EFFICIENT USE OF DAYLIGHT IN COMMERCIAL BUILDINGS

Poul E. Kristensen
ESBENSEN, Consulting Engineers FIDIC, Copenhagen
Denmark

Abstract

Natural daylight is an inexpensive and very efficient light source, provided that the amount of daylight entering a building is controlled according to demand. In commercial buildings electricity for lighting can be cut by 50-75% using daylighting design techniques in combination with efficient artificial lighting. New lighting control technologies and advanced computer simulation tools to optimize large buildings makes it possible to exploit these energy savings.

The Scandinavian Ministries of Energy and the Commission of the European Communities CEC are active in promoting these new daylighting techniques. In an recent CEC design competition "Working in the City", the winning project showed a 76% reduction in electricity load for lighting, and a 50% reduction in overall building energy use. In Uppsala, Sweden, a 15,000 m² office building is being built, where good utilization of daylight via an atrium is a main design element. Another example is a 12,500 m² energy - efficient office building, which will be built in 1992/93 in Brussels, being a project in the CEC THERMIE energy promotion programme.

INTRODUCTION

Modern commercial buildings are much dependant upon artificial lighting and large mechanical ventilation and cooling systems. Consequently, electricity use to provide these facilities constitute a major part of the running costs for such buildings. Reduction of electricity use for lighting is interesting, and as a consequence of this, ventilation and cooling load are reduced also, which further reduce the overall electricity consumption.

Reduction of electricity use for lighting can be achieved in various ways. More efficient light sources can be chosen. Fluorescent lamps with high - frequency ballasts are a very interesting choice, especially when combined with efficient luminaires. Careful optimization of the required light level in the various parts of the building is another important strategy. This paper, however, addresses the complementary, but very powerful strategy of using natural daylight for lighting purposes in commercial buildings.

Natural daylight is free, and it is an efficient light source too, provided that it is controlled according to requirement. Daylight releases less heat than traditional lamps for the same amount of visual light. This is shown in table 1, where the luminous efficacy rated in lumen per watt for various light sources is compared.

Table 1: Luminous efficacy for various light sources, typical values.

Light Source	lumen/watt
Incandescent lamp	15
Low voltage halogen	20
Fluorescent lamp	70
Fluorescent lamp + high frequency ballast	90
Direct sunshine	100
Overcast daylight	120
Clear sky daylight	140

Overheating and high cooling loads are major design considerations in commercial buildings. A high luminous efficacy is therefore desirable, and from Table 1 it is seen, that daylight is as good as the best high - efficiency lamps.

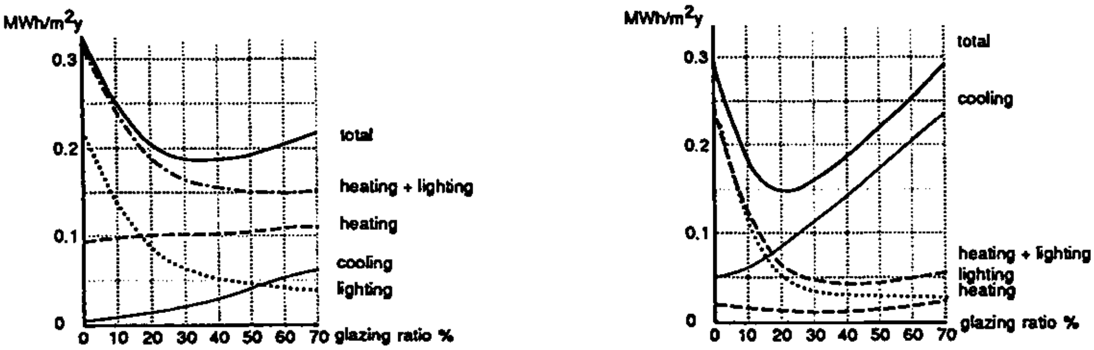
USE OF DAYLIGHT IN BUILDINGS

Natural daylight is available during most of the occupancy time of commercial buildings (offices etc.), and diffuse light is often sufficient to provide adequate lighting levels of 300-500 LUX deep into a building. Efficient use of natural daylight calls for an efficient building layout, that allows daylight deep into the building in adequate quantities. Solar control devices must be installed, which cut off direct radiation and redistribute part of it deeper into building. When these strategies are combined with a high efficient artificial lighting system with daylight - responsive control, electricity use for lighting can be cut by 50 - 75%, without reducing visual comfort. On the contrary, experiences show that access to natural daylight and visual contact with the surroundings are crucial in order to create an agreeable visual milieu in buildings.

CEC COMPETITION "Working in the City"

In 1988 the Commission of the European Communities CEC launched an architectural ideas competition for non - residential buildings. The main idea was to encourage architects to consider utilization of passive solar energy as well as natural ventilation and daylighting strategies as prime design objectives[1,2].

The important interaction between heating, cooling and lighting for an office building is shown in figure 1. The curves show the use of primary energy for heating, cooling and lighting, depending on percentage of glazing in the facade. Primary energy is the energy used at the primary source, i.e. coal used for electricity production etc.



Double glazing. Northern Europe coastal climate

Single glazing. Mediterranean climate

Figure 1: Primary energy use per m² facade versus glazing area for office buildings, south orientation[2].

The most important assumptions behind the curves are: efficient movable solar shading with a shading coefficient of 80%, and a daylight - responsive lighting control system. Maximum daylight is allowed during overcast days, which are frequent in Northern Europe, and excessive cooling loads resulting from solar gains are minimized due to the shading system and the daylight - responsive lighting control system. For further explanation, see reference[2].

In figure 1 it is seen, that lighting load decreases for glazing areas up to 20 - 30% of the facade, whereas the optimum, when considering both heating, cooling and lighting around 30% for Northern Europe, and 20% for Southern Europe.

The winning project of the CEC competition "Working in the City" was a 4,500 m² three story office building from Denmark. The project was designed by KHR A/S Architects, ISLEF Building and Construction Company, Cenergia ApS and ESBENSEN, Consulting Engineers FIDIC. The building is organized with three office blocks, being connected with two glazing atria. Each office block has a glazed staircase room, and to the South-West there is a glazed archade. The exterior window area 30%. The window area in the atria walls is 40% at the top floor, and 60% at the ground floor.

DAYLIGHT ANALYSIS

In order to analyze the daylighting qualities of the design, a 1:20 scale model of a part of the building was built. In fig. 3 the monitoring data are illustrated for the first floor. The daylight efficiency is characterized by the daylight factor = measured light level indoors divided by measured light level outside the building, measured on an overcast day.

The general light level required for offices in Denmark is 200 LUX. An ambient light level of 9,000 LUX is typical for an overcast day, and it is seen, that on such a day, the 200 LUX threshold is achieved in areas where

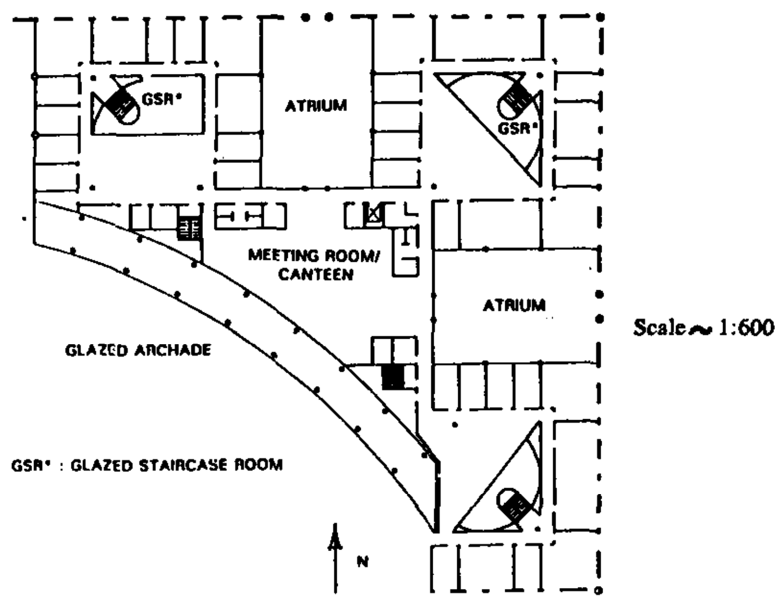


Figure 2: Working in the City competition, winner project, floor plan.

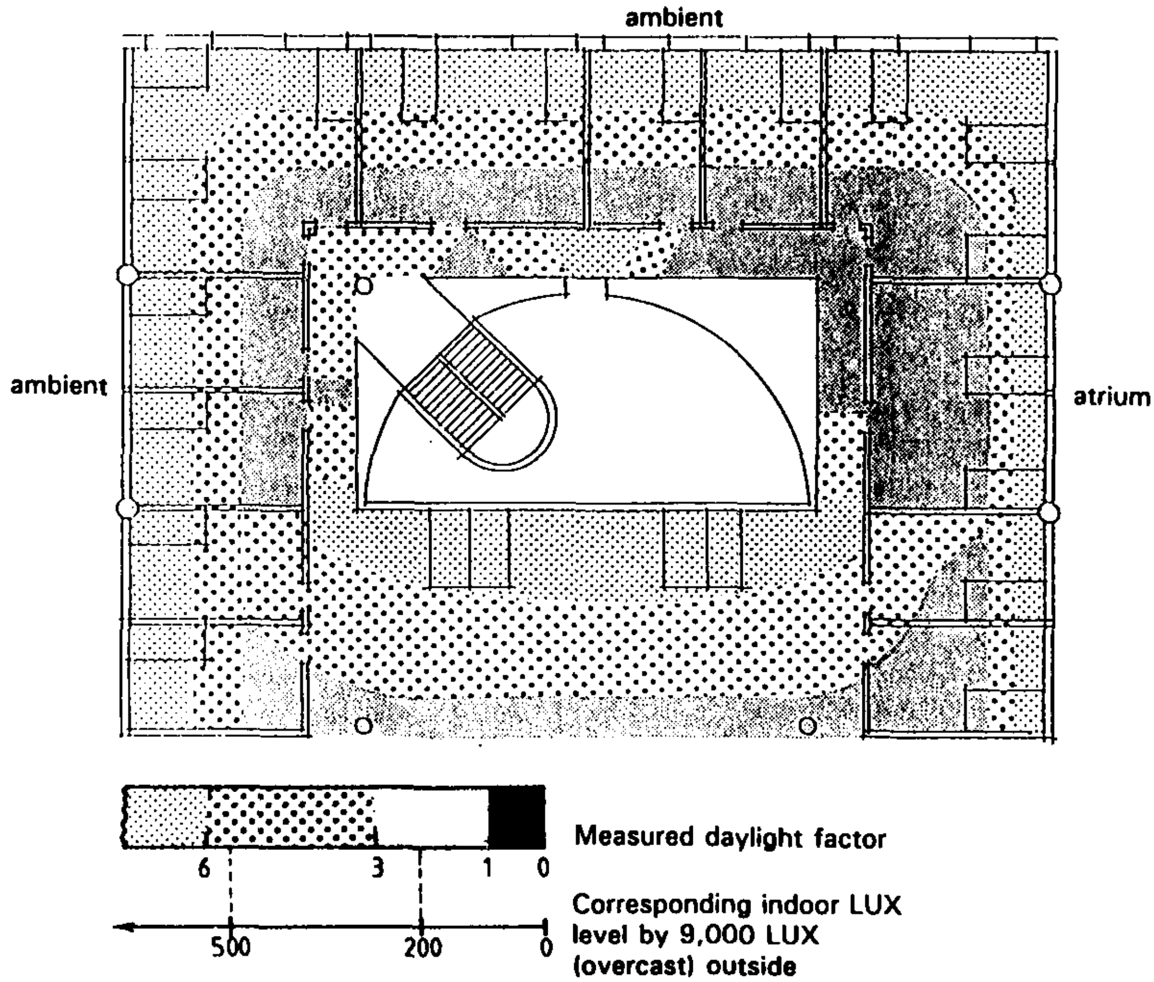


Figure 3: Measured daylight factors in a 1:20 scale model.

daylight factor exceeds 200 LUX/9,000 LUX = 2.2%. This is seen to be the case in most parts of the offices. The required 500 LUX level for the desks calls for a daylight factor larger than 5.6 to satisfy the requirement on a overcast day. This threshold is exceeded for almost all the desk positions shown in figure 3.

It can be concluded that natural daylight will cover the total light requirement in most days, and artificial lighting will only be needed on very dark days during winter, and those parts of winter days when the sun is not up. Based on the model measurements, and the CIE curves[3], the annual savings on electricity for general office lighting has been calculated. The annual saving is 76% of the lighting required during working hours 09.00 - 19.00.

The total primary energy use of the building for heating, lighting and ventilation/cooling is reduced by 50% from 210 kWh/m^2·year down to only 100 kWh/m^2·year. Out of this, electricity for lighting constitutes only 19 kWh/m^2·year, measured as primary fuel, or 5 kWh/m^2·year measured as direct electricity use in the building.

KRISTALLEN in Uppsala.

In 1991/92 a 15,000 m^2 office building is being built in Uppsala, Sweden. A large integrated atrium is a main feature of the building. The design brief for the building called for an environmentally friendly building with special emphasis on a good and stimulating indoor environment. The client is Donald Ericsson AB, Uppsala, and Contekton Architects in Helsingborg designed the building.

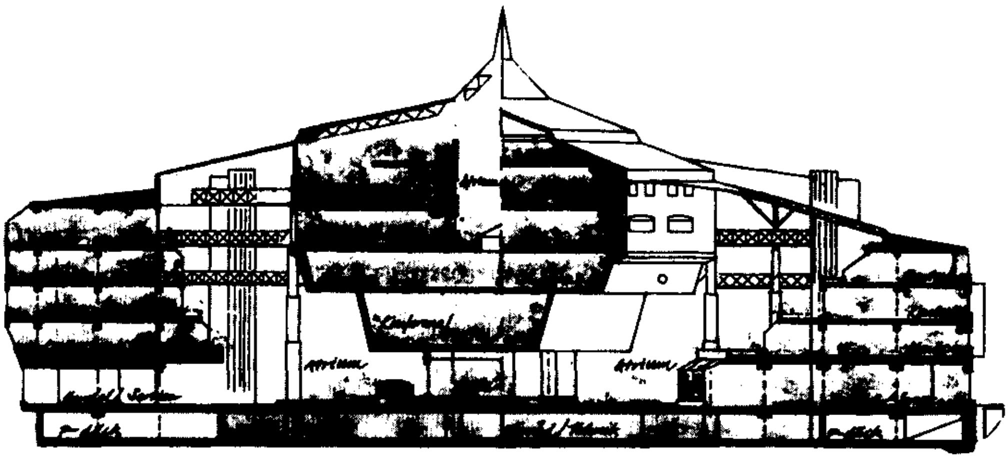


Figure 4: KRISTALLEN in Uppsala, section.

The Swedish Council for Building Research has granted funds for an evaluation of the utilization of passive solar energy and daylighting in Kristallen. The study was carried out by Esbensen, Consulting Engineers Copenhagen[5].

The use of natural daylight in Kristallen was studied using the Superlite simulation programme, developed by Lawrence Berkely Laboratories US. The main conclusion from the study is, that the atrium provides adequate daylight to the offices, even those offices facing the lower part of the atrium, provided that the window area towards the atrium is raised up to 60% of the facade area at first floor level. At the upper level a glazing area of 40% is adequate, whereas the glazing area towards the ambient is 30%. This allows a symmetrical distribution of the light level, see figure 5. In any case light colored walls and ceiling is a main prerequisite for achieving the good daylight performance.

It is noted, that during bright sunshine, the light level required for the desks, 500 LUX, is satisfied up to 3 - 4 meters from the facade, and the requirement for general office lighting, 300 LUX, is satisfied in most of the area. Even for overcast sky conditions it is seen, that the daylight availability at the perimeter of the building is satisfactory. However artificial lighting has to be added in the deeper parts of the building, depending on the light level required by the actual use of the spaces.

Based on the Superlite calculations, the daylight factor in various zones of the building has been established. The daylight factor is the light level in the building divided by ambient light level, both being simultaneously measured on an overcast day. Then the possible percentage of the year where daylight covers 100% of the lighting requirement is estimated using the CIE - curves[3]. The required light level has been set at 300 LUX.

The result is, that natural daylight can cover 69% of the lighting required through a 9.00 to 17.00 working day in a 0 - 4.6 meter perimeter zone of the building, towards the ambient and towards the atrium. In practice this saving can only be achieved, if a daylight responsive control system is installed on artificial lighting. However,

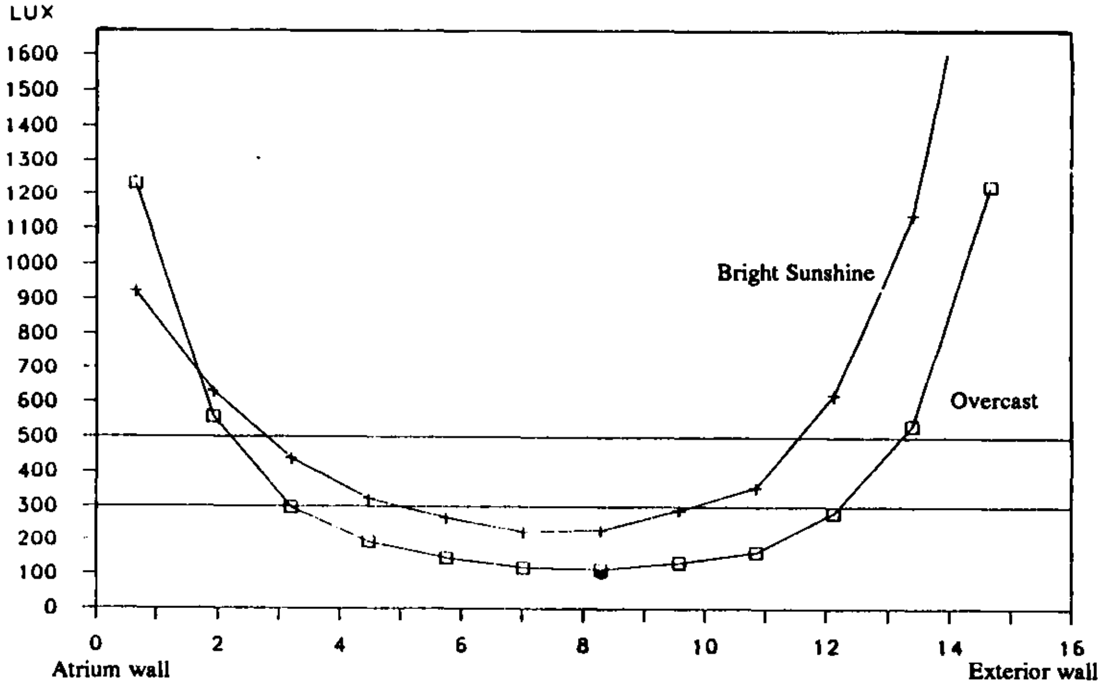


Figure 5: Calculated daylight distribution, 1st floor March 15 at noon.

the saving in practice will be somewhat lower, since even without a control system, the artificial lighting system will be off during some periods of the day and year.

The costs for the lighting control system has not yet been established as a result of a concrete tendering for Kristallen. However it is anticipated, that with the electricity price in Sweden of around 0.10 US $ per kWh, a simple payback period of 10 - 15 years may be attainable.

HELIOS BUILDING IN BRUSSELS

In Brussels a 12,500 m² energy-efficient office building will be built in 1992/93 by Betonimmo/BESIX general

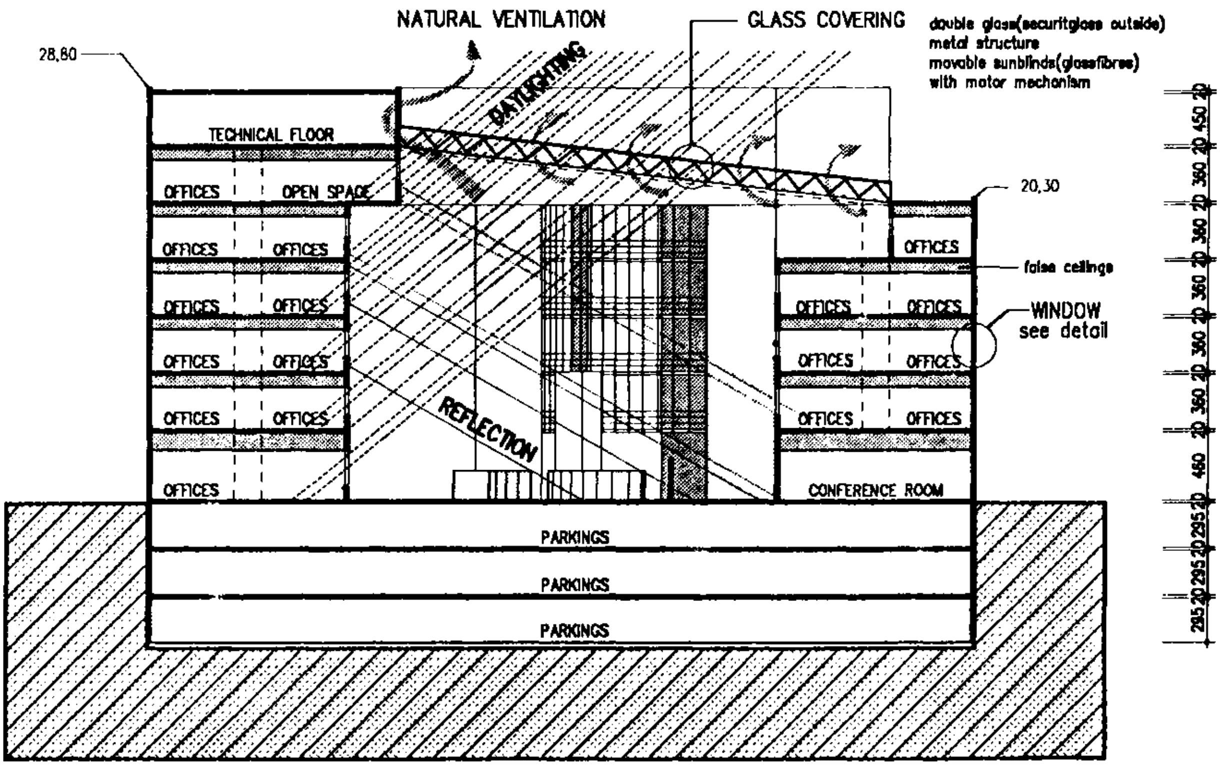
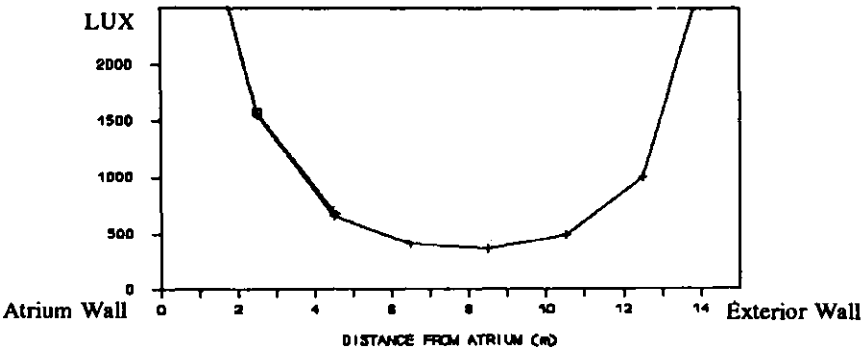


Figure 6: CEC THERMIE Project : 12,500 m² office building in Brussels - Section.

contractors & developers from Brussels, and Birka Holding developers from the Netherlands. The building is shown in figure 6, and it has been optimized to reduce electricity use for lighting and cooling as much as possible. The project has been approved for the CEC THERMIE energy promotion programme.

The building has been optimized using an advanced computer simulation programme: Superlite/Superlink/TSBI3[4]. The Superlite programme, developed by Lawrence Berkeley Laboratory in California, allows calculation of daylight penetration into complex building geometries. The Superlink interface connects this programme to the thermal simulation programme TSBI 3, so that integrated optimization of heating, cooling, lighting and thermal comfort is possible in one programme.

The glazing area to the ambient in the Helios building is 32%, whereas the glazing area towards the atrium varies from 40% at the top to 70% at the bottom of this atrium. Figure 7 shows the calculated light level on first floor on an overcast day mid - March. The variation of the LUX level is shown from the atrium facade, 0 meter, to the exterior facade, 15 meter.



Glazing :
Exterior Wall : 32%
Atrium Wall : 60%

Figure 7: Calculated LUX level, first floor, March 15th, overcast day.

The atrium itself reduces daylight penetration into the offices adjacent to the atrium. This is, however, neutralized by the larger glazing percentage in the atrium wall, as shown in fig. 7.

The electric lighting system designed for the Helios building provides a minimum of 300 LUX general office lighting with an installed lighting power of 10 W/m². The computer analysis shows, that on an annual basis 73% of the lighting load is covered by daylight during the working hours 8.00 - 18.00. Hence the electricity consumption for general office lighting is reduced from 26 kWh/m²·year to only 7 kWh/m²·year.

Solar control is crucial in order to avoid overheating and glare control due to direct sunlight. The windows towards the atrium are protected via shading in the atrium roof. The exterior windows are protected by movable venetian blinds as shown in figure 8.

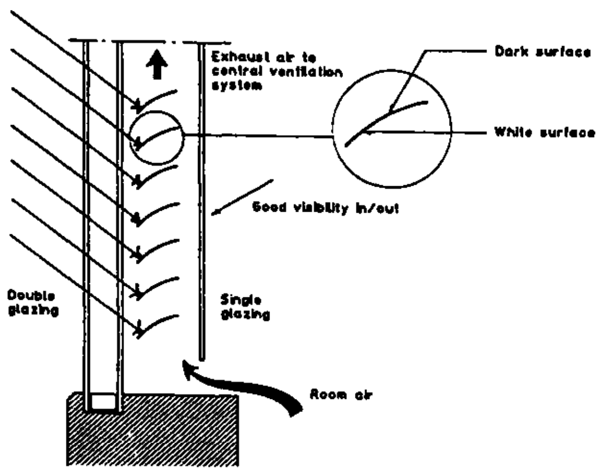
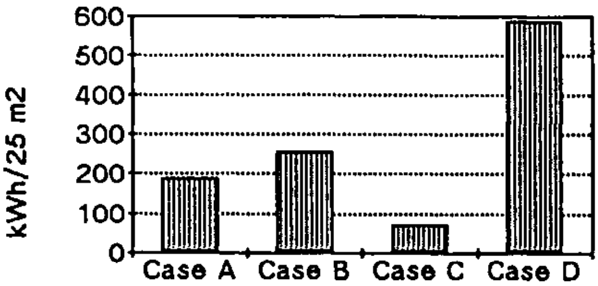


Figure 8: Solar air windows in the Helios building.

The surfaces of the blinds absorb the solar energy, which is then transferred to other parts of the buildings via the ventilation system. When appropriate, daylight can be reflected deeper into the building via the white surfaces of the blinds. In all cases, solar energy which is absorbed in the window is moved away from the facade exposed to sunlight in order to reduce cooling loads, however still allowing adequate daylight into the room. Furthermore the daylight control strategy is also extremely important, in order to avoid excessive cooling loads. This is illustrated in figure 9.



Cases

A : **Reference case**
6 h©1 night ventilation when necessary, 1.5 h^{-1} daytime ventilation. Efficient solar shading, 20% transmission. Light control.

B : No light control.

C : Like A, thermally massive building.

D : Tinted glazing solar shading, 56% transmission.

Figure 9: Helios building: cooling load for a 25 m^2 office room, south orientation, April - Oct. inclusive.

The cooling load for a 25 m^2 office room is shown in four cases. The basic case, case A, represents an energy efficient lightweight office building, with efficient movable solar shading and daylight responsive control of artificial lighting, i.e. the artificial lighting is off when daylight is sufficient. In case B there is no light control, and cooling load increases.

Case C is similar to case A, except that the building is a thermally massive concrete building instead of a lightweight building. Cooling load is decreased drastically, since excessive internal heat gains occurring during daytime are stored in the thermal mass and then vented away during nighttime. It should be noted that this strategy is only valid in climate zones with cool summer nights, i.e. not appropriate in most tropical climates. In case D, solar shading is provided with traditional tinted glazing, which transmits 56% solar energy into the building. Compared to the minimal case, C, the cooling load is nine times higher.

EUROPEAN DAYLIGHTING RESEARCH

In Europe, use of natural daylight in buildings is receiving increasing interest in various research and development programmes. In the coming CEC JOULE research programme, use of natural daylight is expected to be an important research area. In 1991 a Scandinavian (Denmark, Sweden and Norway) daylighting research programme was initiated. The research programme is planned to continue at least until 1994. Also, it is anticipated, that more daylighting demonstration projects, like the Helios building in Brussels, will arrive in the continuation of the CEC THERMIE energy technology programme, which runs from 1990 until 1994 inclusive.

CONCLUSIONS

Utilization of natural daylight via an efficient building design, combined with an efficient artificial lighting system with daylight responsive control means, that the electricity use for lighting can be cut by 50 - 75%, compared to a traditional building with a traditional lighting system. The new daylighting technologies therefore deserves more attention through Research and Demonstration programmes in the coming years. A very promising start of this has been made with the a joint Scandinavian research programme.

REFERENCES

[1] Competition material for the CEC competition "Working in the City". Available from Owen Lewis, School of Architecture, University College Dublin.

[2] Working in the City 1989. Selected entries from the CEC Architectural ideas competition. Edited by Shane O'Thoole and Owen Lewis, School of Architecture, Dublin Ireland.

[3] Commission Internationale de l'Eclairage. Publication No 40, CIE Central Bureau, Kegelgasse 27, A-1030 Vienna.

[4] Daylight analysis using SUPERLITE, SUPERLINK and TSBI 3, 1991. J. E. Christensen and J. Christoffersen, ISES 1991 Solar World Congress, Denver Colorado August 17-24, 1991.

[5] KRISTALLEN New Ideas of The Office Building of the Future (working title).A study of passive solar and daylighting in Kristallen, funded by the Swedish Council for Building Research. Diös Properties, Uppsala and Esbensen Consulting Engineers, Copenhagen. Final report due December 1991.