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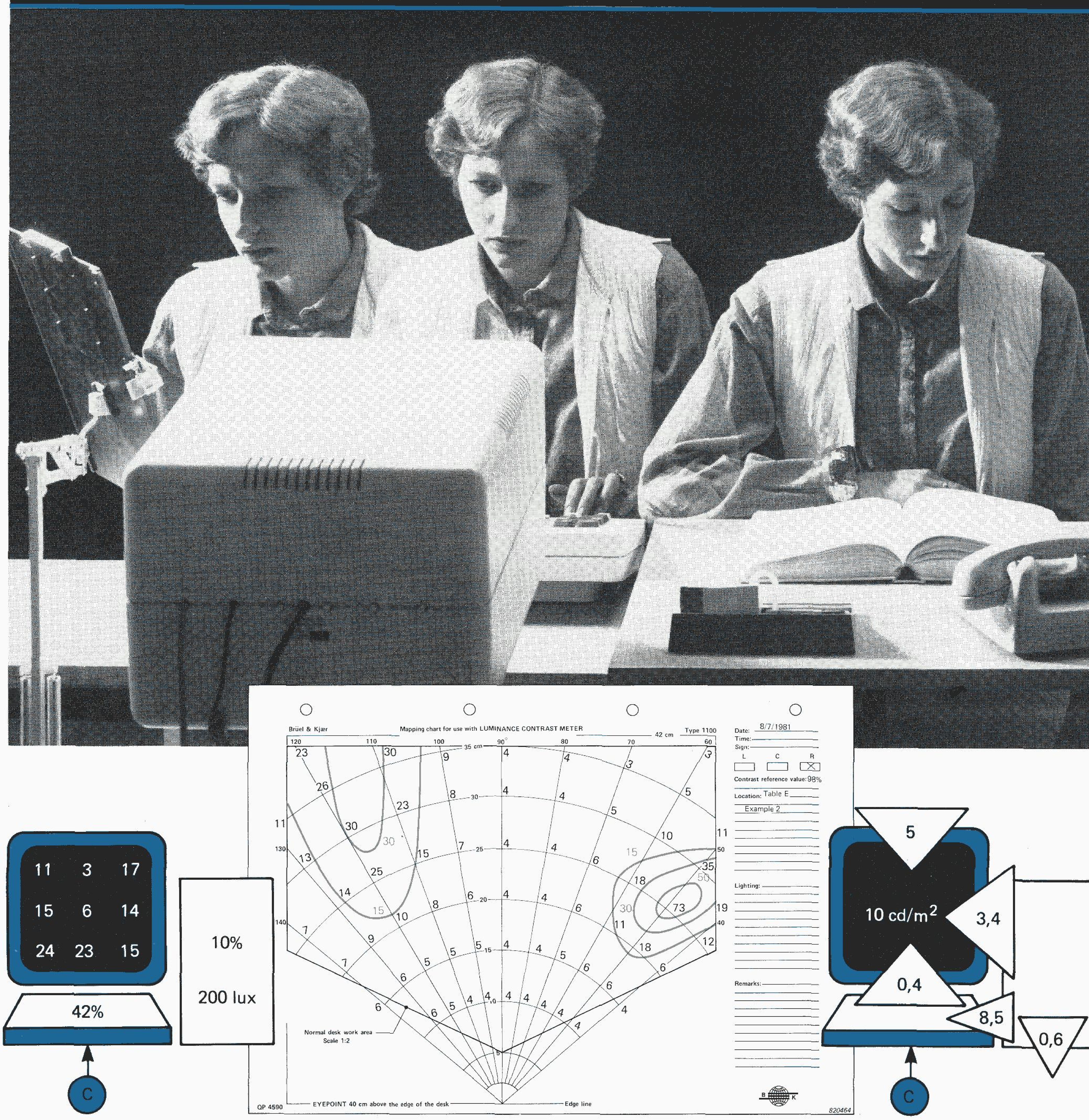
Contrast and Luminance Measurements on work places with CRT display terminal



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Contrast and Luminance Measurements on work places with CRT display terminal

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Abstract

The luminance and contrast conditions of the visual tasks at a work place including cathode-ray-tube display terminals are two important parameters which can be helpful for the setting-up and designing of lighting in offices and computer rooms. Two methods are proposed for measuring the contrast of characters on the screen, the first for use when it is possible to generate small areas on the screen having the luminance of the characters, and the second, more time-consuming and less accurate, calling for measuring areas consisting of capital letters. Measurements of contrast on the screen, the keyboard and the document, as well as measurements of luminance on the terminal and around the terminal, can be made using Brüel & Kjær Luminance Contrast Meter Type 1100. In cases where the operator of the terminal has to work at a desk in the same room, the conditions of contrast at his desk can also be measured with Type 1100. Three examples with different types of terminal and different kinds of work are given to illustrate the possibilities of the proposed methods.

1. Introduction

The rapidly growing introduction of cathode-ray-tube display terminals in office work has given rise to a certain number of occupational health hazards. Operator's visual fatigue or eye strain is the most commonly encountered symptom. In the beginning of the 'sixties, when the first computers were introduced, there were only a few operators and they were highly motivated and willing to discover the "miracles" of computer technology. The situation today is completely different since CRT terminals are introduced in many jobs and the operators are often more or less passive witnesses to the computerization of their office tasks. They do not necessarily consider such an evolution as progress if a great part of their job is transformed into a routine "man-machine" communication which, as well as being monotonous, can be very trying for the eyes. Setting-up of CRT display terminals therefore implies that very close attention is paid to the lighting and the work-place layout, taking account of the special requirements of these new visual tasks. Problems occur often because ordinary office tasks and work at computer display screen have to be carried out in the same office, and requirements for the lighting of both types of visual task are not the same, indeed opposite.

The aim of this paper is to present a rapid measuring method, centred on Brüel & Kjaer Luminance Contrast Meter Type 1100, to facilitate setting-up and designing of lighting at work places including CRT display terminals. The various parameters influencing the visual tasks in an office with CRT display terminals are reviewed and two measurable evaluation factors combining most of these parameters are defined. Then three examples of practical measurements are described to illustrate the possibilities of the method:

a. Computer room with 10 terminals where the operators are designing programmes for microprocessors incorporated in measuring instruments,
b. Two offices with 6 terminals for text processing system,
c. Office with 2 terminals for reading or encoding data in a central computer.

2. Complex Visual Tasks

Modern offices have generally been designed to achieve overall good working conditions for employees dealing with ordinary paperwork. In particular, lighting conditions ensure a good level of illumination and large windows are frequently encountered in open plan landscape offices. The evermore frequent introduction of CRT display terminals in traditional offices has lead to intractable work-place problems. Lighting becomes unsuitable for the new complex visual tasks of CRT display terminals. Situations where the operator has simply switched the light off and works in almost total darkness are not unusual. Switching the light off is of course not a solution, since the operator then cannot read a document placed close to the terminal and he can scarcely see the key engravings on the keyboard. Moreover, when the operator job calls for both work at a terminal and paper work, the ambient illumination in the room should be kept at a level allowing good readability of written and printed documents.

2.1. Visual conditions on a CRT terminal work place

A typical CRT terminal work place is characterized by 3 kinds of visual tasks (Fig. 1.):

- reading a text displayed on the screen
- recognition of letters or function symbols on the keyboard
- reading a written or typed text on a document placed at a normal reading distance close to the terminal.

Fig.1. Three different visual tasks: screen, document and keyboard

It is widely believed that thermal comfort depends on differences of race, age, and sex. However, systematic testing in an environmental test chamber on elderly and youthful subjects, and people from countries with widely differing climates, has shown that the Comfort Equation is independent of these factors. Altogether more than 1300 subjects have been tested. Possible national differences, or differences between the sexes in preferred ambient temperature, seem to be exclusively a function of differences in clothing fashions. Such differences are taken into account in the Thermal Comfort Meter when a clo value is selected for the clothing parameter.

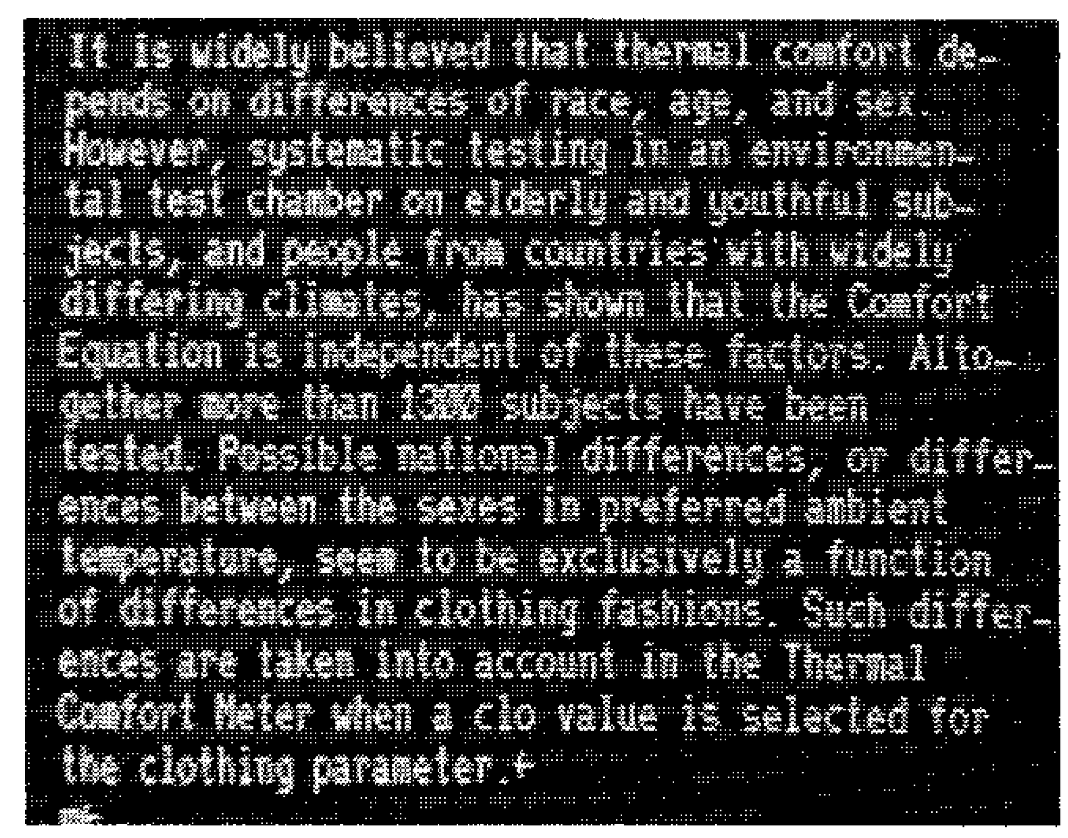

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Fig.2. Example of text with negative contrast (on the paper) and positive contrast (on the screen)

Good visual conditions are only satisfied when all these three visual tasks can be performed optimally. One of the difficulties in obtaining such conditions is that the text on the screen is generally presented as bright letters on a dark background (positive contrast), while the printed or typed text on the document is made of black letters on white paper (negative contrast). See Fig. 2.

The operator has to perform almost simultaneously two visual tasks corresponding to two completely different adaptation levels of his eyes; this is the first part of the difficulty. The second part of the difficulty, as we will see below, is that the requirements to obtain optimal conditions in each case are not compatible. Finally, as shown in Fig. 3, owing to the special nature of a work place with a CRT terminal, there are many zones where the light sources can give veiling reflections and glare effects.

Readability on the screen

A good readability of the text on the document requires a relatively high ambient illumination level, since a higher illumination level corresponds to better visual acuity. However, a high ambient illumination level may reduce the readability of the text displayed on the screen.

Many parameters influence the readability on the screen, like for instance the dimensions of the characters and the sharpness of their con-

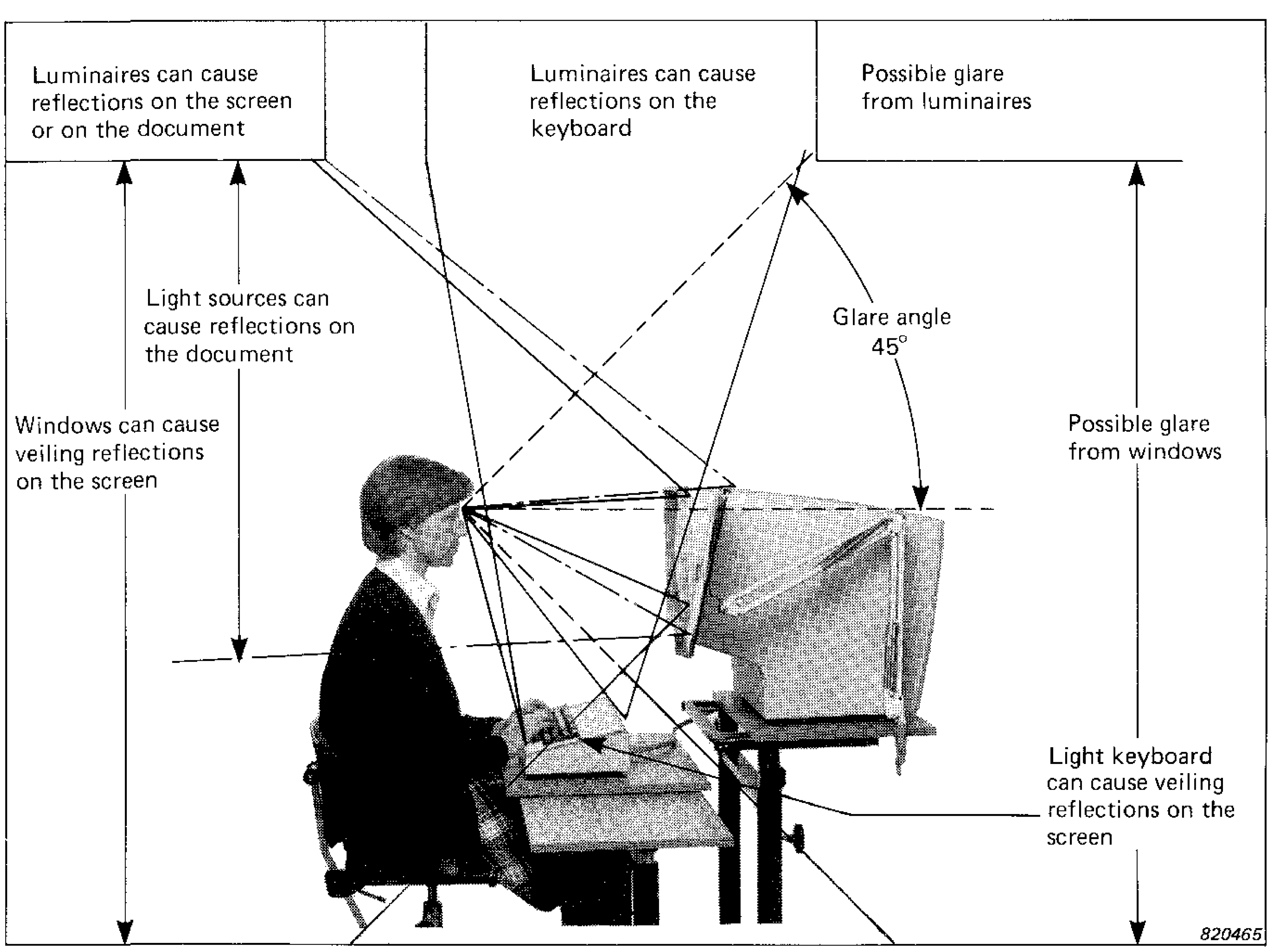


Fig.3. Zones around a screen terminal where light sources can give reflections or cause glare effects

tours, and the colours of the characters and the background. But, one of the most important parameter, undoubtedly, is the contrast between the letters on the screen and the background. The contrast of a visual task is generally* defined [1] as:

$$C = \frac{L_o - L_b}{L_b} \qquad (1)$$

where:
L_o is the luminance of the object (letter)
L_b is the luminance of the background.

If an additional luminance, L_v, due for example to an increased ambient illumination, is superimposed on the screen, the new task contrast will be:

$$C = \frac{(L_o + L_v) - (L_b + L_v)}{L_b + L_v}$$

$$C = \frac{L_o - L_b}{L_b + L_v}$$

That means that the new contrast will almost always be lower than the initial contrast and the readability of the text will be consequently reduced. On a screen, in fact, the additional luminance, L_v, called veiling luminance, may be due to two different effects since the reflectance factor of the screen is usually a combination of diffuse and specular reflection. Increasing the ambient level of illumination about a terminal may raise the mean luminance of the

Fig.4. Veiling reflections on a screen

* This is the general definition of the contrast of a visual task, but as mentioned in section 3.2 (Eqn. 2), the contrast on a screen is commonly evaluated using a simple luminance ratio.

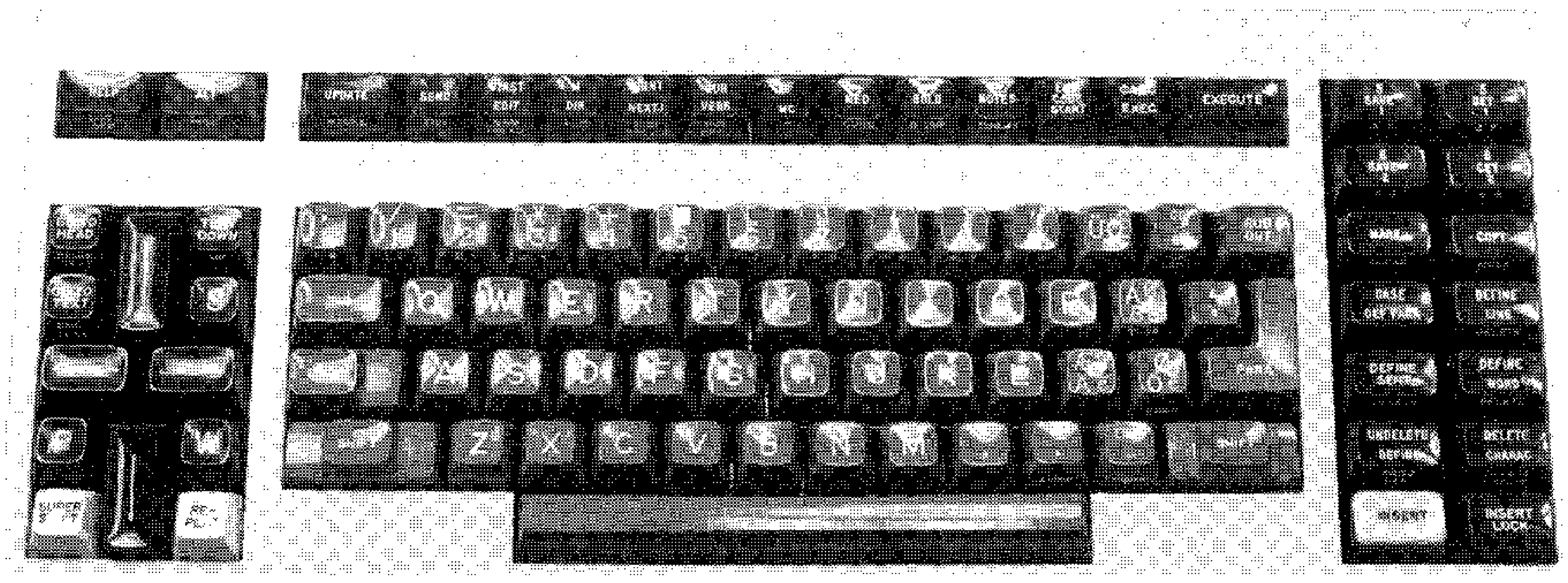


Fig.5. Veiling reflections on a keyboard

background of the screen (diffuse reflection), but simultaneously, lighted objects situated in the reflection field of the screen become brighter and may be seen by the operator as reflected images on the screen (specular reflection). Such images, which are seen on the screen at different viewing distances corresponding to the position of their objects in the room, can disturb the accomodation process of the eyes, which try to accomodate on the text displayed at the surface of the screen (Fig. 4.). In cases where the ambient illumination is mainly due to the natural lighting (terminal in the proximity of large windows), the contrast will vary proportionately with the variation of the daylight illumination at the operator position. This drawback can be partly avoided in some types of modern terminal screen where the background luminance, electronically generated on the screen, can be set by a special control button, independently of the luminance of the characters. The higher the background luminance level is set on, the less the ambient illuminance level and the veiling reflections will influence the readability on the screen.

Readability on the keyboard

Even if the operator can touch-type, he looks at the keyboard relatively often, whenever he has to touch a special function key. This visual task should therefore not be ignored. Reflections on keys may irritate the operator, who begins to make more typing mistakes than usual. Unfortunately, veiling reflections on keys are difficult to avoid, because the surface of the keys becomes glossy by wear and because the keys, which are often concave, reflect light sources from a relatively wide solid angle (Fig. 5.).

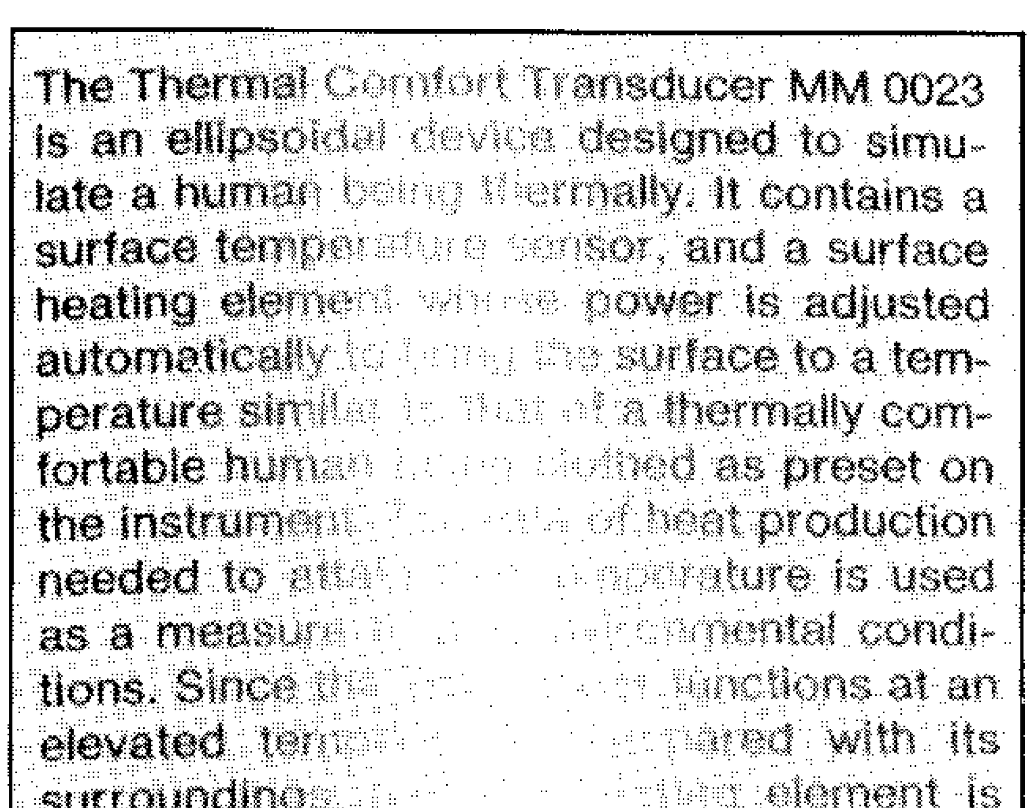
The reflections can be less disturbing if the keys are light and the symbols dark. However, since the keys are observed frequently and for very short periods of time, a contrast of the same sign on the screen and on the keyboard, i.e. light symbols or characters on a dark background, may be advantageous in some cases.

Readability on the document

Situations where work at a CRT terminal doesn't call for any form of document as back-up information are very few. This back-up can be a printed or a hand-written document, or a computer listing which is related to the information the operator wants to read or write on the screen. Readability on the document close to the terminal depends on both the contrast of the text as seen by the operator and the level of adaptation of the operator's eyes.

The contrast on the document between characters and paper is expressed with the relation (Eqn. 1) already mentioned , where L_o is the luminance of the characters and L_b the luminance of the paper.

The contrast of a task depends not only on the reflection properties of



The Thermal Comfort Transducer MM 0023 is an ellipsoidal device designed to simulate a human being thermally. It contains a surface temperature sensor, and a surface heating element whose power is adjusted automatically [illegible] the surface to a temperature sim[illegible] a thermally comfortable hum[illegible] as preset on the instrument [illegible] of heat production needed to [illegible] perature is used as a measure [illegible] mental conditions. Since [illegible] functions at an elevated [illegible] pared with its surroundings [illegible] element is

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Fig.6. Veiling reflections on a document

the task, but also on the way it is lit. For visual tasks with perfectly matt surfaces the light is diffusely reflected, but such surfaces are very seldom encountred in practice. In most cases, the task reflects the incident light in certain directions more than in others. With a certain incidence of the light the contrast between black letters printed on a glossy white paper can become zero or even change its sign, rendering the text illegible. See example on Fig. 6.

The level of adaptation of the operator's eyes depends on the level of illumination on the document and on the reflection characteristics of the document. In Fig. 7, [2], it can be seen that visual acuity increases with increasing level of illumination. But this is the case only if the contrast rendered by the lighting is sufficient. With a document on which the contrast disappears because of veiling reflections, increasing the illumination level will not improve the readability.

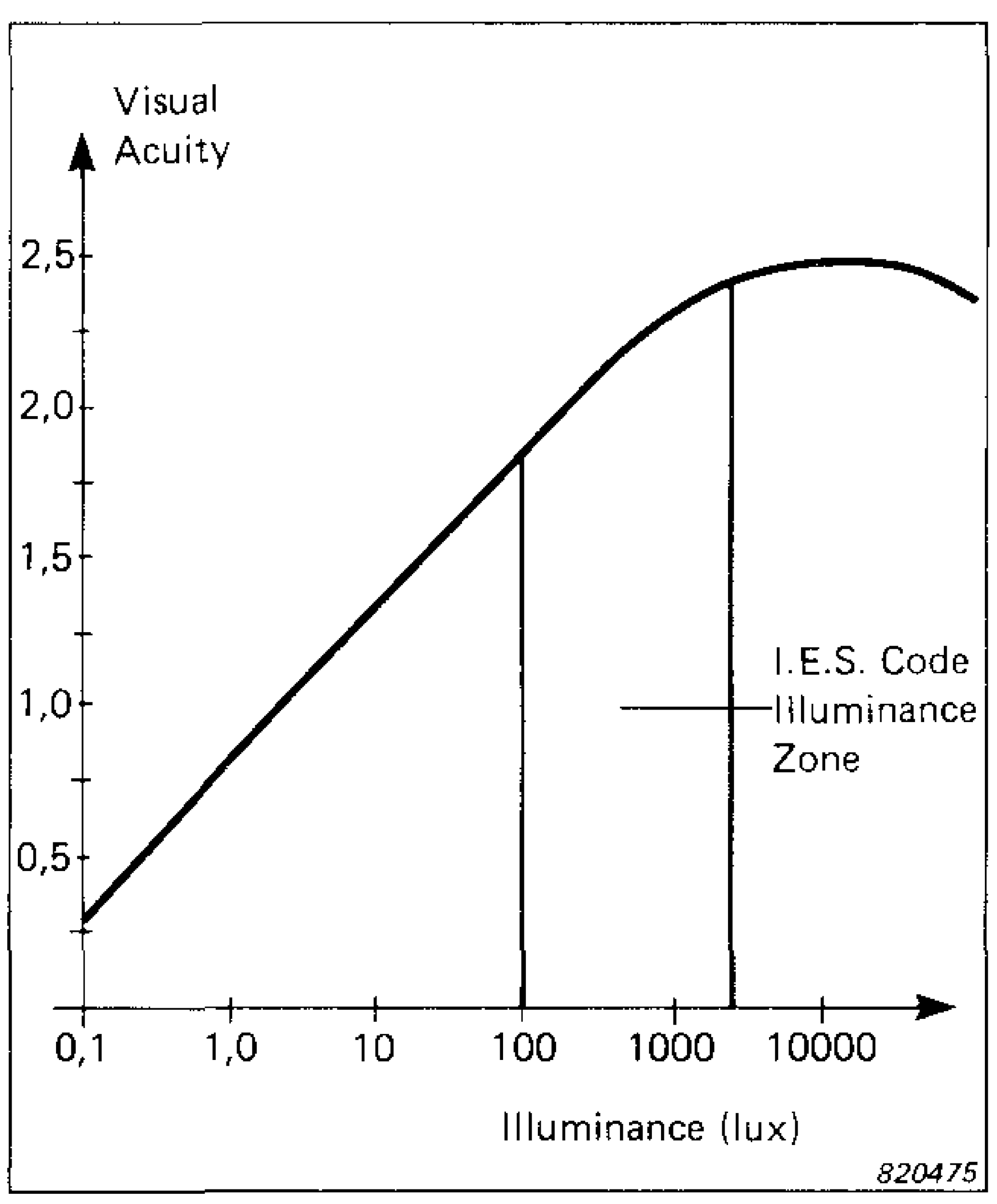


Fig.7. Visual acuity as a function of illuminance

Difficulty of adaptation and glare effects

Work at a CRT display terminal requires frequent changes between the three visual tasks: reading of text on the screen and on a document, and recognition of key symbols on a keyboard. Too much difference between the luminance of these three visual tasks can disturb the adaptation process of the eye. The eye of the operator watching a dark screen is adapted on a low luminance level corresponding to the mean luminous intensity in the visual field. This level is situated in the intermediate field

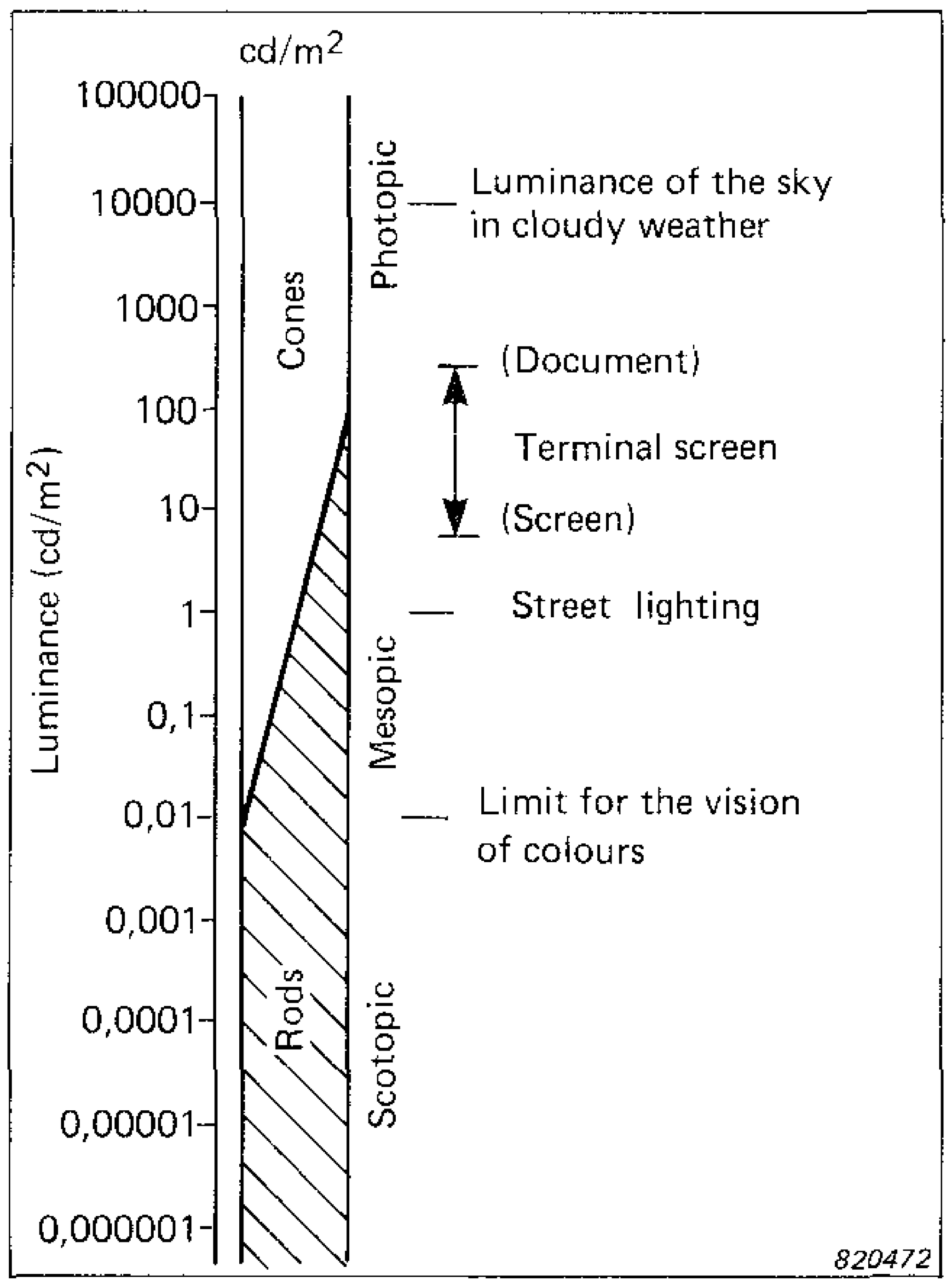


Fig.8. The luminance scale

between light (photopic) and dark (scotopic) vision, as shown on the luminance scale, Fig. 8.

While the adaptation from dark to light conditions requires only a few seconds, the entire adaptation of the cones and the rods of the eye from light to dark conditions can take up to several tens of seconds (Fig. 9), [3]. That means that an operator watching successively a dark screen and a light document and changing frequently between these two visual tasks will almost never reach the complete adaptation on the screen. Beside the difficulty of adaptation, veiling reflections from light sources on the glossy surfaces of the terminal, like e.g. the screen or the keys of the keyboard, can cause glare effects, which can be very annoying.

Moreover, the problem of correct

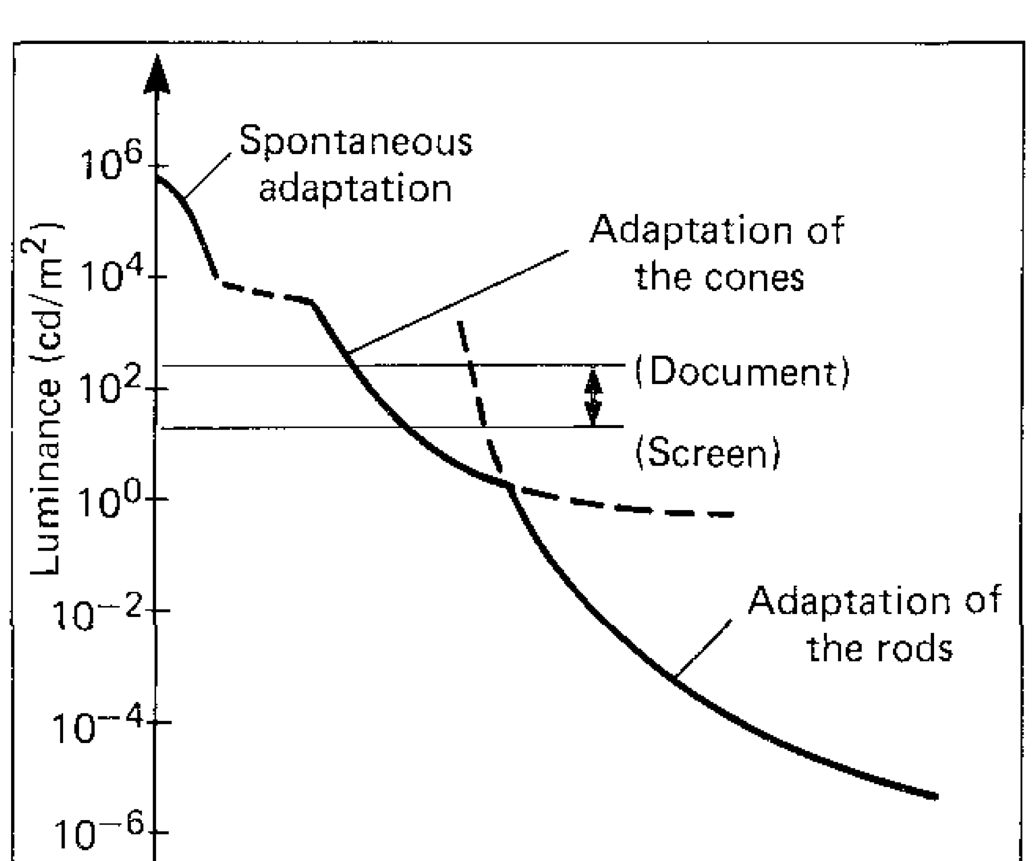


Fig.9. Adaptation of the eye from light to dark condition

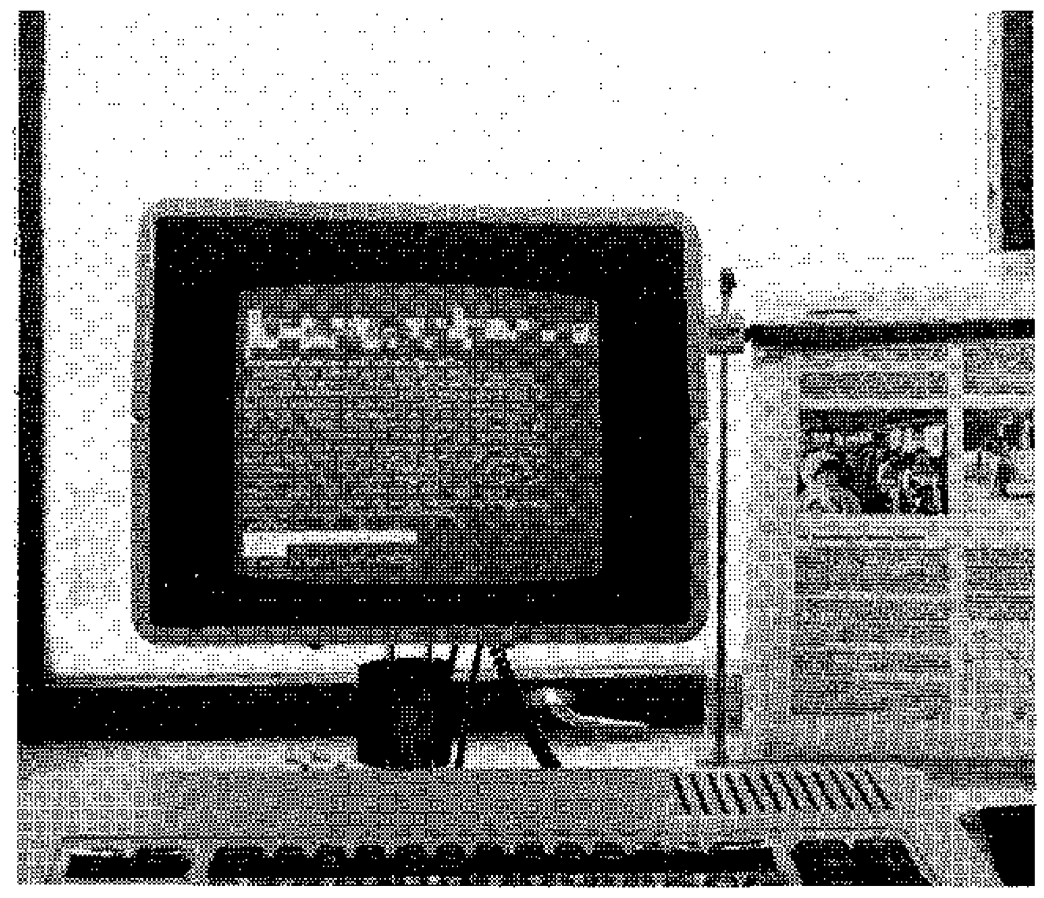


Fig.10. Disability glare effect from a window in the visual field of an operator

lighting of a work place with a CRT terminal is not facilitated by the fact that the viewing direction of an operator watching a screen is raised by about 20° compared to the viewing direction of a person reading a document placed on a desk. The eye of the operator adapted to the low luminance of the screen will be more sensitive to the light. Bright windows and luminaires behind the screen are now situated in the visual field of the operator and can become a cause of disability glare (Fig. 10.).

The flicker effect

The light emission on the screen occurs intermittently at a repetition frequency corresponding to the picture rate (typically 50 to 60 Hz or more). Above a certain repetition frequency the flashing sensation of the observer disappears and the picture becomes stable. This frequency, which is called the critical fusion frequency, is generally not the same from one operator to another and depends on several factors. The critical fusion frequency increases with increasing luminance of the area on which the flicker effect occurs and also when the surface of this area covers a greater part of the visual field. Since the repetition frequency of most types of screen is very close to the critical fusion frequency, the flicker effect sets the practical limit of how much the luminance of the screen can be raised, and consequently, if a reasonable document/screen luminance ratio is not to be exceeded, it sets also the limit of the luminance of the document. On screens where the background luminance is electronically generated and can be controlled manually, the limit is set by the flicker effect on the background itself.

2.2. Visual conditions for ordinary office tasks

Ordinary office tasks calling for continuous attention can be made more difficult in badly planned lighting conditions. As mentioned above, the readability of a text depends both on the level of illumination and the contrast as perceived by the reader. Until now, only few recommendations of lighting for office work mention contrast conditions besides requiring a minimum illumination level (generally 500 lux). In fact, it can be of importance to stipulate optimal contrast conditions, namely to avoid the illogical situation where, after the lighting has been carefully designed, office furniture like desks or working tables are just placed at random in the office without taking account of possible veiling reflections at the place where documents have to be read. However, the conditions of contrast become even more important when ordinary office tasks and tasks at CRT display terminal have to be done by the same operator. An operator performing the difficult visual task of reading a text on a screen for a relatively long time probably considers the work at his desk as visual relaxation, and he will be particularly aware of possible glare or reflection effects on his desk. Consequently, ergonomic investigation of work places in offices where both types of visual task are involved should include investigation of visual conditions of ordinary office tasks.

3. Two Evaluation Parameters

Visual conditions at office work places depend on many factors, such as quality of the visual task, quality of the lighting, glare effects, veiling reflections, flicker effect, position of the operator, etc. The influence of most of these factors on the visual conditions may be evaluated by two parameters:

— Condition of contrast
— Balance of luminance conditions

3.1. Condition of contrast

The condition of contrast of a visual task is the evaluation of the contrast as seen by the observer. This is not the intrinsic contrast of the actual task but the contrast as rendered by the lighting of the task. With this first parameter (contrast rendering at a CRT terminal or for ordinary office tasks) and providing that the level of illumination is known, the readability of the different visual tasks can be evaluated. Factors such as veiling reflections (windows or artificial light sources reflected on a screen, reflections on keyboard or on a document), quality of the lighting, and quality of the visual task on the screen, must be included in the evaluation of the contrast conditions.

Contrast on the screen
Only a few recommendations or standards are actually available dealing with the evaluation of the contrast of the characters on a CRT terminal screen. These recommendations define the contrast of the characters as a simple luminance ratio (Character luminance/Background luminance), which is called "character contrast", C_c.

$$C_c = \frac{L_c}{L_b} \qquad (2)$$

where:

L_c is the luminance of the characters on the screen
L_b is the luminance of the background on the screen

The German Standard DIN 66 234 [4] recommends a luminance ratio on the screen (Character mean luminance/Background mean luminance) between 6:1 and 10:1 and requires a minimum and a maximum luminance ratio of 3:1 and 15:1, respectively. The conclusions of research work at two illumination research institutions in Scandinavia, [5], [6], are in agreement with the German standard, the optimal luminance ratio being given as 10:1.

Variation of contrast on the screen
The contrast should be measured at several points on the screen to take account of possible variations of the contrast of the characters as seen by the operator. These variations can be due to veiling reflections on the screen or to the shadowing effect of the screen frame on the screen. In such situations, if the operator has no opportunity to remove the causes of the veiling reflections or of the shadowing effect, he will try to improve the character contrast on the critical parts of the screen by raising the character luminance. He will very likely obtain too high a contrast on other parts of the screen, even if the text is just readable on the critical parts. The visual task is then not really improved, since the operator now has to read a text with both too much and too little contrast. An evaluation method based on the averaging of the contrast measured at several points on the screen will have a tendency to mask this problem.

The measuring method proposed in section 4.1. uses nine small areas regularly distributed across the screen, on which the character contrast is measured (Fig. 11.). To evaluate the contrast conditions on a screen, the following three questions have to be answered:

— What is the luminance ratio on the nine small areas compared to the optimal values proposed in DIN 66 234 (between 6:1 and 10:1)?
— How much does the luminance ratio vary on the surface of the screen? — This to reveal the

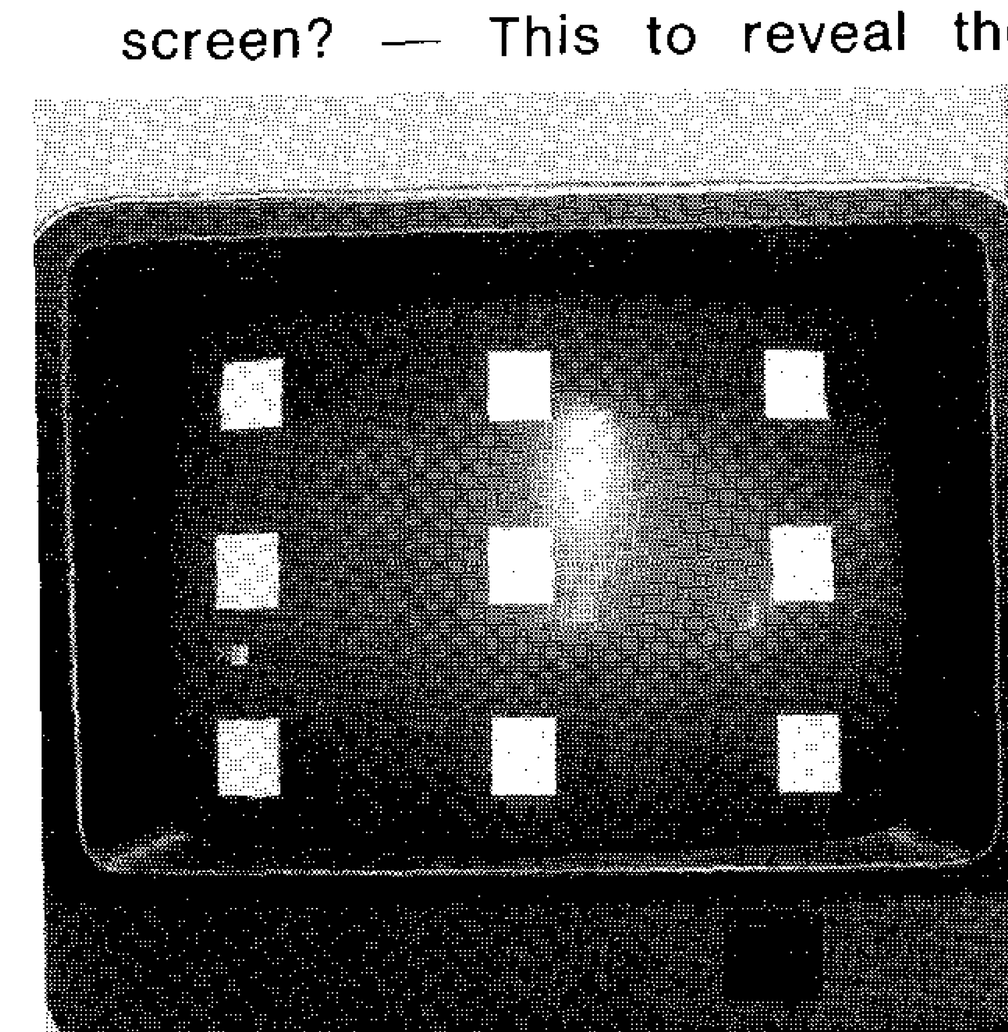


Fig.11. The contrast of the characters can be measured on nine small areas on the screen

presence of possible veiling reflections or shadowing effects
- Is there any area on the screen where the ratio is lower than the minimum required of 3:1 or higher than the maximum of 15:1?

Contrast on the document

The conditions of contrast on the document are evaluated by measuring the contrast reduction [7] on the area where the document is placed. Contrast reduction is measured using the reference contrast task (Fig. 12.) proposed by E. Frederiksen (Illumination Engineering Laboratory, Denmark) at the 1979 CIE Session in Kyoto, Japan [8].

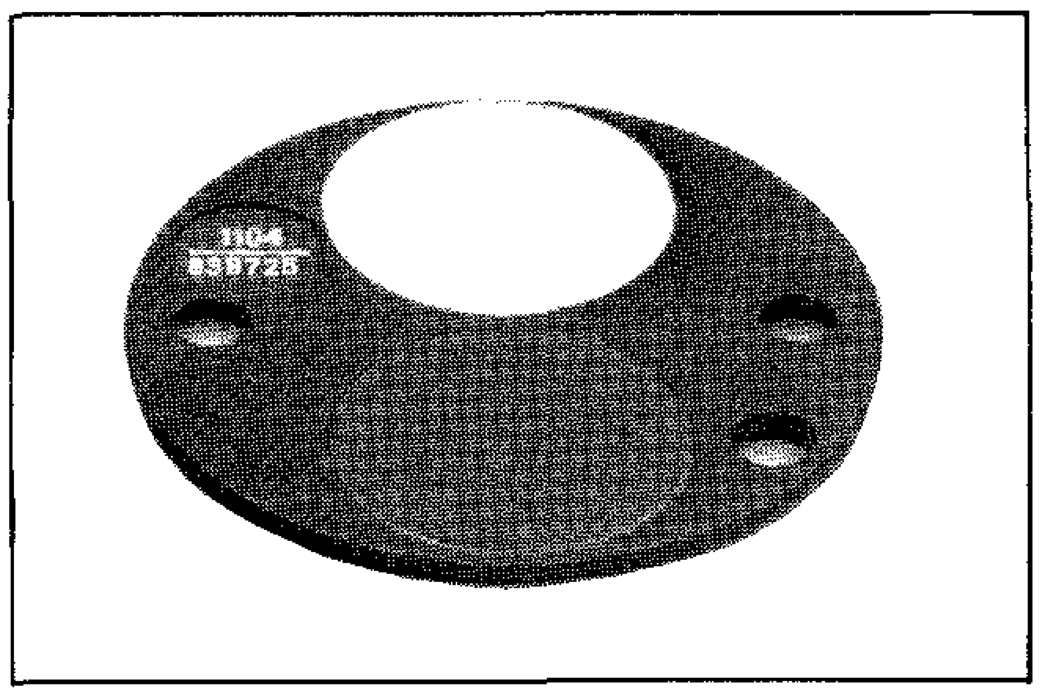


Fig.12. B & K Luminance Contrast Standard Type 1104

The reference contrast task is made of a pair of surfaces (a white and a black) which have the reflection characteristics shown in Fig. 13, [9], and are designed to simulate a typical visual task encounterred in everyday office activity [10]. One can observe that the luminance of the dark surface can exceed the luminance of the light surface when the viewing angle is equal to the angle of

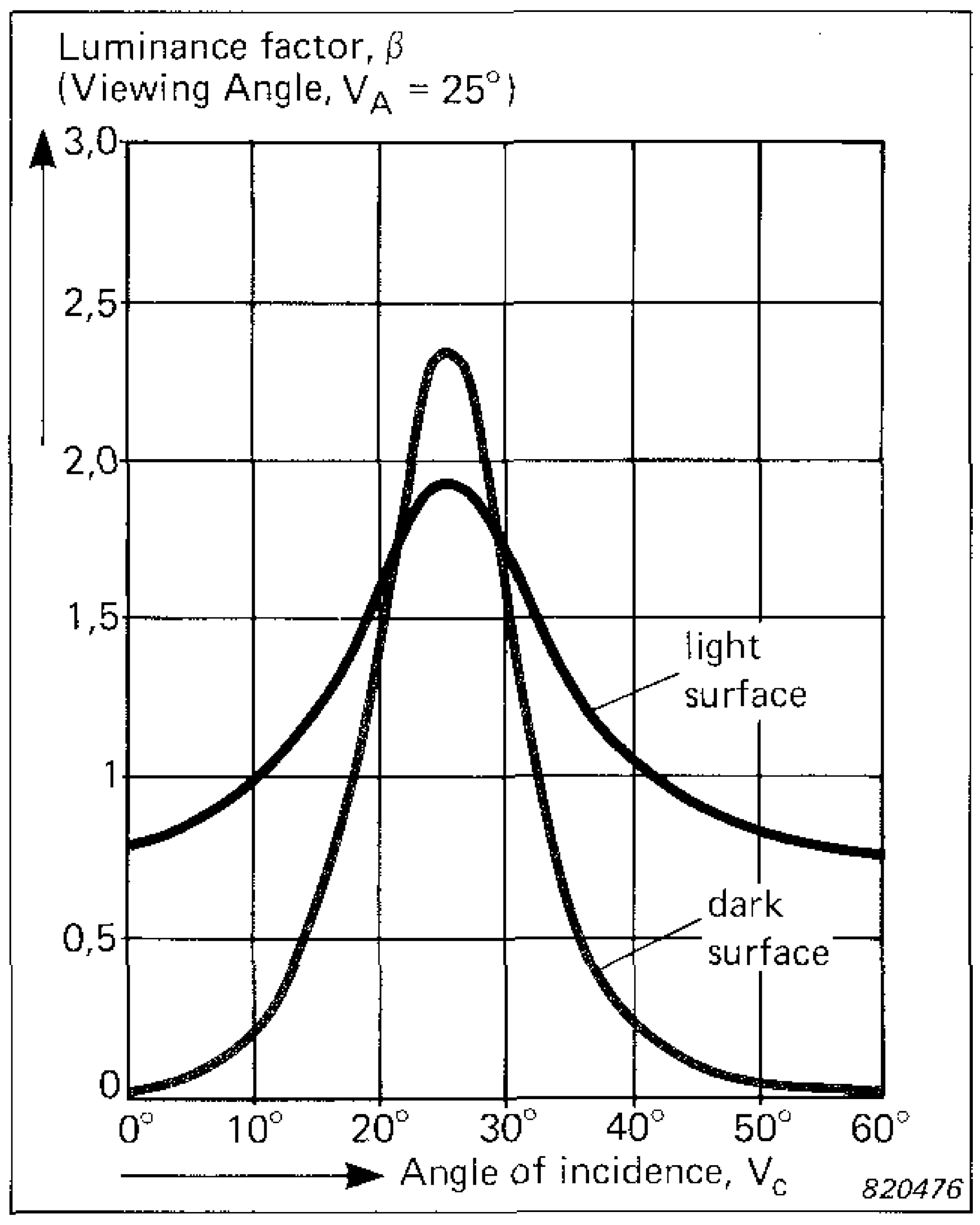


Fig.13. Reflection characteristics of Type 1104

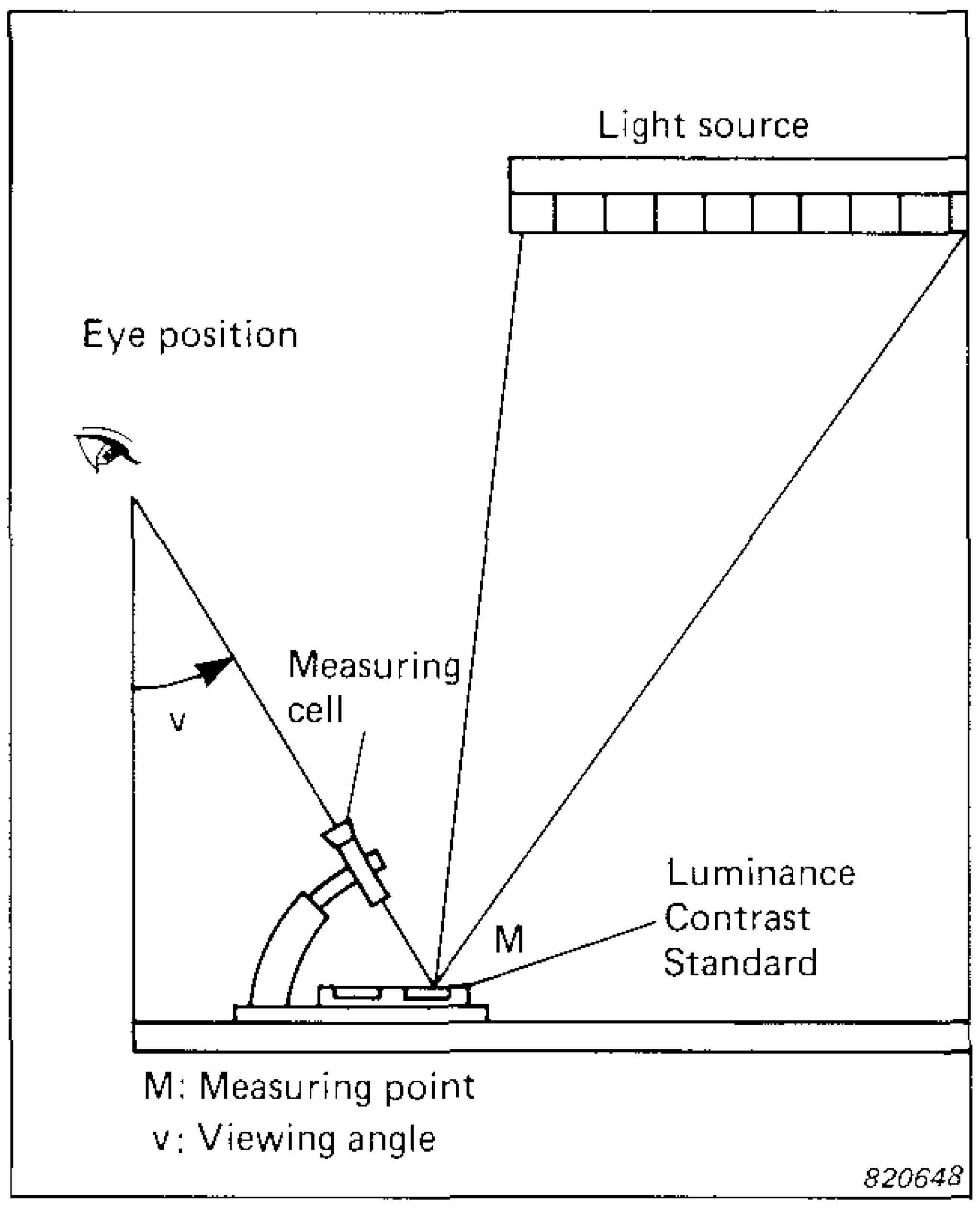


Fig.14. Principle of Contrast Reduction measurement

incidence. This is to include, for example, cases where the text on the document is printed on a glossy paper and where there can be an inversion of contrast.

The reflected luminance of each surface is measured in turn under the actual illumination conditions with a measuring direction corresponding to the actual viewing angle, v, of the operator. See Fig. 14. The contrast for a given point, M, of the working area is defined as:

$$C = \frac{L_{black} - L_{white}}{L_{white}} \quad (3)$$

where L_{black} and L_{white} are the luminance of the black and white surfaces of the contrast standard, as seen from the observer's eye point.

The Percentage Contrast Reduction*, R, at the point M on the document, with reference to the reflection standard is:

$$R = \frac{C_{max} - C}{C_{max}} \times 100\% \quad (4)$$

where C_{max} is the contrast obtained in a reference lighting system (Equivalent Sphere Illumination or Optimal Point Source, for example) and C the contrast at the point M.

Here it should be noted that the measurement of contrast reduction with a contrast standard at the actual work place is not a measurement of the contrast reduction with the particular visual task involved, but it can still tell us about visual performance with the actual task in the actual lighting system. This is a fundamental difference with the proposed evaluation of contrast conditions on a screen, which is based on the measurement of the contrast of the actual visual task (text on the screen).

The working area on which the contrast reduction on the document is measured can be limited to the format of the document involved in the actual working situation (format A4 or A3 as the case may be). The permitted limit of contrast reduction on the document should be relatively stringent (for example $R < 15\%$ with $C_{max} = 98\%$) to allow an eventual reduction of the level of illumination on the document.

It can be necessary to measure the illumination level (in lux) on the document as complementary information for evaluating the readability on the document. What the minimal illumination level should be will depend on the actual case, namely on the background luminance level obtainable on the screen, as mentioned below in section 3.2. In any case, however, the illumination level on the document should not be lower than about 200 lux.

Contrast on the keyboard

The Luminance Contrast Standard Type 1104, which has been specially designed for measuring the contrast rendering at work place dealing with documents, may also be used to evaluate the contrast rendering on a keyboard, but with some precautions. First, since the surface of the keys is generally more glossy than the surface of a document, the maximum permitted contrast reduction on the keyboard must be more stringent than on the document, for instance $R < 10\%$. Secondly, when the surface of the keys is not plane, the measurement must be repeated with the contrast task tilted. Lastly,

* A term used by some workers, and mentioned in CIE Publication No.19 (1972), [11], is the Contrast Rendering Factor, CRF, defined by CRF = C/C_{max}, where C_{max} is referred to Equivalent Sphere Illumination (ESI). This may be obtained from the quantity R using the following identity:

CRF = (100 − R) %

only the difficulty of reading the symbols on the keyboard will be evaluated in this way, but not the possible glare effects due to reflections of light sources on the edges of the keys. In any case, a subjective evaluation of the visual task will be a useful complement to the measurement.

Contrast on a desk or a working table
In the proposal presented at the 1979 CIE Session in Kyoto, Japan [8], a maximum limit to the contrast reduction in office lighting is recommended as follows:
"Where the working materials are mostly rather glossy, the contrast reduction within the defined area (see Fig. 15) should be limited to 15% with regard to the reflection standard object. Where the working materials are rather matt, the contrast reduction should be limited to 30%".

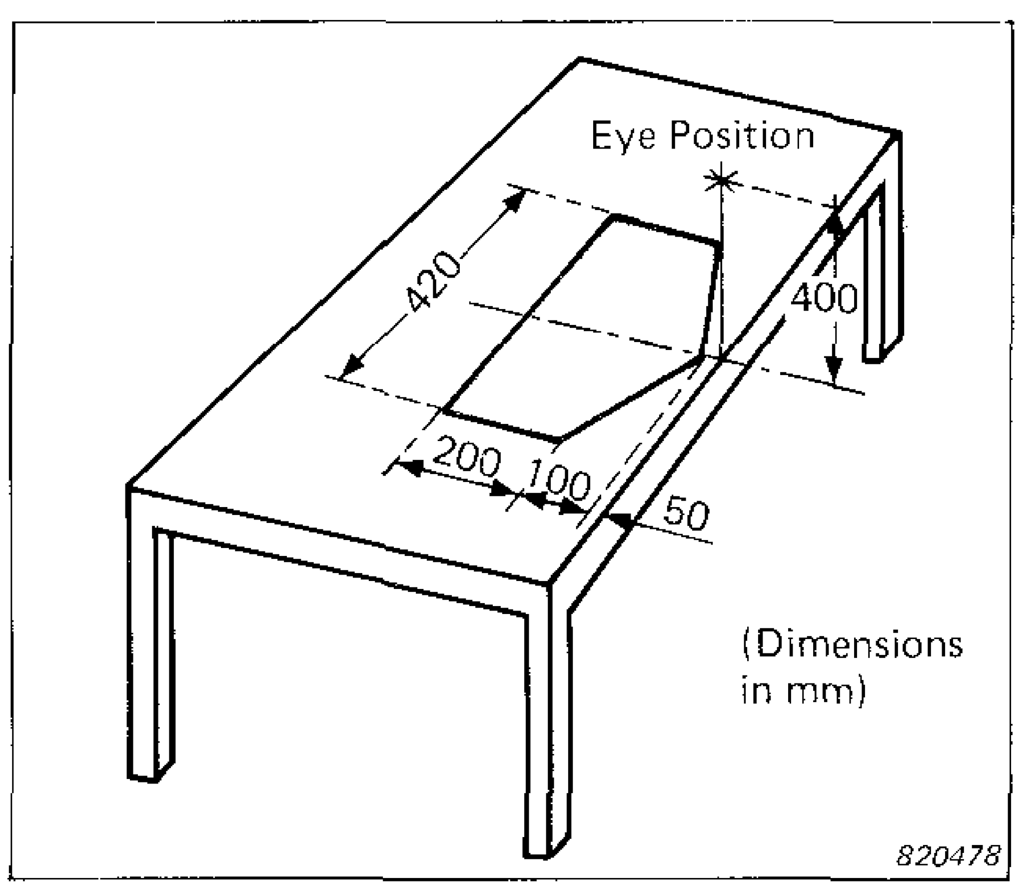


Fig.15. Standard area for measuring the contrast reduction on a working table

3.2. Balance of luminance conditions

Balance in luminance conditions is important mainly for work done at a CRT terminal, since the eyes of the operator are adapted to a relatively low luminance level (mean luminance of the screen). Luminance transitions which are too sharp in the working area or between the screen and the surroundings surfaces, even in the far visual field, can lead to visual fatigue in the long term. It is recommended in some national standards for office lighting [12], [13], that the mean luminance ratio of adjacent surfaces in the working area should be limited to 3:1 and the luminance ratio between the working area and the far surroundings to 10:1.

Although it states that the attention of the operator will be held better by the working object if it is brighter than the surroundings, the German Standard DIN 5035, [12], for example, admits the possibility of a reverse luminance distribution between the working object, the working area and the surroundings. In this case, the Standard recommends a maximum luminance ratio of 1:3 between the working object and the working area and of 1:10 between the working surface and the surfaces in the far surroundings situated in the visual field.

When applied to the work place with a CRT display terminal, these guidelines could be stated as following:

— The luminance ratio between any two of the three visual tasks, screen, keyboard *and document* should not exceed 3.
— The luminance ratio between the luminance of any surface in the far surroundings in the visual field and the mean luminance of the screen (with a text displayed on it, representative of the task usually performed) should not exceed 10.

A recently published French recommendation [14] states these luminance conditions in a slightly different way, since it stipulates that the luminance of the three visual tasks should be the same and the luminances in the visual field behind the screen should not exceed 200 cd/m^2. The luminance of the visual task on the screen is defined as the luminance of the characters and not as a mean luminance (character + background) as above.

The first requirement (luminance ratio lower than 3) can be difficult to fulfil if at the same time the illumination level on the document is required to be at least 500 lux. 500 lux on a white paper having, for instance, a reflectance of 80% gives a luminance of about 130 cd/m^2. This means that the mean luminance of the screen (with a text displayed on it) should be at least 43 cd/m^2. In only one case in the measurement examples described in section 5 (Example 2, Operator C) has a mean luminance on the screen of this order of magnitude been found. In reality, this corresponds to a very bright screen and for some types of terminal screen the flicker effect could begin to be annoying. In fact, it can be necessary to reduce the illumination level on the document (e.g. to 200 to 300 lux), providing that the contrast on the document is the best possible. The relatively slight reduction of visual acuity, in this case, will be fully compensated by a significant improvement in the conditions of adaptation.

The second requirement (surroundings/screen luminance ratio lower than 10) implies that the terminal should not be placed in front of windows, even if they are far away from the screen. Sources of artificial lighting should be placed out of the glare angle (45° from the horizontal line, see Fig. 3.), otherwise they should be designed to have a luminance, seen from the operator position, lower than 10 times the luminance of the screen.

4. Practical Measuring Methods

The measuring methods proposed are based on Brüel & Kjær Contrast Luminance Meter Type 1100 (shown Fig. 16), which has been specially designed for the measurement of contrast and contrast reduction on working surfaces.

4.1. Measuring "Character Contrast" on a screen

Method 1: Uniform measuring areas
Many CRT terminals nowadays incorporate the possibility of displaying the text on the screen in different display modes. By using the space-band key in "Reverse" display mode, where the characters are shown dark on a light background, small measuring areas can be generated on several points on the surface

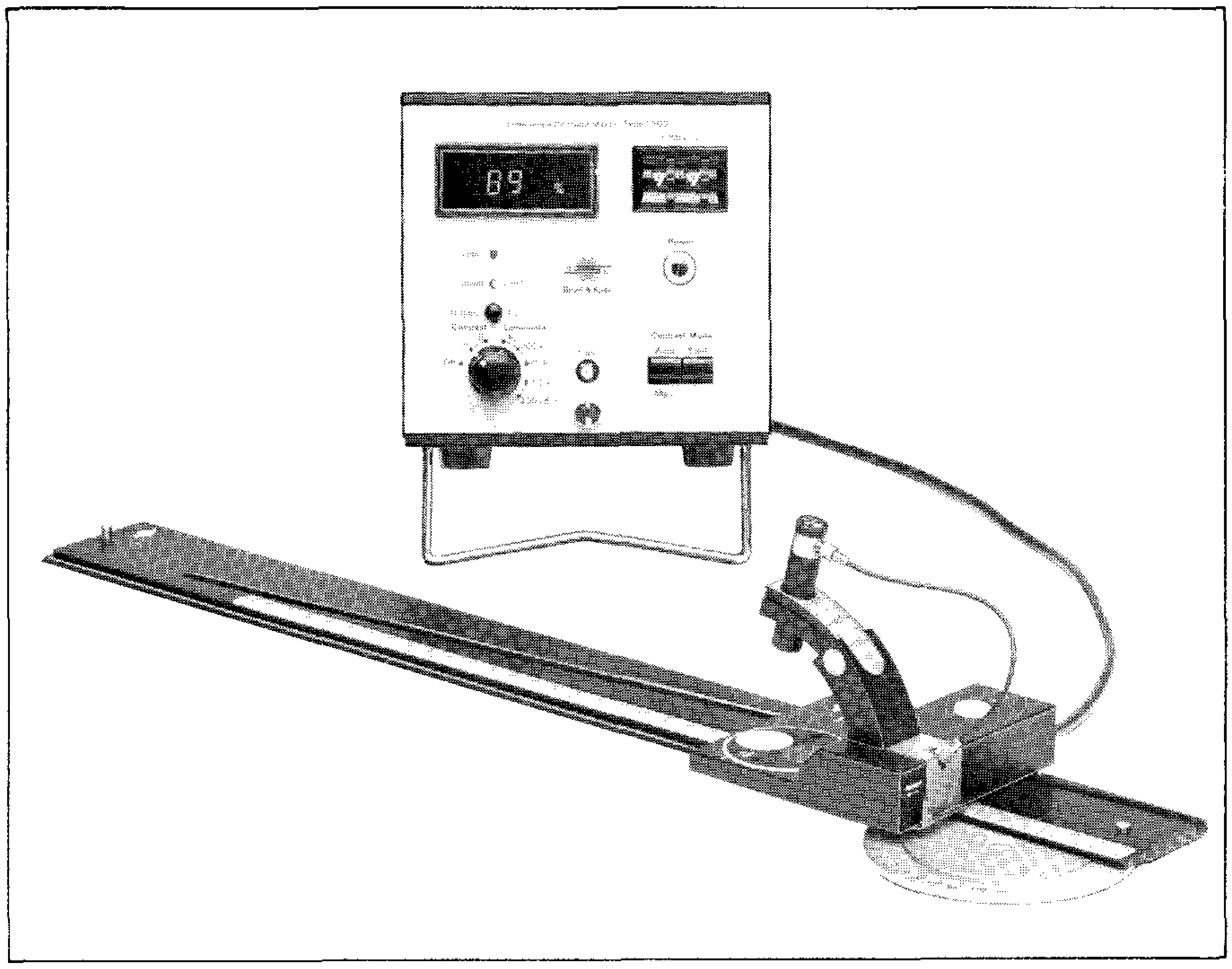


Fig.16. B & K Luminance Contrast Meter Type 1100

of the screen. Generally, the luminance of such areas in "Reverse" display mode is the same as the luminance of the characters in "Normal" display mode (light symbols on dark background). One way to verify that these two luminances are the same is to generate some characters in "Normal" mode close to a measuring area in "Reverse" mode, and, by slowly decreasing the brightness of the characters, to observe that the characters and the small light areas disappear exactly at the same time.

On each measuring area the luminance is measured by holding the measuring cell of the Luminance Contrast Meter Type 1100 in the viewing direction of the operator (See Fig. 17). The distance from the cell to the screen is not critical, since

Fig.17. Measuring "character contrast" on the screen

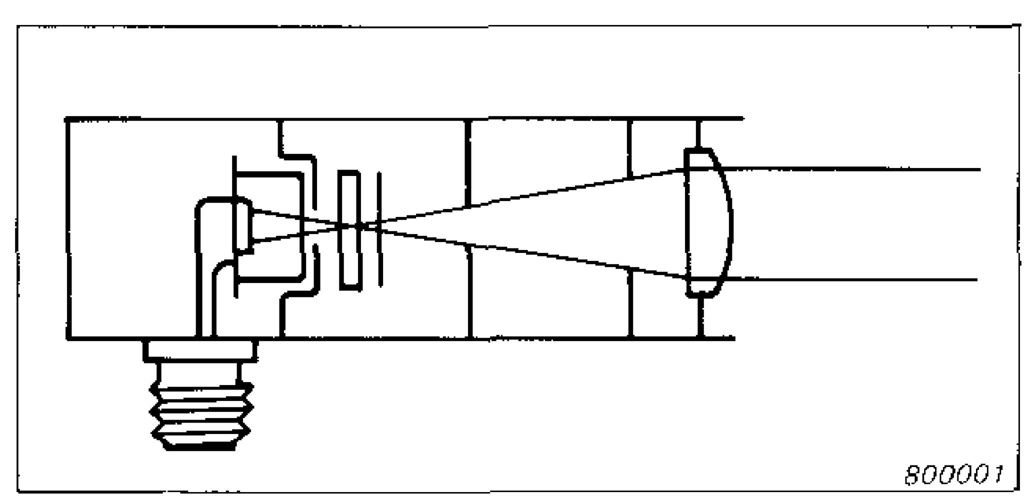


Fig.18. Construction of the measuring cell

the optical system of the cell is virtually focussed at infinity (Fig. 18), the total acceptance angle of the cell being a maximum of 3°. In practice, the measuring distance will be a compromise between ease of aiming the cell at the screen and the necessity of avoiding a shadowing effect from the hand.

In the practical examples discussed in section 5, measurements were made on nine measuring areas of about 25 x 25 mm (Fig. 11) with a typical distance cell-screen of 20 cm thus no special sighting system was required to ensure that the small area covered by the cell was totally inside the measuring area. The choice of nine measuring areas is a compromise between the necessity of obtaining an idea of the contrast variation on the screen and the requirement for a reasonably short measuring time (a few minutes on each terminal). However, if a better resolution on the surface of the screen is required, or for practical reasons, any other test pattern could be used for this purpose.

The measurement is straightforward with the Luminance Contrast Meter Type 1100, and the luminance ratio Background/Character can be read directly on its display. For this purpose, the value of "C_{max}"* dialled into the thumbweel switches (see Fig. 19) is 100%, then the function R (Contrast Reduction) of the instrument is reduced to the simple luminance ratio L_2/L_1, where L_1 is the luminance of the light measuring area representing the symbol luminance, and L_2 the luminance of the background (measured at the same point when the light area is removed or at the direct vicinity of the light measuring area). Then, the inverted luminance ratio L_1/L_2 can be calculated for practical comparison with, for instance, the recommended value of 10:1.

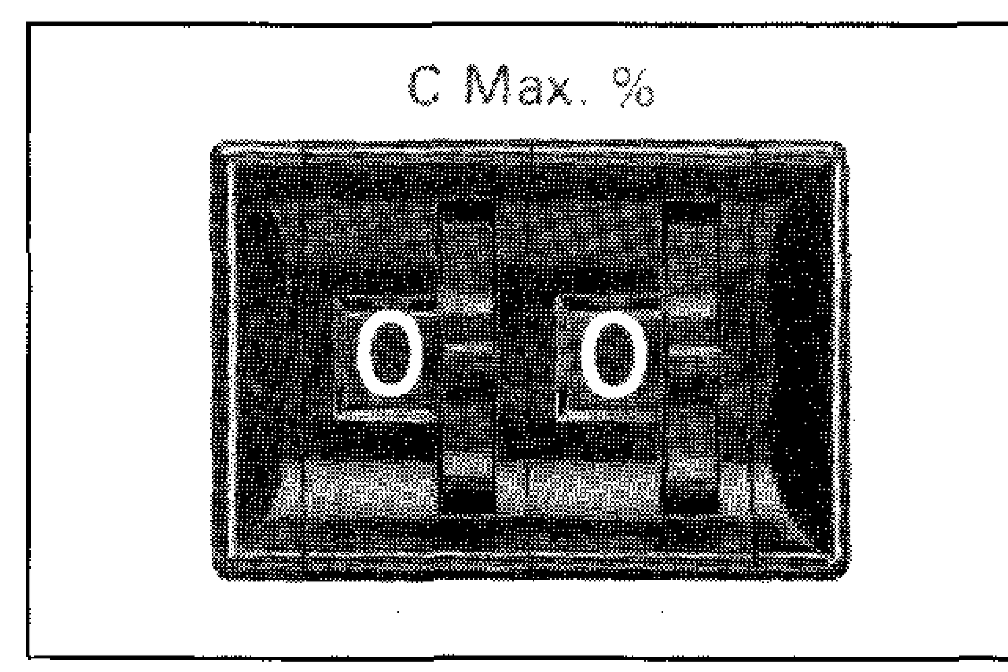


Fig.19. "C_{max}" thumbweel switches set on "00" (i.e. 100%) to measure the contrast of the characters

Method 2: Measuring areas composed of capital letters

In cases where there is no possibility of generating light measuring areas on the screen, representating the luminance of the symbols, the measurements can be performed on lines of capital letters, distributed on nine measuring areas as illustrated on Fig. 20. The mean luminance (letter + background), L_m, and the background luminance, L_b, are measured successively with the measuring cell of Type 1100 at a distance of the screen of 20 to 30 cm. The approximative area covered by the cell is shown by a circle in Fig. 21.

* "C_{max}" is the reference contrast chosen by the user for contrast reduction measurements.

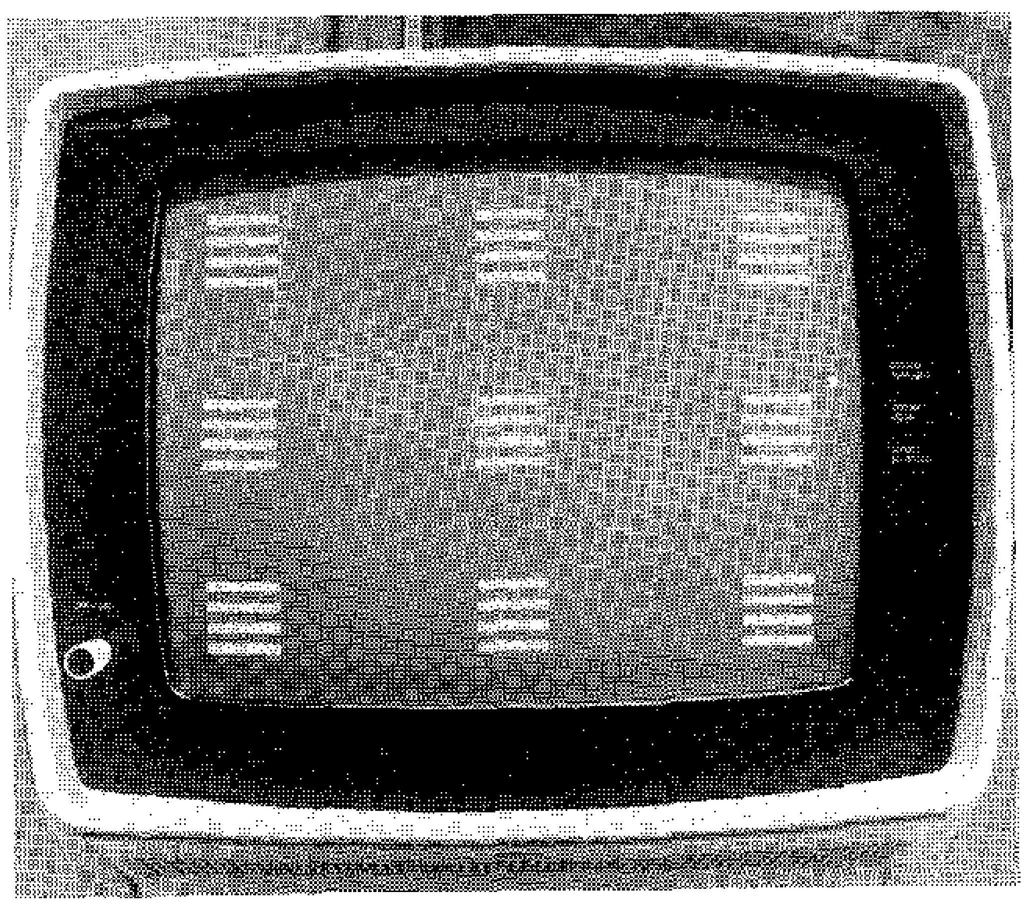


Fig.20. Contrast measurement on capital letters

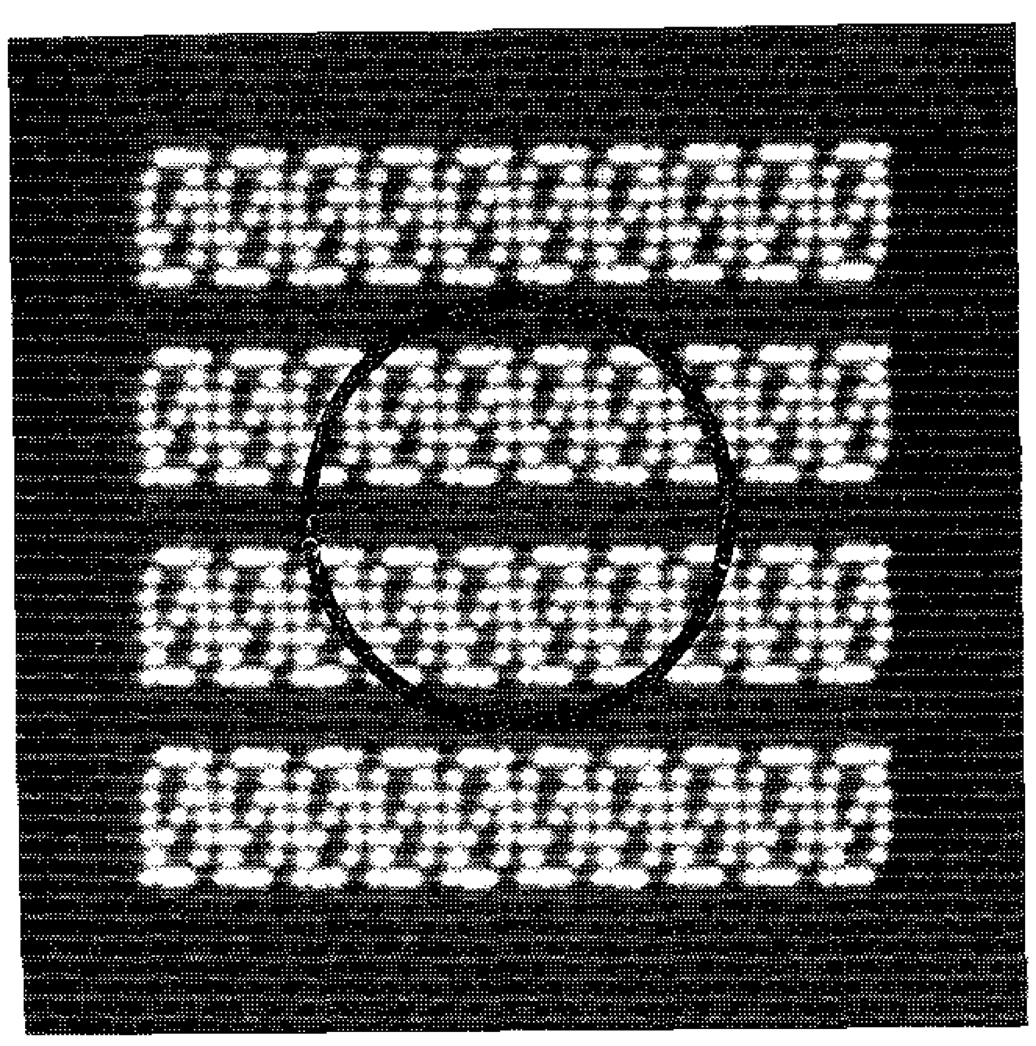


Fig.21. Measuring area covered by the cell

The luminance of the characters displayed on the screen, L_c is then calculated using the following equation, derived in Appendix I:

$$L_c = \frac{L_m}{d} + L_b \left(1 - \frac{1}{d}\right) \qquad (5)$$

where d is the degree of coverage of the characters on the screen (i.e. the area covered by the dots constituting the capital letters divided by the total area covered by the measuring cell).

The degree of coverage, d, can be evaluated from the knowledge of the composition of the letters — which is generally based on a matrix of luminous dots — and of the distance between letters and between lines. Examples of determination of the luminance of several kinds of capital letters from two different types of terminal are given in Appendix I. Comparison of results of measurements of character luminance based on both methods (with letters or with light areas generated on the screen) shows a relatively good agreement for both types of terminal and for character luminances ranging from 30 to 190 cd/m^2.

4.2. Measuring the contrast on the keyboard

The Contrast Reduction, as defined section 3.1 "Contrast on the document", is measured at several points on the surface of the keyboard using the carriage of the Luminance Contrast Meter Type 1100, with the Luminance Contrast Standard Type 1104 fitted. On each measuring point the axis of the cell is aligned with the viewing direction of the operator (Fig. 22). As shown in Fig. 23, it can be necessary to tilt the Contrast Standard slightly to take account of the concavity of the keys. The measuring point where the maximum contrast reduction has been found may eventually be noted on a sketch of the terminal drawn on the mapping chart.

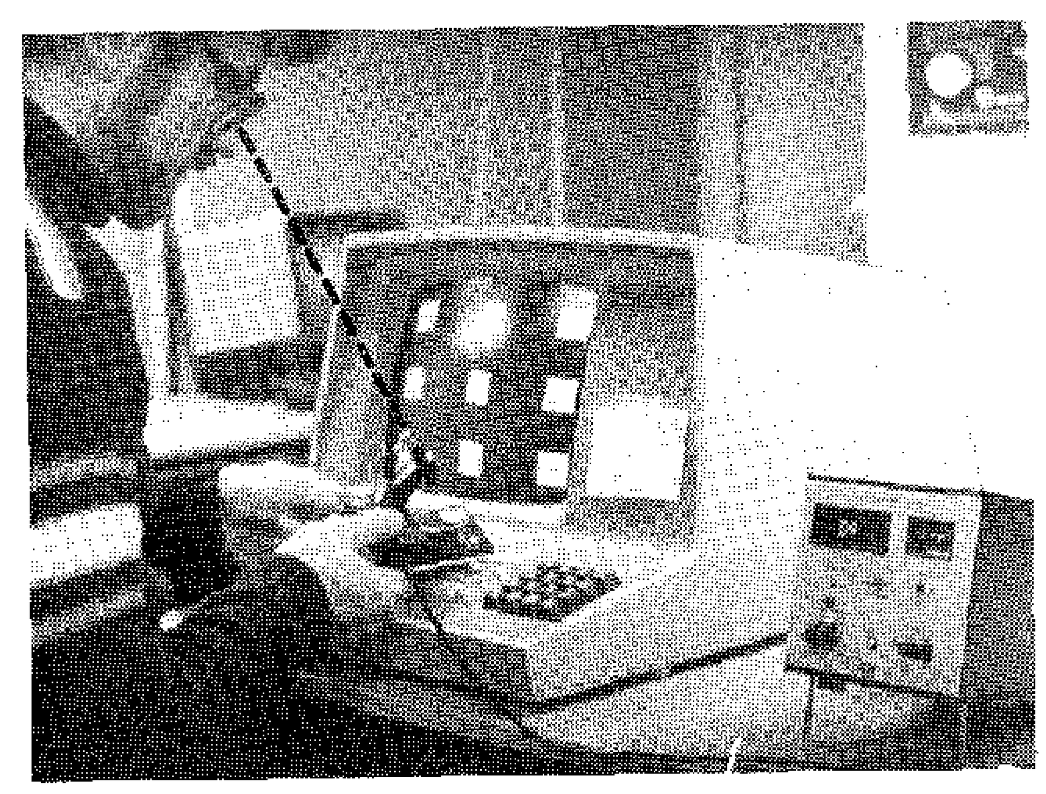


Fig.22. Measurement of contrast reduction on the keyboard

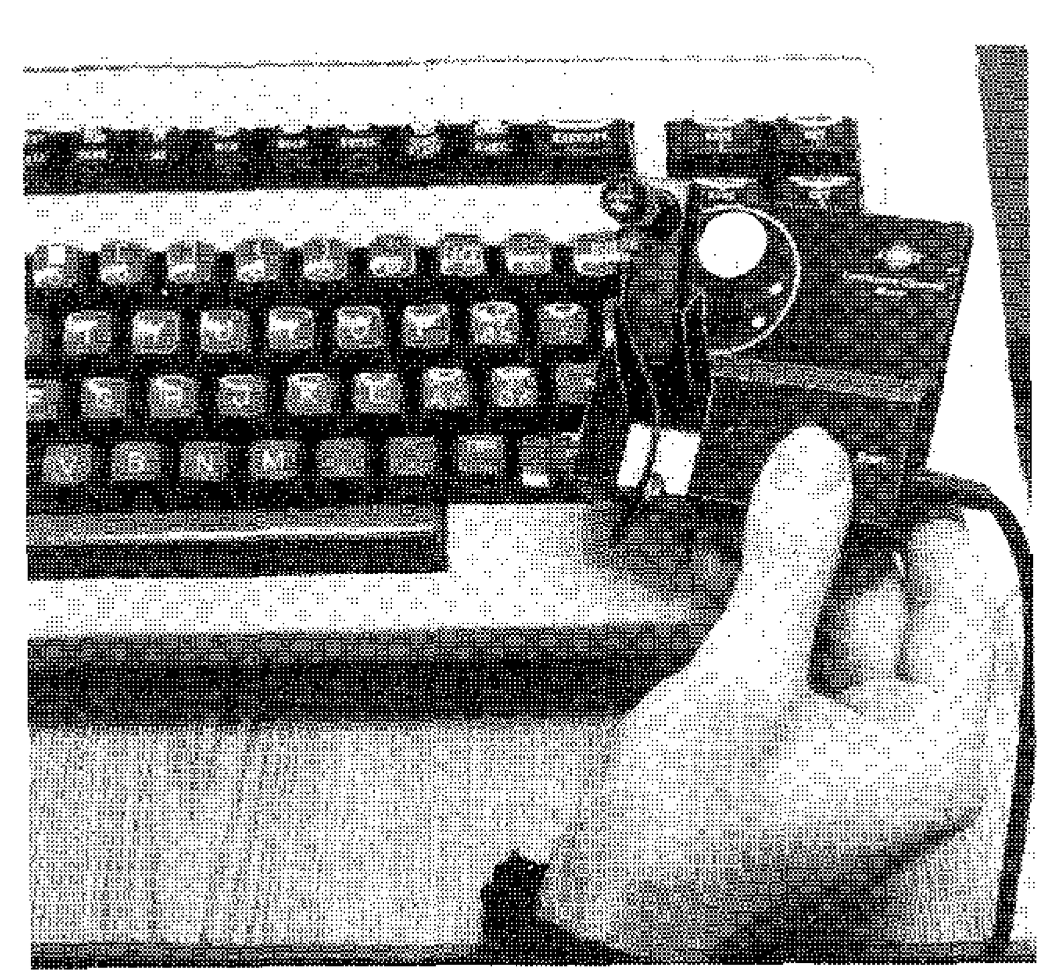


Fig.23. Type 1104 tilted on the surface of the keyboard

4.3. Measuring the contrast on the document

The measurement is performed in the same way as above for the contrast on the keyboard, with the Contrast Standard Type 1104 placed on the carriage alone (Fig. 24).

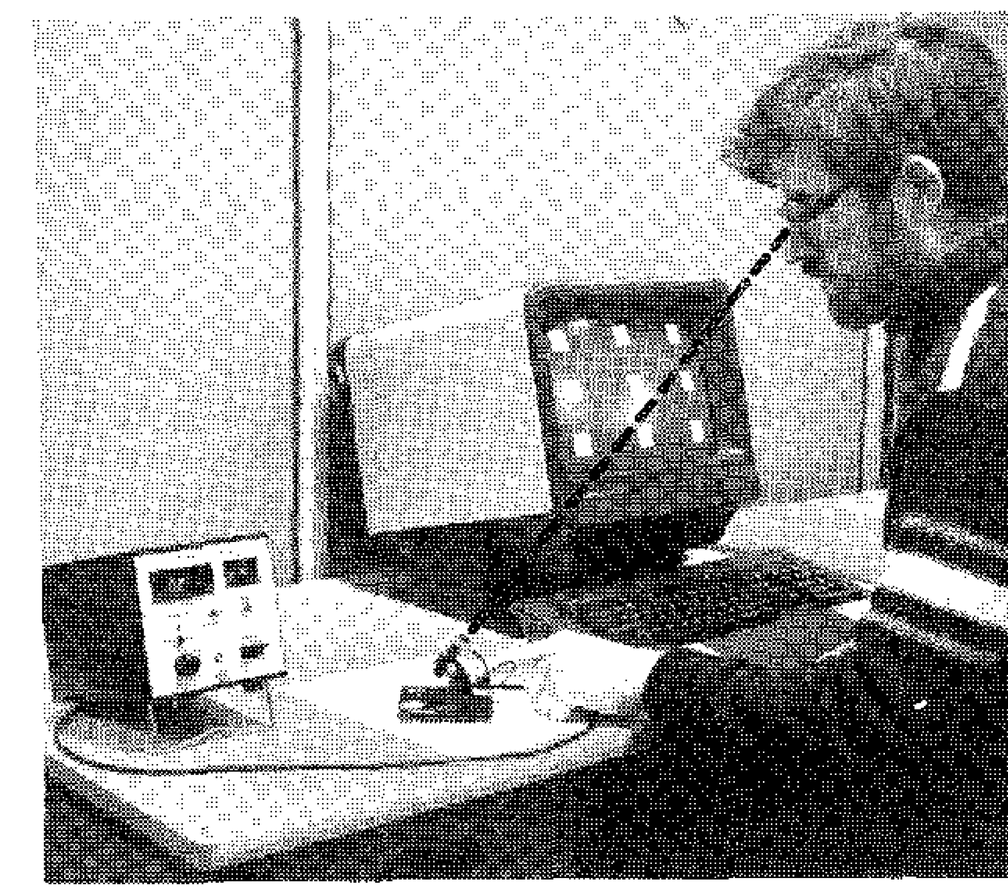


Fig.24. Measurement of contrast reduction on the document

To determine the maximum contrast reduction on the area where the document has to be placed, the carriage is placed at several points on this area with the measuring cell always in the viewing direction of the operator, and the automatic contrast reduction measuring sequence remote controlled from the start button on the carriage itself. It can be of interest to obtain a more detailed documentation of the measurement, for instance to know the distribution of contrast reduction on the document and determine if the veiling reflections occur on a more or less extensive part of the document. For this purpose, the measured area may be divided into small, regularly scattered sections, in each of which the measured contrast reduction can be reported.

The level of illumination on the document or the luminance of the actual document used may provide usefull complementary information for evaluating the readability of the document.

4.4. Luminance measurements about a terminal

Luminance measurements are performed using the measuring cell of the Type 1100. Since the acceptance angle of the cell is relatively small, the mean luminance of the screen (with a text displayed on it representative of the most usual visual task actually performed on the screen) has to be measured at a certain distance from the screen (generally 1,5 to 2 m). At a distance of 2 m, for instance, the cell covers a circle of maximum 10 cm in diameter. A special adaptor can be fitted on the measuring cell, changing the total acceptance angle of the cell from 3° to 24°. To cover a circle of 10 cm in diameter on the screen, the cell should then be hold at a distance of about 25 cm from the screen. This makes the measurement of the mean luminance of the screen more practical.

This adaptor may also be used when measuring the mean luminance of the keyboard since the keys may be of different colours and an averaging of the various luminances of the keys can be required to evaluate the approximate level of adaptation of the operator looking at the keyboard.

Luminance measurements of light sources in the surroundings behind the screen have to be performed bearing in mind that the area covered by the cell (without adaptor) should not be larger than the surface of the source projected on the direction of observation. A hand-held sighting mount is provided enabling the cell to be aimed by eye at the measured source, and a push-button on the front panel of the 1100 allows one to hold the value displayed at the moment where the cell is exactly aimed at the source (Fig. 26).

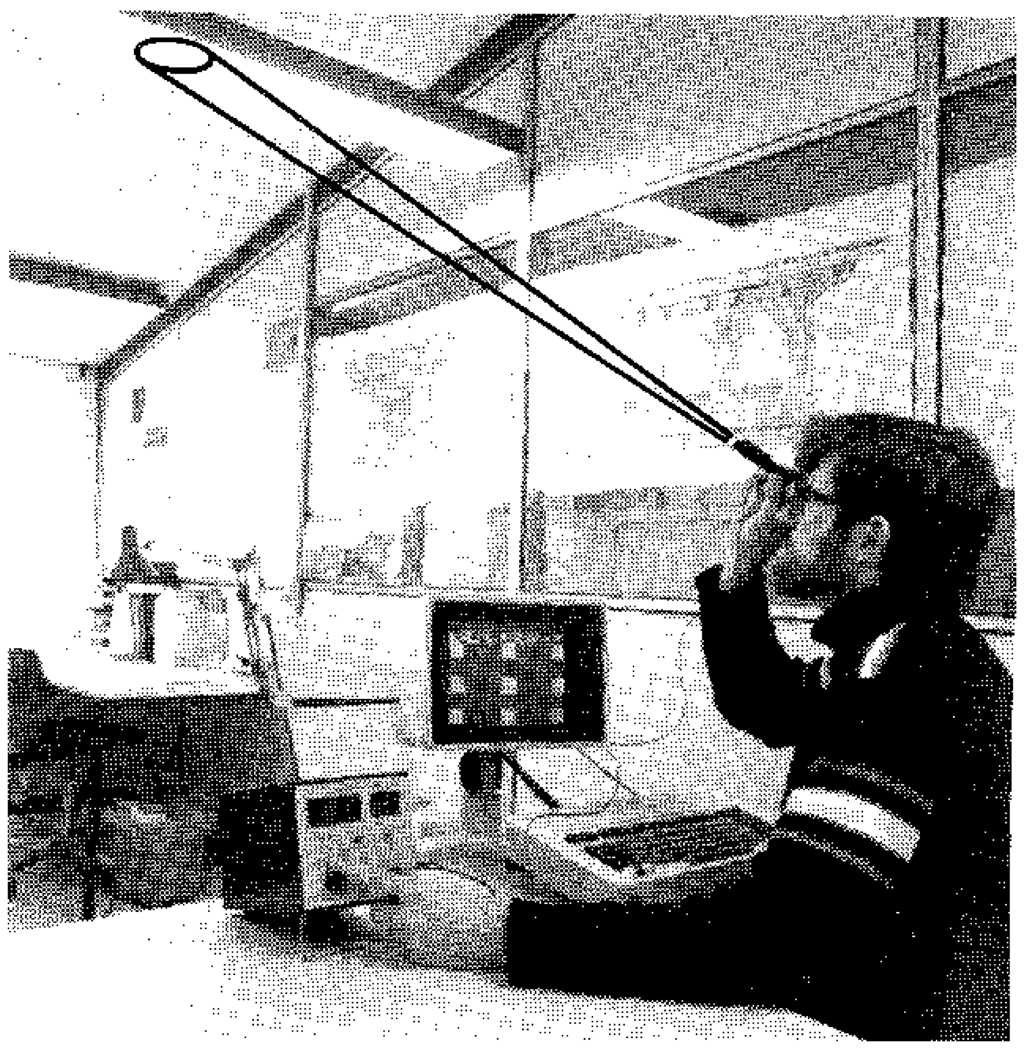


Fig.26. Measurement of the luminance of a luminaire

Measurements of contrast conditions and of luminances about a workplace with CRT terminal are reported as shown in Fig. 25. Both sketches of the terminal (Condition of contrast and Luminance distribution) have to be examined to determine the visual conditions of the work place.

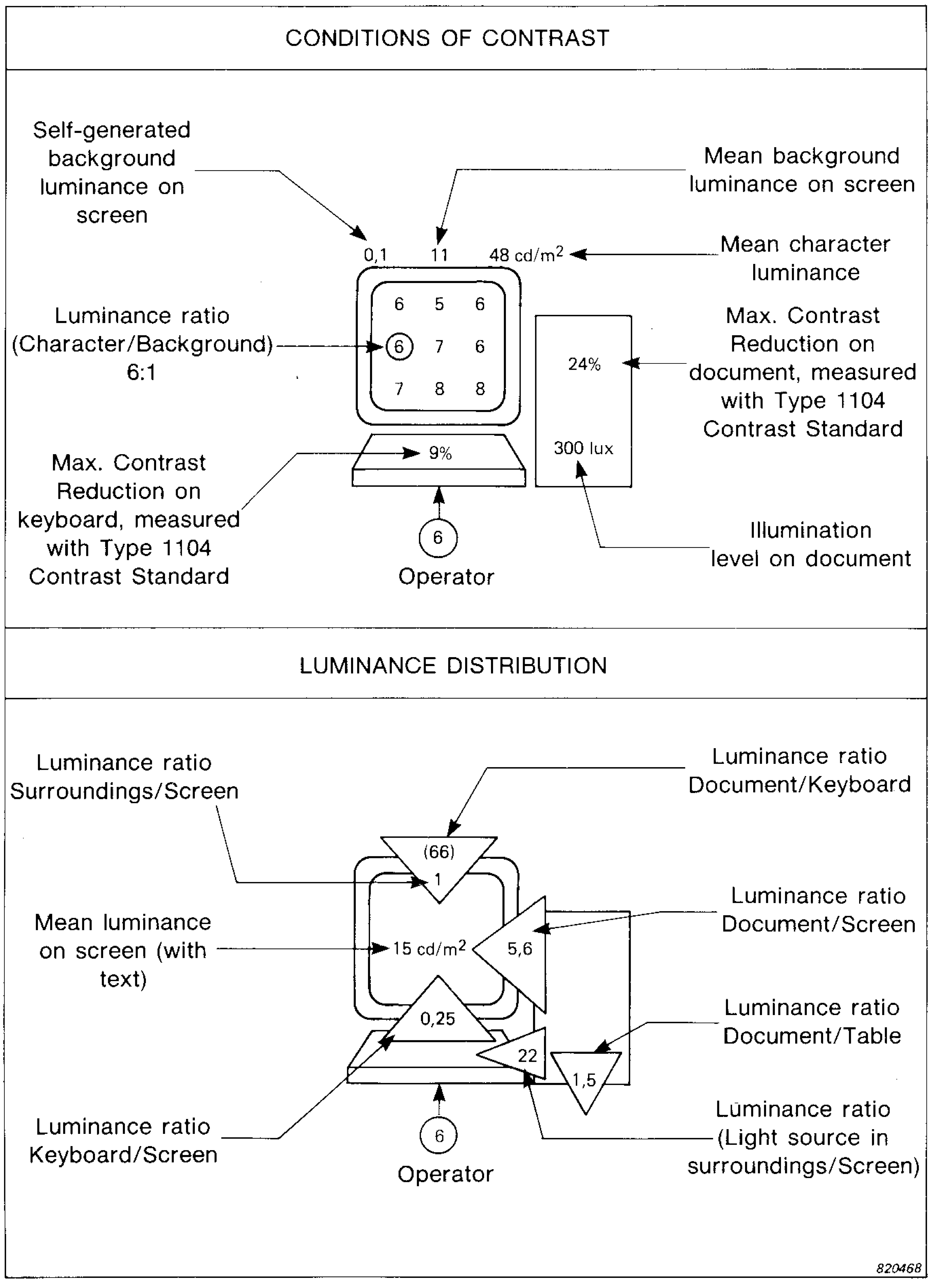


Fig.25. Results of measurement of contrast and luminance conditions on a CRT terminal

4.5. Contrast measurements on a desk

Contrast measurements on a desk or a working table are performed using the radius arm of the Luminance Contrast Meter Type 1100 with the Contrast Standard Type 1104 fitted to the carriage (Fig. 27). A succession of measurements are made on the proposed standard working area (Fig. 15). On each point the measuring direction is automatically aligned with the nominal viewing direction. The nominal eye point is situated 400 mm above the edge of the desk (Fig. 28).

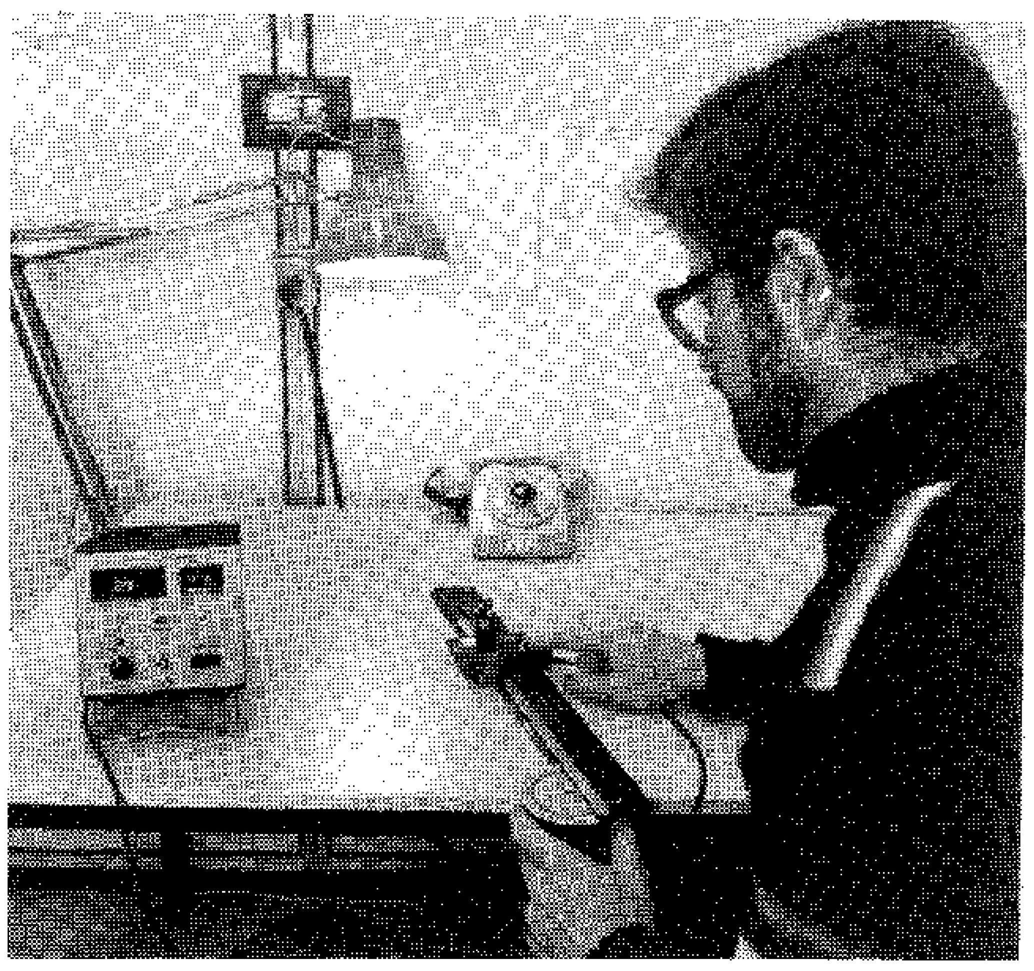


Fig.27. Measurement of contrast reduction on a desk

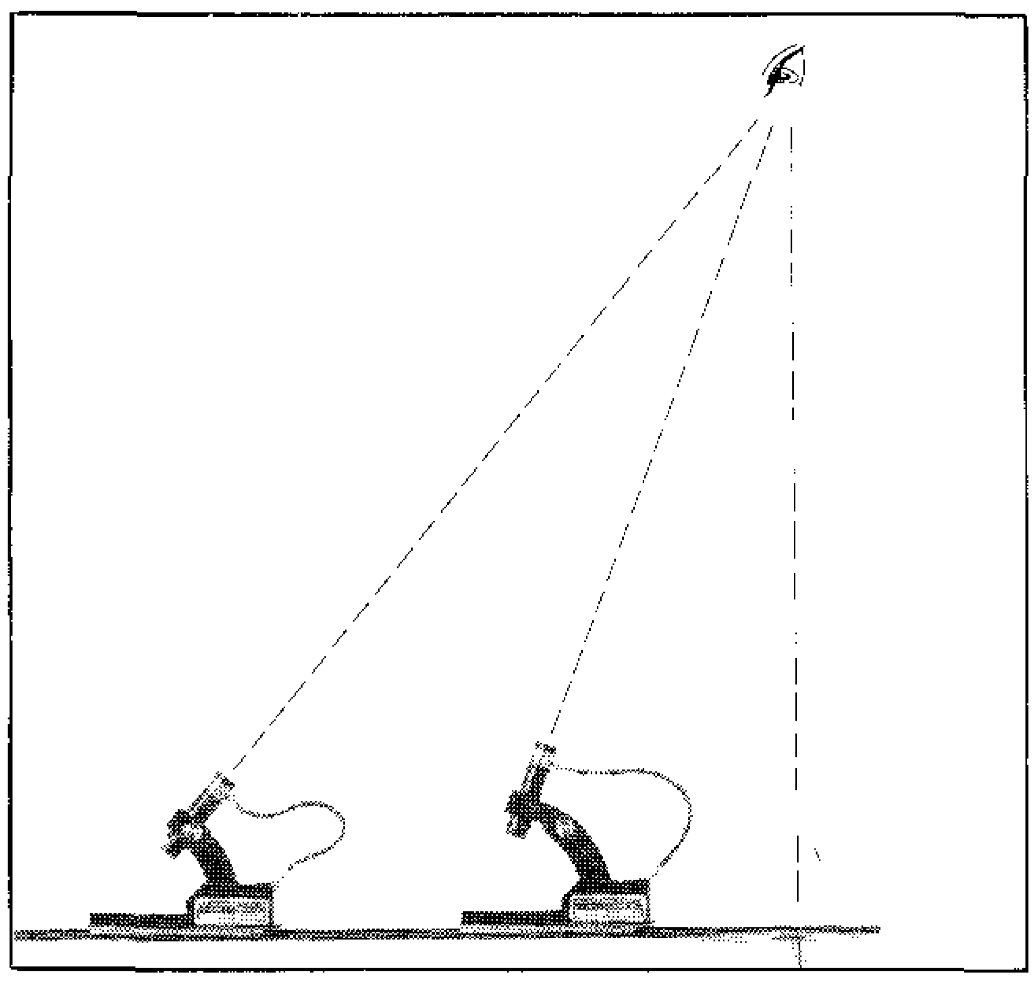


Fig.28. The measuring cell follows the viewing direction on the measuring area

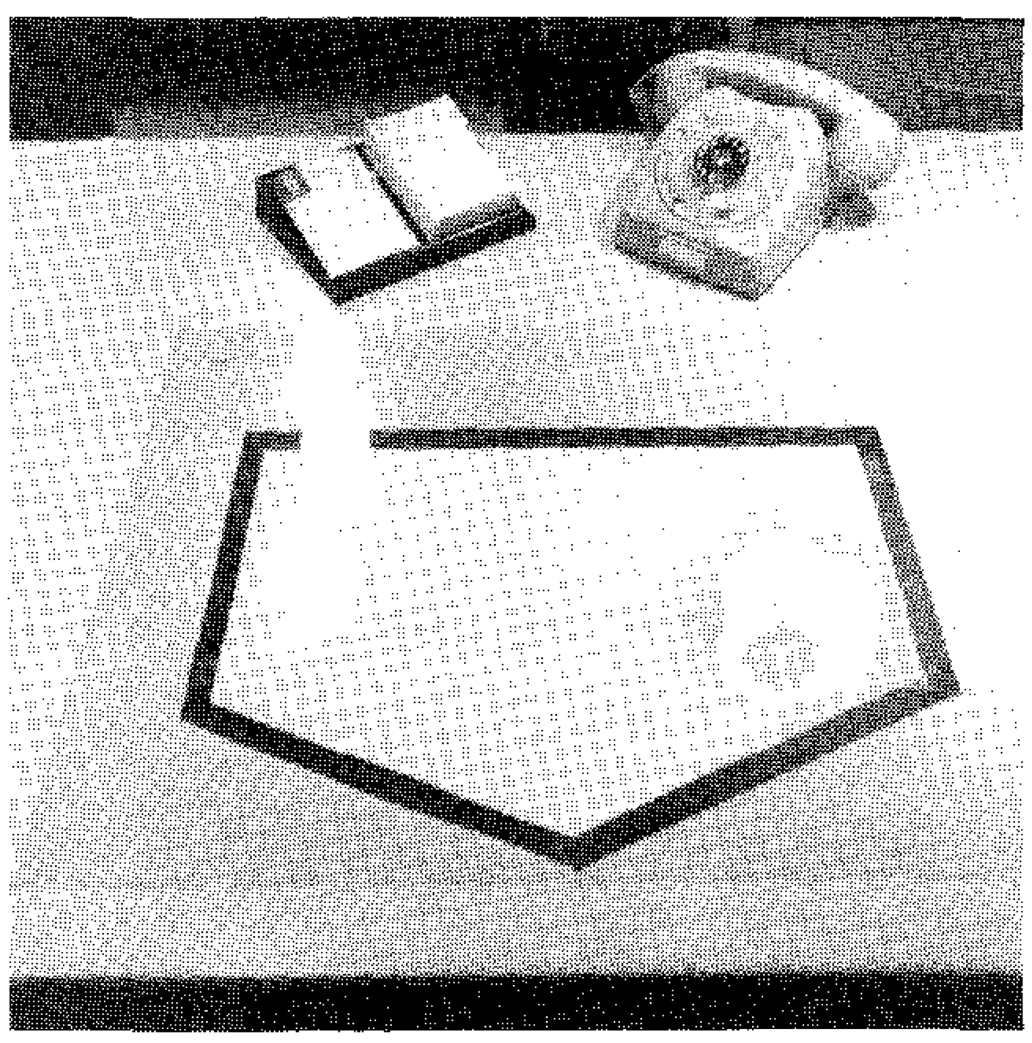


Fig.29. Reflections on the desk of operator E, example 2

Mapping the contrast reduction throughout the visual field enables contours of constant contrast reduction to be traced. Contour lines for contrast reduction of 15%, 30% and 50% are drawn, so that situations where contrast conditions on a desk are not acceptable can be seen at once. An example of representation of veiling reflections on the working area is shown in Fig. 29 & 30.

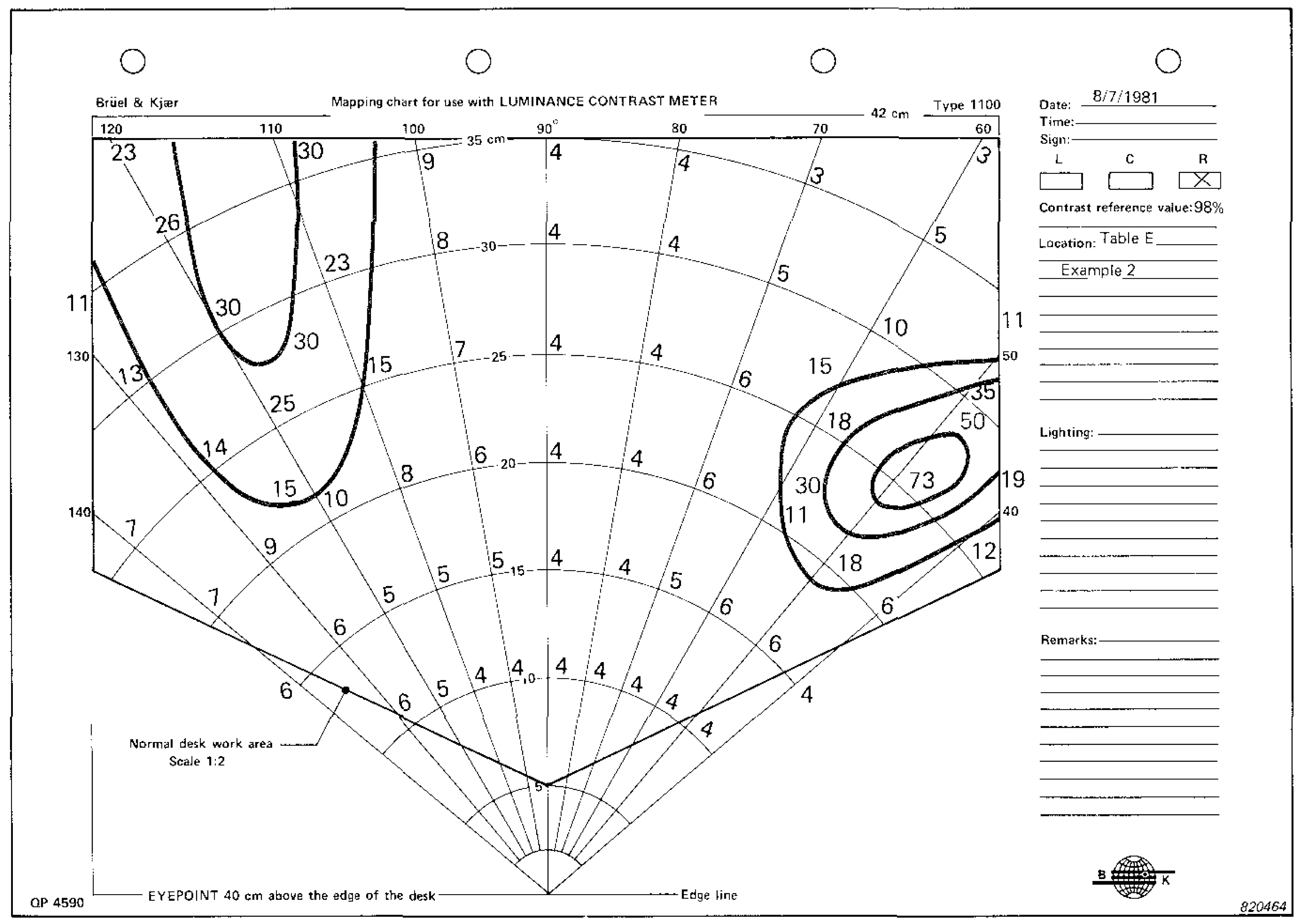


Fig.30. Mapping of the contrast reduction on the desk of operator E from example 2 described in section 5.2.

5. Three Examples

5.1. Example 1: Programming room with 10 CRT display terminals

The work:
The operators spend only a part of their time in this room, sometimes up to 2 or 3 hours a day. The work consists of designing programmes which are intended to be used in microprocessor-controlled measuring instruments. A great part of the job is performed in the operator's own office, then the operator comes in the programming room, selects an unoccupied terminal and types his programme on the terminal.

The room:
The room can be considered as ideal from a lighting engineer's point of view, since there are no windows*, only four skylights in the four corners of the ceiling. With a room without windows, the requirement of no veiling reflection on the screen and of a balance in luminance conditions can be fulfilled more easily. The room is divided into several sections using movable partitions of 1,6 m height (Fig. 31 & 32).

The lighting:
The lighting consists of luminaires placed 2,5 m from the floor and evenly distributed to ensure a uniform illumination level in most part of the room. The luminaires are fitted with white grids of relative high luminance. At none of the operator work places is auxiliary personal lighting used. The four skylights contribute substantially to the lighting of the room. They have been painted white to reduce the effects of the radiation of the sun in the room, mainly in summer.

The terminals:
The text is displayed in light green on a dark green background (or in white on a grey background for some of the older models). The background has a relatively good diffuse reflection factor, so veiling reflection from large bright surfaces reflected on the screen have a tendency to disappear in the background. Only the luminance of the text on the screen can be controlled by the operator, not the luminance of the background, which depends on the ambient lighting. The documents, in cases where they are used, are always placed horizontally on the table beside the terminal. On most of the terminals, the contrast on the

*A room without windows may not be considered as ideal from the operator point of view, even if it is easier to solve the lighting problems in such a room. Other factors like claustrophobia or missing contact with the outside world may influence the psychological feeling of the operator as much as the difficulties of performing visual tasks.

Fig.31. Programming room, view 1

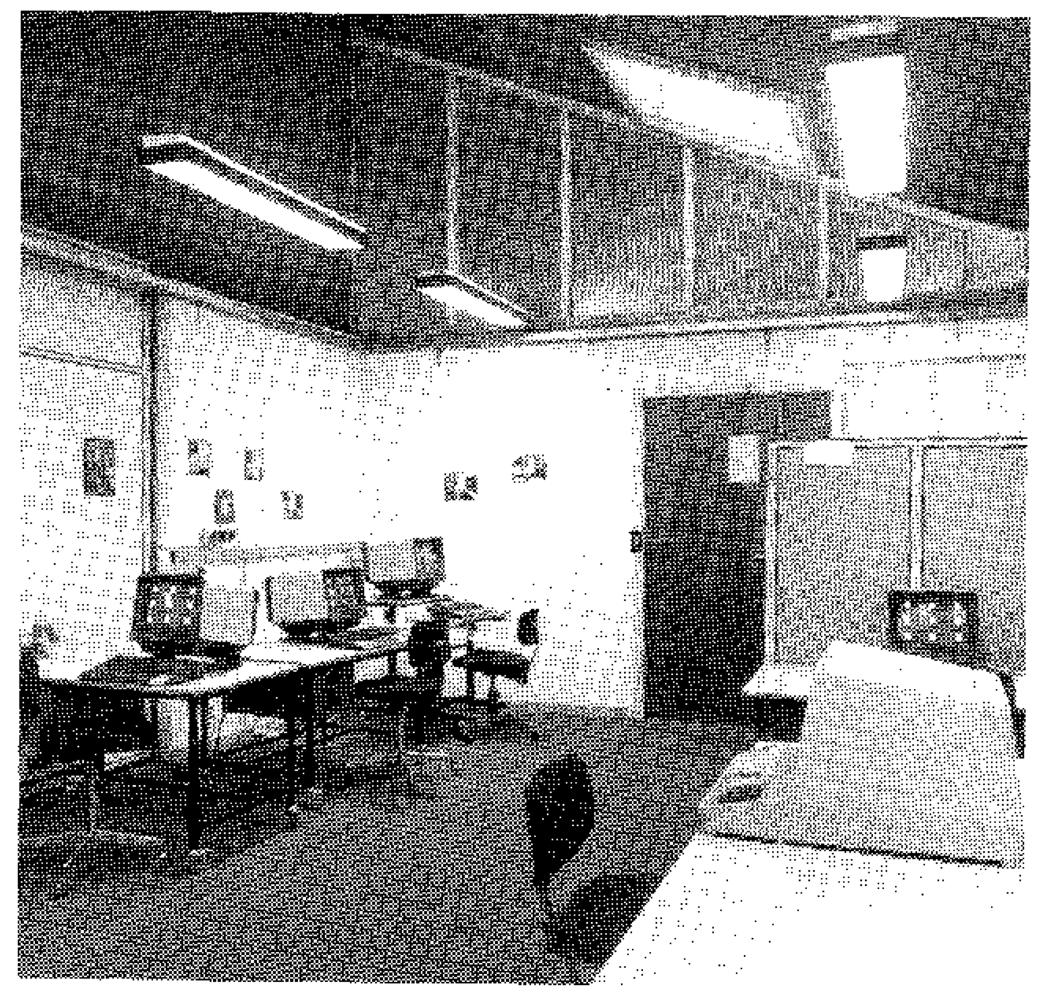


Fig.32. Programming room, view 2

screen has been measured by method 1, on light measuring areas generated on the screen. On the older types, method 2 (with measuring areas consisting of capital letters) has been used (degree of coverage d = 0,43).

Results of measurements:
The results of measurements of conditions of contrast and of luminance distribution are represented on Fig. 34. For the convenience of the drawing, the terminals are shown with the screens turned towards the ceiling and are not to scale, so it may be difficult to draw any conclusion from the relative locations of the terminals and of the sources of lighting on the drawing.

By looking at both parts of the drawing (Conditions of contrast and Luminance distribution) simultaneously, one can observe that only one terminal is correctly placed, namely terminal 7. However, it can be noted that with this terminal, the luminance ratio Document/Table (33) reveals that the *surface of the table is too dark*. The luminance ratio Document/Keyboard (14), which can also be considered as too high, is due to the fact that the keyboard is black.

Because of their incorrect positions relative to the lighting system, one or several of the important requirements for contrast or luminance conditions are not fulfilled with any of the other terminals. If we take terminal 2, for instance, the contrast on the screen is insufficient, since the luminance ratio Character/Background on the upper part of the screen falls to 2, 4 and 3, revealing the presence of veiling reflections from luminaires L_2 and L_6 on the screen. The contrast on the document is not much better, the maximum contrast reduction being 54%, owing to reflections from luminaire L_7 on the document horizontally placed on the table. The luminance ratio between the white document and the black keyboard is too high (30) and the luminaire L_4, which is in the visual field of the operator, may be a source of discomfort glare (luminaire/screen luminance ratio of 200).

The document at terminal 3 is totally unreadable with a contrast reduction of 63% (reflection from the luminaire L_2) and an illumination level of only 60 lux (the luminaire placed between L_1 and L_2 was out of order). The contrast on the screen varies from a luminance ratio of 12 to 33. Owing to reflections on the upper part of the screen from luminaires L_1 and L_4, the operator has probably increased the brightness of the text until it became readable on the critical part of the screen. A similar situation can be seen on the screen of terminal 9 (shown in Fig. 33), where luminaires L_{12} and L_{13} are reflected in the middle part of the screen.

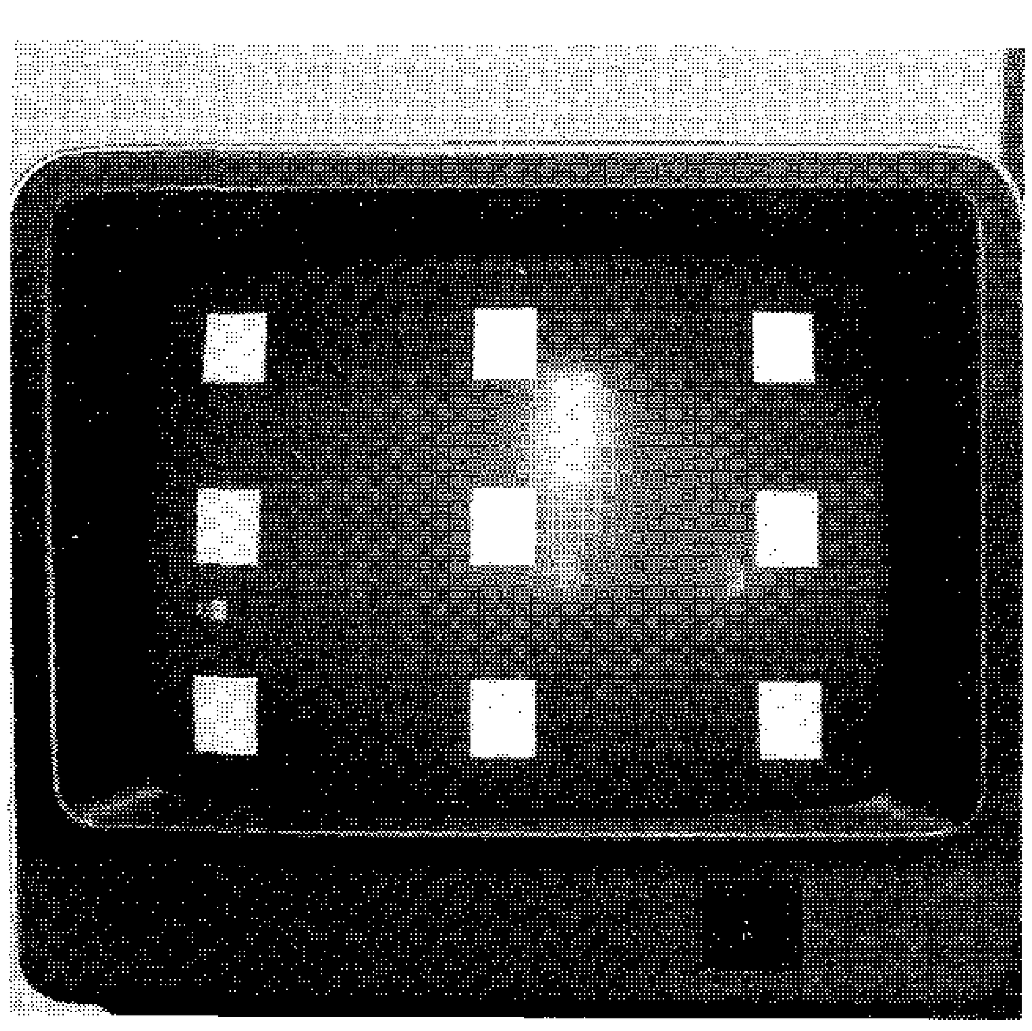


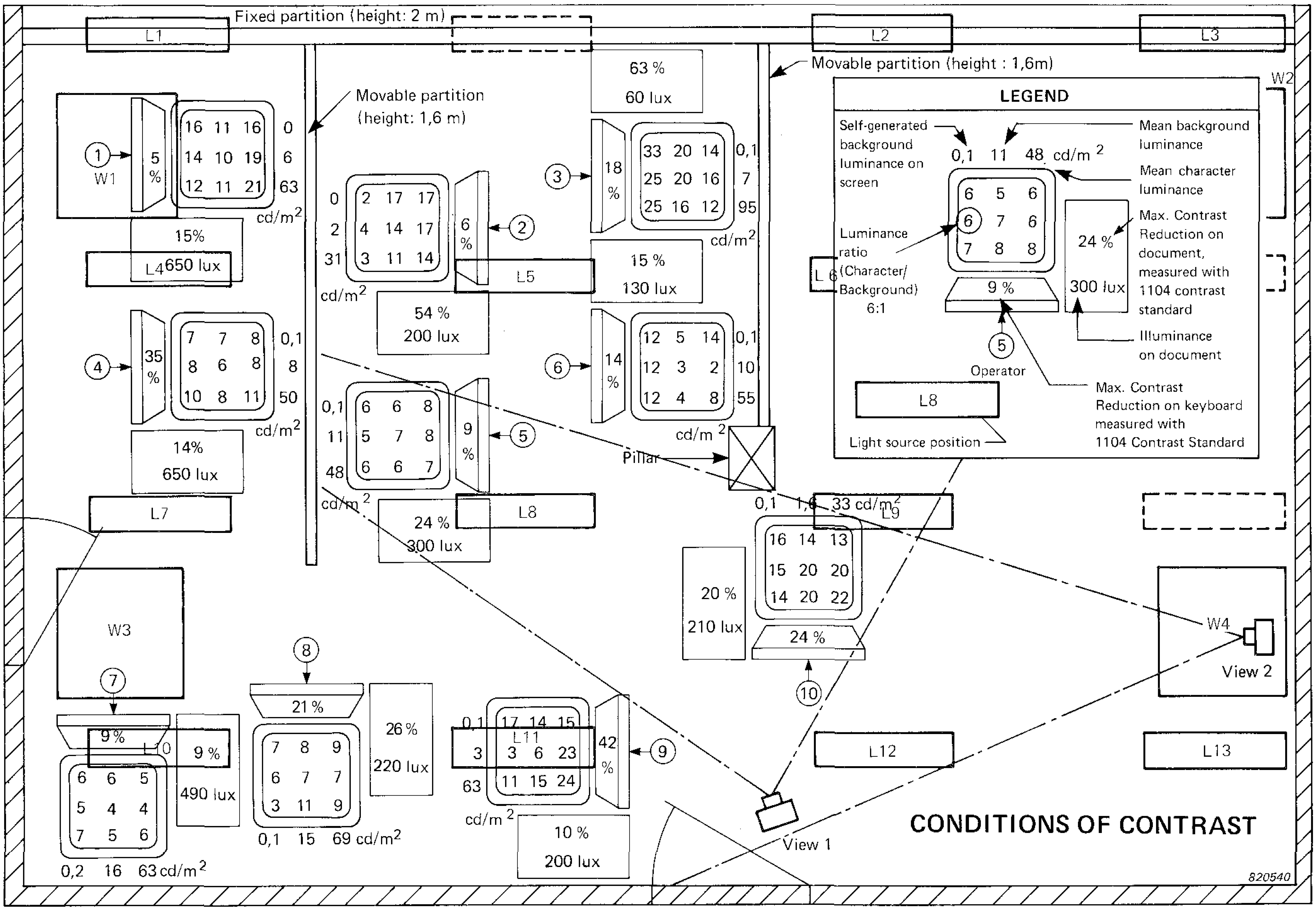
Fig.33. Veiling reflections on terminal 9, example 1

When comparing the contrast of the keyboard of terminals 1 and 4, one can see that a slight difference in the position of the terminal compared to the positions of the luminaires can greatly change the conditions of the visual task. The contrast reduction of 35% on the keyboard of terminal 4 is due to veiling reflections from luminaire L_4 on the keys.

A representation of the results of measurements as shown in Fig. 34 makes obvious most of the visual and lighting problems of each working position, and with a minimum of experience an initial diagnosis can be made. With the present example, which is rather complicated owing to the number of terminals, it is not easy to give a recipe. However, by replacing the grids of all the luminaires by grids of lower luminance, for instance, it would be possible to remove veiling reflections from most of the screens and avoid glare effects caused by luminaires in the visual field of the operator. Then the terminals should be positioned in the room in such a way that contrast reduction on the documents and on the keyboards does not exceed 15 % and 10 % respectively.

5.2. Example 2: Two offices with six CRT display terminals

The work:
The operators are technical writers working both with ordinary office tasks and tasks on a text processing system. On the text processing system, the tasks most usually performed are writing, translation and proof-reading. Writing is probably the task which requires most concentration and one can imagine that it might be difficult to concentrate upon a text displayed on a screen with bad readability. Some of the writers admitted that for this reason they had to rewrite difficult parts of a text with pencil and paper for instance, and they could not always use the editing possibilities of the text processing system. It is difficult



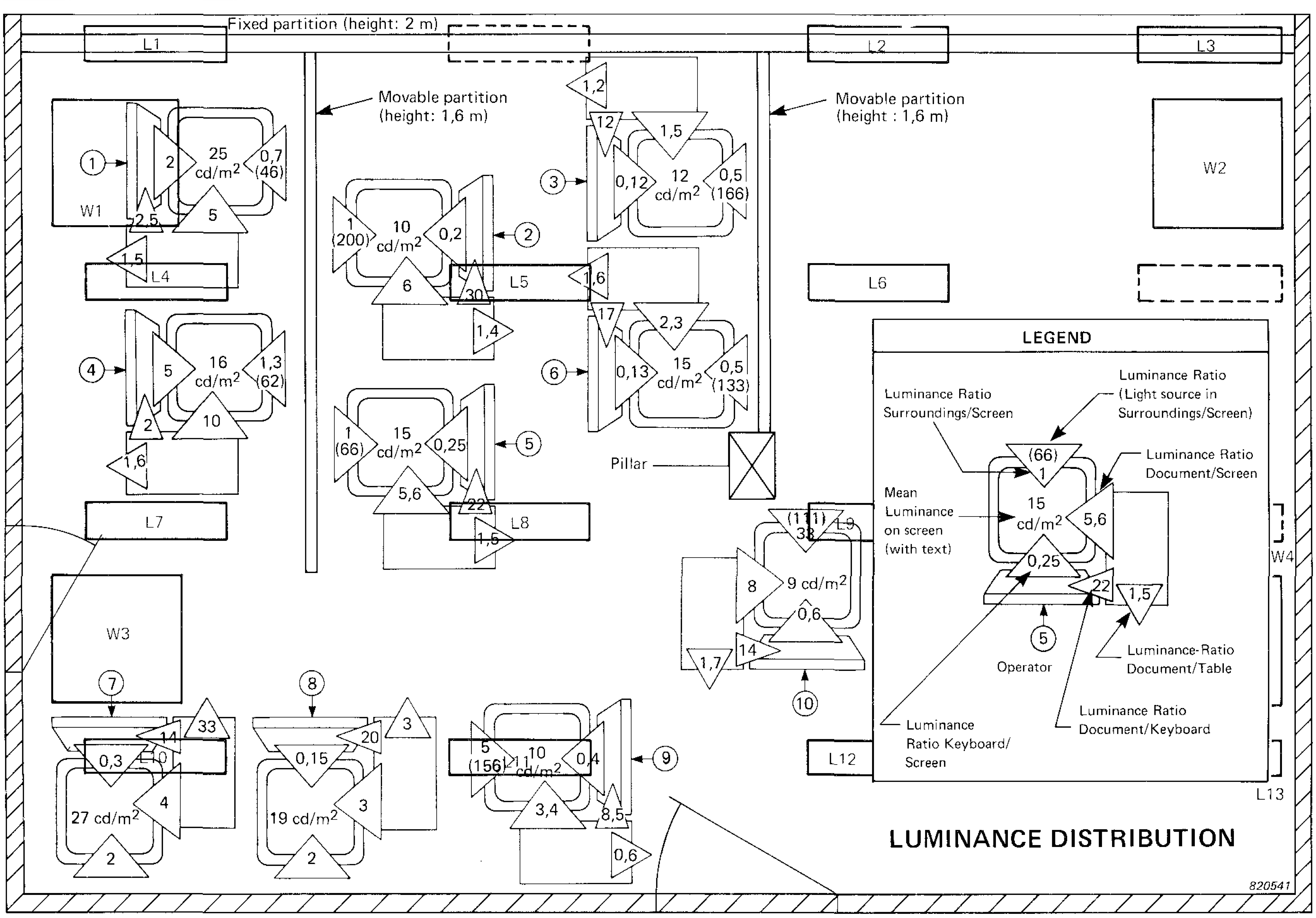


Fig.34. Contrast and luminance conditions for the 10 CRT terminals of the programming room

to estimate how much time on average the operators spend each day at the terminal. However, sometimes, an operator has to work at his screen throughout a working day of 8 hours.

The room:
The room is, in reality, two completely separated offices, each with two windows facing south (Fig. 35 & 36).

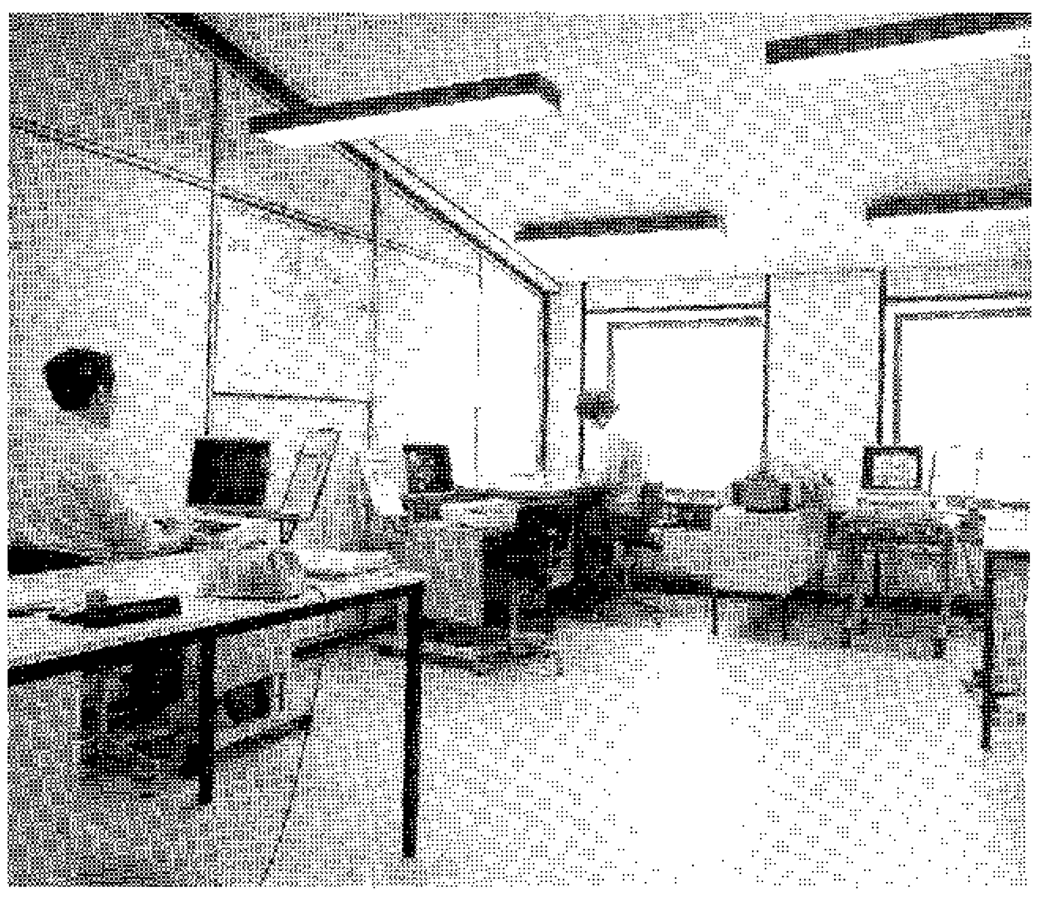


Fig.35. Example 2, view 1

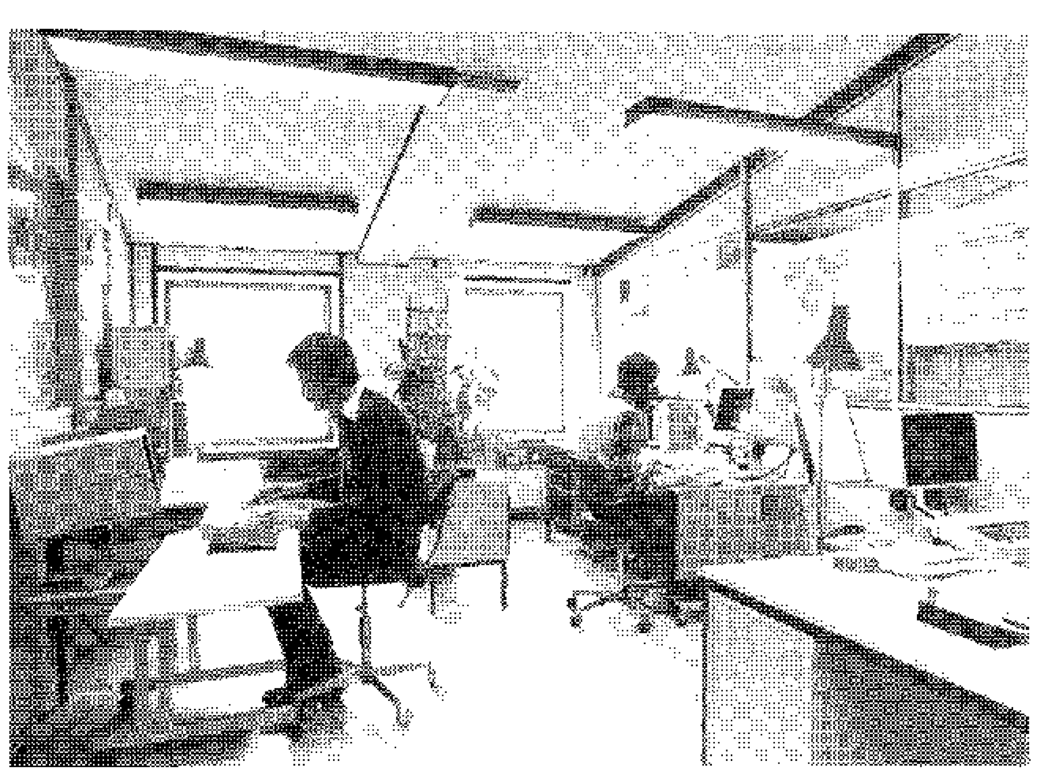


Fig.36. Example 2, view 2

The lighting:
With such an orientation of the windows, the contribution of the daylight to the general lighting is relatively important and direct sunlight in both offices has a substantial influence a great part of the day on the luminance distribution in the rooms. However, the artificial lighting, composed of 3 rows of luminaires, cannot be avoided if a minimal reasonable level of illumination has to be provided at the work places far from the windows. Only three of the six operators use auxiliary localized lighting regularly.

The terminals:
The text is displayed in light green on a darker green background, which is electronically generated as a line raster. There are separate controls for the setting of the contrast and the brightness on the screen. The six terminals of this example are only a part of a group of thirteen terminals, distributed in several offices, which can be used by seventeen writers. Consequently, the terminals have to be moved from one office to another relatively frequently, and when an operator gets a terminal this is not necessarily the same as before, so he may have to readjust the contrast, a procedure which can take up to several minutes.

One interesting feature on this type of terminal is the split-screen facility allowing access to existing jobs from the archives of the text processing system and displaying a file on one half of the screen while editing the same file or translating it to another language on the other half. This, of course, facilitates the problem of "balance in luminance conditions" between the screen and the document for a translator, for instance, since the document is then "moved" on the screen itself. The terminals are installed on special ergonomically designed tables on which the heights of the screen and of the keyboard can be independently adjusted.

Results of measurements:
The conditions of contrast and luminance distribution are represented in Fig. 38. The conditions of contrast now include the contrast reduction at the desk at each work place. The red curves in some of the measured areas on the desks, which are the contours of constant contrast reduction, reveal the presence of veiling reflections on the desks. The measurement areas in Fig. 38 have been exagerated compared to the dimensions of the desks, so that the measured values of contrast reduction are legible. The actual dimensions of the measurement area on each desk are shown in Fig. 15.

If we judge from the results of measurements represented in Fig. 38, none of the operators in either office is working in optimal visual conditions. Only two operators (A and C) have no reflections on the working area on their desk. The terminal and

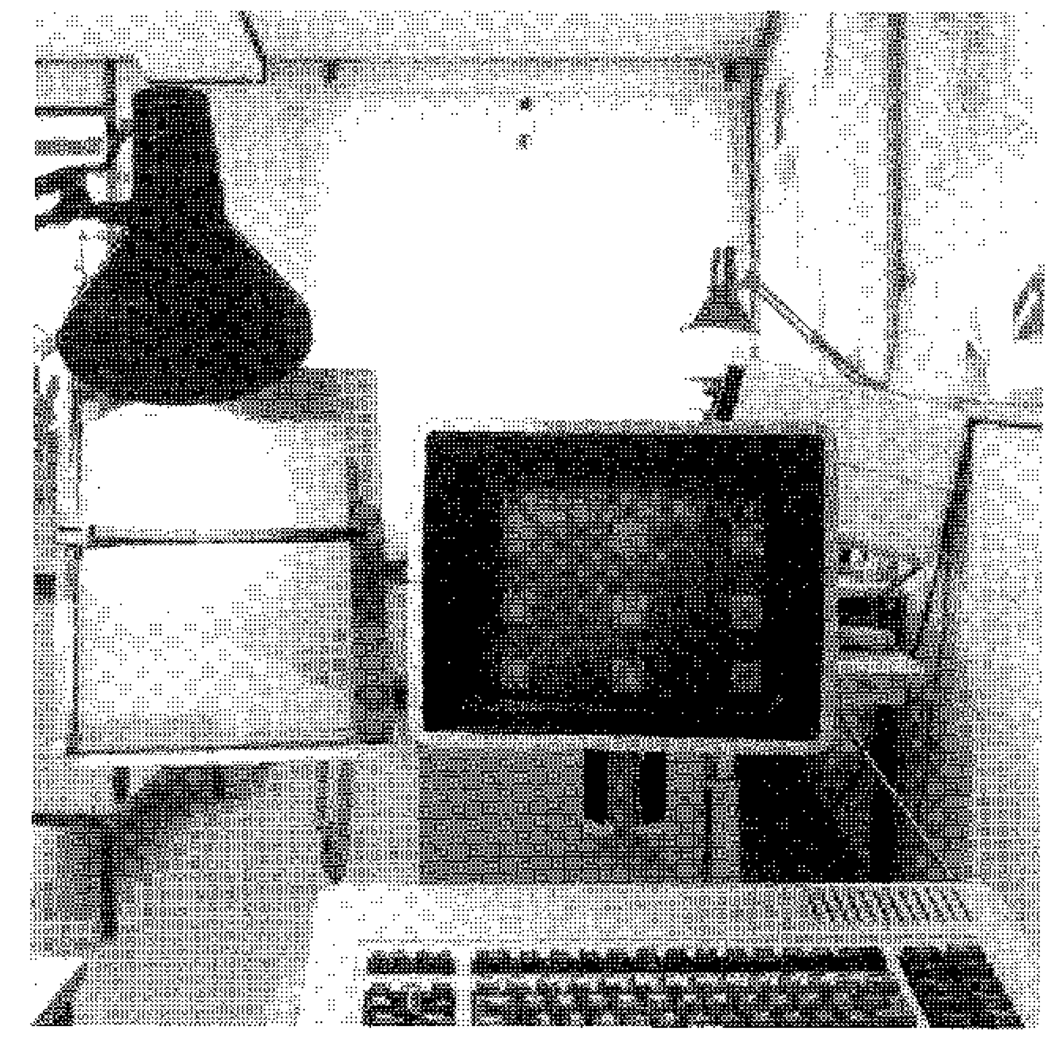


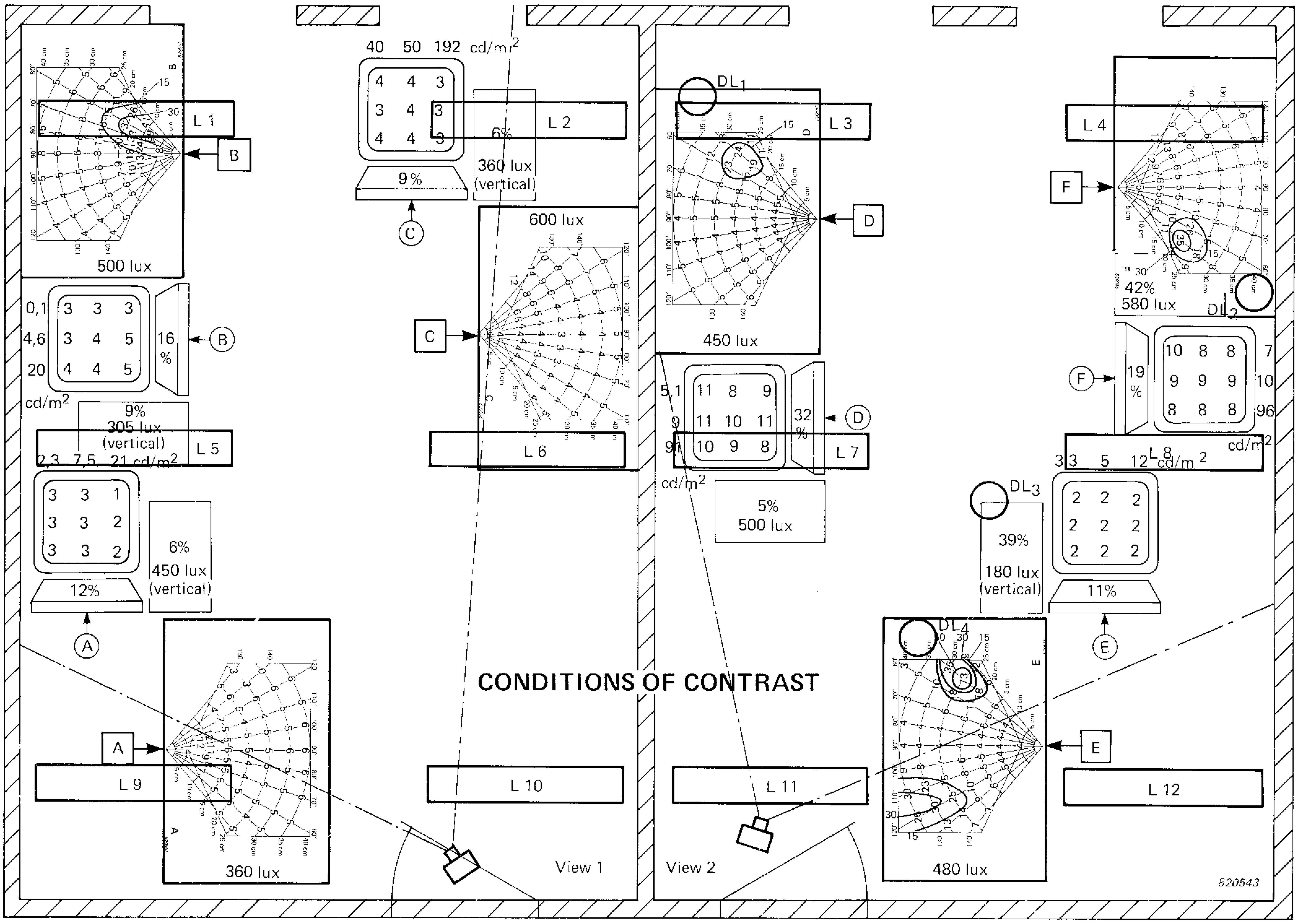
Fig.37. Visual conditions on terminal E, example 2

desk of operator F are correctly placed in the general lighting system, but the auxiliary desk lamp causes reflections on the keyboard, the document and on the working area on the desk.

It seems that operator E has managed to collect the maximum possible number of unsatisfactory visual conditions both at his terminal and at his desk. The screen is oriented against the windows, and the contrast on the screen is set far too low (2:1). The desk lamp, which is moved between the document-holder and the desk (positions DL_3 and DL_4) when the operator works at his desk, causes reflections on the document (39% contrast reduction — see Fig. 37) and on the writing area on the desk. The bulb used in the desk lamp gives a very sharp "blue" light, causing annoying veiling reflections on most printed documents (contrast reduction with the Standard Contrast Type 1104 up to 73%). See Fig. 29 & 30. The other reflection on the desk is due to the luminaire L_{11}. When comparing the contrast conditions on the desk of operator E with that of operator A, it becomes obvious that operator E needs to move his desk only 20 to 30 cm back to avoid any reflection from the luminaires.

5.3. Example 3: Office with 2 CRT display terminals

The work:
The operators are clerical workers occupied most of the time with ordinary office tasks at their desk. They use from time to time one of the two terminals placed at a central posi-



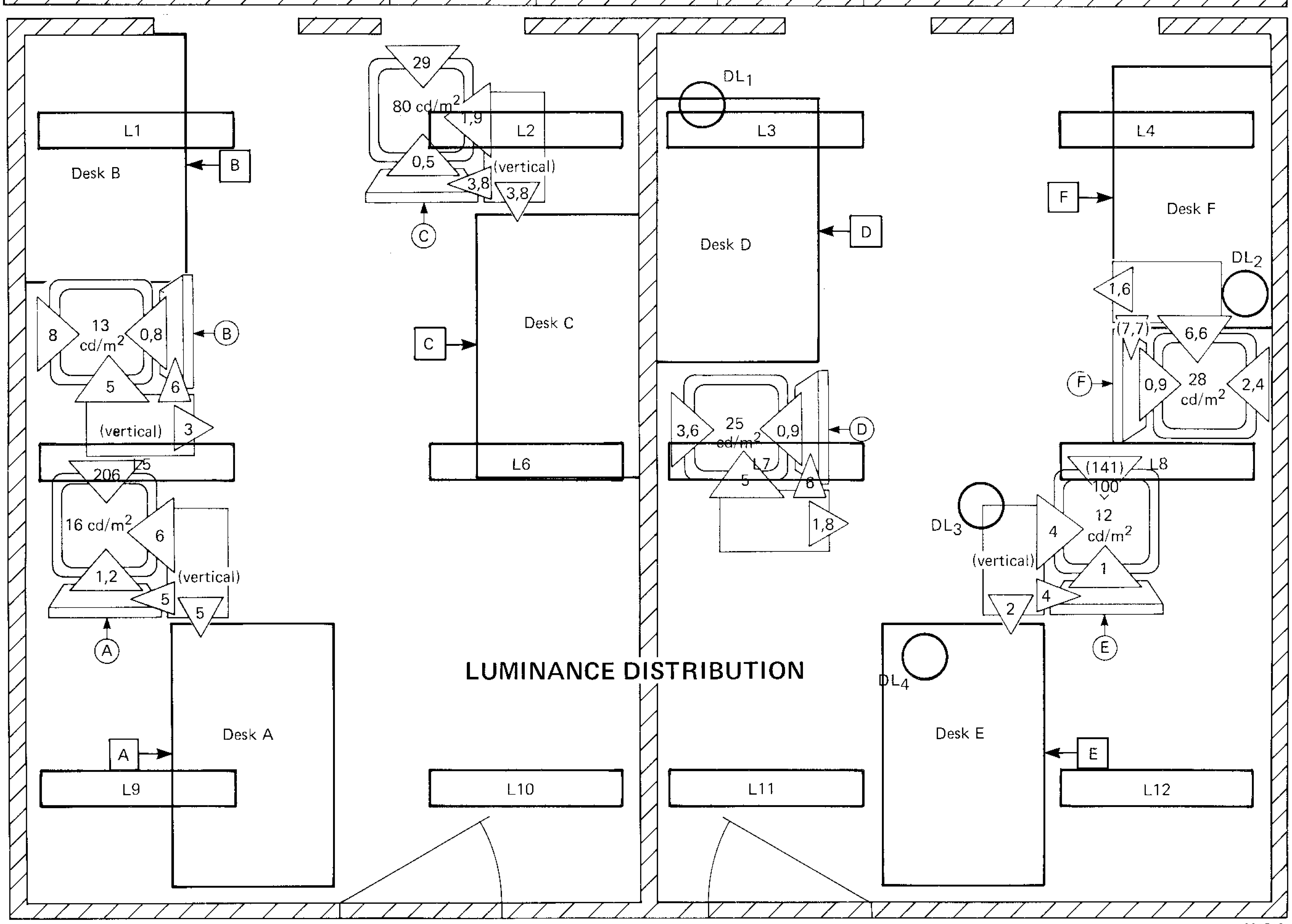


Fig.38. Contrast and luminance conditions for the 6 CRT terminals of the text processing system

tion in the office to read or input data in a central storage computer. The time spent working at a terminal can vary from several minutes to half-an-hour, on average in a day.

The room:
The office is placed in the corner of a building, so there are windows on two of the sides of the office. The desks are placed along the windows in small compartments partly separated by movable walls of 1,6 m height.

The lighting:
Most of the time the daylight provides sufficient light on those desks placed close to the windows, but in the dark period of the year, the general lighting is provided only by naked fluorescent tubes in the ceiling. This kind of light source is unsuitable for the lighting in offices, since the luminance of a fluorescent tube can reach a value of 5 to 6 kcd/m^2 and cause discomfort or even disability glare when they are in the visual field of the observer. In practice, in that office, the fluorescent tubes were switched off by the operators most of the time in winter and the lighting of the desks was provided by personal desk lamps only.

The terminals:
The text is displayed in green on a dark grey background. Only the brightness of the letters can be controlled. The luminance of the background on the screen depends on the illumination level on it. The reflection from this type of terminal is mainly specular, so that the surface of the screen acts almost as a mirror for any light source behind the operator (See Fig. 39 showing veiling reflections from a window and 3 fluorescent tubes on the screen of operator 2 from Fig. 42).

Results of measurements:
The fluorescent tubes T_1 and T_2 (Fig. 42) were switched off because they were directly annoying for operator 2. D is a special desk lamp consisting of a bulb of 40 W and a circular fluorescent tube of 22 W. The lamp D was installed to try to improve the lighting conditions of terminal 1 (Fig. 40). Two other types of individual lamp have been tested instead of lamp D; the measurements are described in Appendix II. Even

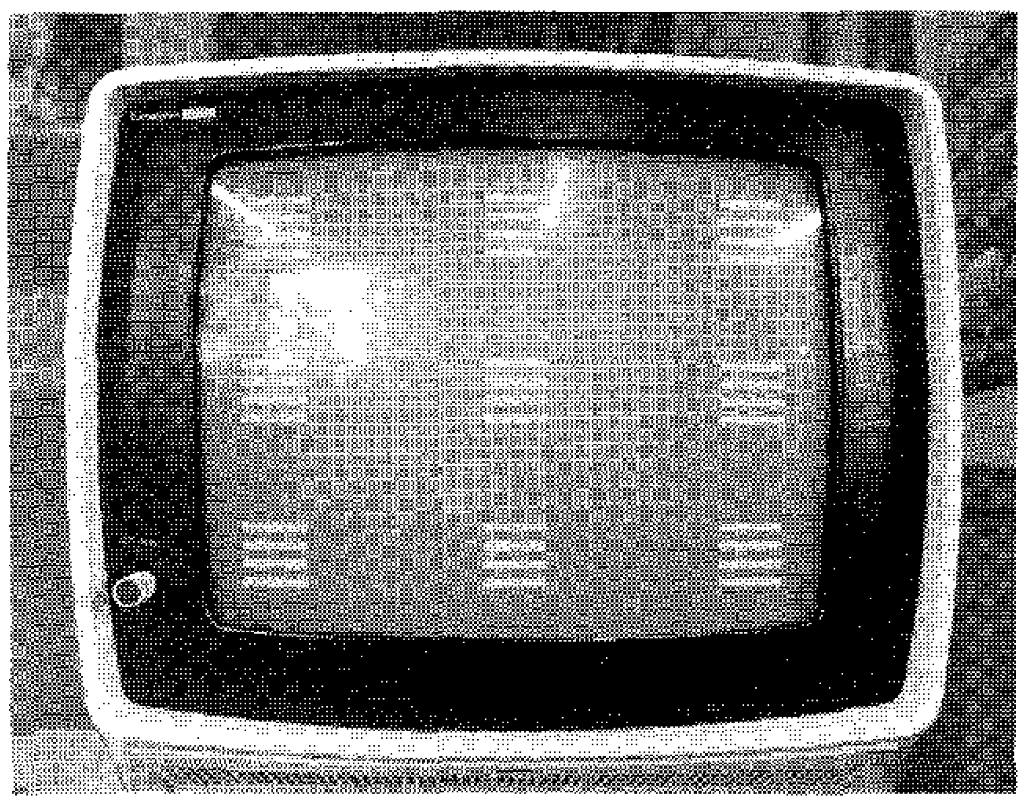


Fig.39. Veiling reflections on terminal 2, example 3

Fig.40. Terminals 1 and 2, example 3

with a quick glance at Fig. 42, it is obvious that both terminals are inadequately installed in the room. The requirement of balance in luminance conditions for terminal 1 is not fulfilled, since there is a light source of too high a luminance (compared to the luminance of the screen) in the visual field of the operator, and the luminance ratios Document/Screen and Document/Keyboard are far too large. While the contrast on the screen of terminal 1 is close to being acceptable (the contrast was just set a bit too high), the contrast on the screen of terminal 2 disappears completely in the upper part of the screen (See the photo, Fig. 39).

How to improve the lighting conditions in this case?
The two solutions proposed are based on the conclusions of investigations about work places with CRT terminal and illustrated in Fig. 41, in which it can be seen that there are two regions around a screen terminal where the installation of sources of general lighting should be avoided.

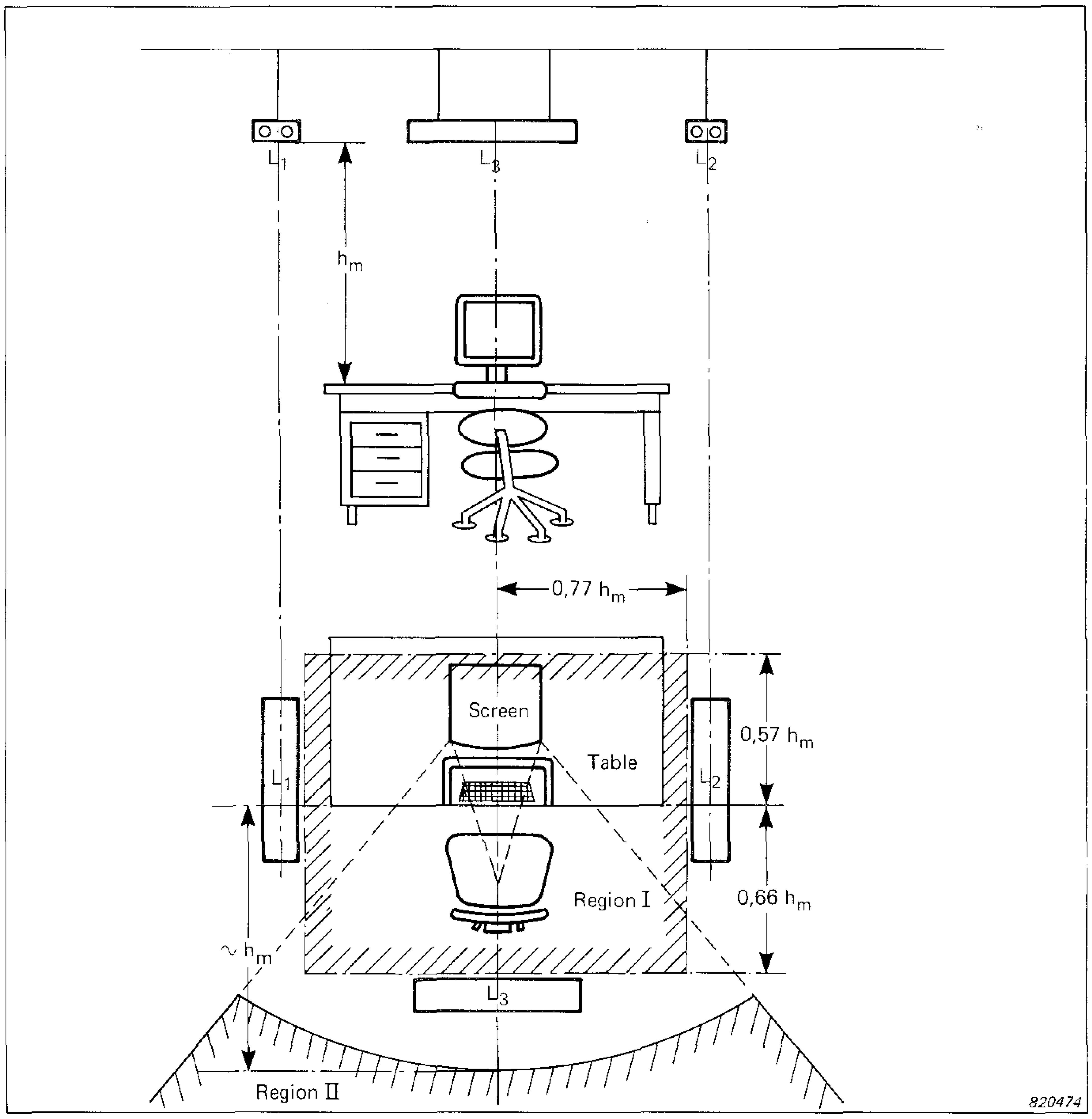
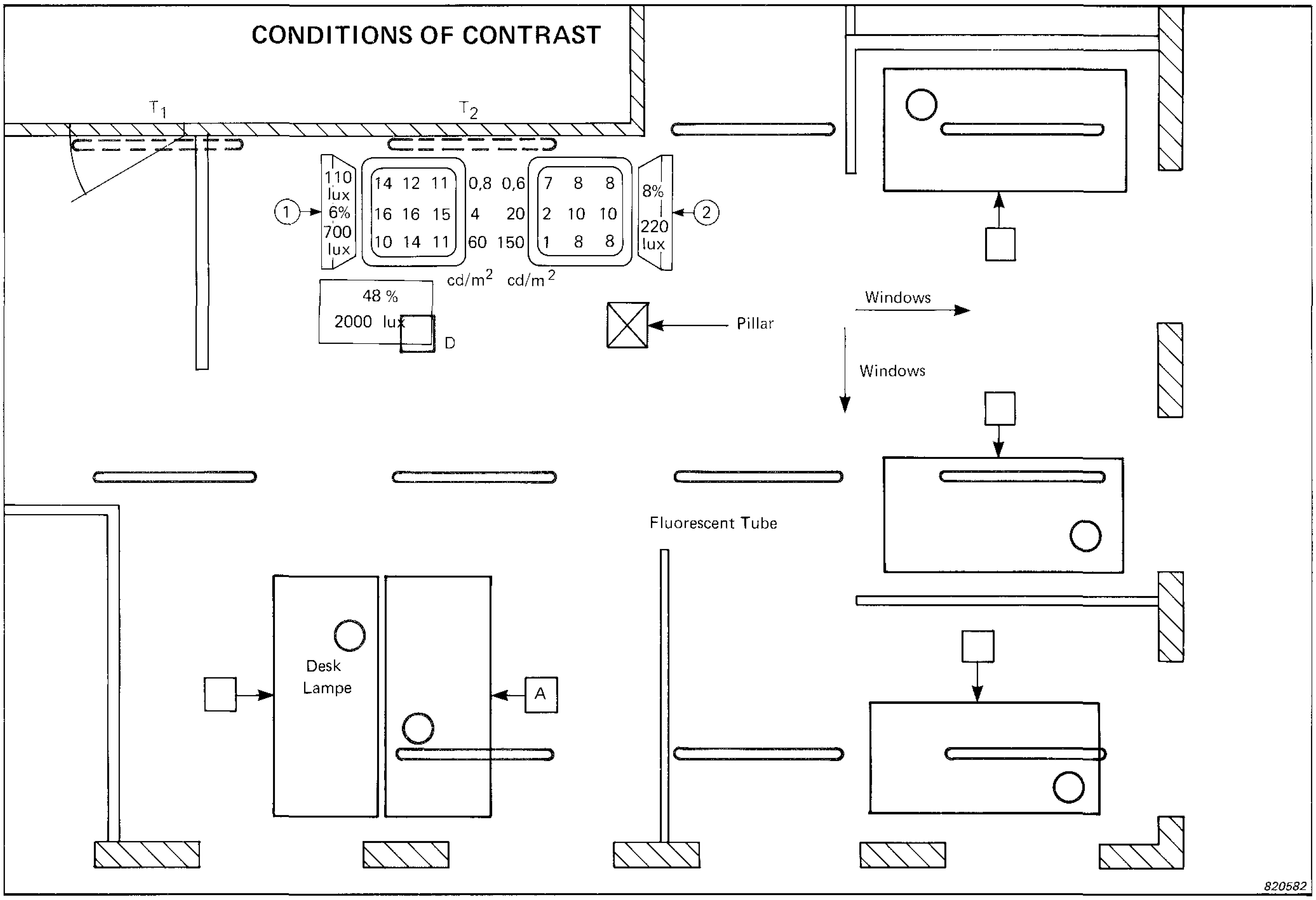


Fig.41. Possible positions of luminaires above a terminal



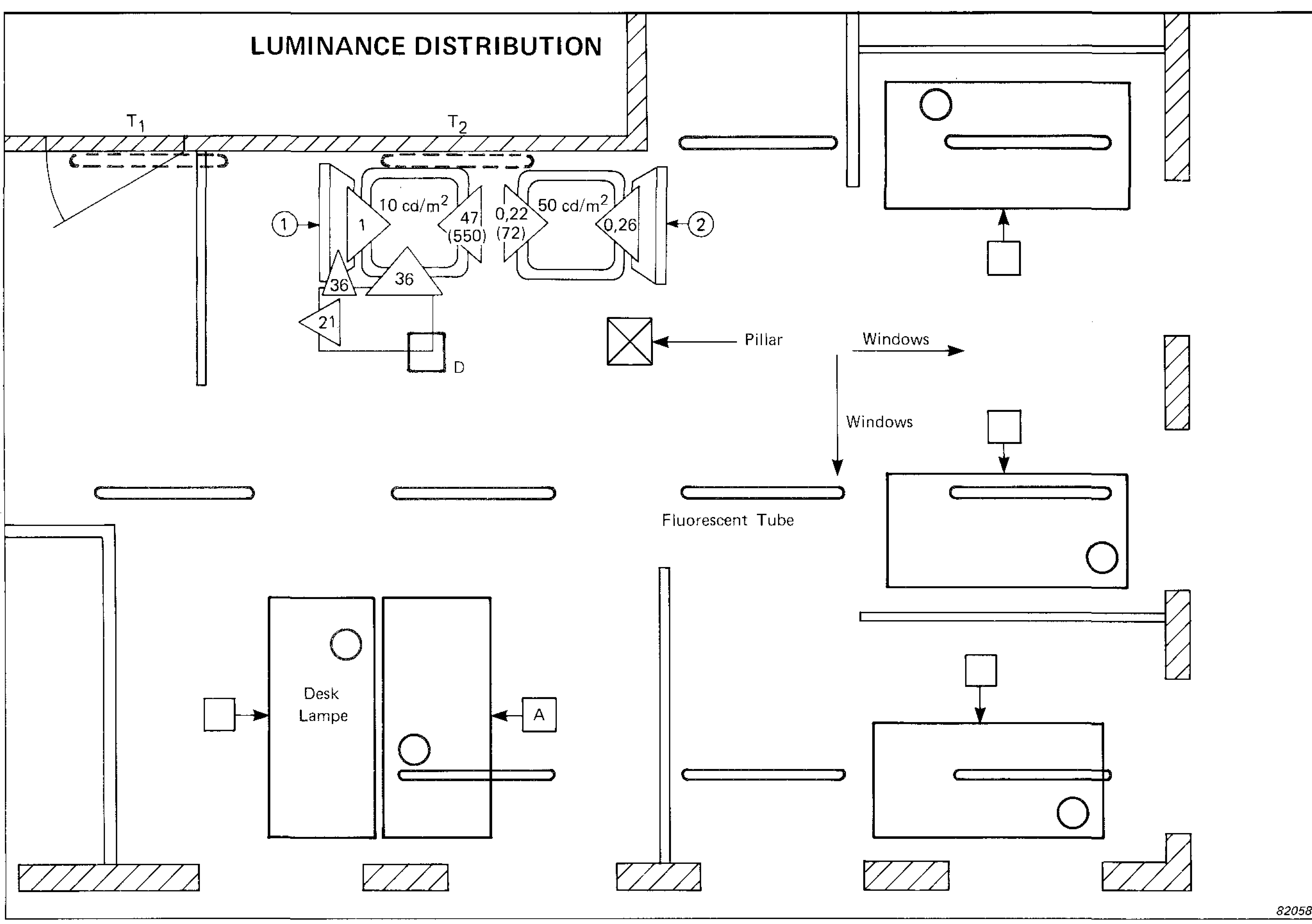


Fig.42. Contrast and luminance conditions for the two terminals in example 3

Region I, delineated by a rectangle above the terminal whose dimensions depend on the distance, h_m, between the terminal table and the source of lighting, is the zone from which luminaires may cause veiling reflections on the keyboard. Region II, behind the operator, is the corresponding offending zone for the veiling reflections on the screen. When these two prohibited regions are represented on the same drawing, it can be observed that there are still two possibilities for placing symmetrical lighting above a terminal which ensure a good illumination of the work place without veiling reflections.

The first possibility consists of a pair of luminaires placed on each side of the rectangle delineating region I, while the second possibility is to place only one luminaire in the zone between the two regions, just above the operator. The solutions proposed below are based on these two possibilities.

Solution 1:
Terminals 1 and 2 are turned through 90° (Fig. 43), and a movable screen of height 1,6 m is placed behind the operators to avoid reflections on the screen from windows. Two lumi-

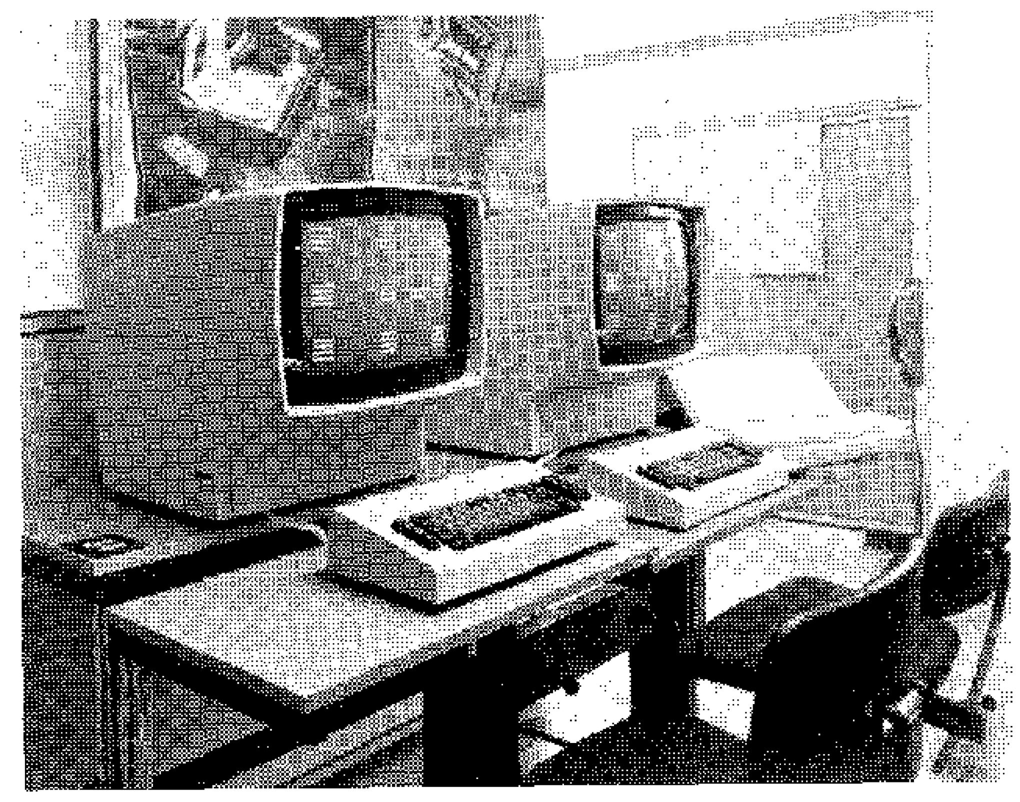


Fig.43. Positions of the terminals in the two proposed solutions

naires L_1 and L_2 are placed on each side of the pair of terminals at a distance of 1,15 m from the nearest operator. The measurements reported in Fig. 45 show that the illumination is uniform on the two work places and the contrast conditions on the screen and the keyboards are good (the contrast on the screen is set too high, but there is no trace of veiling reflection on it). There is still a contrast reduction of 27% on the document of terminal 1, but this value was measured at the extreme lower limit of the document. To remove this reflection completely, the luminaire L_2 needs to be moved only a few centimetres back towards the pillar. Two of the fluorescent tubes from the previous lighting arrangement were switched off to avoid reflections on the screens and discomfort glare effect for operator 1.

Solution 2
Only one luminaire, L_3, is used. It is placed just behind the operators above the movable screen. The measurements reported in Fig. 45 illustrate that both contrast and luminance problems have been solved. The slight variation in contrast on both screens from the upper to the lower part of the screens can also be seen on the photograph of the screen 2 in Fig. 44. This variation is due to the fact that the illumination from the luminaire is not totaly uniform on the screen.

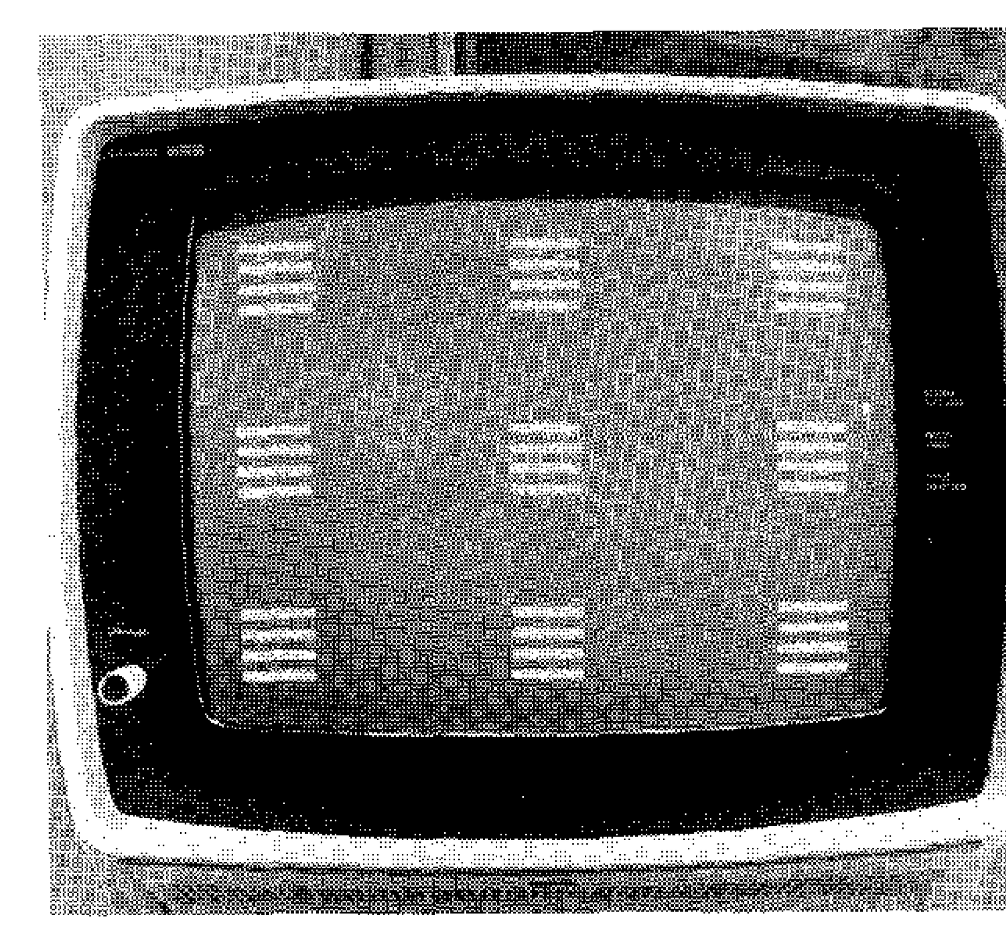


Fig.44. Screen of operator 2, solution 2

6. Conclusion

A common point between these three examples was that only in very few cases were the conditions of lighting of the visual tasks optimum, even though in reality only a few changes were needed to improve the visual conditions in most cases (setting of the contrast on the screen to the optimum range, moving the screens or the desks to remove reflections or glare effects from the luminaires or the windows, etc.). Such a situation seems to be primarily due to the lack of information given to the users of the terminals or the person who has the charge of setting up the terminals in the room where they have to be used. Fortunately, one can observe that progress in the right direction has been made by most of the designers of the screen terminals introduced on the market today. The ergonomic aspects of the equipment on offer nowadays become more and more important compared to the technical aspects. For example, it is now usual to find separate controls for brightness and contrast of the characters on terminals. A similar tendency can be seen with the designers of lighting equipments for whom such aspects as contrast reduction, contrast rendering, [15], [16], or glare effects become almost as important as the luminous efficacy, for instance.

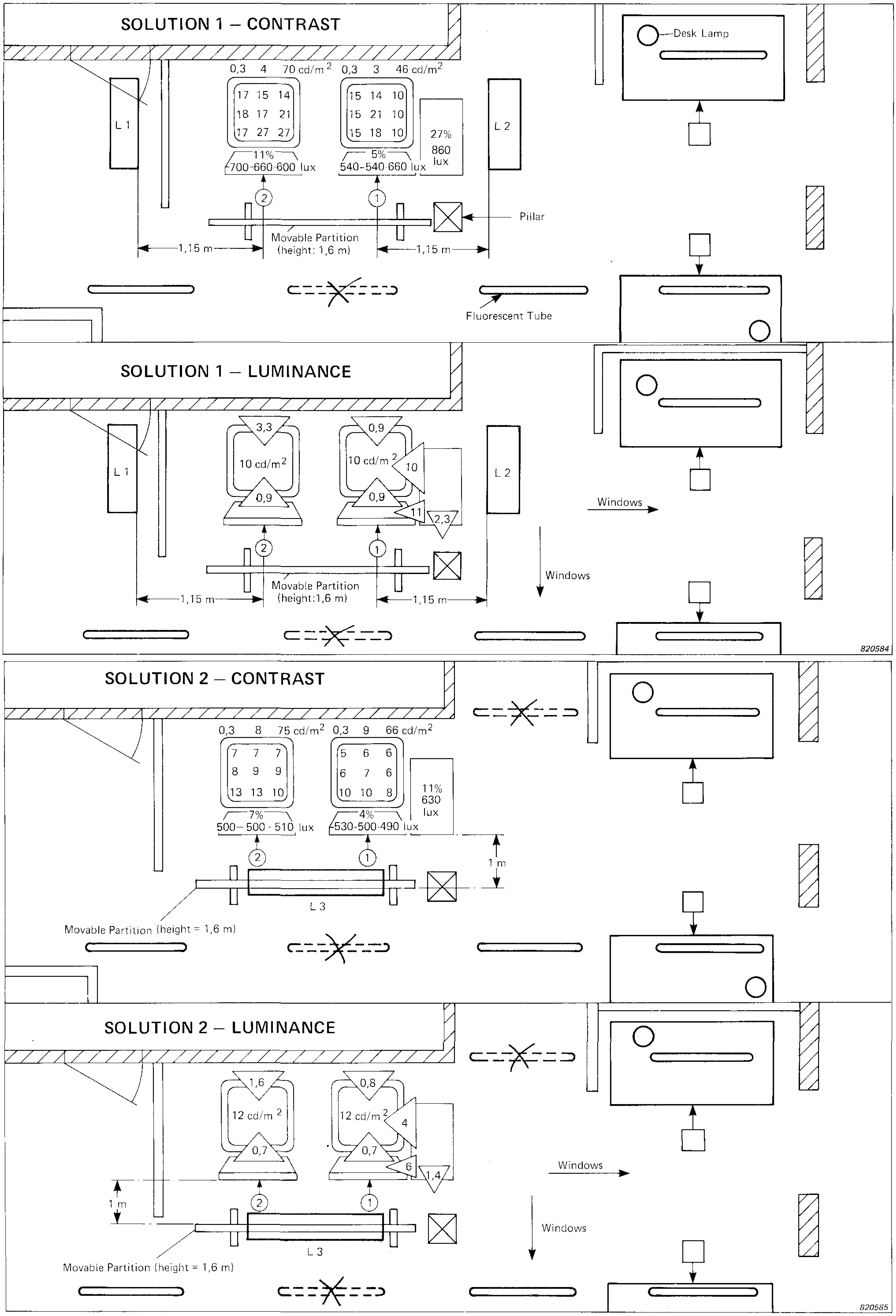


Fig.45. Two solutions to improve contrast and luminance conditions an example 3

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Appendix I

I.1. Derivation of the basic relation of the Method 2

The calculation of the luminance of the letters on the screen is based on the principle that the luminous intensity of a surface composed of two areas of different luminances is the sum of the intensity of the two areas:

$$I_{total} = I_c + I_b \qquad (I — 1)$$

where:

I_c is the luminous intensity of the character on the area covered by the measuring cell

I_b is the luminous intensity of the background on the screen.

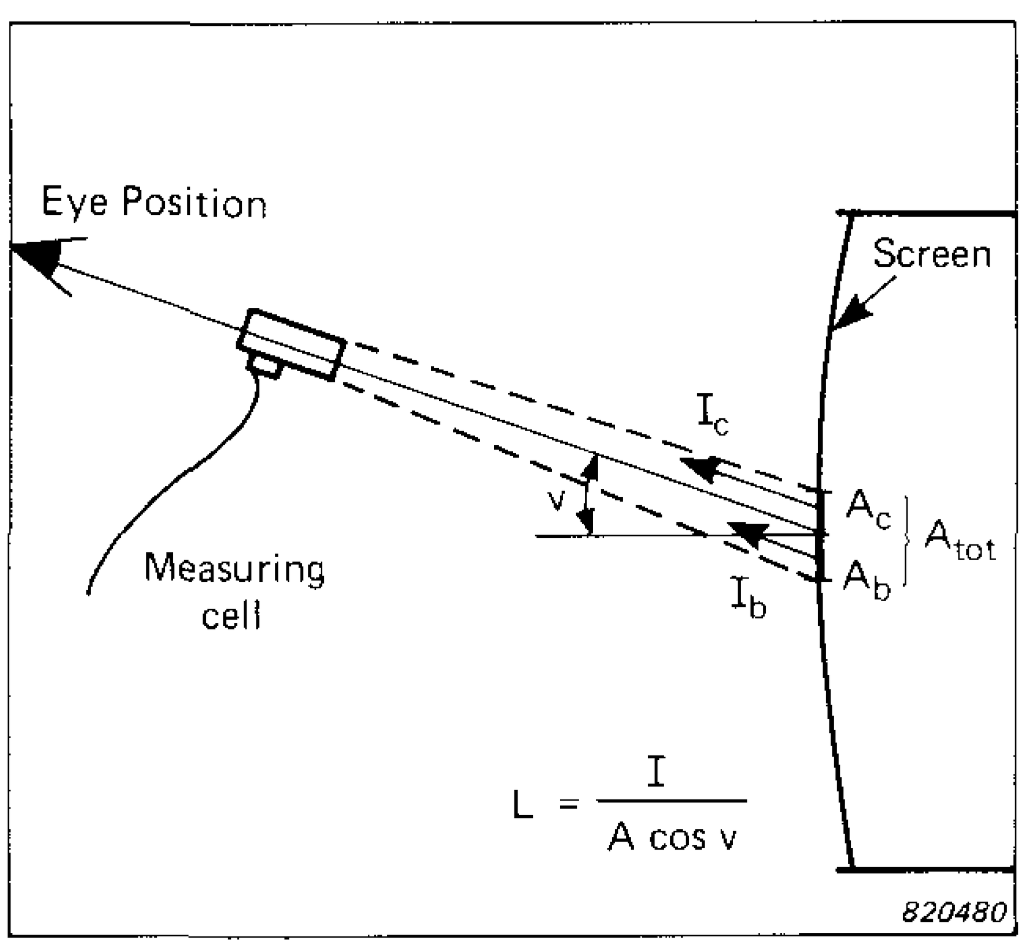


Fig.46. Principle of measurement

The luminance of a surface seen from a given point of observation is by definition the luminous intensity of the surface in the direction of observation divided by the projected area of the surface in the direction of observation (Fig. 46). Hence, the equation (I — 1) becomes:

$$L_m A_{tot} \cos v = L_c A_c \cos v + L_b A_b \cos v \qquad (I — 2)$$

where:

L_m = the mean luminance (character + background) measured on the total area, A_{tot}

A_{tot} = the area covered by the cell

L_c = the luminance of the characters (capital letters)

A_c = the area on A_{tot} covered by the dots of the characters

L_b = the background luminance on the sreen

A_b = the area of A_{tot} not covered by the characters

v = the angle made by the normal to A_{tot} to the direction of observation

The luminance of the characters, L_c, is then obtained from (I — 2) as:

$$L_c = L_m \frac{A_{tot}}{A_c} - L_b \frac{A_b}{A_c} \qquad (I — 3)$$

with

$$A_{tot} = A_c + A_b$$

Then by calling $d = A_c/A_{tot}$ the degree of coverage of the letters on the measuring area, the luminance of the characters becomes finally:

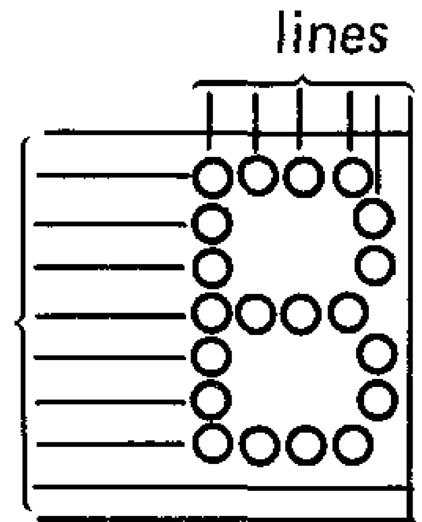
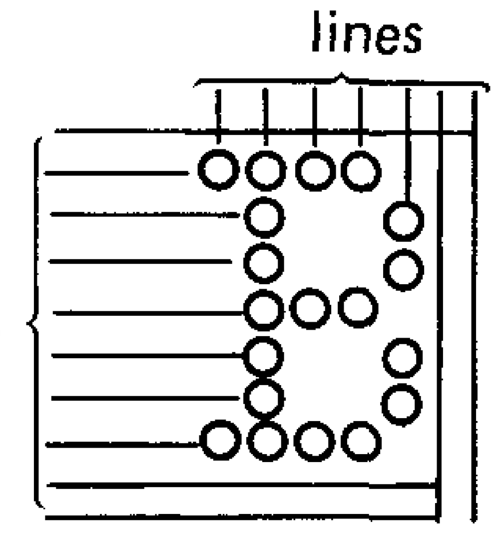
$$L_c = \frac{L_m}{d} + L_b \left(1 - \frac{1}{d}\right) \qquad (5)$$

In Table 1 capital letters based on a matrix of luminous dots are represented from two different types of terminal, with the corresponding values of d.

I.2. Comparison of measurements of the two different methods

The evaluation of the degree of coverage, d, which is made by dividing the number of dots of the letter in question by the hypothetical number of dots constituting the background area of the letter, in reality does not take account of the overlapping of the luminous dots, nor of the fact that the overlapping is generally not the same horizontally and vertically. Another problem is the influence of the possible change of d for different values of the luminance of the letter. One can assume that, when the brightness of the text is set to a relatively high value, the dots of the letters will have a tendency to expand.

To investigate these aspects, measurements have been performed on different capital letters from both types of terminal screen, at different levels of luminance. The results of calculations (Method 2) are compared with measurements performed directly on light measuring

	System 1			System 2		
Constitution of the letter	10 horiz. lines; 6 vertical lines 			10 horiz. lines; 7 vertical lines 		
Letter						
Basic matrix	60	60	60	70	70	70
No. of dots	20	15	14	19	16	16
d	0,33	0,25	0,23	0,27	0,23	0,23

820031

Table 1. Examples of determination of the degree of coverage, d

areas generated on the screen (Method 1) for both types of screen (See Table 2 and Fig. 47).

The agreement between the results of both methods is fairly good, even with a character luminance level as high as 190 cd/m². But, at the same time, it can be seen from the results shown on Table 2 that it is not realistic to expect an accuracy better than 10% with method 2, even with a character consisting of many dots (e.g. B or Ø). This is the reason why the character contrast on the examples in section 5 is given to only one significant figure. However, compared to a method using a smaller acceptance angle, Method 2 has the advantage of averaging the luminance of the character's contours. This is exactly how the observer's eye behaves, because the characters as seen from a certain distance are continuous and not granular.

Letter	A	B	O	Q	Ø
No. of dots	15	20	14	18	21
Degree of coverage, d	0,25	0,33	0,23	0,3	0,35
Measured mean luminance letter + background (deviation on the area in the middle of the screen) cd/m²	13,5 (13,0 - 14,0)	16 (15,7 - 16,3)	13,35 (13,0 - 13,7)	16 (15,5 - 16,5)	17,4 (16,9 - 17,9)
Measured background luminance (Deviation)	4,65 cd/m² (4,4 - 4,9)				
Calculated luminance of the letter (Method 2) cd/m²	40	38,8	42,5	42,5	41
Measured luminance of the letter (Method 1) cd/m²	42				

820044

Table 2. Comparison of the determination of character luminance with Method 1 and Method 2

Appendix II

II.1. Contrast reduction on a desk with different desk lamps

Since the general lighting of the office in example 3 (section 5.3) was unsuitable for providing proper lighting on the different desks without glare effects, especially in dark periods of the year, different individual lamps have been tested on one of the desks. The ambient illuminance was relatively poor (200 lux) since the lighting from the fluorescent tubes was switched off. The desk lamps were placed in order to give reasonably good lighting of the working area on the desk. The position of the four lamps is shown in Fig. 48. From the results of measurements performed with the Luminance Contrast Meter Type 1100, it can be seen that only lamp C (giving an asymmetrical light cone) and lamp D (giving a broad lighting) provide an acceptable illuminance level on the entire measuring area, with a contrast reduction exceeding 15% on only marginal part of the working area on the desk. The lamp A (consisting of a 60 W bulb and a simple conical reflector), which is widely used in many offices, corresponds to the worst case.

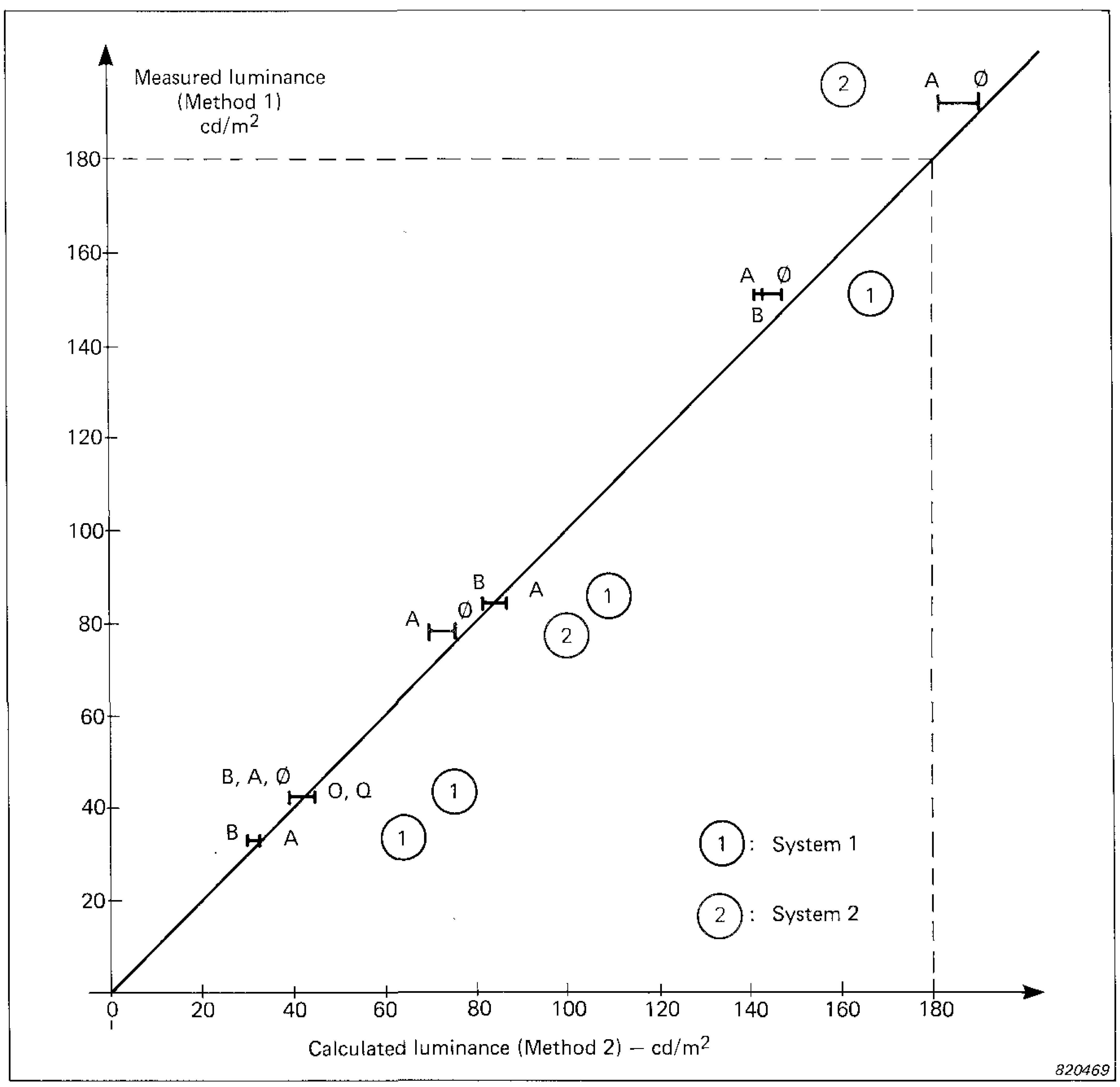


Fig.47. Comparison of results obtained with both methods for two different types of terminals and different capital letters

A complete solution of the lighting problems in example 3 could include one of the two solutions proposed (section 5.3) for the two CRT terminals and a replacement of the fluorescent tubes by, for instance, lumi-

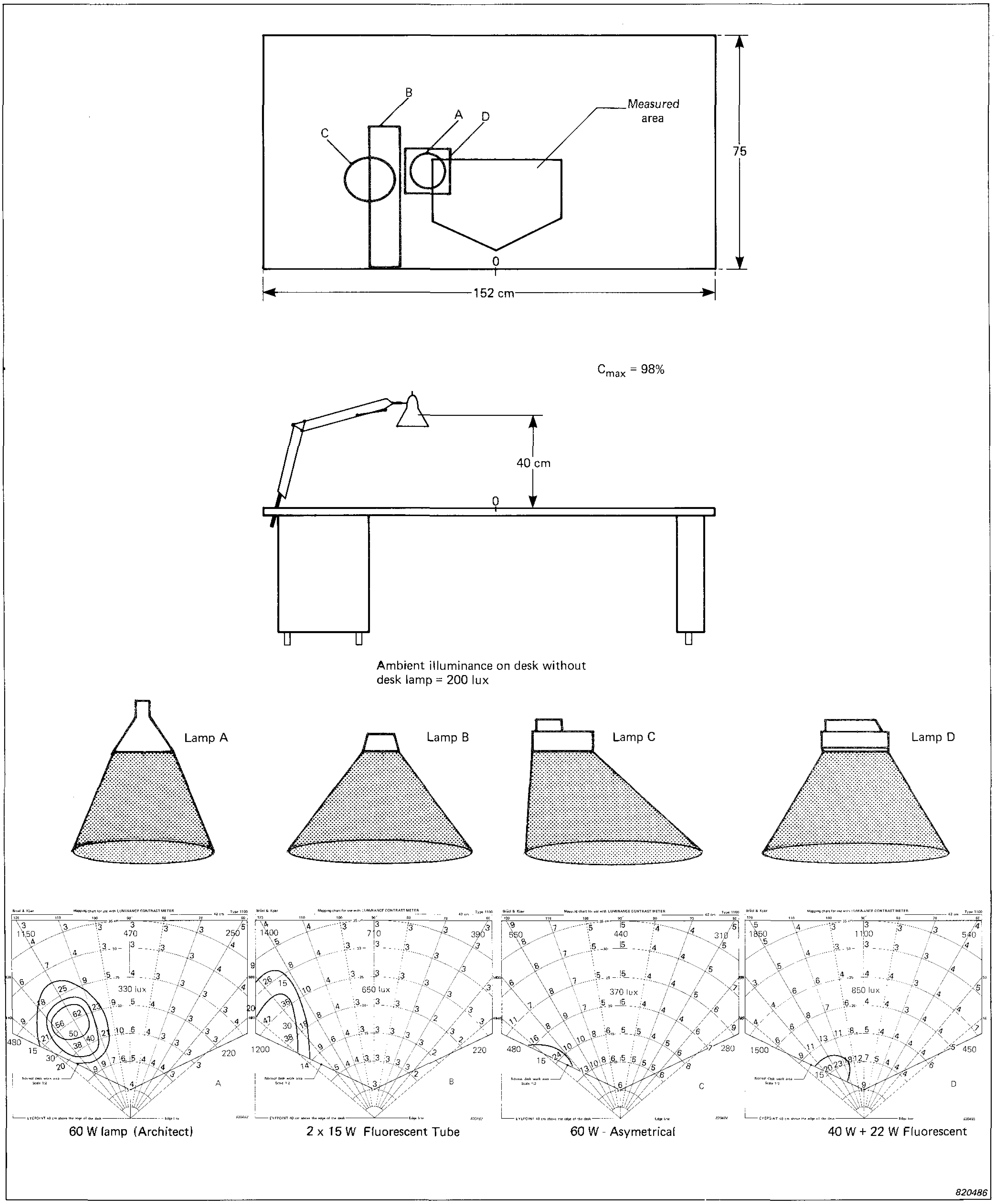


Fig.48. Contrast reduction on a desk with four different desk lamps

naires with low-luminance grids. Then the desks should be positioned so that contrast reduction exceeding 15% could be avoided on the working area on all the desks. Individual lighting could be used eventually where additional illuminance would be required, providing that the resulting contrast reduction still does not exceed 15% on the working area on the desk.

II.2. Contrast and Luminance conditions on terminal 1, example 3, for desk lamps B, C, and D

Additional measurements were made on terminal 1 (example 3) to try to improve the lighting using an individual lamp alone. The lamp was positioned in order to avoid reflections on the screen and on the keyboard. The results of measurements on Fig. 49 show that, in this particular case, with none of the three lamps could the luminance distribution be acceptable. The luminance ratio Document/Keyboard and Document/Screen could be reduced with lamp D by replacing the 40 W bulb by a 25 W bulb, but this would probably not be enough to reach a ratio lower than 3:1.

Fig. 50 & 51 illustrate in another situation that a balance in luminance distribution may be approched using individual lighting, providing that the lighting of the document beside the terminal can be adjusted freely. The document is lit with a spot light (very directional halogen lamp) of which the intensity can be controlled by a potentiometer, while the desk lamp is lamp C, mentioned above, giving an asymmetrical lighting on the working area on the desk without veiling reflections (Fig. 51). Even windows facing north may be sources of glare and reflections. On the other hand, Fig. 50 shows that the window is parallel to the terminal giving a fairly good illumination during the light periods of the day.

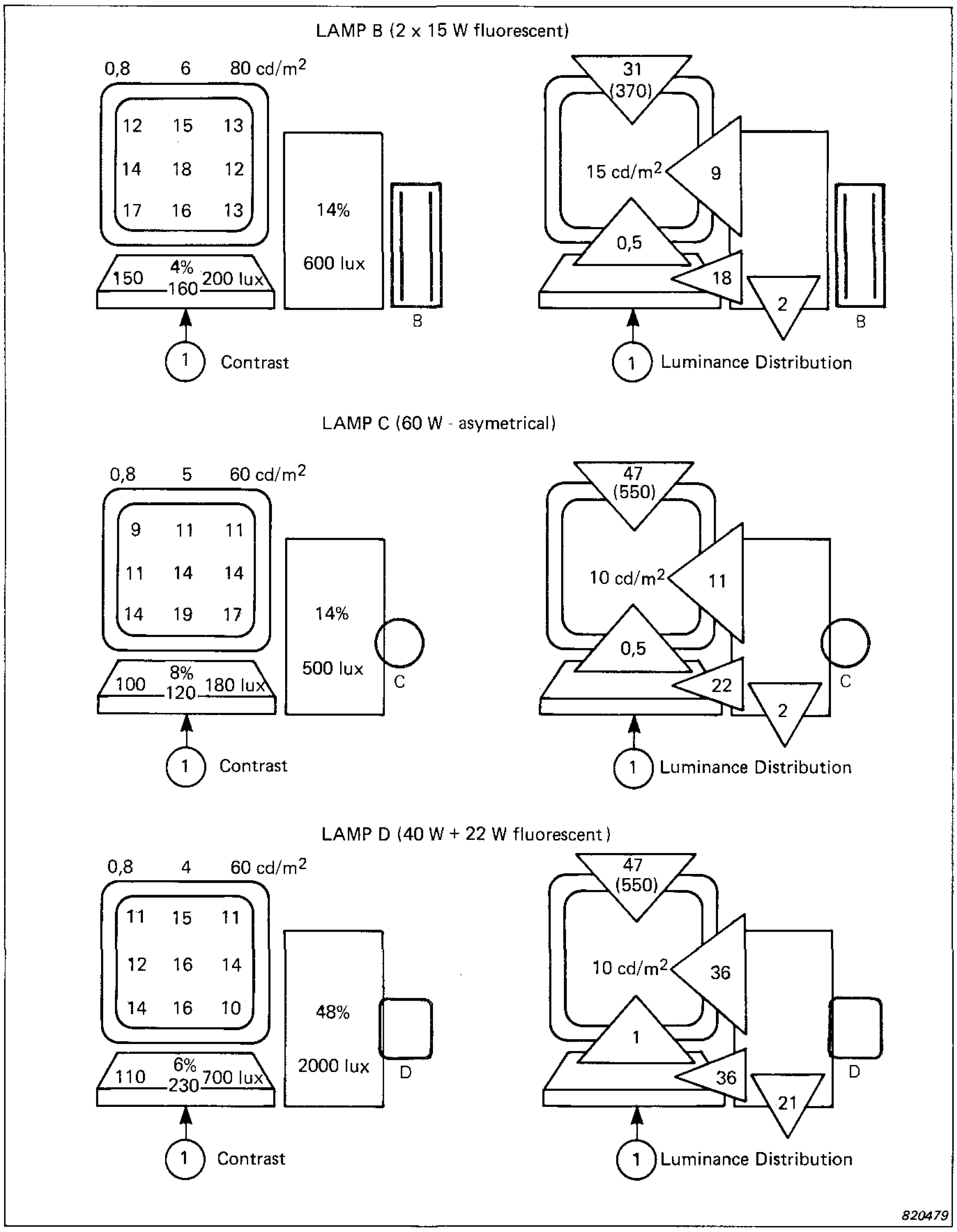


Fig.49. Contrast and luminance conditions on terminal 1 for desk lamps B, C, and D, example 3

Fig.50. View of an office with individual lighting on the desk and on the document close to the screen.

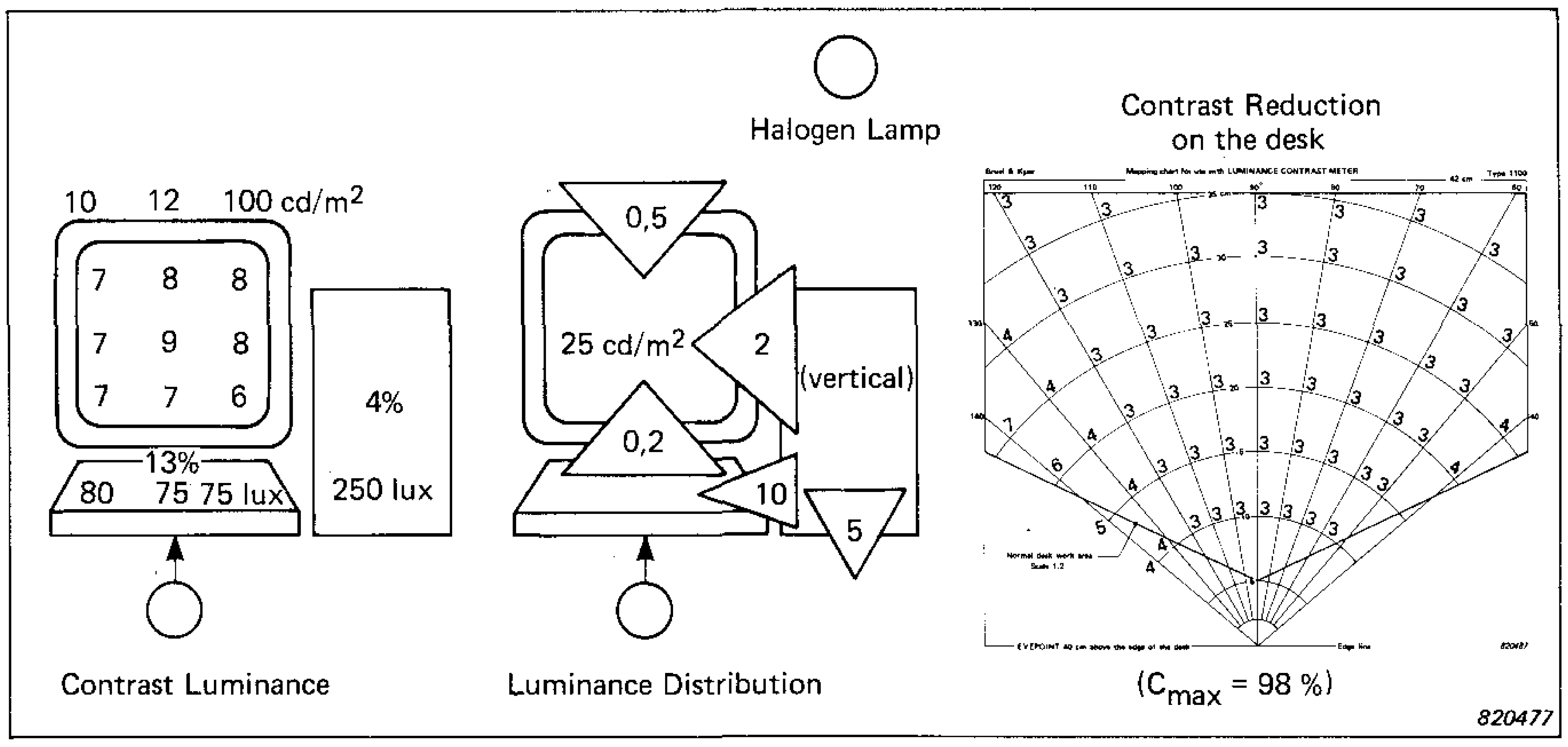
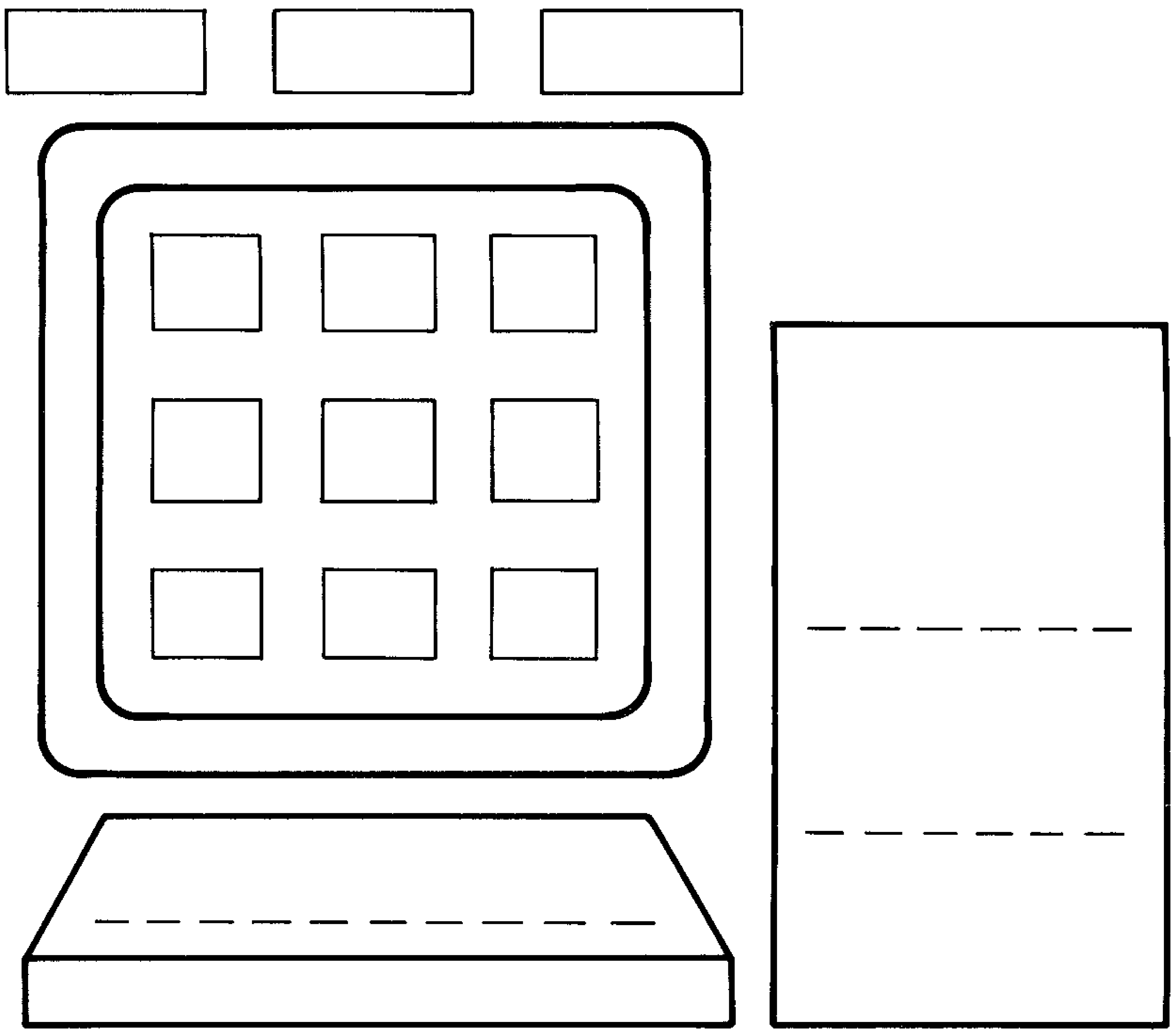


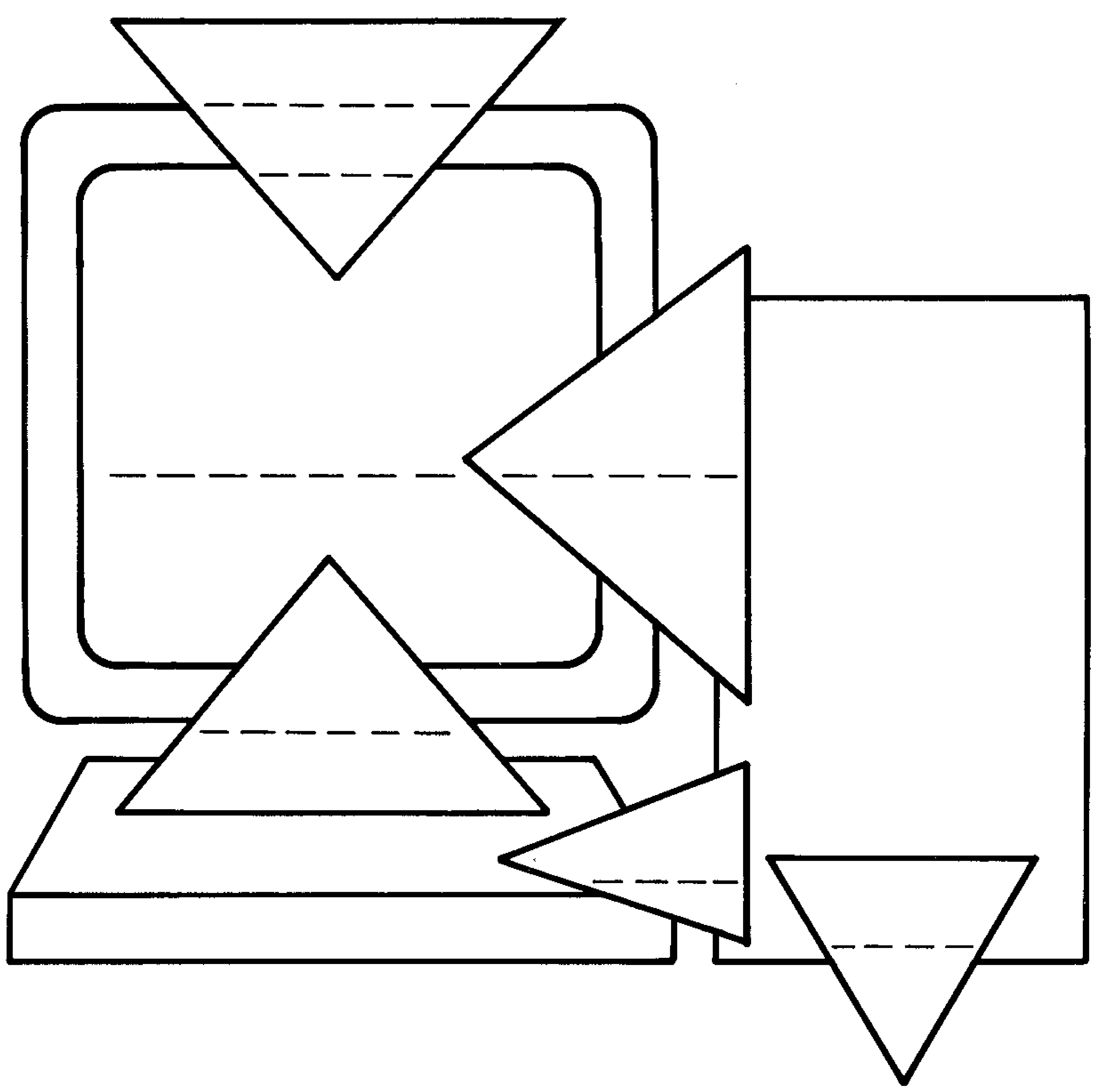
Fig.51. Contrast and luminance conditions in the office shown Fig.50.

MEASUREMENT REPORT

CONDITIONS OF CONTRAST



LUMINANCE DISTRIBUTION



Type of terminal:
....

Operator: ....

Lighting: ....
....
....
....
....

Keyboard:
....
....

Screen:

Colour of characters: ....
Colour of background: ....
....
....

Position of the document:

Left: ☐
Right: ☐
Horizontal: ☐
Vertical: ☐
Other: ....

Contrast on the screen:

Measurement areas:
Uniform: ☐

Capital letters: ☐
(Degree of coverage d = ...)

Measured parameter:
Character luminance and background luminance: ☐

Luminance ratio: ☐
(Dial C_{max} = 00 %)

Contrast on document/keyboard:

Parameter:
C: ☐

R: ☐
(with C_{max} = ...%)

CRF: ☐
(with B & K Type 1104, dial C_{max} = 91 %)

Observations: ....

Date: .... **Sign.:** ....

820736

Bruel & Kjaer Instruments, Inc.
185 Forest Street, Marlborough, Massachusetts 01752 / (617) 481-7000 TWX 710/347-1187

PRINTED IN DENMARK: K. LARSEN & SON A/S . DK-2860 SØBORG