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Fluorescent Lamps: A Practical Assessment

David Saunders

Introduction

Since their introduction in the late 1930s fluorescent lamps have been widely accepted and have become a major method of lighting, particularly in offices, factories and public places. Economically, the fluorescent lamp presents an attractive alternative to, or replacement for, conventional tungsten incandescent lamps. For this reason art galleries and museums have investigated the possibility of employing fluorescent sources.

As an illuminant in circumstances where it is important to reproduce colour faithfully, fluorescent lamps are not without problems. These difficulties with colour-rendering and colour discrimination have been described in a previous volume of this *Bulletin*, which examined the various methods for determining theoretically the colour characteristics of light sources [1]. As a result of this investigation certain colour-rendering criteria were proposed which were to be met by a light source before it could be considered as suitable for gallery lighting. Firstly, the general colour-rendering index (R_a) should be greater than 90, and secondly, the worst colour-rendering index (R_w) should be greater than 80. The derivation of these indices is explained in references [1] and [2].

Selecting a fluorescent lamp

The colour-rendering index of a lamp is not the only factor to be considered when selecting a lamp. Fluorescent tubes are manufactured which emit light of different colour temperatures, from warm light similar to that produced by an incandescent lamp (*c.*2800 K) to cool light which simulates daylight (*c.*6500 K). For museums and galleries there are good reasons for selecting a source that emits light in the 3000–4000 K region [1,3]. As with all illuminants used for picture lighting, the amount of ultra-violet (UV) light reaching the exhibit should be limited, either by selecting a source with low UV emission, or by use of a filter.

A further criterion is the amount of light produced by a tube per watt of electrical power, termed the *efficacy* of the lamp. This should be balanced against the colour-rendering index of the lamp, since it has been demonstrated that objects may appear slightly brighter than would otherwise be expected, if illuminated by a lamp with good colour-rendering properties [4].

Clearly the paintings must be lit to a level at which detail and colour may be appreciated fully, without exceeding the generally recognized conservation criteria.

The ideal lamp would have both a high colour-rendering index and high efficacy. In the past, unfortunately, these two features seem to have been mutually

exclusive. Certain traditional fluorescent tubes produce good quality light (R_a of around 90) but are of quite low efficacy. A later innovation was the so-called triphosphor lamp. R_a for this type of lamp is typically around 80, but R_w can be as low as 50, which may produce metamerism, especially in retouchings [5]. More recently, lamps have been developed which give an R_a of around 95 and R_w of greater than 85. These lamps have an intermediate efficacy and, fortunately, emit rather less UV radiation.

Table 1, which is a revised and updated version of Table 1 in reference [1], contains colour-rendering, colour temperature, UV-content, and efficacy data for all the lamps referred to in the following sections.

The need for a subjective test

Fairly recently, as a result of the work of Loe, *et al.* [6], the recommended highest illuminance for moderately sensitive material has been raised from 150 to 200 lux [7]. Understandably, galleries and luminaires had previously been designed to illuminate the paintings at 150 lux, so the only feasible short-term means of achieving the new level was to use a higher efficacy tube. From an inspection of Table 1 the best choice is between the Philips 94 and Wotan Maxilux 22 lamps (at *c.*4000 K). Sadly, the preferred lamps were either unavailable or incompatible with the existing fittings, and sometimes both.

In view of the difficulty in obtaining suitable lamps, it was suggested that high efficacy triphosphors such as Philips 83, Philips 84 or Thorn Polylux 4000 be introduced for gallery lighting. Theoretically the rendering of colours under these lamps should be poorer than under the currently used Thorn Kolor-rite lamp. In contrast, the colour discrimination indices for Philips 84 and Thorn Kolor-rite lamps are quite similar [6]. The question was whether to use the new lamps available which, in theory, gave poorer colour-rendering, to wait for the preferred lamps to become available, or to make no changes and accept the lower light levels.

From this dilemma arose the idea of conducting a subjective assessment of the appearance of paintings under various different sources. Such experiments are of course fraught with problems, not least because all the comparisons are based on memory of a previous appearance. Nevertheless a procedure was devised to assess the various lamp types. In the first experiment Philips 83 and 84 triphosphor lamps were compared with the Thorn Kolor-rite tube which is at present fitted in all luminaires at the National Gallery.

Table 1 Data for selected fluorescent lamps.

Lamp type	Colour Temperature (K)	R_a	R_w	Crawford Class	UV-content (microwatts /lumen)	Efficacy (lumens /watt)
Thorn Kolor-rite	3930	89	82	C	85	c.45
Philips 38	3830	90	83	C	81	c.45
Thorn Polylux 3000	3150	78	53	F	103	c.90
Thorn Polylux 3500	3470	80	51	F	97	c.90
Thorn Polylux 4000	3870	82	61	E	58	c.90
Philips Colour 84	3940	82	52	F	87	c.85
Philips Colour 83	2980	83	52	F	84	c.85
Wotan Maxilux 21	4030	82	51	F	89	c.90
Wotan Maxilux 31	2900	84	56	F	115	c.90
Philips Colour 94	3780	95	86	C	43	c.65
Philips Colour 93	3010	94	82	C	49	c.65
Wotan Maxilux 22	3780	94	87	C	see notes	c.65
Wotan Maxilux 32	3060	91	77	D	see notes	c.65

Notes:

Based on Table 1 in reference [1].

R_a is the general colour-rendering index; R_w is the lowest (worst) of the eight individual indices.

The Crawford Class system is explained in references [1] and [8]: lamps are categorized in classes A (best) to F (worst).

Conservation limit for UV-content is 75 microwatts/lumen.

It was not possible to calculate the UV-content of the Wotan Maxilux 22 and 32 lamps from the data available.

For comparison, the efficacy of a standard tungsten incandescent lamp is c.13 lumens/watt.

Table 2 Details of the paintings used in the assessments.

	National Gallery Number	Artist	Type of Painting	School	Period
A	3604	Lucas van Leyden	Portrait	Flemish	Early C16
B	3538	Guardi	Town scene	Italian	Mid-late C18
C	3894	Style of Orcagna	Religious	Italian	Mid C14
D	6457	Cézanne	Landscape	French	Late C19
E	1481	Bega	Genre	Dutch	Mid C17

The test procedure for the first assessment

In a room in the Gallery a scaffolding structure was erected to support a number of fluorescent luminaires [9]. The luminaires containing different types of tube could be switched independently. The position and number of lamps was adjusted until the measured illuminance on the picture hanging area was equal under each lamp type, and as even as possible along the length of the wall. Fig.1 shows a general view of the room in which the first assessment was conducted. Over a period of two days subjects were asked to complete a questionnaire whilst viewing a set of five paintings. The same questionnaire was answered for each lamp type. The paintings are detailed in Table 2 and were chosen to reflect, as far as possible with only five works, the

Collection as a whole. The paintings contained a range of colours, tones and subject matter.

Each assessment began with the participants behind a screen, seen to the left in Fig.2, which prevented them from observing the paintings and surrounding wall during the change in illuminant. The test commenced with minimal daylight in the room, the ratio of artificial to daylight at this stage was c.6:1. At a fixed point in the assessment the component of daylight was increased to give a c.2:1 ratio of artificial to daylight. When the assessment had been completed the subjects again moved behind the screen.

Data for each of the lamps tested in this assessment are to be found in Table 1. The order in which the lamps

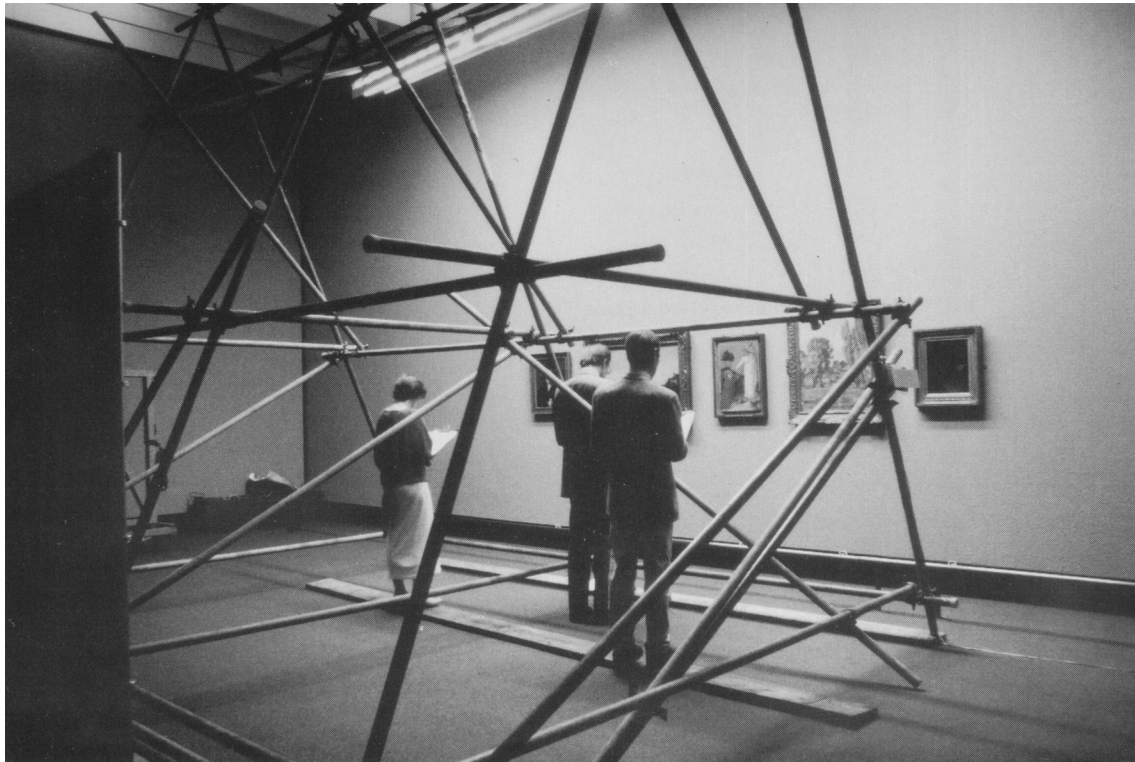


Figure 1 General view of the room used for the first assessment.

were considered was varied, and the first lamp was repeated later in the test. This procedure was adopted in order to overcome the difficulties in judging the first lamp in the absence of a comparison.

During the course of the experiment each of the participants was checked for normal colour vision by the Ishihara method.

A summary of the results of the first assessment

As a result of the Ishihara test, two of the male observers were found to have anomalous colour vision. This was borne in mind when analysing their questionnaires.

Description of the appearance of the paintings under each lamp

In the first question, participants were asked to indicate which adjectives, from a list of over twenty, best described the appearance of the paintings under the light from the lamp under test. The adjectives most used were as follows:

Philips 84: Artificial(9), Cold(9), Stark(8), Harsh(8), Flat(8)

Philips 83: Warm(14), Soft(9), Artificial(8), Rich(7), Restful(6)

Thorn Kolor-rite: Sharp(10), Crisp(9), Subdued(9), Lively(6), Rich(5)

In the next question observers were invited to apply adjectives of their own choice to the appearance of the paintings. The answers to this question served to emphasize the adjectives selected in the first question. For the Philips 84 lamp, 'hardness', 'coldness' and 'flatness' were all emphasized. Other descriptions in-

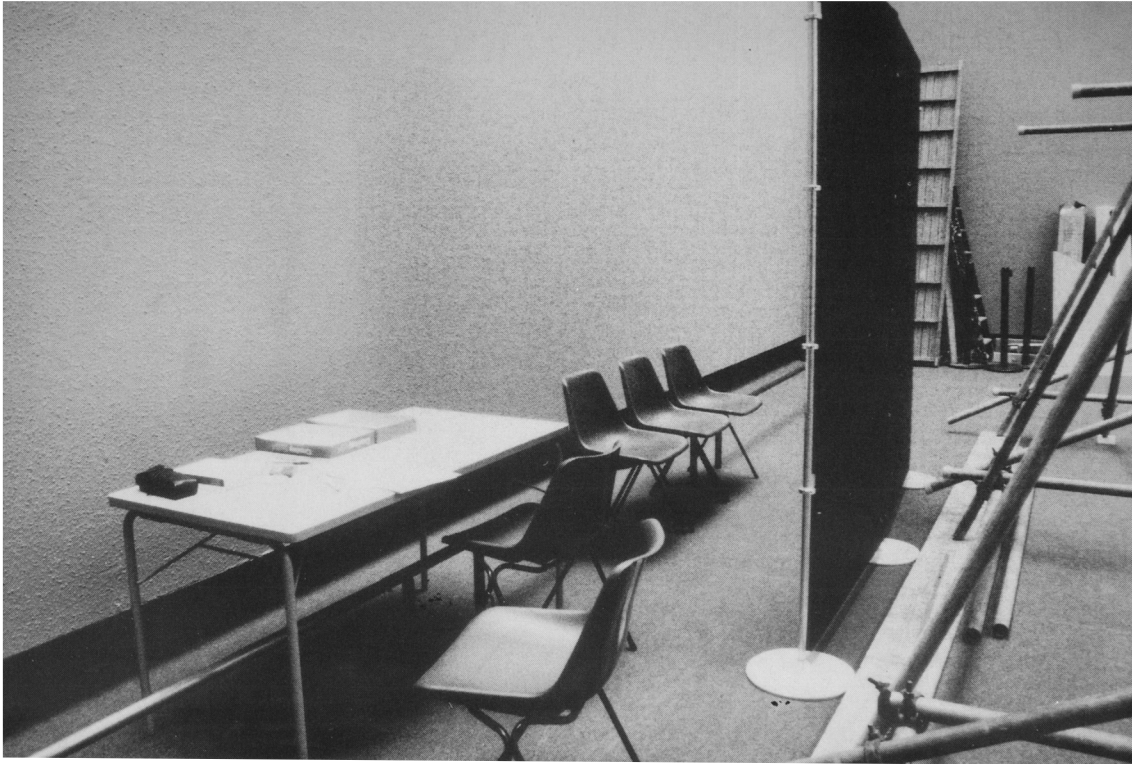
cluded 'blue', 'bleached' and 'clinical'. The lamp was generally thought to be unflattering to the paintings and was disliked. The adjectives used to describe the appearance of the paintings under the Philips 83 tube all emphasized the 'warmth' of this lamp. Opinion was divided on whether this warmth was desirable. Some observers felt the lamp created a pink or yellow cast, others indicated that the warm light was pleasing. Comments about the Kolor-rite lamp were generally positive, using adjectives such as 'clear' and 'interesting'.

Colour and detail discrimination

The next two questions addressed colour discrimination, or differentiation, and detail discrimination. Under the Philips 84 and Kolor-rite lamp, colour and detail discrimination were held to be quite good, whilst with the Philips 83 lamp colour discrimination was considered only passable. It was evident that detail discrimination was improved, as would be expected, by increasing the level of illumination (see below under the effect of admitting daylight).

Colour anomalies

The final questions in the first section dealt with perceived colour anomalies. Many observers indicated that either the reds, the blues or both were distorted under the Philips 84 lamp. Particular reference was made to a *vermilion* cloak in painting C, and to metamerism in the *Prussian blue* sky of painting B. With the warmer light from the Philips 83 tube, reds and pinks were felt to be over-emphasized, the cloak in painting C was again mentioned specifically. A number of observers felt that



the blues and greens were 'slightly wrong' under the Kolor-rite lamp.

The effect of admitting daylight

At this point in the assessment daylight was admitted to the room. Nearly all the participants agreed that the appearance of the paintings was improved by daylight, regardless of the type of fluorescent lamp. Daylight made the light from the Philips 84 lamp 'less harsh', that from the Philips 83 lamp 'less warm', and that from the Kolor-rite lamp 'more stimulating'. The daylight was thought to blend well with the two higher colour temperature lamps but less well with the warmer light from the Philips 83 tube. The admission of daylight appeared to improve colour and detail discrimination, possibly as a result of the rather higher overall illuminance.

Conclusions of the first assessment

Of the three lamps in this initial survey, the preferred lamp seems to be the Thorn Kolor-rite tube currently used by the Gallery. It is encouraging that this lamp was also preferred by observers from outside the Gallery staff who are not necessarily accustomed to viewing paintings under any particular type of lamp. A number of participants liked the warmer Philips 83 lamp, especially in the absence of daylight. The preference for warmer light under these conditions has already been noted [1,3]. The Philips 84 lamp was generally not liked. The presence of daylight enhanced the appearance of the paintings, regardless of the lamp type. There are a number of possible explanations for this. The increase in overall illumination has already been mentioned as a possible factor. It may also be that the excellent colour-

Figure 2 The waiting area in the first room. Note the screen which prevents the participants observing the effect of the lamp change on the opposite wall.

rendering of this 'natural' source contributes to the improvement, or that the diffuse light from a horizontal laylight is preferable to the strongly directional fluorescent light provided in the first part of the assessment.

Both the Philips lamps have lower colour-rendering indices than the Thorn tube used currently. In this particular experiment there seemed to be some correlation between the colour-rendering indices and the opinions of a number of the participants. This should not be taken as an indication that all tests of this type accurately reflect theoretical calculations, although these too ultimately derive from experiments with observers.

The test procedure for the second assessment

As a result of the experience gained in conducting the first assessment, certain changes were made to the procedure for the second assessment. In place of the cumbersome scaffolding structure a specially designed 4m high trolley luminaire was used to illuminate the picture wall [10]. The lighting head contained two sets of independently switched lamps. The trolley could be repositioned for each lamp type to give equal illuminance of the picture hanging area. A general view of the room used for the second assessment is shown in Fig.3. During this assessment no attempt was made to exclude daylight, although two of the experiments were conducted after dark to assess the performance of the various lamps in the absence of daylight. In addition two of the assessments were conducted using a light level three times that normally permitted in the Gallery, and the remainder at the level of ≈ 200 lux.

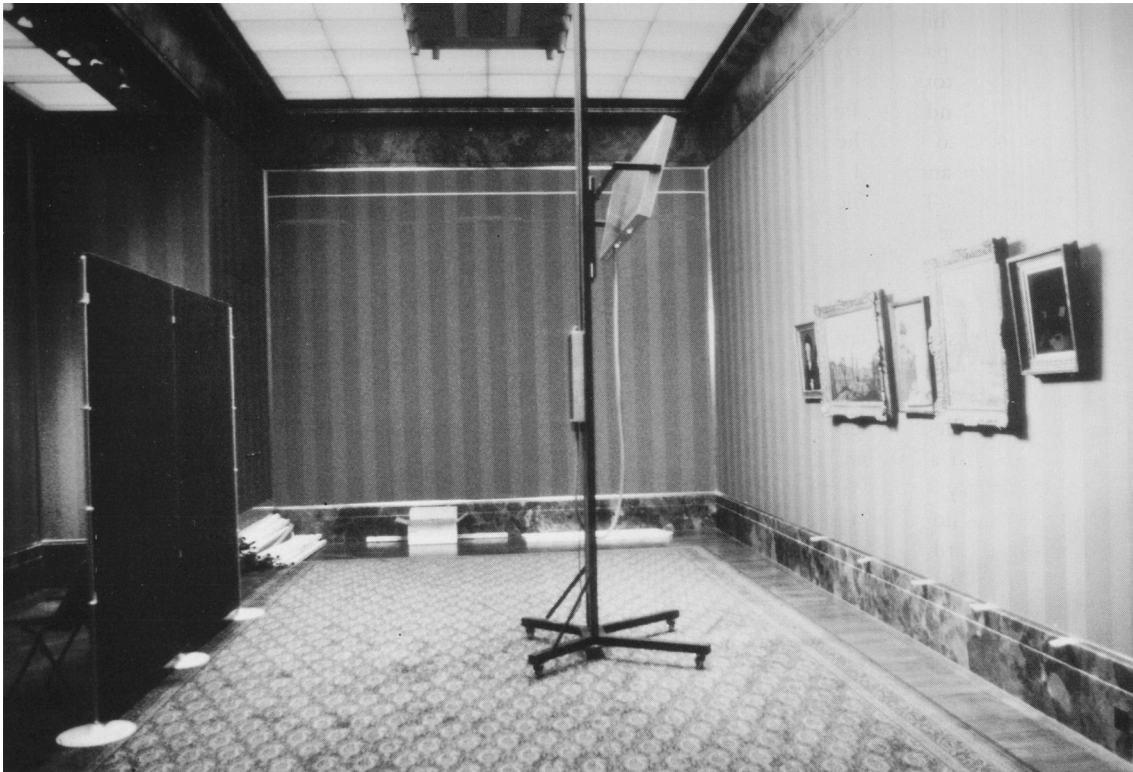


Figure 3 General view of the room used for the second assessment. Note the trolley luminaire at the centre of the photograph.

The same five paintings listed in Table 2 were viewed. Due to the availability of space within the building it was not possible to use the original room for the second experiment, but the wall colour, a pink of moderate lightness, was similar to that in the first experiment.

Four lamps were tested: the Thorn Kolor-rite, used in the first assessment; the high colour-rendering Philips 94 and Wotan 22 lamps; and the Thorn Polyflux 4000 triphosphor lamp [11]. Repeating the procedure for the first assessment, the lamp which was viewed first was also viewed later in the test.

All new participants were tested for normal colour vision by the Ishihara method.

A summary of the results of the second assessment

None of the new observers showed any colour vision anomalies [12].

Description of the appearance of the paintings under each lamp

In the first question participants were again asked to select those adjectives which were most applicable to the appearance of the paintings under the test lamp. For each of the lamps the following were the most used adjectives:

Philips 94: Crisp(11), Lively(11), Vibrant(8), Sharp(6), High-Key(6)

Thorn Kolor-rite: Crisp(8), Lively(7), Subdued(7), Cold(6), Unstimulating(6)

Wotan 22: Restful(8), Warm(7), Crisp(6), Sharp(5), Soft(5)

Thorn Polyflux 4000: Flat(11), Dull(10), Sharp(9), Lively(7), Crisp(7)

As with the previous assessment, the answers to the next question generally emphasized the adjectives chosen in the first question. In the second test, however, opinions differed significantly on more than one of the lamps. Whereas most observers made positive comments about the Philips 94 and Wotan 22 lamps, comments on the other two lamps varied. Both the Thorn lamps are slightly colder than the Wotan or Philips lamps, and it may be that this is the reason for the differences noted. It was evident that the favourable response to the Polyflux 4000 lamp coincided with the tests which were conducted at a higher light level. In these tests the comments indicated that the differences between the lamps were less apparent. This may well reflect the fact that, unlike the first assessment, the lamps used were all of comparable colour temperature and of moderate to good colour-rendering.

Colour and detail discrimination

The third and fourth questions addressed the problems of colour and detail discrimination. As expected, detail discrimination was affected more by the light level used than the lamp. Colour discrimination was considered to be reasonably good under the Wotan and Kolor-rite lamps, good under the Philips lamp, but only moderate under the Polyflux 4000 lamp.

Colour anomalies

The final part of the questionnaire explored any perceived colour anomalies. Under the two marginally

warmer lamps, the Philips and Wotan, the reds were said to be emphasized, particularly the vermilion robe in painting C. The retouchings in the sky of painting B were most visible under the Polylux 4000 lamp, which was also thought to give the blues in painting D a 'disturbing' appearance and to make the reds and browns seem 'flat'. The Kolor-rite lamp was felt to impart a slightly blue cast.

The effect of daylight

Although the admission of daylight was not specifically controlled, it was possible, by virtue of the failing light during the late afternoon sessions, to assess the effect of this factor. Thus, the same set of observers could view the paintings under a combination of fluorescent light and daylight early in the session, and then under fluorescent light alone at a later stage. The results indicated that, regardless of the lamp type, the light was preferred when it was mixed with daylight. As suggested earlier this may be due to the nature of the daylight or to its distribution, coming as it did from a diffuse source, the daylight. The effect of this would be to produce less contrast between the strongly lit picture area and the wall beyond.

Conclusions of the second assessment

Unlike the first assessment it is not possible to state which particular lamp was most favoured. Any preferences seem to be less marked at higher light levels, but since this level of light could not be permitted within the Gallery it is necessary to concentrate on the results at the normal level of *c.*200 lux. At this light level it is apparent that the Thorn Polylux 4000 lamp was liked least. It is worth noting that this subjective opinion corresponds to a lower colour-rendering index for the lamp. It is not clear why the appearance of the paintings should have differed under the Philips 94 and Wotan 22 lamps which, theoretically, are closely similar. The Thorn Kolor-rite lamp, which was much liked in the earlier assessment was, when compared to lamps of higher colour-rendering, not particularly liked.

Conclusions from the two assessments

The results of the two assessments highlight the problems of such a subjective experiment. In the first experiment the colour temperatures and colour-rendering properties of the lamps assessed were markedly different. The results from this assessment were reasonably consistent, with a clearly preferred lamp type emerging. This lamp also happened to be that with the highest colour-rendering index. In contrast, the lamps tested in the second assessment had quite similar colour temperatures and were of reasonable to good colour-rendering. The lamp of lowest colour-rendering index was not liked, but there was little to choose between the other three lamps.

The illuminance must obviously be kept below conservation limits, but should be close to this value for optimum detail and colour discrimination. It perhaps comes as no surprise that the admission of daylight into

the room seems to enhance the appearance of the paintings. The possible reasons for this improvement have already been discussed.

As a result of the first assessment, the decision was made not to use low colour-rendering triphosphor lamps such as Philips 83 and 84 for picture lighting, despite the advantages of higher efficacy. The second assessment indicated that the moderate efficacy, high colour-rendering Philips 94 and Wotan 22 lamps were acceptable as replacements for the Kolor-rite tube in future installations.

This type of assessment is no substitute for colour-rendering calculations, but does give those who are interested the opportunity to judge the appearance of paintings under a variety of sources before a new lamp type is selected. The practical and theoretical techniques may be seen as complementary, providing that the limitations of the subjective method are acknowledged.

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9. The installation of the scaffolding and luminaires for the first assessment was arranged by Tim Heasman of the PSA (MAGG4).
10. The trolley luminaire used in the second assessment was constructed by CLE Designs Ltd.
11. I should like to thank Margaret Halstead and Ian Hamilton of Thorn lighting, and John Proctor and Graham Moore of Philips lighting for supplying lamps and spectral power distribution data.
12. In the first assessment there were seventeen participants: thirteen were men, of whom two were found to have anomalous colour vision. In the second assessment there were twenty-six participants: fifteen men, of whom two were known to have anomalous colour vision as a result of the previous experiment.