POE
Post occupancy evaluation of daylight in buildings

A Report of
IEA SHC TASK 21 / ECBCS ANNEX 29
December 1999

INTERNATIONAL ENERGY AGENCY
Solar Heating & Cooling Programme

International Energy Agency

Energy Conservation in Buildings and Community Systems Programme

This report was printed and is available at:

Centre for Built Environment
BMG – HiG
SE-801 76 Gävle, Sweden

Fax: +46-26-648181
e-mail: staffan.hygge@hig.se

IEA SHC Task 21/ ECBCS Annex 29

Post occupancy evaluation of daylight in buildings

by

Staffan Hygge and Hans Allan Löfberg

KTH - Royal Institute of Technology

Centre for Built Environment

Gävle, Sweden

with the contribution of Subtask D participants

A report of IEA SHC Task 21/ ECBCS Annex 29

Preface

International Energy Agency

The International Energy Agency (IEA) was established in 1974 as an autonomous agency within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. It carries out a comprehensive program of energy co-operation among twenty-five of the OECD's twenty-nine member countries and the Commission of the European Community.

An important part of the Agency's program involves collaboration in the research, development and demonstration of new energy technologies to reduce excessive reliance on imported oil, increase long-term energy security and reduce greenhouse gas emissions. The IEA's R&D activities are headed by the Committee on Energy Research and Technology (CERT) and supported by a small Secretariat staff, headquartered in Paris. In addition, three Working Parties are charged with monitoring the various collaborative energy agreements, identifying new areas for co-operation and advising the CERT on policy matters.

Collaborative programs in the various energy technology areas are conducted under Implementing Agreements, which are signed by contracting parties (government agencies or entities designated by them). There are currently 40 Implementing Agreements covering fossil fuel technologies, renewable energy technologies, efficient energy end-use technologies, nuclear fusion science and technology, and energy technology information centres.

The Solar Heating and Cooling Programme (SHC)

The Solar Heating and Cooling Programme was one of the first IEA Implementing Agreements to be established. Since 1977, its 20 members have been collaborating to advance active solar, passive solar and photovoltaic technologies and their application in buildings.

Australia	Finland	Norway
Austria	France	Spain
Belgium	Italy	Sweden
Canada	Japan	Switzerland
Denmark	Mexico	United Kingdom
European Commission	Netherlands	United States
Germany	New Zealand	

A total of 26 Tasks have been initiated, 19 of which have been completed. Each Task is managed by an Operating Agent from one of the participating countries. Overall control of the program rests with an Executive Committee comprised of one representative from each contracting party to the Implementing Agreement. In addition, a number of special ad hoc activities--working groups, conferences and workshops--have been organised.

The Tasks of the IEA Solar Heating and Cooling Programme, both completed and current, are as follows:

Completed Tasks:
Task 1 Investigation of the Performance of Solar Heating and Cooling Systems
Task 2 Co-ordination of Solar Heating and Cooling R&D
Task 3 Performance Testing of Solar Collectors
Task 4 Development of an Insolation Handbook and Instrument Package
Task 5 Use of Existing Meteorological Information for Solar Energy Application
Task 6 Performance of Solar Systems Using Evacuated Collectors
Task 7 Central Solar Heating Plants with Seasonal Storage
Task 8 Passive and Hybrid Solar Low Energy Buildings
Task 9 Solar Radiation and Pyranometry Studies
Task 10 Solar Materials R&D

Task 11 Passive and Hybrid Solar Commercial Buildings
Task 12 Building Energy Analysis and Design Tools for Solar Applications
Task 13 Advance Solar Low Energy Buildings
Task 14 Advance Active Solar Energy Systems
Task 16 Photovoltaics in Buildings
Task 17 Measuring and Modeling Spectral Radiation
Task 18 Advanced Glazing and Associated Materials for Solar and Building Applications
Task 19 Solar Air Systems
Task 20 Solar Energy in Building Renovation

Completed Working Groups:
CSHPSS
ISOLDE
Materials in Solar Thermal Collectors

Current Tasks:
Task 21 Daylight in Buildings
Task 22 Building Energy Analysis Tools
Task 23 Optimisation of Solar Energy Use in Large Buildings
Task 24 Solar Procurement
Task 25 Solar Assisted Air Conditioning of Buildings
Task 26 Solar Combisystems
Task 27 Performance of Solar Facade Components
Task 28 Solar Sustainable Housing
Task 29 Solar Crop Drying
Task 30 Solar City (Task Definition Phase)

Current Working Groups:
Evaluation of Task 13 Houses
PV/Thermal Systems (Definition Phase)

To receive a publications catalogue or learn more about the IEA Solar Heating and Cooling Programme visit our Internet site at http://www.iea-shc.org or contact the SHC Executive Secretary, Pamela Murphy, Morse Associates Inc., 1808 Corcoran Street, NW, Washington, DC 20009, USA, Tel: +1/202/483-2393, Fax: +1/202/265-2248, E-mail: pmurphy@MorseAssociatesInc.com.

Energy Conservation in Buildings and Community Systems (ECBCS)

Within the programme of Energy Conservation in Buildings and Community Systems the IEA is carrying out various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programs, building monitoring, comparison of calculation methods, as well as air quality and studies of occupancy. Overall control of the programme is maintained by an Executive Committee, which not only monitors existing projects but also identifies new areas where collaborative effort may be beneficial. The twenty-one members of the programme are:

Australia	Germany	Poland
Belgium	Greece	Portugal
Canada	Israel	Sweden
Denmark	Japan	Switzerland
European Commission	Netherlands	Turkey
Finland	New Zealand	United Kingdom
France	Norway	United States

A total of 35 projects, called Annexes have been initiated, 26 of which have been completed. In the list below completed projects are identified by *:

Annex 1 Load Energy Determination of Buildings *
Annex 2 Ekistics and Advanced Community Energy Systems *
Annex 3 Energy Conservation in Residential Buildings *
Annex 4 Glasgow Commercial Building Monitoring *
Annex 5 Air Infiltration and Ventilation Centre
Annex 6 Energy Systems and Design of Communities *
Annex 7 Local Government Energy Planning *
Annex 8 Inhabitant Behaviour with Regard to Ventilation *
Annex 9 Minimum Ventilation Rates *
Annex 10 Building HVAC Systems Simulation *
Annex 11 Energy Auditing *
Annex 12 Windows and Fenestration *
Annex 13 Energy Management in Hospitals *
Annex 14 Condensation *
Annex 15 Energy Efficiency in Schools *
Annex 16 BEMS - 1: Energy Management Procedures *
Annex 17 BEMS - 2: Evaluation and Emulation Techniques *
Annex 18 Demand Controlled Ventilating Systems *
Annex 19 Low Slope Roof Systems *
Annex 20 Air Flow Patterns within Buildings *
Annex 21 Thermal Modelling *
Annex 22 Energy Efficient Communities *
Annex 23 Multi-zone Air Flow Modelling (COMIS) *
Annex 24 Heat Air and Moisture Transfer in Envelopes *
Annex 25 Real Time HEVAC Simulation *
Annex 26 Energy Efficient Ventilation of Large Enclosures *
Annex 27 Evaluation and Demonstration of Domestic Ventilation Systems
Annex 28 Low Energy Cooling Systems*
Annex 29 Daylight in Buildings
Annex 30 Bringing Simulation to Application
Annex 31 Energy Related Environmental Impact of Buildings
Annex 32 Integral Building Envelope Performance Assessment
Annex 33 Advanced Local Energy Planning
Annex 34 Computer-aided Evaluation of HVAC System Performance
Annex 35 Design of Energy Efficient Hybrid Ventilation (HYBVENT)

IEA SHC Task 21 / BCS Annex 29 – List of Participants

Marilyne Andersen
LESO-PB/EPFL
École Polytechnique Fédérale de Lausanne
1015 Lausanne
Switzerland

Heidi Arnesen
Norwegian University of Science and Technology
Faculty of Architecture, Planning and Fine Arts
7491 Trondheim
Norway

Øyvind Aschehoug
Norwegian University of Science and Technology
Faculty of Architecture,
Planning and Fine Arts
7491 Trondheim
Norway

Morad Atif R.
National Research Council Canada
Indoor Environment Research Program
1500. Chemin Montreal Road, (M-24)
Ottawa, Ontario K1A OR6
Canada

Sirri Aydinli
Technische Universität Berlin
Sekr.: E6
Einsteinufer 19
10587 Berlin
Germany

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

Magali Bodart
Université Catholique de Louvain
Architecture et Climat
Place de Levant 1
1348 Louvain-la-Neuve
Belgium

Bjørn Brekke
SEFAS
N-7491 Trondheim
Norway

Stephen Carpenter
Enermodal Engineering Ltd.
650 Riverbend Drive
Kitchener
Ontario N2K 3S2
Canada

William L. Carroll
Lawrence Berkeley National Laboratory
Mailstop 90 - 3026
Berkeley, 94720 CA
USA

Jens Christoffersen
Danish Building Research Institute
Energy and Indoor Climate Division
Postboks 119
2970 Hørsholm
Denmark

Jan de Boer
Fraunhofer-Institut für Bauphysik
Nobelstrasse 12
70569 Stuttgart
Germany

Michael Dirksmöller
Fraunhofer-Institut für Bauphysik
Nobelstrasse 12
70569 Stuttgart
Germany

Michael Donn
Victoria University of Wellington
Centre for Building Performance
P.O.Box 600
Wellington 1
New Zealand

Ian Edmonds
Queensland University of Technology
School of Physics
GPO Box 2434
Brisbane Q 4001
Australia

Hans Erhorn
Fraunhofer-Institut für Bauphysik
Nobelstrasse 12
70569 Stuttgart
Germany

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

Anca Galasiu
National Research Council Canada
Indoor Environment Research Program
Ottawa
Ontario K1A OR6
Canada

Karl Grau
Danish Building Research Institute
Energy and Indoor Climate Division
Postboks 119
2970 Hoersholm
Denmark

Christina Henriksen
Esbensen Consulting Engineers
Vesterbrogade 124 B
1620 Copenhagen V
Denmark

Nicole Hopkirk
EMPA
Überlandstrasse 129
8600 Dübendorf
Switzerland

Staffan Hygge
KTH-Royal Institute of Technology
Built Environment
Box 88
801 02 Gävle
Sweden

Roman Jakobiak
Inst. für Bau-, Umwelt- und Solarforschung
Caspar Theyss Strasse 14 a
14193 Berlin
Germany

Kjeld Johnsen
Danish Building Research Institute
Energy and Indoor Climate Division
Postboks 119
2970 Hørsholm
Denmark

Warren Julian
University of Sydney
Architectural & Design Science
Sydney, NSW 2006
Australia

Martin Kischkoweit-Lopin
FH Köln
Institut für Licht- und Bautechnik
Gremberger Strasse 151 a
51105 Köln
Germany

Martin Klingler
Ing. Büro Martin Klingler
Kaplanstrasse 2
6063 Rum/Innsbruck
Austria

Poul Erik Kristensen
The Technological Institute
Energiafdelingen
Gregersensvej, Postboks 141
2630 Taastrup
Denmark

Heinrich Kaase
Technische Universität Berlin
Institut für Elektronik und Lichttechnik
Einsteinufer 19
10587 Berlin
Germany

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

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

Eleanor Lee
Lawrence Berkeley National Laboratory
Building 90 - Room 3111
94720 Berkeley, CA
USA

Paul Littlefair
Building Research Establishment
Garston
Watford, Herts. WD2 7JR
United Kingdom

James Love
University of Calgary
Faculty of Environmental Design
2500 University Drive N.W.
Calgary, Alberta T2N 1N4
Canada

Ingo Lütkemeyer
Inst. für Bau-, Umwelt- und Solarforschung
Caspar Theyss Strasse 14 a
14193 Berlin
Germany

Hans Allan Löfberg
KTH-Royal Institute of Technology
Built Environment
Box 88
801 02 Gävle
Sweden

Laurent Michel
LESO-PB/EPFL
École Polytechnique Fédérale de Lausanne
1015 Lausanne
Switzerland

Sven Olsson
Signal Control
IDEON
S - 223 70 Lund
Sweden

David Oppenheim
Taylor Oppenheim Architects Pty Ltd
9/696 High Street
East Kew
Victoria 3102
Australia

Bernard Paule
LESO-PB/EPFL
École Polytechnique Fédérale de Lausanne
1015 Lausanne
Switzerland

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

Geoffrey Roy
Murdoch University
School of Engineering
Murdoch, WA. 6150
Australia

Nancy Ruck
University of Sydney
Dept. of Architectural & Design Science
Sydney, NSW 2006
Australia

Jean-Louis Scartezzini
LESO-PB/EPFL
École Polytechnique Fédérale de Lausanne
1015 Lausanne
Switzerland

Steve Selkowitz
Lawrence Berkeley National Laboratory
Building 90 - Room 3111
Berkeley, CA 94720
USA

Simon Simos
Simos Lighting Consultants
30, Chemin du Nant d'Aisy
1247 Anieres
Switzerland

Nils Svendenius
Lund University
Dept. of Atomic Spectroscopy
Sölvegatan 14
223 62 Lund
Sweden

Frans Taeymans
Etap Lighting N.V.
Antwerpsesteenweg 130
2390
Belgium

Ariadne Tenner
Philips Lighting BV
CLAIR, Building EDX
P O Box 80020
5600 JM Eindhoven
The Netherlands

Paul Torcellini
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401
USA

Martine Velds
Delft University of Technology
Berlageweg 1, Room 650
2628 CR Delft
The Netherlands

Jan Wienold
Fraunhofer Institute for Solar Energy Systems
Oltmannsstrasse 5
79 100 Freiburg
Germany

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

Table of contents

Summary

A method to study user reactions to indoor environment, especially daylighting, has been developed. It is based on a questionnaire including not only attitudes to daylight and windows but to the total physical environment.

In the report is described how to use the questionnaire. The criteria that need to be fulfilled before the replies can be statistically analysed and valid conclusions drawn are stated in detail.

The questionnaire was first used in the Joule II Project Daylight Europe and then more extensively used in the IEA SHC Task21 project. Some examples of results are given to show how they can be presented. Through repeated presentation of the questionnaire to the same group of users of a building, both the validity and sensibility of the measurement tool have been tested.

Acknowledgements

The Swedish participation in the IEA SHC Task 21/ ECBCS Annex 29 has been made possible by a grant from the Swedish Council for Building Research (BFR). Valuable comments and suggestions for improvements of the manual and questionnaire have been received from Subtask D participants in particular and IEA SHC Task 21/ ECBCS Annex 29 participants in general. Particularly we want to thank Mr. Kevin Poulton for his contributions.

1. Introduction

This report presents a method to study the reactions and attitudes of users of a building. It should be read as a complement to the protocols and procedures to monitor the daylighting performance of buildings presented within the Subtask D (Atif et al. 1997), and can with some modifications be used in all building types.

The IEA SHC Task 21/ ECBCS Annex 29 focuses on daylighting systems and strategies that can be applied in new and existing buildings with high electricity saving potential such as offices, schools, commercial, and institutional buildings. The daylighting performance provided by these strategies and systems is tested in laboratory facilities, through mo delling and in real case-study buildings.

Results from modelling and measurements of building daylighting systems may show electricity savings compared with a similar building without this system, but the daylighting system will be successfully used only if the building occupants are satisfied with the indoor environment and the operation of the system.

A post occupancy evaluation (POE) of the building indicates how successful the building is, where the problems are, and, to some extent, how the performance can be improved.

Many buildings have been evaluated over the years but in almost all cases a different type of questionnaire for POE has been employed. It is thus very difficult to assess which method is the best and to compare different buildings on the same scale. From the experience reported in previous POE studies (Collins et al., 1989; Elder, Turner, & Rubin, 1979; Energy Edge, 1991) a questionnaire for evaluation of the daylight and other parameters of the office work environment was designed. The design of this questionnaire started in the Joule II project Daylight Europe (Fontoynont, 1999) and was based on questions used in former POE-studies, The questionnaire has now been used in some of the real buildings studied in Task 21/ ECBCS Annex 29.

The questionnaire should not be regarded as the only and complete set of questions to use. For specific buildings some questions are not relevant and can be deleted. For specific features of a building and its systems questions can be added. The important thing is that the main set of questions is preserved from one building to the next. In this way the knowledge about different buildings can be expanded and compared.

The ultimate goal of Subtask D is that both the monitoring protocol and the POE questionnaire become standard tools to evaluate the quality of the daylight design and the user acceptance of a building.

To draw any significant conclusions from a POE, a number of criteria must be met. Since only a few of the buildings studied in the IEA SHC Task 21/ ECBCS Annex 29 fulfil these criteria, the number of cases studied is limited. Several problems and obstacles that can be encountered when planning and carrying out a POE are discussed and suggestions are given on how to minimise these problems.

2. Overview of Subtask D: Daylight monitoring of case studies

This document was developed for the user evaluation of the daylighting performance of IEA SHC Task 21/ ECBCS Annex 29 case studies located in Europe, North America and Australia. It is one of the deliverables in Subtask D research projects.

The main objective of Subtask D, as stated in the Implementing Agreement of Task 21/ ECBCS Annex 29, is ”to demonstrate the viability of daylit buildings in various world climate zones as a means of achieving significant improvements in building energy efficiency while maintaining a satisfactory visual and thermal environment for occupants.” The Annex identifies the scope of the Subtask as limited to the following measured data: ”illuminance, luminance distribution of interior space, electricity use for lighting, total building energy use, and user acceptance of environmental conditions.”

The Subtask includes the following activities:

1. Preparation of documentation program and a database in which the case studies are described in a typological context as a basis for selection of case studies demonstrating integration of daylighting systems and control strategies in various climates.

2. Establishment of adequate monitoring procedures.

3. Development of procedures for the evaluation of user acceptance.

4. Monitoring of buildings and user acceptance studies in selected case studies.

5. Production of case study reports.

This document is a deliverable of activity no. 3 in the above list.

3. Objectives and limitations

3.1 Rationale for POE

The need to complement physical measurements of daylight in a building, lighting energy used etc. with a study of the users' attitude to the building is not always fully understood. Even if a building is technically perfect and energy efficient, its performance can be counteracted if energy control systems are not accepted by the users. The controls must be understood and easy to handle. No discomfort like glare, disturbing reflections, unpleasant thermal conditions or noise should be e xperienced.

If the users are dissatisfied with the environment and the control system, they will most likely find ways to overcome these controls, and/ or add things to improve the work environment like additional lamps, shading of windows to reduce glare, blocking sensors etc.

A systematic survey of the users' attitudes to the indoor environment can help to understand the merits and problems of daylighting systems and controls as adapted to the specific building and the conditions created by the building design and the use of the building. Dissatisfaction expressed should be used to try to understand where and why problems are found. In this way potential changes can be made to improve the indoor environment.

By employing a standardised procedure to study the users' reactions, a better understanding of what is most important in the environment can be gained. Doing this also provides a basis for comparison of different buildings and daylighting systems. Of course, a standardised survey method can not only be used to study the daylighting systems, but also all types of buildings and physical work environments. Since the task of this project is to evaluate daylighting systems the method proposed focuses on this, but can be extended or adapted to other conditions.

Since the users are humans it is not possible to find a system that is accepted by all at all times. This must be borne in mind when designing the survey and also when carrying it out.

Since the daylight changes with the cloudiness of the sky, with the time of day and over the year a spot test or study can not be regarded as representative of the quality of the building and its systems. The user’s reactions to different outdoor conditions must be integrated for a longer period of time, which means that the study must be repeated or at least designed to get a response covering an extended period of use.

The POEs can be supplemented by other indicators of the quality of the work environment. Sick leave, records of spontaneous complaints about work conditions, complaints of tiredness, eye problems related to the visual environment, draughts, cold or hot, noise problems etc.

The number of POE studies carried out in different countries, as a general rule, is very limited. Often, questions and questionnaires are designed for a specific building and used once only. It is, then, very difficult to really tell which is the best set of questions to use and the best way to get the answers.

Often the problems in analysing and drawing conclusions from a questionnaire are not understood. To be able to make statistical analysis and make definite statements about the work environment, a number of criteria must be met. This puts strict limitations, as described in chapter 3.3, on the cases where a formal POE can be carried out.

The aim in Subtask D is to use one questionnaire in a number of buildings, to test if the questions are useful and understood, and with the answers give support to the technical evaluation of the individual buildings and, if possible, make some comparisons between buildings.

In the Joule II project "Daylight Europe" the problems of evaluating the users' reactions were first discussed and a questionnaire proposed. This was based on some studies in the US where user attitudes were investigated in some buildings and the validity of the questionnaire was evaluated. The questionnaire proposed for Daylight Europe was developed and adjusted to focus on the users' attitude towards lighting and daylight, but was never really tested in a large scale due to problems in the administration of the POEs.

3.2 Objectives of the POE questionnaire

The POE questionnaire will give an indication of what the users think of the building as a whole, of its interior work environment, including noise and thermal conditions, and especially how the lit environment is experienced and how well the users think that the lighting and daylighting control systems work. As the indoor environment is varying over time, especially the daylight, and problems might arise just under specific conditions, the questionnaire is designed to get the users' experience over time.

Since individuals differ in attitudes and demands, there will always be a spread in responses. To account for that, the questionnaire must be distributed to a number of users of the building. There are requirements in number of users and other factors, if the results are to be regarded as statistically valid. If the number of users is small the answers can only be regarded as examples of how users might value the specific systems and buildings.

The results of the POE can give an environmental quality stamp on a building as a whole, but also give indications to certain good or certain poor environmental conditions. POE results should be analysed together with the technical results from energy use, costs etc.

The users' reactions should also be used as indicators to problems that could be solved by readjusting something technical or rearranging work place layout, i.e. not just be regarded as a negative outcome of the POE. This could be the most efficient way to find out where problems are before they have led to more severe problems like fatigue, strained muscles or even sick leave.

3.3 Requirements and limitations

To perform a valid or "formal" POE that can be analysed statistically, a number of criteria must be met. If these can't be met, an "informal" POE can be performed and the results may indicate the user's attitudes but the results must be taken with some caution.

The experimenters or persons carrying out the physical measurements, will most probably also get impressions of the quality of the building and get reactions from the users. This adds information to the evaluation of the building, but this information can not be treated statistically.

Formal POEs

Since people are different, a number of user reactions are needed to reduce the confidence intervals in evaluation and thereby increasing the possibility to detect differences. If the users only experience one condition each, more persons are needed, than if the same persons encounter two or more conditions. In the first case we have a *between persons* study and in the second case a *within persons* study.

The group of persons should be as homogeneous as possible in age, education, sex etc to reduce the spread in evaluations. For a fairly homogeneous group of users, about 30 persons are needed in a *between person* comparison and about 15-20 in a *within persons* situation. If the groups are less homogeneous, larger groups are needed to decrease the variance and to detect real differences.

The ideal condition is thus that the users of a building experience more than one system (lighting control or lighting installation). After experiencing one system for a reasonably long period of time, they fill out the questionnaire. The second system they are exposed to should preferably be experienced during the same time of the year. The time of use should be long enough to allow for different climatic conditions to settle. As a rule of thumb the time should be at least one month.

One way to combine different study designs is to have people experience the same conditions for a first measurement period. For the second measurement period they are split up into two groups. One of the groups are subjected to the same conditions as during period one, but the second group a change in daylight conditions. With this design, the control group is also controlling for the time of year.

Informal POEs

If the number of users is smaller than indicated above, it might be difficult to achieve statistically significant results. But the questionnaire could well give interesting information all the same. Especially if some aspects on the building are very pronounced, the analysis of the replies will give valuable information to the building owner.

The restrictions to consider when carrying out a POE are also found in the manual to the POE questionnaire that is published and is found as Appendix 1.

4. Steps to implement a POE

The different steps in implementing a POE are discussed in detail in the manual (see Appendix 2). The more crucial steps are:

The building must be chooses because it has some interesting daylight feature, and preferably this feature is not introduced to all the occupants at the same time.

The number of users should be estimated in advance to judge what kind of study design could be used, and whether a formal POE is possible at all. Already at this step, the possibilities to change the system after some time and to have a within persons study should be strongly considered.

It goes without much saying that it is important to secure the co-operation of the occupants. To secure representative findings, the must be a high return rate of the questionnaires to avoid bias from the too negative or positive persons. In general, occupants are very helpful, particularly if they trust the integrity of the researcher.

Experience has shown that it is utterly important to get not only the consent, but also the active co-operation of the owners/managers of the building. One way or the other, the owner or management must be convinced that also negative responses are important to establish in order to make the correct changes in the indoor env ironment.

Depending on what building or daylight feature is of main interest, adding items to the questionnaire can be considered. As a main rule, to secure comparability between buildings/features questionnaire items should not be taken out.

Since it is important that the occupants trust the research team, one person in the team should be appointed to be in charge of distributing and collecting the questionnaires. This person should also be the one who handles all contacts with the occupants and assures them it will not be possible for anyone outside the research team to identify who has replied what in questionnaire.

The analyses of the replies to the questionnaires should be done by someone who has an expertise in multivariate statistical techniques and behavioural research methods.

5. Post occupancy evaluations (POEs) of five buildings

Post Occupancy Evaluations were performed for a small number of buildings within the IEA SHC Task 21/ ECBCS Annex 29 *Daylight in Buildings* to establish user reactions to the daylight performance of the buildings.

The main objective of the POE was to evaluate the occupant's response to the building. Lighting qualities for electric light and daylight were using interrelated questions with graded replies. To judge the performance of the lighting systems in relation to other valued aspects of the indoor environment, questions about thermal climate, ventilation, noise, privacy etc. were also asked.

5.1. The buildings

Five buildings were selected for POE-studies. For specific details of the buildings, see their respective sections in the Case Study Chapters.

Bayer Headquarters, Lyngby, Denmark - Case study No. 16

This is a four storey L-shaped office building with an atrium following the long axis of both wings. The offices open to the atrium. Most of the offices are single occupancy rooms with a few double occupancy offices. The urban environment is mostly commercial with three- and four-storey office buildings. The surrounding land is flat and there are no obstructions.

The offices have a size of 15.6 m^2 and to increase daylighting, the offices have a depth of only 5.2 meters. The offices are located on second and third floor and are oriented towards north and south.

The daylighting design uses bi-directional lighting. Daylight enters not only through the facade via two daylight windows (placed near the ceiling), but also through a glazed door, which opens to the atrium. Two additional windows on the facade are used also for a view out. Finally, the corridor is both top and side lit. Blinds are integrated between the windowpanes in the vision windows to optimise the offices for computer work. Glare-free lighting was the major design criterion for the offices, because the occupants spend most of their time using computers. The blinds can be tilted, but they are not retractable.

The design was intended to reduce the use of electric lighting in favor of daylighting. Presence detectors and light sensors control the electric light. However, the users can manually override the automatic control of the electric ligh ting.

POEs were done in rooms on the second floor, facing north and south. Before the first POE-wave nothing was changed which means that the lighting control was automatic on and automatic off at both floors. The lighting changes for the second POE-wave included manual on/automatic off on the second floor. The third floor was left intact as a reference.

The first POE-wave was performed in September/October 1997. Thirty-four occupants replied to the first POE-wave. A change in lighting conditions on the second floor was made in November 1997. The second POE-wave started in May 1998 and was concluded with 21 participants from the first wave.

The Götz Office Building, Würzburg, Germany – Case study No. 10

The Götz office building is a square two-storey office building with a completely glazed double facade with automatic controlled blinds. The electric lighting is controlled automatically. The users have manual controls via their desktop computer and can change the settings.

The interior of the building is characterised by open plan office spaces. A fully glazed partition wall system permits the segregation of cellular offices, conference rooms, computer facilities etc. The building is located in an industrial area in the outskirts of Würzburg, Germany. Other buildings do not interfere with the daylighting of the building. The view out is on two sides into green areas, garden and hills, and on the other two sides towards a factory hall.

The POEs mere done mainly on the ground floor. The subjects were evenly spaced over the floor area, making all orientations equally frequent. In April 1997, 19 occupants replied to the first POE. One year later, 14 of these replied to the second POE.

Green on the Grand, Ontario, Canada - Case study No. 4

Green on the Grand is located in Kitchener, Ontario, 80 km west of Toronto in a new low-rise commercial development. The Grand River and Grand River Hiking Trail run along the eastern boundary of the lot.
The building is low-rise, in keeping with the height of other buildings in the area. The perimeter area is increased by offsetting the two halves of the building. This adjustment allows two-thirds of the office area to have access to perimeter daylight (in all four orientations). A typical office is 15 m^2 with one or two exterior windows. Individual windows are placed high on the wall in each office, so that the natural light will reach deep into the room.
In some offices, translucent fabric roller blinds admit diffuse light and reduce glare. In other offices, horizontal blinds have the slats "upside-down" or concave side facing up, in order to deflect light into the rear areas of perimeter offices. A pitched roof (with cathedral ceiling) permits 8 dormer windows to daylight the interior of the top floor. The interior office areas are open plan.

The POE was finished in May 1998 with 56 persons filling out the questionnaire.

The Solar Energy Research Facility (SERF), Golden, Colorado, USA
- Case study No. 3

This is a 10,700 m^2 facility, housing laboratories and offices in three contiguous modules. Each module has an open-office pod in the front and a laboratory in the back. The lighting controls turn off lighting circuits when ample daylighting is available.

The office area has an open plan design with a few single person offices. There are open surroundings around the building.

The total office area is 659 m^2 in a one-storey building orientated towards south with glazing on facades facing east and west. The daylit office pods were placed on the south side of the laboratory building resulting in a dramatic stepped building form that facilitated clerestory lighting. The stepped form included light shelves, clerestories, and shading devices intended to provide a visually pleasing ambient illumination of the office cubicles. The light shelves not only direct the daylighting, but also hide the electric illumination sources. Shared daylight is used for the enclosed offices located at the north of the open office area.

The POE was completed by 57 occupants in the daylit office areas during the spring of 1998. During that period some circuits used to control the lighting system were not functioning as designed.

The EOS-building - Lausanne, Switzerland

Formally, this building is part of the Joule II Daylight Europe Programme, but since it has been employing the same POE-procedure as IEA SHC Task 21/ ECBCS Annex 29 it is worthwhile to also consider these results.

It is a new office building with a central atrium. The close surrounding is urban, but not noisy and allows natural ventilation through window openings. The building is a grouping of two blocks in line, each with an atrium opening to the facade and linked to an entrance platform on the ground floor. A typical facade module has continuous openings on a stem-wall, together with a horizontal aluminium light shelf. The building incorporates a communication and sanitary core and is located on a sloping site (north-south oriented slope).

The building is surrounded by low-rise buildings and beautiful trees. A view to a lake (south to south-west) is very nice. The offices facing north have a view on the surrounding trees. When the POE study was made, mainly south oriented rooms were occupied. The size of a typical office is 5.70 m by 5.20 m, 2.58 m high. One or two persons occupy these offices. The total floor area is about 400 m^2.

There are aluminium light shelves on the south facade. There was a very detailed design study on the light shelves' geometry and photometric characteristics (scale model under an artificial sky). In the building there are high wall and ceiling reflectances. The floor luminaires are using compact fluorescent lamps (direct/indirect), and there is no automatic or other control of the electric light.

A total of 33 persons filled out the POE questionnaires. This was completed by the end of April 1997.

5.2. Background variables for the people in the buildings

The number of participants in the two waves and the percentage women in the POEs in the different buildings are shown in Table 5.1.

building	number of participants wave 1	wave 2	percent women wave 1
Bayer	34	21	20%
Götz	19	14	26%
Green on the Grand	56		45%
SERF	57		23%
EOS	33		33%
Total	199	35	

table 5.1: The number of participants and the percentage women in the POEs in the different buildings.

The gender distribution in Table 5.1 shows that Green on the Grand has a higher percentage of women than the other buildings.

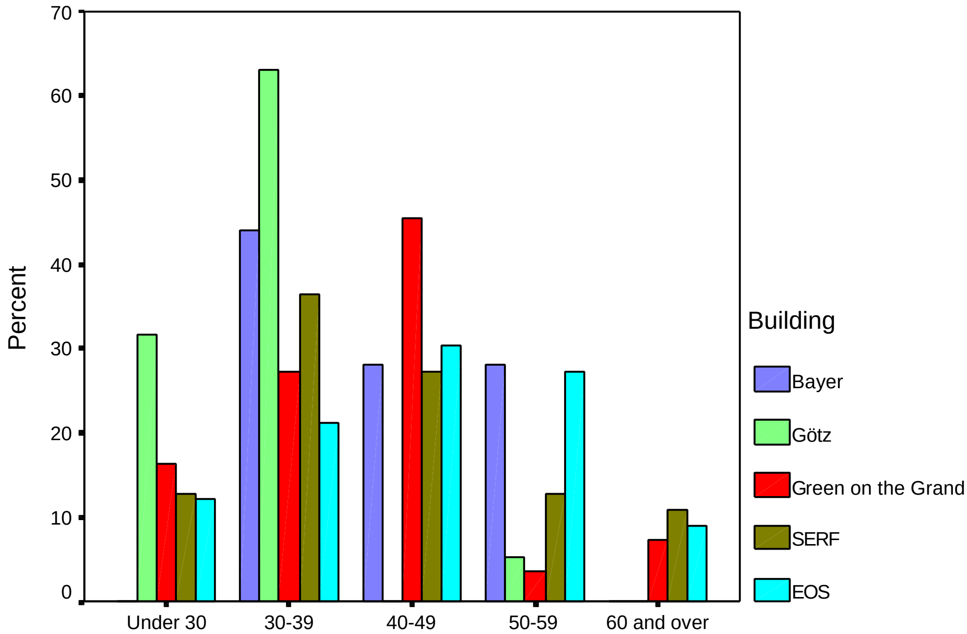


figure 5.1: Age groups in the buildings.

The age distribution in Figure 5.1 shows that Götz has a high fraction of people less than 40 years of age and that EOS and Bayer have high fractions of people aged 50-59.

As shown in Figure 5.2 most persons have an office of their own in the Bayer, SERF and EOS buildings. In the Götz building most people share office with more than 10 others. In the Green on the Grand building this question is not relevant since they share open plan offices

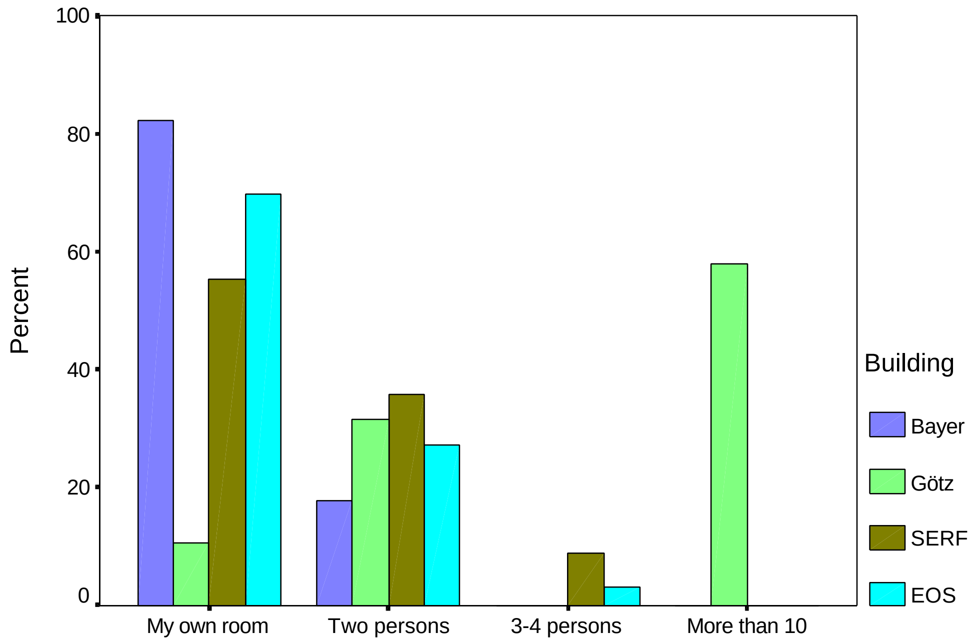


figure 5.2: Number of persons in each office in the buildings.

5.3. What do the occupants want from their indoor office environment?

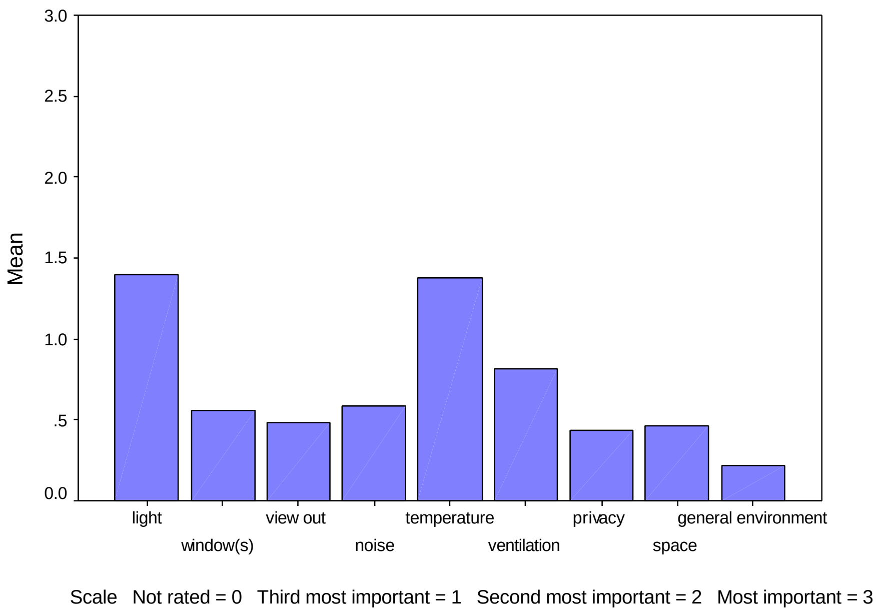


figure 5.3: Mean importance ratings of different aspects of the work place.

Question 5 asked the user to rank the three physical features that are most important in making a work place a pleasant one. They were given a choice between 10 alternatives (comfortable temperature, good light, good ventilation, window(s), general environment (colours, carpets, decoration), noise, privacy, space, view out, and other). The replies to this question were taken as indicators of what the occupants want and not necessarily what they have.

Figures 5.3 shows the mean ranking of the most important features for the workplace. In Figure 5.4 the mean rankings for the separates buildings are shown.

In these figures and several of the following ones, the means are calculated for the scale whose end points are given below the graphs.

Good light and comfortable temperature strongly stand out as the most wanted features. The relative strength between the two varies with building as can be seen in Figure 5.4. In the cases of Götz and Green on the Grand, ventilation is also considered important.

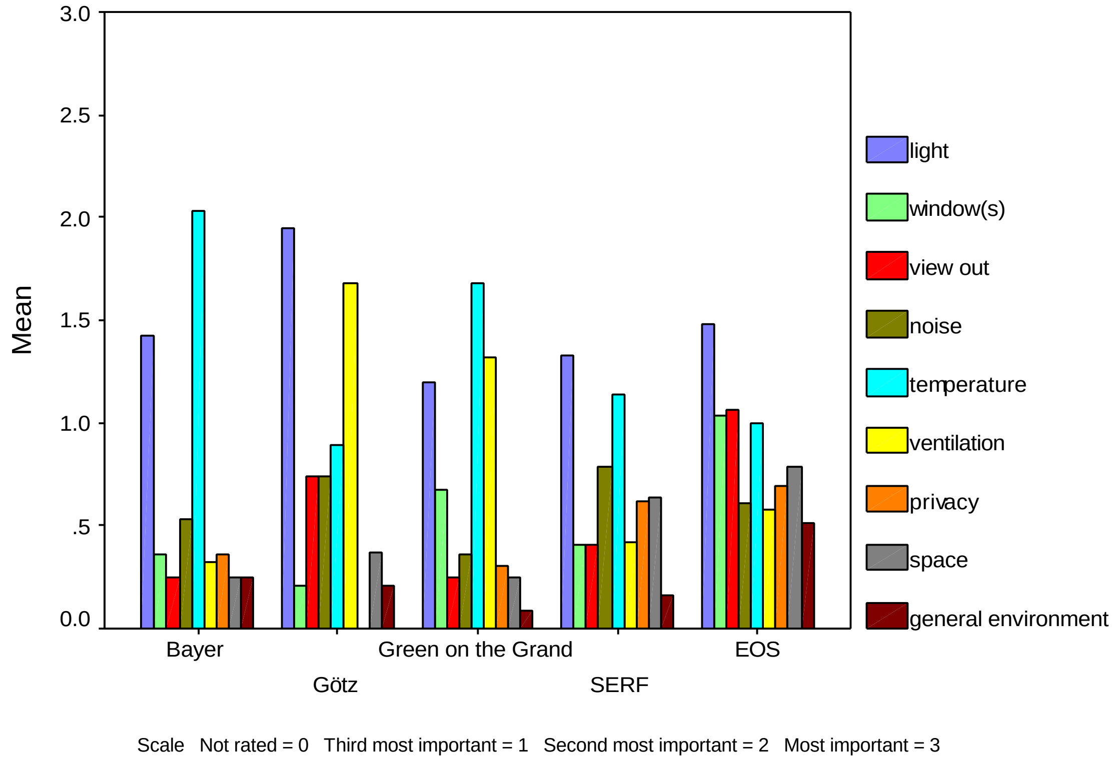


figure 5.4: Mean importance ratings of different aspects of the work place.

5.4. How do the occupants rate their indoor office environment?

The ratings of the indoor environment people encounter in their own offices are shown in Figure 5.5. Lighting, window size, view, space, general environment and (lack of) odour are the features with the highest positive or lowest negative ratings. Ratings of *indifference* are not included in the figure. The following figures 5.6 a-e show comparable values for the individual buildings.

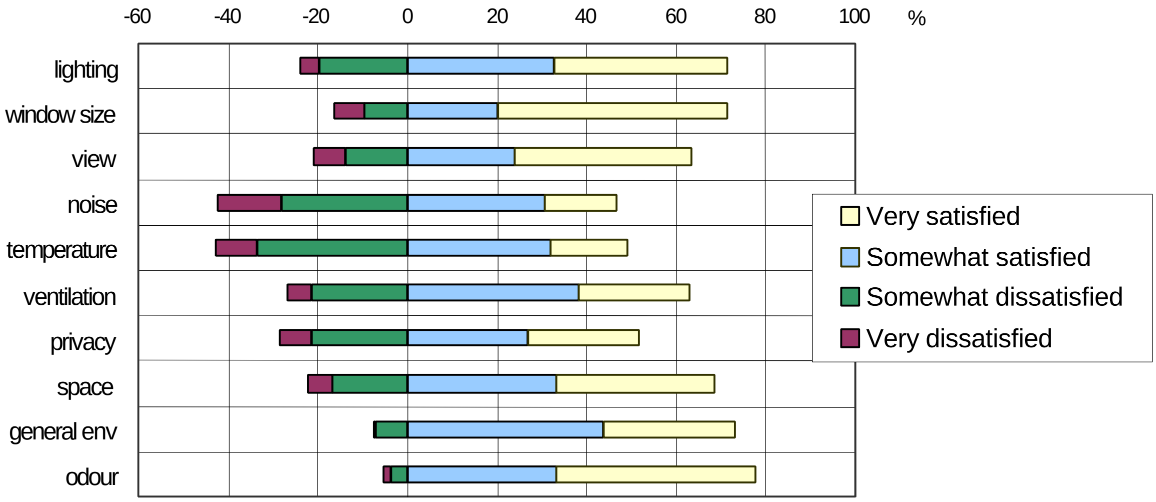
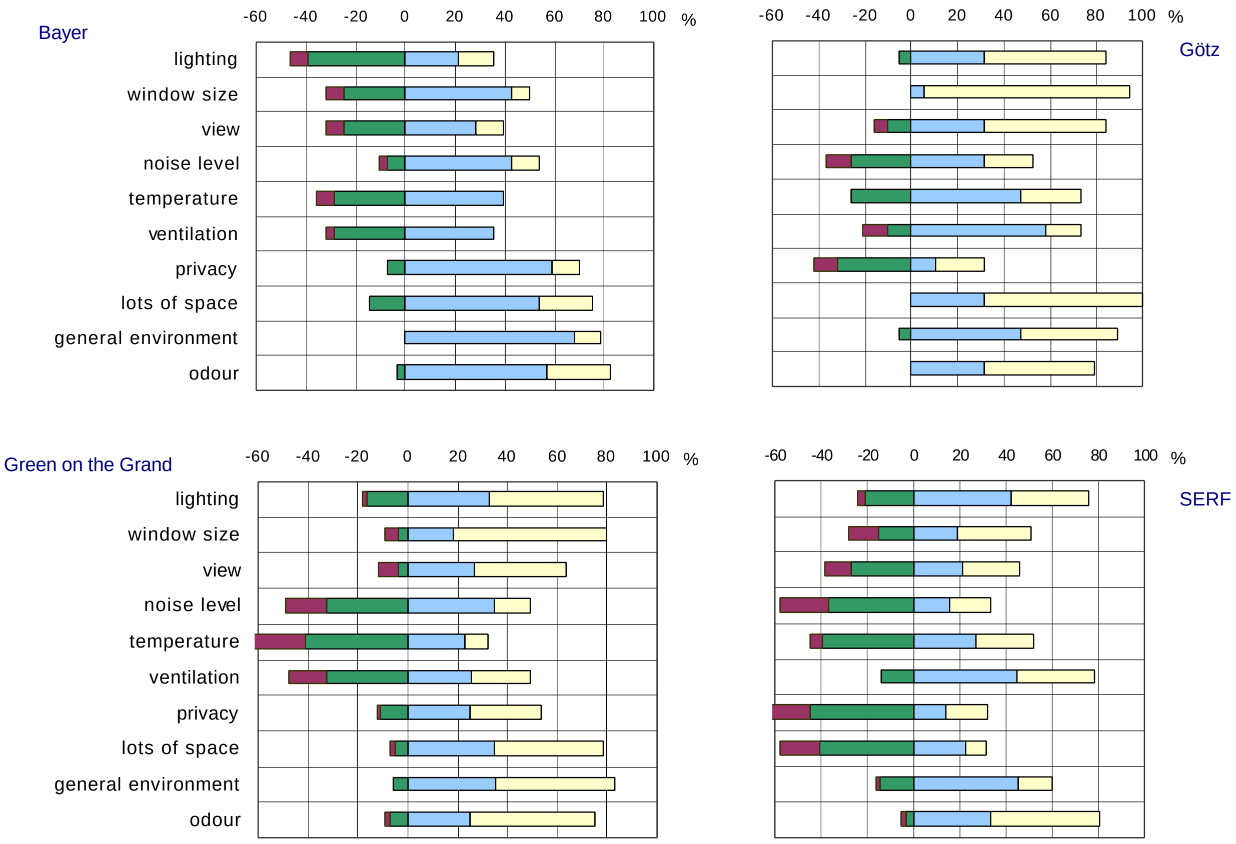
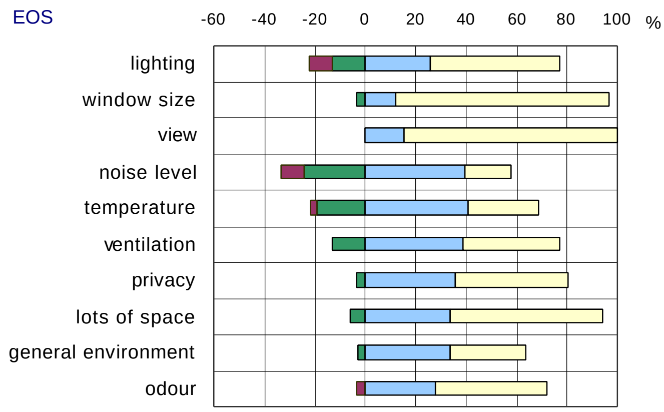


figure 5.5: Mean satisfaction ratings of different aspects of the work place (category *indifferent* not included).



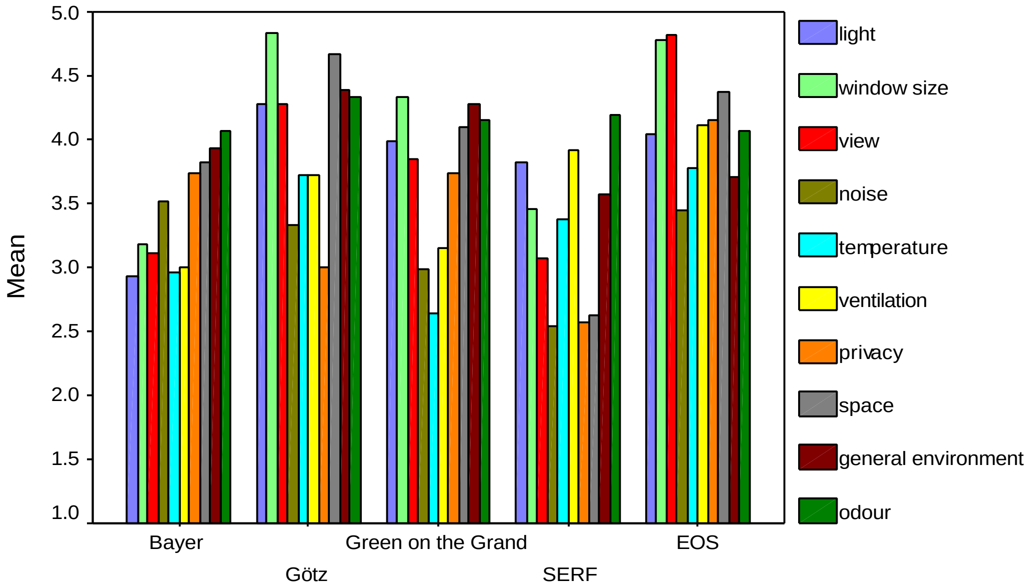
figures 5.6 a – d: Mean satisfaction ratings of different aspects of the workplace in different buildings.



figures 5.6 e: Mean satisfaction ratings of different aspects of the workplace in different buildings.

The values for the individual buildings show that in particular Götz, Green on the Grand and EOS came out very well on the features related to lighting, window size and view.

In Figure 5.7 the satisfaction ratings are split up by the respective buildings and the indifference ratings (value 3) are included to calculate means.



Very dissatisfied = 1   Very satisfied = 5

figure 5.7: Mean satisfaction ratings of different aspects of the work place in the different buildings.

The three most satisfying aspects in each building are shown in Table 5.2.

building	the three most satisfying aspects
Bayer	lack of odour, general environment, space
Götz	window size, space, general environment
Green on the Grand	window size, general environment, lack of odour
SERF	lack of odour, ventilation, light
EOS	window size, view, space

table 5.2: The three highest satisfaction ranks in the different buildings.

General environment, lack of odour and space receive very high ranks in all buildings. Window size ranks high in most buildings except in the Bayer building.

Figure 5.8 shows the ratings for the total light levels at the workplace, in the room and on the VDU, electric light and daylight combined. Light levels were satisfactory (*about right* = scale value 2), except for the Bayer building where the light was rated as closer to *too little*. In the Götz building the light level at the VDU was judged as approaching too much.

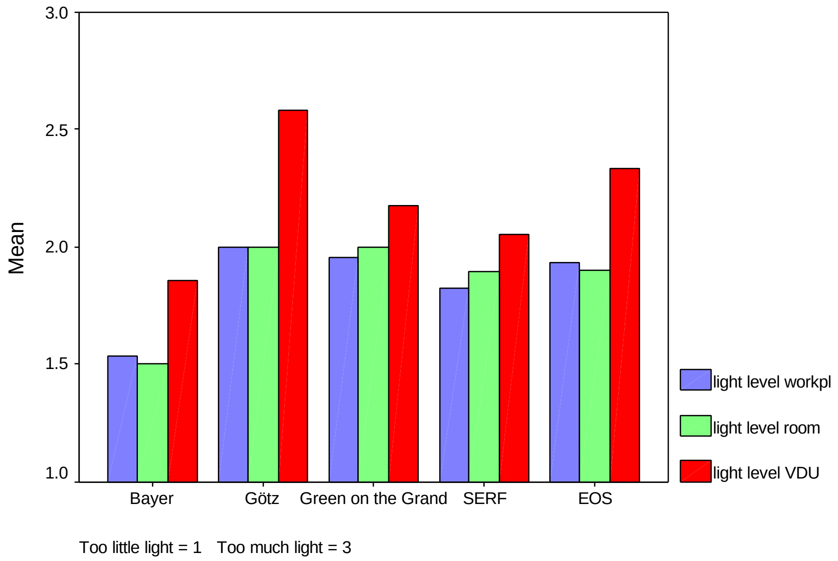


figure 5.8: Mean ratings of light levels in the different buildings.

Figure 5.9 shows how window size is experienced. With the slight exception of the Bayer building the overwhelming response is that of an adequate size of the window. In the case of the Bayer building, the size might have been rated as adequate if there had not been any blinds.

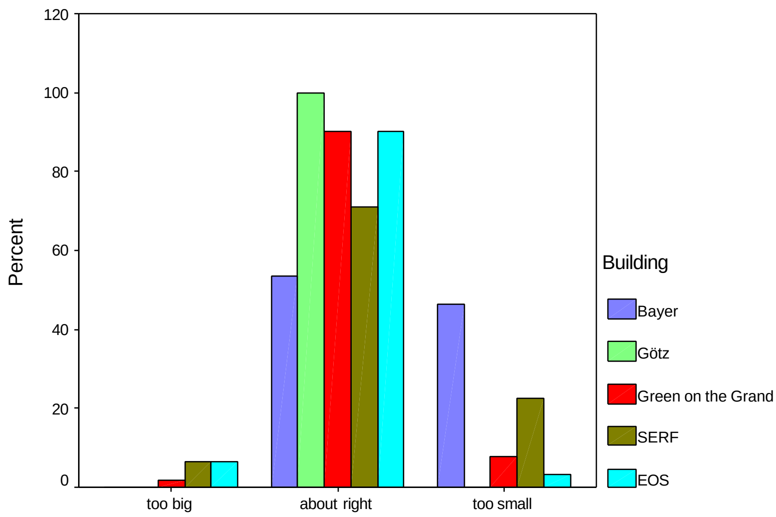


figure 5.9: Rated size of windows in the different buildings.

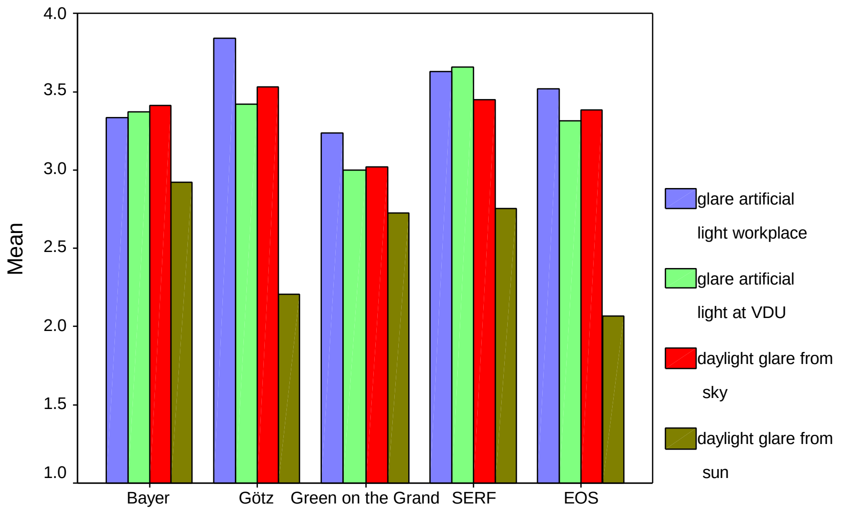
Table 5.3 shows the relation between the rated importance of window and presence of window in the office. There is a significant correlation between having a window in the work area and a high rating of the importance of windows (Spearman's *rho* = .238, *p* = .006).

	window in work area	
importance of window	yes	no
window not important	5.4%	14.3%
window moderately important	18.0%	38.1%
window very important	76.7%	47.6%
Total	N=111	N=21

table 5.3: Rated importance of windows and presence of window in the office (Green on the Grand is not included for presence of windows).

Glare from artificial (electric) light and daylight is reported in Figure 5.10. All the values, except for daylight glare from the sun, are in the region of *only occasionally* (scale value 3) or *never* (scale value 4) . For the daylight glare from the sun the Götz and EOS buildings the ratings are in the region of *sometimes* (scale value 2). None of the ratings come close to *often* (scale value 1).

When there are disturbing reflections they occur on the VDU screen. See Figure 5.11.



Scale Often = 1 Sometimes = 2 Only occasionally = 3 Never = 4

figure 5.10: Mean ratings of how often there is glare in the different buildings.

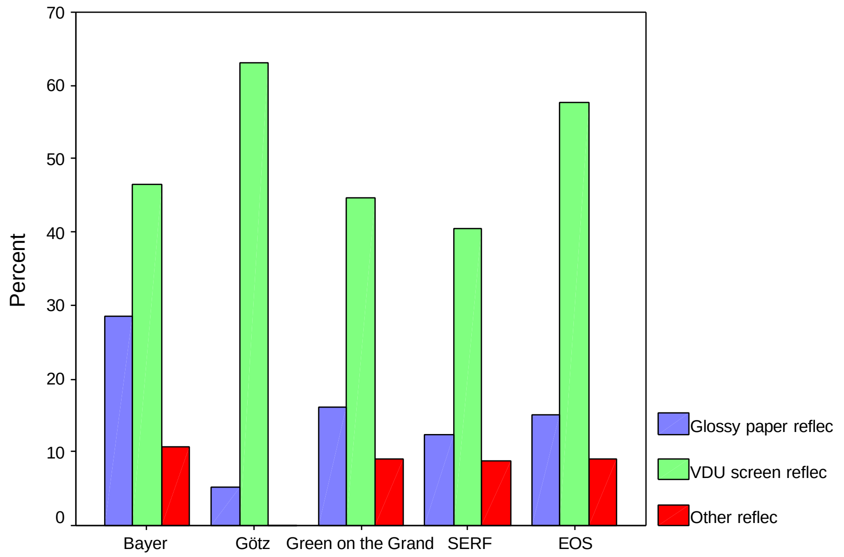


figure 5.11: Percentage persons reporting reflections in different materials.

Two questions in the questionnaire were directed towards the advantages and disadvantages of windows at the actual workplace. The main advantages with windows are letting sunshine in and providing a view out. See Figure 5.12.

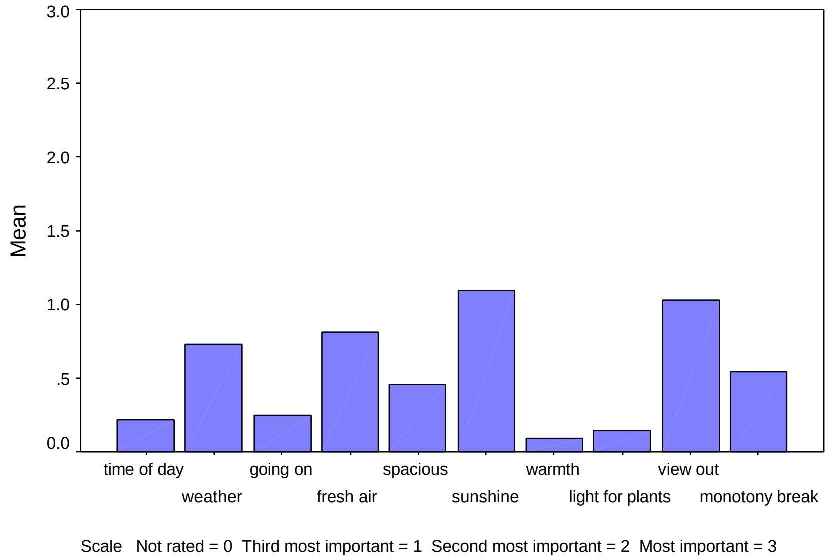


figure 5.12: Mean importance ratings of different advantages of windows.

However, this outcome varies somewhat with building. When the means are calculated separately for each building (not shown in any figure), sunshine receives the highest ranking in the Götz building, Green on the Grand and in the SERF building. In the EOS building the view out is rated the highest and in the Bayer building the possibility to check the weather.

In most buildings, heat and glare are reported as the major disadvantages of windows. See Figure 5.13.

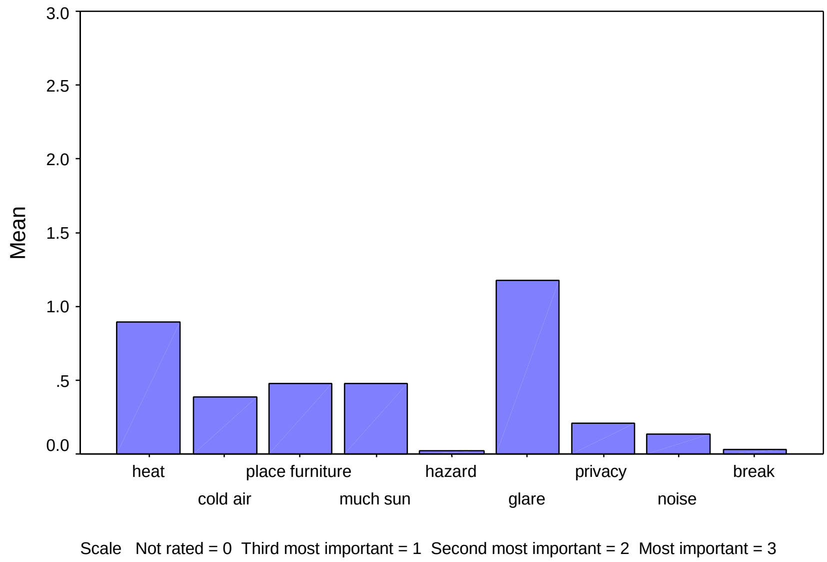
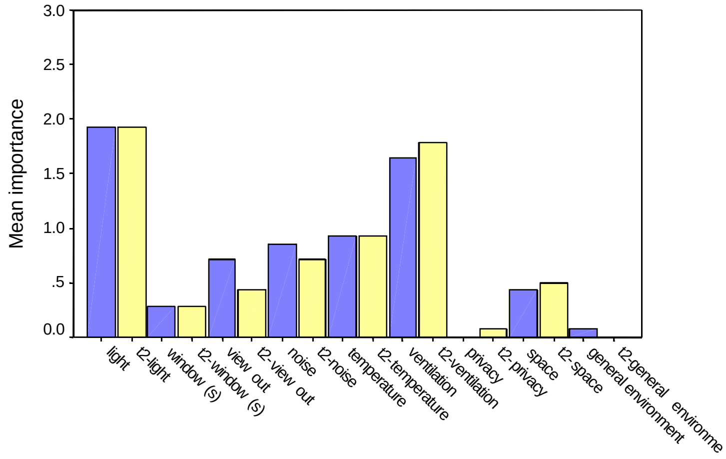


figure 5.13: Mean importance ratings of different disadvantages of windows .

5.5. The reliability of the questionnaire

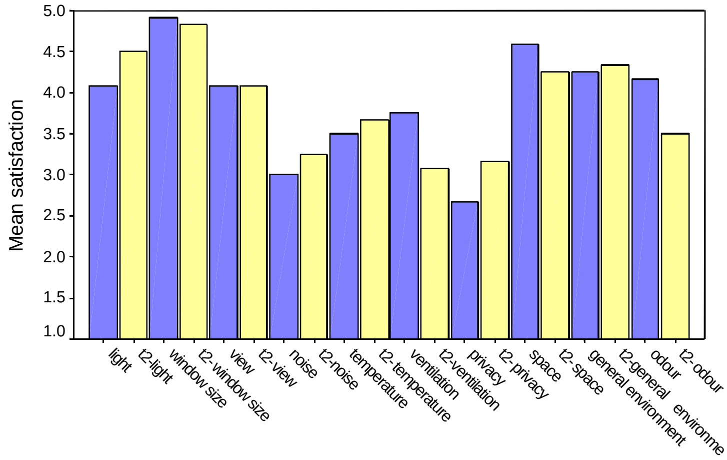
In the Götz building the questionnaire was filled out twice, a year apart, by fourteen persons. No change was made in the building during the year, so the change in ratings from time 1 (t1) to time 2 (t2) can mainly be regarded as the effects of getting used to something and/or new imperfections in the questionnaire.
As can be seen in Figure 5.14 there was not much of a change from t1 to t2 in what people wanted from their offices.



Scale Not rated = 0 Third most important = 1 Second most important = 2 Most important = 3

figure 5.14: Mean importance ratings of different aspects of the work place in the Götz building at t1 and t2.

See Figure 5.15 for satisfaction with the different aspects of the work place at t1 and t2. The mean satisfaction across all the aspects was virtually the same at t1 and t2 (Means: 3.90 at t1 and 3.87 at t2).



Very dissatisfied = 1 Very satisfied = 5

figure 5.15: Mean satisfaction ratings of different aspects of the work place in the Götz building at t1 and t2.

Thus, if there is no change in the building during one year the ratings are fairly stable both for what the occupants want and what they get in their offices environments.

5.6. A change in the control system in the Bayer building

A change in the control system at the second floor in the Bayer building to automatic off and manual on was introduced between waves 1 and 2. Conditions at the third floor were kept constant. As can be seen in Figure 5.16 this improved the average degree of satisfaction for the experimental group, but the satisfaction in the reference group did not change. The greater difference in change from t1 to t2 for the experimental groups is significant at p = .08. For all of the features of the work place taken one by one there was an increase in satisfaction rating in the experimental group (not shown here). In the reference group there was also a slight tendency towards better ratings at t2, with the exception of odour, but the average increase was higher in experimental group. Thus, the shift from automatic on/automatic off to manual on/ automatic off on the second floor was an improvement.

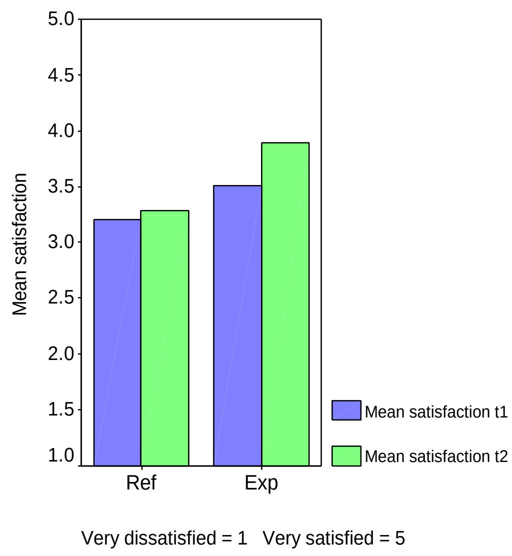


figure 5.16: Mean satisfaction ratings in the Bayer building before and after a change in the control system was introduced (see text).

5.7. The satisfaction with and importance of the view out

Do people rate the importance of having a nice view out as high because they do not have a nice view out? Or is it the opposite way? The general issue here is whether high ratings of the importance of a feature depends of being deprived of it or not. One answer to this question is given in Figure 5.17.

As seen from the figure, the more important the view out is considered, the higher the satisfaction rating is. Thus, the high rating of the impor-tance of the view out is not a matter of being deprived of it. If anything, the opposite is true. The more favourably the view out is rated, the more important it is to have a nice view out.

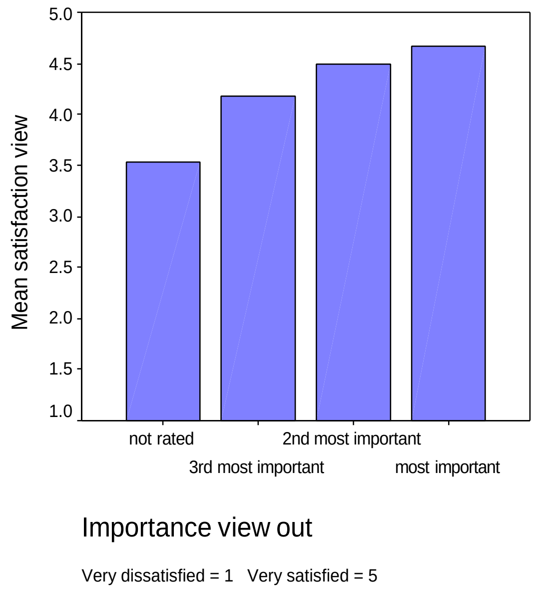


figure 5.17: Mean satisfaction with view out by ratings of importance of view out.

5.8. Conclusions

The most wanted indoor features in an office are good light and good temperature conditions.

Window related features, such as window size and view out, received high, but not the highest, satisfaction ratings of the indoor environment characteristics studied.

Light levels in the room and at the workplace were adequate in most buildings, but the light levels at the VDUs were on the high side, causing reflections and glare.

Letting sunshine in and providing a view out are rated as the main advantages with windows. Glare is reported as the main disadvantage with windows.

The questionnaire employed for the POE-studies has a reasonable reliability. If it is to be used in other studies, it is wise to employ identical sets of indoor parameters both in the lists of desired features in an office and in the lists of features rated for satisfaction.

The questionnaire also has validity. When a change was introduced for some of the occupants in the Bayer building, both not for others, the replies on the questionnaire items differentiated between the groups in spite of the low number of occupants in the comparison.

A high satisfaction with the view out is positively related to high ratings of the importance of a nice view out. Thus, it is not the case that being deprived of a nice view out leads to high ratings of the importance of the view out.

Dissatisfaction with daylight in buildings are mainly caused by glare, in particular at the VDU screens. Glare should therefore receive special attention in daylight design Some of the problems with glare and VDU-screens may disappear with the coming of flat-screen monitors.

6. References

Collins, B. et al. (1989). Post-occupancy evaluation of several U.S. Government buildings. U.S. Department of Commerce, National Bureau of Standards, NISTIR 89-4175, Gaithersburg, USA.

Elder, J., Turner, G. E., & Rubin, A. I. (1979). Post-occupancy evaluation: A case study of the evaluation process. Center for Building Technology, National Engineering Laboratory, National Bureau of Standards (NBSIR 79-1780), Gaithersburg, USA.

Energy Edge (1991). Energy Edge - Post-occupancy evaluation project, Final report, University of Washington, Seattle, USA.

Fontoynont, M. (Ed.) (1999). Daylight performance of Buildings. European Commission Directorate General XII for Science, Research & Development. Hong Kong: James & James.

7. Photos

Picture 1

The Bayer Head Quarter.
Two pictures showing typical room with different workplace orientation.

Picture 2

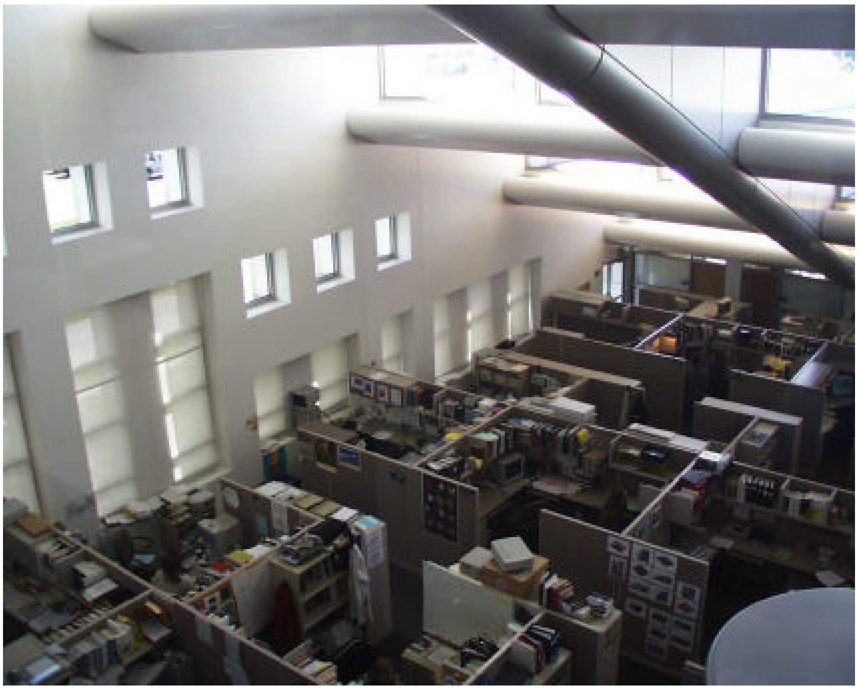
The open plan office of the Götz Office Building

Picture 3

Green on the Grand. Two different ways to orientate the computer. One of them results in screening the window.

Picture 4

The SERF Building. The picture shows the office landscape with daylight primarily from overhead, and very restricted view out.



Appendix 1

A manual for post-occupancy evaluation (POE) and test-room studies

1. Introduction

The aim of a POE-study is to carry out a systematic assessment of the performance of a facility once it has been occupied and used.

It is to determine if the facility meets the level of expectation that was envisaged in the conceptual stages of the design, in terms of both the human occupants and the building services that it encloses.

This is done by a systematic gathering and analysis of the information collected from within the building when it is in use.

After analysis, the findings are forwarded for:

- corrective action and "fine tuning" of the facility
- identifying design features to be avoided
- identifying features of future use
- establishing if design goals, energy targets, standards and guidelines are act ually achieved
- identifying design aspects for long term research and investigation

The reality is, that unless the occupants are totally satisfied with the facility they will never reach their full potential or totally accept the technology, especially if it is not perceived to be of immediate benefit to them.

2. Process for the POE-studies

The process for carrying out a POE study follows a systematic, step by step approaches, and concentrates on two levels of information gathering:

- from the building itself - often referred to as the "walkthrough"
- from files, plans, briefing notes, i.e., a document search

The walkthrough centres around a tour of the building, especially identifying groups from which opinions, reactions, comments and recommendations are sought.

This is generally done by means of a questionnaire and more will be said about that later in the manual.

The walkthrough is intended to be pragmatic and with a short duration with a maximum of two or three days, depending of the size of the facility. This should aim to minimize the impact of the evaluation on the daily operations, while maximizing the effective participation of all personnel.

When a particular item is noted or considered to need further investigation, a "focus" study may be carried out and this study may isolate parts of:

- the building, e.g., the windows
- human complaints or comments - e.g., too hot or too cold
- building services - e.g., power density, W/m^2 too high etc

Focus study reports can be separated from the main POE-report and can be initiated independently from a POE-study. These may then be forwarded directly to a Technical Specialist without being processed through the normal administrative channels.

3. Specific objectives for POEs in experimental daylight buildings

This manual provides examples of how to do a POE and how to run comfort studies in a test-room, and a list of items to consider when collecting data from the respo ndents.

The basic tool for the POE is the questionnaire compiled by Hans Allan Löfberg and Staffan Hygge. Its final version with instructions how to use it, is found at the end of this manual.

The main objective with the POE is to evaluate the quality of the buildings from the users' point of view. The outcome of such an evaluation will then be compared the technical evaluation which concentrate on the energy aspects and function of the technical systems like controls for HVAC, lighting, sunshading etc.

The evaluations should concentrate on lighting quality both for artificial lighting, day-lighting and the combination of these. It must also consider the whole physical environment (noise, thermal conditions) and provide the user with an opportunity to rate the importance of lighting quality against other qualities of the work environment and work conditions.

The main objective is to evaluate the quality of the buildings both from a technical point and from the users' point of view. The technical evaluation will concentrate on the energy aspects and function of the technical systems like controls for HVAC, lighting, sunshading etc.

The POE will concentrate on their attitudes to the building with its controls and specifically on the lighting qualities both for artificial lighting, day-lighting and the combination of these.

In order to get results from the occupants (users) that can be compared between the buildings you need a reference situation. This will probably not be possible to obtain.

What you can get from the users is an evaluation, integrated over a time-period, of their attitudes to their working conditions.

One possible way to get a comparison between the buildings is to have a group of "Experts" that visits all the buildings and evaluate the conditions. This might focus the evaluation on aspects that are not so important to the users and missing other factors that you can not judge during a short visit.

If you have possibility to give the users alternative lighting installations and control systems you can have a more reliable situation when trying to decide what parameters are most important.

In a field experiment where windows and daylight are important factors you always have the problem with the daylight varying both in quantity and quality. It is thus very difficult to have good experimental control over your test situation.

The opinion from an experienced researcher involved in studies of SBS and its roots is that the best ruler is the user. And the user can give reliable estimates of the seriousness of problems and the frequency of their occurrence.

A questionnaire is better than interviews if you want to be fairly sure that all buildings are evaluated in the same way.

The evaluations should concentrate on lighting quality, but must also consider the whole physical environment (noise, thermal conditions) and also give the user a possibility to rate the importance of lighting quality to other qualities of the work environment and work conditions.

4. The questionnaire

There are very few POEs specifically focused on the lighting of a building. Most studies cover a much wider spectrum of aspects. Very few POEs are seriously evaluated as such and you never find the same method/questionnaire used repeatedly to gather experience of it as a tool. Internationally some efforts have been made to design questionnaires in order to get this experience, but so far there has not been any success in the efforts. No questionnaire can thus be used as it is, with known merits and weaknesses.

The enclosed proposal for a questionnaire is to a large extent based on questions used by Elder, Turner, and Rubin (1979) at NBS, USA, in a study of the evaluation process. Their questionnaire covers also other aspects of the user environment such as the building and its layout and suitability for its purposes and tries to find where the feedback to the design process could be improved.

The now proposed questionnaire is meant to get the user's opinion of the work environment integrated over time. This can give a quality profile of the building to be used when evaluating the total merits of the buildings and comparing differences that could be the basis for the different user opinions. It is thus important that the same questionnaire is used in all participating buildings. Of course you could add questions if you are interested in certain aspects of a particular building or work condition.

The questionnaire should be issued after at least one year of work in the building if you want to get a view and estimate of how often problems arise or how serious they are. If the questionnaire is used in a building where the lighting installation, control system and so forth is changed, you must give the user time to experience different daylight and work situations.

5. The logic of comparisons

Basically, the results of the POEs will be in terms of a difference in how one combination of lighting installations and control systems (C1) is rated against another (C2). The degree of difference in ratings can and will be tested statistically to a ssess the strength and probability of the difference.

To maximize the odds that a difference in POEs between conditions comes out statistically significant, and is solely caused by the difference in conditions,

The two conditions and their users should be as equal as possible in all respects other than being exposed to different conditions. One way to achieve that is to use the same persons in different conditions. This is called a within-person design and is the preferred design for the POEs. Thus, when considering a POE, first try to find a way to change the lighting installations and control systems within the same room(s) for the same persons.

The alternative to the within-person design is the between-person design, where different persons are exposed to the different conditions. The between-person design can be made more similar to the within-person design by attempts to match the persons in conditions C1 and C2 on characteristics such as age, sex, education, health, type of work, status etc. Since people are genuinely different the variance in between-person designs is greater than in within-person designs, and consequently more persons are needed in the between-person designs to make a difference in means come out statistically significant.

As a rule of thumb 30 persons or more are needed in each group in between-person designs, if they are properly matched. Around 15 persons are a minimum for the within-person designs.

6. An example of a within-person design

An office-building is an ideal object for a POE. Particularly if the lighting conditions within the same rooms in the building can be changed, e.g., automatic (A) and manual (M) choice of how much artificial light is provided.

The person in charge for the POE (POE-operator) should inform the persons in the rooms that from time to time, with several months in between, the system for controlling the artificial light will change, that they will be informed about in advance and that they will be asked to fill out questionnaires about how they experience the lighting conditions. When the change has been introduced by the POE-operator something like 2 months should pass before the questionnaire is handed out. For practical reasons the questionnaire should be filled in around equinox in the spring and in the fall. However, since at least two months must pass from the change of conditions until the questionnaire is filled out, the times may have to change a little to give two months of stable installations and control systems after the summer and Christmas vacations.

In the within-person design it is an absolute demand that the persons can be identified from one measurement wave to the next. If names can't be used as identifiers, think about asking the persons to use a security code, a PIN-code for their charge card or something else they can remember to the next time the questionnaire is to be filled out.

Care and consideration must be given to the participants in the study in order to preserve their motivation to repeatedly fill out the questionnaires. Loss of participants undermine the validity of the conclusions that can be drawn, because of the risk that the subjects who drop out are those who are discontent with the conditions. Thus, the importance of staying in the study, even if displeased with the lighting conditions, must be stressed from the very start.

7. An example of a between-person design

Again, imagine an office-building as the ideal object for a POE. Since, by definition, the lighting installations and control systems can't be changed within rooms, a lot of care must be taken to ensure that the matching of persons in different rooms with different light conditions is properly made.

In particular, type of work, age and sex of the persons, their work status, the size of the room, orientation and floor levels, physical arrangements in the respective offices, window size and shape, etc. must be as equal as possible. Ideally, only the lighting installations and control systems in the different rooms, two or more, should be different. As an example, and as above, the difference could be one set of rooms with automatic (A) and another set with manual (M) choice of how much artificial light is provided.

As in the within-person design, the POE-operator should inform the persons in the rooms in advance that they will be asked to fill out questionnaires about their experience with the lighting conditions. At least two months with unchanged lighting installations and control systems should pass before the questionnaire is filled out, and the time for filling them out should be around equinox in the spring and fall.

In the between-person design it is not mandatory to identify the respondents, but if there is a possibility to repeat the filling out of the questionnaires under changed conditions at a later time, try to find a way to identify the person as in the within-person design.

8. Standard cases

The examples of within- and between persons designs can be expanded on and combined in different ways with doing laboratory or field studies. A few basic standard cases can be discerned.

8.1. Test-room or laboratory study

Lighting conditions can be changed within minutes and many persons can be called in to make short-term comfort ratings. Thus, long-term effects can not be studied.

Choose parameters of interest (P_1, P_2, ... P_n) and number of levels for each parameter (L_{P1}, L_{P2}, ... L_{Pn}). If $L_{P1} \times L_{P2} \times ... \times L_{Pn} \sim 12$-15, an evaluation could be done with ~ 60 participants. However, some work should be devoted to the experimental design and counterbalancing of the order in which the conditions are presented. For more about a test-room or laboratory study, see the next section.

8.2. Field study - between-person design

This case is characterized by real buildings, many rooms, different lighting installations and control systems between rooms but lighting installations and control systems can not be changed within rooms

If the rooms within lighting condition A1 are similar also in other respects (orientation, size, indoor climate etc.) to each other, and similar to a set of rooms with lighting condition A2 (A1 and A2 differ only in one parameter), are occupied by similar persons (sex, age, years at work etc.), and doing similar kinds of work, an evaluation can be made with the questionnaire if each lighting condition has more than 30 persons.

If rooms in lighting condition A1 have their respective match or twin in lighting condition A2 on all characteristics (rooms, persons) except the lighting conditions, it is worthwhile to consider an evaluation with the questionnaire even if each lighting condition has a little less than 30 persons.

If the lighting conditions A1 are changed to A2 and A2 to A1 after some time, a new evaluation with the questionnaire should be done 3-4 months after the switch over. Outdoor lighting conditions should be about the same.

The evaluation will be strongly strengthened by finding a reference condition for the occupants to evaluate. For example, if the cafeteria or a library in an office-building is not subjected to changes in lighting installation and controls, it is an advantage to let the occupants also rate that room. A modified questionnaire may be needed to do that. It is also wise to administer the questionnaire to the people taking part in the study before they are switched over to the new lighting conditions. In those ways, a kind of base line for each individual must be established, a base line against which to compare their subsequent responses to the lighting environment. This is of use even if the occupants come from buildings with different lighting and indoor conditions.

8.3. Field study - within-person design

Real buildings, lighting installations and controls can be changed at different times within different rooms.

This is a very desirable experimental setup. Would strongly be considered for repeated administration (3-4 months after a change in lighting installations and control systems) of the questionnaire if the number of occupants are the same and ~ 15 or more.

8.4. Field study - few subjects

Real buildings, but the possibility of changing lighting installations and control systems in a single room is limited and there are too few persons to qualify in any of the above standard cases. A formal POE can not be performed, but of course it's valuable to aim at some kind of snap-shot of user reactions, or asking experienced experts to informally rate the lighting qualities of the faci lity.

9. More about laboratory or test-room studies

Imagine you have test-rooms where you would like to study a large number of subjects to find out how they rate different lighting conditions, e.g., the same automatic dimming device under three daylight conditions: (A) clear skies, (B) overcast, and in-between (C).

Also, let us assume that you want ratings from the subjects as they perform three types of tasks: reading (1), working with a PC-monitor (2), and talking with someone (3). Note that you primarily want their rating of the lighting conditions as they perform the task, not a measure of how good they perform on the task.

Thus you have two sets of independent variables: lighting conditions with levels A, B, and C, and tasks with levels 1, 2, and 3.

Your next choice is between using all the subjects in all conditions or different groups for different conditions. We strongly suggest using all the subjects in all conditions, i.e., a within-person design.

In our example it is not feasible for the experimenter to vary outdoor lighting conditions. You must make do with what you have and wait for the right time. This implies that from time to time you will have to ask the subject to come back another day when you hope that the daylight conditions (overcast, in-between, clear skies) are met.

9.1 Balanced presentation orders

As regards conditions A, B, and C there are six different presentation orders. For each of the six different presentation orders of A, B, and C, there are twelve different ways in which the tasks 1, 2, and 3 can appear. To avoid the possibility that presentation order is crucial for the comfort ratings, the presentation order must be balanced. This can be achieved in two ways. The first way is to use all logically possible combin ations, which is shown here.

A	B	C	combination No.
123	231	312	1
123	312	231	2
132	321	213	3
132	213	321	4
213	132	321	5
213	321	132	6
231	312	123	7
231	123	312	8
312	123	231	9
312	231	123	10
321	213	132	11
321	132	213	12

and the same for

A	C	B	13-24
B	A	C	25-36
B	C	A	37-48
C	A	B	49-60
C	B	A	61-72

To explain, the first row labeled combination No. 1, means that the three sessions with lighting conditions A, B, and C appear in that time order. Within each session there is a counterbalanced or of the three tasks 1, 2, and 3 so that they appear equally often in the three positions.

This yields 6 x 12 combinations, which ideally should take 72 subjects, or multiples thereof. Do not run subjects in the order 1-72. Make a list of a random o rder.

If it is not possible to get as many persons as the full set of possible presentation orders demand, there is a way to reduce the number of presentation orders. The basic idea behind the reduction is the Latin square. In a Latin square the different combinations of e.g., A, B, and C appear once and only once in each row and column of the 3 x 3 matrix. That is,

ABC
BCA
CAB

Thus, the above complete matrix can be reduced from 72 to 36 combinations by employing only the combinations headed by ABC, BCA, and CAB. Also, with the same Latin square idea, all the presentation orders of 1, 2, and 3 can be r educed to

123
231
312

ending up with six different orders of tasks under each order of daylight cond itions.

A	B	C	combination No.
123	231	312	1
123	312	231	2
231	312	123	3
231	123	312	4
312	123	231	5
312	231	312	6

and the same for

B	C	A	7-12
C	A	B	13-18

In the above examples it is assumed that the ratings are taken only once for each task (1,2,3) in each daylight session (A,B,C). It's preferable that the ratings are taken several times during the session. To balance the order of let's say three ratings each of 1, 2 and 3 the combination No. 1 above can be expanded in the following way according the Latin square idea.

A	B	C	combination No. 1
123	231	312	1st rating
231	312	123	2nd rating
312	123	231	3rd rating

Rating Nos. 1-3 within each session can easily be expanded in the same way for the other combinations.

9.2. Remarks on the choice of subjects and procedure for testing

The basic aim of a test-room study is to find out whether there is a difference between combinations of lighting conditions. In order to maximize the statistical chance to find differences where there are real differences, it is important to employ homogeneous groups. For instance, mixing old and young persons, people with different educational background and professional experience will probably add to the variance of the error-term in statistical testing making it more difficult to detect real differences between conditions. Employing homogeneous groups and letting all subjects encounter all conditions, is as a rule, a more reliable way to detect the real differences than mixing all kinds of persons in the same study. This recommendation rests on the assumption that people basically have the same kind of reaction to different conditions even if the degree of the reaction may vary with e.g., age group, sex and background.

In practice, students may in many cases be the most easily available homogeneous group for a test-room study. You should not hesitate to use such a group even if you may suspect that old and sick people may be more sensitive to the difference in lighting conditions that are young healthy students. You can not cover all kinds of background variables in one study, so it's better to start with young and healthy persons.

Be careful to use the same, or approximately the same time of day for testing the subjects. Let the subjects get acquainted with the test-room. Let them for instance fill out the rating scales one time just for practice before the real experiment starts.

Of course it's a good thing to run the tests at the same time of the year, or e.g., around equinox.

10. Remarks

The experimental conditions must be verified by measurements, which are chosen in agreement with the guidelines from the project coordinators and the manuals specifying the measurement methods.

At each study site, one person should be in complete charge of conducting the POE-study and changing the conditions. There are several practical and methodological reasons for this. Employing the same procedure each time the forms are filled out and behaving in the same consistent manner towards the participants, are the most important ones.

Both in the between and within-person design the evaluation will be strongly strengthened by finding a reference condition for the occupants to evaluate. For example, if the cafeteria or a library in an office-building is not subjected to changes in lighting conditions, it is an advantage to let the occupants also rate that room. A slightly modified questionnaire may be needed to do that.

Basically, forget about comparing different people working in different rooms under different conditions. Such a between-person study, i.e., where different groups take part in only one of the conditions can only be hoped to yield any significant differences when the rooms and the persons are homogenous sets, and the number of persons are at least 30 in each set, and there is one set of persons for each experimental condition.

It is of course legitimate to be interested in an overall opinion from the users on what lighting conditions they prefer when given a choice, and not what combination of parameters that may have caused them, but such study is no substitute for an experimental approach (c.f. point 5 below).

Try to aim for employing the same set of persons and rooms before and after changes in lighting conditions. This is a within-person design and such a design is more (statistically) sensitive in picking up differences. The minimum number of persons is open to our best judgement, and we would say that 10-15 is the absolute minimum.

The evaluation will be strongly strengthened by finding a reference or base-line condition for the occupants to evaluate. For example, if the cafeteria or the library in an office-building is not subjected to changes in lighting conditions, it is an advantage to let the occupants also rate that room. It is also wise to administer the questionnaire to the people taking part before they move to new lighting conditions.

The basic layout of the experimental study design is to introduce one change in one parameter at a time, and to take evaluations of the same subjects before and after that change. The change must be given time to stabilise, which presumably will take months. The strict experimental approach also implies that all other conditions, such as weather, amount of daylight, time of day and year, physical arrangements in the respective offices, window size and shape, etc. must not change. The only thing that is allowed to change is the planned change from time to time in one parameter introduced by and controlled by the experimenter. If not, the effect of the experimental change is confounded by extraneous variables and no conclusion of the experimental treatment can be drawn.

The demand for experimental control also precludes the evaluation of lighting conditions that are controlled by and changed by the occupants. Since those changes are not according to the experimental plan, they basically can not be evaluated in the same way. However, by courtesy and by an interest in finding out what combinations of conditions the occupants actually choose when at liberty, the free choice situation should preferably be employed in between forced conditions.

Thus, changes in lighting must be introduced and controlled exclusively by the experimenter. If the occupants are choosing the lighting combinations they want in their separate rooms, the causal link from lighting to comfort can not be properly disentangled from the effects of perceived control. In such cases a preference study is performed and the results would be to present dominant profiles.

No single questionnaire can be expected to cover all the experimental manipulations wanted in the different studies. Extra questions can be added to the questionnaire dependent upon what changes in conditions are of interest. Hans Allan Löfberg and Staffan Hygge will be your consultants on that.

The experimental conditions must be verified by measurements, which are chosen in agreement with the guidelines from the project co-ordinators and the manuals specifying the measurement methods.

If the number of persons available for a POE-study is too small, a panel of trained observers could be used. We have suggested a checklist for what the panel should evaluate (see point 4 in the section before the present one). Although not an ideal situation, a panel of trained observers is better than nothing.

Care and consideration must be given to the participants of the study in order to preserve their motivation to repeatedly fill out the questionnaires. Loss of participants undermine the validity of the conclusions that can be drawn, because of the risk that the subjects who drop out are those who are discontent with the conditions. Thus, the importance of staying in the study, even if displeased with the lighting conditions, must be stressed from the very start.

At each study site, one person should be in complete charge of conducting the POE-study. There are several practical and methodological reasons for this. Employing the same procedure each time the forms are filled out and behaving in the same consistent manner to the participants, are the most important ones.

11. Analyses

Parametric statistical tests such as t-tests and analysis of variance (ANOVA) will be preferred. If so wished, Staffan Hygge can help out with the analyses.

12. References

Elder, J., Turner, G. E., & Rubin, A. I. (1979). Post-occupancy evaluation: A case study of the evaluation process. Center for Building Technology, National Engineering Laboratory, National Bureau of Standards (NBSIR 79-1780).

Appendix 2

Lighting conditions survey

This building is one of many buildings in different parts of the world which are being monitored.

The aim of this survey is to gauge the opinion of occupants on the lighting conditions. The survey complements measurements of daylight and artificial light as well as energy consumption.

Please complete and return the questionnaire as you are instructed.

Be frank and honest in your answers.

Your answers will only be used as part of a statistical analysis and it will not be possible to identify any person individually. At the end of the questionnaire you will be asked to give a personal identification that you can remember if you are asked to fill in the questionnaire again at a later time.

Thank you very much for your time and cooperation.

Turn over

Name and address of person
responsible for the survey

QUESTIONNAIRE

Date:...............

First a few questions about the building

1. **Is there anything you particularly like about the ....(name of building)?**

O Yes
O No

If yes. What do you like?

....

....

....

2. **Is there anything you particularly dislike about the ...(name of building)?**

O Yes
O No

If yes. What do you dislike?

....

....

....

Then questions related to the conditions in your work area

Identification:

Floor:................. Room number:................... Other id:....................
or work area name

3. **Please read all the categories and then mark the kind of work area you are in** (only one alternative).

O A private room enclosed with full height walls
O A room enclosed with full height walls, shared with one other person
O An open room (no dividers or furniture that blocks the view) shared with 2 or more other persons
O An individual space enclosed (or mostly enclosed) by dividers, plants or file cabinets etc. in an otherwise open office. Have little or no view of other employees
O Have some dividers, plants, file cabinets that tend to break up an open room but do not enclose the work space. Can easily see other employees

4. **How many persons share your current room or work space?**

- O Have a room of my own.
- O Two persons
- O 3-4 persons
- O 5-10 persons
- O More than 10

5. **Mark the <u>three</u> physical features that are most important to you in making a work place a pleasant one for you to work in.** Mark from 1 to 3, with 1 = the most important.

- O Comfortable temperature
- O Good light
- O Good ventilation
- O Window(s)
- O General environment (colours, carpet, decoration)
- O Freedom from noise
- O Privacy
- O Plenty of space
- O View out
- O Other (please specify) ....

6. **How satisfied are you with the following aspects of your work place?**

	Very satisfied	Somewhat satisfied	Indif-ferent	Somewhat dissatisfied	Very dis-satisfied
a. lighting	O	O	O	O	O
b. noise level	O	O	O	O	O
c. odour	O	O	O	O	O
d. ventilation	O	O	O	O	O
e. temperature	O	O	O	O	O
f. window size	O	O	O	O	O
g. privacy	O	O	O	O	O
h. lots of space	O	O	O	O	O
i. view	O	O	O	O	O
j. general environment (colours, carpet, decoration)	O	O	O	O	O

7. **Do you have a desktop lamp or similar at your workplace?**

- O Yes
- O No

If Yes, do you use it

- O Always
- O Often
- O Seldom
- O Never

If No: Do you think that a desktop lamp would improve your working conditions?

- O Yes
- O No

8. **Do you prefer working in natural light, artificial light or a combination of natural and artificial?**

O Prefer natural
O Prefer artificial
O Prefer combination

9. **In general how do you rate the light level, artificial and natural combined?**

	Too little light	About right	Too much light
a. at the workplace	O	O	O
b. in the room in general	O	O	O
c. at the VDU	O	O	O

10. **Does the artificial light ever cause glare strong enough to bother you?**

	Often	Some-times	Only oc-casionly	Never
a. at the workplace	O	O	O	O
b. at the VDU	O	O	O	O

11. **Does the daylight ever cause glare strong enough to bother you?**

	Often	Some-times	Only oc-casionly	Never
a. from the sky	O	O	O	O
b. from the sun	O	O	O	O

12. **Does the lighting cause reflections in your work material?**

	Not distur-bing	Slightly disturbing	Moderately disturbing	Very disturbing
a. from the ceiling lighting	O	O	O	O
b. from desk top lighting	O	O	O	O
c. from the daylight	O	O	O	O

13. **If there are reflections that disturb you, in what work material do they occur?**

O Glossy paper
O VDU screen
O Other (please specify) ....

14. **What is your general impression of your room/work area?** (Mark as many as apply)

O Bright
O Dark
O Good colours
O Unevenly lit
O Other (please specify) ....

15. **How important is it to you to have a window in your room or immediate work area?**

O Very important
O Moderately important
O Not important

16. **Do you have a window in your room or work area?**

O Yes
O No
If no go to item 26

17. **How is your workplace orientated in relation to the windows?** Please indicate your position (point) and main viewing direction (arrow) in a sketch over the room/work area. Give the approximate distance to the nearest window.

18. **Are you right handed or left handed?**

- O Right handed
- O Left handed

19. **Are you able to see as much of the outside world as you would like from your workplace/desk?**

- O Yes
- O No

20. **Which of the following best describe the view out of the window closest to you?** (Mark as many as apply)

O	satisfying	O	open
O	limited	O	bright
O	simple	O	uncluttered
O	pleasant	O	frustrating
O	confined	O	complex
O	dim	O	boring
O	stimulating	O	unpleasant
O	cluttered	O	spacious

21. **Do you ever work using only the light from the windows?**

- O Often
- O Sometimes
- O Only occasionally
- O Never

If it happens, can you specify when?

....

22. **Does it ever become too hot because of the sunshine coming in through the windows?**

- O Often
- O Sometimes
- O Only occasionally
- O Never

If it happens, can you specify when?

....

23. **Can you control the heat radiation through the windows?**

- O With external blinds or similar devices
- O With internal blinds
- O With curtains
- O Other ways (please specify)...
- O No

24. **Do you ever notice cold draughts near the windows?**

- O Often
- O Sometimes
- O Only occasionally
- O Never

25. **How about the size of your window, is it:**

- O too big
- O about right
- O too small

26. **Listed below are some of the advantages of windows. Mark the three that are most important to you at your workplace.**
Mark from 1 to 3, with 1 = the most important.

- O Let you tell the time of day
- O Let you know what the weather is
- O Let you see what is going on outside
- O A way for fresh air to enter
- O Make room seem more spacious
- O Other (please specify) ....
- O Let sunshine in
- O Let in warmth
- O Provide light for plants
- O View out
- O Break monotony

27. **Listed below are some of the disadvantages of windows. Mark the three that you feel are the biggest disadvantages at your workplace.** Mark from 1 to 3, with 1 = the most important.

- O Let in too much heat in summer
- O Let in too much cold air in winter
- O Limit ways furniture can be placed
- O Give too much sunlight
- O Present a hazard (person might fall)
- O Other (please specify) ....
- O Cause glare
- O Reduce privacy
- O Let in outside noise
- O Present a hazard (might brake)

28. **Which of the following activities are a normal part of your job?**
Mark each one you usually do as a part of your job with 1 for the most common activity.

- O Using PC or other keyboard machines
- O Typewriting
- O Filing
- O Making drawings
- O Using the telephone
- O Supervising the work of others
- O Other (please specify) ....
- O Reading
- O Writing by hand
- O Working with numbers
- O Laboratory work
- O Interviewing or holding small meetings

29. **In general how much time do you spend in your office or immediate work area?**

- O All the time (7-8 hours a day)
- O Most of the time (4-6 hours a day)
- O Very little (less than 4 hours a day)
- O Other (please specify) ....

30. **Do you consider yourself as very sensitive to glare?**

- O Yes
- O No

31. **Do you wear glasses or contact lenses when working?**

- O No
- O Yes

If yes
- O Simple
- O Progressive
- O Bi-focals
- O Contact lenses
- O Special glasses/lenses for VDU work

32. **Do you often wear sunglasses indoors and outdoors?**

- O Yes, outdoors
- O Yes, indoors
- O No

33. **In general terms, what kind of job do you have?** (For example clerk, typist, supervisor, physician, etc)

....

....

34. **If you have any further comments about the building please write them here:**

....

....

....

....

....

....

....

....

The following information is needed for data analysis only. It will not be used to identify any individual respondent.

35. **How long have you been working in the ....(name of building)?**

....

36. **Sex**

O Female
O Male

37. **Age**

O Under 30
O 30-39
O 40-49
O 50-59
O 60 and over

Please chose any combination of digits and/or letters as your personal code and remember it until you may be asked to fill out the questionnaire again in the future. The purpose of this code is only to make it possible to find out if there are changes in a person's response when the lighting conditions change. Only you know your code!

In order for you to remember the code, chose events or persons of personal importance and take their names or the date, year and month of the event, the name of the place or the event etc.

Code (digits and/or letters) ....

Thank you for completing the questionnaire.