Alternative strategies for artificial lighting using electronic ballasts

Antonio Almeida, A. Gomes Martins, Paulo Rodrigues and Eliseu Ribeiro, Instituto de Engenharia deSistemas e Computadores

1. SYNOPSIS

Dimming is, for some types of buildings, not attractive enough to replace on/off control of lighting. On/off control is especially effective when adequately integrated with architecture.

2. ABSTRACT

A secondary school in Portugal has been designed according to energy efficiency criteria. It incorporates several passive solar devices both for thermal comfort and daylighting, such as, for instance, thermal masses, natural cross-ventilation of classrooms, south windows provided with external and internal shading and reflective blades, skylights, light ducts. Besides, the main support systems have high efficiency, as the artificial lighting system. It has electronic ballasts and correspondingly adapted fluorescent tubes. A data acquisition and control system provides, among many other functions, automatic control of artificial lighting, according to occupancy of rooms and light availability, both internal and external. In the design, dimming has not been considered, though it seemed the "smarter" approach, namely owing to the potential good use of the computational system for this purpose. The paper presents the alternative between dimming and qualified on-off control, both from the economic and the visual comfort points of view. Both energy consumption estimates and subjective matters such as the roles of manual overriding for light control and the existence of discrete steps of luminous flux have been taken into consideration in the analysis. They are the basis for concluding for the advantage of the present implementation of light control in the building. Some remarks are made about the conditions to be verified for the validity of the conclusions in other cases.

3. INTRODUCTION

The ideas developed in this paper resulted from the need to design an energy efficient secondary school. An integrated approach has been used which includes contributions for minimizing energy consumption ranging from architecture to computational control: passive solar features, energy efficient active systems and a supervisory control and data acquisition system. From the point of view of lighting, the general problem consisted in the assessment of the combined utilization of natural and artificial lighting, in order to obtain a compromise solution with low energy consumption.

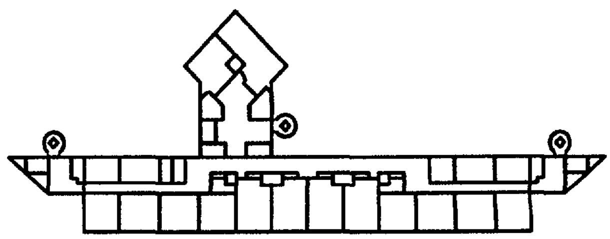

Figure 1. ***Layout of the first floor of the building***

As an outcome of the particular technology choices made for artificial lighting a decision had to be taken about the control strategy: either qualified on/off or dimming.

4. IMPLEMENTATION

4.1. Daylighting

The majority of the classrooms in the building are located along the south facade. The windows' dimensions represent, as they should, a compromise between heating and daylighting needs.

The windows on the south facade are provided with both interior and exterior light shelves, which direct sunlight onto the white ceiling, that acts as a diffuser.
South rooms are of two kinds as regards to length: the deepest have 10m and the others 7m. The 10m long classrooms have systems for providing daylight at the back zone, that differ between the two floors. There are roof lights at the upper floor, which have a movable shade, highly reflective and with good insulation, that may be positioned either in the North or in the South faces of the roof light. Thus it is possible to use North diffuse light in Summer, in which case a gap for natural ventilation is provided, or direct light from the South in Winter. In the ground floor, daylight is directed to the back of the deepest rooms by means of light ducts with highly reflective interior surfaces. See Figures 2 and 3 for details.

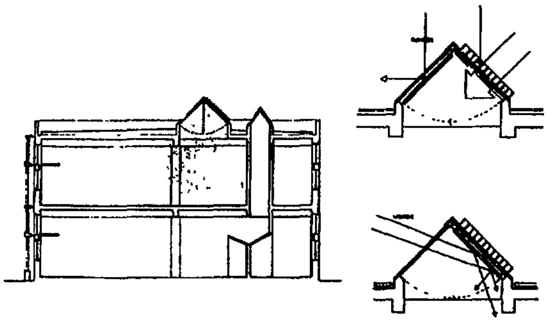

Figure 2. ***Cross elivation showing two classrooms and roof light operation detail***

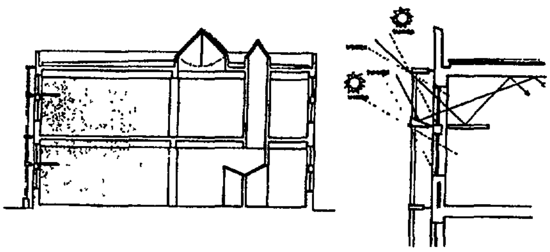

Figure 3. ***Cross elivation showing two classrooms and light shelves detail***

4.2. Artificial lighting

Even with a good design for visual comfort based on natural light, variable meteorological conditions and possible occupation at night determine the need for a lighting system. It should provide simultaneously low energy consumption and visual comfort conditions adequate for a school building (Carvalho 1983).

To fulfill these requirements electronic ballasts and fluorescent tubes (1,5 m length, 26 mm diameter) in two-lamp fixtures have been used. This solution was considered especially adequate for classrooms because it has characteristics such as noise absence, flicker free operation, no stroboscopic effects, constant luminous flux for low variations of the supply voltage, etc.

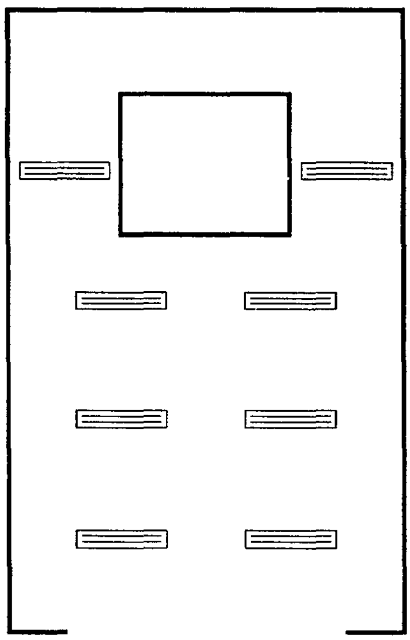

Figure 4. ***Upper floor classroom with fixture arrangement and roof light location***

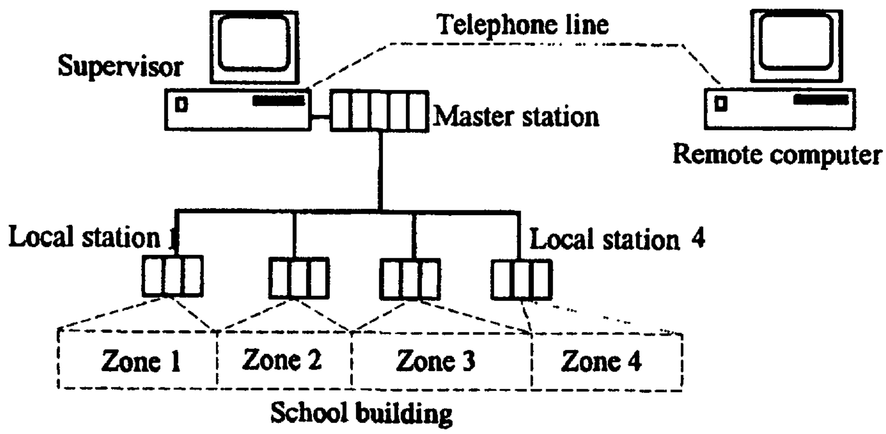

Figure 5. ***Main structure of the DAEMS***

A balance between the artificial light system use and the availability of natural light has been achieved by manipulating the fixtures locations and switching priorities. In Figure 4 a scheme of the fixtures locations is depicted for a 10m long classroom in the upper floor.

4.3. Supervisory control

A distributed data acquisition and energy management system (DAEMS) is used, consisting of a network of 4 computer-based local stations dependent on a master computer designated supervisor.

Each station monitors a set of transducers and detectors of a zone of the building. The system performs a set of functions among which are artificial lighting control and energy performance monitoring. Through performance monitoring the most effective systems, design solutions and control strategies may be identified and considered for future implementations.

The transducers in the interior and exterior of the building monitor a great number of physical quantities among which are illuminance, solar radiation and luminance, both direct and diffuse.

The circuits for actuator control consist mainly of relays that establish the interface for switching artificial lighting circuits automatically.

The DAEMS characteristics briefly described allow the implementation of the lighting control strategies, as specified (Martins 1992).

5. CONTROL STRATEGIES

An optimum use of energy for artificial lighting also depends on the ability to consider the varying operating conditions of the building. Adaptability depends solely on the control strategies, once the control system and the main technological choices have been made. On the other hand, the definition of a control strategy depends on the specific characteristics of the different rooms under control. However, subjective aspects of human visual comfort and cost are two additional key issues to be taken into consideration.

5.1. Control strategy adopted

Qualified on/off control is the d esignation used for the control strategy adopted. Its definition is based on the following four requirements:

- previous knowledge of the possible times of use of each room (scheduling).
- room occupation detection (occupancy sensors).
- need of artificial light, depending on natural light availability (external and internal light sensors).
- independently switched lighting circuits to complement daylight in a stepwise manner.

5.2. Alternatives not implemented

If dimming had been used, some other m ethods could have been envisaged:

- daylight control, considered as a continuous adaptation to natural light variations.
- lumen maintenance, to compensate lamp output depreciation.
- tuning, to adapt luminous flux to specific tasks.

6. QUALIFIED ON/OFF VERSUS DIMMING

An attempt is made in the following to identify the main advantages and disadvantages of both strategies: qualified on/off and dimming.

The main advantages of qualified on/off may be stated as:

- daylight responsive light switchi ng is easily organized around independent electric circuits in the same room, provided with interface relays for automatic control.
- manual override facilities are technically and economically feasible.
- it is easily integrated with scheduled occupancy times and effective occupancy when DAEMS retires the manual overrides at the end of a lesson.
- the hardware is less expensive than for dimming.
- artificial light variations in steps avoid the adverse psychological effects of intolerance to continuous light.

On the other hand, with qualified on/off it is not possible to implement lumen maintenance or tuning. Besides, electric light response is discontinuous and, as a consequence, there is always a slight mismatch between the exact light requirements, as dict ated by standards, and the real conditions, leading to lower savings than the total potential. The reverse in all cases happens with dimming.

However, dimming has several disadvantages:

- it is more expensive than qualified on/off. Namely when considering automatic control, digital-to-analog conversion facilities are needed, as opposed to ordinary digital outputs for qualified on/off. This aspect assumes particular importance for buildings with a high number of rooms.

- it is prone to human intolerance to continuous light (Fontoynont 1988).

- when a building has many rooms with different dimensions, different daylight conditions (see Figure 1 for an example), different numbers of independent lighting circuits, an effective dimming strategy tha t avoids the uneconomical dimming at each individual room, actually requires the same switching facilities needed for qualified on/off if discrimination between occupied and unoccupied rooms is specified.

- manual override facilities are complex, especially if dimming is to be made also manually controllable.

7. WHY DIMMING MAY BE DISCARDED

7.1 Psychological factors

An integrated approach to building design must not only include energy efficiency requirements but also seek for a comfortable inter nal environment. The general concept of comfort includes, beyond the visual and thermal aspects, some important subjective items, namely those that may lead to attitudes of rejection of automatic control systems when they exist (Heerwagen and Diamond 1992).

It is important that the users feel they are not permanently dependent on the decisions of an automatic system as regards to the building operation. Hence, manual override control facilities should always be available to users. There are also function al reasons for manual override, such as the need for different light conditions for specific tasks, as for example slide viewing. The hardware complexity of dimming with manual override, already mentioned, discourages the use of this combination of featur es.

The human body is adapted to natural discrete variations of light--for instance, sequences shadow-light-shadow due to natural obstacles, temporary cloudy sky. Continuous light provided by dimming systems may cause psychological discomfort due to the absence of naturally expected step variations of light (Fontoynont 1988). Qualified on/off intrinsically causes discrete variations that avoid this effect.

7.2 Comparison of energy savings

Energy consumption has been estimated for a sample case of an upper floor classroom provided with a skylight (see Figure 4). Three situations as regards to control strategies have been considered: manual light switching with conventional gear, qualified o n/off and dimming, both using electronic ballasts. The results are represented in Figure 6 and assume a total of 2400 hours of operation per year. In the case of manual light switching, an arbitrary correction factor of 0.75 has been utilized to account for the minimum awareness, that always exists among users, of t he need to avoid unnecessary lighting.

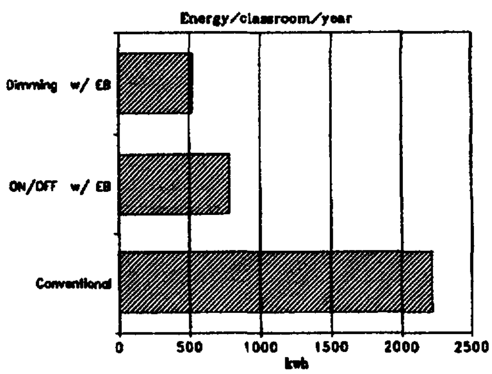

Figure 6. ***Annual energy consumption of lighting for different control strategies***

It is evident that the difference between the energy consumptions of qualified on/off and dimming is small when compared to the difference between the case of manual switching and any of the two former (Hancock 1988). This assertion would still be valid even if the correction factor used for manual switching was lower, down to e.g. 0.50, which would represent a rather unusual awareness of occupants towards rational use of energy.

It should be noted that there is, for the present cases and the case of buildings with similar structure and characteristics, a significant difference of investment between the implementation of qualified on/off control and dimming control, in contrast wi th the smal l difference in savings. On the other hand, the implementation of dimming with manual override facilities would need a set of devices and circuit arrangement with many points in common with the hardware required for qualified on/off. Hence, besides increa sing cost it would add significantly to the complexity of the qualified on/off alternative, leading to a lower reliability.

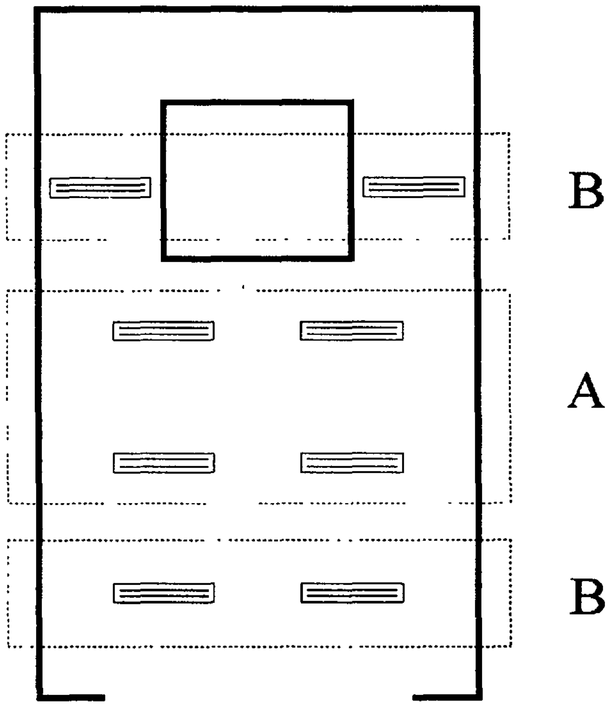

Figure 7. Upper floor classroom showing lighting circuits grouping

8. THE ADOPTED SOLUTION

In each room artificial lighting is organized in independently switched circuits, which are daylight responsive. Figure 7 refers to the same room that has been used as an example along the text. Fixtures A are normally switched on before fixtures B.

The DAEMS is able to control artificial lighting by means of interface relays, adopting the qualified on/off strategy discussed above. The relays are connected in such a way that manual control may be requested by the user and canceled either by time-out or by the user himself. As the DAEMS collects data from the whole array of sensor s in the building, including luminance and illuminance, and the timetable for each room is present in alterable memory, the integration of the information needed for qualified on/off control is possible. Hence, when rooms are occupied the lighting circuit s are gradually deactivated and activated according to daylight availability and to the particular needs of each room.

9. CONCLUSIONS

The design of artificial lighting systems in a building which has been conceived to use the most of daylight must be coherent with the interior organization of spaces. A school building has been used as a case-study, where an artificial lighting system has been implemented, having a good performance for a reasonable investment. An automatic on/off control scheme has bee n adopted instead of dimming, both for economic reasons and for subjective comfort considerations.

It is believed that the options presented here are, in general, adequate for buildings with a great number of rooms of different geometry, sizes and funct ional objectives, as the example of a school illustrates rather well. The drawbacks pointed for dimming may not be valid in different types of buildings, with wide interior spaces, allowing a more economical implementation of dimming. However, the conside rations regarding psychological factors are applicable to any building because they depend on people and not on hardware or economics, and should be taken into account in any case.

ACKNOWLEDGMENTS

The project of the secondary school of Valongo do Vouga has been one of the design studies included in the CEC DGXII Programme BUILDING 2000, from which it received support, namely technical consultancy on passive solar techniques and design, both for visual and thermal comfort and energy efficiency.

The Regional Directorate for Education of the Ministry of Education in Coimbra (DREC), has made possible the use of the school building.

The National Institute for Scientific Research (INIC) has funded much of the research work in its early stages.

REFERENCES

Carvalho, L. 1983. *Energy Conservation when Meeting Visual Comfort Requirements in School Buildings* . Memória n° 600. Laboratório Nacional de Engenharia Civil, Lisboa.

Fontoynont, M. 1988. "Building 2000 Barcelona Seminar on Daylighting" and Chairman Report. *Proceedings from the Building 2000 Workshops* , pp.13-18 and pp. 73-77. Comission of the European Communities.

Hancock, C.J., J. Littler. 1988. "Newbury Central Library--Building 2000. An Example of a Daylight Design Study". *Proceedin gs from the Building 2000 Workshops* , pp.47-64. Comission of the European Communities.

Heerwagen, J., R. C. Diamond. 1992. "Adaptations and Coping: Occupant Response to Discomfort in Energy Efficient Buildings". *Proceedings from the ACEEE 1992 Summer Study on Energy Efficiency in Buildings* , Volume 10, pp 10.83-10.90. American Council for an Energy-Efficient Economy, Washington, D.C.

Martins, A., A. Almeida, E. Ribeiro, P. Rodrigues, R. Costa. 1992. "An Integrated Approach to the Intelligent Use of Ener gy in School Buildings--a Case-Study of a Portuguese Secondary School". *Proceedings from the 2nd International Congress on Energy, Environment and Technological Innovation* , Volume 1, pp. 307-312. Università di Roma "La Sapienza", Rome.