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WINDOW DESIGN ; VISUAL AND THERMAL CONSEQUENCES

Analysis of the thermal and daylighting performance of windows

By: Mrs. P.M. van Bergem-Jansen and R.S. Soeleman

FENSTERENTWURF ; VISUELLE UND THERMISCHE FOLGEN

Analyse der Fensterausführung in Bezug auf Wärme und Tageslichtbeleuchtung

Von: Frau P.M. van Bergem-Jansen und R.S. Soeleman

PROJET DE LA FENÊTRE ; CONSÉQUENCES VISUELLES ET THERMIQUES

Analyse de l'exécution thermique et d'éclairage de la fenêtre

Par: Mme. P.M. van Bergem-Jansen et R.S. Soeleman

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## ABSTRACT

Selected results of an analysis for the thermal and lighting requirements associated with windows in utility buildings are presented. This analysis concerns the effects of window size and shape, orientation and of different ways of supplementing the daylight by artificial light for a typical office situation in the Netherlands.
Thereby it is assumed that daylight could replace or supplement artificial light whenever it could supply a specified minimum level of illuminance on the working plane.
The selective operation of a sunshading device is taken into account to prevent glare by direct sunshine.
It is shown that substantial savings in energy consumption for lighting can be made by a combination of reasonable daylight contribution and a rational switching or dimming policy in response to daylight variations. Of those two the dimming system considered gives the greatest savings. The reduction in electricity demands for lighting results in less savings on the thermal requirements. Here the weather loads are more significant than the lighting load. Because of the great variations in the weather conditions considered in this study, the authors give preference to the use of real weather data in thermal and energy calculations above reference ones.

## ZUSAMMENFASSUNG

Es werden einige selektierte Ergebnisse einer Analyse der thermischen und Beleuchtungsanforderungen an Fenster in Bürogebäuden gegeben. Es betrifft hier die Effekte von Fensterabmessungen und Form, Orientierung und verschiedenen Möglichkeiten, das Tageslicht in einer typischen Bürosituation in den Niederlanden mit Kunstlicht zu ergänzen.
Dabei wird angenommen, dass Tageslicht Kunstlicht ersetzen oder ergänzen kann, wenn es nur ein spezifisches Mindestbeleuchtungsniveau auf der Arbeitsfläche liefern kann.
Auch die selektive Wirkung eines Sonnenschutzgeräts wird berücksichtigt, um Blendung bei direktem Sonnenschein zu verhindern.
Es wird gezeigt, dass eine bedeutende Energie-einsparung für Beleuchtung möglich ist, wenn man das Tageslicht mit einer rationellen Einschaltungs und Regelungspolitik gegenüber den Tageslichtschwankungen kombiniert.

Von diesen beiden liefert das betrachtete Lichtregelungssystem die grössten Einsparungen.
Die Abnahme des Elektrizitätsverbrauches für Beleuchtung hat wenigere Einsparungen der thermischen Anforderungen zur Folge. Die Wetterbelastungen sind hier bedeutender als die Belastung der Beleuchtung. Wegen der grossen Schwankungen in den Wetterlagen, die hier betrachtet werden, bevorzugen die Verfasser die Verwendung wirklicher Wetterdaten in thermischen und Energie-berechnungen vor der Verwendung Referenz-daten.

RESUME

On présente quelques résultats sélectionnés d'une analyse des demandes thermiques et d'éclairage aux fenêtres dans des bâtiments d'utilité publique. Il concerne ici les effets des dimensions et de la forme de la fenêtre, l'orientation et les différentes manières de suppléer de la lumière artificielle à la lumière du jour dans une situation typique de bureau aux Pays Bas.
On suppose que la lumière du jour peut remplacer ou compléter la lumière artificielle, au moment qu'elle peut fournir un niveau d'éclairage minimum spécifié au le plan de travail.
L'action sélective d'un appareil protecteur contre le soleil est aussi considérée, pour empêcher de la lumière éblouissante par du soleil direct.
Il est montré, qu'on peut économiser considérablement sur énergie pour éclairage, si on comdine la lumière du jour avec une politique rationelle d'éclairer et de régler en réponse aux variations de la lumière du jour.
De ces deux systèmes, le système de régler considéré donne d'économie pour les demandes thermiques. Ici, les charges du temps sont plus importantes que la charge de l'éclairage. A cause des grandes variations du temps, que sont considérées ici, les auteurs préfèrent à user les données du temps réelles dans les calculations thermiques et d'énergie.

## 1. INTRDUCTION

The energy required for electricity in utility buildings can be very high. It has been shown that the energy used for the indoor lighting constitutes a major portion of this (Euser 1978).
Maximum use of daylight can reduce enrgy consumption for electric light. In addition, the use of daylight can also reduce the cooling loads resulting from artificial lighting.
In the area near the window to approximately 5 m distance from the window wall, daylight can be sufficient for illumination of the visual task. The utilization of daylight, however, requires larger window areas, which can result in increased winter heat loss and summer heat gain. The reduction of energy usage for lighting and cooling by using daylight could, therefore, be partly or completely offset by an increase in energy consumption for heating or cooling. Furthermore, visual task performance and comfort might be adversely affected by glare produced by daylight and direct sunshine.
Although, these effects can be reduced somewhat by the proper operation of sunshading devices, studies on this subjects are needed. The results of these studies might be useful, 1. to the designer in determining the optimum ammount of fenestration and window design that balances the benefits and disadvantages concerning the use of daylight, 2. to the engineer in deciding which energy conservation system is effective with a given window configuration.

Here a beginning with this approach is made. An analysis of the thermal and daylighting performance of windows of various sizes is used. Whereby,the effect of the selective operation of a sunshading device and of different ways of supplementing the daylight by artificial light are studied.
Selective results for a typical office situation in the Netherlands are presented to illustrate the effects on lighting and thermal requirements.

## 2. DESCRIPTION OF THE ANALYSIS

### 2.1 Description of the office module

A multi-person office in a building in the Dutch region is considered, with a width of 7.2 m, a depth of 7.2 m, and a height of 2.7 m.(Fig. 1) The office has one external facade and is located in the middle of a

Figure 1

highrise building. Thus, all the non-facade areas are considered to have no heat transfer. Calculations are carried out for an average building construction. Afixed thermal load due to human occupancy was set to 5 persons occupying the office the whole working period except during lunchtime. An equipment load was fixed to simulate office equipment such as type writers and calculators (not computers). See Appendix A.

figure 2

The artificial lighting installation is of the general fluorescent type and designed on a mean lighting level (in place and time) of 650 lux at desk top level (lighting load : 23 $W/m^2$) - See fig. 2. Three window sizes are considered: 30%, 50% and 70%.
Each glass percentage is divided over the outer wall in such a way that:

a) a view out is guaranteed
b) a maximum entering of daylight is provided on the working plane, which means that the window sill is not lower than 0.8 m above floor and the window height reaches the ceiling.
c) the daylight distribution over the room width is uniform.

No opposite buildings are considered (Fig. 3).

figure 3

Venetian blinds of light colour are installed on the inside, which forms common practice nowadays. The windows are double glazed. Two orientations are considered : SE and NW.

## 2.2 Operation of the sunshading device

The above mentioned sun shading device is considered to be operated automatically; as soon as the direct sunlight reaches further than 1 m into the room on the working plane, the sun shading device is used completely. To let as much daylight enter the room the louvres are blocked at $45^o$.

## 2.3 Glare from daylighting

In the analysis the factor glare is not taken into account completely. As the blinds are automatically used when direct sunlight penetrates the interior (par. 2.2), glare is controlled in that case. In the other cases, for example on bright days without direct sunlight penetration in the interior, it is supposed that the occupants do not experience glare discomfort. This assumption can only be accepted when the occupants do not face the windows directly and the interior surface areas are of high reflectances. That is why the following (high) reflectances are taken into account: ceiling - 70%, walls - 50%, floor - 10%.

2.4 Possibilities of supplementing daylight by artificial light

Two ways of supplementing daylight by artificial light are to be distinguished: switching and dimming. For both possibilities it means that the artificial light will be used where and when it is necessary, that is if the daylight level is below a certain value.

In this study the following control schemes are considered during normal working hours ( 8.00 - 17.00 o'clock) :

a. per hour the following decisions are made, based on the hourly mean admission of daylight in four zones of the working plane which correspond with the four rows of luminaires parallel to the window wall:

1. switching system: which row of luminaires can be switched off
2. dimming system: which row of luminaires can be switched off and which one can be dimmed to which level

b. per hour the following decisions are made, based on the hourly mean admission of daylight in one reference point of the working plane at 2.5 m distance fron the window wall and between the side walls:

1. switching system: can the whole lighting installation be switched off.
2. dimming system: can the whole lighting installation be switched off or can it be dimmed and if so to which level.

c. during the whole working period the whole lighting installation will be switched on.

In every scheme considered the lights will be switched off during lunch time (12.00 - 13.00 o'clock). As criterion will be applied that the concerning part of the lighting installation can be switched off as soon as the daylight level in the concerning zone or in the reference point equals or exceeds 650 lux. In deciding the dimming percentages a dimming system is used that controls fluorescent lighting installations with traditional ballast circuits. The lowest possible light output this system and the lamp type used is 72%, as the lamps start flickering or switch off at lower levels.

## 2.5 Thermal calculations

The presence of windows and lighting fixtures involves light as well as heat radiation coming into the room. This radiation as such can not be picked up by the room-air. First this energy is taken up by the floor and the walls (also by the furniture etc.).
Second, when the floor and wall temperature have become higher than the room air temperature, a part of it is supplied to the room air. This amount of heat supply depends on the physical properties of the building mass of floor and walls. In the analysis an average building mass is considered.
As the artificial lighting installation and the sunshading device are both activated along different criteria, the amount of lighting energy and the amount of solar heat gain are determined seperately. The amount heat gain through the facade and by ventilation are also quantified. In this way the influence of the use of daylight with the concerning window designs can be determined more systematically, just as the effect of the building construction.

There are several methods for calculating the heating / cooling demand in buildings. The one used here is
a computer program which calculates the momentary (dependent on time-step) values of all temperatures and heatflows for one room in a building with or without temperature control. It makes use of so-called response functions. It simulates all thermal resistances and capacities and ventilating air flows. Specifications as to the indoor conditions to be maintained are given in Appendix A.
In this analysis the calculations are carried out using real weather data.

## 2.6 Daylight calculations

A computer subroutine is developed to determine the hourly mean amount of daylight antering a window.
The daylight calculation procedure for thr situation without sunshading device is based upon the daylight factor approach (Hopkinson 1966). As this is the same concept as used fot the preparation of the TNO-Daylighting-Diagrams (Van Bergem-Jansen 1978,1979), these diagrams - for the

clear as well as for the overcast sky - have been used in this analysis. This has the advantage that the distribution of the entering daylight over the working plane can be obtained directly.
Then, after having determined the mean amount of internally reflected daylight, the indoor illuminance is for each hour obtained from the hourly available mean horizontal outdoor illuminance.
For the situation with sunshading device it is considered that the Venetian blinds diffuses the daylight entering through the window into the room. The calculation method for the illuminance from a rectangular uniform source is used here (IES 1972).
The hourly available mean illuminance outdoors on the vertical window-pane and on the horizontal plane, needed for both calculations, are obtained using those for the clear and overcast sky and taking into account the real sunshine periods for the Dutch region. According to (Rattunde 1975) this calculation method leads to reasonable results.

A scheme for switching off or reducing the artificial lighting whenever the daylighting level at a given point or in a given zone in the room exceeds a prescribed value of illumination for a specified task, is included in this computer program.

## 3. RESULTS

Results are presented for two weeks: one week in November 1971 and one week in May 1972. Those two weeks represent respectively a week in the winter and one in the summer. For the week in May the summer time is taken into account.
For every working day the normal working hours (8.00 - 17.00 o'clock) are considered to determine the use of daylight.

The scheme for switching off or reducing the artificial lighting, included in the daylight program, can be based on two different reference situations:

a) whenever the mean daylight level in a given zone of the working plane exceeds a prescribed value of illuminance, the corresponding row of luminaires are switched off or dimmed.

b) whenever the daylight level in a given point of the working plane exceeds a prescribed value of illuminance, the whole lighting installation is switched off or dimmed.

figure 4

As the criterion for the lighting of the office room is a mean illuminance of 650 lux at desk top level in the entire room, the reference situation b, concerning a reference point at 2.5 m distance from the window wall, is not useful here. Figure 4 shows the mean lighting situations for one hour based on both reference situations a and b for the switchting system. From figure 4b it is clear that reference situation b results in a lighting level at the back of the room that does not fullfil the above mentioned requirement. Therefor the following results given in graphes, only concern the reference situation mentioned under a (switching or dimming in zones).

figure 5

figure 6

figure 7

## 4. CONCLUSIONS

The following conclusions are drawn from the results presented with the lighting situation "all lights on" (par.2.4 under c) as the reference situation:

### 4.1 concerning the electricity demand for lighting

The larger the glass percentage, the greater the savings on the electricity demand for lighting, caused by switching as well as by dimming policy. Due to the increasing amount of daylight penetration the necessary supplement of artificial lighting decreases. Here savings upto 65% are calculated.

The dimming system results in more electrical energy savings than the switching system does. The artificial lighting can only be switched off as a specified level of illuminance is available by daylight. Whenever daylight is only sufficient to provide a fraction of this specified level of illuminance, it is "topped up" by artificial lighting when a dimming system is used.

NW-orientation gives more savings than SE-orientation. Due to the more frequent necessary use of the sunshading device at the SE-orientation, the NW-orientation results in a greater amount of daylight penetration.

As in the month of May the outdoor illuminances are higher than in the month of November, the electricity demand for the necessary supplement by artificial light is less.

4.2 concerning the thermal requirements

The reduction of the thermal demands is not proportionate to the reduction of the electricity demand; it is much smaller.
In the situations considered here the weather loads and the glass percentage are more significant.
Whenever heating is necessary the reduction of the cooling load is accompanied by the increase of the heating load.

4.3 concerning the lighting and thermal requirements

Though it seems to be obvious that maximum use of daylight with large window areas would lead to the greatest savings, from this study it can be concluded that small windows together with dimming policy are more energy effective.

From this study no optimum can be found, because of the greater influence of the weather load and the glass percentage.

Because of the great variations in the weather conditions and their influence on the results obtained here, the use of real weather data in thermal and energy calculations should be prefered.

Further reduction of the light output than is possible with the dimming system considered and a more sophisticated sunshading device could have given more significant results.

## 5. RECOMMENDATIONS FOR FUTURE RESEARCH

Further research is needed to verify the energy savings predicted in this paper in field situations.

In the model the demands concerning the luminance variations are not taken into account completely and some assumptions are made. Further extension of the computer subroutine on this field is necessary.

Research on human acceptability of several ways of lighting management is needed.

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## 7. ACKNOWLEDGEMENT

The authors thank B.V. REM v/h Croon en Co for the detailed information on the dimming system considered in the calculations.

EB/adv
May 1979

Figure 1 - Office module for a multi-person office in the Dutch region.

Figure 2 - Artificial lighting installation:
12 x 2 x 40 W fluorescent/cool-white

Figure 3 - Window designs

Figure 4 - Lighting situation on a sunny day in May 1972 between 15.00 - 16.00 h; orientation SE, 50% glass.

- a. Switching system, based on the mean admission of daylight in four zones of the working plane
- b. Switching system, based on the mean admission of daylight in one reference point of the working plane at 2.5 m distance from window wall.

Figure 5 - 24-hours course of (momentary) thermal and lighting requirements for a sunny day in May 1972; orientations SE, 30% glass

- a. All the lights are switched on during working period (8.00 - 17.00 h).
- b. Switching system, based on the hourly mean admission of daylight in four zones of the working plane.
- c. Dimming system, based on the hourly mean admission of daylight in four zones of the working plane.

Figure 6 - Course of thermal and lighting requirements for six days of a week in May 1972; orientation SE, 30% glass

- a. All the lights are switched on during working period (8.00 - 17.00 h).
- b. Switching system, based on the hourly mean admission of daylight in four zones of the working plane
- c. Dimming system, based on the hourly mean admission of daylight in four zones of the working plane

Figure 7 - The total requirements for lighting and air-conditioning for one week in May 1972,

a) orientation NW

b) orientation SE

Figure 8 - The total requirements for lighting and air-conditioning for one week in November 1971,

a) orientation NW

b) orientation SE

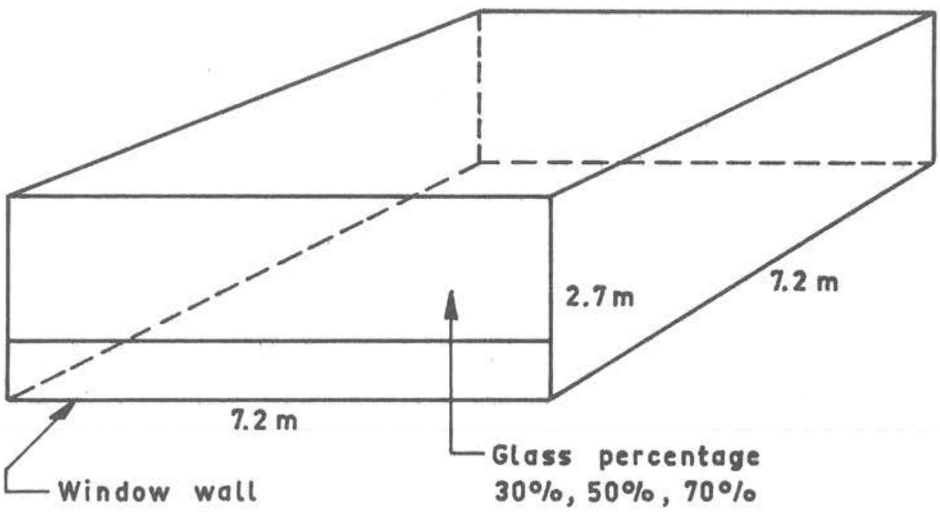



fig. 1

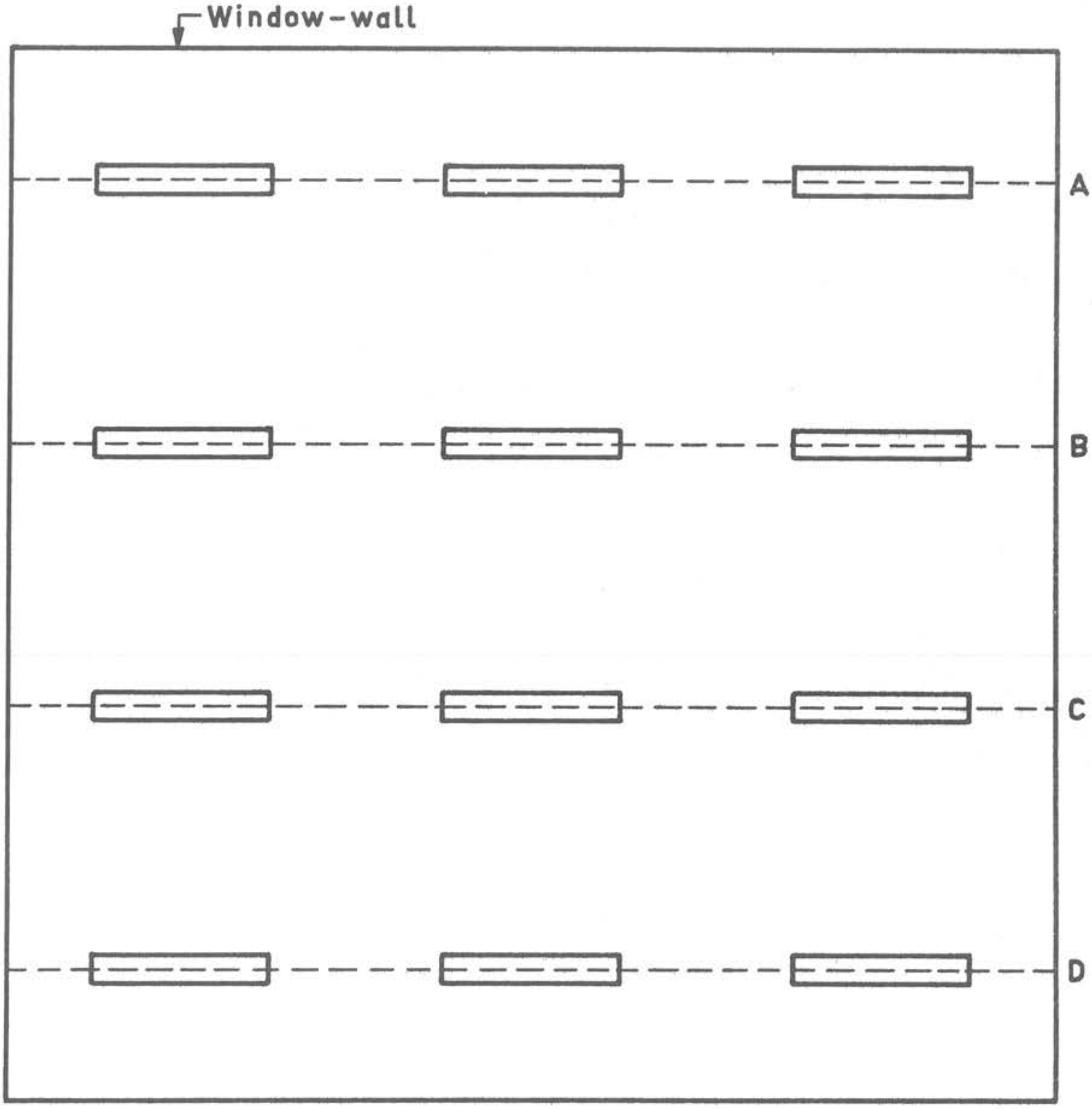
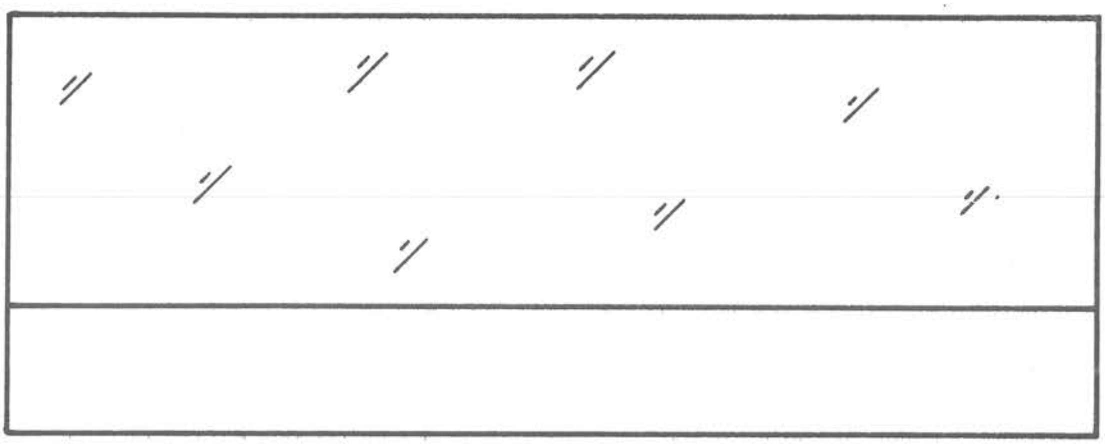
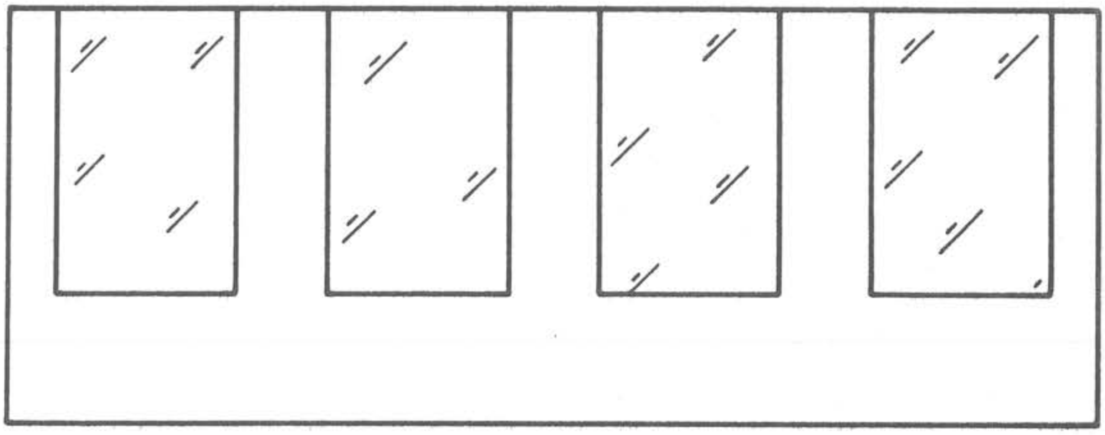


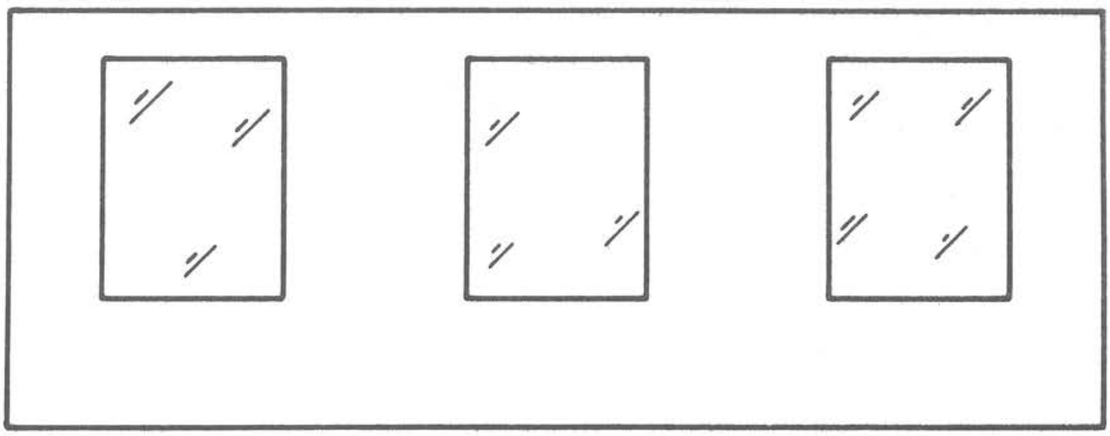

fig. 2



70 % glass



50 % glass



30 % glass

fig. 3

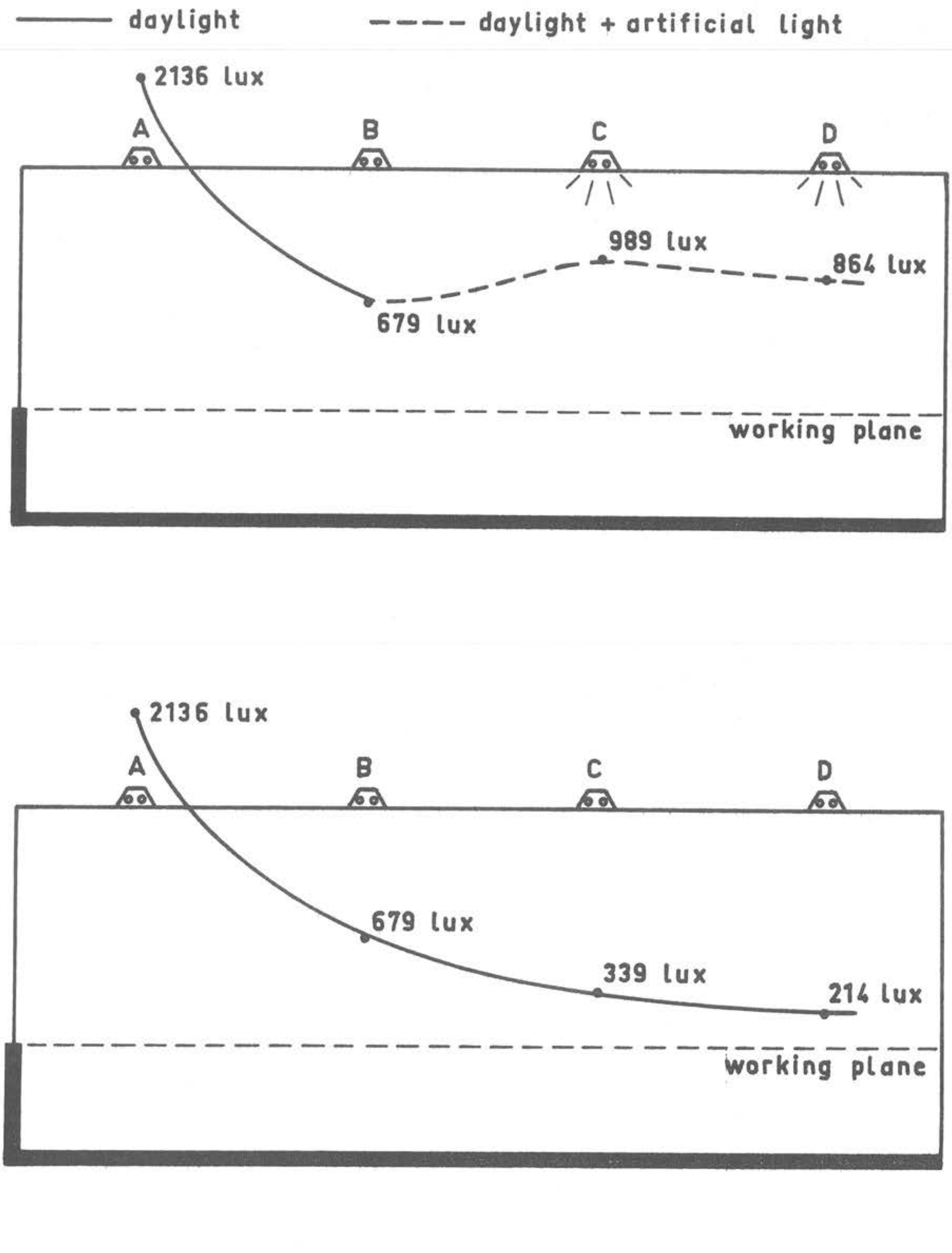
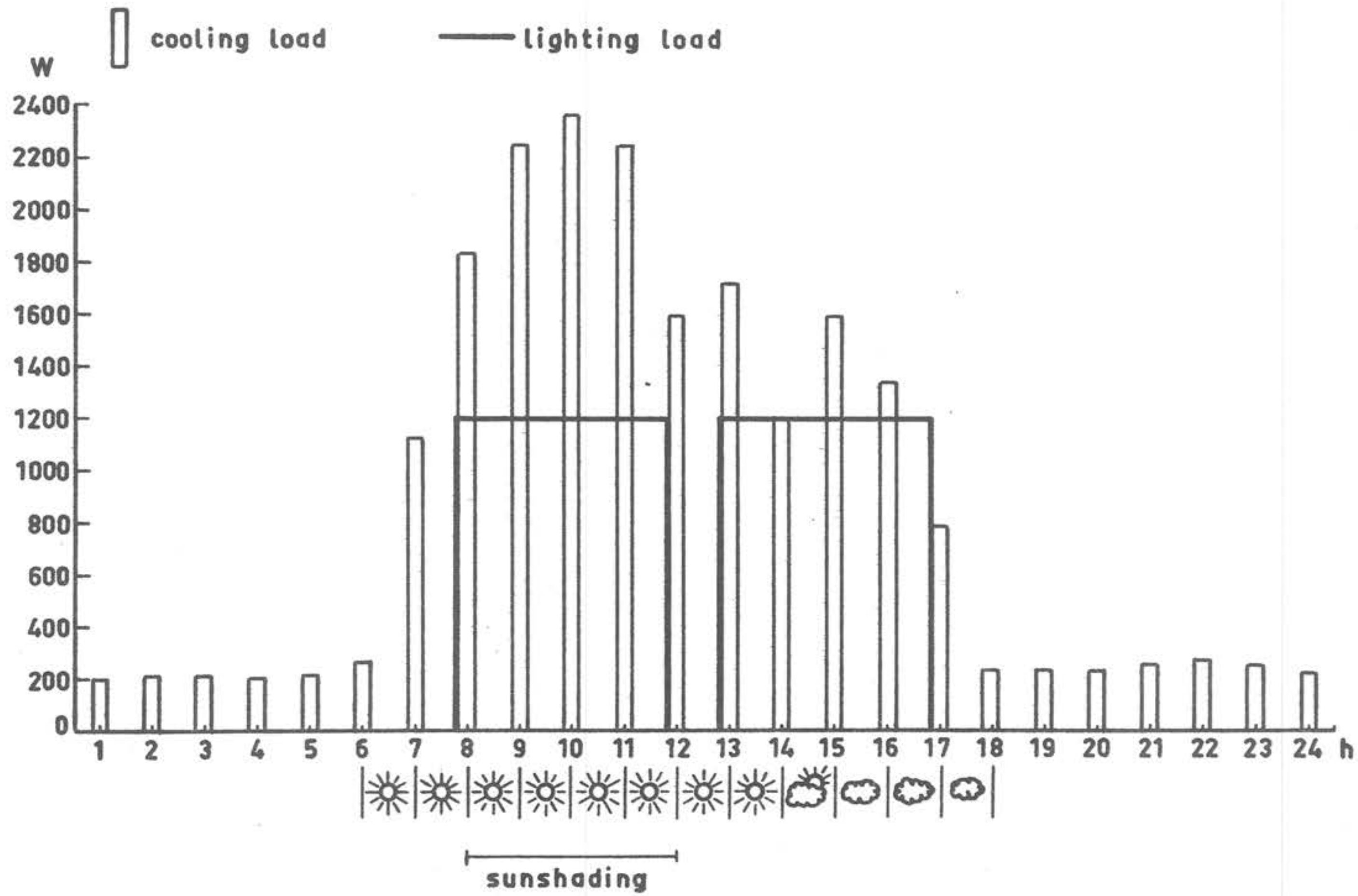

daylight
daylight + artificial light
2136 lux
A
B
C
D
989 lux
864 lux
679 lux
working plane
2136 lux
A
B
C
D
679 lux
339 lux
214 lux
working plane

fig. 4a,b



cooling load
lighting load
W
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 h
sunshading


fig. 5a

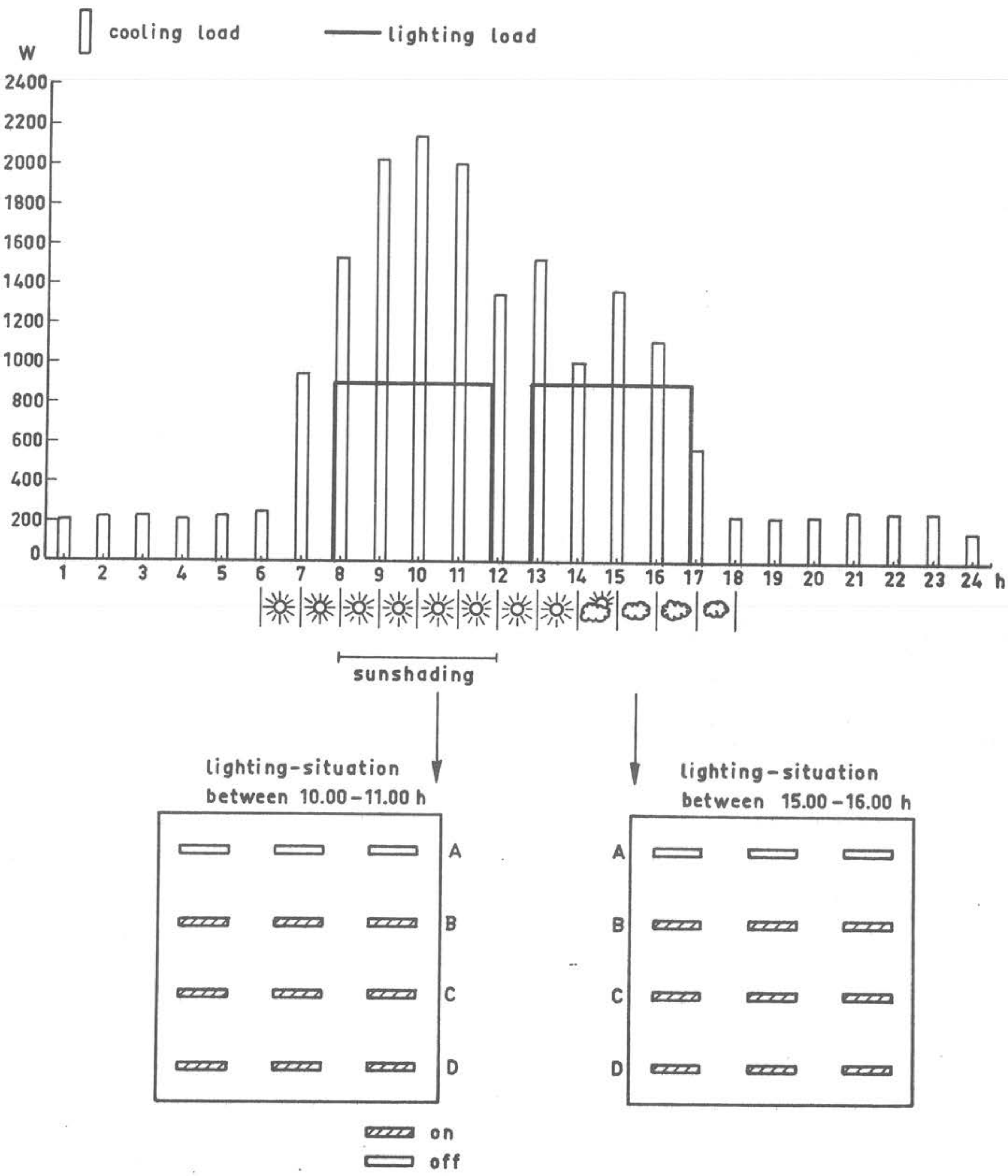

cooling load
lighting load
W
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 h
sunshading
lighting-situation
between 10.00 - 11.00 h
lighting-situation
between 15.00 - 16.00 h
A
B
C
D
on
off

fig. 5b

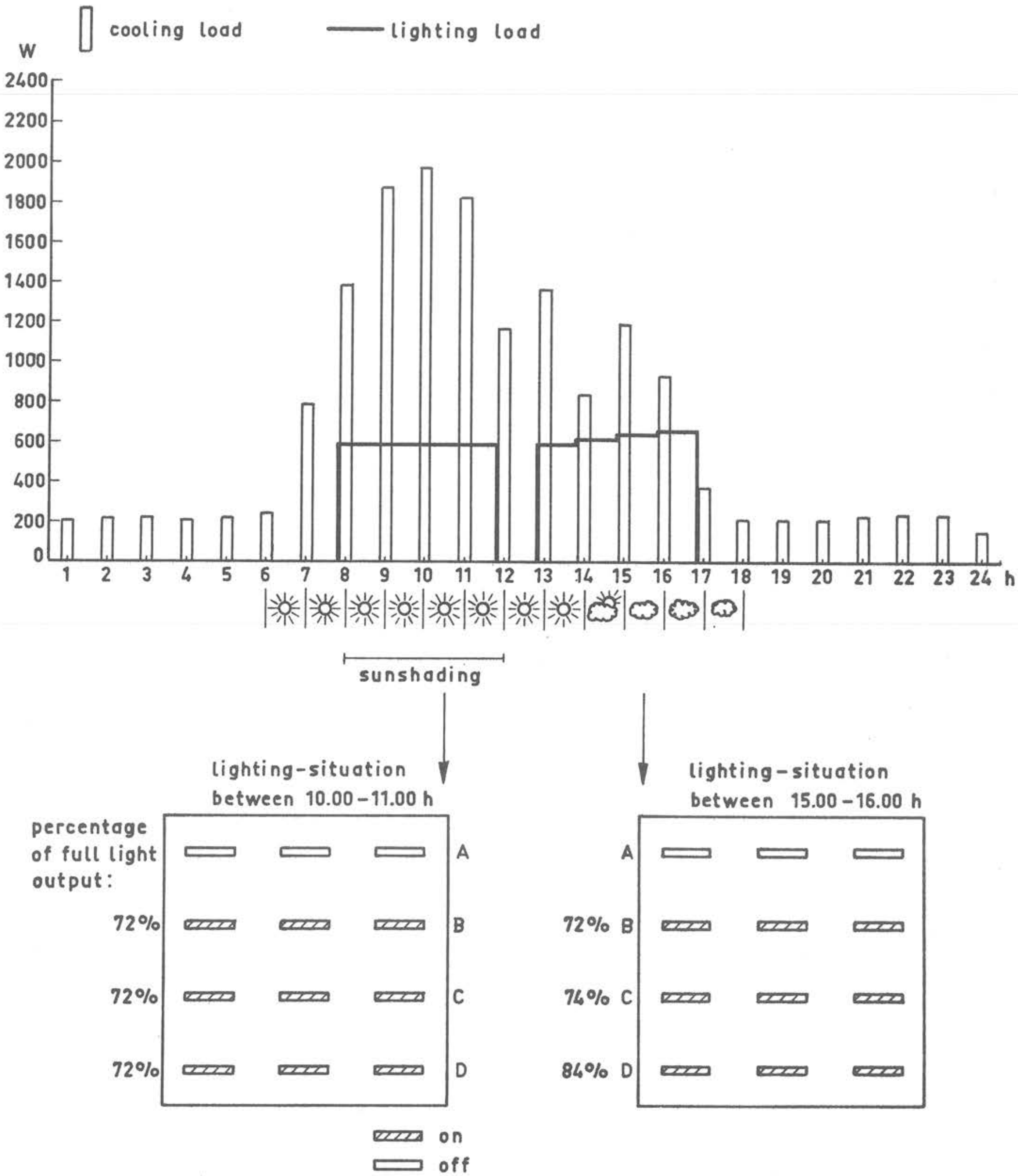
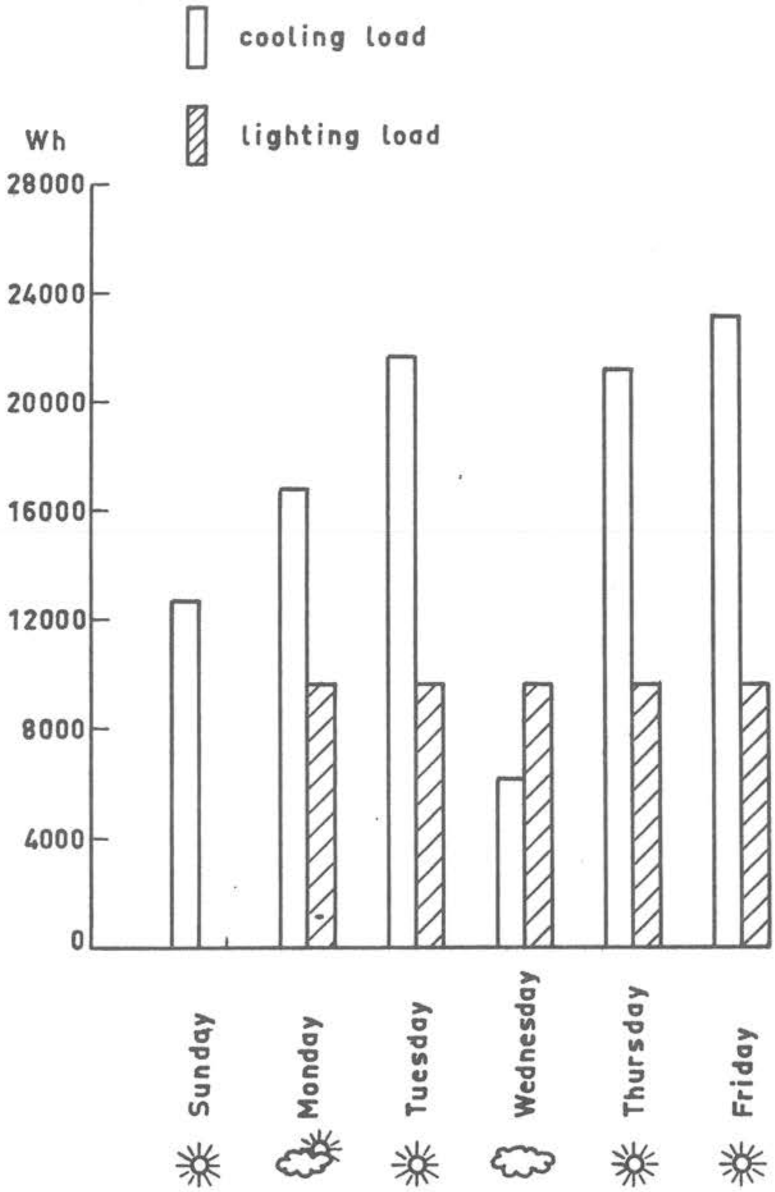

cooling load
lighting load
W
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 h
sunshading
lighting-situation
between 10.00-11.00 h
percentage
of full light
output:
72%
72%
72%
A
B
C
D
lighting-situation
between 15.00-16.00 h
A
72% B
74% C
84% D
on
off

fig. 5c



cooling load
lighting load
Wh
28000
24000
20000
16000
12000
8000
4000
0
Sunday
Monday
Tuesday
Wednesday
Thursday
Friday


fig. 6a

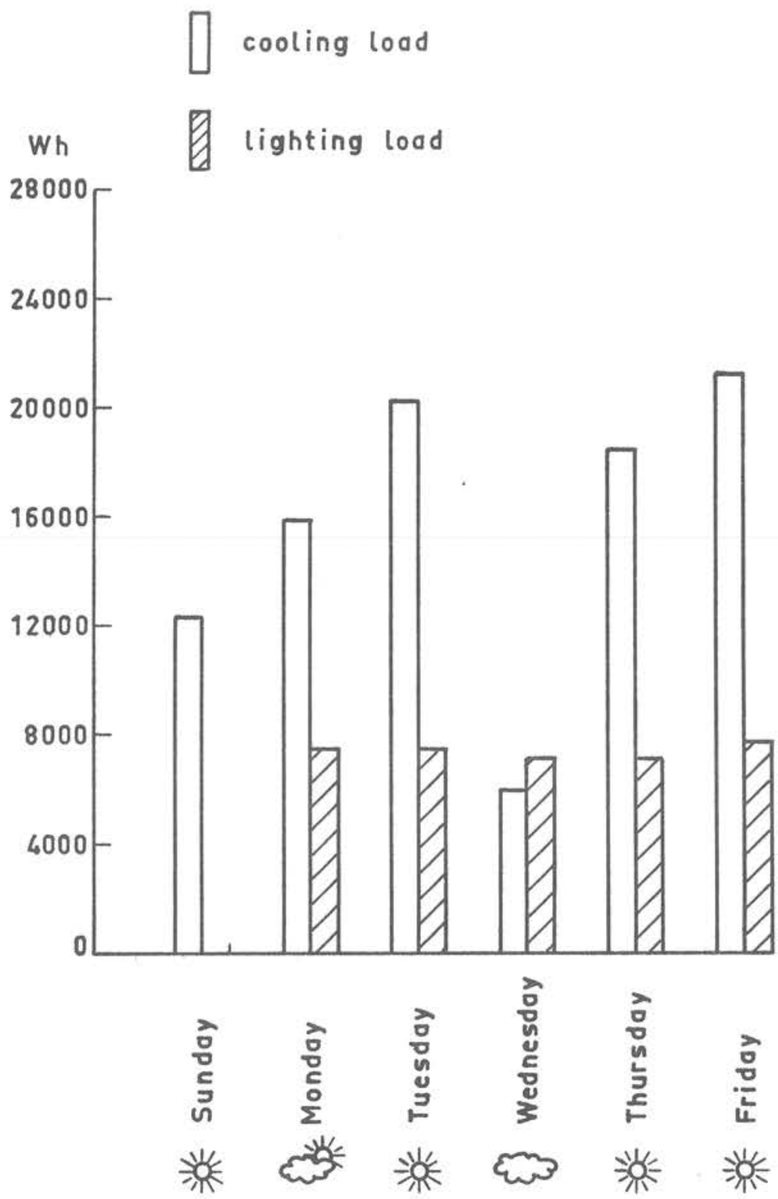

cooling load
lighting load
Wh
28000
24000
20000
16000
12000
8000
4000
0
Sunday
Monday
Tuesday
Wednesday
Thursday
Friday

fig. 6b

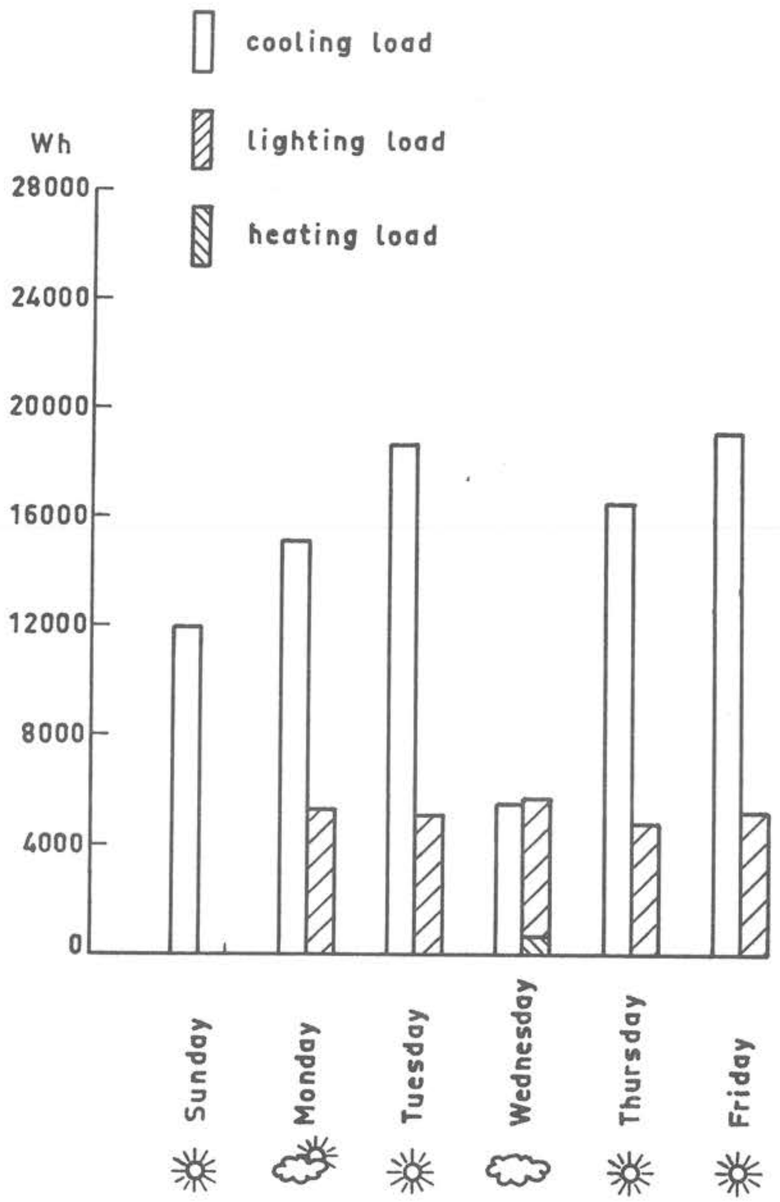
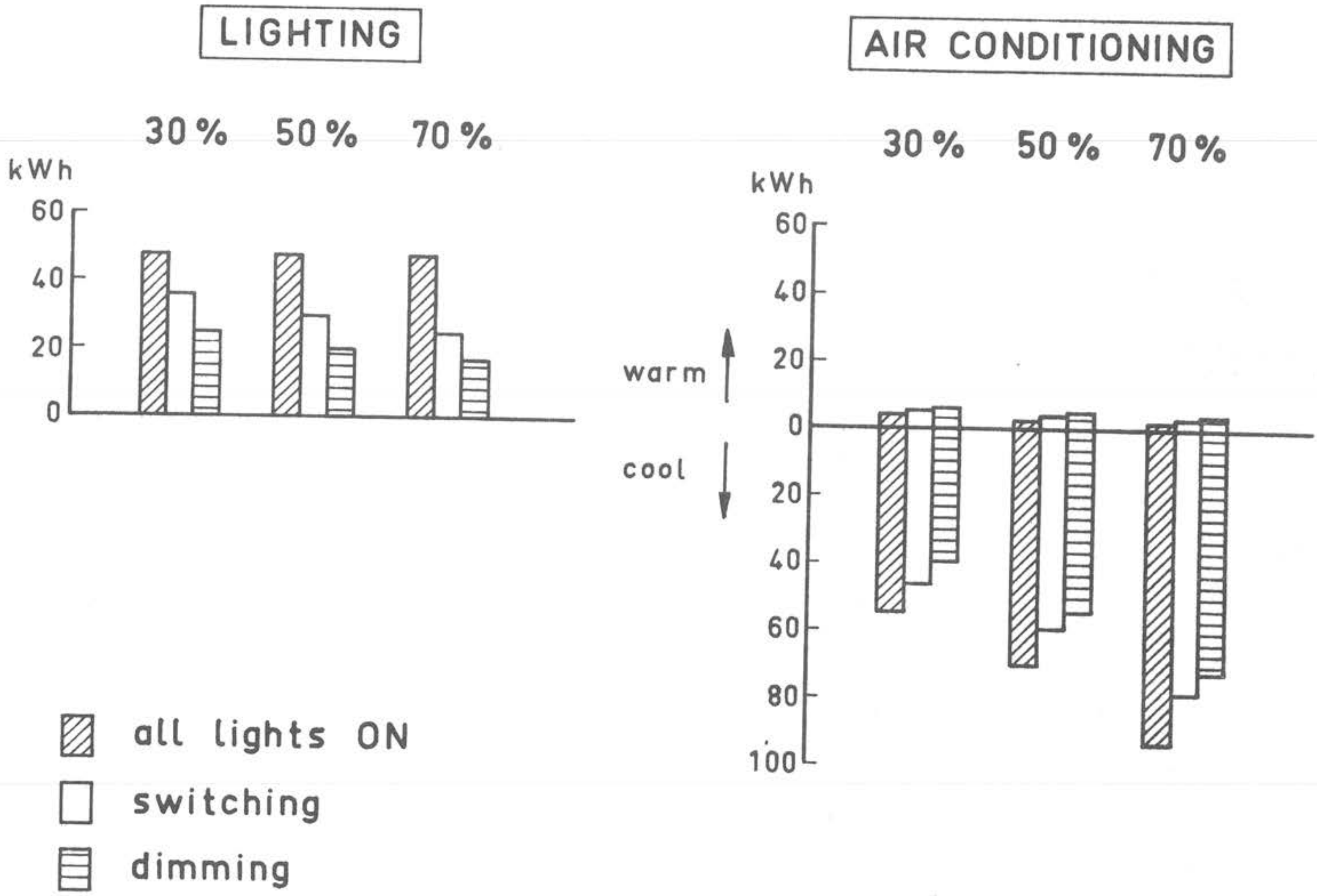

cooling load
lighting load
heating load
Wh
28000
24000
20000
16000
12000
8000
4000
0
Sunday
Monday
Tuesday
Wednesday
Thursday
Friday

fig. 6c


LIGHTING
30 %
50 %
70 %
kWh
60
40
20
0
AIR CONDITIONING
30 %
50 %
70 %
kWh
60
40
20
0
20
40
60
80
100
warm
cool
all lights ON
switching
dimming

MAY - NW

Fig. 7a

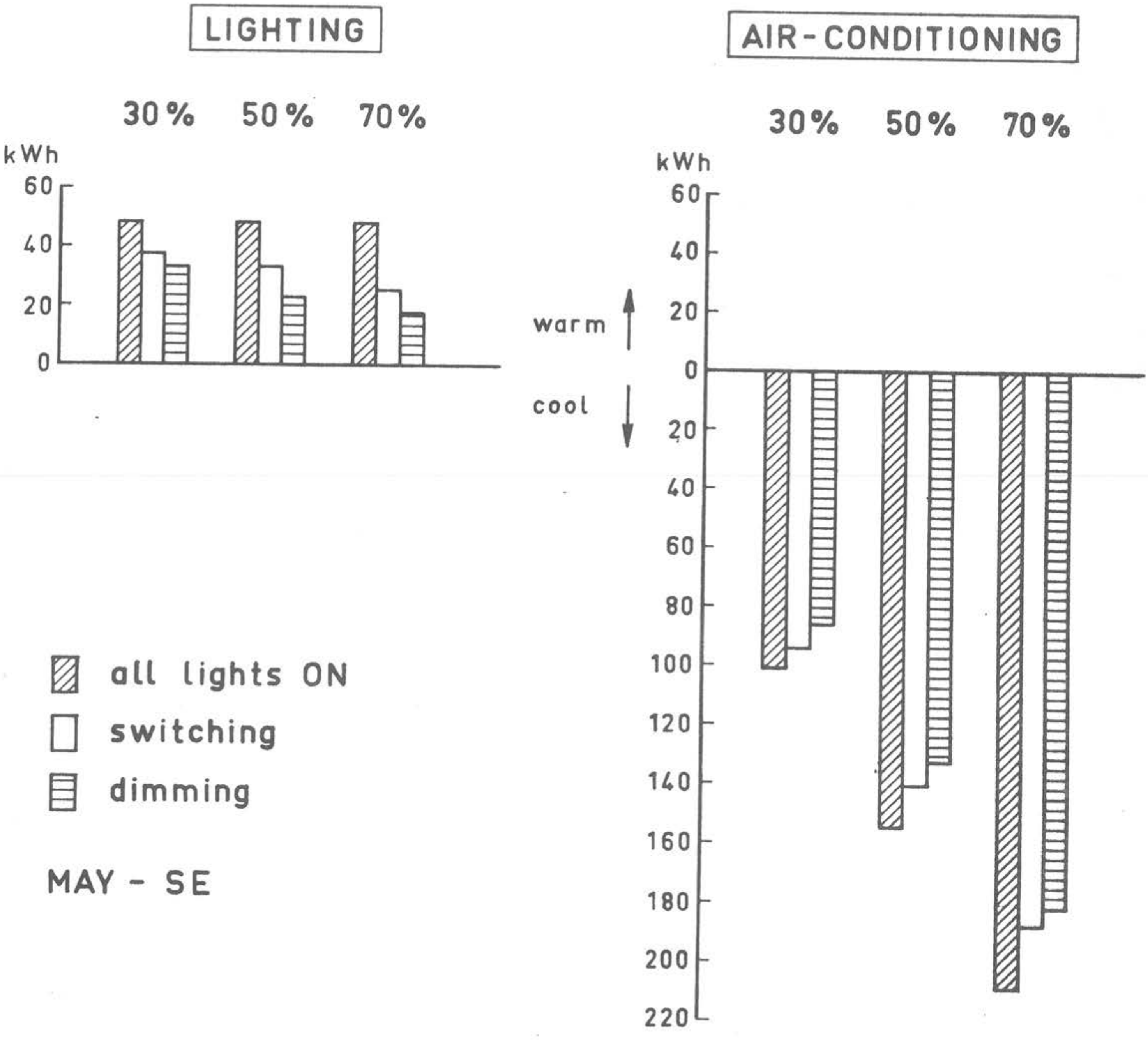

LIGHTING
30 %
50 %
70 %
kWh
60
40
20
0
AIR-CONDITIONING
30 %
50 %
70 %
kWh
60
40
20
0
20
40
60
80
100
120
140
160
180
200
220
warm
cool
all lights ON
switching
dimming
MAY - SE

Fig. 7b

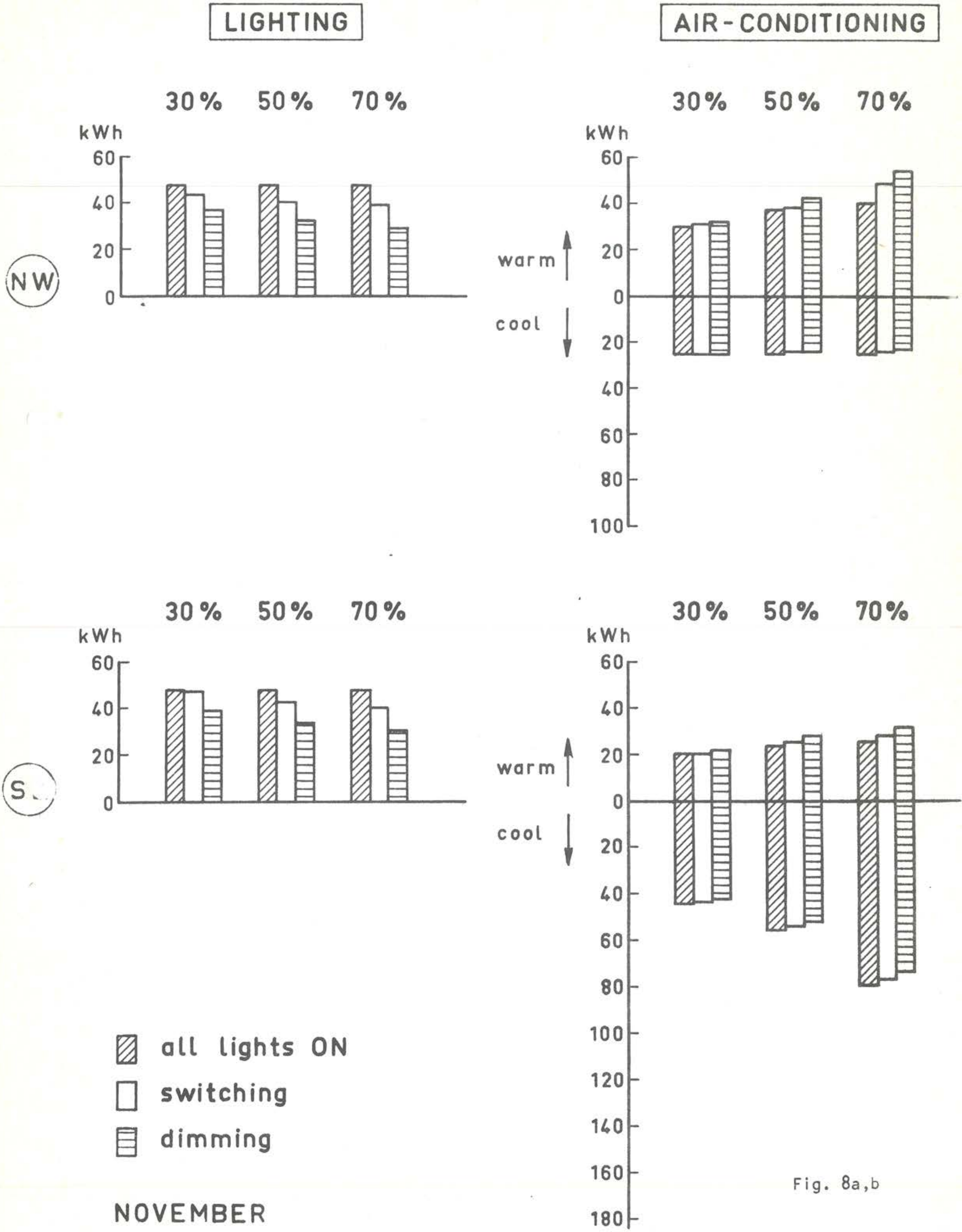

LIGHTING
AIR-CONDITIONING
30 %
50 %
70 %
kWh
60
40
20
0
NW
warm
cool
80
100
S
120
140
160
180
all lights ON
switching
dimming
NOVEMBER

Fig. 8a,b

## Appendix A

### Description of the HVAC-system considered

Temperature control by the heating and cooling equipment is set from 7.00 - 18.00 o'clock. The required room air temperature during these hours is 22 °C.

After this on-period the structure of the room can cool down to 15 °C. Then this temperature is held constant by heating.

The air-temperature in the corridor is assumed to be 19 °C during the whole day.

The ventilation rate during the on-period is 4.

During the rest of the day it is assumed that the natural ventilation rate is 0.5.

An average building construction is considered; medium weight structure. The windows are double-glazed. The internal sunshading device is assumed to operate automatically on the sunlight-penetration (see par. 3.2).

The heat radiation from the lighting fixtures coming into the room is set at 60% of the total.

The calculations are carried out using real weather data.