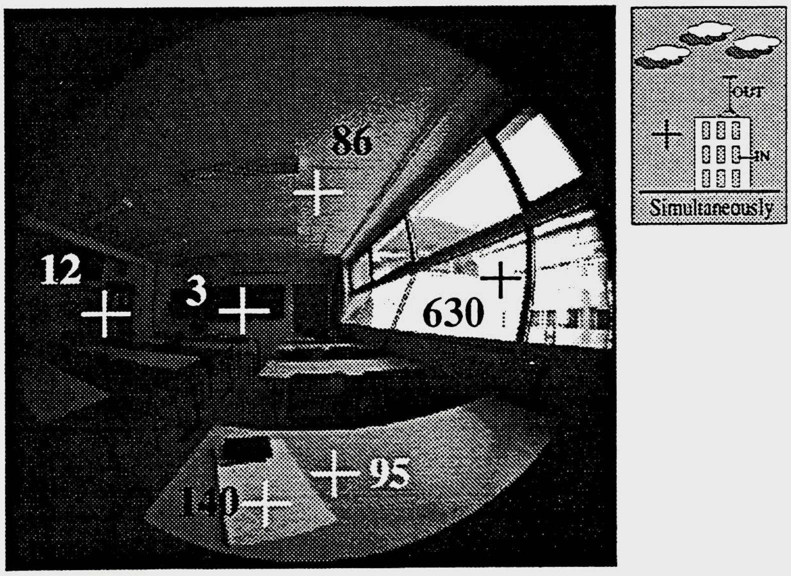
Figure 2.32: Measurement of vertical daylight factors on internal window panes and VDT screens [Ber 95a]

2.2.4 Users' lighting environment

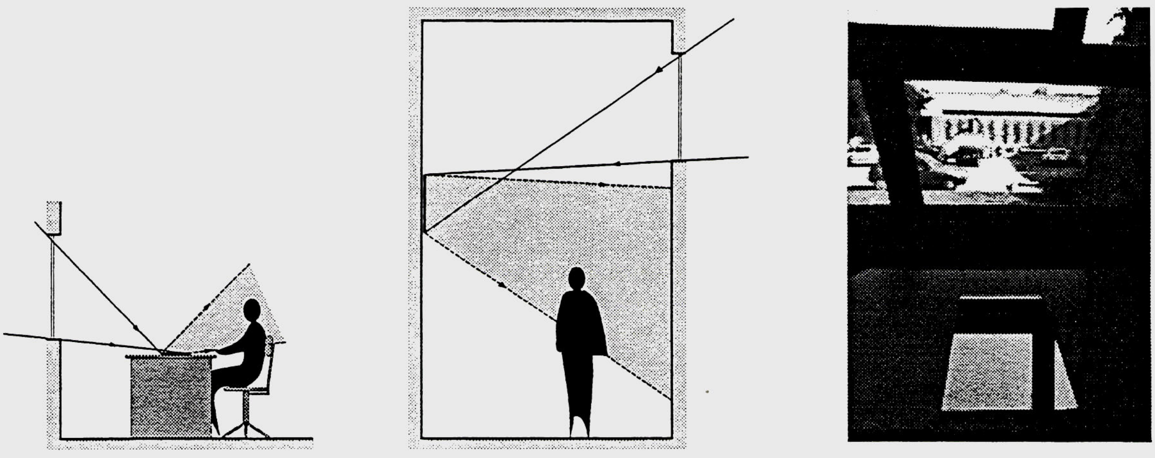
The luminance was measured at chosen places (typically work desks) in several typical sight directions while the horizontal outdoor illuminance was assessed simultaneously.

The measured luminance values were then normalized for a 10 kLux outdoor illuminance reference value and reported on wide-angle pictures taken at the chosen location, to allow a better visualization of the working environment (cf. Fig. 2.33).

Possible veiling reflections were identified by placing an A4-size mirror on the reference planes (i.e. the work desk). Pictures were used to report this data on the reference plane (including the mirror and the surroundings).



a)



b)

Figure 2.33: Assessment of users lighting conditions

a) by measuring and normalizing the luminance values for a 10 kLux external illuminance

b) by identifying possible veiling reflections.

2.3 Monitored daylighting performances

The monitoring of daylighting performances carried out by Simos Eclairagiste was coordinated with the assessment of electric lighting performance (cf. paragraph 2). The following principal results were obtained.

<u>*Collège de la Terre Sainte*</u>

Figure 2.34 shows the distribution of the daylight factor measured horizontally on the reference plane. The distribution obtained is characteristic of a sidelit room; it shows a quasi-exponential decrease of daylight factors from the window to the back wall.

It can be outlined that:

- a negligible amount of daylight comes through the borrowed light openings of the back wall;

- translucent glazing in the openings and the location of the walkways are responsible for that situation;

- half of the class room, characterized by a daylight factor lower than 2%, has no daylighting autonomy and will, as a consequence, rely on electric lighting all year round and at any time of the day.

It must be emphasized, however, that the glazed walkways and atria are perceived as a positive factor regarding visual feeling, even at ground level.

DAYLIGHT FACTORS DISTRIBUTION

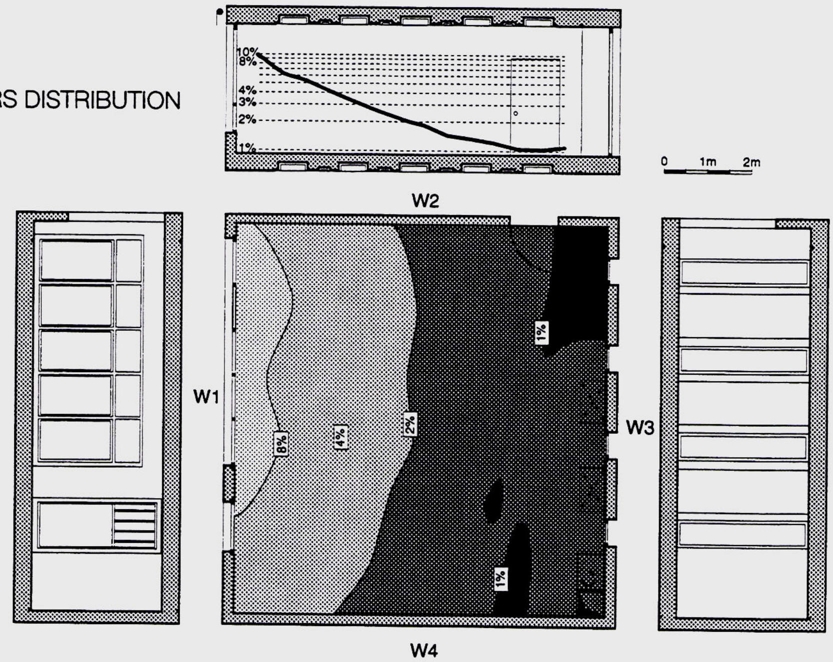


Figure 2.34: Daylight factor distribution in the monitored classroom of Collège de la Terre Sainte (Date of monitoring: 16 December 1995).

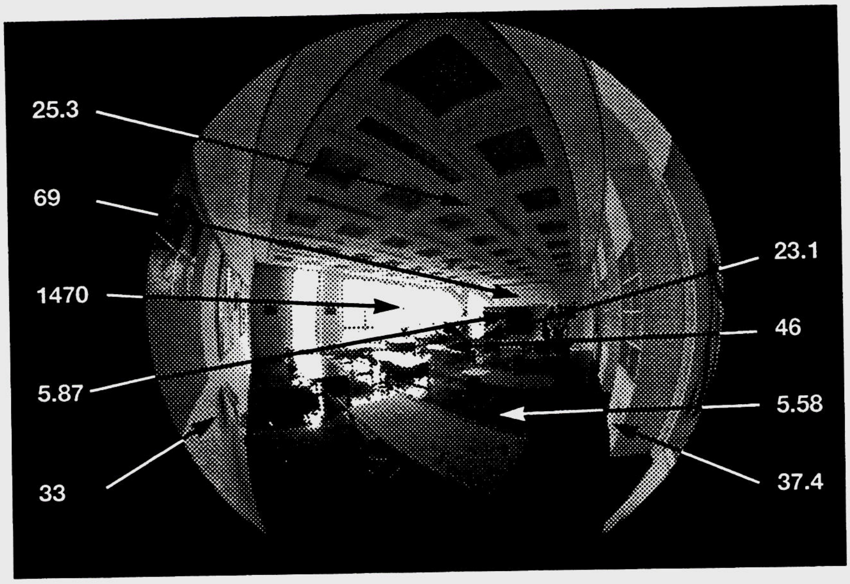


Figure 2.35: Luminance values normalized for a 10 kLux external illuminance and fish-eye view of the monitored classroom.

The luminance measurements illustrated in Fig. 2.35 show the following results:

- acceptable luminance contrasts were observed in the users' view field except in the direction of the windows (1470 Cd/m^2) and the floor (5.5 Cd/m^2);
- the first value indicates that blinds that allow accurate luminance control (movable louvers) are necessary;
- the second one shows that the floor reflection factor is too low as the room is not optimised photometrically.

The electricity consumption of the building corresponds to this rather standard daylighting performance; for details see paragraph 2.4 of this report.

<u>*EOS Headquarters*</u>

Daylighting performance monitoring of the EOS building showed results that appear consistent with those from computer simulations (cf. chapter 3). Figure 2.36 gives the daylight factor distribution of the monitored room, which is characteristic for daylighting systems like light shelves (more even daylight factor distribution). The results can be summarized as follows:

- low daylight factors were observed for the overall room compared to conventional sidelit rooms without light shelves (5% max. daylight factor);
- an even daylight factor distribution was observed, which leads to a possible improvement of visual comfort and performance;
- the contribution of the borrowed light openings of the backwall is nill.

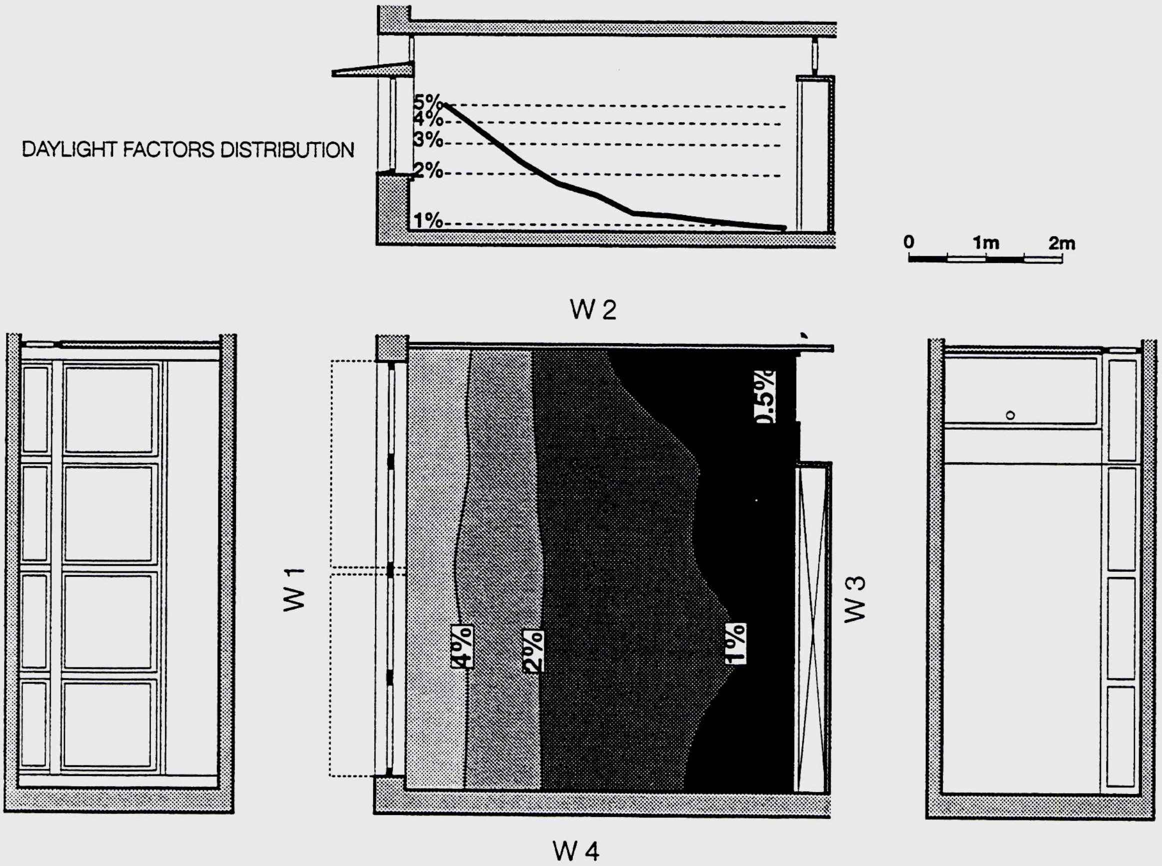


Figure 2.36: Daylight factor distribution in the monitored office room of the EOS building. (Date of monitoring: 26 January 1996)

Luminance measurements confirmed these results in so far as (cf. Fig. 2.37):

- appropriate luminance contrasts were experienced in the room, almost even for the values measured through the windows (impact of light shelves);

- glare risks from the upper lightshelf window exists for low solar altitudes (winter season); interior fabric rollers were installed later on the inner side of the windows to reduce that risk.

The measurement of the vertical daylight factor on a VDT screen (0.83%) confirmed the low general daylight illuminance of the room, more compatible with VDT tasks.

It must be emphasized, moreover, that the central atrium contributed to the general positive appreciation of the lighting environment of the building. Good energy figures were observed for the building (cf. chapter 2.4), which confirm the adequacy of the daylighting strategy for VDT tasks: the use of a task lighting electric fixture is probably also responsible for this positive result.

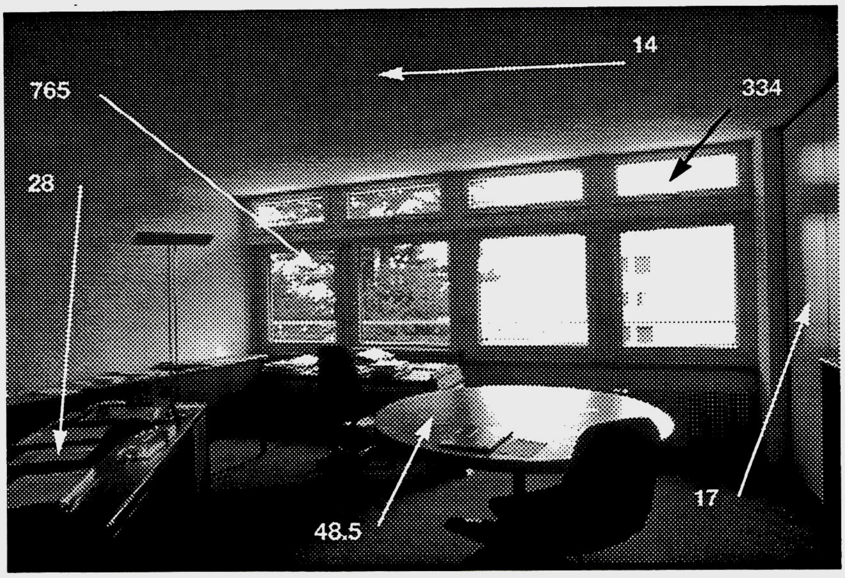


Figure 2.37: Luminances (normalised for 10 kLux) and fish-eye view of an office room (EOS building)

<u>*Reiterstrasse Building*</u>

The monitoring of the Reiterstrasse building allowed evaluating the contribution of a borrowed daylighting system adjacent to different courtyards. Figure 2.39 a and b show the impact of this system, which was obstructed in the case of Fig. 2.39b. The following conclusions can be drawn:

- the borrowed light system increases by 1% the daylight factor in the back of the room;
- more than half the office room area benefits from a significative daylighting autonomy (daylight factor higher than 2%);
- the rather even daylight distribution contributes to a pleasant visual impression in the room, and possible energy savings.

It must be emphasized, moreover, that the general daylighting concept of the building (central glazed walkway, glazed courtyards, etc.) produces a real diversity of visual impressions for a person who moves around in the building: as a consequence, the users express a positive feeling.

The luminance measurements carried out under non-perfect overcast sky conditions (presence of a sun spot) confirms the even luminance distribution one may expect from this room. Excessive luminance contrasts are, however, observed for direction viewing through the windows; they remain reasonable for partly sunny conditions.

Figure 2.38: Luminance values and fish-eye view of the Reiterstrasse monitored room

The positive results of the monitored performance of the electric lighting confirmed the appropriate daylighting features of the room (cf. paragraph 2.4). Energy performance indexes of the building corroborate these results.

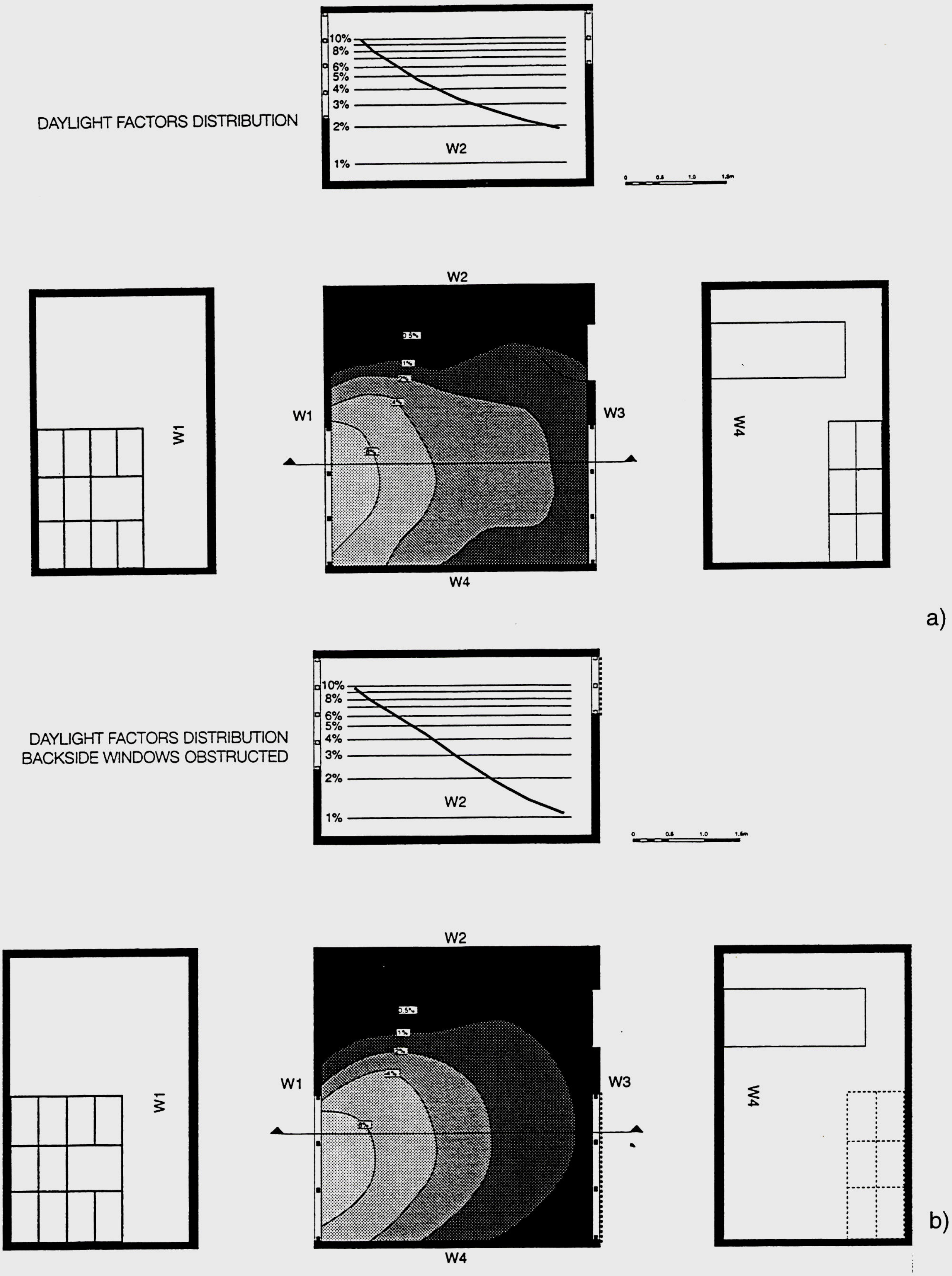


Figure 2.39: Daylight factor distribution of the monitored room at Reiterstrasse
a) Unobstructed openings
b) With obstructed borrowed light openings
(Date of monitoring: 21 March 1996)

UAP Building

The daylight factor distribution in the UAP building shows typical features of a sidelit room with a rather high glazing ratio (cf. paragraph 2.2). The monitoring results can be summarized as follows:

- two thirds of the room benefit from a significant daylighting autonomy (daylight factor higher than 2%);
- significant energy savings are made due to the daylight responsive control of electric lighting for the part of the room closer to the window (daylighting autonomy higher than 60%).

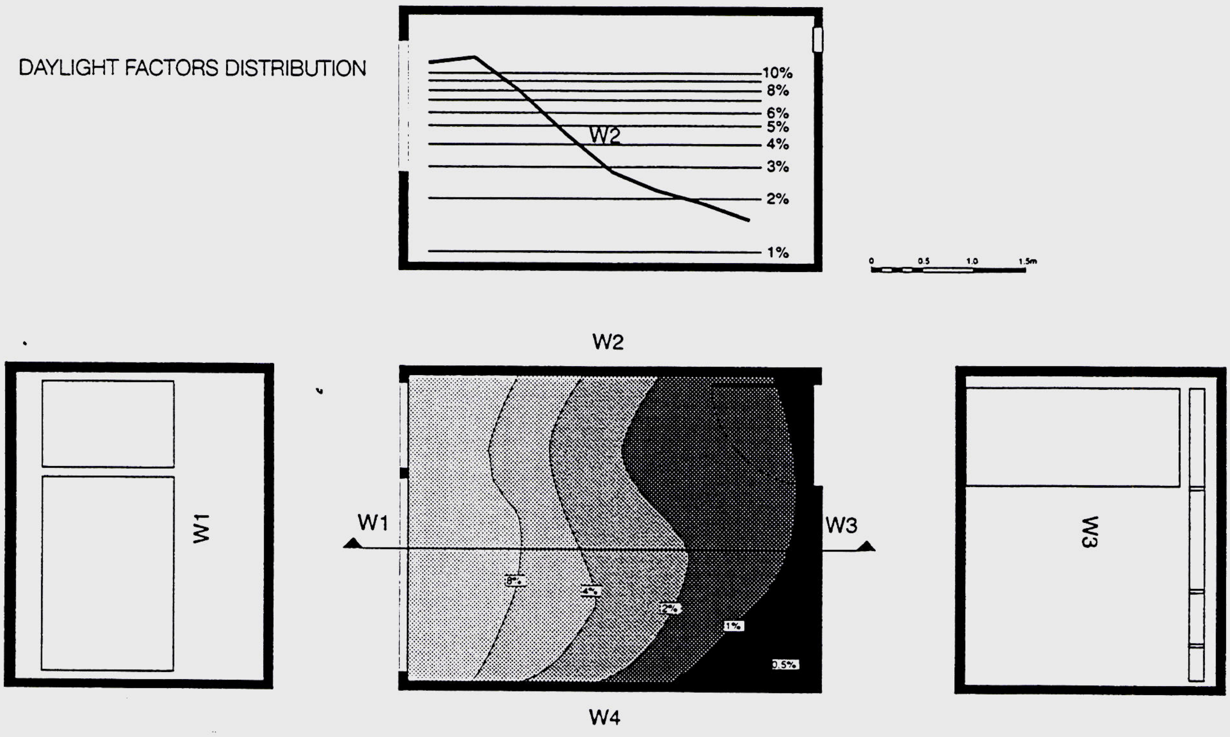


Figure 2.40: Daylight factor distribution within the UAP building office room. (Date of monitoring: 4 July 1995 and 14 November 1996)

It must be emphasized, moreover, that no contribution can be expected (nor observed) from the small window area located on the back office wall.

Luminance measurements (cf. Fig. 2.41) confirmed the good photometric design of the room:

- appropriate luminance contrasts were observed from the back of the room;
- obstructions due to the urban situation of the building moderate the luminance values through the window.

Figure 2.41: Luminance values and fish-eye view of the UAP office room

The energy performance of the building proved to correspond to standard values, close to the average figures for administrative building equipped with mechanical ventilation systems. Non-optimal results were observed for the daylight responsive control system as shown in paragraph 2.4.

<u>*CNA/SUVA Building*</u>

Monitoring of the CNA/SUVA building allowed assessing the performance of a novel daylighting system (prismatic panels integrated in a double-skin facade). Figure 2.42 shows the results of this monitoring; the following conclusions can be drawn:

- very low daylight factors were observed (lower than 2% for two thirds of the room), i.e. a poor daylighting autonomy;
- a more even illuminance distribution was observed, however.

This can be explained by the rather low transmittance of the prismatic glazing panels (ρ_{hh} = 0.4), which leads to poor daylighting conditions under overcast sky: a general impression of dimmed light prevails in the rooms as seen by a person who walks through the building.

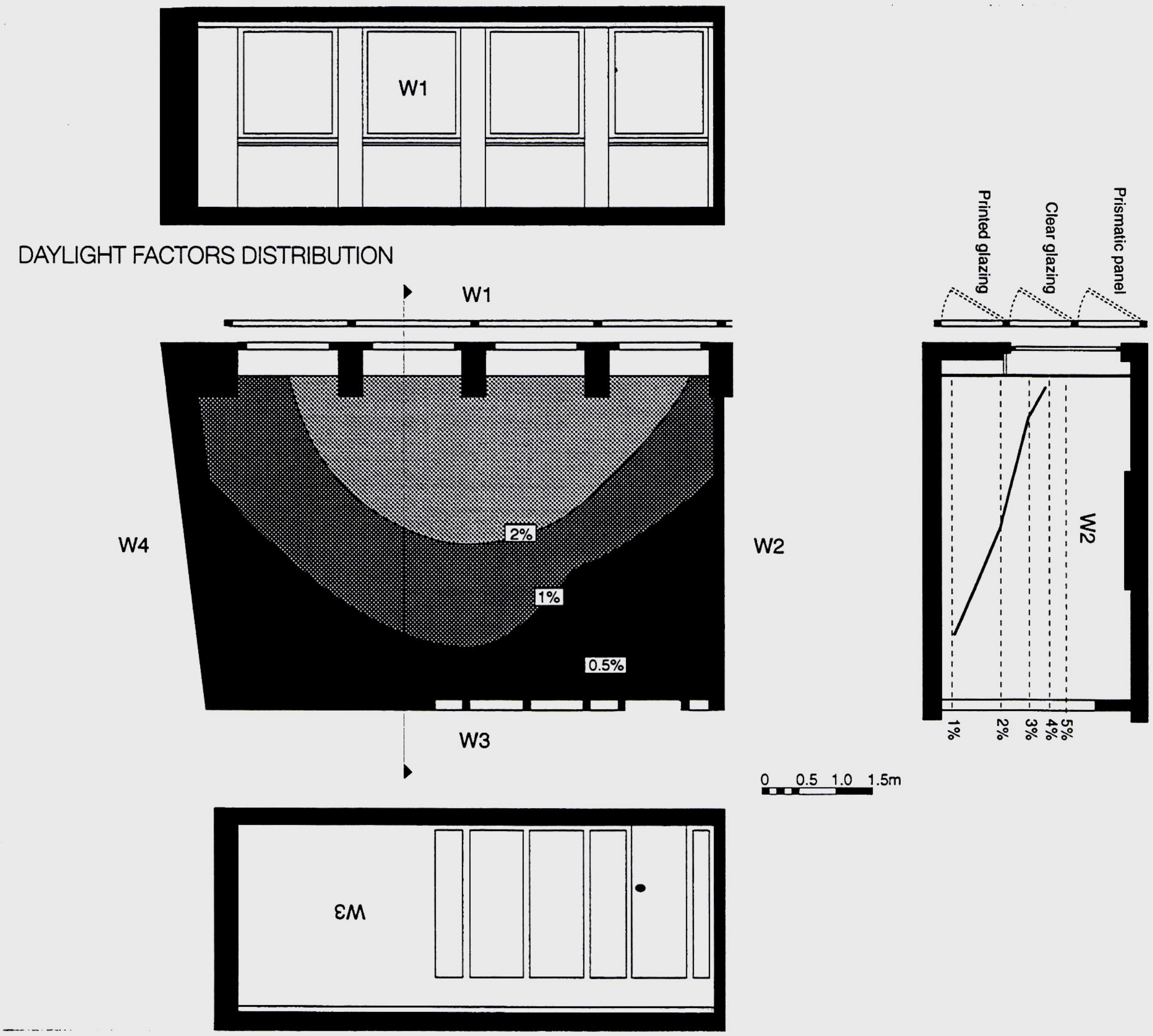


Figure 2.42: Daylight factor distribution in the CNA/SUVA office room.
(Date of monitoring: 21 January 1997)

Luminance measurements confirmed the even distribution of light (cf. Figure 2.43): low absolute values and contrasts were experienced (except through the window opening).

Low glare risks can be expected from the measured luminance values. However, even if the computer control of the prismatic panels was improved (the panels follow the course of the sun even under overcast sky conditions which avoids possible glare risks), high lighting energy consumption could be expected from this building design.

Energy-related figures confirmed this; they showed an electricity consumption higher than the heating energy consumption.

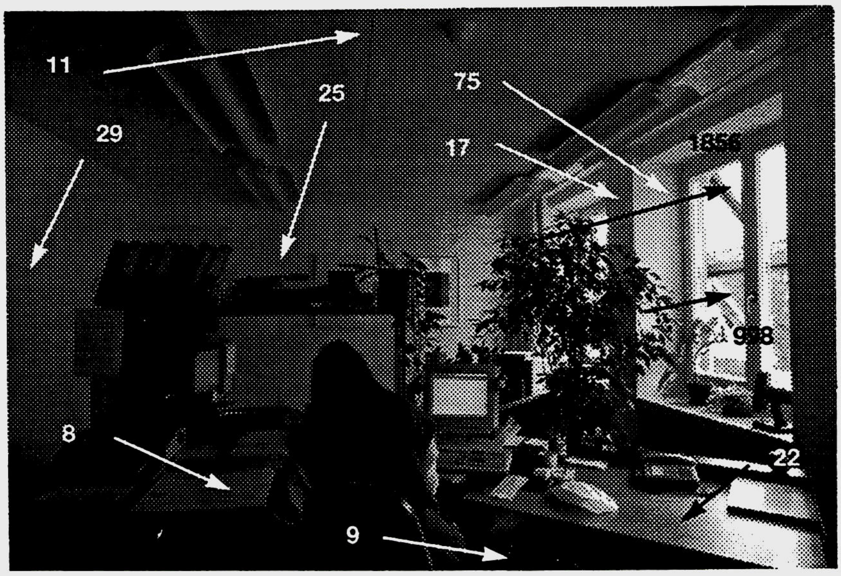


Figure 2.43: Luminance values and fish-eye view CNA/SUVA office room

2.4 On-site assessment of electric lighting consumption

Intensive use of daylight can substantially reduce electric lighting needs in a building and thus lead to considerable energy savings.

Good daylighting due to efficient building design is, however, not in itself a guarantee for electricity savings from lighting: appropriate operation of the electric lighting system by the users is equally important. Substantial energy savings can be achieved only if all of the following requirements are met:

- a reasonably high daylight factor at the workplace (3% < D < 5%), together with acceptable visual comfort conditions,
- efficient light sources and luminaires in the considered part of the building ($P_{max} < 10$ [W/m^2]),
- an appropriate daylight responsive control system that drives the luminous intensity of the electric lighting fixtures.

The assessment of the daylighting performance of buildings (daylight factor profiles, luminance ratios, etc.) does consequently not provide enough information on building operation with regard to the use of electricity. In order to reach that goal, it is necessary to monitor the following physical data:

- instantaneous electric power supplied to the lighting fixtures
- presence rate of users in the considered building space
- daylight provision at the work place.

Such monitoring was carried out in the five selected Swiss case studies in order to assess the real impact of daylighting design on the building electricity consumption for lighting. The description of the experimental procedure used for that purpose is presented in this paragraph, together with the main results of the monitoring campaign.

2.4.1 Evaluation of occupancy monitoring equipment

Monitoring of lighting operation and occupancy patterns in buildings is not an easy task; few professional and research teams have understood the issue [Rea 87].

Energy consumption does not provide a complete picture of efficient utilization of electricity for lighting. Occupancy must also be taken into account in determining whether electricity is used efficiently when occupants are present. The same remark applies to daylighting provision, which must coincide with room occupancy.

Several techniques hold potential for simultaneously monitoring energy consumption, occupancy and daylighting illuminance under office working conditions. Rea and Jaekel carried out an extensive comparison of different techniques [Rea 87] such as:

- video recording equipment
- ultrasonic movement detector
- infrared movement detector
- personal visits to office rooms
- light ray beams.

A similar test procedure was applied during the project in order to identify the optimal occupancy monitoring technique. However, for the sake of convenience, only three monitoring techniques were considered for testing (video recording, radar and infrared detectors). Questionnaires to be filled in by the users were not considered due to their lack of accuracy on the basis of former experiments.

The three monitoring devices have the following technical characteristics:

Video recorder

Type:	JVC HQ video camera and recorder used in long play mode (VHS-240, 8 hours record)
Position:	Hanging from a ceiling corner, providing a wide angle view of the room

Radar motion detector

Type:	RK 41 Umilux
Position:	fixed to the ceiling
Response time:	0.5 - 3s
View field:	45° - 90°
Delay time:	none

Infrared detector

Type:	ECO-IR 360A
Position:	Fixed at the ceiling, in the middle of the room
Response time:	none
View field:	120°
Delay time:	2 mn (minimum)

Figure 2.44 gives a view of these monitoring devices. They were installed simultaneously for a period of two weeks in an office room of the LESO experimental building [Fai 83].

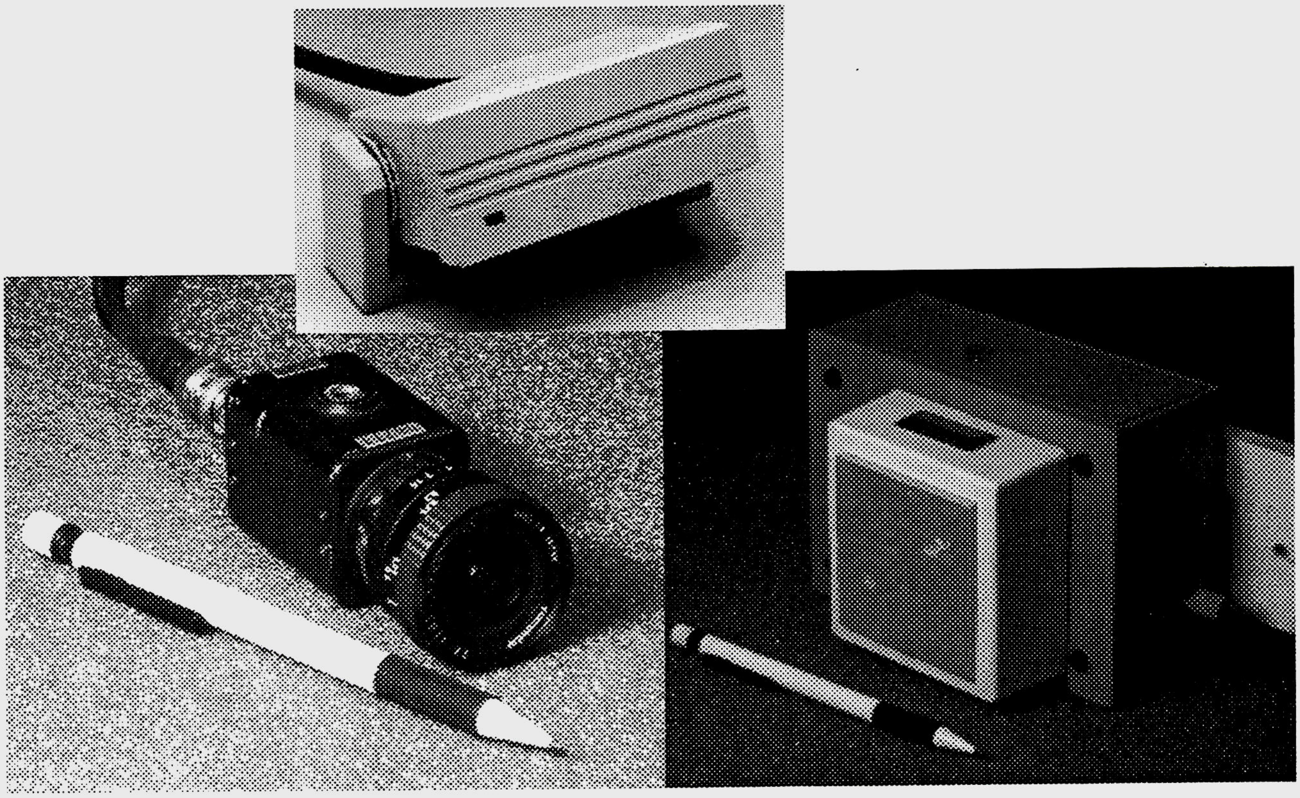


Figure 2.44 : View of user presence monitoring equipment (video recorder, radar and infrared detector).

The room was occupied by one person; its floor area equals 9.4 m2 (2.0 m x 4.7 m). The room is south facing and equipped with insulated double-glazing with a high opening ratio (36% of the floor area).

Electric lighting consists of a single direct/indirect Zumtobel luminaire placed above the workplace, 1.3 m from the window and parallel to it. The luminaire is equipped with two 28 mm Osram 58 W fluorescent tubes that are powered by electronic ballast. It is controlled through Luxmate hand switches, which allow the following lighting control options at the work place:

- choice of 3 different task illuminance levels (150, 350 and 700 Lux),
- continuous dimming between 150 and 750 Lux.

Using the video recording as a reference, the accuracy of the two other detection techniques were assessed. Figure 2.45 gives a comparison of the detection signals provided by the two devices.

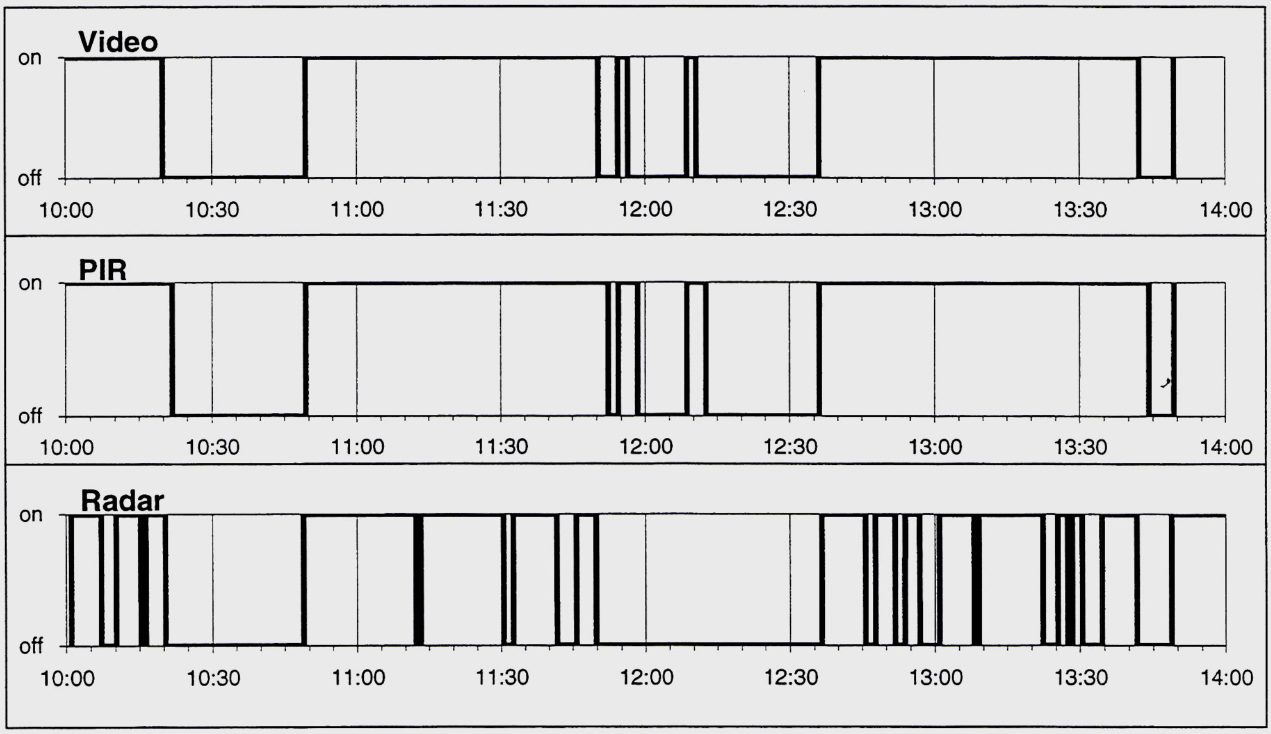


Figure 2.45 :Comparison of user presence detection techniques (video recording, radar and passive infrared sensors).

The main features of the detection techniques are shown in this figure. It appears that:

- the infrared movement detector shows a bias due to the 2 mn minimal delay time;
- the radar movement detector is unable to detect small displacements in the room;
- video recording can be considered as a "zero" bias technique, however, it shows serious practical limitations (limited storage, painful analysis, etc.).

Table 2.4 gives a summary of the positive and negative features of the three techniques.

Detection technique	Advantages	Disadvantages
Video recording	• almost infallible • accurate • no bias	• expensive and bulky • intrusion in private life of users • limited storage time (long play mode: 8hrs) • long and tiresome analysis
Radar motion detector	• compact and cheap	• bad reliability (small displacements not detected)
Passive infrared detector	• compact and cheap • reliable	• delay time

Table 2.4: Main positive and negative features of the three user presence monitoring techniques

Following this testing procedure, the infrared detector was chosen as the user monitoring device for the project; the impact of the 2 mn delay time was suppressed during the processing of the user presence monitoring data.

2.4.2 Description of on-site monitoring equipment

In order to be able to assess the efficiency of the use of the electric lighting system, the former apparatus was completed with the appropriate monitoring devices, giving the following equipment list:

- two watt meters to monitor the power consumption of the electric lighting
- an illuminance meter to monitor electric and daylight provision on the work plane
- a passive infrared movement detector
- a set of distributed and miniaturized microloggers.

A short description of this equipment is given hereafter.

Watt meters

Power measurements were carried out with a one-phase VIP96 ELCONTROL and a three-phase CIRCUITOR power meter (cf. Figure 2.46).

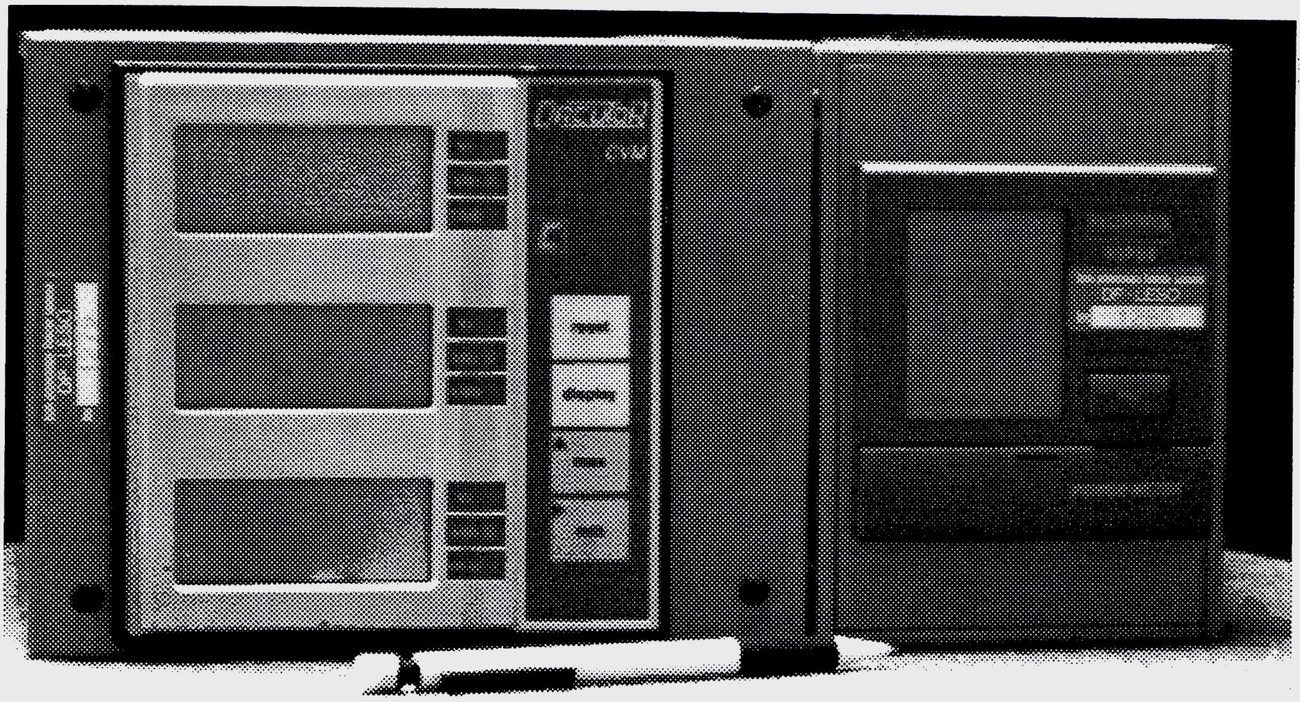


Figure 2.46 :One-phase and three-phase power meter used to monitor electric lighting consumption.

Both meters gave an accuracy of 1% and were chosen for their capability of measuring either acting or reacting power. In the case of a dimming lighting control system, both meters delivered an analog output signal, which was directly read by the logger. Their installation often requires the intervention of a professional electrician to connect the meters to the power line of the lighting system.

For simple on-off lighting systems, a photodiode was used to monitor the status of the electric lighting. Preliminary measurements of the consumption of the system were carried out prior to the monitoring.

Illuminance meters

The measurements of the work plane illuminance were carried out using Minolta T-1M illuminance meters. Electric and daylight provisions were monitored on the desk, placing the sensor (diameter 14 mm) in a holder to avoid possible disturbances to the monitoring by the users. Figure 2.47 gives a view of this monitoring device.

Figure 2.47: View of the illuminance sensor and its holder, placed on a desk.

The Minolta illuminance meter is characterized by a good photometric response ($f_1' < 2\%$) and a good cosine correction ($f_2 < 2\%$ à 30° incidence angle). The sensor has a range of 0 - 100'000 Lux; its linearity is better than 1%.

Preliminary measurements of the electric light provision (desk illuminance) were done in the office room in order to be able to distinguish it from daylight provision during the monitoring.

PIR movement detector

The user presence detector is a passive infrared ECO-IR 360A movement detector (cf. paragraph 2.4.1). Figure 2.44 gives a view of this occupancy-sensing device.

The PIR detector was installed at the ceiling of the monitored office rooms. The view field of the sensor is characterized by an angle of 2 x 60° relative to the normal of the device: the sensed field is equal to 6 x 6 meters for a 2.5 m ceiling mount (8 x 8 m for a 3 m ceiling mount). The minimal delay time is 2 mn; the angular resolution is sufficiently high to be able to detect short-range movements of users whenever they sit at their desk.

Datalogger

The datalogger is a "Logger Maurer instruments" device, characterized by its very high flexibility. It consists of 6 compact and independent devices (dimensions: 12 cm x 6.5 cm), each one able to handle 2 data channels.

Each device is self-powered by a small internal battery and has a storage capability of 64 kB, allowing 4-week monitoring. Figure 2.48 shows a view of these acquisition units, which allow avoiding an excessive amount of cables in the monitored rooms.

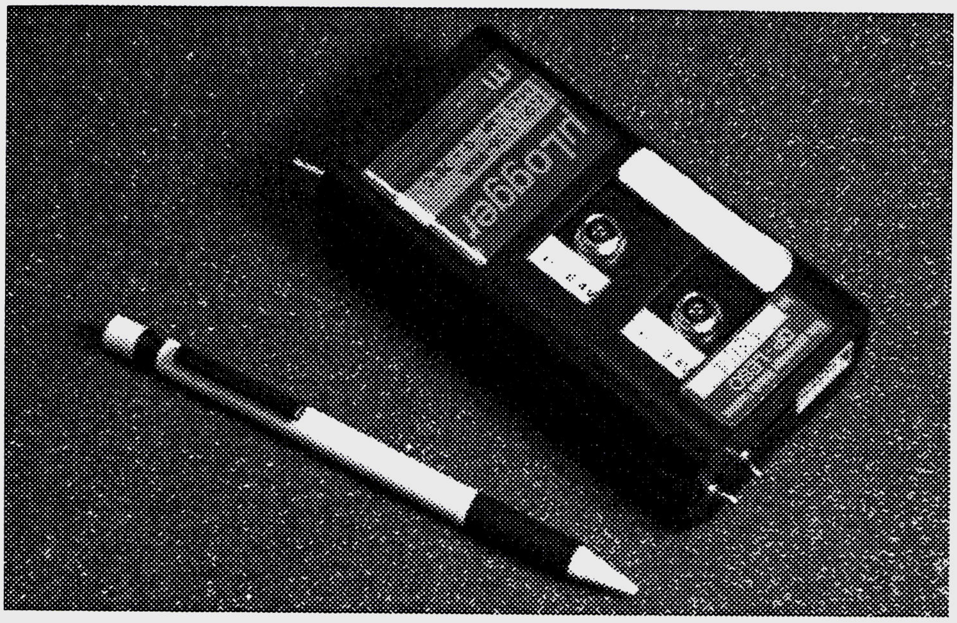


Figure 2.48 :Distributed data acquisition unit, characterized by its high flexibility and compact size.

The dataloggers were programmed at the Laboratory before the monitoring periods, using the appropriate software. They were unloaded the same way, their data being stored on a PC for further processing of the data.

2.4.3 Processing of monitored data

Monitoring of the five Swiss case studies was undertaken in monitoring periods of two weeks. Data acquisition was carried out in a continuous manner during these periods, using dynamic sampling data intervals (varying from 10 sec. to 5 min.).

Figure 2.49 illustrates the monitoring of a classroom in the "Collège de la Terre-Sainte" in Coppet (Switzerland). Lighting provision was monitored at different places of the classroom (teacher and pupil desks, blackboard). Lighting energy consumption, utilization time of electrical lighting and occupancy hours of the classroom are shown in the same figure.

These data were processed further in order to retrieve a performance index for the utilization of the electric lighting. The former index is based on the methodology described within a recommendation of the Swiss Society of Engineers and Architects [SIA 96].

An exploitation unit had to be defined for that purpose: it corresponds to the part of the building that is lit by the electric lighting system (a classroom in the case of Coppet f.i.).

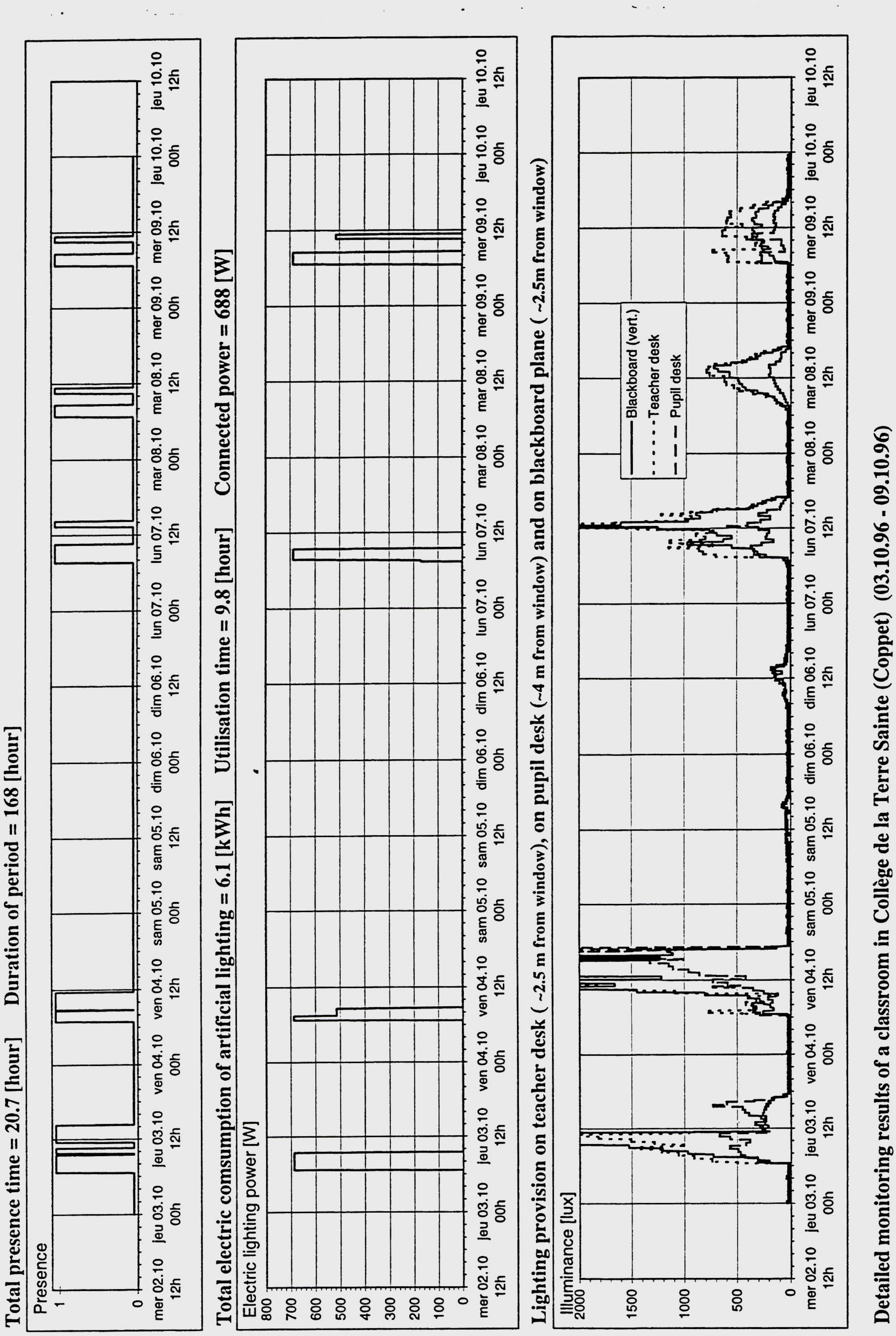


Figure 2.49: Monitoring data of a classroom at the "Collège de la Terre-Sainte" in Coppet (Switzerland)

The following key figures had to be determined for this exploitation unit to assess the exploitation factor of the electric lighting system, which served as a performance index:

h_u [hours/day] — the utilization time of the exploitation unit, effectively measured during the monitoring (a standard utilization time is used if the measured one does not differ more than 10% from it)

Pav [W/m2] — the average specific power obtained by dividing the energy consumption by the utilization time and the area of the exploitation unit

Pmax [W/m2] — the specific power of the electric lighting system, obtained by dividing the connected power by the area of the exploitation unit.

The exploitation factor fe [-] is obtained by dividing P_{av} by P_{max}. The following relation gives thus the performance index :

$$fe = \frac{P_{av}}{P_{max}} \quad [-]$$

Figure 2.50 illustrates the different figures for the case of a standard utilization time of the exploitation unit (hu = 8 [h/d]), corresponding to standard office working hours (8 am to 6 pm). The exploitation time of the electric lighting (he on this figure) is shorter than the utilization time of the office room (hu). In both cases, a value he > hu can be observed: it corresponds to an extremely poor management of an office room, where electric lighting is kept on all the day long and is generally switched off by the building cleaning staff only. Such a situation leads to a fe value greater than unity (fe > 1.0).

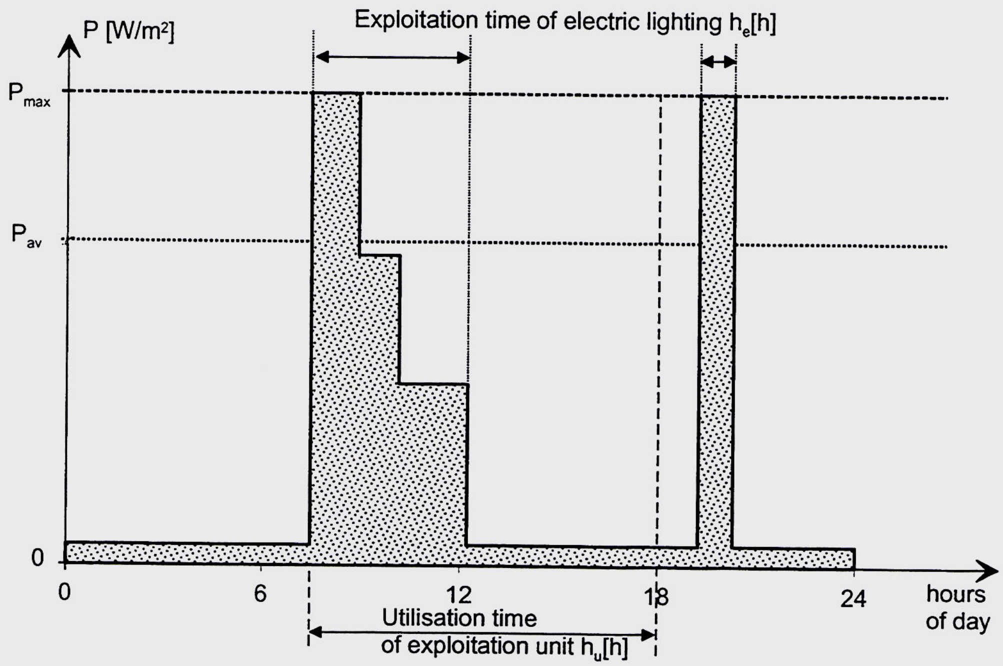


Figure 2.50 : Illustration of key figures used to assess the performance index of the utilization of the electric lighting system.

The average lighting provision (including both contributions of day and electric lighting) is also assessed through illuminance measurements at different work places in the presence of occupants (lighting of work space in absence of users is not necessary).

Table 2.5 illustrates these different figures for the case of Coppet. A rather low exploitation factor (fe = 0.57) was observed in this school room, together with a standard value of specific connected power for lighting (9.7 W/m2): the good motivation and discipline prevailing in schools with regard to lighting explains these results.

The lighting provision values are fully satisfactory (288 Lux on pupil desks, for instance); accounting for the good acuity of young children: the values on the teacher's desk and on the blackboard are higher.

Name	Allocation	Period	Area of unit [m2]	Normal utilisation time [h/d]	[d/y]	[h/y]	Utilisation time of unit [h/d]	Connected power [W/m2]	Average power [W/m2]	Exploi-tation factor [-]	Average light provision on work surface [lux]
Collège de la Terre Sainte (Coppet)	classroom	12.12.95 - 18.12.95	73.39	3.5	190	665	3.48	9.4	5.5	0.59	pupil desk: 288 teacher desk: 856 blackboard (vert.): 1121
Collège de la Terre Sainte (Coppet)	classroom	03.10.96 - 09.10.96	73.39	3	190	570	4.29	9.4	7.2	0.76	pupil desk: 294 teacher desk: 772 blackboard (vert.): 634

Table 2.5 : Assessment of the exploitation factor of electric lighting in the case of Coppet.

Annex B gives different reference values published within the framework of SIA recommendations [SIA 96] for :

- nominal task illuminance
- specific connected power for lighting
- exploitation factor of electric lighting
- utilization time of exploitation unit.

Monitored values, observed in the building case studies, can be compared to these references in order to obtain an appreciation of its performances regarding the use of electricity for lighting.

2.4.4 Monitoring results

Several monitoring campaigns were undertaken for the five Swiss case studies : they were undertaken, whenever possible, at moments close to winter / summer solstices or spring / autumn equinoxes. Table 2.6 summarizes these different monitoring periods chosen at periods close to the sun solstices and equinoxes.

Case study	Winter 1	2	3	Spring 4	5	6	Summer 7	8	9	Autumn 10	11	12
Administration Reiterstrasse (Bern)				■	■						■	■
EOS (Lausanne)		■	■									■
Collège de la Terre Sainte (Coppet)										■		■
CNA (Basel)	■							■	■			
UAP (Lausanne)												
old offices	■								■			
renovated offices	■								■			

Table 2.6 : Summary of monitoring periods of the five case studies (dated approximately)

The Technical Report gives the overall monitoring results of these campaigns; their main outcomes are given hereafter.

<u>Administration office, Reiterstrasse (Bern)</u>

The office room monitored in this building, which is slightly different from the one described in paragraph 2.1, is equipped with two rows of luminaires, fitted with two fluorescent fixtures (1 x 36 W Philips). The rows are parallel to the window facade and mounted with magnetic ballast (see Figure 2.51).

There is no automatic control of the luminaires: two hand switches, placed by the door (one for each row) can be manipulated by the users of the room to control the electric lighting. The room is occupied by one person.

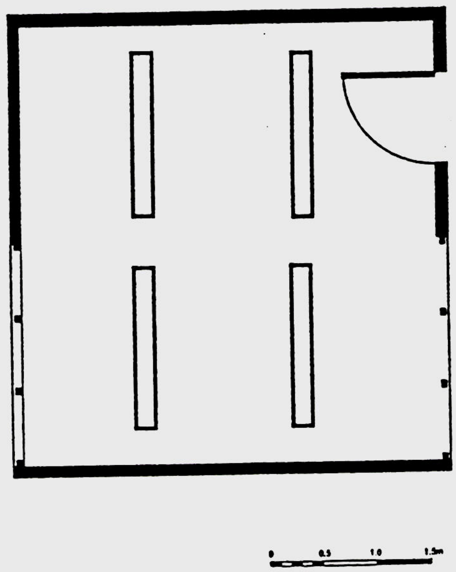


Figure 2.51 :Schematic drawing of the electrical installation of the monitored room.

Table 2.7 shows the monitoring results of this room: a spring and an autumn period were considered for that case.

Name	Allocation	Period	Area of unit [m2]	Normal utilisation time [h/d]	[d/y]	[h/y]	Utilisation time of unit [h/d]	Connected power [W/m2]	Average power [W/m2]	Exploitation factor [-]	Average light provision on work surface [lux]
Building Reiterstrasse, Bern	office	22.04.96 - 05.05.96	12.7	11	250	2750	12.85	16.6	0.1	0.00	main desk: 2181 (0.80 m from window) discussion table: 687
Building Reiterstrasse, Bern	office	20.11.96 - 05.12.96	12.7	11	250	2750	6.73	16.6	1.0	0.06	main desk: 1600 (0.80 m from window) discussion table: 990

Table 2.7: Main monitoring results of the administrative office Reiterstrasse (Bern)

The most significant results of this monitoring are the following:

- an extremely low exploitation factor (fe < 0.1), corresponding to an extremely low average electric power (Pave < 1 W/m2) was observed,
- a high provision of lighting was measured on average at the main desk, as well as on the meeting table (1600 - 2200 Lux),
- the room shows a high specific connected power (16.6 W/m2 as compared to the 6 to 10 W/m2 recommended by SIA 380/4), which can be explained by the construction date of the building (1979-1987).

All these results indicate very efficient use of the electric lighting system. The observed exploitation factors are definitively lower than the standard values indicated by the recommendations, even in the case of automatic lighting control (fe = 0.35-0.50 for a room with a daylight factor of 2% - 3%).

The overall electricity consumption of the building confirms these results, which can be explained by the energy-conscious behavior of the building users and by the good daylighting concept of the building (D > 2% for the greatest part of the room, cf. par. 2.2). A rather low electric energy intensity of 98 MJ/m^2year is achieved on average over the years 1985 to 1996 (150 MJ/m^2year on average for such buildings). The thermal energy intensity is low as well with 228 MJ/m^2year instead of 550 (Swiss average).

EOS Administrative office (Lausanne)

The monitored office room is representative of the different southern rooms of the building: it is occupied by one person.

There is no ceiling lighting fixture in the office; one floor luminaire is installed per working place. The fixture uses three compact fluorescent tubes (3 x TL 55W) in a direct/indirect mode. Each luminaire has a hand switch; apart from those, there is no general lighting in the office room.

Figure 2.52 gives a schematic plan of the room, the working place and the luminaire.

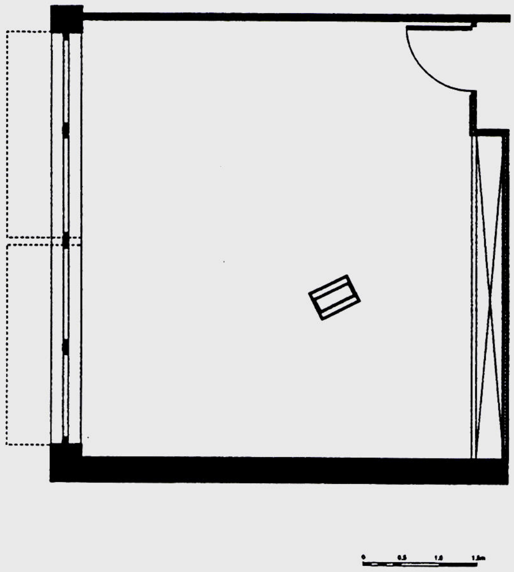


Figure 2.52: Schematic drawing of the electric installation of the monitored office room

Table 2.8 shows the main results of this monitoring. The outcome can be summarized as follows:

- a reasonable specific connected power (9.4 W/m2) characterizes this office room;
- extremely low and extremely high exploitation factors (fe = 0.07 and 1.11) were observed over the two periods;
- satisfactory lighting provision was measured on the desk plane, even in extreme winter conditions.

Name	Allocation	Period	Area of unit [m2]	Normal utilisation time [h/d]	[d/y]	[h/y]	Utilisation time of unit [h/d]	Connected power [W/m2]	Average power [W/m2]	Exploi-tation factor [-]	Average light provision on work surface [lux]
EOS, Lausanne	office	22.02.96 - 06.03.96	30.3	11	250	2750	4.27	9.4	0.6	0.07	669
EOS, Lausanne	office	11.12.96 - 19.12.96	30.3	11	250	2750	3.83	9.4	10.4	1.11	516

Table 2.8: Main monitoring results of EOS administrative office (Lausanne)

These results indicate a high variability of the user behavior: no direct explanation can be given for that. It must be emphasized, however, that light shelves contribute strongly to even out the daylight distribution in a room. This can lead to a uniform and appropriate daylighting level for sunny conditions (spring period) and an inappropriate level in cloudy conditions (winter period). The electricity consumption of the buildings confirms this explanation. More even user behavior leads collectively to this result. A low electrical energy intensity is achieved by the building (41 MJ/m^2year) and the thermal performance is good as well (272 MJ/m^2year).

A post-occupancy evaluation of the EOS building, carried out by means of a questionnaire distributed to 33 building users confirmed the positive appreciation of the daylighting features of the building.

Collège de la Terre-Sainte (Coppet)

The monitored classroom is equipped with recessed fluorescent fixtures. There are four rows of four luminaires (1 x 36 W), fitted with conventional magnetic ballast.

The classroom has three light switches, placed near the entrance door. The switches allow the following lighting configuration:

- switch on/off the row of four luminaires closer to the blackboard
- switch on/off two rows near the windows
- switch on/off two rows at the back of the room.

Figure 2.53 gives a schematic drawing of the classroom as well as the configuration of the luminaires.

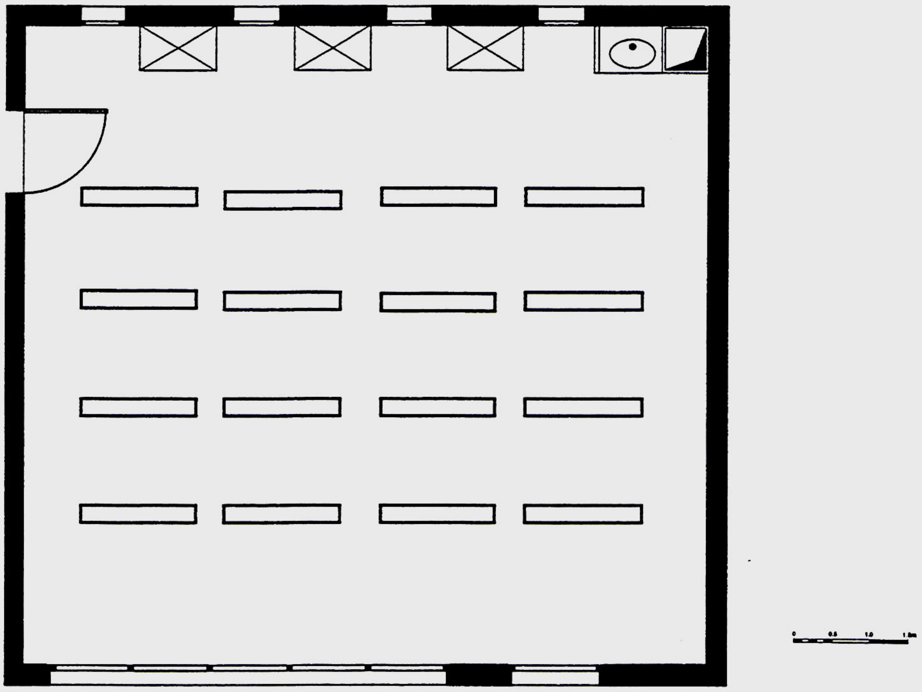


Figure 2.53: Schematic drawing of the electric installation of the monitored class room

Name	Allocation	Period	Area of unit [m2]	Normal utilisation time [h/d]	[d/y]	[h/y]	Utilisation time of unit [h/d]	Connected power [W/m2]	Average power [W/m2]	Exploi-tation factor [-]	Average light provision on work surface [lux]
Collège de la Terre Sainte (Coppet)	classroom	12.12.95 - 18.12.95	73.39	3.5	190	665	3.48	9.4	5.5	0.59	pupil desk: 288 teacher desk: 856 blackboard (vert.): 1121
Collège de la Terre Sainte (Coppet)	classroom	03.10.96 - 09.10.96	73.39	3	190	570	4.29	9.4	7.2	0.76	pupil desk: 294 teacher desk: 772 blackboard (vert.): 634

Table 2.9: Main monitoring results of the Collège de la Terre Sainte (Coppet).

The main results of the building monitoring are as follows:
- a moderate exploitation factor (fe ≈ 0.5 - 0.75) was observed,
- a reasonable specific connected power was monitored (9.4 W/m2),
- satisfactory lighting provisions were measured at the three considered places (desks and blackboard).

The reasonable daylight factor in the room (D > 2% for more than half the classroom) together with the good discipline of the teachers and pupils goes to explain these results. It must be emphasized, moreover, that the fe value corresponds to the one obtained in rooms with the same daylighting conditions but equipped with automatic lighting control (see Annex B). User motivation can, in this way, achieve comparable results.

The overall energy figures of the building partly confirm this result:

- a low energy intensity for heating (260 MJ/m^2year) is achieved with regard to the average Swiss school buildings (680 MJ/m^2year average for Swiss schools [Wic 84]),
- a standard energy intensity for electricity (60 MJ/m^2year) is achieved with regard to the Swiss average for schools (50 MJ/m^2year).

It must be emphasized, however, for the second figure, that the electricity consumption includes all types of electrical appliances and not only lighting equipment.

<u>*CNA office building (Basel)*</u>

The office room of the CNA building is an open space located on the third floor of the building. In spite of this, the daylight factor monitored over the overall office space is low (D < 2%), corresponding to a poor daylighting contribution from the facade and a very low daylighting autonomy (no autonomy at all when applying the Swiss standards for a 300 Lux required illuminance [AVE 89]).

The office space is equipped with two rows of 4 fluorescent fittings (1 x 36 W, Osram 21) with electronic ballast. The rows are parallel to the window and mounted with a double hand switch close to the entrance door (one switch per row).

Table 2.10 shows the main monitoring results of this building. Figure 2.54 gives a schematic plan of the office and the rows of luminaires

Name	Allocation	Period	Area of unit [m2]	Normal utilisation time [h/d]	[d/y]	[h/y]	Utilisation time of unit [h/d]	Connected power [W/m2]	Average power [W/m2]	Exploi-tation factor [-]	Average light provision on work surface [lux]
CNA Basel (all lamps)	office	05.08.96 - 18.08.96	30.3	11	250	2750	9.12	10.5	8.1	0.77	
CNA Basel (all lamps)	office	10.09.96 - 27.09.96	30.3	11	250	2750	9.00	10.5	7.1	0.67	Workplace 1: 336 Workplace 2: 416
CNA Basel (all lamps)	office	14.01.97 - 30.01.97	30.3	11	250	2750	9.09	10.5	9.9	0.94	Workplace 1: 247 Workplace 2: 429

Table 2.10: Main monitoring results of the CNA building.

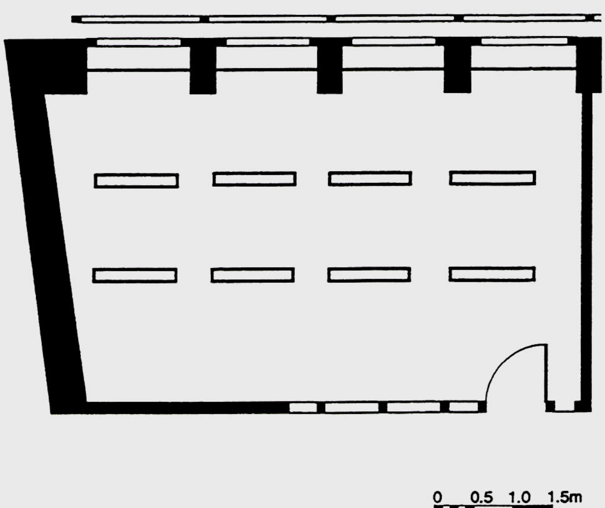


Figure 2.54: Schematic plan of the electric installation of the monitored open space

The CNA building shows the following main results:

- a standard specific connected power (10.5 W/m^2) was observed (recommendations fall between 6 and 10 W/m^2);
- a rather high exploitation factor (fe = 0.67 - 0.94) was monitored during the three periods;
- a sufficient lighting provision was measured (except for the winter period of January).

The two rather disappointing results can be explained by the very low daylight factor monitored in the office space, due to the low light transmission of the overall double skin facade. Consistent behavior is, however, observed for the three periods, which lead to comparable and coherent results (high exploitation factor in winter).

The overall energy performance of the building confirms the benefit of retrofitting with regard to thermal aspects (thermal intensity of 211 MJ/m^2year). Electricity consumption, which includes not only lighting needs but also the other appliances, is high (277 MJ/m^2year).

UAP office building (Lausanne)

Two office rooms were monitored within this building:
- one room corresponding to the original status of the building (construction year: 1969),
- a recently renovated room, placed on the same facade but on another floor (renovation year: 1991).

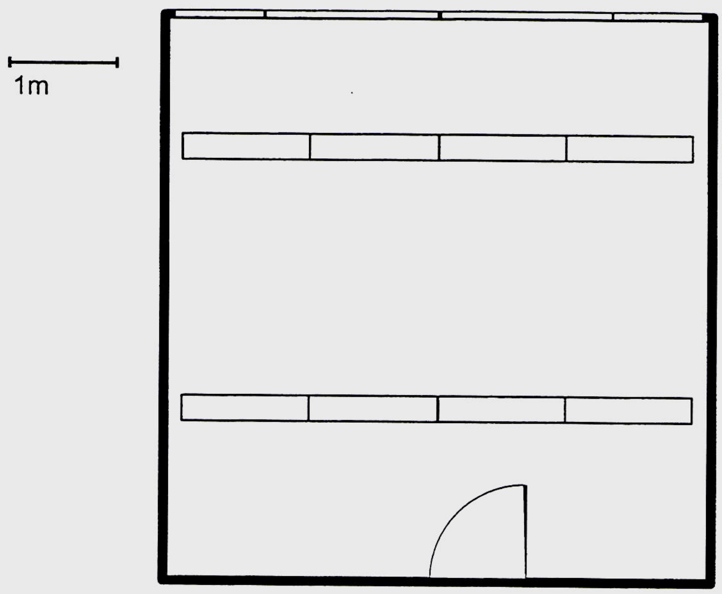


Figure 2.55: Schematic drawing of original office room and lighting equipment.

The first office room is equipped with old luminaires, fitted with a single fluorescent tube and covered with a translucent acrylic protection. The non-renovated room features two rows of single-tube luminaires, parallel to the facade. One hand switch, placed close to the entrance door, can be used to control the lighting installation. Figure 2.55 gives a view of the original office room and lighting equipment.

The second room, renovated in 1991, is fitted with three rows of recessed high efficiency luminaires (1 x 50W Philips 84). All luminaires are parallel to the facade and equipped with electronic ballast.

A daylight responsive controller (Philips Trios) drives the two rows of luminaires closer to the window; the light sensor is placed in the middle of the room and at equal distance for the two rows. Two hand switches are placed close to the door: one switches the two rows of dimmable luminaires, the other the undimmable last row situated at the back of the room. Figure 2.56 gives a schematic drawing of the room and the electric lighting installation.

Name	Allocation	Period	Area of unit [m2]	Normal utilisation time [h/d]	[d/y]	[h/y]	Utilisation time of unit [h/d]	Connected power [W/m2]	Average power [W/m2]	Exploi-tation factor [-]	Average light provision on work surface [lux]
UAP, Lausanne (renovated)	office	04.09.95 - 17.09.95	12.52	11	250	2750	8.90	14.4	6.9	0.48	530
UAP, Lausanne (renovated)	office	12.01.96 - 25.01.96	12.52	11	250	2750	9.00	14.4	11.8	0.82	438
UAP, Lausanne (old)	office	04.09.95 - 17.09.95	27.76	11	250	2750	8.40	14.4	11.2	0.78	1417
UAP, Lausanne (old)	office	12.01.96 - 25.01.96	27.76	11	250	2750	9.10	14.4	12.8	0.89	584

Table 2.11: Main monitoring results of UAP building.

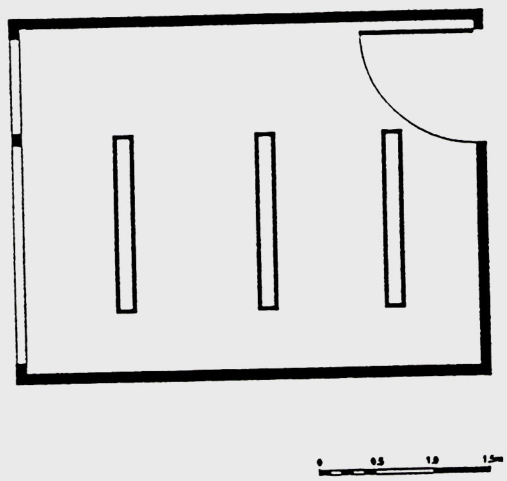


Figure 2.56: Schematic drawings of a renovated office room and lighting equipment

The main results of the monitoring, given in Table 2.11, can be outlined as follows:

- the specific connected power shows an excessive value (14.4 W/m2) compared to the recommended figures (6 - 10 W/m2 for such a daylit space), even in the renovated room;

- the exploitation factors reach lower values in case of a daylight responsive control of the electric lighting (fe = 0.48/0.82 instead of 0.78/0.89 for autumn/winter);

- the values are rather high for such a well daylit space (D > 4% for half of the space would lead to fe = 0.35 accounting to the recommendation [SIA 96]);

- the lighting provisions are sufficient, but even higher in the case of the non-renovated office room.

These contradicting results cannot directly be explained, except by the configuration status of the lighting control device: this is the case of the illuminance set point of the dimming control, which had been fixed at an excessively high level of 600 Lux.

Further recalibration and resetting of the control device would probably lead to better performance. The electrical energy intensity observed for the building confirmed the rather high consumption (327 MJ/m^2year instead of the Swiss average of 150 MJ/ m^2year).

2.4.5 *Balance of building monitoring*

The monitoring carried out to assess the possible correlation between the daylighting features of the buildings and the expected efficient use of electric light, was not intended to produce a statistically sound set of data. Due to the number of building rooms and users, it was simply not possible to carry out extensive monitoring of these numerous objects.

The experimental data complete, however, in an excellent way the daylighting performance figures, which were assessed during the project. They allow the identification of some trends regarding the real electricity consumption of the building office rooms.

Figure 2.57 gives an overall view of the main figures of this monitoring (average and connected power.

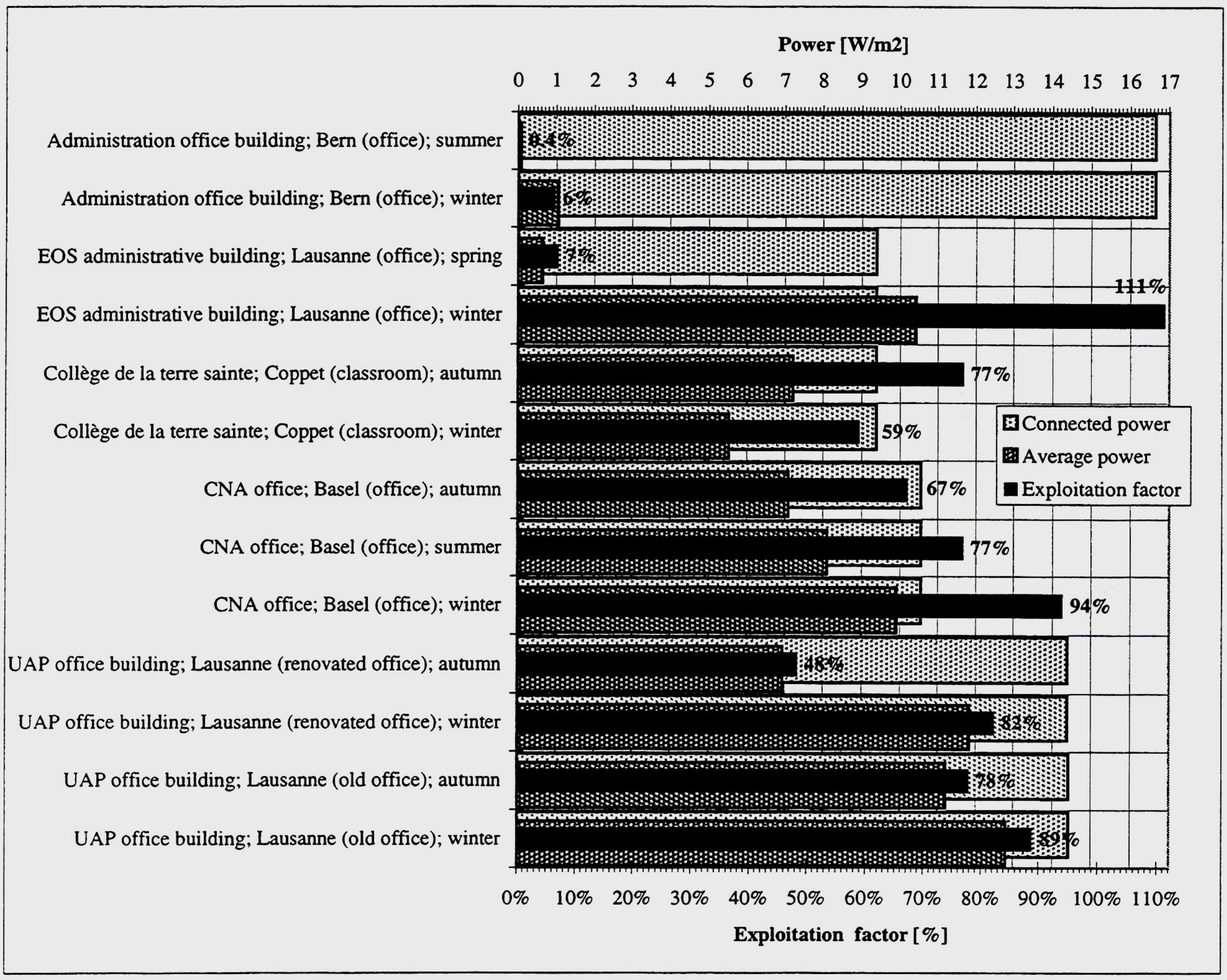


Figure 2.57: Results of electric lighting monitoring of the five case studies.

The following conclusion can be drawn from these results:

- low energy consumption can be obtained by appropriate behavior of building users (efficient use of lighting), even in the case of an excessive connected electrical power (f.i. administration building, Reiterstrasse, Bern);
- a reasonable low connected power is, however, the only warranty that inefficient use of lighting or inadequate daylighting design will not lead to an excessive electricity consumption (f.i. CNA building);
- there is a serious indication that good daylighting performance (high daylight factor) and energy savings (low exploitation factor) are correlated with regard to lighting;
- daylight-responsive control systems do not systematically lead to a more efficient use than energy-conscious users, especially in the case of inappropriate settings of the controller (f.i. UAP building).

The same type of monitoring would have benefited the other buildings in Europe, for which no such assessment has been made.

It is believed, however, that such systematic monitoring of daylit buildings is necessary to confirm the pertinence of some daylighting design with regard to energy savings. User behavior and acceptance of daylighting fixtures will in this sense always play a significant role concerning energy performance of buildings.

3 COMPUTER SIMULATION OF VIRTUAL CASE STUDIES

The aim of the simulation effort made within the EU project was to provide general design guidance based on the results of several case studies (virtual case studies).

The daylighting performance of these buildings and their thermal characteristics were assessed through computer simulation. A comparison of the results with the values of reference cases (the same buildings but without daylighting features) was carried out simultaneously.

The Swiss contribution to this work had the following goals:

- development of a computer simulation methodology for the assessment of the thermal and daylighting performance of buildings,

- application of this methodology during the simulation of selected Swiss case studies.

An overview of the work done is given in this chapter. A detailed presentation of the computer simulation activities is moreover given in the Technical Report (cf. Chapter 2 [Sca 97b]).

3.1 Definition of a computer simulation methodology

A performance assessment methodology, provided later as a standard to the different simulation teams, was set up in collaboration with the Energy Systems Research Unit of University of Strathclyde [Cla 96]. This methodology, which was designed before any computer simulation was carried out, had the following objectives:

- to assess the overall building performance (daylight, energy savings, user comfort etc.),

- to ensure that daylighting performance is not achieved at the expense of other building performance criteria (visual comfort, heating and cooling loads, etc.),

- to undertake daylighting system optimization,

- to conduct parametric studies of the selected buildings in support of the case studies monitoring.

Thermal and daylighting computer simulation programs were used for that purpose; the following simulation procedure was applied:

- a computer model of the building "as built" was created to the level of detail required by the simulation tools ("as-built case");

- a corresponding reference model was then created through the removing of the particular daylight capture/control features ("reference case");

- the simulation results of the "as-built case" were compared with those of the "reference case" in order to quantify the effects of the removed daylighting features.

Once established, the computer models were also used for parametric studies and daylighting component optimization. The "as-built" and "reference" models were finally incorporated in a computer "model manager" which allows 3D browsing, model exporting to CAD and further exploratory thermal and lighting analysis.

Computer simulation tools

The buildings were simulated with two different pieces of software:

- RADIANCE, for the assessment of the daylighting performance of buildings [War 92],
- ESP-r for the determination of their thermal characteristics [Cla 93].

The two programs were made available to the different simulation teams and can very briefly be described as follows:

- *RADIANCE*

A simulation package developed by LBL and partly by EPFL, for the visualization and analysis of daylighting and electric lighting design, using backward ray tracing techniques.

Input files define the building geometry (program scene), the surface photometric characteristics (nature of light reflection, color), sky luminance distribution (overcast or sunny day), luminaire characteristics (light distribution, position, etc) together with the date and time of day. No limitations with regard to complexity of the building geometry and surface characteristics exist.

Calculated values include the luminance of the simulated "program scene", illuminance distribution on the work surface and glare indexes for a given position and direction views. Simulation results can be displayed as synthetic color images (scene rendering) or colored contoured plots of illuminance.

- *ESP-r*

A simulation environment, which originated at the University of Strathclyde and is able to simulate building and plant energy flows as well as their interconnections.

The computer package offers climate, construction and plant databases; it is able to support energy, air flow, condensation, shading, control and lighting assessments, including special components such as photovoltaic panels, advanced glazing systems and renewable technologies. Building services are modeled using a schematic description of heating and cooling systems and their control, following a well-defined strategy.

Both programs run under the UNIX environment. The computer models are contained within a "project management environment" that supports model browsing and exporting to analysis tools as well as AutoCad modeler. The project results can be disseminated in a novel way as both programs support on-line exploration of the building models and simulation results.

Detailed simulation procedure

Among the 60 European buildings considered for monitoring within the EU project (cf. Chapter 2), eleven were selected for their architectural approach to daylighting. Table 3.1 gives a list of these buildings as well as their geographical location and principal daylighting characteristics.

Building name	**Building site**	**Principal daylighting features**
Collège la Vanoise	Modane (Fra)	Light shelves, atrium and lighting system control
Victoria Quay	Edinburgh (Scot)	Mix of open plan and cellular offices, multiple lighting control possibilities, atria
Queens Building	Leicester (UK)	Bilateral lighting and light shelves
Trundholm Town Hall	Trundholm (Dk)	Lighting control and atrium
Conphoebus S.C.R.L.	Catania (It)	Smart windows and a shading grid with three facade variations
Berthold Brecht School	Dresden (Ger)	Renovation of atrium into a modular school layout with external light shelves and skylights
Pharmacy Faculty	Lisbon (Por)	External blind systems and split windows in an academic building
Tractabel Ingeniere	Brussels (Bel)	Flexible lighting systems in an office building with large glazing area
EOS Headquarters	Lausanne (CH)	Light shelves and atrium
CNA Office	Basle (CH)	Prismatic movable panels, solar shading and solar air collectors
Statoil Research Centre	Trondheim (Nor)	Prismatic and reflective films with automatic lighting control

Table 3.1: Selected virtual case studies (buildings simulated by computer)

The eleven buildings were simulated after a pilot case study made of the building of Collège de la Vanoise (France), all according to the same detailed simulation procedure, which includes the following steps:

- *Description of building construction and geometry*

The computer representation of buildings was generally based on information extracted from architectural design drawings and on-site inspections. Thermo-physical properties of windows and walls were defined on the basis of appropriate engineering handbooks. Photometric data of internal building surfaces were generally supplied by the monitoring groups or extracted from existing photometric data bases.

The buildings were modeled as different interconnected thermal zones, subdivided into different spaces according to the electric lighting fixtures. Glazing was explicitly modeled to account for its thermal and optical characteristics (visible transmittance coefficient, thermal conductance, etc.).

- *Description of building usage and environmental systems*

Building usage and environmental systems had to be defined with regard to their direct impact on internal energy gains. On-site inspections and some case assumptions led to the definition of the following data:

- number of occupants and building occupancy schedule
- number and type of electric appliances
- characteristics of electric lighting system and control
- description of heating system and operation schedule
- description of ventilation system and operation schedule.

All these data are given in detail in the different reports that describe each simulation case study (see f.i. the case of the EOS building given in the Technical Report).

- *Description of climatic data*

Thermal simulations were carried out on the basis of hourly radiation (direct and diffuse components) and ambient temperature data, retrieved from Test Reference Years (TRY). Wind speed and direction were generally taken into account during the simulations; for the sake of simplicity, however, the building air exchange rate was used in some cases to avoid creating an air mass flow network.

The annual energy consumption was assessed through extrapolation of three typical weeks, selected for their representativity of the climate throughout the year. For the site of Modane, the site of Collège de la Vanoise, these three typical weeks were chosen as indicated in Table 3.2.

PERIOD	Beginning	End
Winter	4 January	10 January
Transient	8 March	14 March
Summer	7 June	13 June

Table 3.2: Weeks representative of the climate of Modane (France) during a year and chosen for the pilot virtual case study.

The three weeks were chosen after analysis of the hourly weather data files and separation of the year into three periods according to its degree-days. A typical week was selected for each period on the basis of the values for solar radiation and ambient temperature. The annual energy consumption was simply extrapolated through ponderation of the consumption of each typical week by the degree-days of the corresponding period.

Daylight simulations were carried out on the basis of standardized sky luminance distributions defined for the CIE overcast sky model [CIE 70]. They were consequently based on stationary daylighting conditions defined by this model. External obstructions were taken into account for these simulations.

- *Validation procedure*

Before using the established computer model, a simple validation procedure was applied to the simulations. This procedure was centered on the accuracy of the daylight factor calculations. The simulated daylight factor values were compared to those monitored in given parts of the building.

In case of disagreement, the building model related to the daylighting simulation was tuned up to achieve satisfactory results. Figure 3.1 shows simulated and monitored daylight factor profiles used to validate the daylighting computer model of the Collège de la Vanoise (Modane) building [Cit 97].

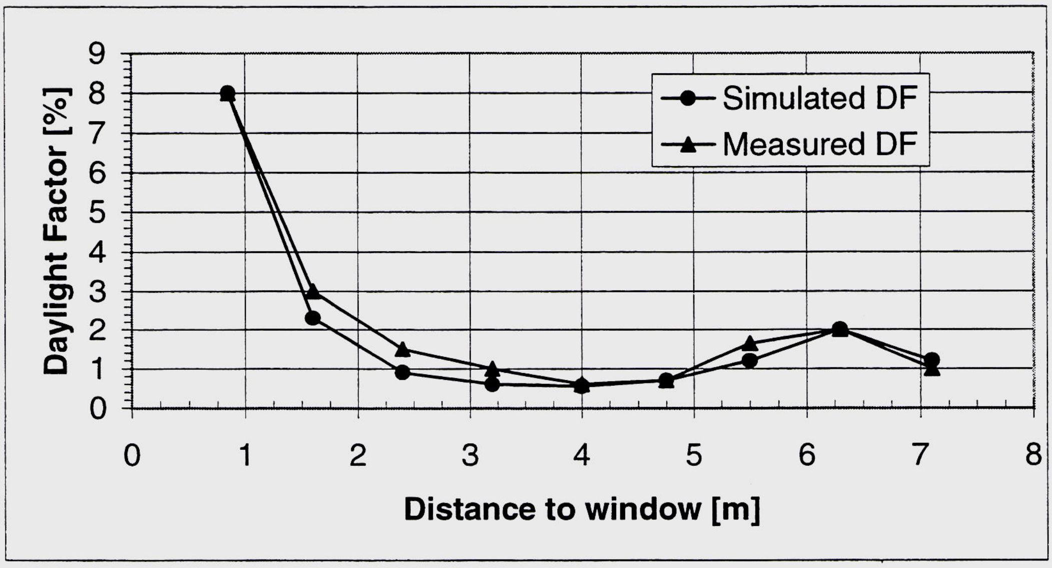


Figure 3.1: Simulated and monitored daylight factors in an office room of the Collège de la Vanoise (Modane) building

3.2 Selection of building performance indicators

Building performance indicators were chosen in order to highlight the following building aspects:

- heating energy and electric lighting consumption
- thermal and visual comfort
- environmental impact.

Seven typical indicators were selected for that purpose and grouped together within a synthetic representation form providing an Integrated Performance View (IPV) of the case studies. Figure 3.2 gives an example of an IPV form established for the school of Modane, France (pilot case for the simulation methodology). The following indicators were chosen to build the IPV:

- maximum power capacity
- primary energy consumption
- emissions of pollutants
- thermal comfort
- daylight factor
- identification of glare sources
- visual comfort.

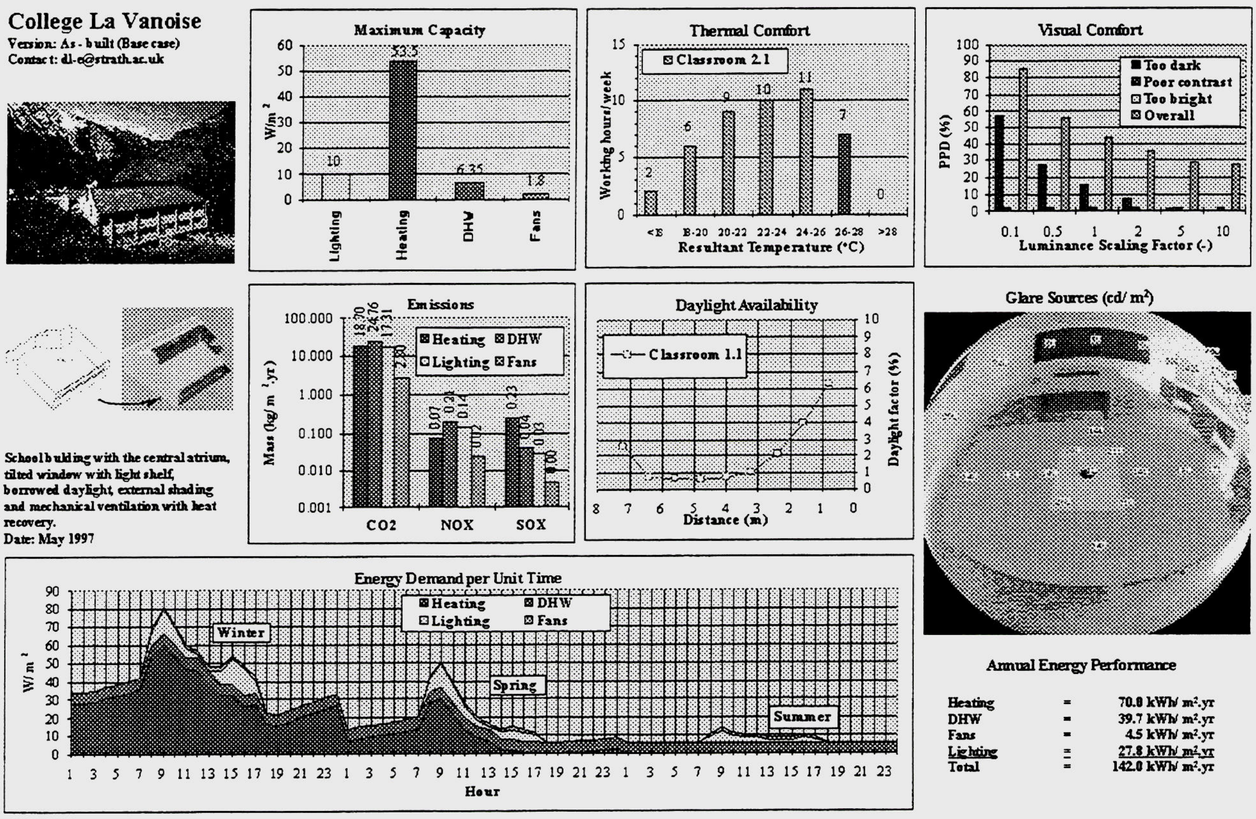


Figure 3.2: Example of a building Integrated Performance View (IPV)

The first six indicators are well known and defined. As a consequence, only a short description thereof will be given in the following chapter.

The visual comfort indicator is based on a novel approach (J-index [Fra 97]) and will consequently be presented in a more explicit manner in the next paragraph.

Maximum power capacity

The maximum power capacity of the building's technical installations is the maximum power required by the different energy appliances in the building, as f.i. for lighting, heating and cooling, in a worst case situation. In the case of heating, the maximum capacity is determined for the coldest possible winter period of the climatic site (-6° for Lausanne).

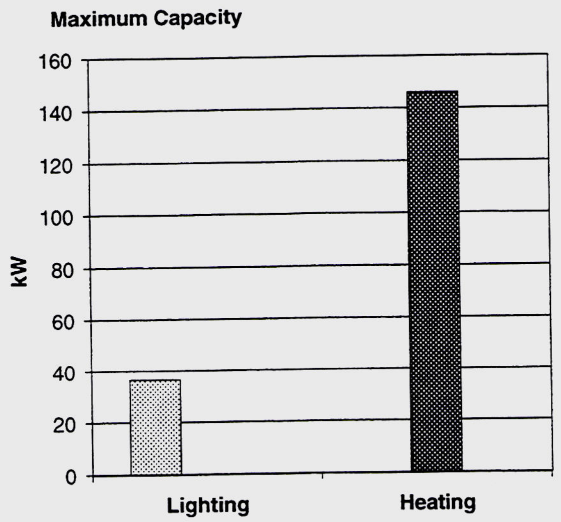


Figure 3.3: Maximum power capacity for lighting and heating (EOS building); no cooling available.

Primary energy consumption

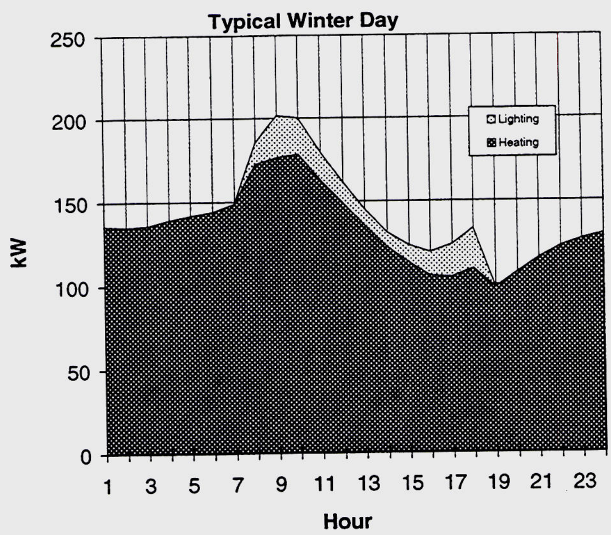


Figure 3.4 Primary energy profile for a typical winter day (EOS building)

Hourly primary energy profiles for lighting, heating and cooling of the whole building are determined on a daily basis. For each of the three typical weeks, a typical day is chosen according to its degree-days, which must be close to the average degree-day of the whole week. Solar radiation and ambient temperature profiles of the selected days are used to calculate the corresponding power demand for lighting, heating and cooling. The peak demands for each typical day can also be retrieved from these profiles.

Emission of pollutants

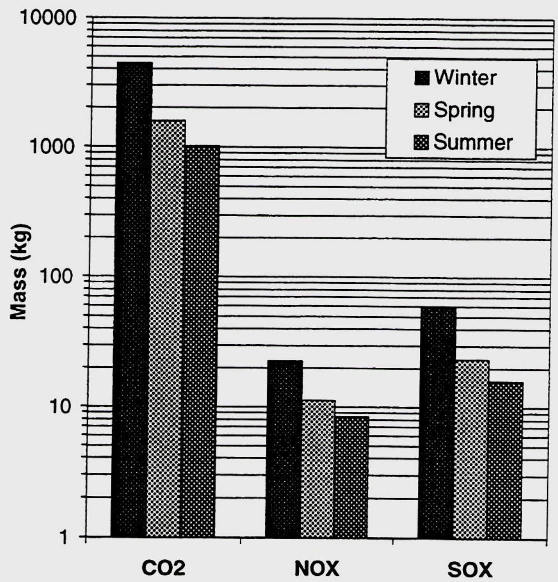


Figure 3.5 Emissions of principal air pollutants due to building operation (EOS building)

The principal emissions of air pollutants (CO2, NO_x and SO_x) due to building operation (heating, cooling and lighting) are determined as a function of the building energy consumption. Conversion factors between the energy source (gas, electricity, coal and oil) and the mass of pollutants are used in accordance with European standards; they are given by the following values:

	CO_2	No_x	SO_x
Oil	0.16	0.0006	0.002
Gas	0.13	0.0002	0.00001
Electricity	0.36	0.003	0.0057

Table 3.3: Conversion factors (kg/kWh)

Values corresponding to a weeklong operation are given for the three typical periods.

Thermal comfort

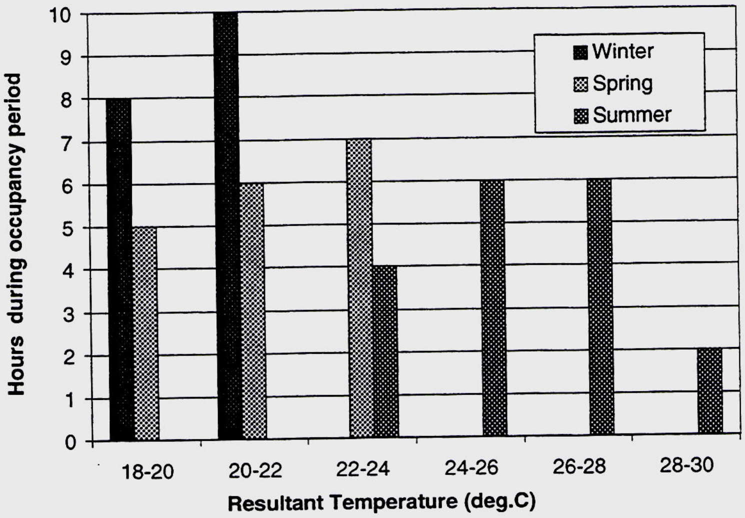


Figure 3.6 Thermal comfort assessment in a typical office (EOS building)

Thermal comfort in the building is assessed by determining the statistical distribution of the radiant temperature over the period of occupancy of the building during the three typical weeks. Radiant temperature is calculated on an hourly basis; radiant temperature bins correspond to 2°C.

The radiant temperature is calculated for the more representative window orientations.

Daylight factor

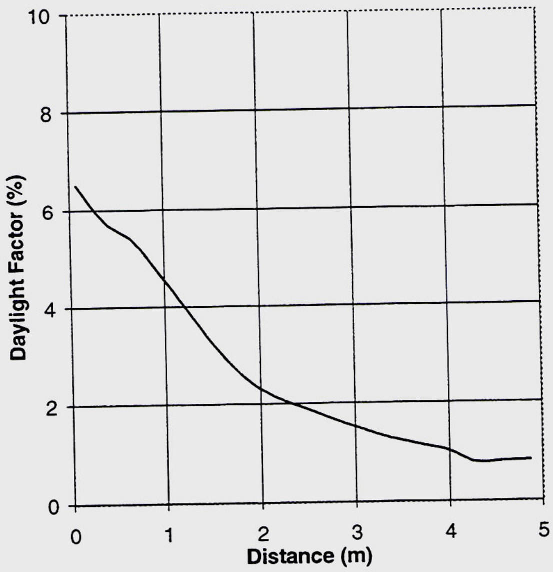


Figure 3.7: Daylight factor profile of a typical office (EOS building)

A daylight factor profile is calculated for a room that is representative for the whole building and generally corresponds to a monitored room of the building. The profile is determined at the level of the work plane (0.8 m above the floor), perpendicularly to the window and in the middle of the room.

For asymmetric rooms, it was recommended to evaluate several daylight factor profiles in order to determine the optimal work place location in the room. For offices with different window orientations, it was recommended to calculate daylight factor profiles for each window orientation as well.

Identification of glare sources

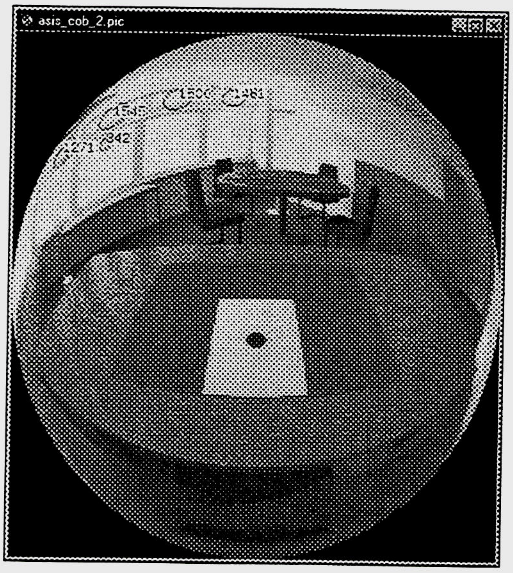


Figure 3.8: Glare sources in a typical office room (EOS building)

Glare sources, as perceived from a work place, were identified by calculating the ratio between the glare source luminance and the average scene luminance. A detected glare source is marked with a contour line; the average luminance of the surrounded points is calculated and displayed on the image scene.

Visual comfort

The visual comfort assessment was based on an experimental procedure (J-index method), developed by J.J. Meyer and D. Francioli at the Institut Universitaire Romand de Santé au Travail (IURST) of University of Lausanne [Fra 97].

The procedure is based on the scanning of luminance values within the field of view of users sitting at a given work place. An analytical model of visual discomfort uses this luminance scanning to compute a Predicted Percentage of Dissatisfied People (PPD) who express visual discomfort. The model is able to distinguish between various causes of visual discomfort, such as a lack of light on the desk, an excess of light or excessive luminance contrasts. This method has been tested successfully in-situ through luminance measurements.

A specific routing (J-index routine) was developed for the computing of PPD values during simulations. The routine was implemented in RADIANCE, which enhanced the computation capabilities of the program. A detailed presentation of this method is given hereafter.

3.3 Description of the J-index method

The J-index method describes the visual performance of a person on the basis of the visual acuity required to execute a given task (writing, reading, etc.). It assumes that visual discomfort is perceived by a subject when his acuity A for given lighting conditions is lower than a threshold acuity A_e necessary to carry out the same task under normal conditions. Following this hypothesis, a visual discomfort index J can be defined using the expression:

$$J = \frac{A_{max} - A}{A_{max}} \quad [-]$$

where

A_{max} is the maximal acuity that can reach the person under optimal lighting conditions

A is the acuity of the same person under the considered lighting conditions.

Using ample and systematic investigation with a great number of people, a visual discomfort model was set up, which served to calculate the Predicted Percentage of Dissatisfied People (PPD) displeased with the luminance distribution in the view field. The PPD can be determined from the following four luminance and illuminance values:

L_c [cd/m^2] luminance of characters perceived on a given target (sheet of paper or VDT screen).

L_t [cd/m^2] luminance of the target (located at the center of the view field)

L_e [cd/m^2] equivalent luminance of the surrounding view field

E_v [Lux] pupil illuminance at the eyes

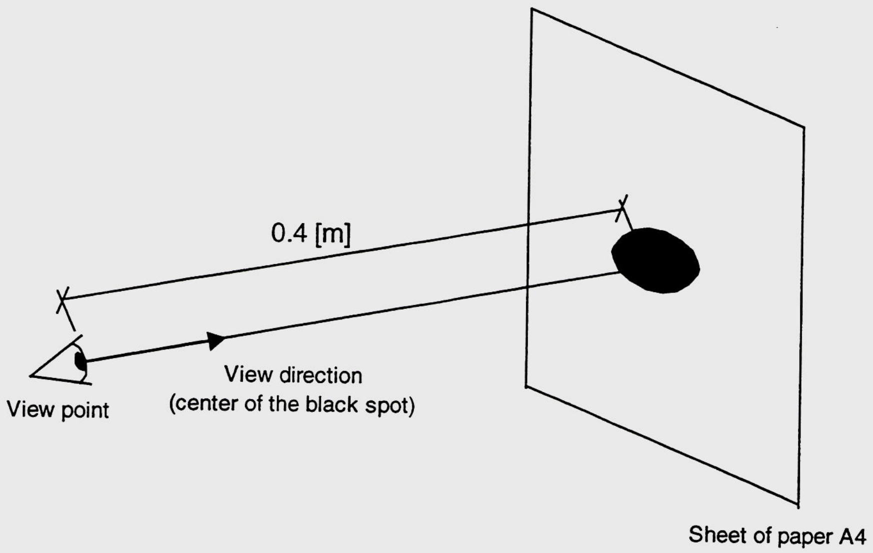
L_c, L_t and E_v can be determined directly by computer simulation; L_e is determined by weighting luminance values in the surroundings of the target using the Guth position index [Guth 63]. The view field considered for this calculation corresponds to a 140 degree aperture cone whose summit is placed at eye level. The field of application of the method is limited to positive contrast situations where $L_c < L_t$ (black characters printed on a white sheet of paper).

To calculate the J-index, all luminance values of a Radiance scene are used. As lighting conditions at the work place were to be analyzed with this method, a "standard scene" was created for that purpose; this offers also the possibility of comparing visual comfort conditions at the work place for different buildings. The "standard scene" can be described as follows:

Scene description

The viewpoint is located 1.2 m above the floor level and corresponds to a seated person. The visual target is a sheet of white paper (A4 format). In order to be able to determine the characters' luminance L_c, a black circle is placed at the center of the sheet of paper. The view direction points exactly toward the center of the circle. Two different situations are considered (cf. fig. 3.9):

1. a vertical target (simulation of a vertical reading task or a VDT workplace)
2. a horizontal target (simulation of a desk workplace).



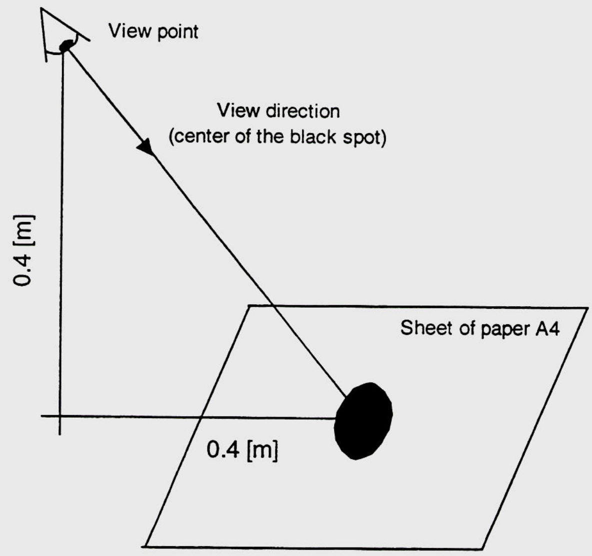


Figure 3.9: Configuration of the targets used to determine the J-index (above: VDT screen, low: desk task)

As the furniture affects the perceived luminance in the view field through its reflection of daylight, it is included in the scene to improve the realism of the visual comfort calculations. The desktop is placed 0.8 m above the floor to meet the standard position of visual targets in the case of a reading task. The body of a person seated at the workplace could also be modeled to account for its shadowing effect on the task. Up to now, no "standard" body was defined, this will probably be the case in the near future.

J-index calculation procedure

Assuming that a 'scene' that describes the office room with its daylighting systems is available, the following procedure is applied to assess the J-index:

1. position the visual target (A4 sheet of paper) at the right place and add furniture and body model;
2. produce a hemispherical picture with an aperture larger than 140 degrees (picture resolution should be at least 256 x 256 pixels);
3. analyze the picture using the J-index routine.

Table 3.4 gives an example of J-index calculation results as obtained following this procedure, for the case of a horizontal sheet of paper.

J-INDEX VISUAL COMFORT ANALYSIS								
xL_c	L_t	L_e	E_v	L_c	JPPD<	JPPD~	JPPD>	JPPD
0.100	0.1	3.3	3.5	10.6	40.0	3.6	0.0	69.7
0.500	0.6	16.5	17.7	53.1	13.2	3.6	0.0	42.9
1.000	1.2	33.1	35.4	106.2	6.0	3.6	0.0	69.7
2.000	2.5	66.1	70.8	212.4	1.7	3.6	0.1	42.9
5.000	6.1	165.3	177.0	531.1	0.0	3.6	0.0	35.7
10.000	12.3	330.6	353.9	1062.2	0.1	3.6	1.2	31.5

Table 3.4: Typical output results of a J-index calculation for a horizontal task.

To take into account the sensitivity of visual comfort analysis in the variations of lighting conditions (especially relevant for daylighting), six different calculations were carried out by scaling the original luminance values by a multiplication factor (see left column of Table 3.4). The four corresponding field luminance values are listed in the same table, together with the resulting PPD values, which are defined as follows:

1. JPPD< is the percentage of people dissatisfied because of a lack of light
2. JPPD~ is the percentage of people dissatisfied because of inadequate contrasts
3. JPPD> is the percentage of people dissatisfied because of excess of light
4. JPPD is the total percentage of dissatisfied people.

It must be emphasized that a fraction of 25% of people are expected to be dissatisfied even in optimal lighting conditions. This is due to the acuity required to perform the task, which is not met by everyone. This fraction is in a certain sense similar to the minimal value of 5% that characterizes the PDD assessment in thermal comfort analysis [Fan 82].

In the case of a VDT workplace assessment (vertical target), three different screen luminance values are considered for the white background (25, 50 and 100 [Cd/m^2]), which covers the most common screen settings.

Table 3.5 gives the J-index calculation results, of such a case, including the variations of the lighting conditions (six scaling factors).

Target: VDT screen (25 Cd/m^2)								
xL_c	L_t	L_e	E_v	L_c	JPPD<	JPPD~	JPPD>	JPPD
0.100	0.4	25.4	3.5	15.9	32.8	3.4	0.0	62.3
0.500	2.0	27.0	17.7	55.6	12.6	3.6	0.0	42.3
1.000	3.9	28.9	35.4	105.2	5.8	10.2	0.0	42.1
2.000	7.8	32.8	70.8	204.5	7.8	30.8	0.5	65.1
5.000	19.6	44.6	177.0	502.1	0.0	73.9	0.0	100.0
10.000	39.2	64.2	353.9	998.3	0.0	73.9	0.0	100.0

Target: VDT screen (50 Cd/m^2)								
xL_c	L_t	L_e	E_v	L_c	JPPD<	JPPD~	JPPD>	JPPD
0.100	0.4	50.4	3.5	21.9	24.7	5.6	0.0	56.3
0.500	2.0	52.0	17.7	61.6	12.2	2.1	0.0	40.4
1.000	3.9	53.9	53.4	111.2	5.6	3.6	0.0	35.3
2.000	7.8	57.8	70.8	210.5	1.7	10.2	0.1	38.1
5.000	19.6	69.6	177.0	508.1	0.0	41.1	0.0	67.2
10.000	39.2	89.2	353.9	1004.3	0.0	73.9	0.0	100.0

Target: VDT screen (100 Cd/m^2)								
xL_c	L_t	L_e	E_v	L_c	JPPD<	JPPD~	JPPD>	JPPD
0.100	0.4	100.4	3.5	33.9	17.4	8.2	0.0	51.7
0.500	2.0	102.0	17.7	73.6	9.7	2.9	0.0	38.7
1.000	3.9	103.9	35.4	123.2	5.2	2.1	0.1	33.4
2.000	7.8	107.8	70.8	222.5	1.5	3.6	0.1	31.2
5.000	19.6	119.6	177.0	520.1	0.0	14.6	0.0	40.6
10.000	39.2	139.2	353.9	1016.3	0.9	41.1	7.5	75.5

Table 3.5: J-index calculations for a vertical target (VDT screen)

Graphical representation of the PDD values allows a better visualization of the lighting environment within the building, together with a comparison of other systems. Figure 3.10 shows such a representation for the EOS building in the case of a desk task (horizontal sheet of paper).

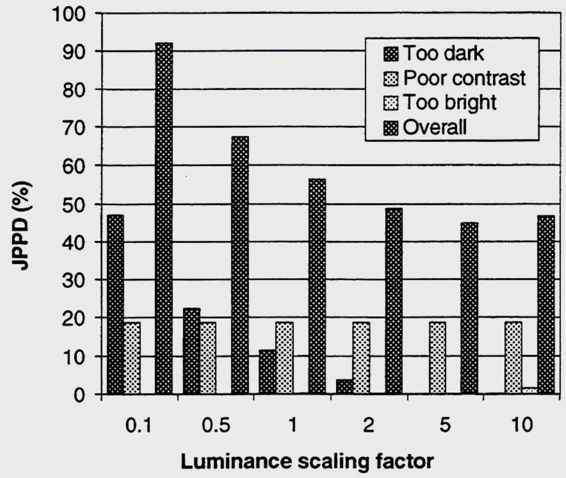


Figure 3.10: Graphical representation of PPD values for a desk task (horizontal sheet of paper)

3.4 "EOS building" simulation case study

The "Energie Ouest Suisse" headquarters, located in Lausanne (Latitude 46^{32}N, altitude 495 m), was selected for a virtual case study for Switzerland. A detailed computer simulation of the building was undertaken for the EU project.

A full description of the building simulation results is given in the Technical Report [Cit 97]; only the most significant part of this work is given hereafter.

Building description

The "EOS building" is a non-residential four-story building, recently erected in the center of Lausanne (construction date: 1994-1995).

Two main daylighting features characterize the building:

- external lightshelves, installed on the south-western facade above a row of windows of office rooms
- a central atrium providing daylighting to the circulation zone together with a secondary window located at the back of each room.

Figure 3.11 shows a building cross-section that illustrates the main daylighting fixtures of the building.

The design of the lightshelves was carefully studied before building construction, with the aim of optimizing their geometry (slanting angle) and their photometry (type of material and specularity); a good overview of this study is given in [Chu 94].

Figure 3.11: Cross-section of EOS building

<u>Building construction and geometry</u>

The EOS building was described by a computer model made of 21 thermal zones (cf. Figure 3.12). Eighteen zones are located on the second and third floor of the western part of the building. They describe the offices, circulation-atrium and the raised floor. The three remaining zones make up the rest of the building shape.

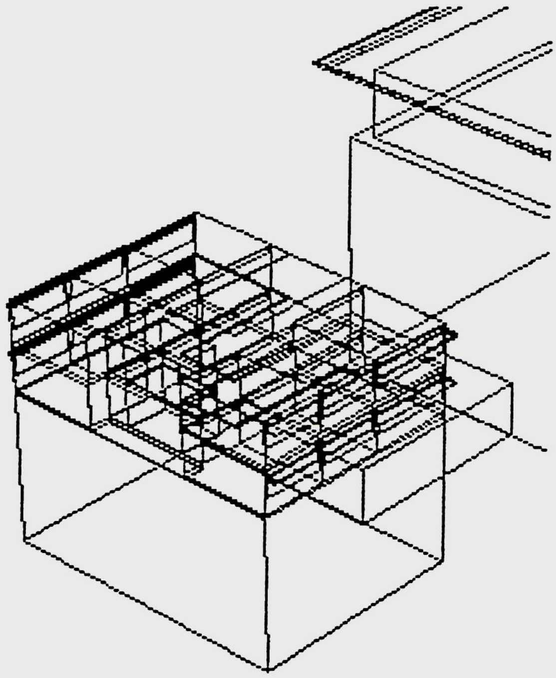


Figure 3.12: Computer model representation of EOS building

The EOS building uses Superglass glazing for the facade windows (U-value of 0.77 W/m^2K). It is made of double clear float glass filled with Krypton, with two low-emissivity coatings tight in the gas gap.

The internal windows (between the office and the atrium) consist of double clear float glass filled with air.

Figure 3.13 shows a detailed representation of the computer model used to represent the external lightshelves.

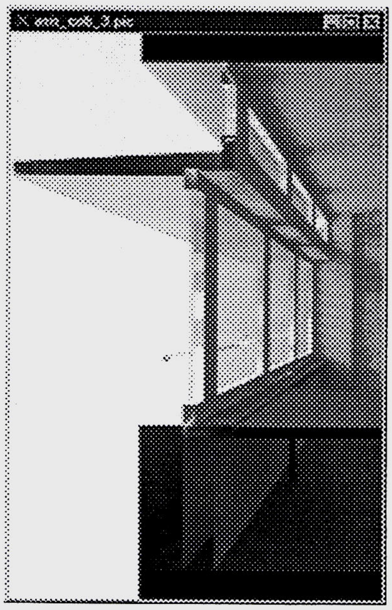


Figure 3.13: Computer model representation of the external lightshelf

The information regarding construction was extracted from architectural drawings and on-site investigations. Thermo-physical properties were determined from detailed architectural drawings, from manufacturer data and from engineering handbooks.

<u>Usage and environmental systems</u>

Computer simulation was restricted to the monitored part of the building, i.e. the southwestern office rooms. The following data were used for these simulations:

- occupancy schedule corresponds to 7 a.m. to 6 p.m. during work days (11 hours/day);

- internal gains due to electrical appliances (mainly personal computers) were evaluated at 160 W during work hours;

- lighting of office rooms consists in one floor luminaire per work place (3 x 55 W fluorescent tubes), corresponding to about 9W/m^2 connected power (500 Lux required desk illuminance);
- heat is supplied by water radiators from a central gas heating plant (20°C temperature setting);
- the building is naturally ventilated (only meeting rooms are mechanically ventilated).

All these parameters were taken into account by the two simulation programs.

Climatic data

Three different periods were used to assess the performance of the building. As stated in the computer simulation methodology (cf. paragraph 3.1), a typical day and week were selected from each period in order to perform the simulations. Table 3.6 shows both of them.

Period	Winter	Spring/Autumn	Summer
Typical week	22 - 28 January	9 - 15 April	10 - 16 July
Typical day	27 January	14 April	14 July

Table 3.6: Selected weeks and typical days (climate of Lausanne) for use in computer simulation

Case study results

The overall performance of the EOS building, evaluated with ESP-r and RADIANCE simulations, were expressed in the form of an Integrated Performance View (IPV) for the building "as-built" (with external lightshelves) and the"reference building" (external lightshelfs removed). Figures 3.14 and 3.15 show both IPV.

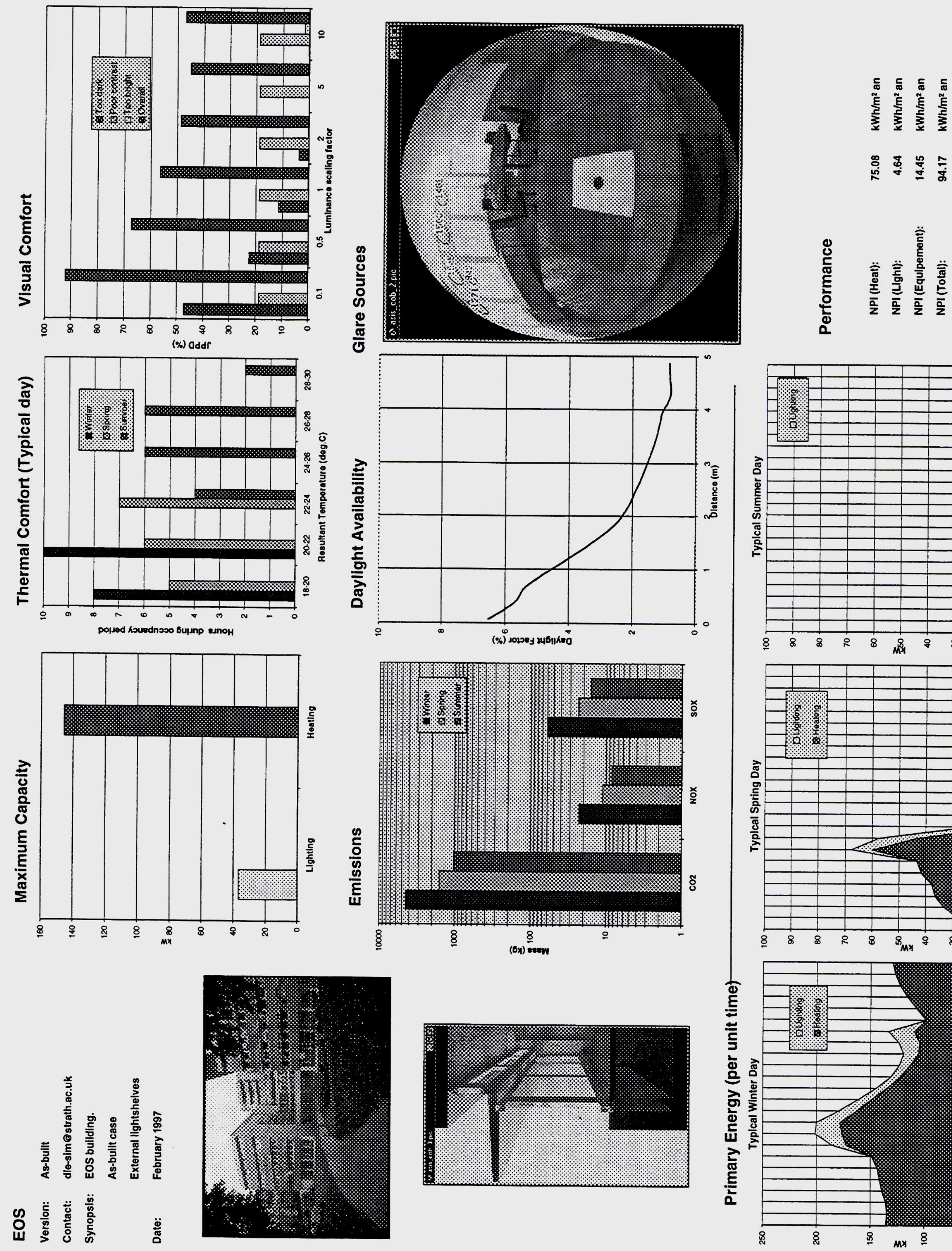


Figure 3.14: Integrated Performance View of the EOS building ("as-built" case)

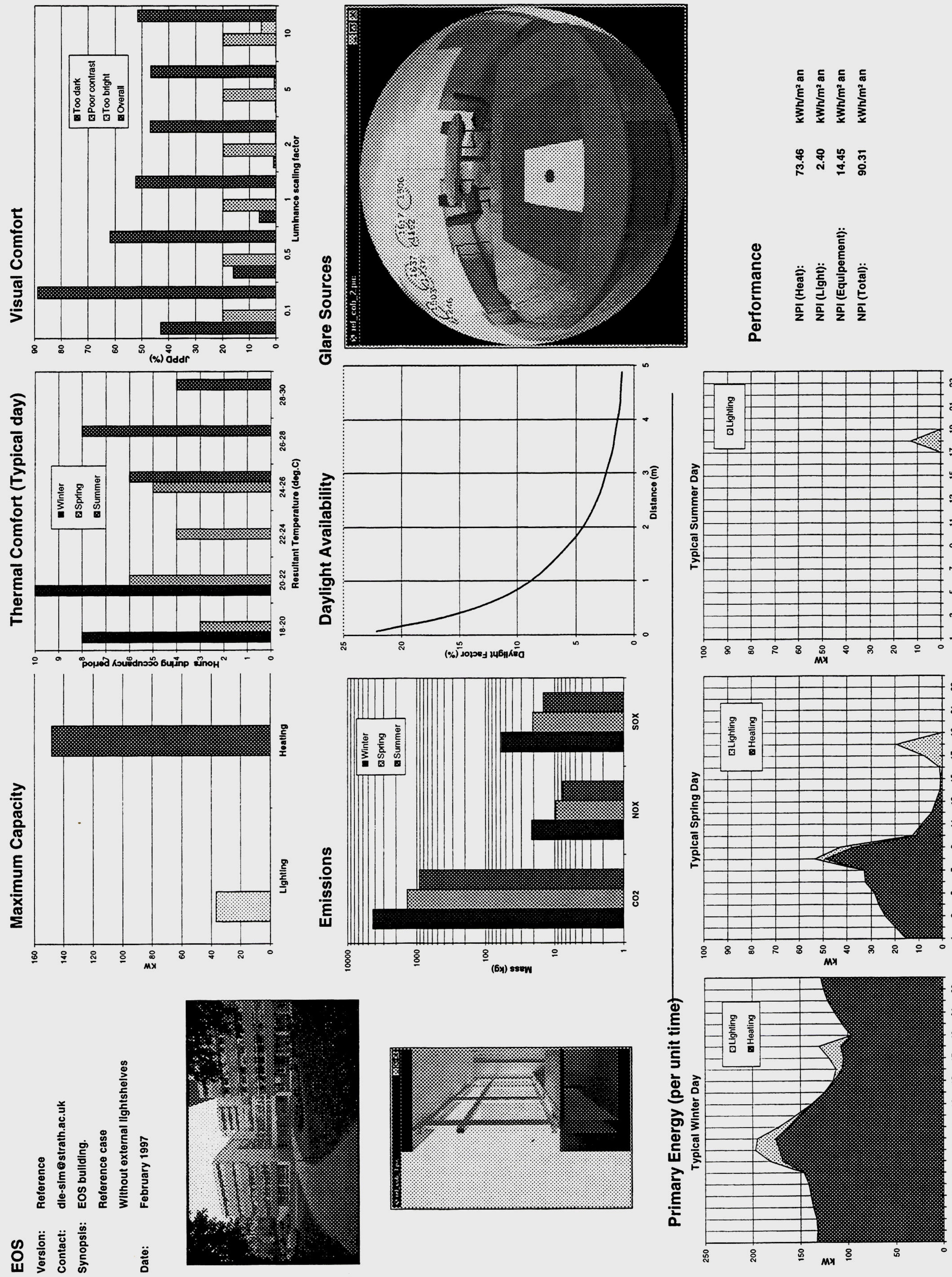


Figure 3.15: Integrated Performance View of the EOS building without daylighting features ("reference case")

A comparison yields the following results:

- *Maximum power capacity*
  The maximum heat load of the "as-built" and "reference building" are similar (2.1% difference only)

- *Primary energy consumption*
  The lighting energy consumption of the "reference case" (without lightshelves) is significantly lower than that of the "as-built" building (with lightshelves)

- *Environmental emissions*
  Principal environmental emissions are lower in the range of 10% for the "reference case" compared to the "as-built" building

- *Thermal comfort*
  The number of hours of excessive indoor temperature is lower in the "as-built" building due to the solar protection effect of the lightshelves

- *Daylight availability*
  A better daylight uniformity ratio is achieved in the "as-built" building (0.30 instead of 0.18 in the reference case) due to the lightshelves.

- *Visual comfort*
  Slightly better visual comfort is achieved in the "as-built" case at a desk placed 3 m behind the window (PPD of 48% instead of 52% in the reference case).

- *Energy performance indicators*
  Both the "reference" and the "as-built" buildings have a very reasonable thermal intensity value (270 MJ/m2 year for the "as-built" case); the value of the reference case is, however, slightly lower than the "as-built" case (half is due to the reduction of heating needs and half to the reduction of lighting needs).

It appears from these results that the implementation of lightshelves on a building in the typical overcast winter weather of Central Europe is more justified by the uniformization of daylight illuminance than by an enhancement of daylight penetration into the rooms, which can be considered as significant from an energy saving point of view.

The formal architectural aspect of the building given by such a daylight strategy remains, however, an important source of motivation for the architects.

The post-occupancy evaluation of the building confirmed the excellent appreciation of the daylighting features by the building users (cf. Annex C).

3.5 Results of building computer simulations

The simulation of different buildings, based on the computer assessment methodology mentioned above, provided significant knowledge on the benefits and drawbacks of different daylighting systems.

General guidance rules were produced that way and integrated into the "European Daylighting Design Handbook" [CEC 98b]. Detailed results are given in different virtual case studies reports: those in which participated the Swiss team are included in the "Technical Report" [Sca 97b].

These cases represent a part of the 11 virtual case studies of the project (cf. Table 3.1) and correspond to the following buildings:

- Collège la Vanoise, Modane (France)
- Queens Building, Leicester (UK)
- Victoria Quay, Edinburgh (Scotland)
- EOS Building, Lausanne (Switzerland).

All these buildings benefit light collected from internal open building spaces (atrium, courtyards) through secondary openings in the office rooms. The majority are equipped with lightshelves on the external envelope (except the Victoria Quay building).

Their simulation with identical thermal and daylighting simulation tools provided similar conclusions regarding performance. They can be summarized as follows:

Impact of atrium and courtyards

'Borrowed light' systems, which face generally courtyards or atria, showed contradictory results regarding daylighting performance. It appears that two different parameters significantly influenced the daylight factor values obtained at the back of the office rooms:

- the glazing fraction of the back wall
- the floor level of the office room.

The following design guidelines can be drawn from the analysis of the simulation results:

- Significant improvement of the daylight factor values can only be achieved at the back of the room (cf. fig. 3.16 for the case of Collège de la Vanoise) with a glazing fraction of the room back wall that is larger than 50%; Collège de la Vanoise (France) and Victoria Quay (Scottland) comply with this criterion.

- No improvement of the daylight factor at the back of the room is obtained with glazing fractions lower than 20% (cf. fig. 3.17, EOS building); this is the case with the Queens building (UK) and the EOS building (CH).

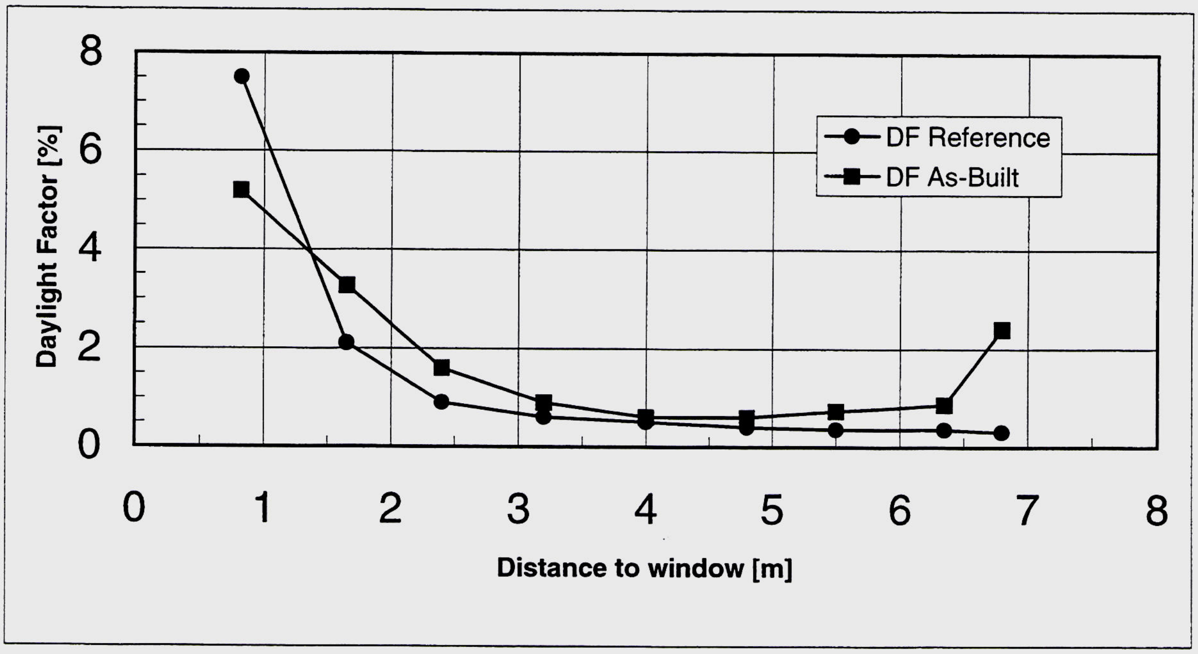


Figure 3.16: Significant improvement of daylight factor at the back of the office room (case of Collège de la Vanoise) due to a high glazing factor of the back wall

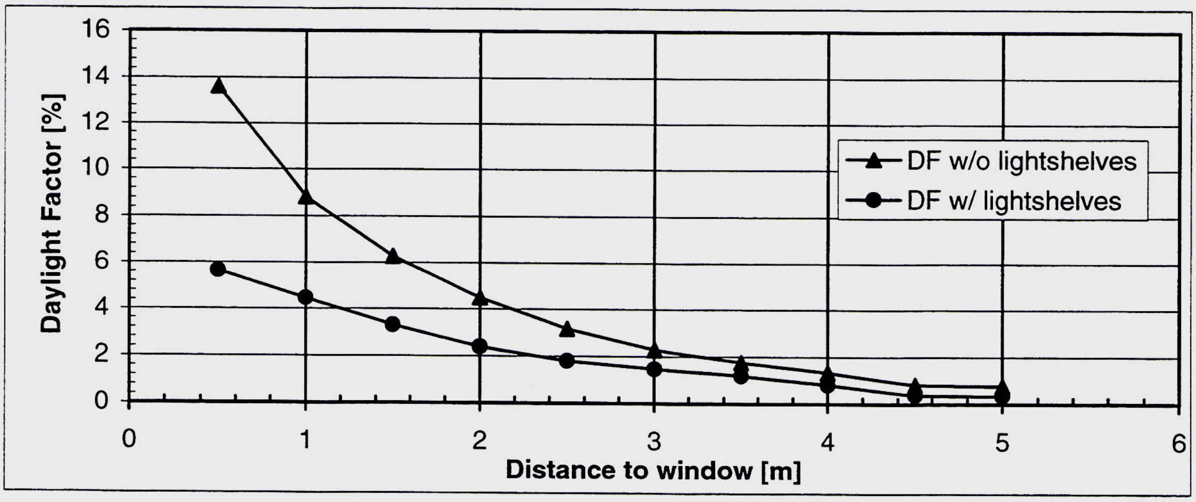


Figure 3.17: Absence of improvement of the daylight factor at the back of the office room (case of ESO building) due to a low glazing fraction of the back wall

Office rooms located on higher building floors benefit from more daylight at the back of the room. An optimization of the shape of the atrium (f.i. V-shape instead of vertical walls) improves significantly the daylight level, as observed for the Collège de la Vanoise for instance.

Moving the glazing fraction of the back wall down to floor level (higher glazing fraction at lower levels) is another way to optimize daylight penetration in the back part of the room.

Impact of light shelves

Light shelves showed rather disappointing results regarding daylighting performance. In all cases they led to the following results:

- lower daylight factors were generally observed at the back of the room in presence of light shelves (cf. EOS building, Fig. 3.17)
- a more uniform illuminance level was, however, achieved in the office room, contributing to lower luminance contrasts.

Even if energy savings, generally calculated on the basis of daylight factors, could not be confirmed by computer simulations, it must be emphasized that more even daylighting levels lead to more adequate lighting conditions for VDT tasks. User reactions, attempting to balance the illuminance gradients through the use of electric light, can be expected to be less frequent in this case, which may lead to energy savings.

Distance to window [m]	Radiance simulation	
	Without external light shelves [%]	With external light shelves [%]
0.5	13.60	5.64
1.0	8.83	4.45
1.5	6.26	3.29
2.0	4.48	2.38
2.5	3.15	1.80
3.0	2.28	1.46
3.5	1.75	1.19
4.0	1.32	0.81
4.5	0.81	0.37
5.0	0.78	0.34

Table 3.7: Impact of light shelves on daylight factor profiles in the EOS office rooms.

Other building-related performance results

In most cases, it appears that the combination of different daylighting features led to the following building performance aspects:

- significant reduction of electricity consumption regarding artificial lighting,
- no significant reduction of the maximum heating load and therefore plant capital costs,
- no significant influence on heating energy consumption,
- general improvement of thermal and visual comfort.

The performance of some buildings differ slightly from the above mentioned general results due to their own architectural characteristics or climate: the corresponding data are given in the Technical Report [Sca 97b].

4 MONITORING OF DAYLIGHTING TEST MODULES

The monitoring of daylighting test modules was a novel contribution to the EU project issued from Switzerland.

In addition to the opportunity of undertaking the 1:1 scale monitoring of advanced daylighting systems (anidolic systems [Com 93 a, b]), it provided a significant source of information for the "Daylighting Design Guidelines". The experimentation of advanced daylighting systems completed moreover the knowledge acquired from a different demonstration facility (DIANE modules), within the framework of previous dissemination activities [Sca 96].

A short description of the daylighting test modules set up for this project is given in the following chapter; more details can be found in reference [ARG 97]. The daylighting performance assessment of advanced systems, designed by the LESO-PB/EPFL and carried out on these daylighting modules, is presented in this chapter.

4.1 Description of the daylighting test modules

The two test modules were set up on the EPFL campus thanks to the financial support of the Nationaler Energieforschungsfonds (NEFF project 658: "DEMONA daylighting test modules"). In order to be able to truly identify the benefits of the use of daylighting systems, different functions were assigned to them:

- one of the modules is used as a reference room; it is equipped with a conventional double glazing facade;

- the second one is used as a test room, hosting novel daylighting systems.

Figure 4.1 gives a front view of the two modules, facing exactly the same direction. Both are placed on the same circular platform in order to guarantee strictly identical outdoor daylighting conditions (see Figure 4.2). The modules stand side by side and are mounted on rollers: consequently they can be oriented in any direction. There are no physical obstructions around them at an altitude any higher than 10° above the horizon (see Figure 4.3).

Each module can be equipped with different facade types on both sides (external facade dimensions: 3.45 m x 3.45 m), which leads to a very flexible utilization. An opaque curtain can be placed at the opposite side of a facade under test to avoid interference from external light during experimentation.

Each facade can be dismantled and replaced by another one in a short period: a couple of days are necessary for this operation.

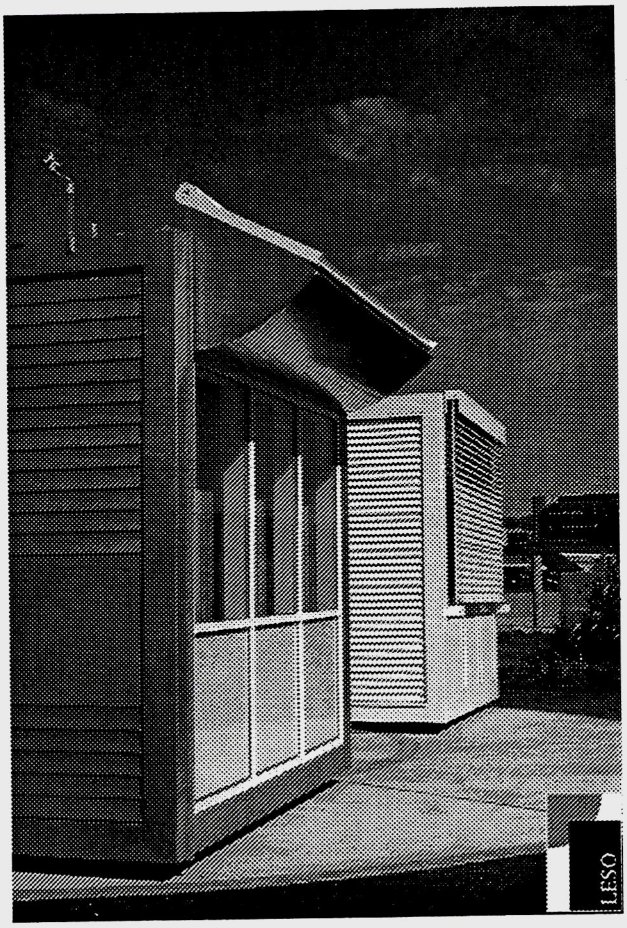


Figure 4.1: *Front view of the two daylighting modules:*
Foreground: test module
Background: reference module

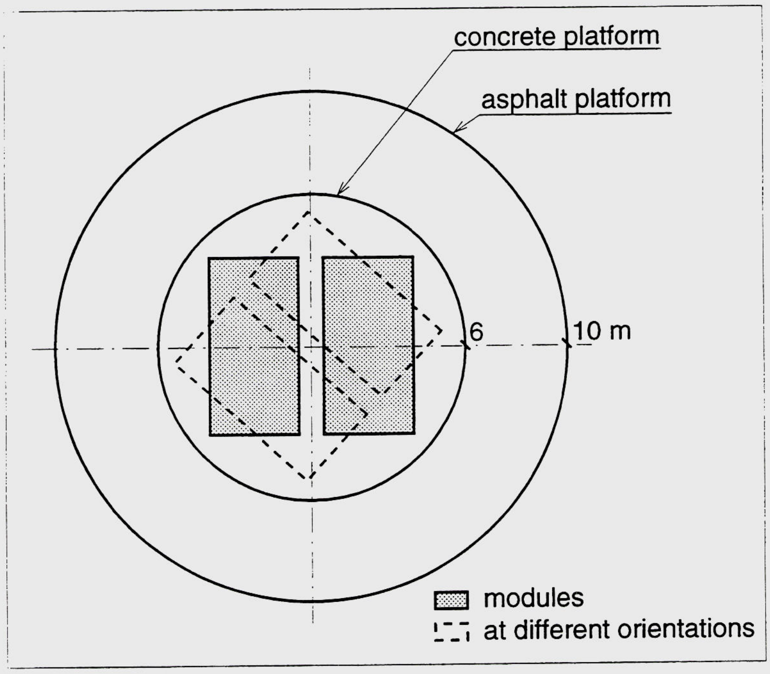


Figure 4.2: *Set-up configuration of the two daylighting test modules on their circular platform.*

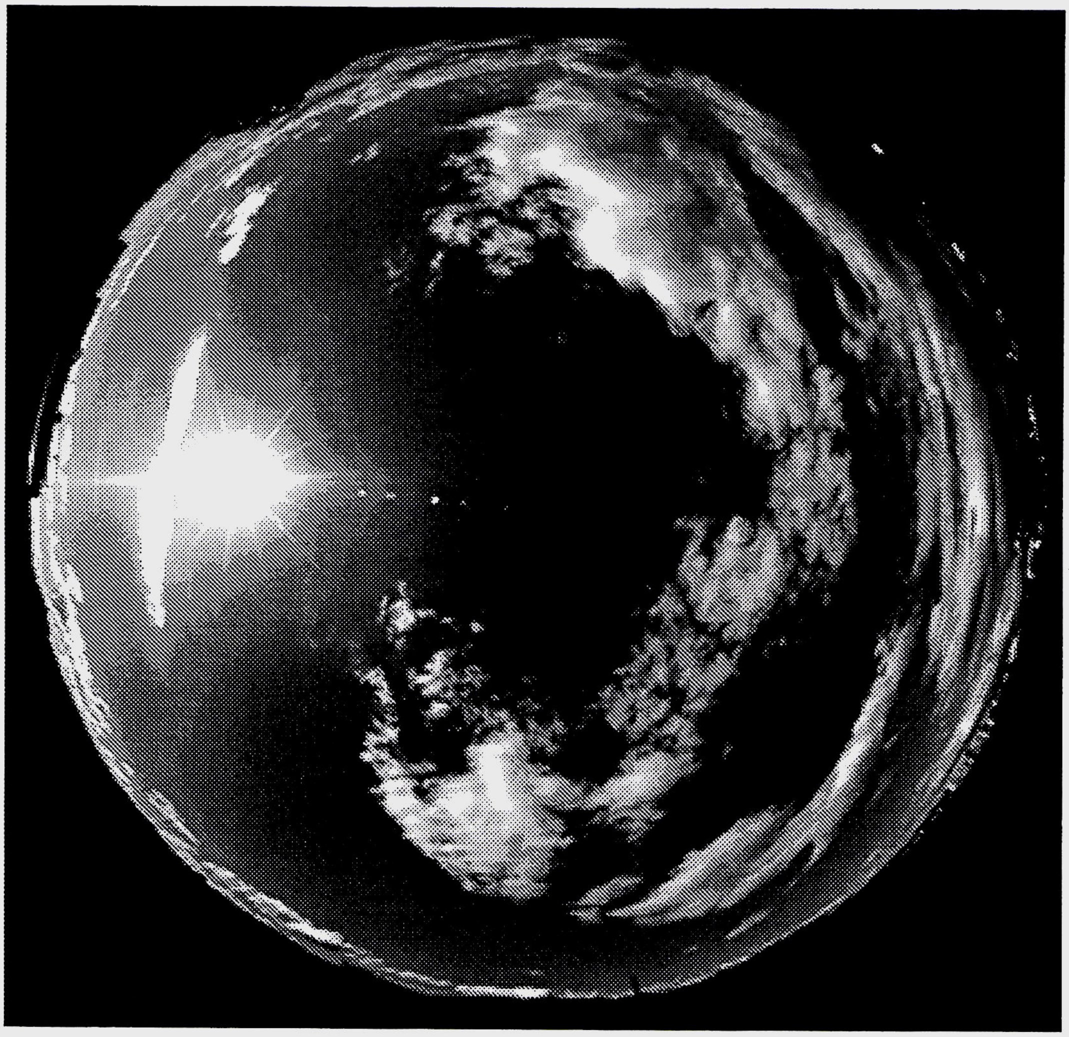


Figure 4.3: Fish-eye view of the sky, taken on the roof of one of the modules

The two modules mock up conventional office rooms: the indoor surfaces are achromatic and painted white (walls, ceiling) or gray (floor carpet). To allow a sound comparison of daylighting performances, they have strictly identical geometrical and photometrical indoor features:

Internal dimensions:	3.05 m (l) x 6.55 m (d) x 3.05 m (h)	
Surface reflection coefficients:	Walls:	0.80 (± 0.01)
	Ceiling:	0.80 (± 0.01)
	Frames:	0.81 (± 0.03)
	Floor:	0.15 (± 0.01)
Glazed facade:	Glazing ratio:	0.26
	Window transmittance (at normal incidence):	0.81

All features were carefully checked and measured on-site. Figure 4.4 shows a scheme of the double-glazing facade installed on the reference module. Figure 4.5 gives a cross-section of the module, together with the two working desks placed perpendicular to the window plane (optimal position with regard to visual comfort). The same desk positions and type were used in the other module (test module).

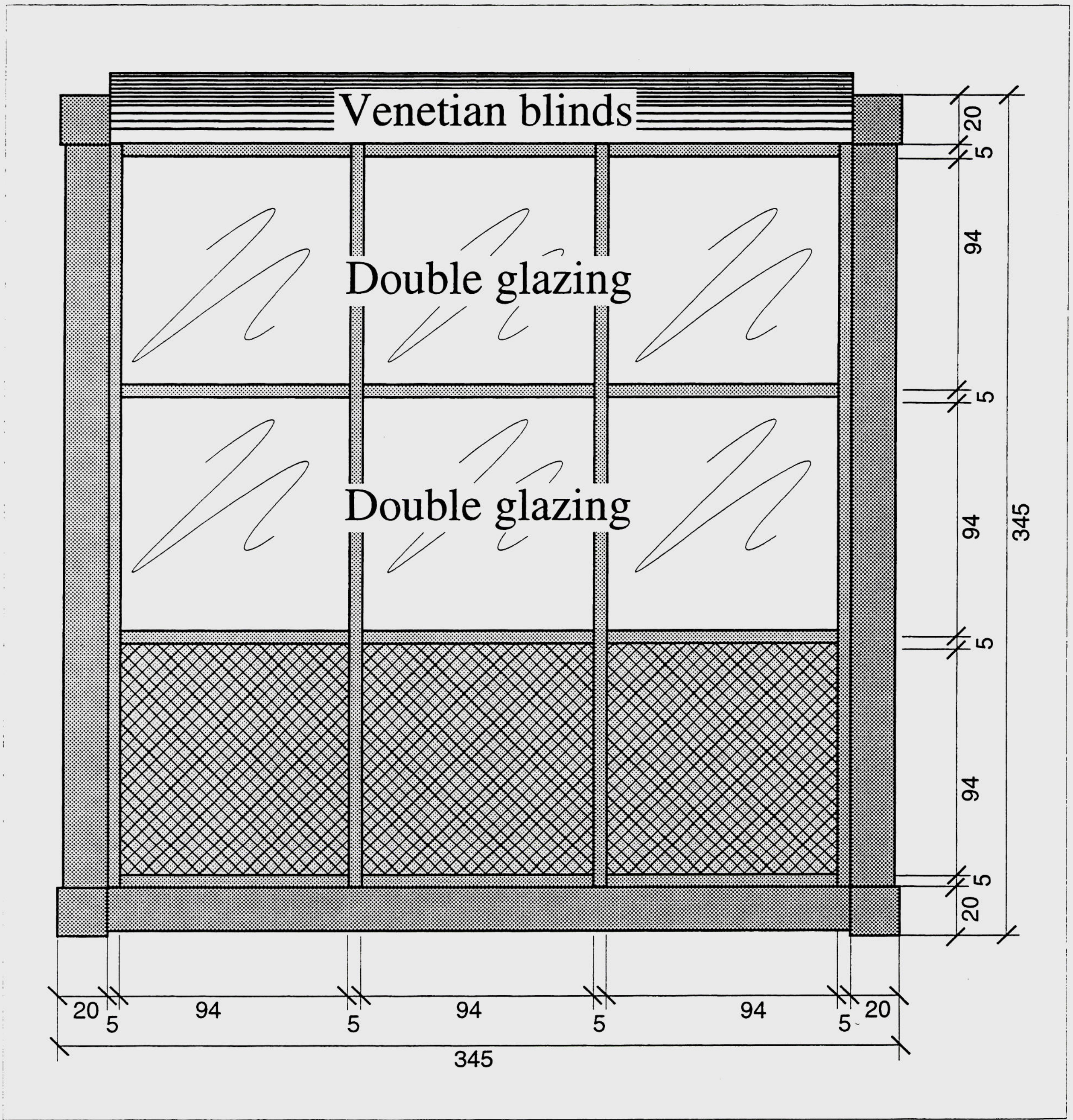


Figure 4.4: Front scheme of the reference facade (double glazing facade).

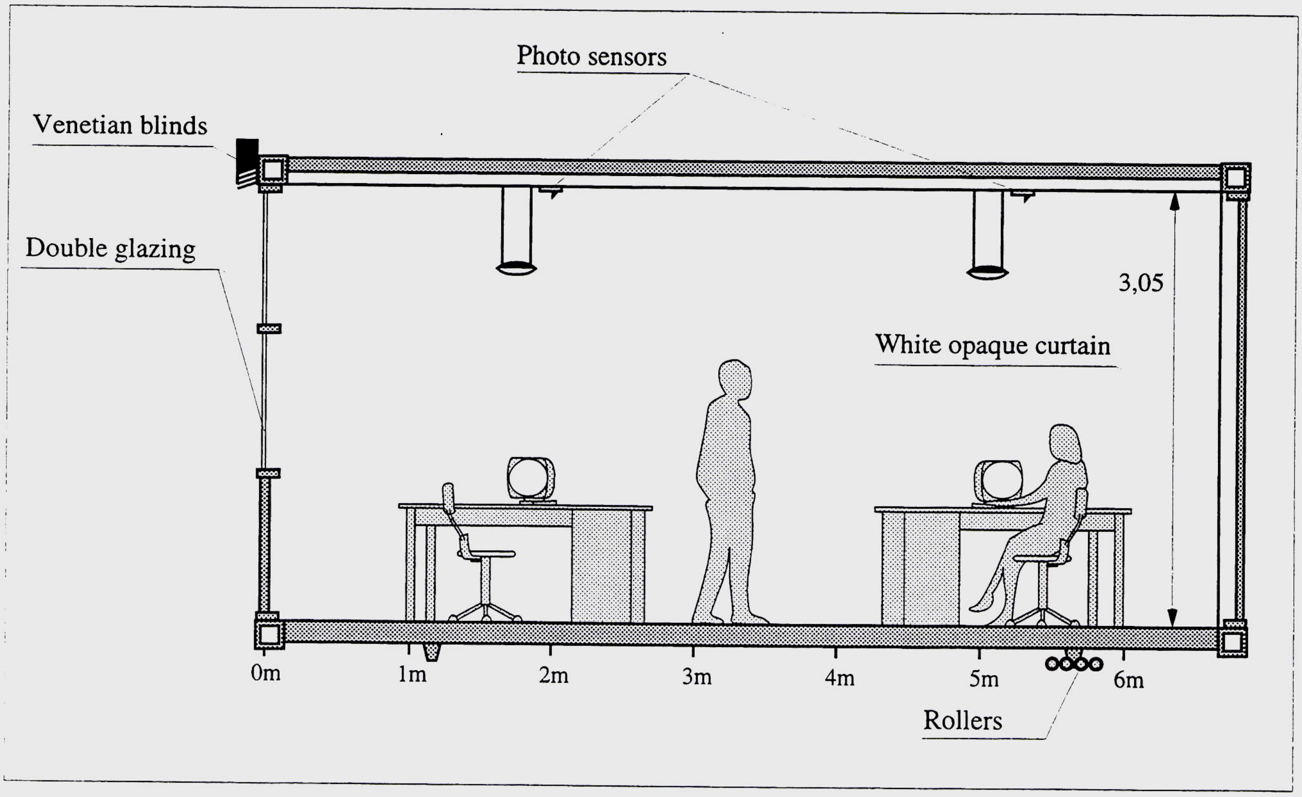


Figure 4.5: Cross-section of the reference module, including work desks.

Both modules are fitted up with the same electrical appliances: two rows of recessed luminaires (Zumtobel), located respectively at 1.7 m and 5 m from the front facade (cf. Figure 4.5). Each luminaire is equipped with two 36 W fluorescent tubes, driven by electronic ballast. A daylight responsive controller (Philips Trios) allows dimming of each of them through a photo sensor that is fixed to the ceiling behind the luminaires and oriented toward the back of the room.

The work plane illuminance was set at 300 Lux (± 15%) on each desk; it was checked regularly through nighttime measurements. The lights are automatically switched on at 8h00 and off at 18h30 (legal time).

4.2 Description of the monitoring equipment

Indoor illuminance measurements were done with two sets of seven sensors (BEA 93407 illuminance meters): they were fixed at regular distances on a horizontal girder placed at desk height (0.75 m). All sensors were calibrated before the monitoring campaign, leading to an accuracy estimation better than 3.5% on average. Figure 4.6 gives a view of the indoor illuminance sensors' configuration.

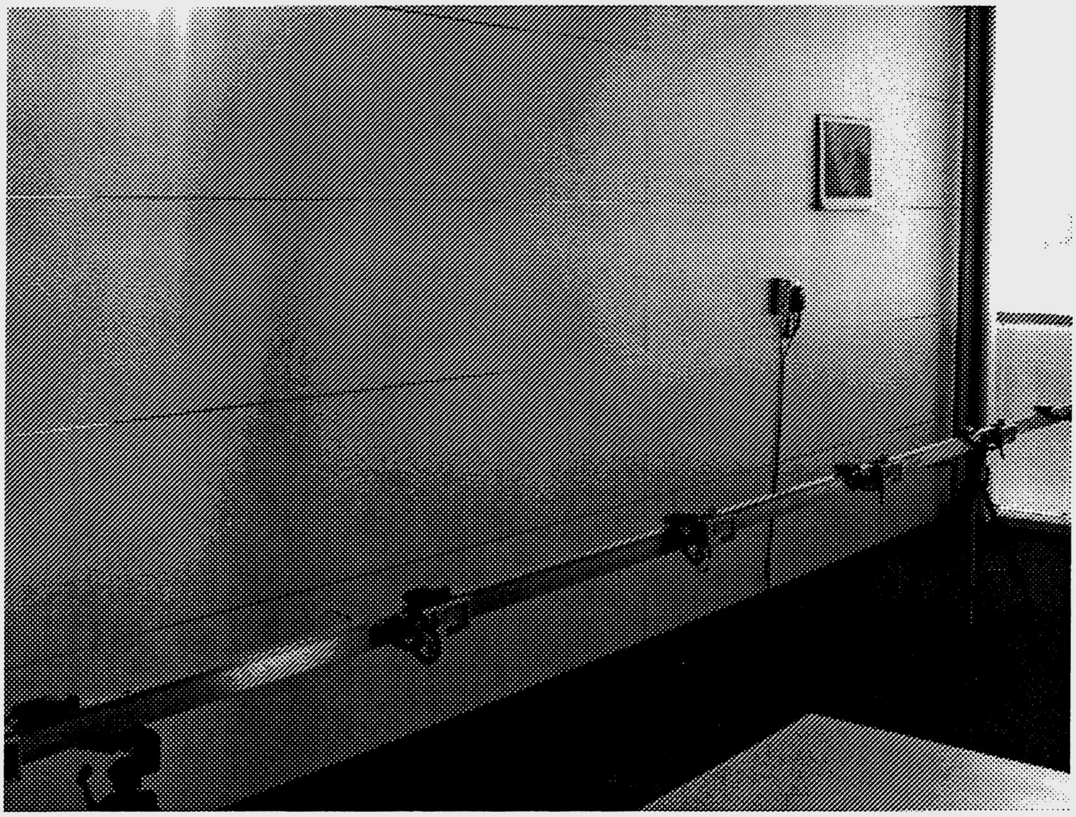


Figure 4.6: View of the indoor illuminance sensors

The two modules were monitored with a 32-channel monitoring device (Campbell Datalogger) which gave data on daylighting performance and lighting energy consumption under different weather conditions. These values were then processed by a computer. (See Figure 4.7).

Indoor and outdoor daylighting conditions were monitored with different illuminance sensors. A "sensor head", placed on the roof of a module, was used to assess the daylighting availability (see Figure 4.8).

The "sensor head" is made of 5 illuminance meters (LMT BAP30FLT and Hagner ELV-641) measuring the following physical data:

- the horizontal global illuminance
- the vertical global illuminances on the different planes of the facades.

All sensors are waterproof and fitted with a temperature drifting correction circuit: their accuracy is estimated better than 2.5% for the horizontal sensor (LMT) and 3% for the vertical ones (Hagner). They are fixed on a platform painted in black and made of honeycomb steel to avoid parasitic reflection from the roof.

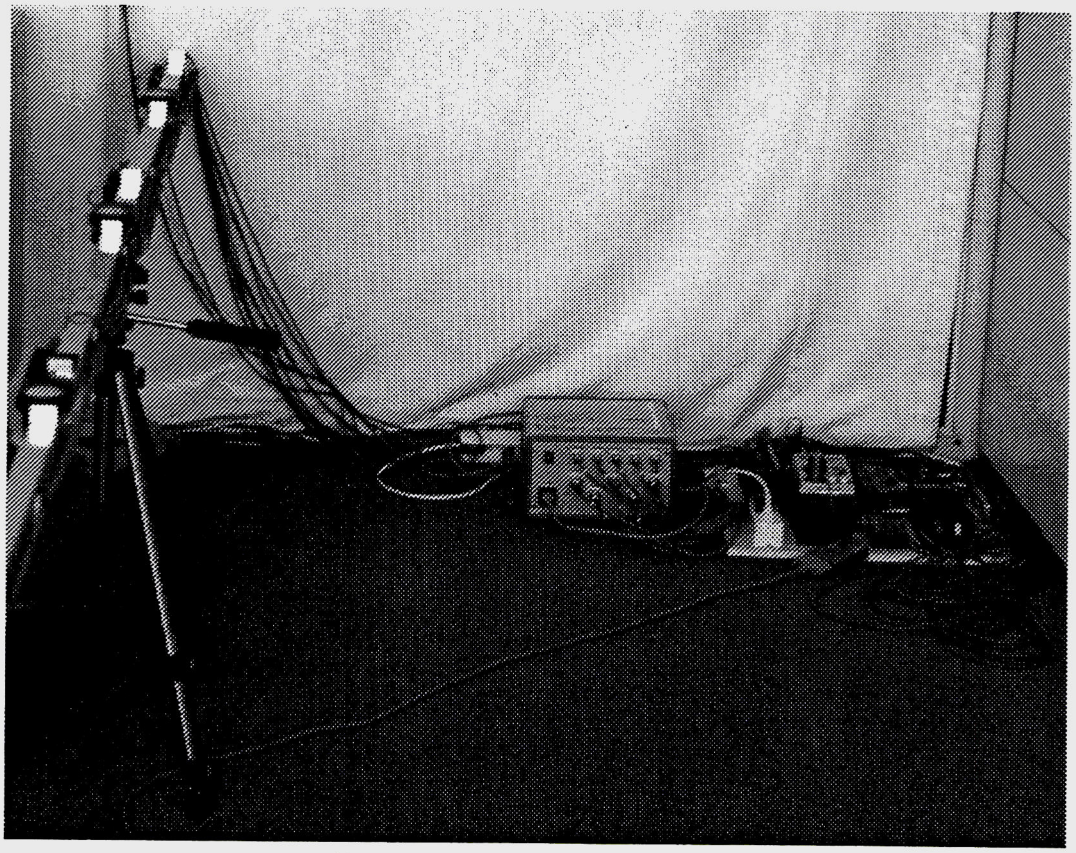


Figure 4.7: View of the data collecting device

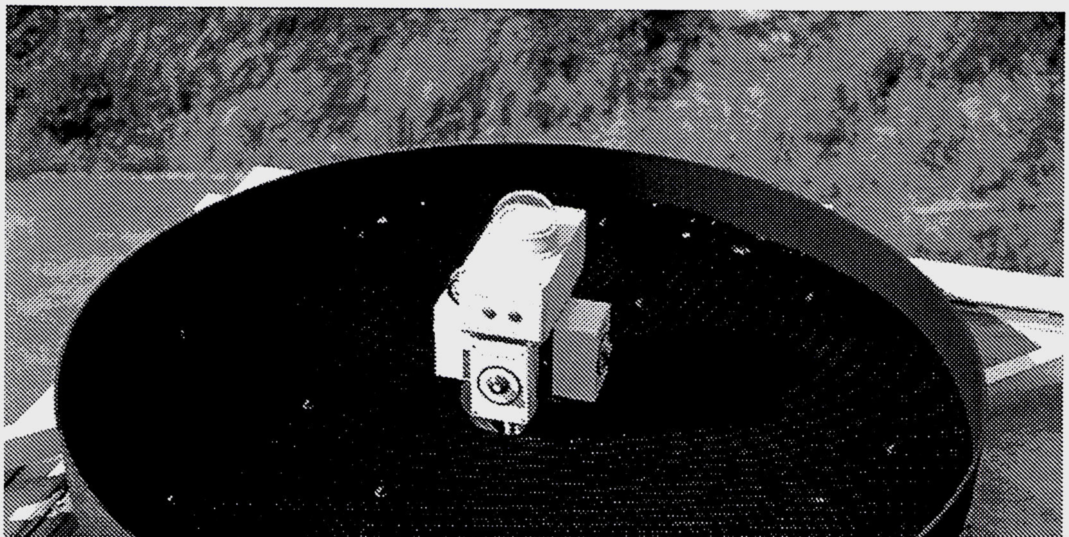


Figure 4.8: View of the outdoor illuminance "sensor head"

Lighting electricity consumption was measured in both modules with WSE LUM210 watt meters that give an impulse every 1 Wh (1.5% accuracy).

All monitored data were sampled and simultaneously collected every 10 minutes. Monitoring campaigns of several weeks at the time were undertaken around winter/summer solstices and spring/autumn equinoxes.

4.3 Performance assessment of an Anidolic Ceiling

Non-imaging optics has proven to be very valuable for the development of efficient optical systems, if one can afford image distortion [Wel 89]. This is typically the case for daylighting applications in buildings, where a maximal light flux is sought together with appropriate control of the angular spreading of light rays for optimal visual performances and comfort.

A first configuration of anidolic daylighting systems was successfully designed and evaluated at EPFL within previous daylighting demonstration projects [Com 93] ("anidolic" is synonymous to "non-imaging" in ancient Greek [Min 91]). Outstanding daylighting performance (daylight factors of 3% at 6 m from the window), together with reasonable visual comfort conditions, were achieved that way [Sca 96].

With the development of an anidolic ceiling even better performances were aimed, especially with regard to system integration and visual comfort parameters [Cou 96]. The new daylighting test modules offered the opportunity of assessing the performance of this novel system through a 1:1 scale experiment.

4.3.1 Principles of the Anidolic Ceiling

The daylighting system developed within this project uses a light duct integrated into a ceiling to guide a large flux of daylight into an office space (cf. Figure 4.9).

The design of such a duct had to meet the following requirements:

- the available daylight must be efficiently collected from the sky dome and guided into the light duct even during the worst overcast sky conditions (usually winter period);

- the light guide dimensions (bounding section) must be compatible with the available building space (impact on building cost and room space).

The theory of anidolic optics was expressly used to bypass these difficulties (cf. Figure 4.9):

- an anidolic daylight collector was designed and placed in front of the light guide to collect and concentrate the daylight at the entrance of the duct;

- another anidolic device was installed at the end of the duct to distribute the flux of daylight into the room so as to avoid visual discomfort.

Light concentration is essential to achieve adequate performances of the overall device, even if the diffuse nature of daylight in the case of overcast sky limits considerable the possibility of concentration (second principle of thermodynamics). Translated into the Lagrange Invariant Law of optics, which naturally applies also to anidolic optics [Wel 89], it only means that concentrated bundles of light rays show an increase in angular spreading. This appears typically at the entrance of the light duct, where daylight is concentrated by the first anidolic device (cf. Fig. 4.9); a reverse phenomenon occurs at the end of the guide where light is in practice "de-concentrated" by the second anidolic device.

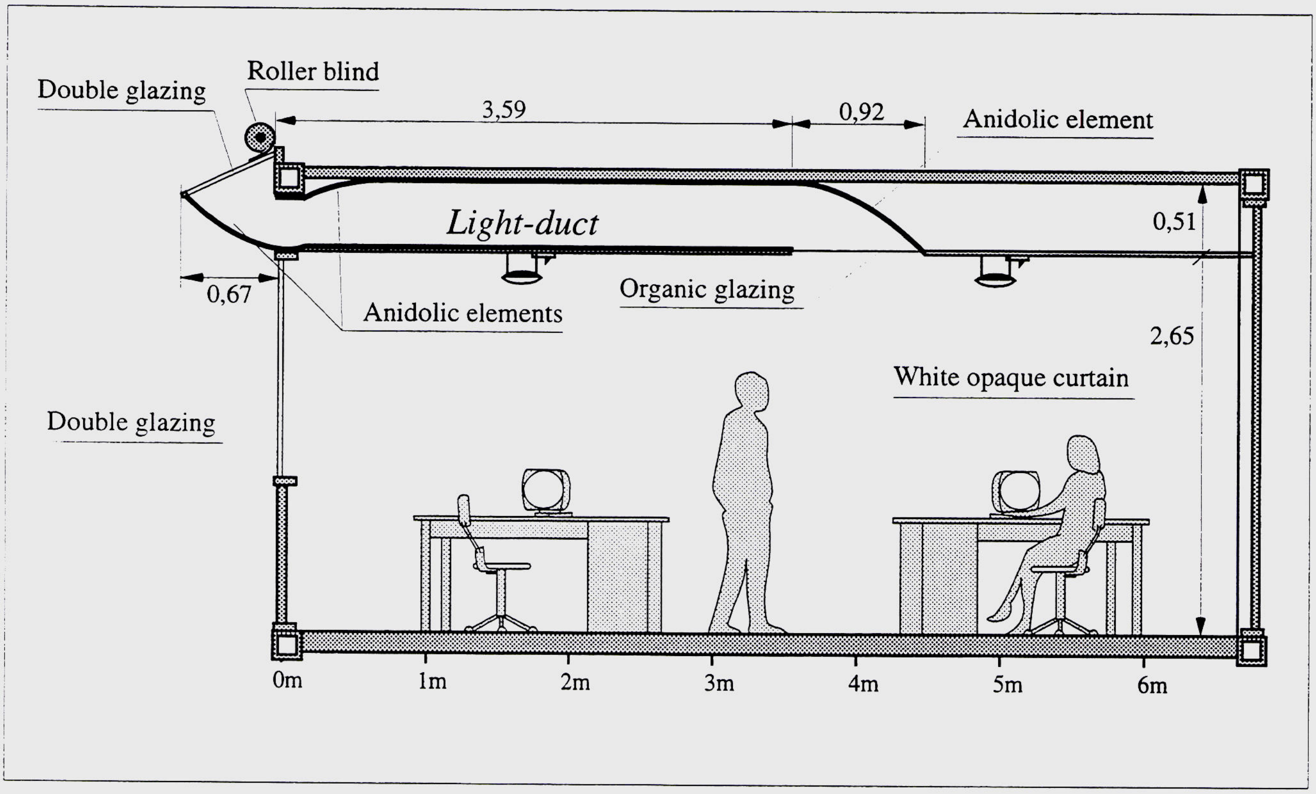


Figure 4.9: Cross-section of the test room, fitted with an anidolic ceiling

As in the case of previous anidolic systems [Com 93], the elements considered here are two-dimensional, non-symmetrical Compound Parabolic Concentrators (CPC), which make up the majority of anidolic systems [Wel 89]. Figure 4.10 shows the principle of these anidolic devices whose main features are listed below:

High angular selectivity

Anidolic systems show a light ray admission sector that is characterized by extremely sharp edges. All rays included in this admission sector are fully transmitted by the device; all others are fully rejected. Such a feature can be used to define from which part of the sky dome daylight will be collected with a maximal theoretical efficiency (from the horizon to the zenith for the anidolic device of Figure 4.11, for instance).

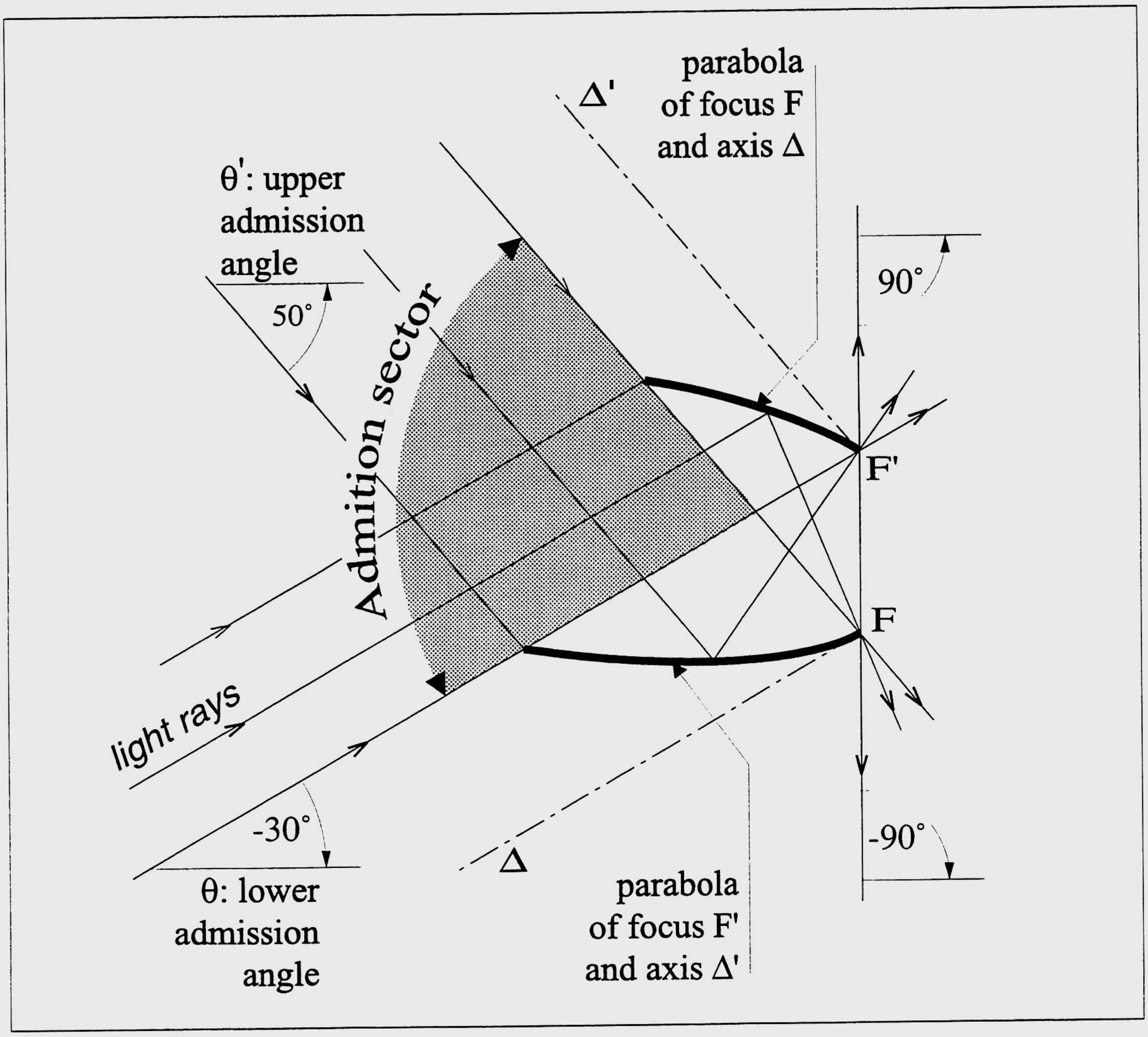


Figure 4.10: Principles of two-dimensional non-symmetrical anidolic system (Compound Parabolic Collector)

The same features hold for light rays propagating in a reverse way in the anidolic device (case of the second element of Figure 4.9), leading to an optimal control of the spreading of the light beam (emerging light rays contained in a well-defined angular sector).

<u>High optical efficiency</u>

Anidolic systems show a very high optical efficiency. Each admitted ray is at the most reflected once on its way through the duct. Absorption losses within the device are consequently reduced to a minimal theoretical value, which cannot be reached with any other optics within the two-dimensional analysis.

The first anidolic device was scaled in a way to allow the light duct to be mounted behind a false ceiling, the second was placed in the middle of the room to distribute daylight downward.

The external collector was originally designed so that its admission sector matches the part of the sky dome visible from the building facade (between horizontal line and zenith). On its highest bound, however, a girder placed under the slab edge (usual feature of building structures), makes a significant obstruction to the light rays. In order to avoid this shadowing effect, the anidolic device was improved using the method of "variable extreme direction" [Gor 92]: this means that the admittance angle of the admission sector varies along the entrance aperture from 90° (external edge) to 55° (internal edge). Figure 4.11 illustrates this.

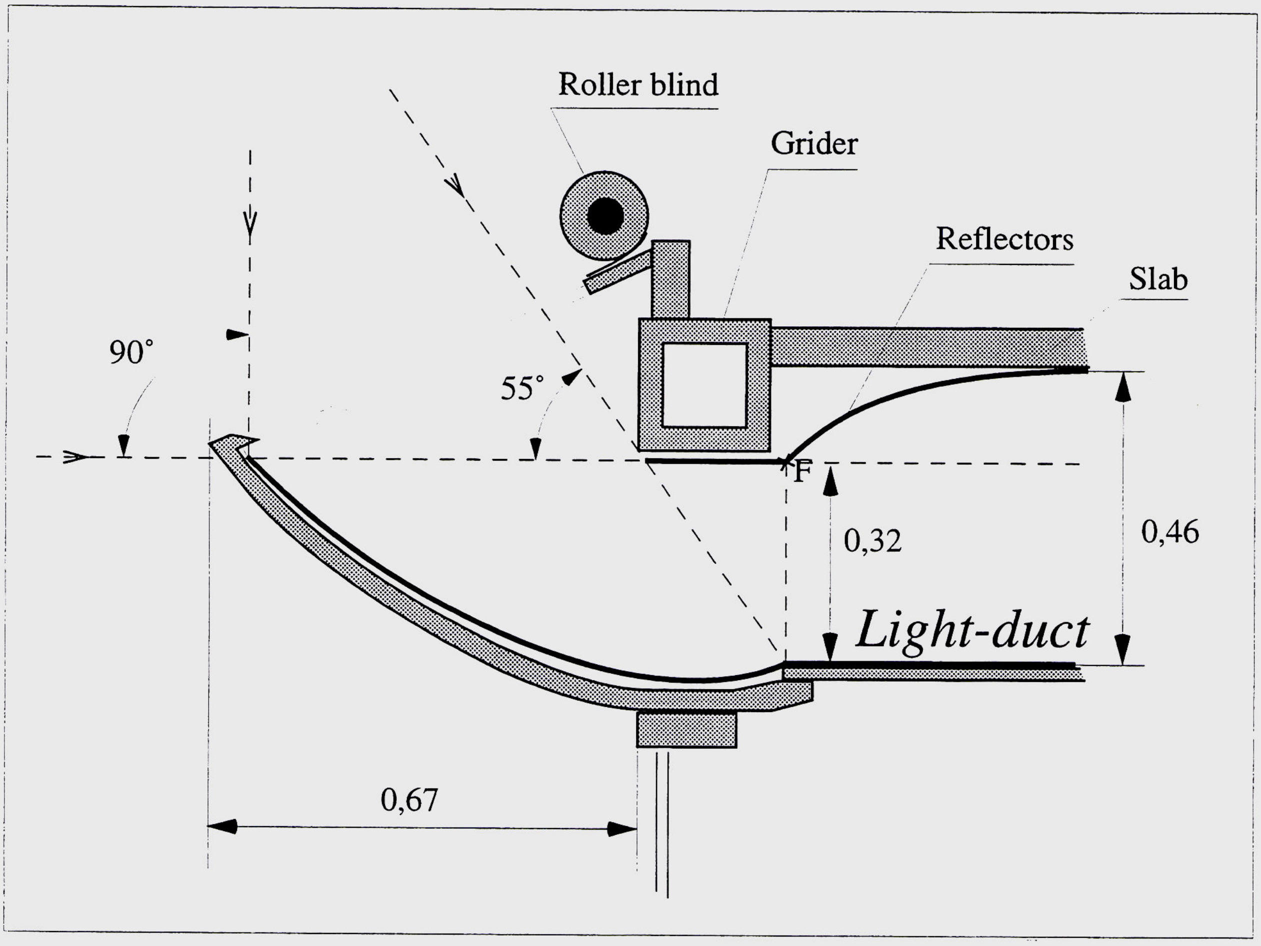


Figure 4.11: Cross-section of the anidolic daylight collector (two-dimensional non-symmetrical anidolic device).

Two significant advantages were reached:

- the width of the external part of the anidolic collecting device was reduced in comparison to the previous anidolic development (0.67 m instead of 1.08 m), improving the building integration of the system

- in the case of multistory buildings, the sky obstruction due to the similar element placed at the floor above does no longer influence in a negative way the performance of the collector (upper collector out of the admission sector of the internal edge) .

A flat element was placed at the upper part of the collecting device for the sake of simplicity. All other anidolic components were designed with a "constant admission" sector: the exit part of the light duct has a 90° angle admission sector, which means that no light ray can be reflected back into the duct.

All the surfaces of the anidolic ceiling were covered with highly reflective optical material generally used for luminaires, including the rectangular shaped light duct. This material is made of anodized aluminum foil (0.5mm thickness), characterized by a very high regular reflectance (ρ_r=0.9).

The use aluminum foil leads to a non-negligible amount of embodied energy (18 MJ/m2 in the case of recycled aluminum, 360 MJ/m2 in the case of primary aluminum [Koh 86]). Industrial production of this daylighting device will consequently probably have to rely on aluminum deposition, which requires far less production energy (thickness of a few micrometers).

The anidolic ceiling is covered with a insulated double glazing (regular transmittance: τ_r=0.81) at the entrance aperture for thermal reasons (see Figure 4.9). A single panel made of organic material (plastic element) was placed at the exit aperture for safety and maintenance purposes (regular transmittance: τ_r=0.9). The entrance pane has a tilt angle of 25°, contributing to its clearing through rainfall and showing a more favorable incidence angle for light rays coming form the upper sky dome (bright part of the sky).

All the external parts of the system are thermally insulated to avoid thermal bridges and water condensation (7 cm of insulation material).

4.3.2 Design simulations of the anidolic ceiling

Numerical simulations were used to validate the anidolic ceiling design and proceed to a first assessment of its daylighting performance.

The computer simulations were carried out with ADELINE/Radiance [War 94], based on backward adaptive stochastic ray tracing. Illuminance and daylight factor profiles were calculated on a Sun Sparc 20 work station for overcast conditions (CIE overcast model [CIE 70]).

Two test rooms, one equipped with an anidolic ceiling and the other fitted with a conventional double glazing facade (reference room) were compared. To make this comparison relevant regarding the volumetric aspects, the total vertical area through which the light propagates is the same in both cases.

Identical physical characteristics (equal to those of the daylighting monitoring modules; cf. paragraph 4.1) were assumed for both simulated rooms. Their glazing ratio is 0.26; external ground reflectance was assumed to be 0.20. Horizontal indoor illuminance values were calculated for seven different points inside the rooms, regularly spaced along a central longitudinal line placed at desk height (0.75 m above the floor).

Daylight factor profiles

Daylight factor profiles calculated in both rooms, are given in Figure 4.12, showing an obvious enhancement of the daylight factor values at the back of the test room due to the anidolic ceiling. The average daylight factor D_{rear} [%], calculated for the four deepest points in both rooms (3.7 m to 6.4 m from the window), is multiplied by a factor 2.0 in the anidolic test room compared to the reference room. It means that the anidolic ceiling, even if it takes only one fifth of the facade's glazing area, brings practically as much light as the overall glazed area to the back part of the room. Besides, a decrease in the daylight factor close to the window (from 18% to 14%) is obtained through the anidolic ceiling thanks to an overhang effect.

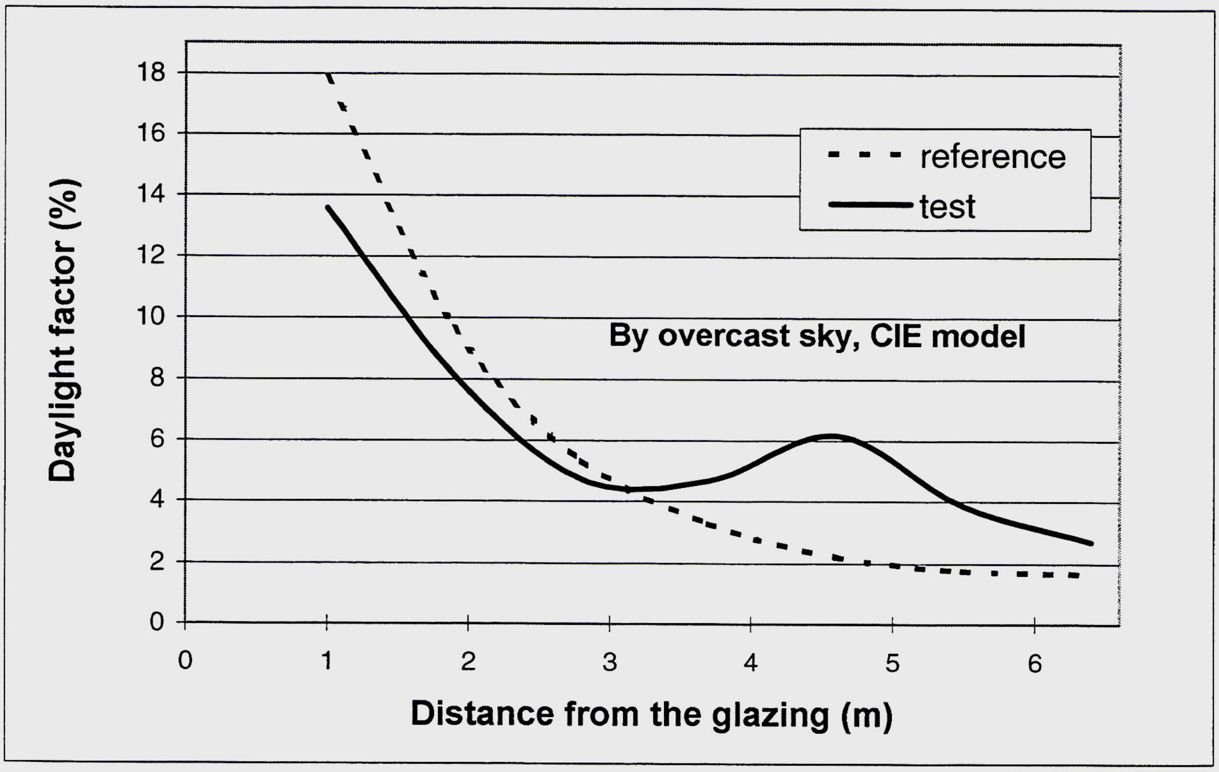


Figure 4.12: Comparison of simulated daylight factor profiles in the anidolic test and the reference room with double glazing.

Table 4.1 summarizes the principal daylighting performance data compared within the two simulated rooms, including different overcast sky models (isotropic sky, CIE model, urban conditions). An illuminance uniformity ratio based on the ratio of standard deviation and average illuminance is also given in this table.

Overcast Sky Model	Average Daylight Factor D_{rear}[%]			Uniformity ratio (standard deviation over average illuminance)	
	Test	Reference	Test/Ref.	Test	Reference
Isotropic	5.0	2.9	1.7	0.54	0.84
CIE	4.4	2.2	2.0	0.54	0.92
CIE with 40°obstruction / urban	3.4	1.2	2.8	0.53	1.11

Table 4.1: Comparison of daylighting performance data calculated by computer simulations in both rooms for different overcast sky models.

The comparison of the simulated data shows the following significant results:

- the average daylight factor at the back of the rooms D_{rear} is improved by a factor 1.7 assuming an isotropic overcast sky (5.0% instead of 2.9%);
- it is improved by a factor 2.0 when assuming a CIE overcast model (4.4% instead of 2.2%);
- the daylight factor improvement ratio reaches a factor 2.8 in urban surroundings (40° height obstruction above the horizon);
- the illuminance uniformity ratio is significantly improved by the anidolic ceiling (0.54 as compared to 0.92 in the reference room).

All these figures show that significant improvement of the daylighting conditions at the back of the office room can be expected from an anidolic ceiling.

System lighting efficiency

The daylight flux through the anidolic device and the light duct were calculated by integration of the sky luminance over the collector admission section. Figure 4.13 illustrates the values of the light flux at different cross planes of the light duct, obtained for a CIE overcast sky with up to 10000 Lux on the horizontal plan and no obstruction.

To take into account the obstruction constituted by the facade and the upper collectors or the flux available at the entrance aperture, the facade is assumed infinitely larger than the room cross-section (uniform boundary condition) and its reflectance is set to 0.2.

The optical efficiency of the different components of the anidolic ceiling was determined through calculation of the ratios of the emerging and incoming light fluxes at different sections. The following efficiency values were obtained:

- double glazing, at entrance aperture: 78%
- anidolic collector efficiency: 72%
- lighting duct efficiency: 68%
- simple glazing, at exit aperture: 84%

The total efficiency of the whole anidolic system, including glazing, is 32%.

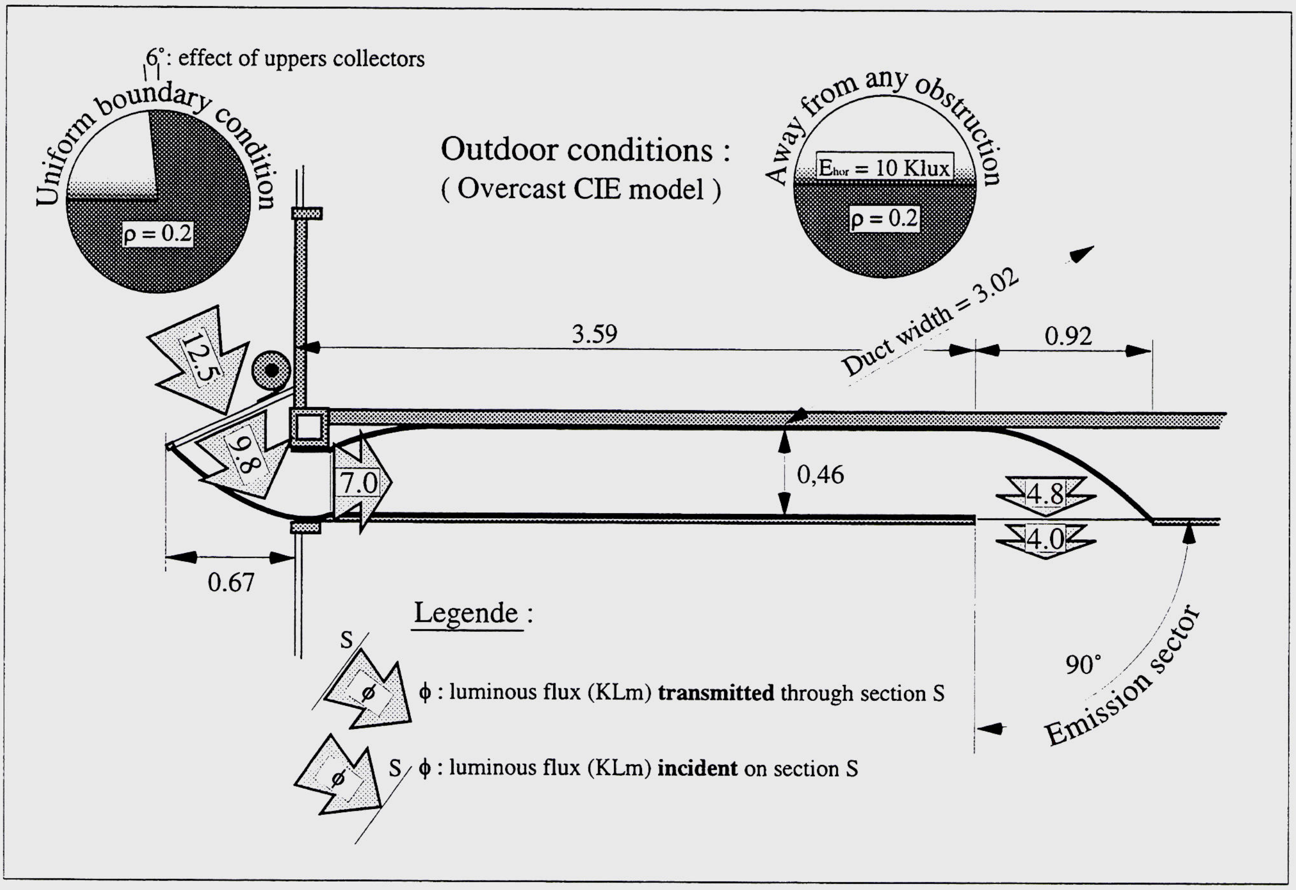


Figure 4.13: Daylighting flux at different cross-section planes of the anidolic ceiling

Impact of anidolic elements

To assess the impact of the anidolic optical systems, together with the reflectivity of the system's surfaces, the following computer simulations were carried out:

- all the anidolic curved parts of the system were replaced by flat surfaces (ρ_r was kept unchanged);

- the regular reflection coefficient of the system surfaces was reduced from 0.9 to 0.8 (the shape of the anidolic elements was kept unchanged).

Figure 4.14 shows the results of these comparisons: it appears that both modifications have a significant impact on daylighting performance.

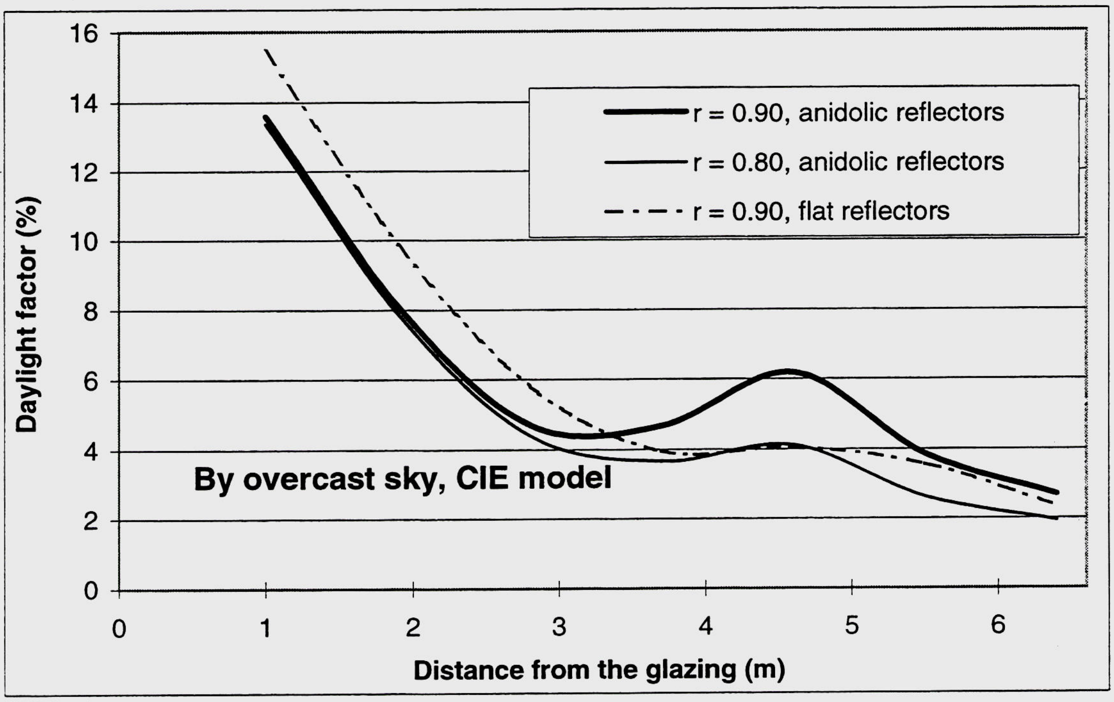


Figure 4.14: Impact of anidolic optic and surface reflectivity on the daylighting system performance.

The following conclusions can be drawn form this analysis:

- the use of conventional optical elements (flat surfaces) instead of anidolic components reduces the overall system efficiency by 60%;
- a lower reflectivity of the anidolic ceiling surfaces (0.8 instead of 0.9) reduces the same efficiency by 45%.

As a consequence of this analysis, particular attention was paid to carefully producing and mounting the different components of the anidolic ceiling.

4.3.3 Monitored daylighting performance

The daylighting performance of the anidolic ceiling was monitored for different weather conditions (overcast and clear skies). Several monitoring periods and module orientations were considered for that purpose, using the monitoring equipment described above (cf. paragraph 4.2).

<u>*Performance under overcast sky*</u>

Both modules were oriented due north to assess the daylighting performance of the anidolic ceiling under overcast sky (more stable and uniform luminance distribution). A first set of 43 data acquisition operations was carried out at variable time intervals during a period of 40 mn: visual observation was used to check the persistence of overcast sky conditions during the whole period.

In order to obtain sounder and more reproducible data of the daylighting conditions, a Sky Asymmetry Index (SAI) equal to the ratio of the standard deviation of the four external vertical illuminance values σ_E to their average $\overline{E}$ was proposed (instantaneous values). The following equation gives the mathematical definition of this index:

$$SAI = \frac{\sigma_E}{\overline{E}} = \frac{1}{2} \cdot \sqrt{\sum_{i=1}^{i=4} \left(\frac{E_i}{\overline{E}} - 1 \right)^2}$$

where

E_i is the external vertical illuminance,
i varies from 1 to 4, one item per plane of the 4 sides

This indicator shows a high sensitivity to the sky luminance distribution in the case of cloudy skies. Measurements over days of changing weather conditions led to considering a fully clouded sky vault for SAI values lower than 10%, as overcast skies show a higher symmetry.

Figure 4.15 shows the daylight factor profiles monitored in both rooms after averaging of the monitored data.

The comparison of the monitored and calculated profiles shows good agreement for the two rooms, assuming a CIE standard overcast model for the computer simulations. For the reference room (double glazing facade), the difference between the two different profiles is even lower than 1% for positions close to the window (about 1 m from the facade), although modeling of the window frame brings about some inaccuracy here.

For the test room (anidolic ceiling), the monitoring confirmed the performance assessment through simulations; the calculated profile fitted well within the error bars of the measurements for a majority of points. This is not the case with the values corresponding to the points that lie directly under the light duct aperture, which show significant discrepancies that reach up to 20% (4.9% monitored instead of 6.2% calculated). The average daylight factors of the rear part of the room (D_{rear}) correspond, however, reasonably well (4.0% monitored instead of 4.4%); a close multiplication factor of D_{rear} is observed due to the anidolic ceiling (value of 1.7).

There are explanations for the observed discrepancy between the two curves:

- inaccuracies during the construction of the modules' structure (estimated at ± 2 cm) penalized the positioning of the anidolic daylighting collector during its set-up (cf. Figure 4.9);

- irregularities of the system's reflective surfaces (thermal strains, gluing problems, etc.) decrease the efficiency of the anidolic ceiling compared to the theoretical values.

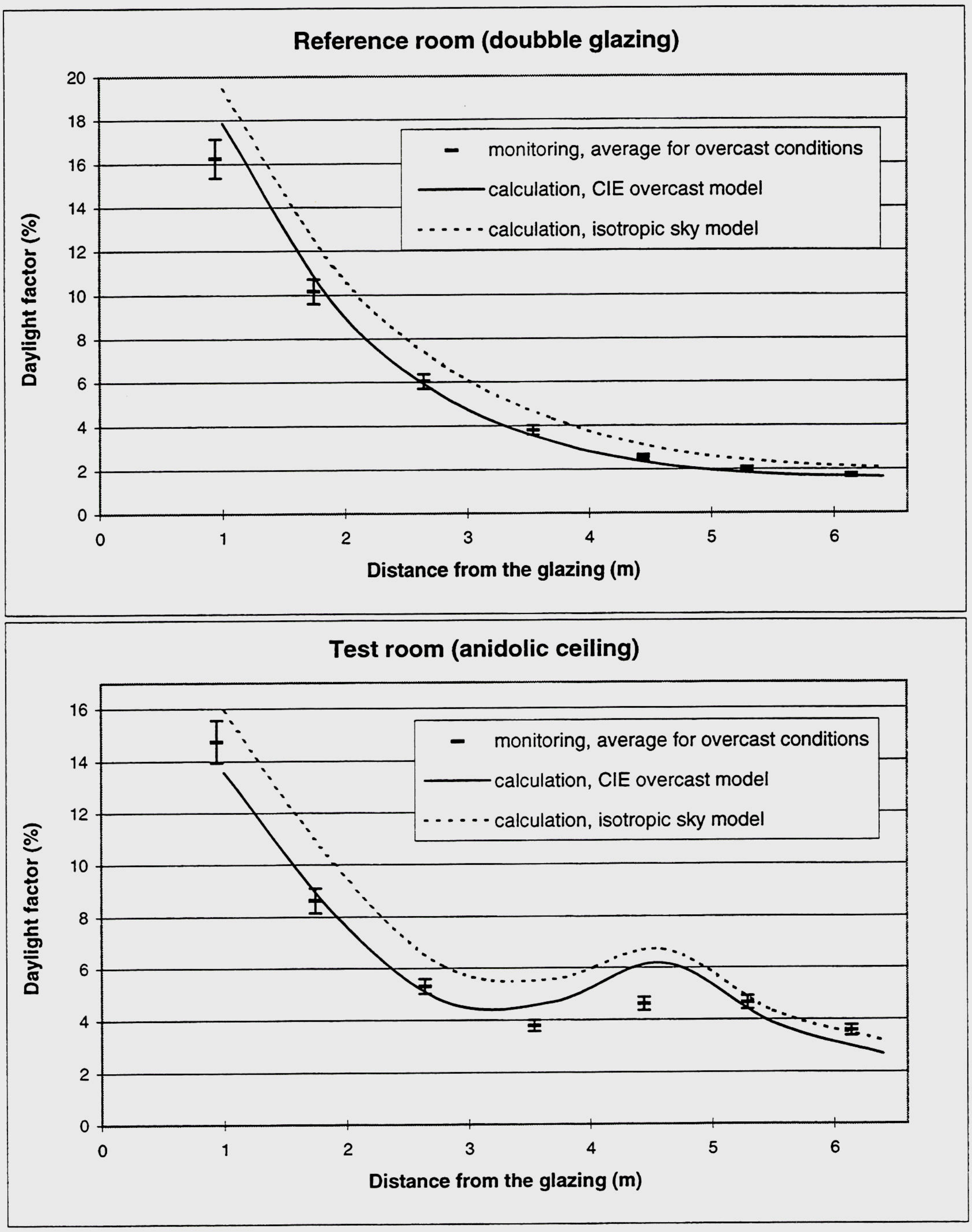


Figure 4.15: Comparison of monitored and calculated daylight factor profiles in the test room (anidolic ceiling) and in the reference room (double glazing facade).

The monitored data confirm, however, that the outstanding daylighting factors at the back of the room overpass any existing daylighting system.

Placing a hollow acrylic plate on the exit aperture of the light duct even further improved the daylight distribution in the room, making the perceived luminance on the walls smoother and blurring the vision of the reflectors. The daylight factor profiles are kept almost unchanged when this element is added (less than 0.6% variation): it was therefore left in this position during the rest of the experimentation.

Performance under clear sky

The daylighting modules were oriented in different direction for the assessment in sunny conditions:

- to the south, to investigate the effect of sunlight penetration through the facade (cf. Figure 4.16)

- to the north, to investigate the opposite case (absence of solar penetration).

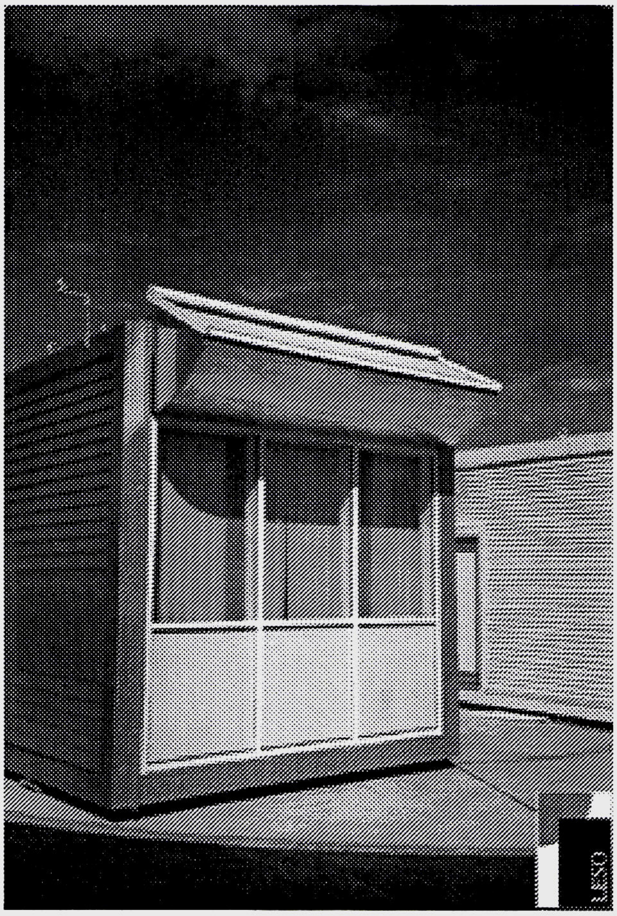


Figure 4.16: Front view of the test room with the anidolic ceiling for sunny conditions (sunshine on the facade)

Figures 4.17 (a) through 4.17 (d) show comparisons of daylight illuminance profiles in both monitoring modules under clear skies in absence of any solar protection on the anidolic collector.

Very high illuminance values are obtained under the system exit aperture for certain conditions (15 to 30 kLux) when there is sunshine on the facade; for some situations, the illuminance observed for the anidolic ceiling are closer to the reference values.

The different behaviors are directly linked to the sun position relative to the main facade (solar altitude and relative azimuth). It can be seen that:

- a multiplication of the daylight factor, reaching the value of 12, is observed at 5.3 m from the window for a high solar position (65°) and a normal sun position on the facade (cf. Fig. 4.17a);
- the illumination at the bottom of the room is generally uneven (cf. Fig. 4.17 a, c and d);
- for extremely low incidence angles of sunlight on the facade (cf. Figure 4.17d), both profiles are similar.

The very high measured illuminance values confirm the necessity of equipping the anidolic collector with external solar protection.

Two different solar protection systems were installed on the test room facade:

- a curtain of vertical mobile slats in off-white fabric was hung up in front of the window;
- an automatically controlled fabric blind was installed in front of the anidolic collector glazing.

Closing of these solar protection blinds led to more reasonable values in the test room: typically 1 kLux in summer (cf. Fig. 4.18a) and 3 kLux in winter (cf. Fig. 4.18b) for skewed sunshine (45° azimuth angle on the facade).

These illuminance levels remain relatively high for computer office desks; they can be reduced further by pulling down external venetian blinds that anyhow provide more appropriate protection from a thermal comfort point of view.

In absence of any sunshine on the facade (modules oriented to the north), measurements show that the penetration of daylight is similar in both rooms (cf. Figure 4.19); in particular, the level of illuminance reached at the rear of both rooms is equal. This indicates that the light flux due to the anidolic ceiling offsets the shading effect of its overhang.

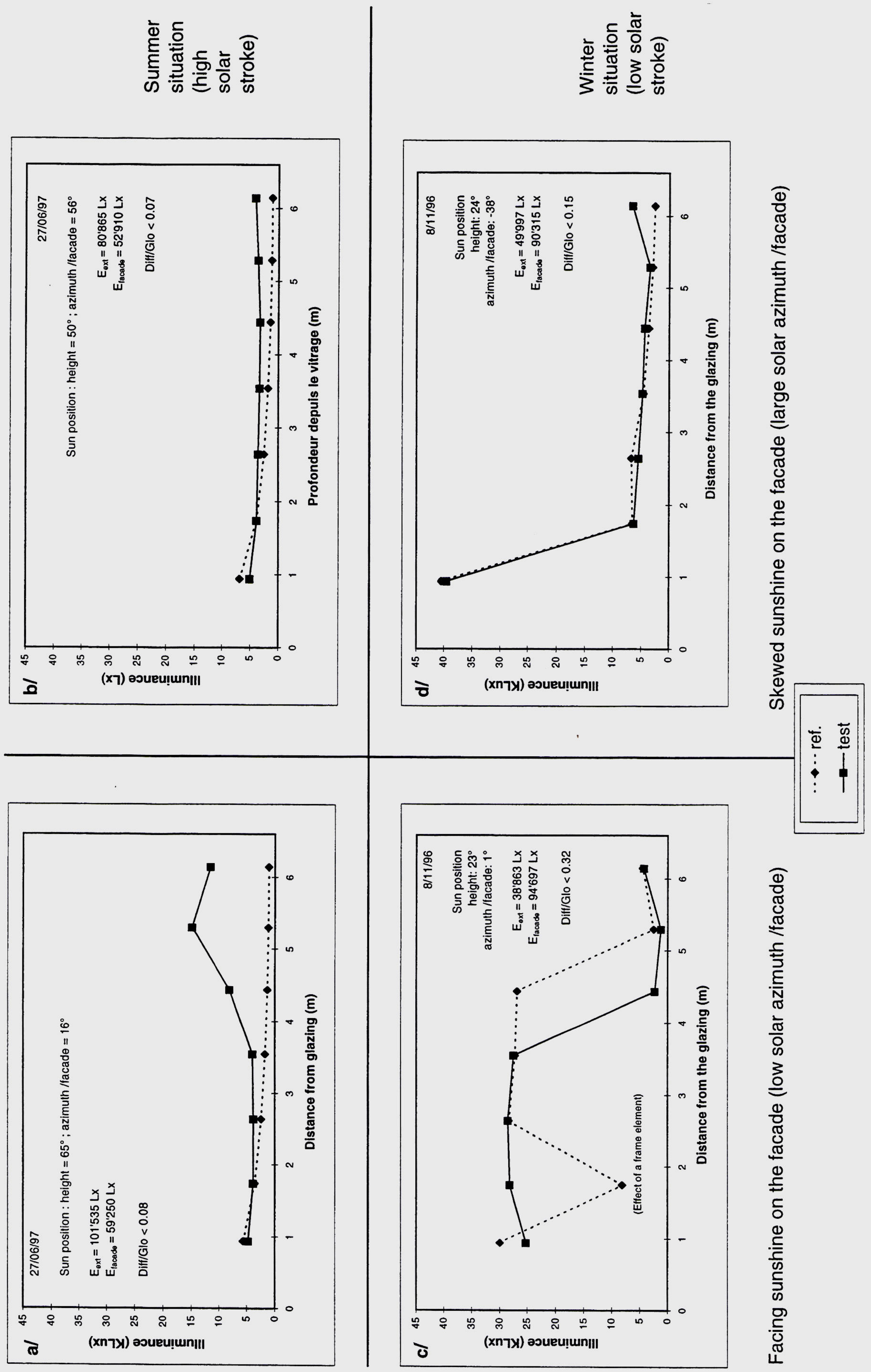
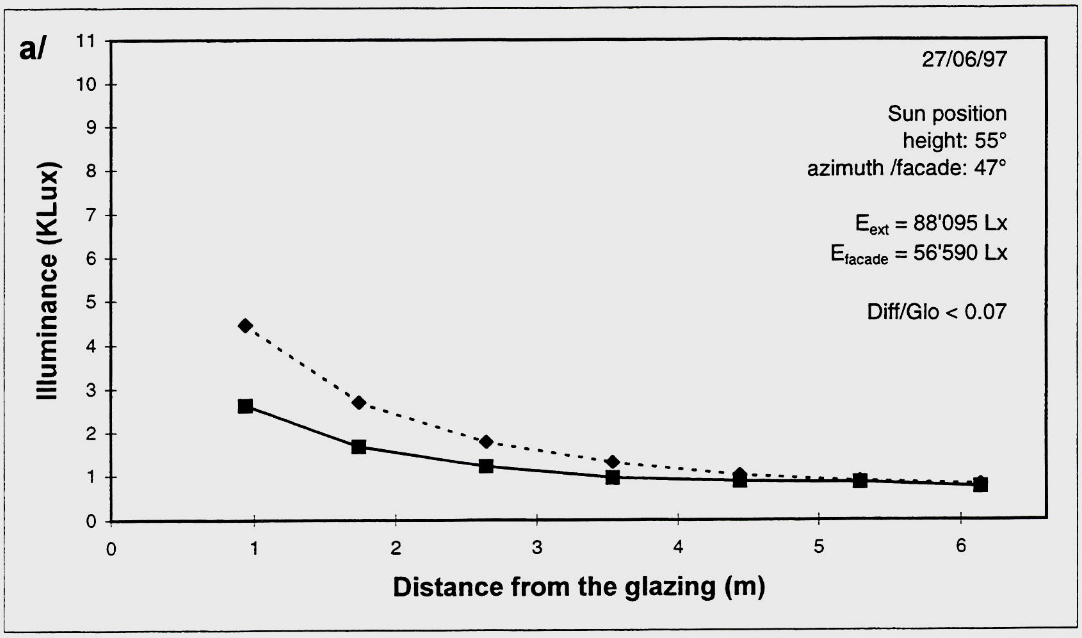
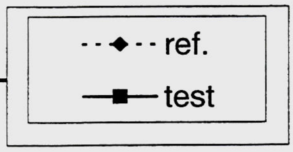
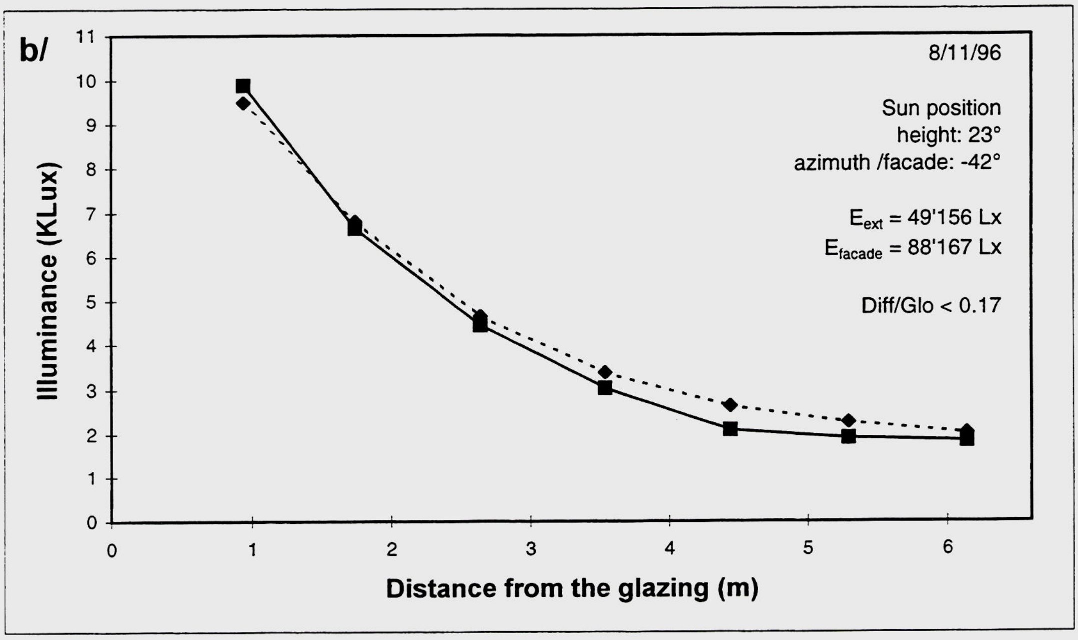


Figure 4.17: Monitored daylighting illuminance profiles in both rooms in absence of any solar protection on the collector.



Summer situation (high solar stroke)





Winter situation (low solar stroke)

Figure 4.18: Monitored daylighting illuminance profiles in both rooms in the presence of solar protections (fabric blinds rolled down).

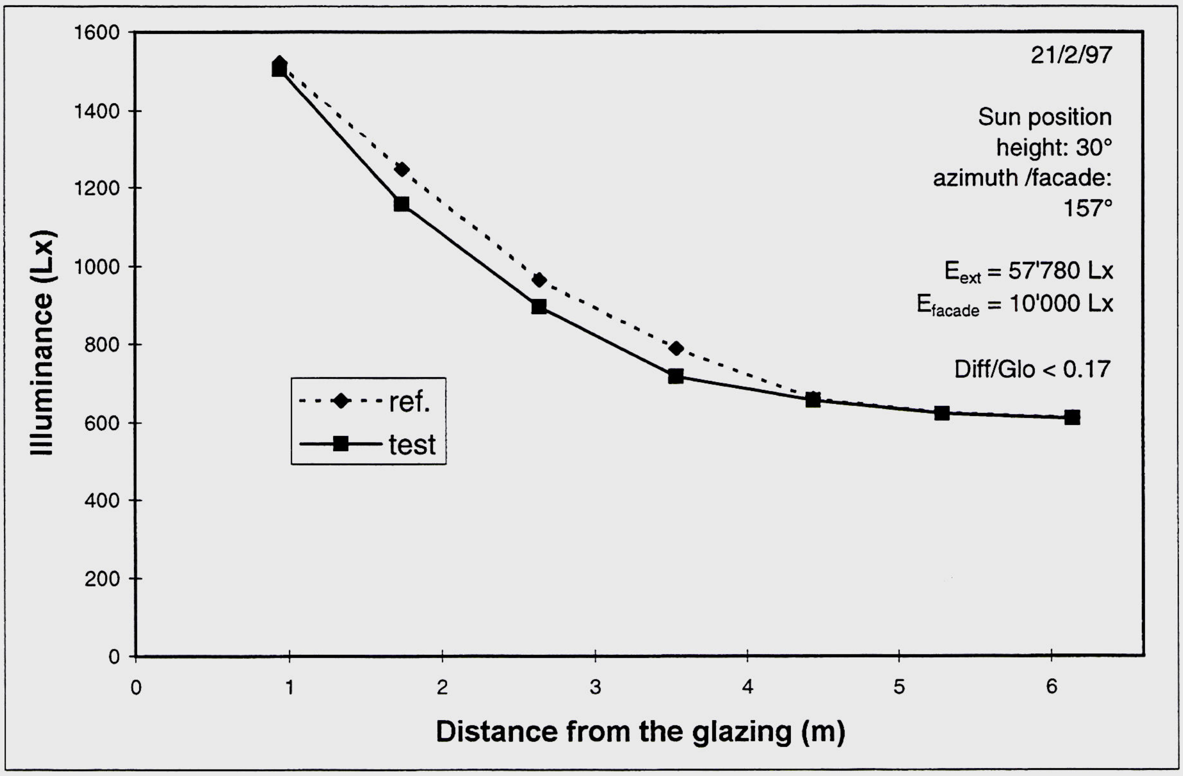


Figure 4.19: Monitored daylight illuminance profiles in both rooms in sunny conditions and in absence of any sunshine on the facade (northern orientation).

The data monitored during sunny conditions confirm the efficiency of the anidolic ceiling in redirecting daylight to the back part of an office room. The integration of solar protection on the external anidolic collector is, however, a "must" considering the high light flux emerging from the system when the facade is in full sunshine.

4.3.4 Monitored energy performance

Although energy savings from room heating can obviously be expected from an anidolic ceiling thanks to the additional solar gains obtained from the daylighting system in winter, energy monitoring was deliberately limited to the assessment of energy savings from lighting.

A detailed description of the electric lighting system installed in both daylighting modules has been given above (see paragraph 4.2); this is also the case for the monitoring equipment, which was kept unchanged during the monitoring experiments. Before experimentation, the desk illuminance (300 Lux ± 15%) was carefully balanced in both rooms for the electric light dimming control.

Energy performance for northern orientation

The energy performance with regard to lighting (savings due to the anidolic ceiling) in practice strongly depends on user behavior. Visual comfort imperatives usually drive the users' utilization of louvers and blinds. An assessment of the system in the presence of users was, however, out of the scope of this particular project: the monitoring of energy performance was therefore carried out in the 'optimal conditions' corresponding to empty office rooms (no user impact).

The two daylighting modules were oriented due north for this experiment in order to avoid any interference from blind management on the results. It is assumed that a northern orientation offers stable and adequate visual comfort conditions even with no use of blinds.

24 half-days of measurements spread over 14 weeks from February through June were considered in order to benefit from a monitoring period representative of a semester of utilization. Considering energy consumption over half-day time intervals allows taking advantage of the daylight periodicity. Illuminance and energy related data were simultaneously monitored during these periods with a 10 mn time step. Figure 4.20 shows the lighting energy consumption monitored in both rooms over these 24 half-days.

A comparison of the overall lighting electricity consumption of the two modules monitored over the whole period, shows 31% savings in favor of the anidolic ceiling. The following absolute figures were measured during this period:

Lighting consumption of test room:	1.949 kWh
Lighting consumption of reference room:	2.828 kWh

These monitoring results stand in good agreement with the savings figures calculated according to the Swiss recommendation for daylighting [ASE 89]: yearly lighting savings of 30% are predicted by this method which allows the statistical calculation of the daylighting autonomy of an office room for a given nominal desk illuminance (300 Lux in this case) on the basis of the daylighting factor.

Electricity savings of a third of the consumption for lighting can reasonably be expected from an anidolic ceiling in a conventional office room (20 m^2 floor area). When compared to a normal double-glazing facade, these savings are achieved at the back of the room (5 m from the window), where the second desk is placed.

It must be emphasized, however, that this savings figure assumes fully automatic control of the electric lighting (perfect daylight responsive dimming), independent on user behavior. The utilization of solar blinds as well as lighting control through users can lead to totally different figures, depending on user consciousness regarding energy savings.

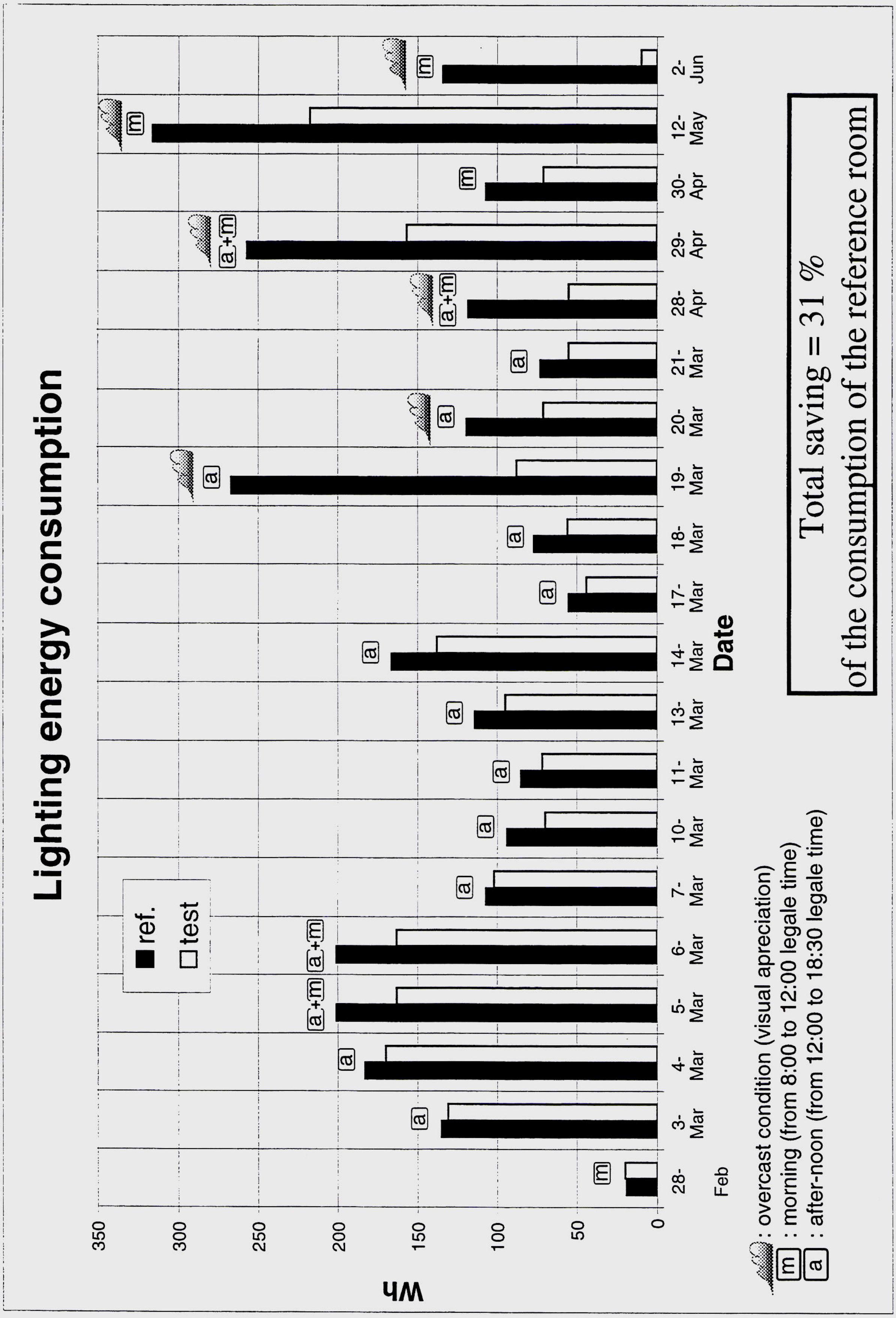


Figure 4.20: Lighting energy consumption monitored in the two rooms for the period of February to June.

Impact of daylighting conditions

As the savings due to the anidolic ceiling depend on the sky luminance distribution, a detailed analysis of the influence of the external daylighting conditions (sky cloudiness, outdoor illuminance, etc) over lighting savings was carried out.

Half-day saving fractions (SF_{hd}) and half-day sky asymmetry indexes (SAI_{hd}) were determined and plotted together in order to retrieve a possible relation between them. Figure 4.21 illustrates the correlation between the two parameters obtained through monitoring. The hyperbolic correlation function given by the equation

$$SF_{hd} = \frac{1.1}{SAI_{hd}} \qquad [\%]$$

shows that electricity savings for lighting are inversely proportional to the sky asymmetry index in the case of a northern orientation.

This relation shows that savings are much larger under overcast conditions (symmetrical sky) than when the sky is clear. This can be explained by the fact that on clear days, the lights are off during almost the whole daylight period in both rooms, whereas, on overcast days, the difference in daylight factors in the rooms brings about large differences in power and duration of the electricity supply for the rear desk.

Figure 4.22 shows, moreover, how the quantity of electricity savings depends on the relative value of the desk daylight illuminance ($E_{ext} \cdot D_{rear}$) to the required desk illuminance E_o. When the sky is overcast, three different situations can be distinguished regarding savings:

- a first case where the desk daylight illuminance in both rooms is lower than the required illuminance ($E_{ext} \cdot D_{rear\ test} < E_o$), leading to low savings (beginning and end of daytime);

- a second case where only the desk daylight illuminance in the test room is higher than the required illuminance ($E_{ext} \cdot D_{rear\ test} > E_o > E_{ext} \cdot D_{rear\ ref}$), which leads to high savings (intermediate periods);

- a third case where both desk daylight illuminance values are higher than the required level ($E_{ext} \cdot D_{rear\ ref} > E_o$), which leads to the switching off of the lighting in both cases (no savings, summer days).

It must be emphasized that, for a southern office orientation, the relation between savings and sky brightness (E_{ext}) would be more dependent on the time delay of the daylight control system (15 mn in the present situation). The absolute sky luminance values being higher in the southern direction, it is probable that higher savings would be achieved in a deeper room.

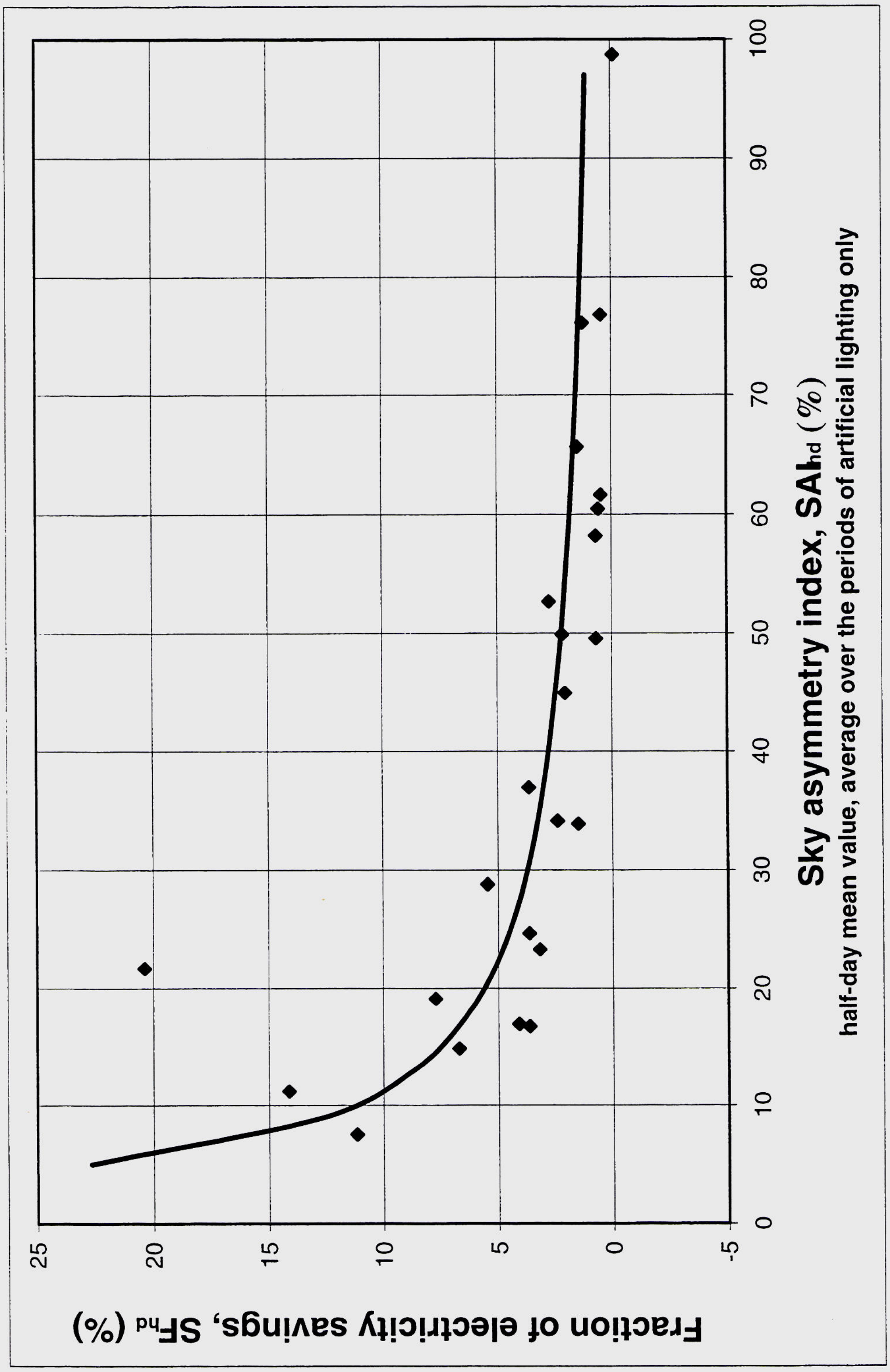


Figure 4.21: Empirical correlation observed between the electricity savings fraction (SF_{hd}) and sky asymmetry index (SAI_{hd}) averaged over half-day periods.

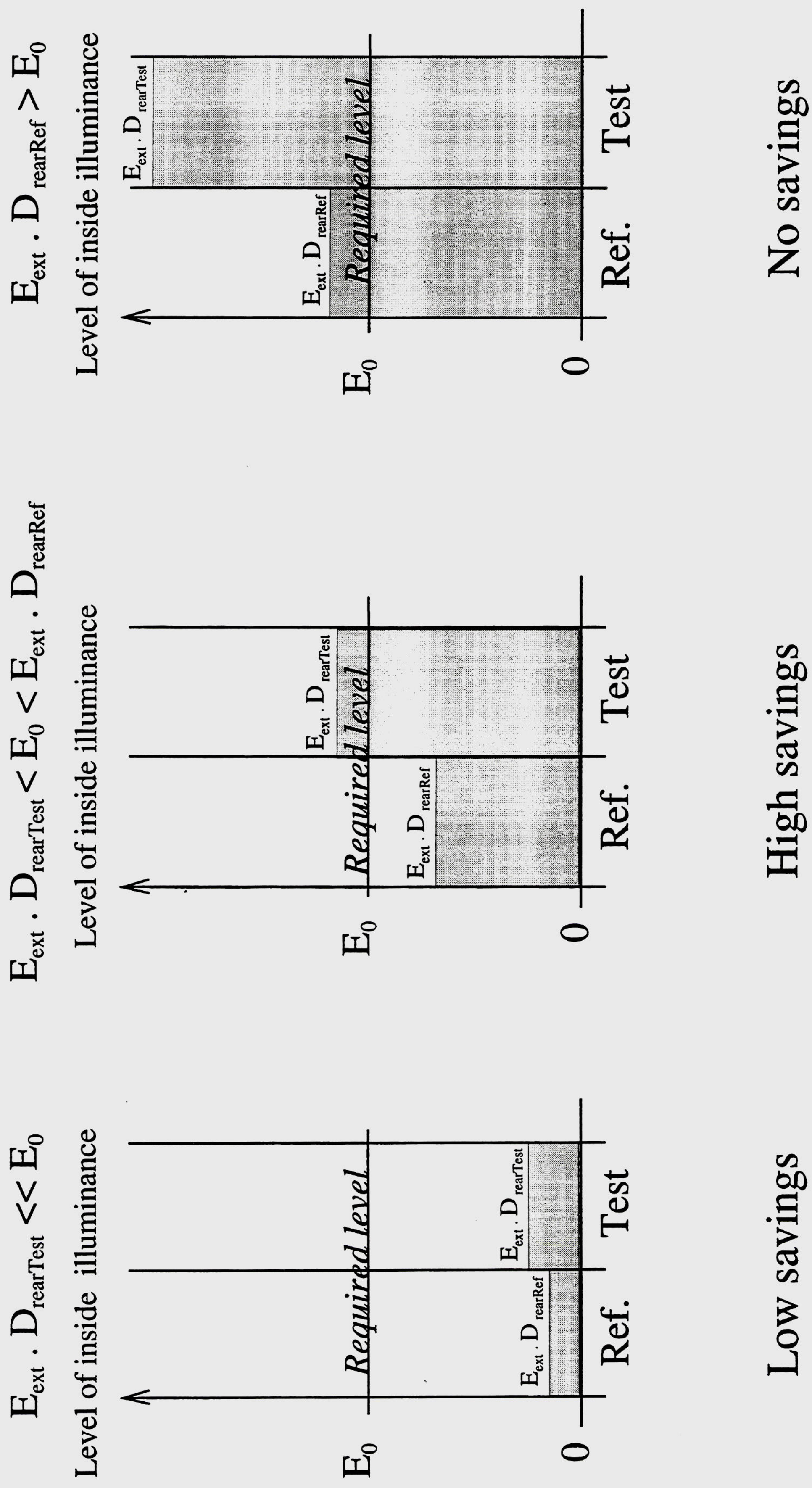


Figure 4.22: Schematic behavior of lighting savings as a function of the external daylight illuminance E_{ext}.

4.3.5 *Monitored luminous work environment*

An evaluation of the quality of the luminous work environment in both modules with regard to daylighting was carried out within this project. The following procedure was used to assess the visual comfort and performance for that purpose:

- visual comfort conditions at the work desk were determined through luminance scanning,
- human response tests to lighting conditions were carried out on a group of subjects.

Both modules were oriented due south for that analysis; this orientation was chosen in order to take into account possible glare risks due to the direct sun penetration into the modules. Furniture, desks and video display terminals (VDT) were identically set in both rooms in order to allow an objective comparison of the luminous work environment in the two modules.

Two desks were placed in each module at different distances from the window, corresponding to typical desk positions in office spaces (cf. Figure 4.5 and Figure 4.9). Their orientation was chosen following recommendations in ergonomics so that the main vision axis of the desk users is parallel to the window.

The analysis of the luminous work environment was on purpose limited to the second work place (cf. Figure 4.23), located behind the exit aperture of the anidolic ceiling (1 m after the aperture).

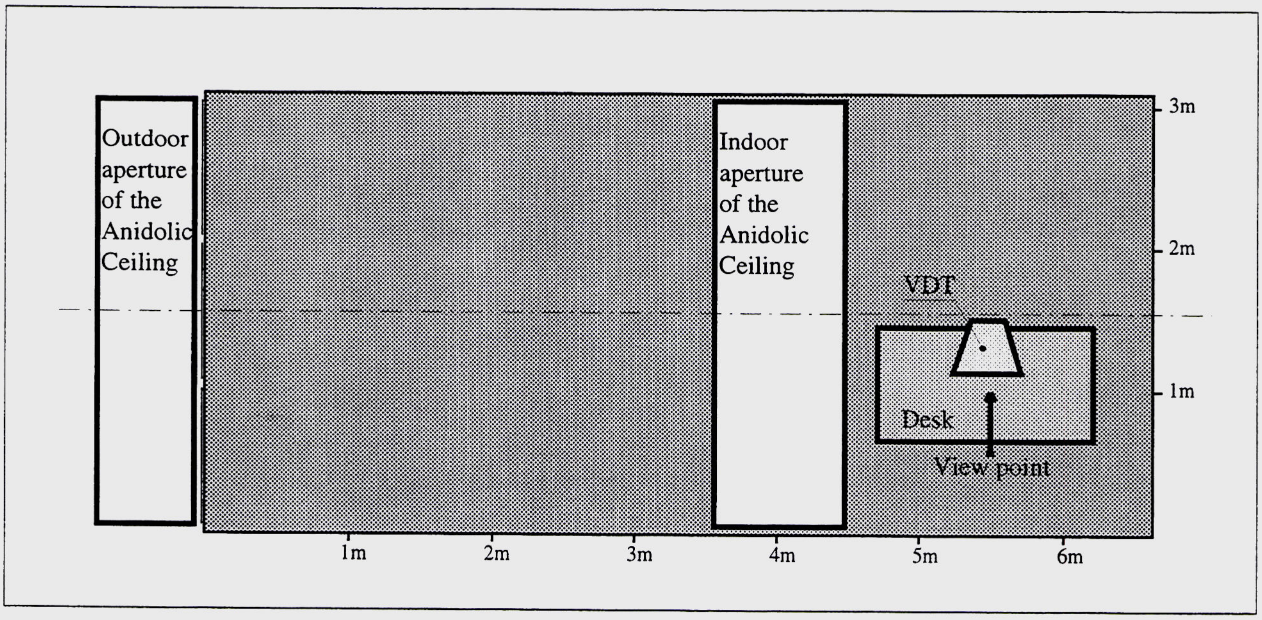


Figure 4.23: Position of the work place analyzed regarding luminous work environment

Visual comfort parameters

A first assessment of the visual comfort parameters was carried out through measurement of the luminance of different points located in the view field of a user seated at the rear desk. The sky was clear and there was full sunshine on the facade. Figure 4.24 shows the luminance values measured for different significant points of the user's view field in the test room (anidolic ceiling) and in the reference room (double glazing facade). Figure 4.25 shows similar data measured for clear sky conditions in the test room in absence and in presence of solar blinds in front of the anidolic collector.

The analysis of the first experimental assessment of visual comfort at the work desk in sunny conditions (cf. Figure 4.24) shows that:

- apart from the effect of sunshine on internal fabric slats (L > 10'000 [Cd/m^2]) on the right of the figure, appropriate luminance ratios were measured in both rooms (ratio lower than 10)

- the anidolic ceiling contributes to smoothening the luminance distribution on the walls and on the ceiling, improving slightly the perceived luminous environment at the desk (lower luminance gradient).

The analysis of the data observed for the anidolic ceiling in presence and absence of solar blinds (cf. Figure 4.25) shows that:

- excessive luminance values at the exit aperture of the anidolic system (L ≈ 3500 [Cd/m^2]) can be perceived at the rear desk in absence of any solar protection during sunny days (leading to discomfort glare)

- very satisfying luminance ratios (except those related to the conventional window) are experienced in case of the use of solar blinds (even for extremely sunny days).

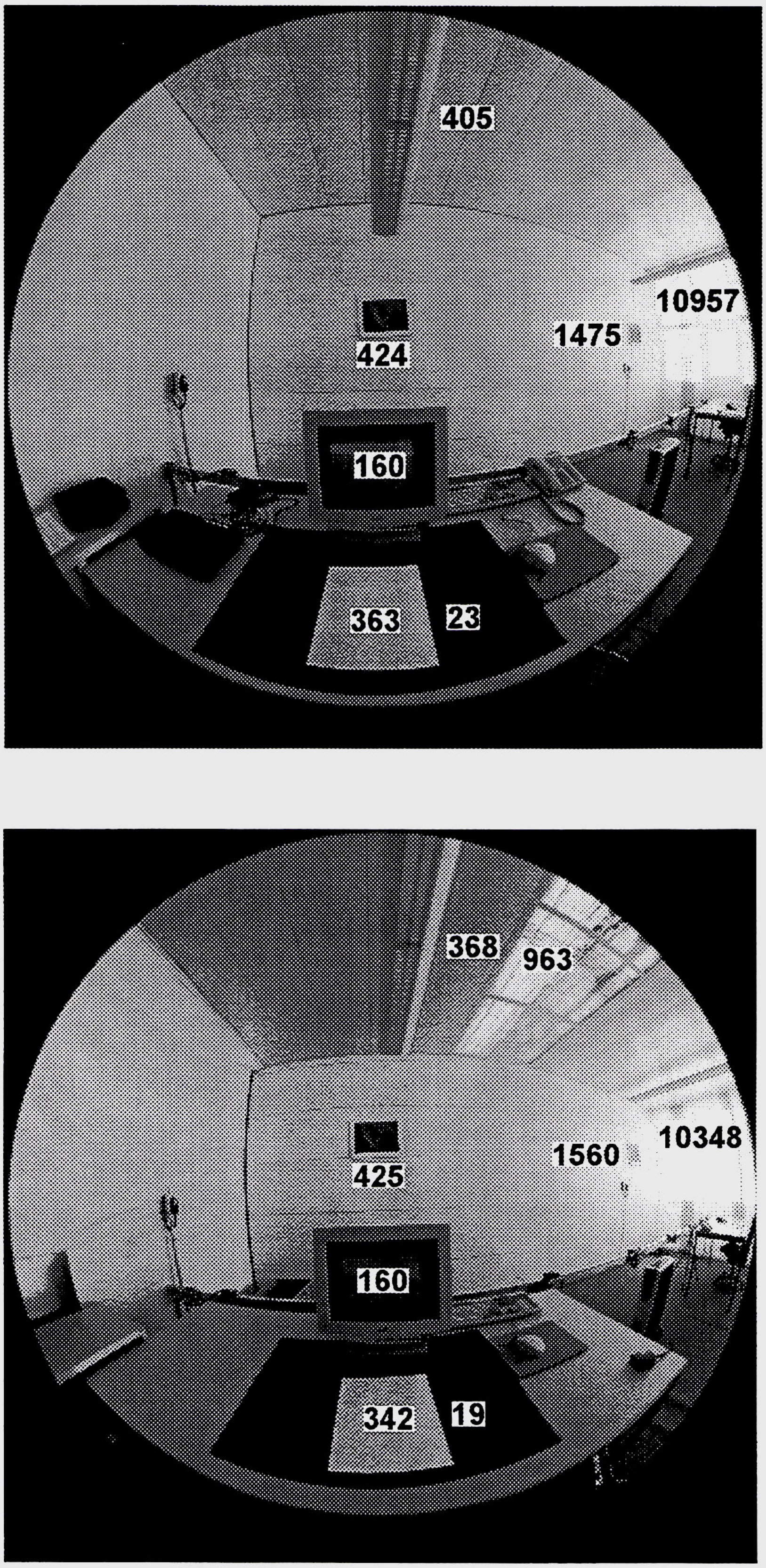


Figure 4.24: *Comparison of luminance values measured in the view field of a desk user in the test and in the reference room (clear sky conditions, anidolic collector and vertical window shaded)*

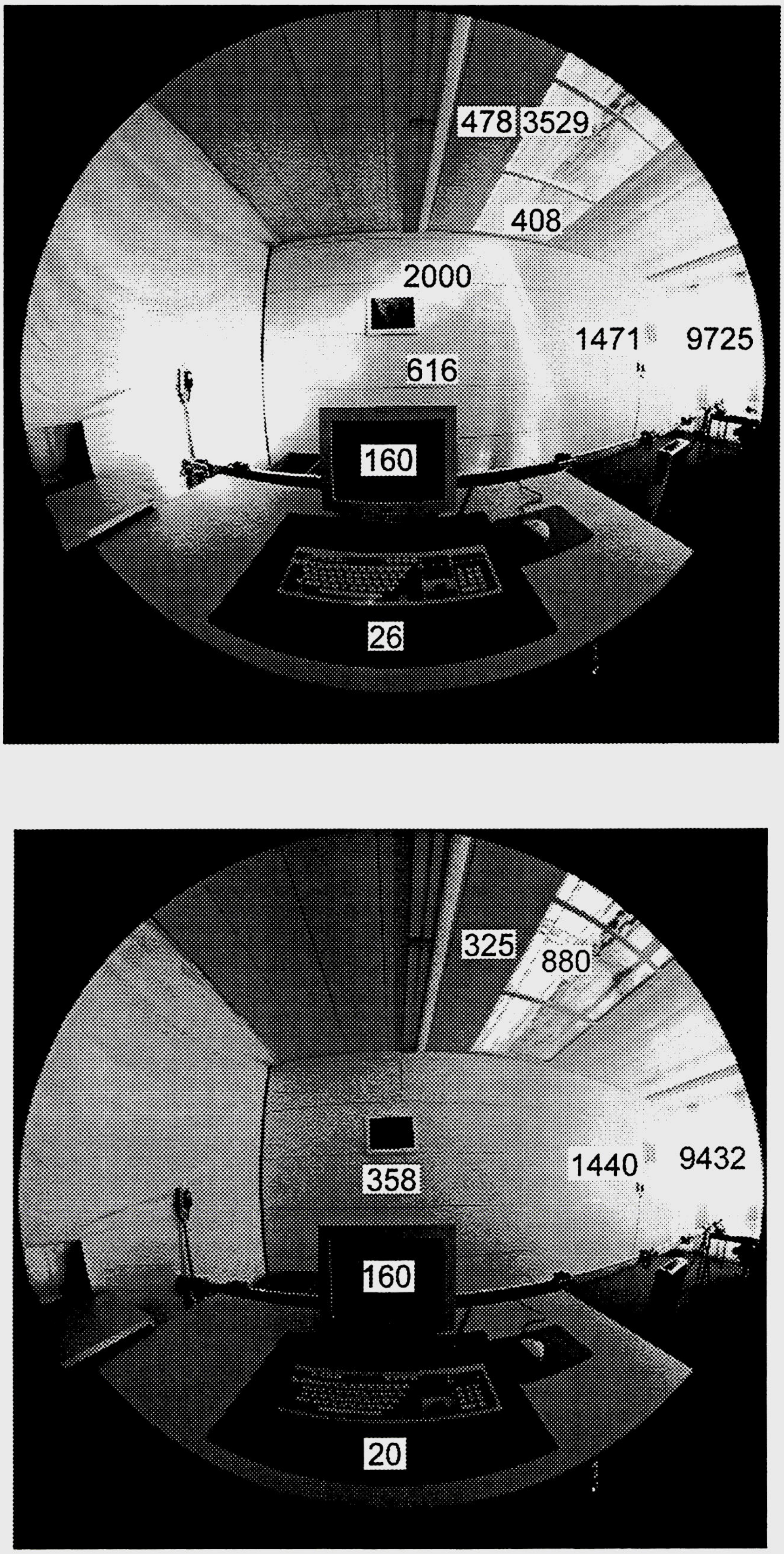


Figure 4.25: Luminance scanning in the view field of a desk user placed underneath the exit aperture of the anidolic ceiling (clear sky conditions)

The visual comfort analysis was refined further by applying the assessment methodology developed by the Laboratoire d'Ergonomie de la Vision of Université de Lausanne [Mey 93 a, b] [Fra 93] [Mey 94].

This methodology is also based on a hemispherical scanning of the luminance mesured at the workplace. A directional sampling is input in a physiological mathematical model of visual acuity, which gives a prediction of the Percentage of Dissatisfied People (PPD). The method assumes two kinds of user tasks:

- reading of a black/white printed document
- reading of a VDT computer screen (100 [Cd/m^2] average luminance).

Table 4.2 and 4.3 summarize this analysis, giving the PPD values assessed for overcast and clear sky conditions: in practice, a 38% PPD value is considered as an upper limit regarding visual comfort, as higher values express visual discomfort (discomfort glare).

	Test	Reference
Mean luminance ratio (surroundings vs. VDT)	0.7	0.3
Mean luminance of the document [Cd/m^2]	65	27
Pupil illuminance [Lux]	158	53
PPD for a printed document [%]	32	40
PPD at VDT [%]	32	40

Table 4.2: Visual comfort assessment at work desk carried out using the LEV method (overcast sky conditions, all blinds open, external horizontal illuminance normalized at 10kLux)

	Test		Reference
Anidolic Ceiling solar protection position	down	up	
Mean luminance ratio (surroundings vs. VDT)	1.7	1.9	1.5
Mean luminance of the document [Cd/m^2]	163	311	244
Pupil illuminance [Lux]	383	1021	602
PPD for a printed document [%]	30	33	31
PPD at VDT [%]	44	86	56

Table 4.3: Visual comfort assessment at the work desk carried out using the LEV method (clear sky conditions, sunshine on the facade internal fabric blinds closed)

The assessed visual comfort under overcast sky conditions (cf. Table 4.2) shows that the additional daylight flux brought by the anidolic ceiling improves the luminance ratio in the view field (ratio closer to unity) and reduces significantly the PPD values for paper as well as for VDT reading tasks.

The analysis of the situation under clear sky conditions (cf. Table 4.3) shows mixed results, depending on the presence or absence of a solar protection in front of the anidolic collector; they can be summarized as follows:

- the PPD values at the desk are lower for the anidolic ceiling, providing adequate visual comfort even for VDT tasks when solar blinds are down;

- for VDT tasks excessive PPD values (higher than 38%) are experienced when the solar protection is open.

The assessment of visual comfort shows that the anidolic ceiling provides a fully adequate lighting work environment, even for extremely high illuminance values characterizing sunny skies. The necessity to integrate solar protection in front of the anidolic collector is, moreover, fully confirmed by this analysis, which shows that its absence can lead to severe visual discomfort.

The use of translucent glazed elements placed at the exit aperture of the anidolic system was found to be an excellent compromise between optimization of overcast sky daylighting performance (cf. paragraph 4.3.3) and moderation of glare risks during sunny periods. This study confirmed, moreover, that the anidolic ceiling does not lead to any glaring situation for overcast days, even when blinds are open, which confirms the improvement of the novel anidolic device in comparison to the first prototype [Sca 96].

Human visual response tests

A group of 33 persons (13 women and 20 men) volunteered for human response tests carried out in the two daylighting modules. Their age ranges from 20 to 60 years (cf. Figure 4.26) although two thirds of them were less than 30 years old, 55% wear medical glasses. A preliminary ergo-ophthalmic examination established that this population sample has eyesight features close to those of a medical data bank of 790 persons.

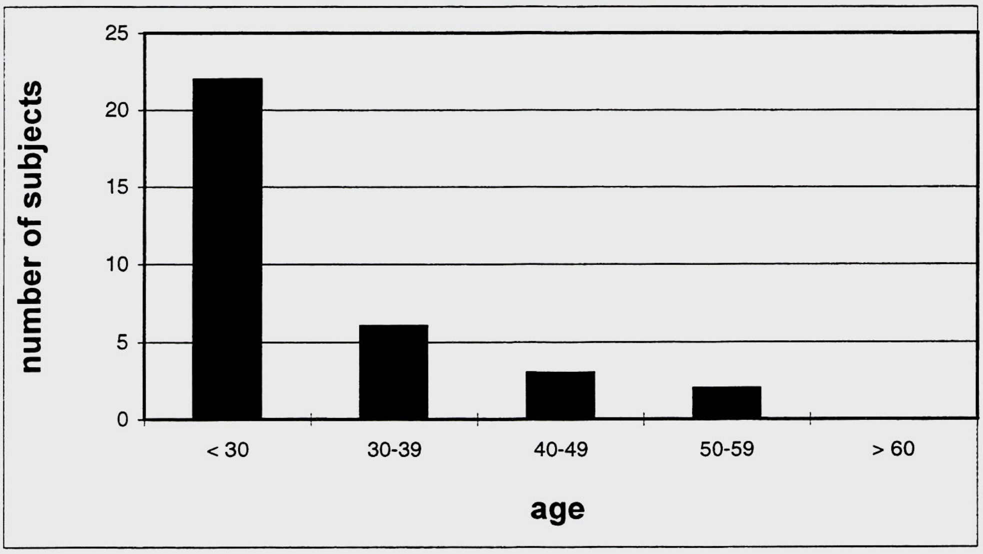


Figure 4.26: Age distribution of the people submitted to the human response test.

Three different types of response tests were submitted to the group of volunteers:

- a test of acuity based on black/white document reading
- a test of acuity based on VDT reading
- a questionnaire of user acceptance.

The tests took place in mid-autumn between 10:00 and 16:00 legal time; daylighting was substantial during this period but not always sufficient. The same series of tests was submitted simultaneously to two subjects, each one placed in a room (cf. Figure 4.27); after completion of their tasks, they changed room starting the same series of tests again at the other work place. Learning effects and impact of weather conditions were limited that way.

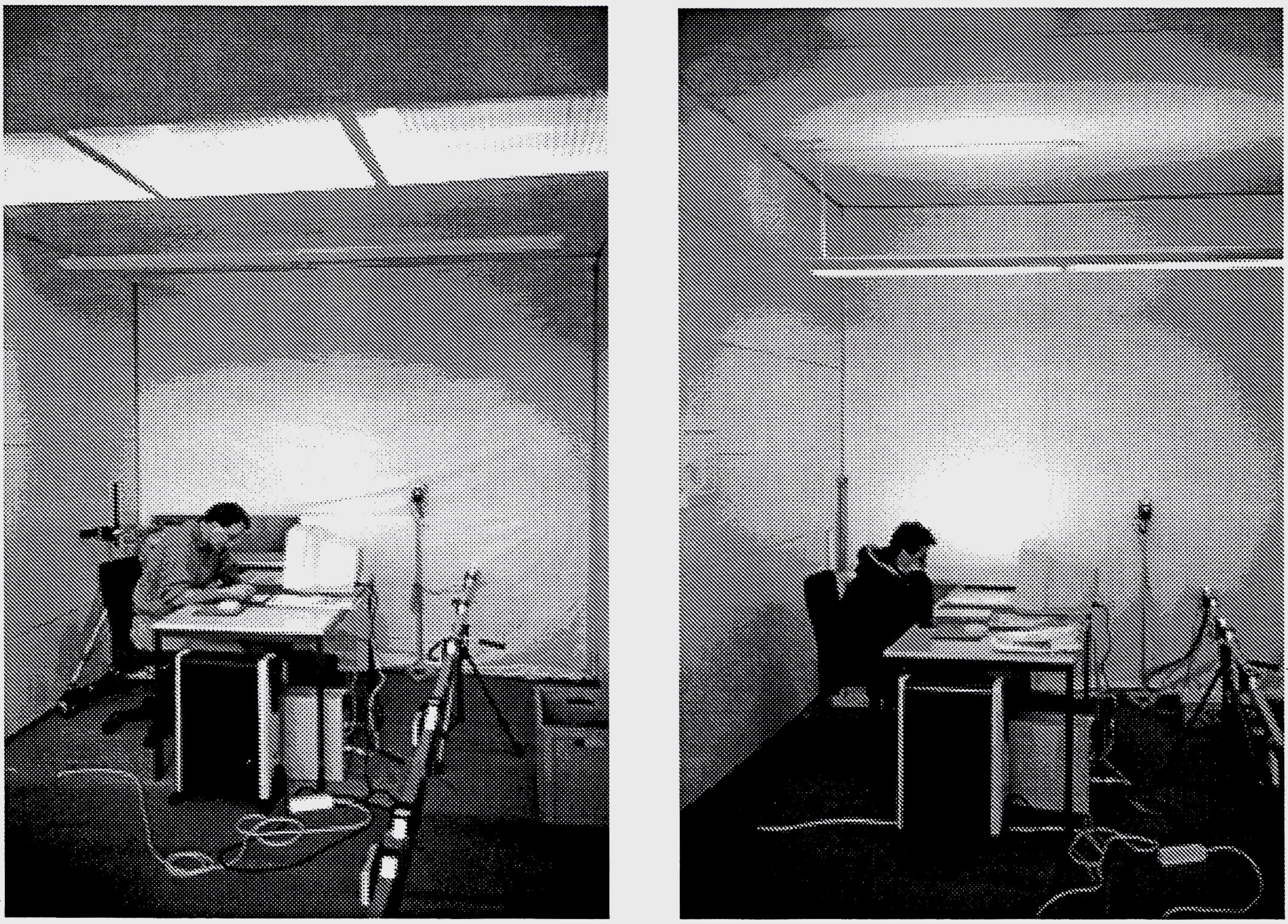


Figure 4.27: View of subjects submitted to human response tests in the test room (left) and the reference room (right)

During the whole test procedure, the subjects were allowed to use electric light and solar protection at their convenience. Two lighting control modes were available:

- an automatic daylighting responsive control dimmer,
- a manually operated dimming controller.

The weather conditions were not equal for all subjects: a wide variety of conditions were observed. It appears that two tests took place with clear sky, six with variable weather and twenty-five on continuously overcast days.

Acuity for document reading

The document presented to the subjects is a page of mat white paper (A4 format) containing a table of 96 Landolt rings (cf. Annex D); the rings were printed in gray with a density adjusted so that reading errors were likely to occur.

The number of errors made by the subjects in each room in determining the orientation of the Landolt rings were counted. The difference for each subject between the number of errors in each room was used as a measure of a possible modification of the users' visual performance due to the anidolic ceiling.

Figure 4.28 gives the statistical distribution of the error difference, which reached (-0.25) in favor of the test room over 116 test samples (the reading error variable is sampled four times, one per ring orientation). This negative value means that a subject makes on average 38% less reading errors in the room with an anidolic ceiling than in the reference room.

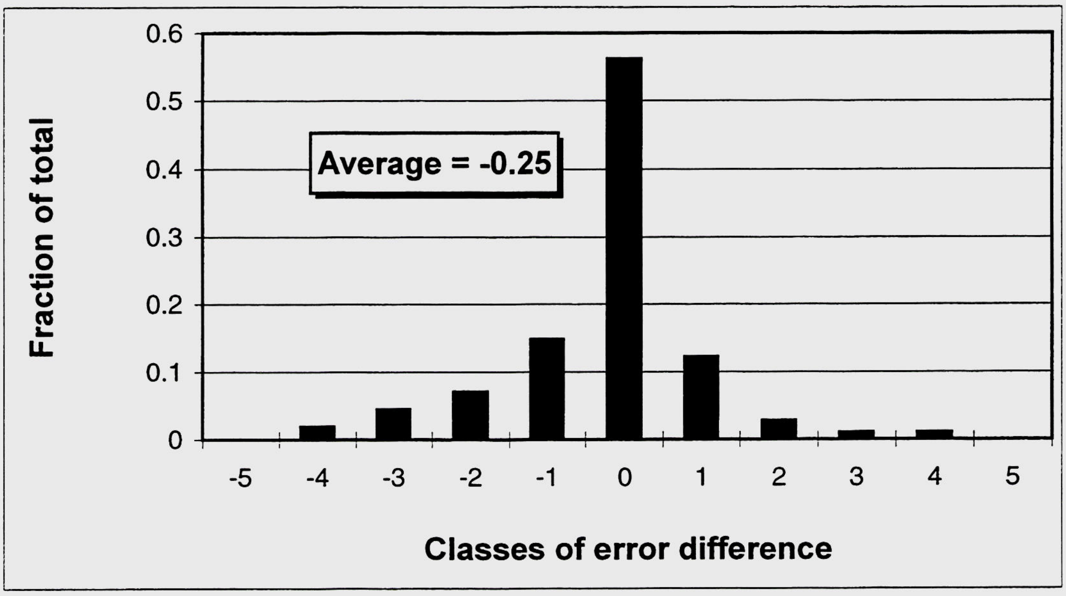


Figure 4.28 Statistical distribution of the difference of reading errors for a subject in the two rooms (a negative value means that less reading errors occur in the test room as opposed to the reference room).

A significance test was applied to these data to confirm by statistical hypothesis testing that the reduction of the error is significant. The following hypothesis

> H_0 = the difference of error has an expected value (true mean value) equal to zero.

is tested against the following alternative hypothesis

> H_1 = the difference of error has an expected value which is negative.

The sample number being higher than 30, the average variation versus sampling can be assimilated to a normal low. In the present situation, its expected value is supposed to be null (H_0), and its standard variation is estimated from the actual experimentation (1.21). Calculations result in the following: a deviation as large as that experienced, or larger, would occur by chance in the expected negative direction (H_1) only about 2.5 times in 100. This probability is enough low to reject H_0 and accept H_1 with a confidence coefficient higher than 97%. This leads to the following conclusion: the reduction of reading error number between the tests achieved in the test and reference rooms is significant in regards to sampling random effects.

Further analysis of the lighting modes chosen by the subjects during their testing procedure showed an important difference between the two rooms, with daylighting preferred in the test room (presence of a light flux issued from the anidolic ceiling). Figure 4.29 illustrates this.

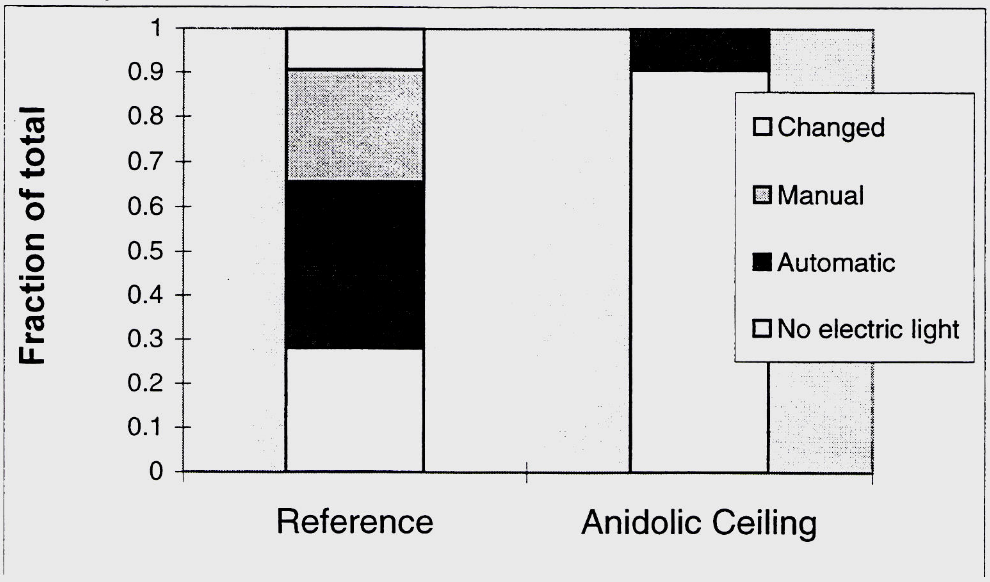


Figure 4.29: Lighting mode used by the subjects in the different rooms (subjects could choose their lighting mode at their convenience).

Keeping within the original statistical sample, only the test data for which no electrical lighting was used to improve the visual conditions were considered (36 samples). Obviously, a greater difference in acuity was observed between the two rooms (cf. Figure 4.30).

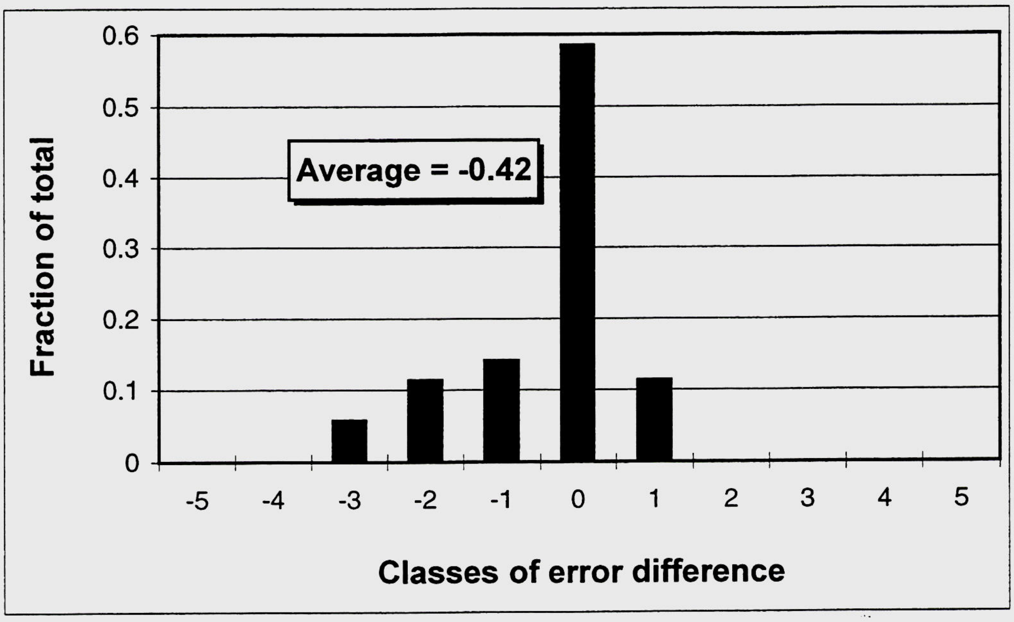


Figure 4.30: Statistical distribution of the difference of reading errors in the two rooms in absence of complementary electric lighting (a negative value means less errors in the test room)

The average difference of reading errors was found in this case to be equal to -0.42 and the confidence coefficient greater than 98%, showing the improvement due to illumination increase. Considering now the remaining cases (80 samples) for which the subject used electric light, at least in one of the rooms (mostly in the reference room, cf. Fig. 4.29), the average is still negative (-0.18) but the confidence coefficient is lower than 77%.

Acuity for VDT readings

The subjects were requested to recognize a series of one digit numbers, automatically displayed on a VDT screen thanks to software developed by the LEV.

At the beginning of the procedure, the screen is fully white, as the contrast of the figure is null; by clicking of the mouse, the subject can enhance the contrast step by step, up to the point where he recognizes the number. If the person has succeeded, the program displays another number; in case of failure, the contrast is enhanced further until the number is recognized (the number of tries was limited to three).

The size of the displayed number is decreased by one step every four numbers to increase the acuity (the subjects are requested to remain at a constant distance of 60 cm from the screen). In the considered sequence, the acuity steps required to read the figures were 0.25, 0.3, 0.5, 0.6 and 0.8; going any further was not possible due to the limited screen resolution (screen diagonal: 15 inches, resolution: 1024 x 768 pixels, scanning frequency: 75Hz).

The users' performance was measured through determination of the threshold contrast of each reading; corresponding to the contrast value required by each subject until he recognizes a figure. The difference of threshold contrasts in the two rooms for a given subject was considered as a measure of a possible modification of the lighting work environment due to the anidolic ceiling.

Considering the test carried out under overcast sky conditions (25 cases over 33) and the values obtained for the highest acuity needs (0.8), shows a diminution of the contrast threshold of 10% on average (cf. Figure 4.31). The level of confidence is calculated according to the same method as the one used above for acuity on a printed document. But this time, the sample number is smaller than 30 and the expected value is therefore supposed to be distributed according to a Student-Fisher Law. The confidence coefficient is found to be above 98%.

The following conclusion can thus be advanced: less luminance contrast is necessary to read a number on a VDT screen in the test room than in the reference room. This tendency is consistent with the assessment of visual comfort; it indicates that the visual performance enhancement is probably due to a more appropriate luminance ratio of the surroundings to the VDT screen.

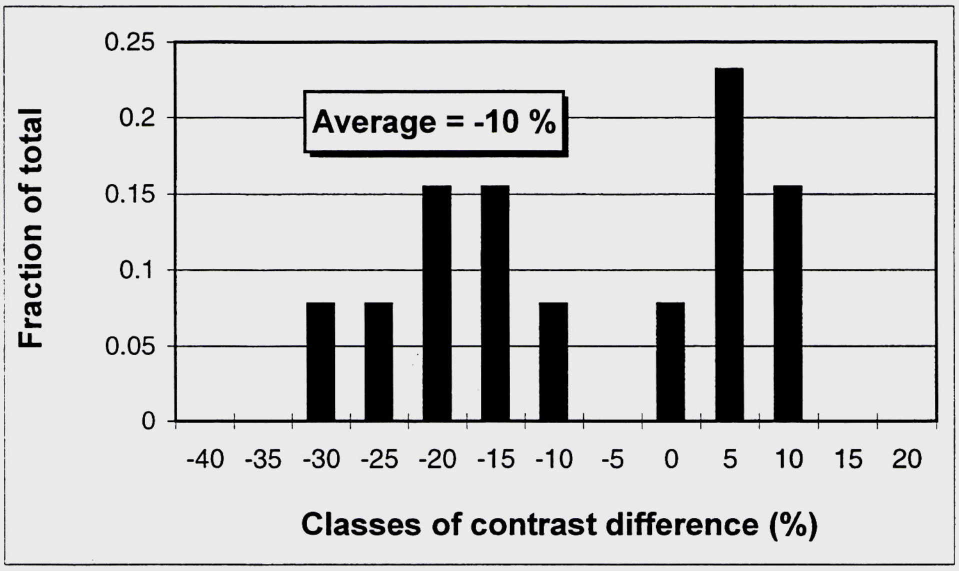


Figure 4.31: Statistical distribution of the threshold contrast difference at highest acuity (0.8) in the two rooms for overcast skies (a negative value means a lower contrast threshold in the test room).

User acceptance questionnaire

The subjects were asked to fill in a questionnaire regarding their personal perception of the comfort in the test and reference room; furthermore, an appreciation of the particular luminous environment was requested.

The questionnaire was based on a document elaborated by Hygge and al [Hyg 96], used within the EU project for Post-Occupancy Evaluation of buildings (POE). Most of the questions are multi-choice.

Figure 4.32 shows the preferences of the group of subjects regarding the aspects of the rooms, which make the work place a pleasant one: "good lighting conditions" appears, followed by "good thermal comfort conditions" and "the presence of a window" as the most relevant aspects for a majority of persons.

Figure 4.33 shows, moreover, that "good lighting conditions at the work place" together with the "presence of a good protection against glare" are the two aspects the users considered the most important.

The comparison of the perceived visual atmosphere in the two rooms led to the following interesting results (cf. Figure 4.34):

- a brighter visual atmosphere was perceived in the test room
- the colors in the test room were found more pleasant (although they were physically the same)
- no negative comments were recorded for the test room (darkness, colorless, etc.).

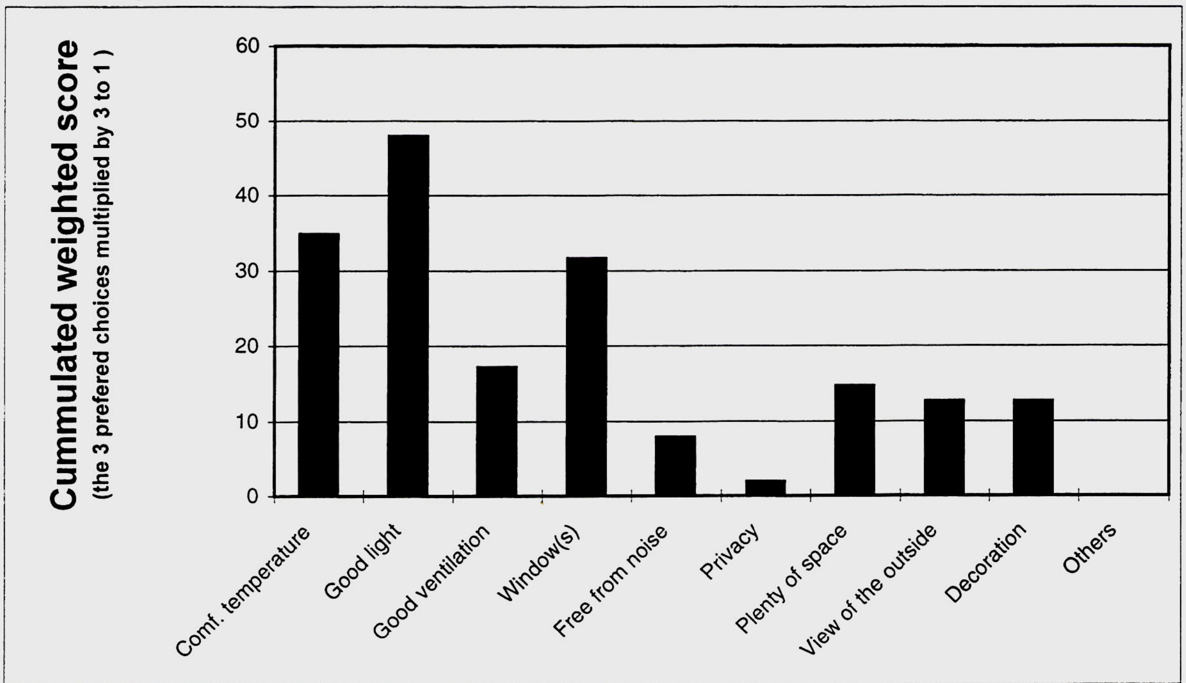


Figure 4.32: Preferences of the group of subjects in the two office-rooms

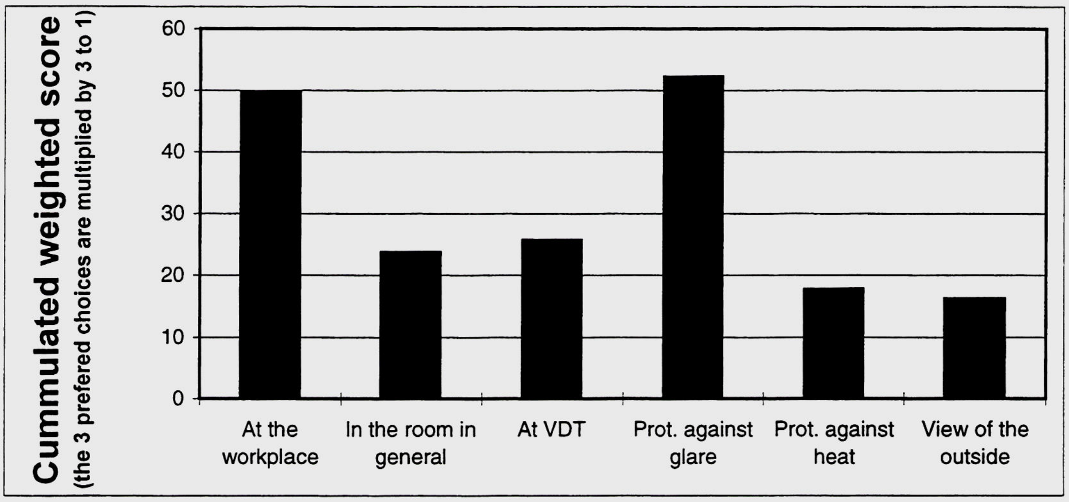


Figure 4.33: Appreciation of the lighting conditions in the two office-rooms by the group of subjects

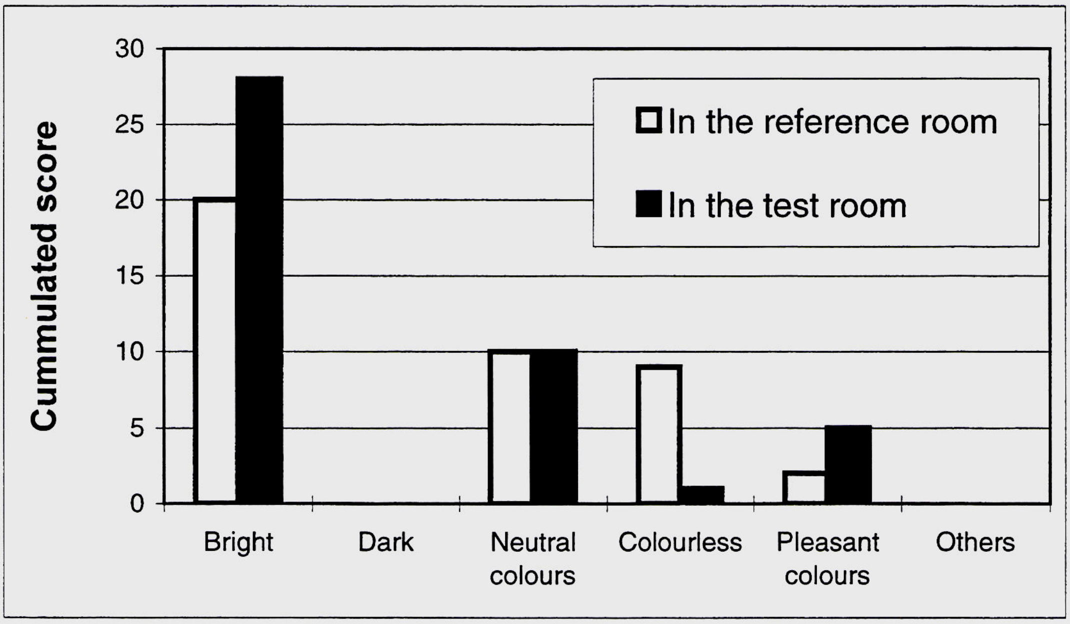


Figure 4.34: Comparison of the perceived visual atmosphere by the subjects in the two office-rooms

The fact that the appreciation of the anidolic ceiling with regard to lighting conditions was positive is remarkable, considering the fact that both rooms were alike in all other aspects (photometry, furniture, etc). Other questions related to window usage led to similar results for the two rooms: no unpleasant color phenomena (cf. Kruithoff Law) were reported in the test room.

4.3.6 Balance of the anidolic ceiling performance

The anidolic ceiling was developed with the aim to improve the performance of a first configuration of an anidolic system (anidolic zenithal collector), especially with regard to the system integration in buildings and visual comfort.

The system described uses a light duct (integrated into a ceiling) which channels a considerable flux of daylight deep into an office space. Two anidolic elements are used, one to collect the daylight from the sky vault and transmit it into the duct and the other to retrieve the light from the duct and distribute it optimally in the room.

The computer simulation design and the performance assessment of the system have proven to be successful. Following very significant results are obtained by the system and were demonstrated experimentally:

- a considerable daylight flux is channeled deep into the room by the anidolic ceiling, increasing significantly the illuminance level at the back of the room
- a factor (2.0) improvement of the daylight factor on the work plane 5 meters from the window was observed in comparison to a conventional double glazing facade

- 30% electricity savings can be expected through the use of such a system in an office room of conventional depth (6.6 m in the present case). More savings could be expected in a deeper room.
- a significant improvement of the lighting work environment was observed leading to a better visual comfort at the work place in the rear of the room and a better visual performance.

The type of integration investigated (integration into a ceiling) was found to be very promising with regard to retrofitting building activities (cf. Figure 4.35).

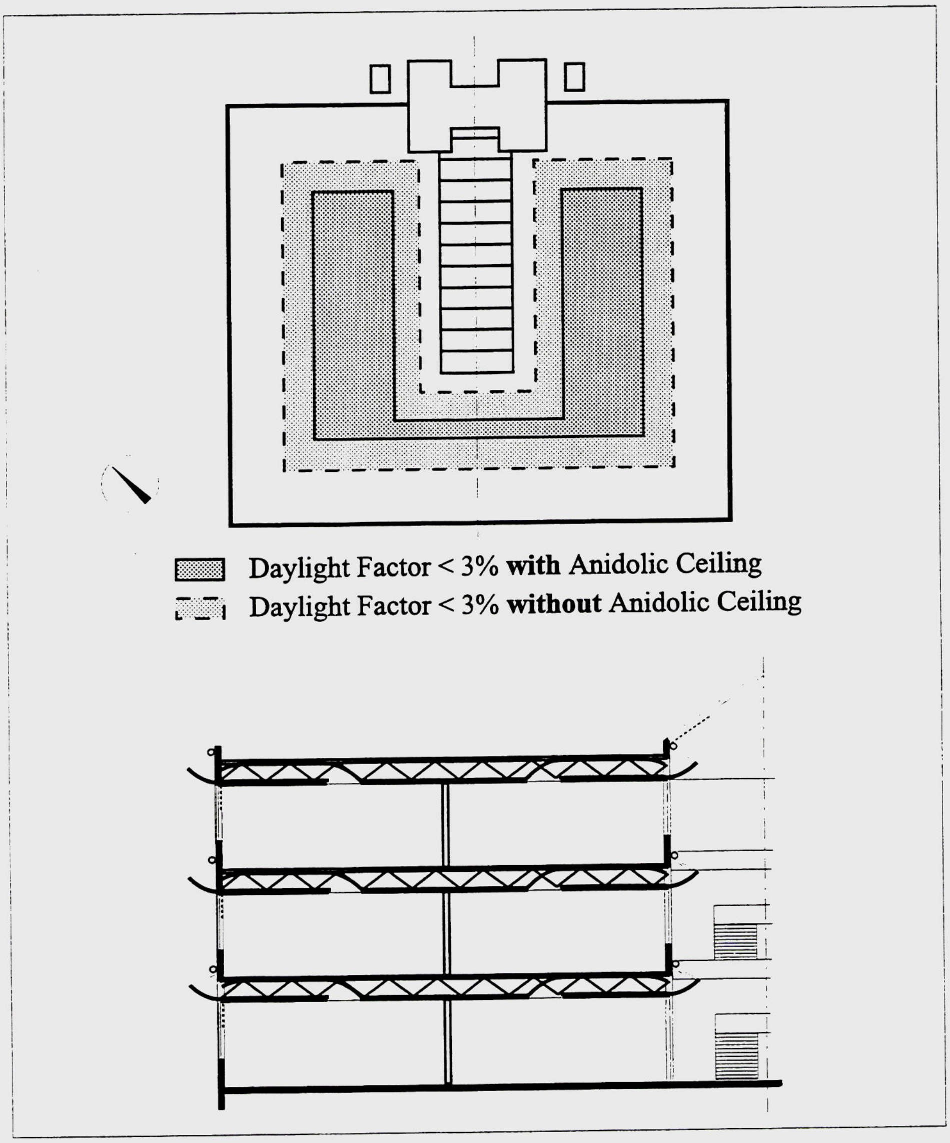


Figure 4.35: Possibility of integration of an anidolic ceiling in case of retrofitting of large open space offices

Typical open space offices of the sixties could provide excellent integration opportunities for anidolic ceilings due to their generally large recessed ceiling. The impact of the integration of the daylighting system on other technical equipment is being studied and will lead to a final view of all aspects of this integration [Her 97].

5 VALORIZATION OF THE PROJECT RESULTS

The research carried out in Switzerland within the framework of the EU project allowed meeting the following specific objectives (cf. Chapters 2, 3 and 4):

- five Swiss selected case studies were carried out (monitoring of daylighting and energy performance);
- a computer simulation of virtual case studies was carried out (with an appropriate simulation methodology);
- the performance of advanced daylighting systems (anidolic systems within experimental test modules) was assessed within test modules (DEMONA).

Beside that, a considerable effort was made to valorize the results obtained for these specific objectives by means of:

- an analysis and final sum-up of the experimental and computer simulation results,
- the writing of contributions to the main deliverables of the EU project ("Case Studies Report", "European Daylighting Design Guidelines").

A presentation of the valorization efforts of the project results is given in this chapter. Most of the documents written for that purpose are given in the Technical Report [Sca 97b], which complements the present document.

5.1 Case studies monitoring results

The monitoring of five Swiss selected case studies implied the acquisition of many different physical data over several periods of the year (cf. Chapter 2). Important knowledge was gained regarding these buildings, which had to be synthesized in an appropriate manner for the target audience of the EU project (architects, building engineers, etc.).

Five synoptic documents were written for that purpose and used as basis for the "Case Studies Report" [CEC 97a]: an overview of these documents is given in the Chapter 1 of the "Technical Report" which complements the present one.

The structure of the synoptic building performance description was inspired by similar documents written for more than 20 buildings within the framework of the national daylighting research project LUMEN [Gol 94]. They followed recommendations made in the course of the EU project, which led to a rather similar structure of documents.

Figure 5.1 *Front page of the synoptic documents describing the daylighting and energy performance of the monitored buildings (case of the EOS Building and the CNA-SUVA Building).*

The most important features of the monitored buildings were included in these documents comprising:

- illustrations of the main building facades,
- description of the building location (geographical coordinates, altitude, etc), orientation (site map) and size (space volume, floor area, etc.),
- illustration of the monitored rooms (including the daylighting system),
- description of the room geometry (dimensions, window area, etc.) and photometry (surface reflection coefficients),
- daylight factor mapping of the monitored room (including a daylight factor main profile),
- luminance measurements at the work desk (including a 20 mm focus picture),
- description of the electric lighting system (lighting mode, connected power, etc.),
- energy performance of electric lighting (average specific power consumption, exploitation factor).

Most of this information was reproduced in the EU document made on the basis of the "Case Studies Report" [CEC 97a]. Compared to the data delivered by the other project partners, the Swiss contribution showed an original feature, constituted by the energy performance figures of the electric lighting, which were not assessed by the other groups (cf. Chapter 2.4).

Part of these data was reproduced within the EU final document to unify the presentation of different buildings. The "Technical Report" [Sca 97b] gives an overview of these documents produced for the Switzerland-specific building case studies. Figure 5.1 shows an illustration of the front page of these documents for the case of the EOS Building and the CNA-SUVA Building.

5.2 Computer simulation results

The Swiss contribution to the computer simulation efforts allowed developing a simulation methodology to assess the thermal and daylighting performance of some selected monitored buildings (eleven virtual case studies). This methodology was then applied to the different buildings by the national teams. The Swiss team took care of one case study in Switzerland (EOS building), but contributed to the simulation of 3 European buildings (cf. chapter 3.5).

Different documents were produced during this process to which the Swiss team also contributed. Chapter 2 of the "Technical Report" gives an overview of the documents.

A first document aimed at the different national simulation groups [Cla 95a] describes the simulation methodology, consisting of:

- the building computer modelling procedure (geometry, boundary conditions),

- the "Reference model" used to outline the daylighting performance of the "As-built" building,

- the model calibration procedure (comparison of simulated and monitored daylight factors),

- the representation of the Integrated Performance View of the building.

This methodology was first applied to a pilot simulation case ("Collège de la Vanoise", France) and reported in a way to define a reporting format [Cla 95b], the IPV chart being the most important element of this report (cf. Chapter 2). Figure 5.2 gives an illustration of such a chart (case of "EOS building").

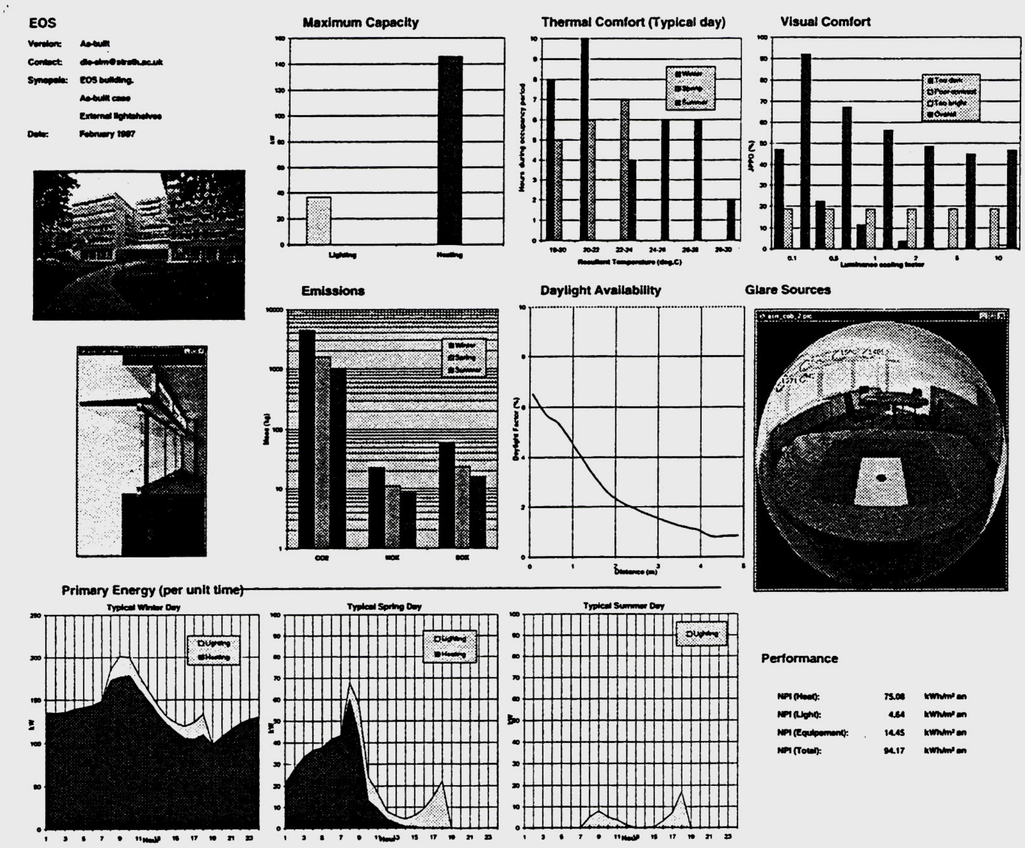


Figure 5.2: Illustration of an IPV chart, representing the main thermal and daylighting features of a virtual case study.

The Swiss case study report on the EOS building was written following that format [Cit 97] and served as a basis for the "European Daylighting Design Guidelines" [CEC 98b]. The "Technical Report" gives an overview of this document (cf. Chapter 2).

5.3 Test modules monitoring results

Advanced daylighting systems (anidolic systems) were monitored within experimental test modules during different periods that led to the conclusive evaluation of a novel daylighting strategy.

The specific results of this monitoring campaign were integrated into different documents (cf. "Technical Report", Chapter 3), which were to provide the basis for the "European Design Guidelines. Chapter 4 of the present document relates them in detail.

The two written contributions provide, however, sound information about the possibility of integrating anidolic systems in practice. A comparison of their performance with that of other daylighting strategies is given, moreover, showing the real benefits of these novel devices.

5.4 Contributions to the "Daylighting Design Handbook"

The preparation of documents that served as a basis for the "Daylighting Design Handbook" had high priority. These contributions directly match some of the chapters of the Handbook, which has the following structure:

1.0 Climate and context
2.0 Building form and daylight
3.0 The daylight design of rooms
4.0 Refurbishment of existing buildings
5.0 Light, colour and surfaces
6.0 The design of windows
7.0 Artificial lighting controls
8.0 Advanced daylighting elements
9.0 Visual comfort and occupancy response.

Following this structure, the Swiss team wrote three specific contributions on the topics of:

- Design tools: Physical modelling
  (Chapter 3 of the Handbook) [Mic 97]

- Modular Daylighting Test Modules
  (Chapter 8 of the Handbook) [Sca 97]

- Advanced Daylighting Systems
  (Chapter 8 of the Handbook) [Cou 97].

The three contributions are given in an explicit manner in the "Technical Report" (cf. Chapter 3 of the document); they made up a part of the "Daylighting Design Handbook" [CEC 98b].

6 CONCLUSION

The EU project "Daylighting Design of European Buildings" aims at making daylighting design rules for buildings available to the European building industry. Its focus is placed on the use of daylighting in buildings to reduce artificial lighting needs while simultaneously improving the visual comfort of users and the architectural aspects of building.

The project was carried out by a team of about 20 individual European research institutions including Swiss participants.

The following objectives were met:

- 60 non-residential buildings in Europe were monitored regarding daylighting, energy performance and user reaction (case studies monitoring);
- a selected fraction of these buildings was simulated through computer modeling in order to generalize daylighting and energy performance rules for practicing architects and engineers (virtual case studies modeling).

On the basis of the results obtained, information material for architects and engineers was produced and disseminated. It consists of the following deliverables:

- "European Daylighting Design Guidelines" for appropriate integration of daylighting technologies in non-residential buildings [CEC 98a];
- a sourcebook of "60 European Case Studies" that illustrates appropriate daylighting solutions through the presentation of existing buildings [CEC 98b].

The activities of the Swiss research team supported the overall goals of the EU project. They benefited moreover from the extensive know-how acquired in Switzerland during the eighties within the framework of national daylighting research programs (LUMEN research program [Sca 93][Sca 94]).

The activities of the Swiss participants in the project led to the following results.

6.1 Monitoring of case studies

The aim of the monitoring of case study buildings throughout Europe was to provide background information for the preparation of the "European Daylighting Design Guidelines".

The Swiss contribution to this work had the following objectives:

- to monitor the daylighting performance of 5 non-residential Swiss buildings
- to assess the energy efficiency of the associated daylight-responsive electric lighting installations.

Both objectives were fulfilled in a satisfactory way.

Daylighting performance of buildings

Five buildings were selected in Switzerland in four different towns according to given criteria (architectural features, daylighting systems, etc.). These objects, both new and refurbished, are:

- Collège de la Terre Sainte (Coppet / atrium)
- EOS Headquarters (Lausanne / atrium, light shelves)
- Reiterstrasse administration building (Bern / courtyards)
- UAP insurance building (Lausanne / renovated facade)
- CNA/SUVA insurance building (Basel / prismatic panels).

The five buildings were monitored following a common monitoring procedure that comprises:

- the physical description of the buildings (pictures, drawings)
- the characterization of the photometric properties of materials (glazing, inner surfaces, etc).
- the measurement of daylight factors (reference plane, eye level, etc.)
- the assessment of the users' lighting environment (luminance scanning, veiling reflections, etc.).

The monitoring of the daylight factors within the 5 buildings, coordinated with the assessment of the electric lighting performance, delivered the following results:

- the contribution of borrowed light systems that characterize almost all monitored buidings (except the UAP buiding), was found to be negligible in almost all cases (glazing area too small);

- only one building (Reiterstrasse) that has a higher glazing ratio of borowed light openings (0.18), showed a significant contribution to the daylight factor at the back of the room;

- light shelves clearly reduced the absolute value of the daylight factor while smoothening the illuminance distribution inside the room (case of EOS building);

- the use of sophisticated daylighting systems (prismatic panels) integrated into a double-skin facade (case of CNA/SUVA building) surprisingly reduced the daylight factor values and led to a dimmed lighting environment.

The assessment of visual conditions through luminance scanning showed reasonable values in all buildings (except direct view through the main openings) and particularly low luminance contrast ratios in the case of light shelves (EOS building) and prismatic panels (CNA/SUVA building). It can be expected that more appropriate VDT tasks light conditions are offered that way.

Assessment of electric lighting consumption

Lighting operation and occupancy patterns of buildings were monitored in the 5 Swiss selected case studies to assess the possible correlation between the daylighting performance of the buildings and the efficiency of use of the lighting installation.

The monitoring was carried out with appropriate equipment, selected after investigation for that purpose (watt meter, PIR detector, etc.).

The following conclusions can be drawn from this monitoring:

- low energy consumption was observed even in the case of excessive connected power (appropriate user behavior);
- there is a serious indication that good daylighting performance is correlated with energy savings (low exploitation factor of lighting installation);
- daylight responsive control systems do not systematically lead to a more efficient use of lighting than energy-conscious users (especially in the case of inappropriate setting).

The same assessment of the efficiency of the use of lighting would have benefited other buildings in Europe: it is believed that such monitoring of daylit buildings is still necessary to confirm the pertinence of their architectural design regarding energy savings.

6.2 Computer simulation of virtual case studies

The aim of the simulation effort made within the EU project was to provide general design guidance based on the results of several case studies (virtual case studies).

The Swiss contribution to this work had the following goals:

- development of a computer simulation methodology for the assessment of the thermal and daylighting performance of buildings,
- application of this methodology during the simulation of selected Swiss case studies.

Both goals were met during the project.

Computer simulation methodology

A performance assessment methodology provided as a standard to the different simulation teams was defined in collaboration with the Energy Systems Research Unit of University of Strathclyde. Thermal and a daylighting computer simulation program were used for that purpose (ESP-r, RADIANCE).

The overall performance of the building was assessed by comparison of the measured performance ("as-built case") to that calculated for the same building without daylighting features ("reference case").

Computer models of the buildings were made for that purpose based on the following parameters:

- building construction and geometry
- building usage and environmental systems
- climatic data
- validation of the model.

Building performance indicators were chosen in order to highlight the main performance aspects:

- heating energy and electric lighting consumption
- thermal and visual comfort
- environmental impact.

Seven typical indicators were selected for that purpose and grouped together within a synthetic representation form that provided an Integrated Performance View (IPV) of the case studies.

The following indicators were chosen:

- maximum power capacity
- primary energy consumption
- emission of pollutants
- thermal comfort scale
- daylight factor
- identification of glare sources
- visual comfort.

Serious effort was dedicated to implementing a new visual comfort index (J-index) developed within the framework of the Swiss national research program LUMEN.

Building computer simulation

The computer simulation methodology was successfully applied to eleven buildings within the EU project. The Swiss team participated directly in the simulation of four of them (Collège de la Vanoise, Queens building, Victoria Quay and EOS building).

The four buildings are characterized by borrowed light systems, which collect daylight through open building spaces (atrium, courtyards); the majority is equipped with light shelves (except Victoria Quay).

Their simulation by the assessed computer methodology provided the following similar conclusions:

- borrowed light systems contribute to a significant improvement of daylight factors in the back of the room only in the case of a wall glazing fraction larger than 50%;

- light shelves reduce daylight factors in rooms but provide a more uniform distribution of light.

In most cases, it appears that the combination of different daylighting features led to the following building performance results:

- significant reduction of electricity consumption regarding artificial lighting,

- no significant reduction of the maximum heating load and therefore of plant capital costs,

- no significant influence on heating energy consumption,

- general improvement of thermal and visual comfort.

The performance of some buildings differs slightly from the above mentioned general results due to their own architectural characteristics or climate.

6.3 Monitoring of daylighting test modules

The monitoring of daylighting test modules was a novel contribution to the EU project issued from Switzerland. In addition to the opportunity of undertaking the 1:1 scale monitoring of advanced daylighting systems (anidolic systems [Com 93 a, b]), it provided a significant source of information for the "European Daylighting Design Guidelines".

Investigated anidolic systems

An anidolic ceiling was developed with the aim to improve the performance of a first configuration of an anidolic system (anidolic zenithal collector), especially with regard to the system integration in buildings and visual comfort [Cou 97].

It uses a light duct integrated into a ceiling and coated with highly reflective material to guide a large flux of daylight deep into an office space.

The theory of anidolic optics ("anidolic" is a synonym of "non-imaging") was used to maximize the optical performance of the system. Two anidolic elements are part of the device:

- a first one to efficiently collect the daylight diffused by the sky vault

- a second one to retrieve the light from the duct and distribute it optimally deep into the room.

Computer simulations were used to improve the design of the anidolic ceiling. They led to the following results:

- a high optical efficiency is achieved by the anidolic elements of the ceiling (72% for the external collector),
- the use of conventional optical elements instead of anidolic components would reduce the system's overall efficiency in a drastic way (60%),
- the use of surfaces with a lower reflectivity (0.8 instead of 0.9) would reduce the same efficiency by 45%.

Particular attention was consequently paid to the production and mounting of the different components of the anidolic ceiling.

Monitored daylighting performance

Two test modules, located on the EPFL campus, were used to assess the performance of the anidolic ceiling:

- a first module, equipped with a conventional double glazing facade, was used as a reference room,
- a second facade, with the novel daylighting system, was used as a test room.

The modules stand side by side on an unobstructed site and are mounted on rollers; they can consequently be oriented in any direction. They are characterized by strictly identical geometrical and photometric features and equipped with identical electric lighting installations (two rows of recessed luminaires of 2 x 36 W), controlled by a daylight responsive dimmer (300 Lux work plane illuminance).

Monitoring of both modules was undertaken during the period of December 96 through June 97 (10-minute sampling intervals). It comprised the acquisition of several key data regarding the system daylighting and energy performance (daylight factors, sky luminance symmetry, and power consumption).

The monitoring of the modules was undertaken for different weather conditions (overcast and clear skies). Several orientations were considered for that purpose, with the following, very positive results:

- a considerable daylight flux is channeled deep into the room by the anidolic ceiling, increasing significantly the illuminance level at the back of the room,
- a factor (2.0) improvement of the daylight factor on the work plane 5 meters from the window (overcast sky conditions) was observed in comparison to a conventional double glazing facade;
- a factor (12.0) was observed for sunny sky conditions (sun normal to the facade) in case the external solar protection of the system is relieved;

- 30% electricity savings were observed for the considered monitoring period, the most important fraction occurring during overcast days.

An evaluation of the luminous work environment in both modules with regard to daylighting was carried out in addition. Visual comfort conditions at the work desk (luminance scanning and J-index evaluation) and user acceptance of the system (questionnaire distributed to 30 subjects) were assessed in both rooms, which led to the following results:

- better visual comfort conditions (lower PPD) were experienced for the anidolic ceiling even in the case of VDT tasks in comparison with the reference facade (double glazing)

- better visual performance was observed (acuity for document and VDT reading) for a group of 30 persons who volunteered for human response tests.

The comparison of the perceived visual atmosphere by the same group in the two rooms confirmed the better appreciation of the anidolic ceiling regarding light conditions and color perception.

6.4 Valorization of project results

A considerable effort was made by the Swiss participants to valorize the significant results obtained within the different specific research actions.

The effort was mainly oriented toward the support of the main deliverables of the EU project ("Case Studies Report", "European Daylighting Design Guidelines"). This valorization effort led to the production of the following material by the Swiss team:

- five synoptic documents were written on the five Swiss building case studies as a basis of the "Case Studies Report",

- an "Integrated Performance View" of several buildings (incl. EOS building) was established for the "Guidelines",

- several Swiss specific contributions for the "Guidelines" were delivered to the EU project.

It is expected that the two main project deliverables, which target architects and engineers, will reflect the extensive contribution of the Swiss participants to the EU project.

REFERENCES

[ARG 97] ARGE, AWE and LESO-PB/EPFL, "DEMONA: Forschungs und Demonstrationsmodule für innovative Tageslicht-Technologien", Schlussbericht, NEFF Projekt 658, 1997.

[ASE 89] Association Suisse des Electriciens, "Eclairage intérieur par la lumière du jour", Norme Suisse SEV 8911, Berne, 1989

[Ber 95a] V. Berrutto and M. Fontoyoant, "Joule II Daylight Europe - Level 1 and 2 Monitoring procedure", ENTPE/DGCB, Vaulx-en-Velin, France, 1995

[Ber 95b] V. Berrutto and M. Fontoyoant, "Joule II Daylight Europe - Assessment of daylighting quality with field measurements", ENTPE/DGCB, Vaulx-en-Velin, France, 1995

[Box 78] G.E.P. Box, W.G. Hunter and J.S. Hunter, "Statistics for experimenters", J. Wiley, New York USA, 1979

[CEC 93] "Daylight in Architecture - A European Reference Book", edited by N. Baker, Fanchiotti and K. Steemers, publilshed for CEC DG XII by James and James Publ., London (1997)

[CEC 98a] European Commission DG XII, "Daylighting performance of buildings: 60 European case studies", Edited by ENTPE and University Collège Dublin, 1998

[CEC 98b] European Commission DG XII, "European Daylighting Design Handbook", Edited by University of Cambridge, 1998

[CIE 70] Daylight, CIE Publ. N° 16 (E-3.2), 1970.

[CIE 73] Commission Internationale de l'Eclairage, "Standardization of Luminance Distribution on Clear Skies", CIE publication N° 22, 1973

[CIE 87] "Vocabulaire International de l'éclairage", CIE Publ. N° 17.4, 1987

[Cit 97] S. Citherlet, R. Compagnon, G. Courret and J.-L. Scartezzini, "Simulation Case Study: Energie Ouest Suisse Headquarters, Lausanne", LESO-PB / EPFL, 1997

[Cla 93] J.A. Clarke J A, "Assessing Building Performance by Simulation', Building and Environment, V28, N4, pp419-427, 1993.

[Cla 95a] J. Clarke, R. Compagnon, J. Hand, J. Hensen, K. Johnsen, M. Janak, I. Macdonald, C. Madsen, K. Wittchen, "Performance Assessment Method for DL-E Case Study Simulations", University of Strathclyde / LESO-PB / SBI, 1995

[Cla 95b] J. Clarke, R. Compagnon, J. Hand, J. Hensen, K. Johnsen, M. Janak, I. MasDonald, C. Madsen and K. Wittchen, "Simulation Case Study: Collège de la Vanoise, France", University of Strathclyde / LESO-PB / SBI, 1995

[Cla 96] J.A. Clarke, H.W. Hand, J.L.H. Hensen, K. Johnsen, K. Wittchen, C. Madsen and R. Compagnon, Integrated Performance Appraisal of Daylight-Europe Case Study Buildings, Proc. 4th European Conference on Solar Energy in Architecture and Urban Planning, Berlin, March 1996

[Com 93a] R. Compagnon, J.L. Scartezzini, B. Paule, Application of Nonimaging Optics to the Development of new Daylighting Systems, ISES Solar World Congress, Budapest, Hungary, 1993

[Com 93b] R. Compagnon, Simulations numériques de systèmes d'éclairage naturel à pénétration latérale, PhD Thesis N° 1193, Ecole Polytechnique Fédérale de Lausanne, 1993

[Cou 96] G. Courret, R. Compagnon, J.L. Scartezzini, Anidolische Decke, Licht'96: Gemeinschaftstagung der Lichttechnischen Gesellschaften Deutschlands, der Niederlande, Österreichs und der Schweiz, Tagungsberichte, pp. 466-71, Leipzig, Deutschland, Octobre 1996

[Cou 97] G. Courret, R. Compagnon, "Advanced Daylighting System", Swiss contribution to the Handbook, LESO-PB / EPFL, 1997

[DEM 97] "DEMONA: Forschung- und Demonstrationsmodule für innovative Tageslicht-Technologien", ARGE-Electrowatt Engineering - LESO-PB/EPFL, NEFF Project 658, 1997

[Fai 83] A. Faist, J.-B. Gay, A. Razafirdoibe, J.-L. Scartezzini, F. Thevenon, "The passive solar energy building LESO: a new tool for passive and hybrid systems investigation", Proc. of ICBEM 83, Ames/Iowa, USA, (1983)

[Fan 82] P.O. Fanger, "Thermal Comfort", R.E. Krieger, Malabar, USA

[Fra 93] D. Francioli, Un modèle du confort visuel, Etudes et recherches 93, publication IMSP Fac. Méd. Université de Genève, p 25, 1993

[Fra 97] D. Francioli, J.-J, Meyer, H.Kerkhoven, "Simplified measuring methods for the evaluation of visual comfort conditions at the screen by means of the "J"-Index", Proceedings of the 8th European Lighting Conference, pp 663-675, Amsterdam 1997

[Gol 94] Y. Golay et al, "Etudes typologiques - Programme interdisciplinaire LUMEN", ITB/EPFL, Lausanne, 1994

[Gor 92] J.M. Gordon and A. Rabl, Non-imaging compound parabolic concentrator-type reflectors with variable extreme direction, Applied Optics, vol. 31, N° 43, 1992.

[Gut 63] S.K. Guth, "A method for the Evaluation of Discomfort Glare", Illuminating Engineering, May 1993

[Her 97] J. Hertig, "Intégration de systèmes anidoliques à l'architecture", Travail de Maîtrise, Master européen en architecture et développement durable, EPFL, 1997.

[Hyg 96] Staffan Hygge, Hans Allan Löfberg, "Lighting conditions survey - Questionnaire", intern. communication of Task 21 of the AIE, 1996

[Koh 86] N.A. Kohler, "Analyse énergétique de la construction de l'utilisation et de la démolition de bâtiment", Thèse EPFL N° 623, Dépt. d'Architecture,

[Mey 93a] J.J. Meyer, D. Francioli, P. Rey, Observed variation of lighting conditions versus feelings of visual discomfort in VDT operators. Application of a new model, Conference Proceedings Lux Europa Edimbourg, April1993.

[Mey 93b] J.J. Meyer, D. Francioli, P. Rey, F. Benoît – B&G. Ingénieurs-conseils, Visual discomfort: evaluation after introducting modulated light equipment. Proceedings Right Light 2nd European Conference on Energy-Efficient Lighting, September 1993.

[Mey 94] J.J. Meyer, D. Francioli, P. Rey, L. Deschamps, R. Compagnon, Le nouvel indice d'inconfort visuel, Ergonomie et Ingéniérie, WWIXe congrès de la self, 1994.

[Mey 96] J.J. Meyer, D. Francioli, H. Kerkhoven, "A new model for the assessment of visual comfort at VDT-workstations", Advances in Occupational Ergonomic and Safety, Mital Krueger ed. International Society for Occupational Ergonomic and Safety, Cincinnati USA, pp. 233-238, 1996

[Mic 96] L. Michel, "Design tools (Physical modelling)", Swiss contribution to the Handbook, LESO-PB / EPFL, 1997

[Mic 97] L. Michel, "Joule II Daylight Europe - In-situ measurements of lighting consumption", LESO-PB/EPFL, Switzerland, 1996

[Min 91] J.C. Miñano, A. Luque, Angular confining cavities for photovoltaics, SPIE vol. 1528, Nonimaging Optics: Maximum Efficiency Light Transfer, 1991.

[Rea 87] M.S. Rea and R. R. Jaekel, "Monitoring occupancy and light operation", Lighting Research and Technology 19, 45-49, (1987)

[Sca 93] J.-L. Scartezzini, R. Compagnon, G. Ward and B. Paule, "Daylighting computer design tools", Project NEFF 435.2, Uni GE / EPFL, 1993

[Sca 94] J.-L. Scartezzini, L. Michel, C. Roecker and R. Thyner, "Daylighting Laboratory", Uni GE / EPFL, 1993

[Sca 96] J.L. Scartezzini, B. Paule, R. Compagnon, G. Courret, Espace modulaire de démonstration en éclairage naturel. SLG'96, Rapport de la journée de l'Association Suisse de l'Eclairage, pp 87-101, Bern, Switzerland, October 1996

[Sca 97a] J.-L. Scartezzini, B. Paule, "Modular Daylighting Test modules: a Case Study", Swiss contribution to the Handbook, LESO-PB / EPFL, 1997

[Sca 97b] J.-L. Scartezzini, R. Compagnon, S. Citherlet, L. Michel, B. Paule, G. Courret, S. Simos, "Daylighting Design of European Buildings - Technical Report", LESO-PB/EPFL, EIG, Lausanne, 1997

[SIA 96] SIA 380/4, "Electrical installations within buildings", Recommendation of Swiss Society of Engineers and Architects, Zurich (1996)

[War 94] Ward G., The RADIANCE Lighting Simulation and Rendering System, Computer Graphics 22, 1994.

[Wel 89] W.T. Welford and R. Winston, Nonimaging Optics, Academic Press, USA, 1989

[Wic 84] B. Wick, "Statistique des consommations d'énergie des bâtiments suisses", Editions M.S.E.E., (1984)

ANNEX A - Detailed organization of the project

EU Project Coordinator

Esbensen Consulting Engineers
Teknikerbyen 38, 2830 Virum, Danemark
P. Kristensen & C.E. Madsen

Monitoring Group

ENTPE / DGCB
Rue Maurice Audin
69518 Vaulx-en-Velin, France
M. Fontoynont & V. Berutto

LNEC
Av. do. Brasil 101
1799 Lisboa, Portugal
L. Carvalho

University of Athens
Lab. of meteorology
33 Ippokratous str., 106 80 Athens, Greece
D. Asimakopoulos & M. Santamouris

Fraunhofer - Institut für Bauphysik
Nobelstrasse 12, 70569 Stuttgart, Germany
H. Erhorn

Belgian Building Research Institute
Violetstraat 21-23, 1000 Brussels, Belgium
P. Wouters & L. Vandaele

Building Services Engineering
Chalmers University of Technology
412 96 Göteborg, Sweden
L. Jagemar

Danish Building Research Institute
Postboks, 2970 Horsholm, Danemark
K. Johnsen & E. Petersen

BRE Garston
Watford WD2 7JR, United Kingdom
P. Littlefair

Conphoebus s.c.r.l.
Zona Industriale, Casella Postale,
95030 Catania, Italy
S. Sciuto

Simos Architecte-Eclairagiste
Place du Temple 15
1227 Carouge, Switzerland
S. Simos & O. Crivelin

Modeling Group

University of Strathclyde
75 Montrose Street
Galsgow G1 1XJ, Scotland
J. Clarke, J. Hand, C. Johnstone, I. Macdonald

Esbensen Consulting Engineers
Teknikerbyen 38, 2830 Virum,
Danemark
C.E. Madsen

LNEC
Av. do. Brasil 101
1799 Lisboa, Portugal
L. Carvalho

LESO-PB / EPFL
1015 Lausanne, Switzerland
R. Compagnon (until 30 Sept. 1996),
S. Citherlet, G. Courret

Design Guide Sources Group

LESO-PB / EPFL
1015 Lausanne, Switzerland
G. Courret, L. Michel

Royal Institute of Technology
Built Environment
Box 88, S-801 02 Gävle, Sweden
H. A. Lötberg

Design Guidelines Group

The Martin Centre
6 Chaucer Road, Cambridge CB2 2EB, UK
N. Baker & R. Compagnon (since 1 October 1996)

UPC-Architecture
Av. Diagonal 649, 80028 Barcelona,
Spain
R. Serra & H. Koch

University College Dublin
Energy Research Group
Richview Clonskeagh
Dublin 14, Ireland
J. Goulding & O. Lewis

Norwegian Institute of Technology
Faculty of Architecture, 7034
Trondheim, Norway
O. Aschehoug & B. Brekke

A.N. Tombazis and ass. Architects
85, Marathonodromou str.
154 52 Psychico, Greece
A. Tombazis

LESO-PB / EPFL
1015 Lausanne, Switzerland
J.-L. Scartezzini, R. Compagnon (until 30 Sept. 1996),
B. Paule

ANNEX B - Recommended values of electric lighting consumption (SIA 38014 Electric installations in buildings)

Valeurs de référence pour les éclairements et les puissances spécifiques installées

Catégorie	Utilisation du local, genre d'activité	Eclairement nominal E_n (Lux)	Puissance spécifique installée [1]) P_{LU} (W/m²)
1	- Surfaces extérieures - parking	20	1 - 2
2	- dépôt de matériel - surfaces de circulation dans les bâtiments - escaliers, couloirs, halls d'entrée - installations de production sans besoins particuliers - locaux d'habitation - théâtre (surface destinée aux spectateurs	100	3 - 5
3	- dépôts avec tâches de lecture - café-restaurant - installation de production occupée en permanence	200	3 - 8
4	- bureau individuel près de fenêtres - bibliothèques - salles de cours - salles de conférences - surfaces de ventes sans exigences particulières	300	6 - 10
5	- bureaux à grandes surfaces - auditoires spéciaux - surfaces de ventes avec exigences plus élevées - cuisines - halles de démonstration et d'exposition - installations de production avec exigences élevées	500	10 - 15
6	Utilisations particulières	> 500 [2])	

[1]) Valable pour des systèmes conçus en fonction des économies d'énergie, valeurs comprenant les pertes des ballasts et l'influence du vieillissement.

[2]) Avec recommandations pour un éclairage général relativement faible et l'utilisation d'éclairage particulier aux places de travail.

Temps d'utilisation normale

	(h/d)	(d/a)	(h/a)
Bureaux	11	250	2750
Surfaces de ventes [1])	12	300	3600
Salles de cours [2])	10	200	2000
Chambres à coucher (d'hôpital, d'hôtel)	24	365	8760
Salles de conférence [2])	5,5	250	1375
Auditoires [2])	6	200	1200
Hall de réception [2])	11	250	2750
Restaurant [2])	12	300	3600
Parking [2])	11	250	2750

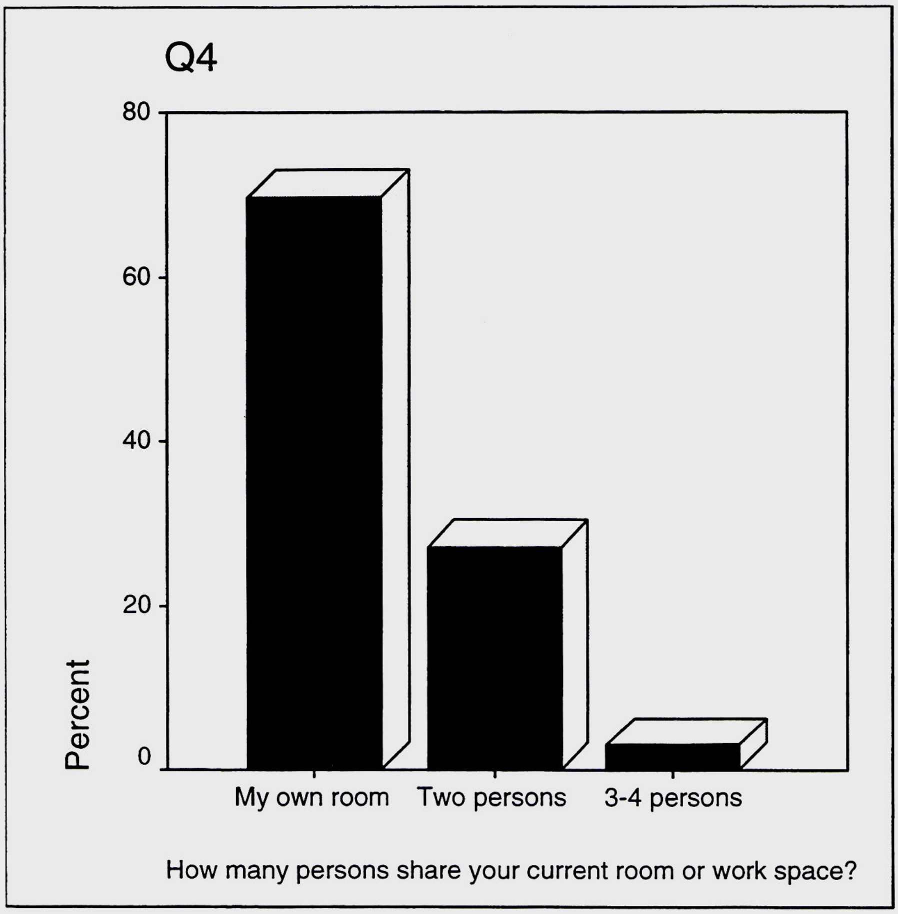
Facteurs d'exploitation f_b pour l'éclairage de bureau

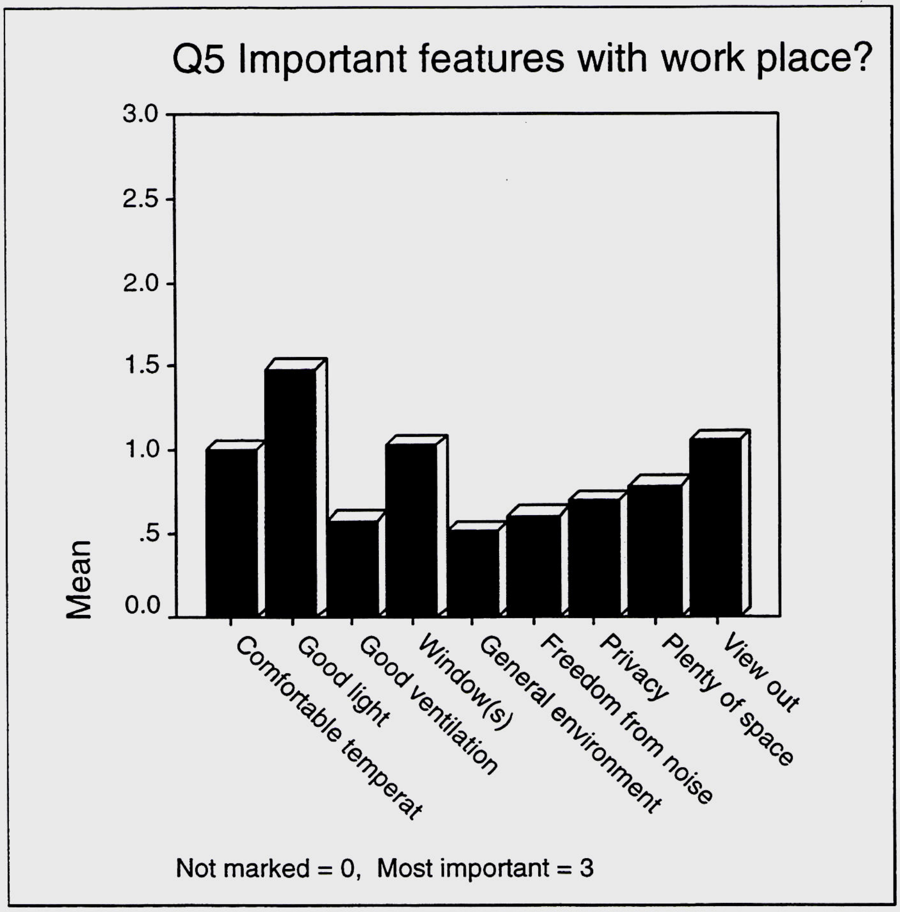
Durée d'utilisation des locaux : 2750 h/a (250 x 11h/jour)

f_b (-)	Durée d'enclenchement de l'éclairage (h/a)	Classe 1 d'éclairage
0,35	1000	très clair, D > 3%
0,50	1400	clair, D env. 2%
0,65	1800	sombre, D < 1%
1	2750	locaux internes

D : facteur de lumière du jour, mesuré à 4 m de distance de la fenêtre (2e rangée de places de travail).
Eclairage général : 500 lx,
facteur d'exploitation f_b : valeur théorique, moyenne de 2 rangées d'éclairage

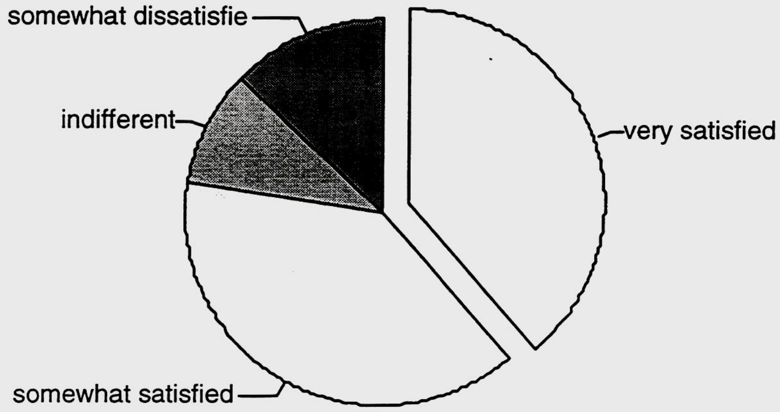
Remarques:
Ces valeurs sont valables pour un enclenchement automatique ou continu de l'éclairage. Pour une commande manuelle, le facteur fb doit être augmenté de 20%, sans dépasser toutefois fb=1.


Q4
80
60
40
20
0
Percent
My own room
Two persons
3-4 persons
How many persons share your current room or work space?


Q5 Important features with work place?
3.0
2.5
2.0
1.5
1.0
.5
0.0
Mean
Comfortable temperat
Good light
Good ventilation
Window(s)
General environment
Freedom from noise
Privacy
Plenty of space
View out
Not marked = 0, Most important = 3

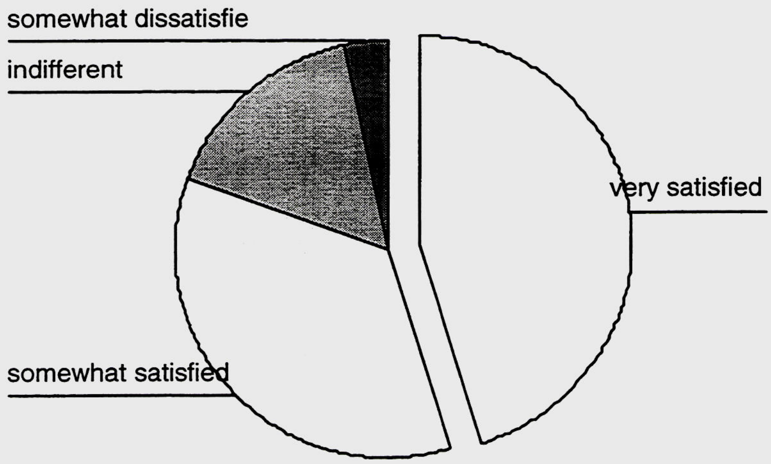
Q6D How satisfied are you with the following aspects of your work place?

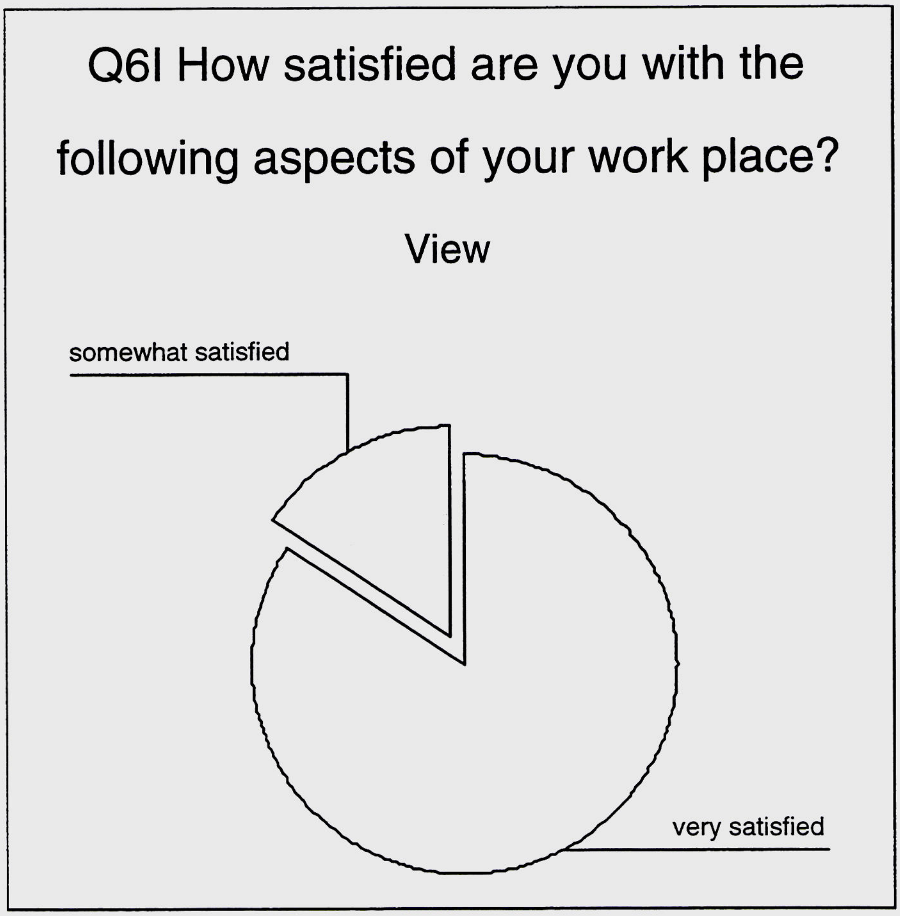
Ventilation

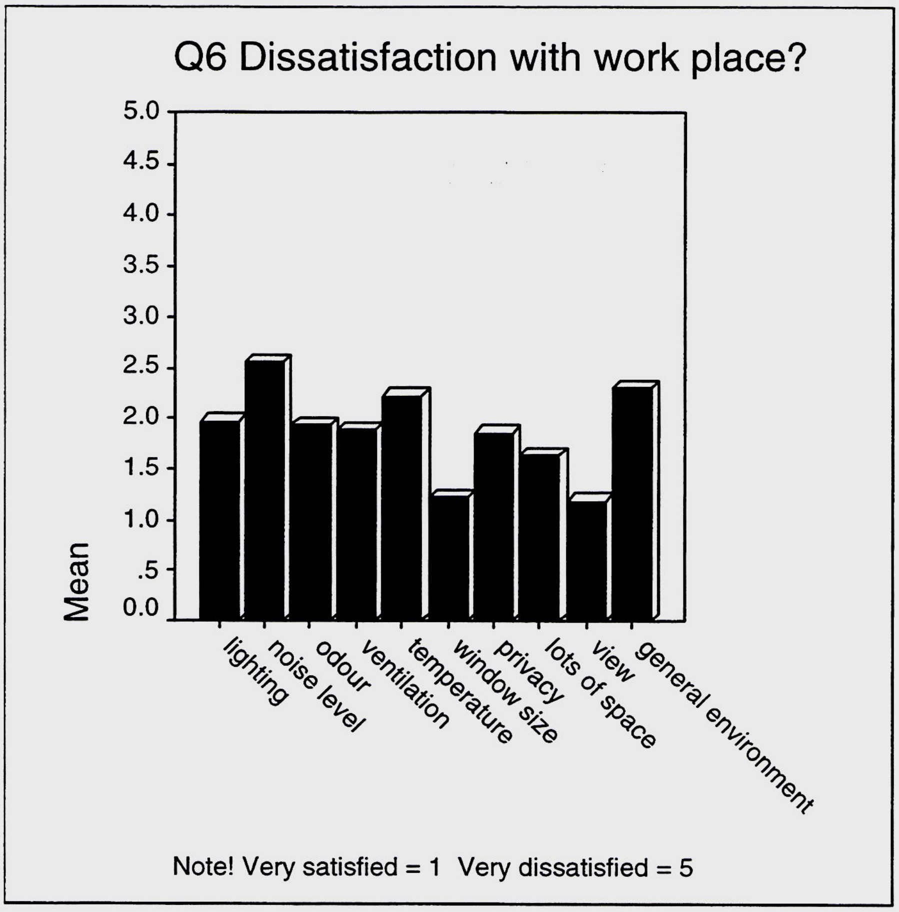


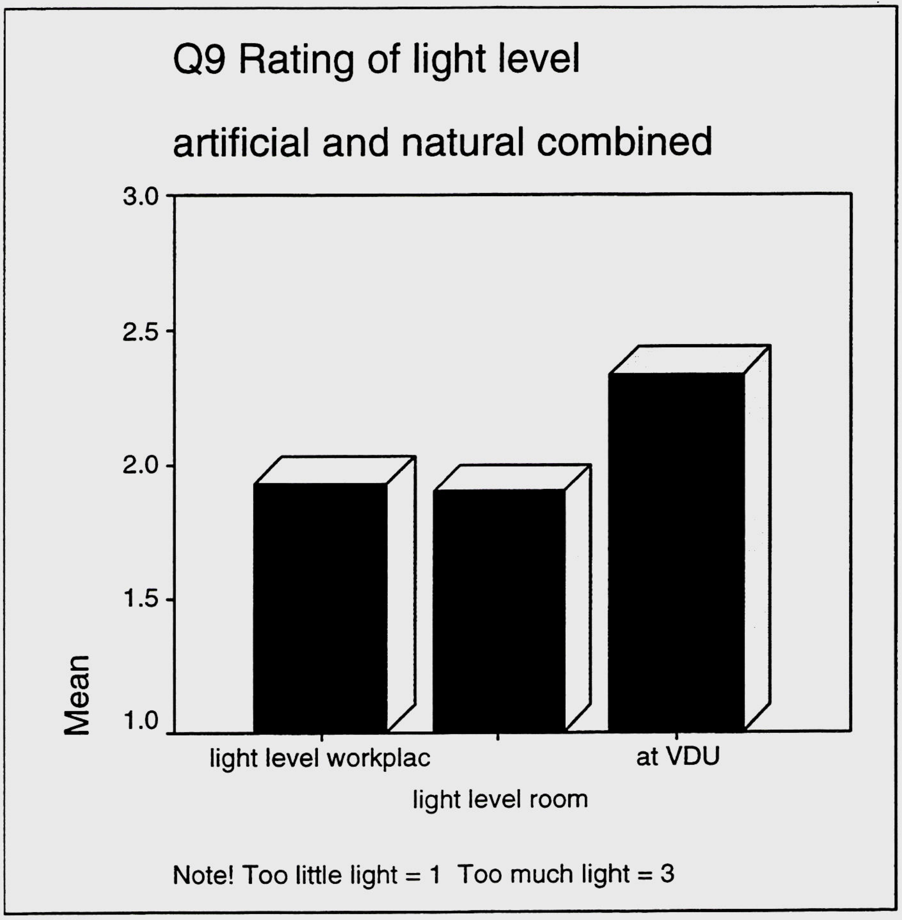
Q6G How satisfied are you with the following aspects of your work place?

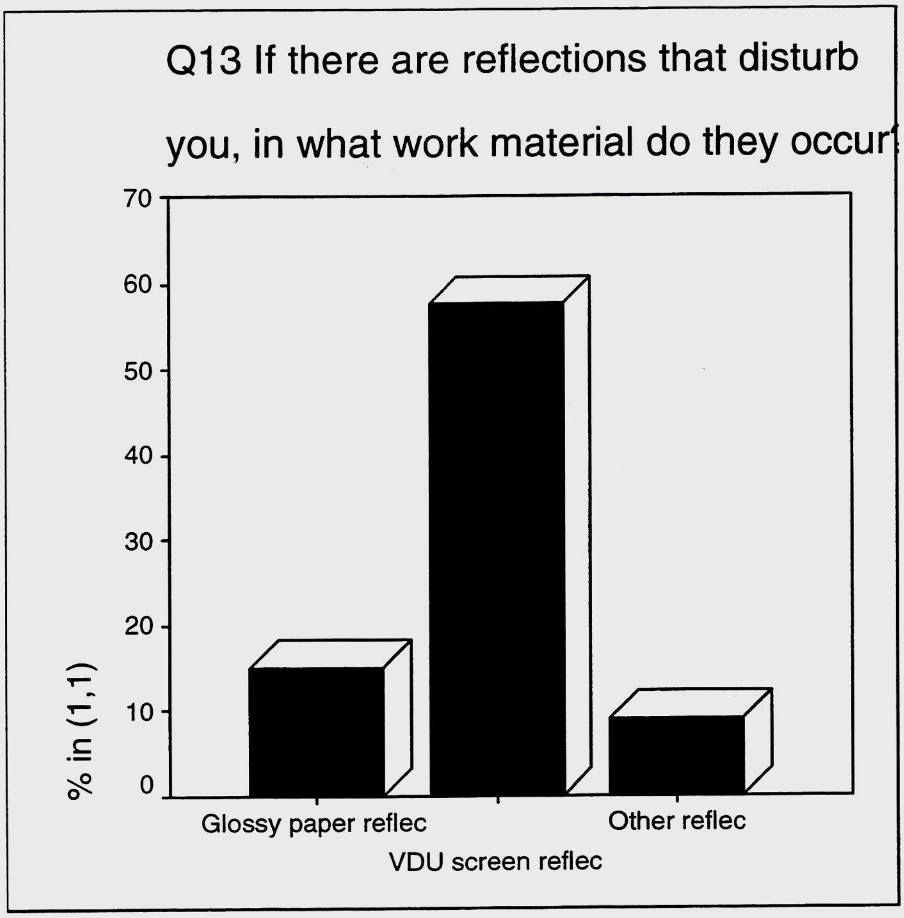
Privacy



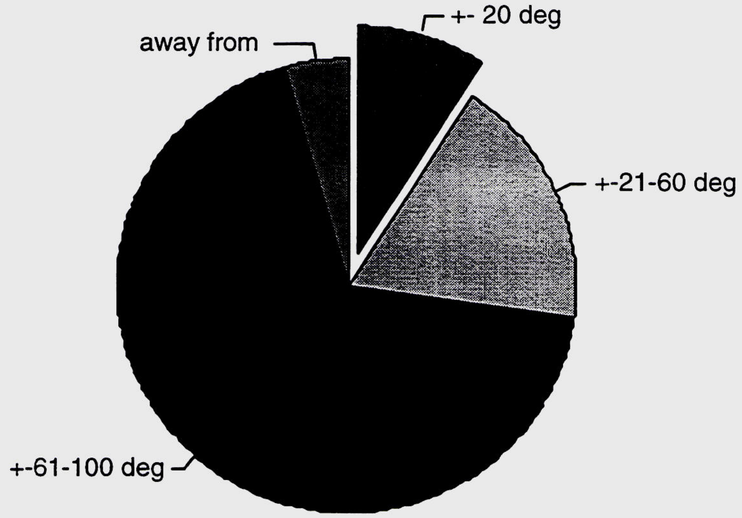

Q6l How satisfied are you with the
following aspects of your work place?
View
somewhat satisfied
very satisfied


Q6 Dissatisfaction with work place?
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0.0
Mean
lighting
noise level
odour
ventilation
temperature
window size
privacy
lots of space
view
general environment
Note! Very satisfied = 1 Very dissatisfied = 5

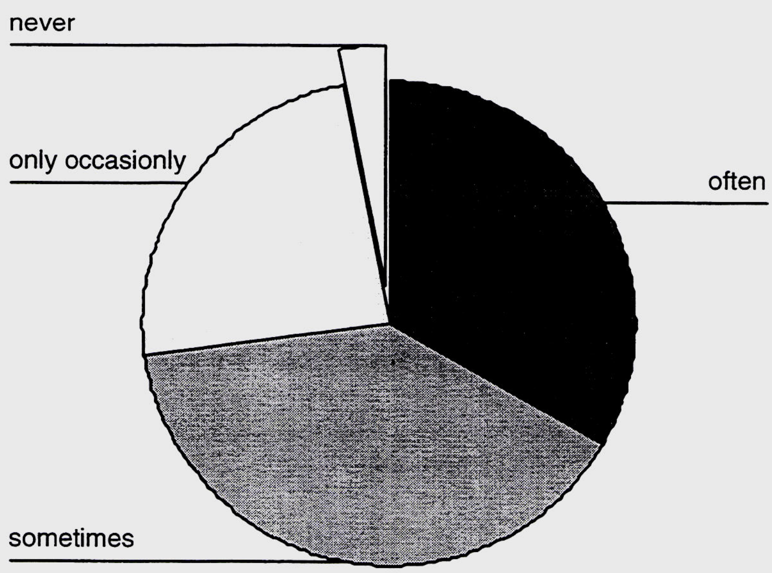

Q9 Rating of light level
artificial and natural combined
Mean
3.0
2.5
2.0
1.5
1.0
light level workplac
light level room
at VDU
Note! Too little light = 1 Too much light = 3

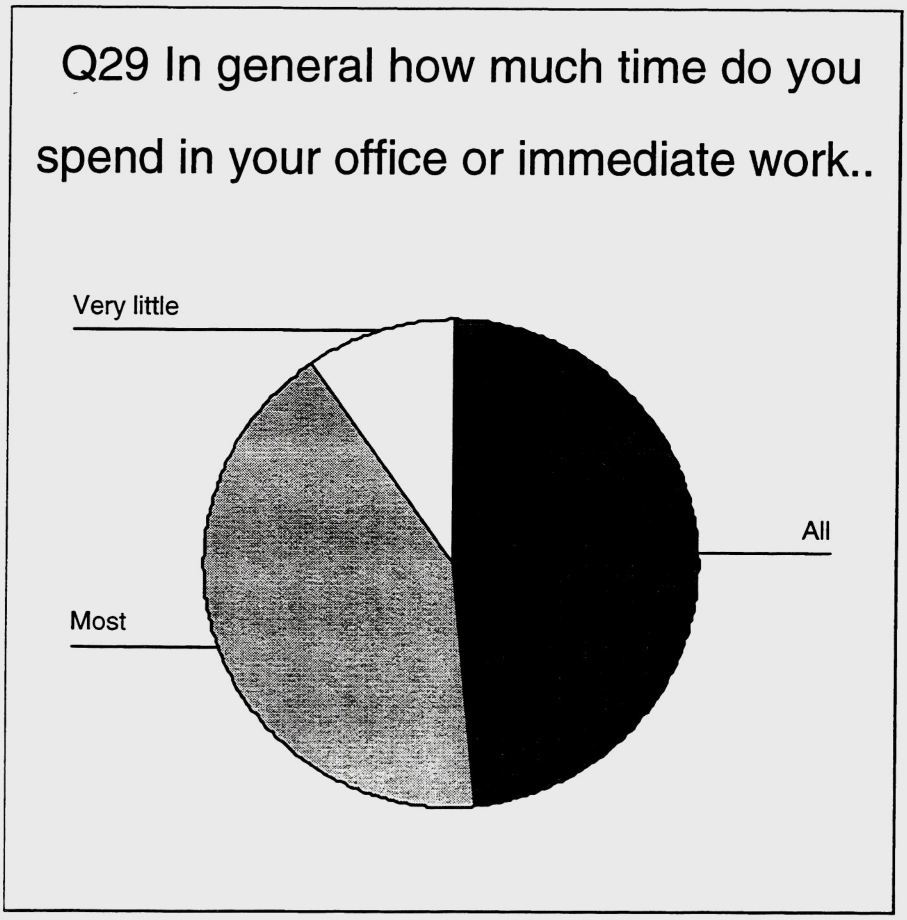

Q13 If there are reflections that disturb
you, in what work material do they occur?
% in (1,1)
70
60
50
40
30
20
10
0
Glossy paper reflec
VDU screen reflec
Other reflec

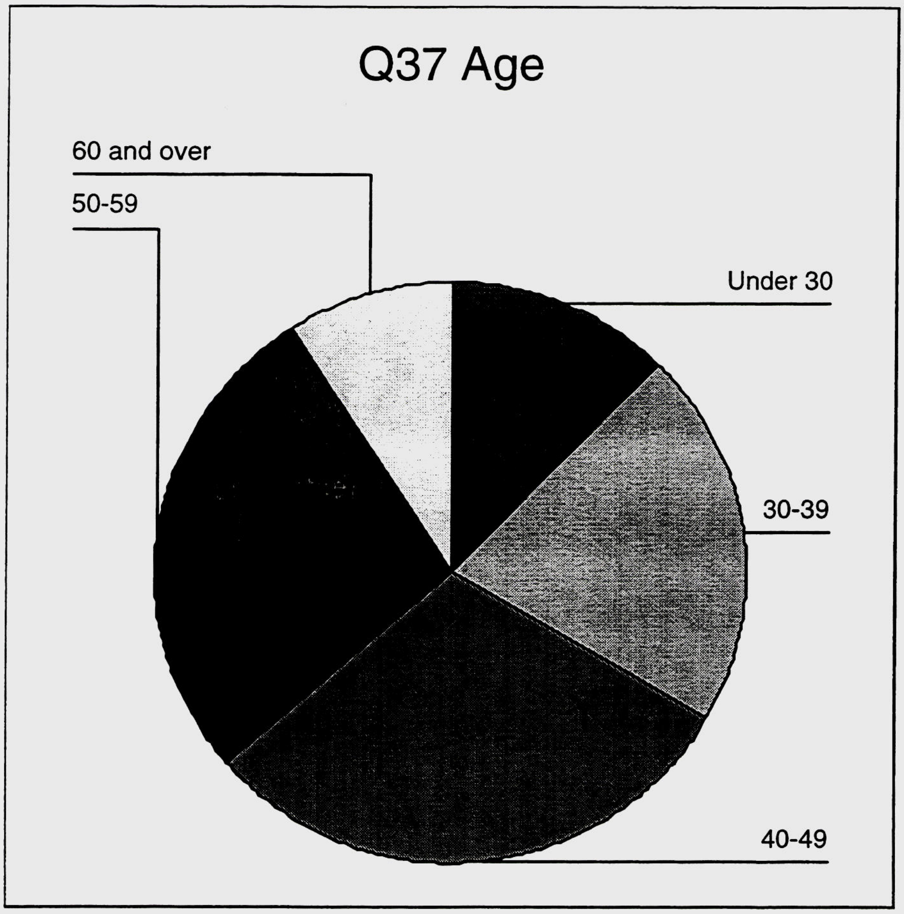
Q17A How is your workplace oriented in relation to the windows?



Q22 Does it ever become too hot because of the sunshine coming in...

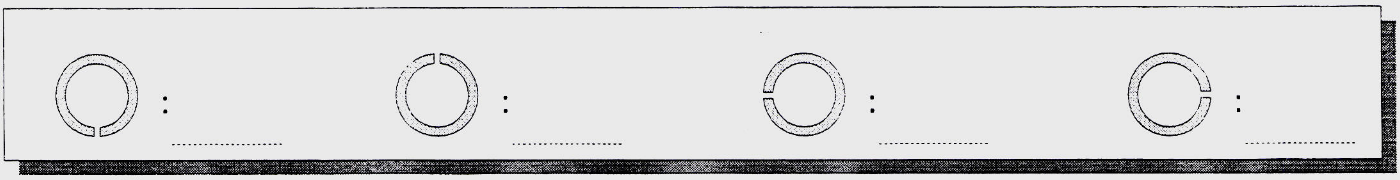



Q29 In general how much time do you spend in your office or immediate work..
Very little
All
Most


Q37 Age
60 and over
50-59
Under 30
30-39
40-49

ANNEX D - Test of acuity (Landolt Rings)

Compter les anneaux en fonction de leur orientation
et inscrire ci-dessous le nombre trouvé pour chaque catégorie
(Effectuez cet exercice le plus rapidement possible
sans faire de marque sur les anneaux)



Avez-vous allumé l'éclairage éléctrique pour effectuer ce test ?

- ○ oui
- ○ non
- ○ j'ai effectué plusieurs changements

Si oui, quel mode était utilisé

- ○ manuel
- ○ automatique (régulation en fonction de la lumière naturelle)
- ○ j'ai effectué plusieurs changements

ACKNOWLEDGEMENTS

The following institutions and/or people supported this research project:

- the Swiss Federal Office of Education and Science (OFES/BBW), who financed the main part of the project,
- the Swiss Federal Institute of Technology in Lausanne (EPFL), who provided support and the technical infrastructure,
- Dr. P.E. Zinsli and Dr. P. Berlincourt from OFES/BBW, who ensured the follow-up of the project,
- Prof. C. Morel, from the Building Technology Institute (ITB) of the EPFL, who volunteered to follow and comment our work,
- Mrs. B. Smith for the correction of English and typewriting of the whole report.

The authors express their thanks to all of them.