High Lighting Quality Targets with Minimum Electric Power Density: Results of Experimentation

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ABSTRACT

We have conducted a campaign of testing efficient lighting installations during 6 months in the area of Lyon, France. 26 work places were tested, each of them with a specific lighting scheme. The goal was to identify directions in preferred lighting schemes requiring less electrical power. Users could adjust their lighting conditions thanks to different control systems : dimmer, daylight and occupancy sensors, separate ambient/task luminaires. The preferred lighting schemes were carefully recorded through measurements of illuminance distribution, luminance values in the field of view, electric power required by the lighting installation for the selected lighting scheme.

Selected electric power densities and lighting quality parameters were compared. No correlation was found between perceived lighting quality parameters and electric power densities, but some solutions were found, with the best assessment in quality and power densities below 10W/m^2.

Fig 1. Laurent Escaffre and Christophe Marty from Ingélux Consultants testing performance of office luminaries. (luminous flux output, illuminance distribution, luminance distribution, optimal positioning)

INTRODUCTION

ENTPE and Ingélux consultants are conducting various campaigns to explore the fundamental needs of occupants regarding their luminous environment. The objective is to identify directions for energy conscious lighting design. What are the fundamental targets which should be reached at “all costs”, and in which domains can substantial energy savings be accepted?

Former studies in this domains have been conducted. J. Veitch (Veitch & Newsham 1998) demonstrated through the testing of various work places by observers that the perceived quality of the luminous environment was not related with the electric power used by the installation. Virgile Charton (Charton, 2002) proposed various lighting scenarios using computer generated images in stereographic mode. He concentrated on work spaces in cunicles with partition limited in height. He demonstrated the preferences of observers for scenes presenting some contrast of luminances (non uniformity on the work plane and role of luminance of walls located far away from the cubicles. More recently, Coutelier (Coutelier 2006) tried to identify pertinent descriptors of lighting quality. He presented on a large screen, in a stereographic mode, various scenes (offices, class-rooms, shops, museums) and corelated preferences of observers with various possible descriptors. He identified the most relevant set of parameters which could be associated to various words decribing luminous scenes: brightness, uniformity, intimacy, comfort, stimulating, original, etc

Fig 2. Example of computer generated images of various lighting schemes for cubicles tested to identify preferences among observers (source: Charton, ENTPE)

CONDITIONS OF THE EXPERIMENTATION

The spaces belong to an existing office building in Lyon, France (Mat Electrique), with various depth from window : from 4 m to 9 m. Ceiling height was 2.64 m, window frame are 1.25m in width. Each work station offers a specific floor area 15-27 m² in individual, 9-13 m² if shared, 9 m² in open space. Surface of desks were around 1.6mx0.8m, and each work station offered a storage furniture.

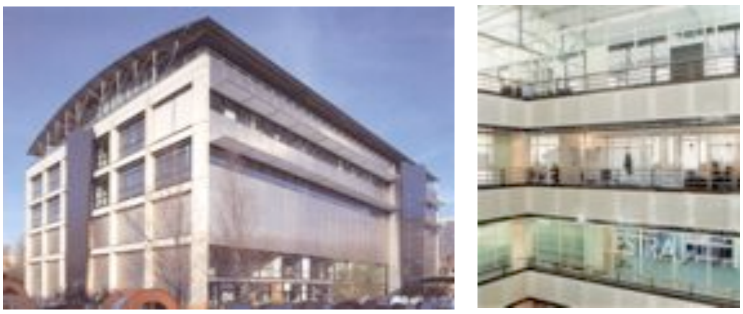

Fig 3. Office building, Lyon, France. Third floor offered open and individual spaces for the tests.

ORGANISATION OF THE CAMPAIGN

Various lighting installations were tested during a period of 4 months in real work places in the building.
Twenty-six work places were concerned, most of them being in an open space area and some of them in individual or shared offices, all are equipped with a computer and a visual display terminal.

First of all, diagnosis was made for each workplace by interviews and measurements (natural and artificial lighting : illuminances, luminances, shadows, blinds, control habits, optical characteristics of the worker).

Then, we proposed 26 lighting adapted schemes, distributed in the following families: recessed ceiling luminaries, direct / indirect suspended, stand alone, desk mounted. Most of them were equipped with a dimming system (so that the occupants could adjust freely the power to the system) or automatic sensors (occupancy + daylight), or separated ambient/task switch.

Occupants were interviewed at various occasions and were asked to evaluate the quality of their luminous environment with respect to the light distribution in their work area, the visual comfort (evaluation of glare), the light distribution on surrounding surfaces (walls, ceiling).

We measured the luminances from the typical location of the eye, and we recorded the illuminances on the surfaces. The exact electric power used was measured with a watt-meter. From these data we tried to identify two major general parameters.

One being the electric power density used by the occupant (W/m2 over the entire work area).

The other being a “general perceived lighting quality index”. This was a major difficulty to establish.
To do so, we reviewed the comments of the occupants and managed to put them in a general single scale of satisfaction. We could call this parameter the “satisfaction index” to simplify.
Here is the proposed rating obtained through interviews: Soft, satisfactory (4 points) , Lack of uniformity, lack of brightness, poor aesthetics (3 points), Unpleasant, sad (2 points), Glary, aggressive, tiring (1 point).
Lighting quality was measured through the following parameters :
Dimming capability, illuminance levels, uniformity on work plane, value of UGR, maximum perceptible luminance (overhead glare), maximum luminance of scene without luminance of luminaire.

RESULTS

There was a clear rejection of any directly visible fluorescent tube (T5 or T8, Compact Fluorescent tube). We found however that when fluorescent tubes were partly dimmed, the luminance of the tubes was acceptable. It seems that the threshold value is 7 000 cd/m^2: fluorescent tubes above head with luminances below 7 000 cd/m^2 seem to be acceptable.
There was also a clear preference for systems hiding totally the vision of the fluorescent tubes, and indirect lighting systems.

There was a clear preference for powerful task lighting contributing also to the ambient light), able to supply up to 500 lx on the desk, 380 to 450 average lx average, with a good uniformity (0.6 to 0.8). The uniformity on the desk is the ratio of the minimum illuminance (230 to 350 lx) to the average illuminance (around 400 lx).

There was a great satisfaction to provide dimming systems with individual controls. Although occupants did not use them often, they offer a guaranty that they could adjust the illuminance level according to their needs and physical state (fatigue, stress, etc.).

We observed a large variation in energetic efficiency of lighting solutions. The lowest were obtained with suspended direct-indirect luminaries shared by two occupants (6W/m^2). Very low power densities were found for task/ambient solutions (below 8W/m^2).

As a conclusion, it appears that the optical performance of a significant fraction of the supply in office luminaries needs to be improved. Individual task lamps could be designed with a power of 25-40 W, able to provide excellent illuminance distribution on the work plane. In these conditions, power densities of about 6W/m^2 are achievable, with very high visual performances.

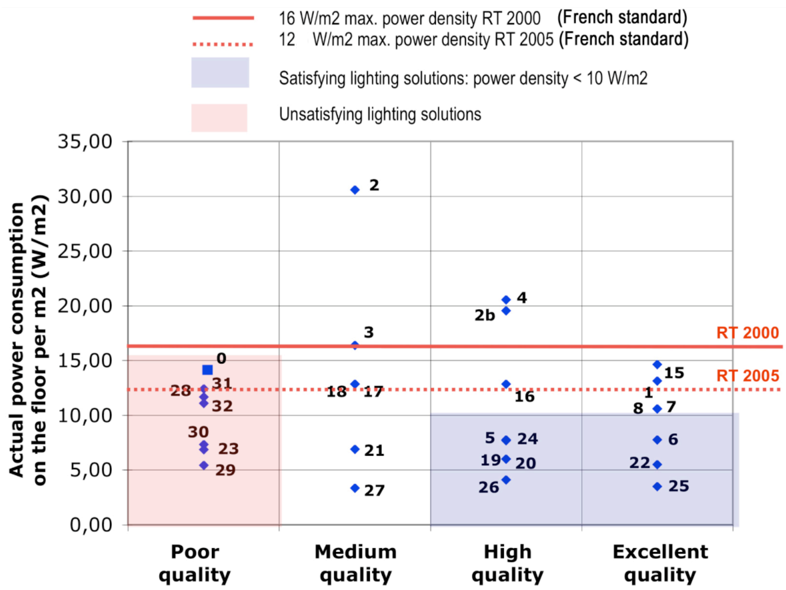

Fig 4. Perceived visual quality as a function of the electric power density for lighting for 26 lighting schemes.

MOST EFFICIENT SCHEMES

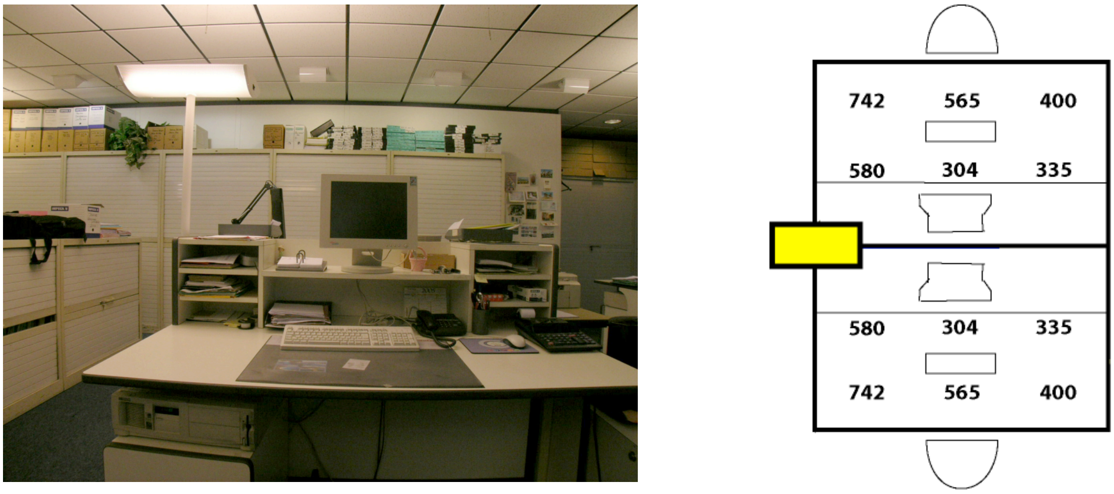

Fig 5. Direct-indirect stand alone luminaire. Its independence with the ceiling allow to locate the luminaire very precisely near the work space. The users appreciated the dimming option associated to the daylighting-occupancy sensor. Can be shared with another occupant. Considered as high standing. Typically 100W per work space required, less than 8W/m^2 in open plan office. Typical light sources about 2 CFL 55W per occupant, partly dimmed.

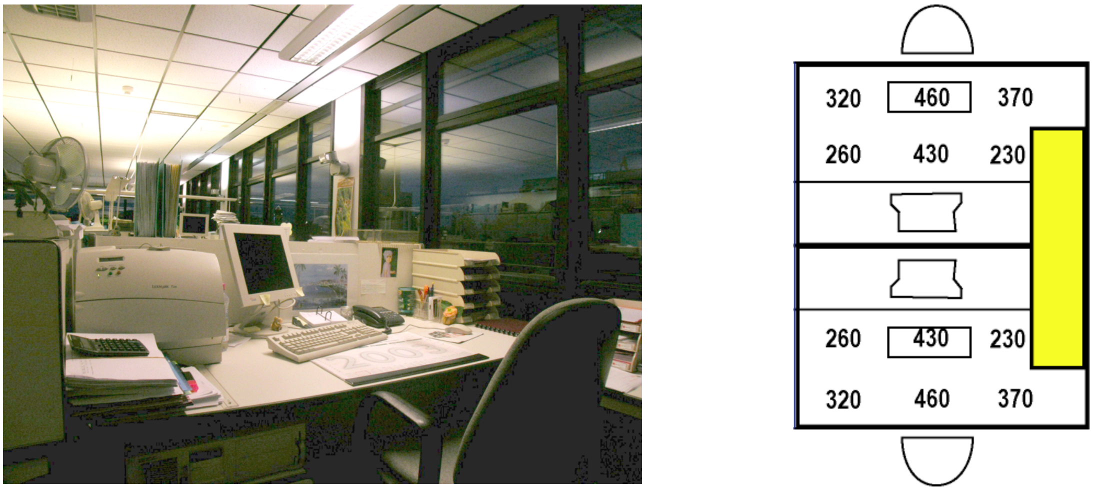

Fig 6. Direct-indirect suspended luminaire. Allow usage of 1.20 or 1.50m fluorescent tube. But work place cannot move if luminaire position is fixed. Leads to the lowest electrical consumption: 6W/m^2. In open plan office. Could use 2x54 W fluorescent tubes for two people.

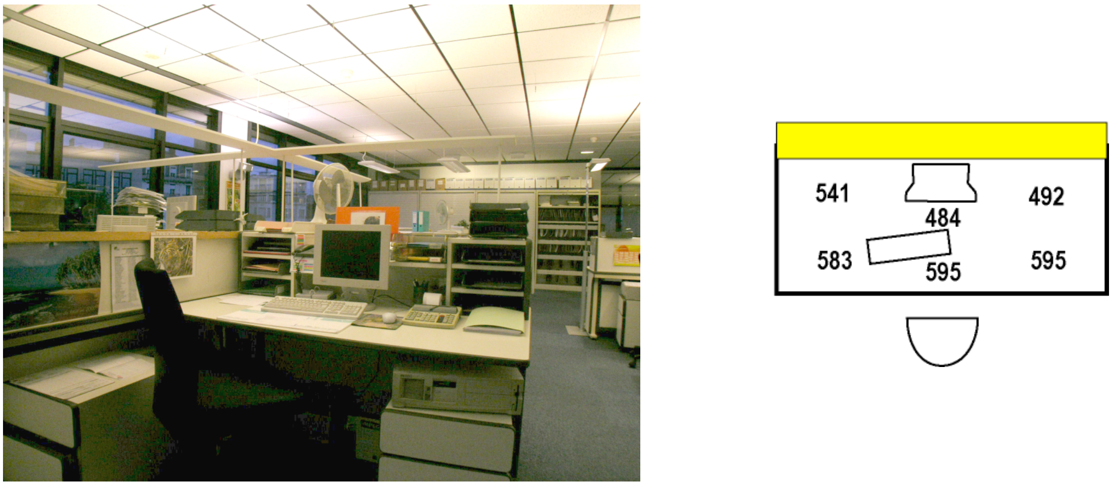

Fig 7. Indirect luminaire integrated to the furniture. Judged as very comfortable, the ceiling luminances are moderate, but the general feeling tends to have a work plane looking darker that the rest of the room. Requires about 2x35 W fluorescent tubes per work place.

CONCLUSION

Here are in summary the possible specifications of lighting installations in offices perceived as high quality:
Hide sources so that the maximum luminance of the luminaire, in all direction is below 7000 cd/m^2. Reduce uniformity on work plane to a value between 0.6 and 0.8 to provide a feeling of contrast while avoiding shadows. Allow individual control (dimming) so that the user get the exact illuminance he/she wishes. Select equipment with good optical performance. Prefer single fluorescent tube to compact fluorescent lamps to lower electric power requirement. Share luminaries between work places: best performance are obtained with one luminaire providing light for two workplaces.

Our study is being compared with other such experiences among participants of IEA Annex 45. We expect to develop more robust guidelines for highly efficient, high quality, lighting options for work places.

ACKNOWLEDGEMENTS

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IEA ANNEX 45, Energy Efficient Lighting, http://www.lightinglab.fi/IEAAnnex45/