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Anidolic Ceiling - Technical file

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ANIDOLIC CEILING

TECHNICAL FILE

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Laboratoire d'Energie solaire et de physique du bâtiment - ITB - DA JUILLET 1997

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DA - ITB - Laboratoire d'Energie solaire et physique du bâtiment

ANIDOLIC CEILINGS

1. TECHNICAL DESCRIPTION

i) Components

This device is a new version of anidolic daylighting system for side lighting. This version consists of a light duct that is integrated in a suspended ceiling and leads midway into the office. Anidolic (non-imaging) elements are placed on either end of the duct, on the outside to collect light rays from the sky and on the inside to control the direction of the emitted light. The light is reflected on specular reflectors whose geometry is two-dimensional: moving a profile in a translatory movement along a horizontal axis, parallel to the front side, can generate the reflective surface. Both lateral ends are closed with plane reflectors, which are perpendicular to the axis of translation.

Outside the façade, a concentrator captures the upper area of the sky, which is usually the brightest by overcast condition. At the exit aperture of this duct, a parabolic reflector distributes the flux downwards, avoiding any backward reflection. Direct penetration of sunlight is controlled by a blind that can be unrolled down over the entrance glazing. The whole device, called Anidolic Ceiling, is presented on Figure 1.

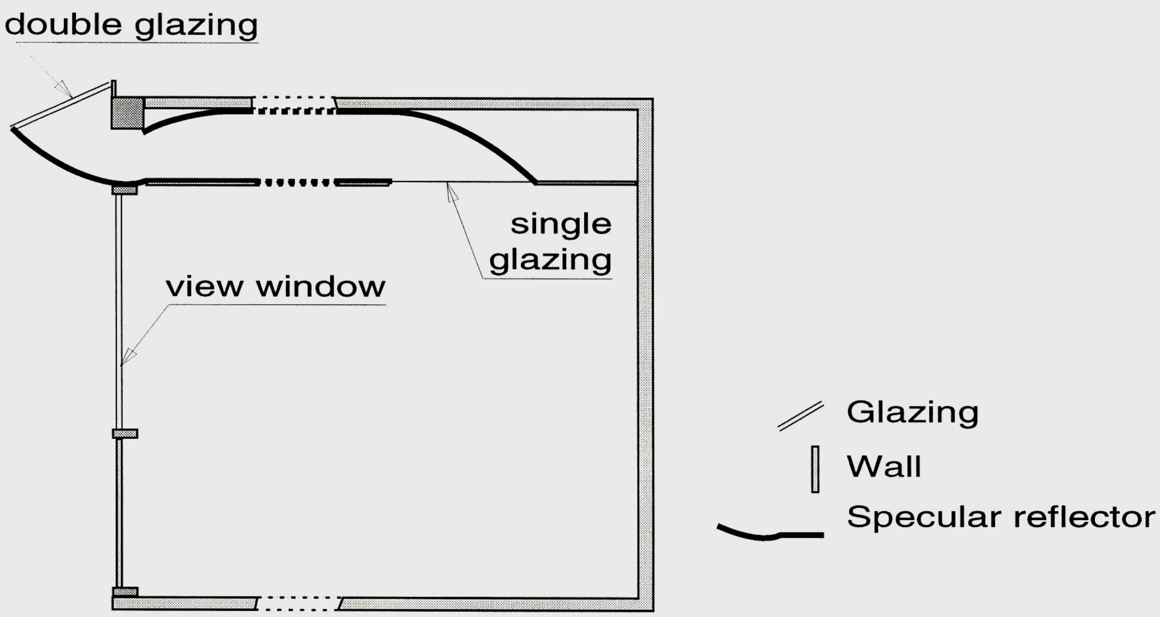

Figure 1 : Constitution of an Anidolic Ceiling

ii) How are they produced?

Reflectors consist of anodised aluminium foils (regular reflectance $\rho_r = 0.9$) which are fixed on shaped frames made of wood. If the quantity allows to pay back a mould, the frame is made of composite, like for example fibreglass/epoxy, coated with a reflective metal. At global scale, no extra precision compared to usual building practices, is needed.

iii) Location in window system

This system is designed to be located on façade; neither special orientation nor latitude is required. The optimum location is the upper part of the window so that enough area is kept free for the view.

iv) Technical barriers for use or improvement

This system does not introduce any colour dispersion.
Increasing the penetration of daylight from facades is achieved by channelling the light in a duct. This is certainly the only efficient solution which does not create any glaring situation inside, since the ceiling would have to be otherwise either mainly diffusive or serrated. When the sun is used as the main source, high concentration factor is feasible, allowing reducing the section of the duct. But the present application aims to provide daylighting by any weather ; diffuse skylight need to be considered. In that case, concentration cannot exceed a factor 2 or 3, and a non-negligible bounding volume is thus required. The present design has been studied to optimise this compromise, as well as the architectural integration aspects.

2. APPLICATION

Anidolic Ceilings can be used in urban as well as country areas; their effect is however more important in urban environment since obstructions increase the difference of brightness between the upper and the lower incidences. They can be used under both clear and cloudy skies.

Anidolic ceilings can be used in commercial, industrial or institutional buildings. No restriction about climate or latitude limits its applicability. Application to refurbishment of building with metallic thick frame is particularly appropriate (cf. Fig. 2).

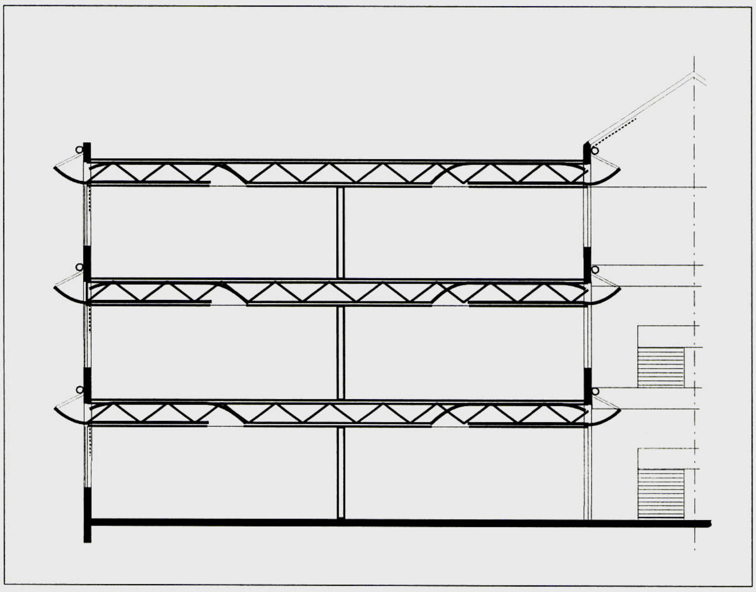

Figure 2 : Refurbishment of offices, integration in a metallic thick frame

3. PHYSICAL PRINCIPLES AND CHARACTERISTICS

The design of this system is based on anidolic optics ("anidolic" is synonymous to "non-imaging" in ancient Greek). The design of such a duct had to meet the following requirements:

- The available daylight must be efficiently collected from the sky dome and guided into the light duct even during the worst overcast sky conditions (usually winter period);
- The light guide dimensions (bounding section) must be compatible with the available building space (impact on building cost and room space).

The theory of anidolic optics was expressly used to bypass these difficulties (cf. Fig. 3):

- An anidolic daylight collector was designed and placed in front of the light guide to collect and concentrate the daylight at the entrance of the duct;
- Another anidolic device was installed at the end of the duct to distribute the flux of daylight into the room so as to avoid visual discomfort.

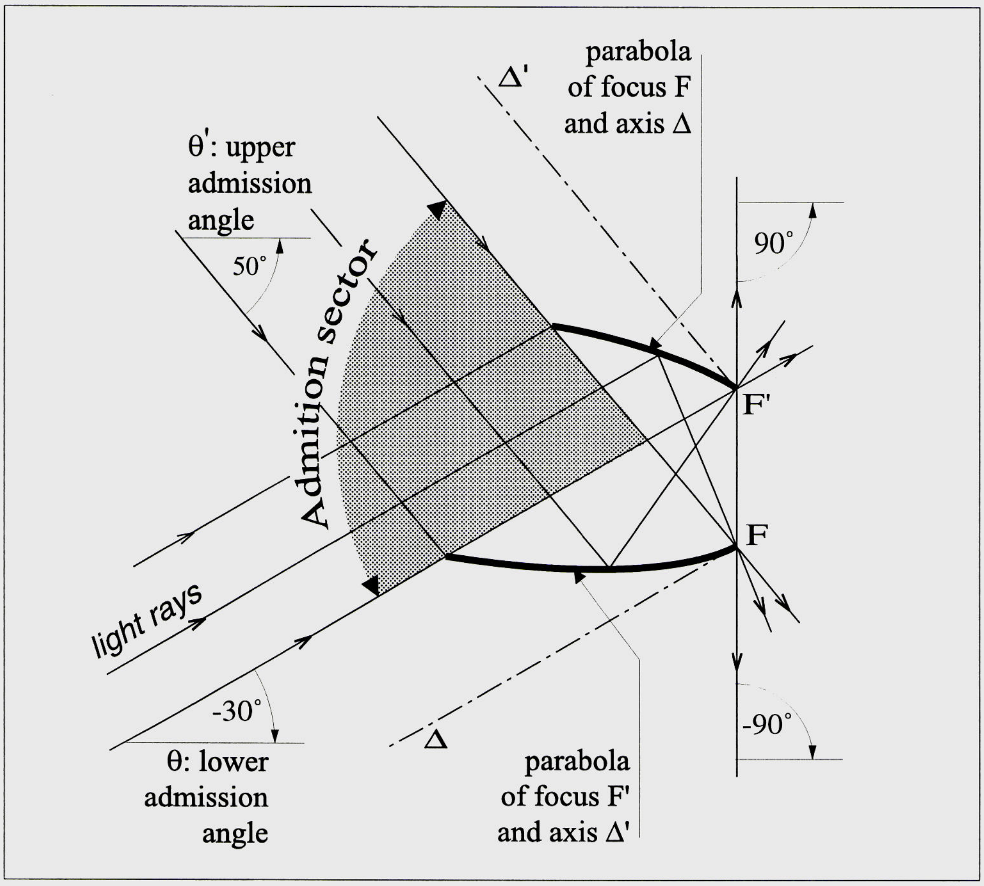

Figure 3 : Principles of two-dimensional non-symmetrical anidolic system (Compound Parabolic Collector)

Light concentration is essential to achieve adequate performances of the overall device, even if the diffuse nature of daylight in the case of overcast sky limits considerable the possibility of concentration : the Lagrange Invariant Law of optics specifies that concentrated bundles of light rays show an increase in angular spreading. This appears typically at the entrance of the light duct, where daylight is concentrated by the first anidolic device (cf. Fig. 1); a reverse phenomenon occurs at the end of the guide where light is in practice "de-concentrated" by the second anidolic device.

4. CONTROL

Comparing to a conventional double glazing facade, luminance scanning at desk place in the rear of a pair of twin mock offices has shown that :

- The anidolic ceiling contributes to smooth the luminance distribution on the walls and on the ceiling, improving slightly the perceived luminous environment at the desk (lower luminance gradient).
- The additional daylight flux brought by the anidolic ceiling improves the luminance ratio in the view field (ratio closer to unity)

These two effects increase significantly the visual comfort for paper as well as for VDT reading tasks. These features have been measured by overcast sky as well as by sunshine on the facade, the blinds being pulled down.

5. MAINTENANCE

In normal air conditions (not particularly dusty) and under mid-European climate, the rains should be enough to clean the entrance pane enough to maintain normal performances.

6. COST AND ENERGY SAVINGS

In countries of temperate climate, overcast sky conditions occur frequently, particularly in winter and mid-season. In those conditions, the daylight factor is a major factor in lighting autonomy. Figure 4 shows the daylight factor profiles monitored in two identical mock offices after averaging of the monitored data measured by overcast sky; the test room is fitted up with the anidolic ceiling and reference room has a conventional double glazing facade (both facades were oriented due north).

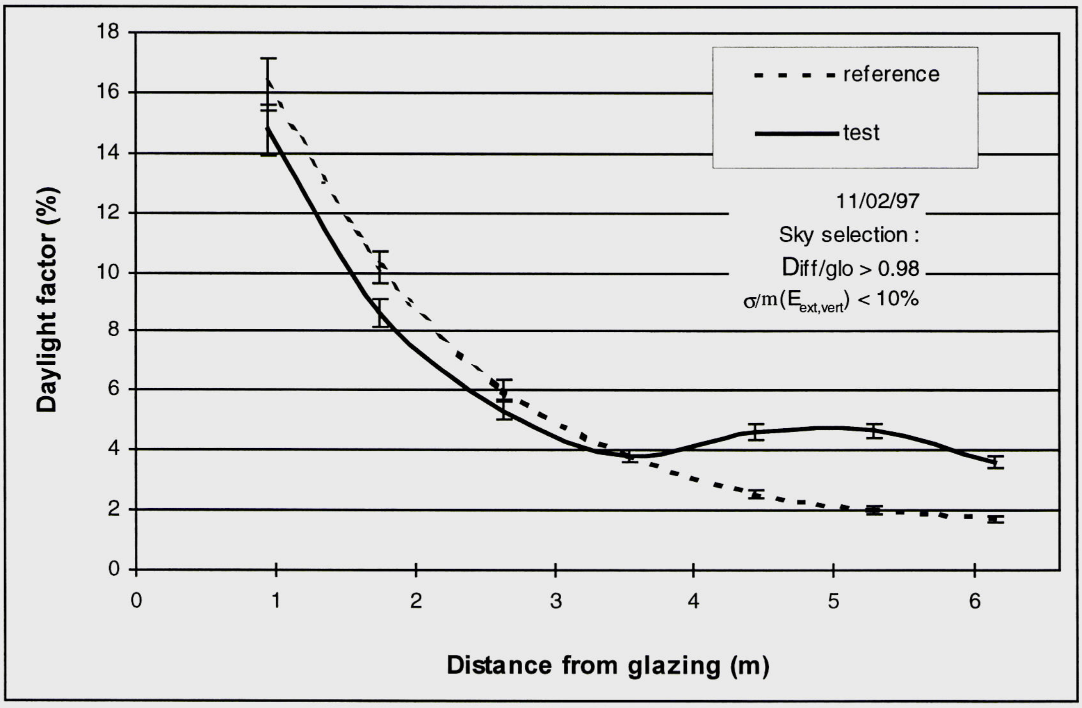

Figure 4 : Comparison of daylight factor profiles in the test room (anidolic ceiling) and in the reference room (double glazing facade).

The daylight factor on the work plane at 5 meters from the window is more than doubled ; its average over the back half of the rooms is improved by a factor 1.7. There were no physical obstructions in front of the facades; it has been nevertheless established through numerical simulation that this ratio could reaches 2.8 in an urban environment (40° obstruction). Besides, a decrease in the daylight factor close to the window is obtained thanks to the overhang of the anidolic system, improving in this way the uniformity of the daylight distribution (CIE uniformity ratio goes from 0.3 to 0.6).

Figure 5 shows the monitoring of the lighting energy consumption; the desk illuminance (300 Lux ± 15%) was carefully balanced in both rooms for the electric light dimming control. This experiment has shown that 31% electricity savings can be expected through the use of the anidolic ceiling in an office room of conventional depth (6.6 m in the present case); more savings could be expected in a deeper room. These savings are achieved at the back of the room (5 m from the window), where a second desk is placed.

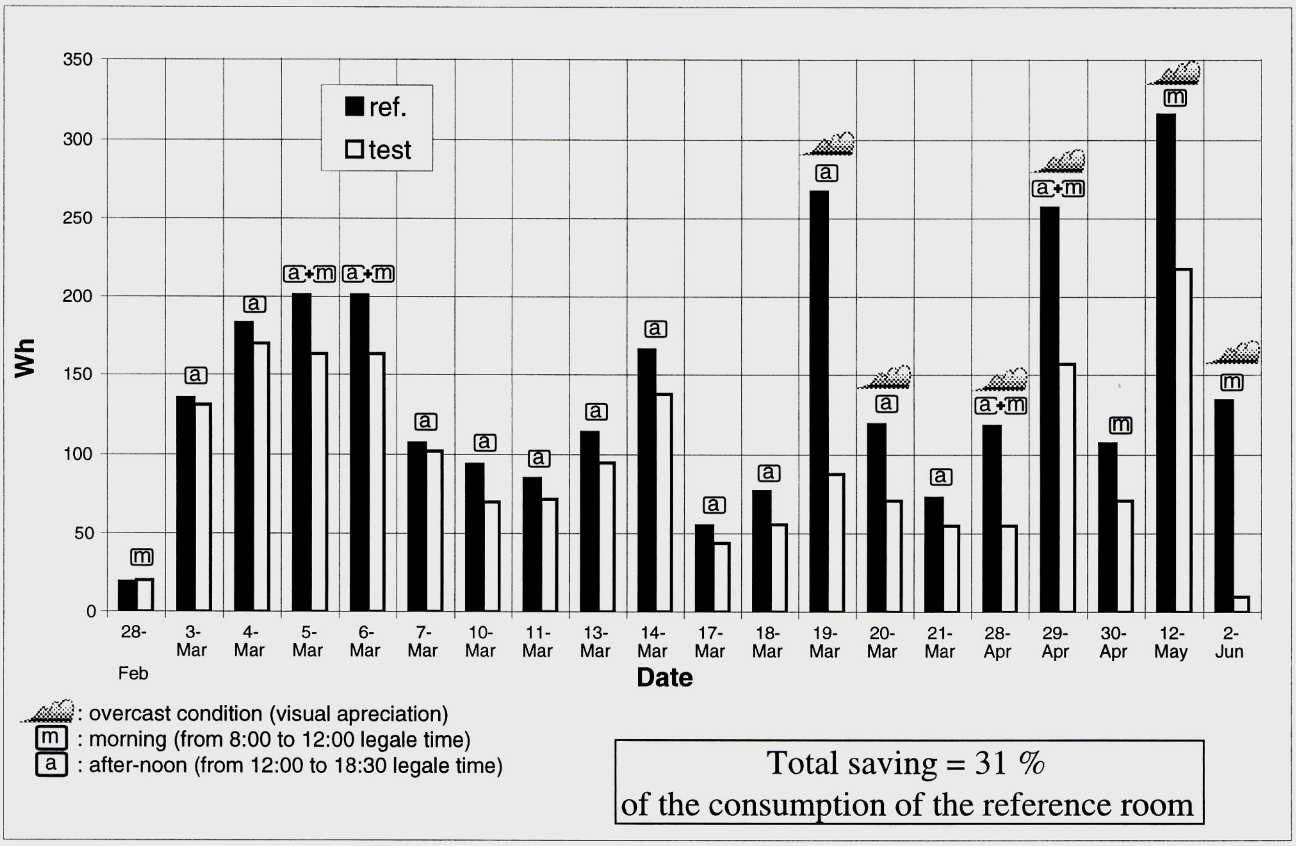

Figure 5 : Lighting energy consumption monitored in the two rooms for the period of February to June.

These monitoring results stand in good agreement with the savings figures calculated according to the Swiss recommendation for daylighting [SEV 8911.1989]: yearly lighting savings of 30% are predicted by this method which allows the statistical calculation of the daylighting autonomy of an office room for a given nominal desk illuminance (300 Lux in this case) on the basis of the daylighting factor.

It must be emphasised, however, that this savings figure assumes fully automatic control of the electric lighting (perfect daylight responsive dimming), independent on user behaviour. The utilisation of solar blinds as well as lighting control through users can lead to totally different figures, especially for south oriented facades.

7. SUMMARY - PROS AND CONS

Pros

- increases daylight penetration
- increases the uniformity of the daylighting
- avoids glare from sun
- rejects solar heat gain
- provides energy savings (through daylighting and cooling load reduction)
- functions in all sky conditions
- no colour dispersion
- partially movable
- no tracking is necessary
- distorts view out enough to guaranty privacy, but allows the perception of the colour of the sky.

Cons

- motion of the blind, controlled or not, is required
- maintenance is necessary, especially for the movable blind (motor, energy supply, control system,...)
- expensive
- reduces partially the view of the sky.
- reduces the ceiling height
- impact on the appearance of the front side demands a collaboration at the earliest step of the design.

8. SOME EXAMPLES OF USE

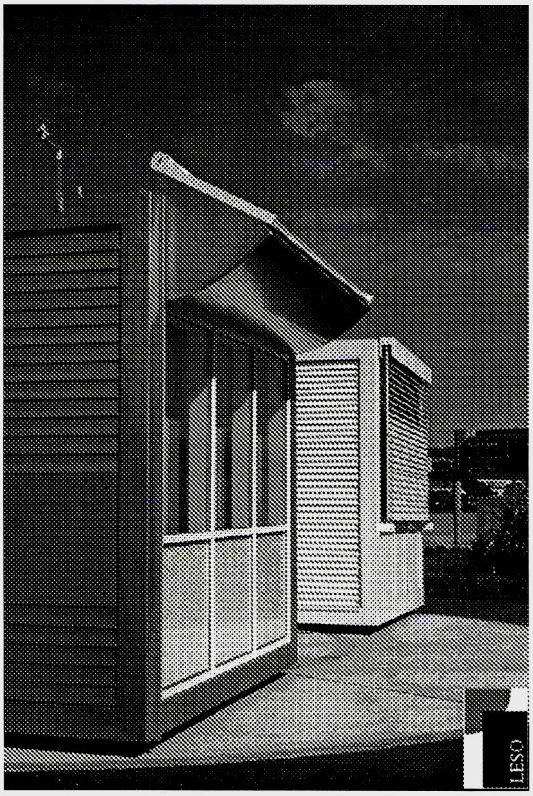

Figure 6 : Front view of the two daylighting modules:
Foreground: test module (anidolic ceiling)
Background: reference module (double glazing facade).

9. EXISTING SIMULATION AND MEASURED RESULTS

In addition to the monitoring campaign reported at sections 4 and 6, human response tests to lighting conditions were carried out on a group of 33 subjects in the two twin rooms used for the monitoring (cf. Fig. 6). Although two thirds of the volunteers were less than 30 years old, 55% wear medical glasses

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

The work places were located in the rear of the rooms (5 m behind the window). Their orientation was chosen following recommendations in ergonomics so that the main vision axis of the desk users is parallel to the window.

Three different types of response tests were submitted:

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

The tests took place in mid-autumn between 10:00 and 16:00 legal time; two tests took place with clear sky, six with variable weather and twenty-five on continuously overcast days. Daylighting was substantial during this period but not always sufficient. The same series of tests was submitted simultaneously to two subjects, each one placed in a room; after completion of their tasks, they changed room starting the same series of tests again at the other work place. Learning effects and impact of weather conditions were limited that way.

The acuity test for document reading showed that a subject makes on average 38% less reading errors in the room with an anidolic ceiling than in the reference room. Analysis of the lighting modes chosen by the subjects during their testing procedure showed an important difference between the two rooms, with daylighting preferred in the test room (presence of a light flux issued from the anidolic ceiling). Figure 7 illustrates this.

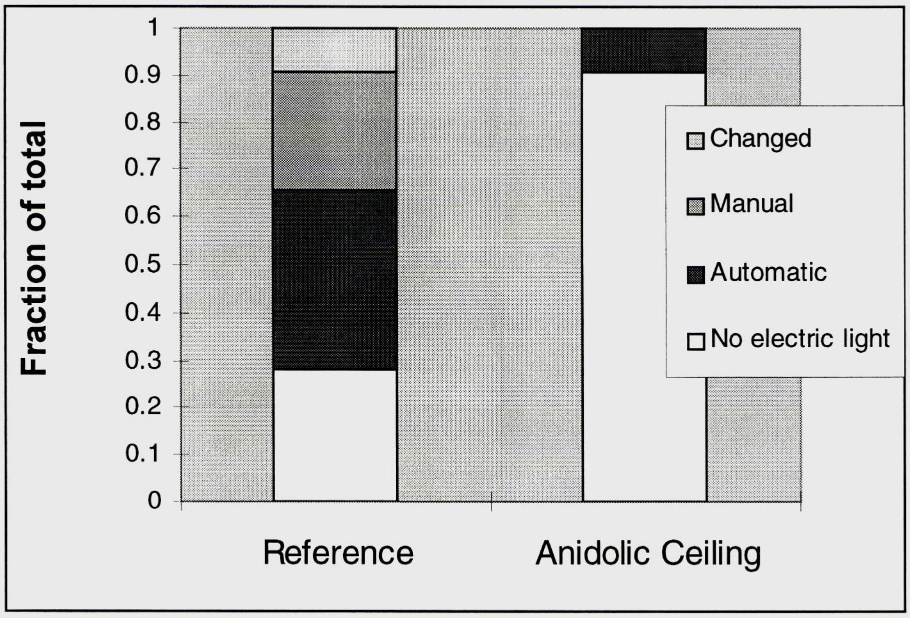

Figure 7 : Lighting mode used by the subjects in the different rooms (subjects could choose their

lighting mode at their convenience)

The acuity test for VDT reading showed that less luminance contrast is necessary to read a number on a VDT screen in the test room than in the reference room (diminution of the contrast threshold of 10 %). This tendency is consistent with the assessment of visual comfort (cf. section 4); it indicates that the visual performance enhancement is probably due to a more appropriate luminance ratio of the surroundings to the VDT screen.

The questionnaire of user acceptance allowed the comparison of the perceived visual atmosphere in the two rooms, leading to the following interesting results (cf. Fig. 8):

- A brighter visual atmosphere was perceived in the test room.
- The colors in the test room were found more pleasant although they were physically the same.

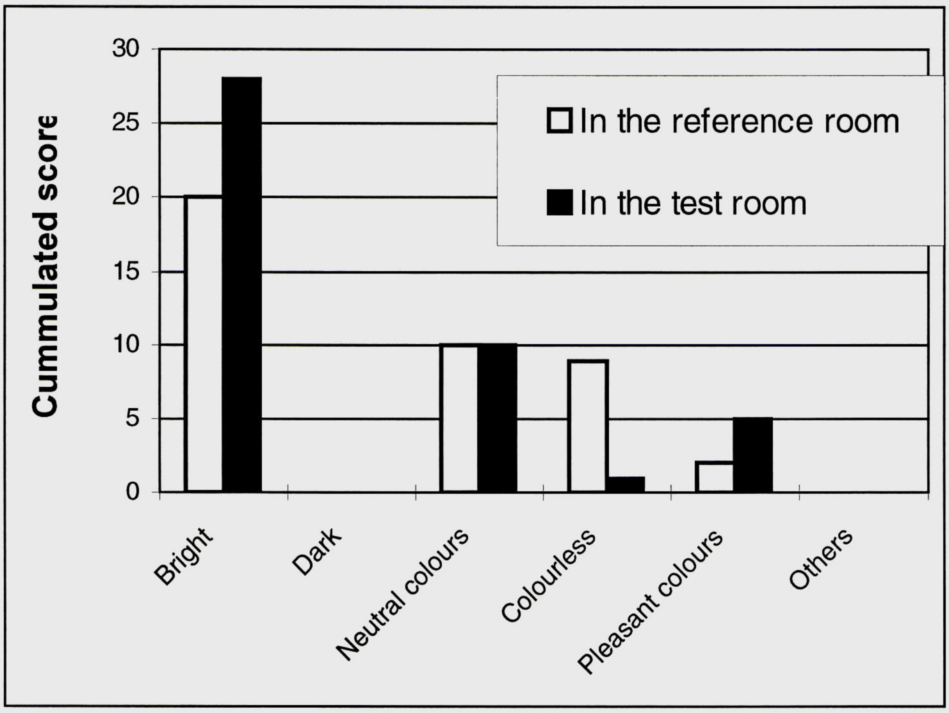

Figure 8 : Preferences of the group of subjects in the two office-rooms

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