Energy-Efficient People: Redefining Energy-Efficient Lighting in Terms of Support for Human Activity

HAYDEN WILLEY
Associate Professor, Department of Architecture, University of Auckland, New Zealand

ABSTRACT

IT IS ARGUED THAT ENERGY-EFFICIENCY in lighting should not be considered in terms of the mere production of light but, rather, in terms of the support it provides for human activities. Energy consumption by lighting can be considered non-wasteful only to the extent that it provides a lit environment appropriate to such activities. A broader-based economic analysis is suggested as a basis for a new definition of energy efficiency. Lighting installations which allow some degree of control by people are discussed, and appropriate strategies for switching are developed employing fuzzy control and cybernetic theory. A comprehensive theoretical framework is outlined to support this approach to energy-efficiency in lighting.

INTRODUCTION

All too frequently, we speak of the energy-efficiency of lighting as a comparison between the energy supplied to the lighting installation and the output from the lamps or (more thoughtfully) the luminaires. This, however, represents a very limited view of lighting – that the outcome we seek from the energy investment is merely the production of light. If we take the more far-sighted view that lighting should be designed to support human activities (in the broadest sense), then the energy investment can be seen to have the provision of this support as its intended outcome and the energy efficiency of the lighting needs to be assessed in these terms. This more extensive concept of energy efficiency clearly embraces the energy efficiency of the production of light but couples this with the effectiveness with which that light supports human activities (including, for example, reading in a library, walking safely down a street at night, and studying a piece of art in a gallery). If the human activity is not well supported, then the energy consumed by the lighting has been used wastefully, however energy-efficient the lamps and luminaires might be in their own terms.

Coupling the production of light with the effectiveness with which the light supports human activity should ensure that we do not devise energy-efficient strategies that focus exclusively on the former to the detriment of the latter. (It could be argued, but it would be a digression to do so here, that the sick building syndrome came about through just such a narrowly-focussed and short-sighted approach to energy efficiency across the thermal environment and ventilation technologies in recently-constructed or renovated buildings.)

The concept of ”support for human activities” should not be confined to support for visual performance. It should include the careful design of the lit appearance of the spaces in which the activities take place. ”Support” thus extends to the provision of an appropriately pleasant and stimulating lit environment, to psychologically support the occupants of the space and thereby enhance the outcome of their activities.

An aspect of the psychological considerations would be the extent to which building occupants are satisfied with the opportunities they have to control, or at least fine-tune, the lighting of the space they occupy. While control opportunities would not necessarily extend to street lighting or the lighting of an art gallery (and may, indeed, be counterproductive), they could be a significant factor in the lighting of libraries, offices, graphic art studios and any other building type in which each occupant might expect to be able to establish, temporarily or long-term, a personal space.

The challenge in these circumstances would be to provide the opportunities for control in such a way that energy efficiency was improved rather than compromised, and that the lighting modification produced by such control actions enhanced rather than detracted from the lit appearance of the space. If this goal could be achieved, the people occupying the space could be considered an integral component of the whole ”lighting system”; not simply as passive receivers of the lighting provided but as active participants in its provision. Then, we might properly extend the idea of energy-efficient lighting, not only to embrace ”energy-efficient support for human activities” but to include, or imply, the concept of ”energy-efficient people”.

ECONOMIC CONSIDERATIONS IN SUPPORT FOR HUMAN ACTIVITIES

The provision of lighting has both capital costs and running costs associated with it, and these are often seen as being in a ”trade-off” relationship (such as in the cost involved in providing more energy-efficient ballasts for fluorescent lighting). An alternative viewpoint would be to consider that the capital costs of lighting equipment might significantly reflect the embodied energy in the materials it contains and its method of manufacture. Energy considerations might therefore require us to reduce capital costs as well.

Combining these viewpoints suggests that we should seek to reduce the sum of the running costs and of the capital costs amortised over the life of the installation. It would not necessarily follow that each of these two costs should be individually minimised, if, say, the minimum total cost could be achieved by allowing a greater-than-minimum capital outlay.

Task-ambient lighting represents a (much-debated) approach to lighting that has potential for significant energy savings as well as providing a better lit appearance, for both an interior space and also the people and objects within it, than can be achieved by uniform illumination of the working plane by a regular array of luminaires. At the same time, it offers separate control of each component, enabling energy efficiency to be achieved through automatic control of the ambient component (usually the one that consumes the larger proportion of the energy – suggesting a possible renaming of the strategy as ”ambient-task lighting”) while the building occupants have control over the task component, potentially satisfying their desire to shape the lit appearance of their personal space.

The advantages of non-uniform lighting had been noted in the 1960s (Hopkinson and Kay 1969), as a reaction to the increasingly common strategy of providing uniform illuminance from ceiling-mounted luminaires. These advantages included a more interesting lit appearance for the interior (so long as glare was avoided) and a better luminance gradient from the visual task through the immediate surround to the background – better in that attention was held on the task if it were somewhat brighter than its surroundings. Within a few years, the potential this technique held for reduced energy consumption was also attracting attention (Alexander et al. 1982).

The disadvantages of non-uniform lighting were also noted, including the reduced flexibility of workplace layout compared to a uniformly-lit space. Other disadvantages were the lack of a simple design procedure that included an analysis of energy budgeting and the lack, at that time, of suitable task lighting equipment – with manufacturers producing equipment for local lighting rather than the localised lighting that surveys showed was preferred by building occupants (Alexander et al. 1983). Since task-ambient installations can have a higher installed electrical load than uniform lighting (depending on the lamp types employed), this could conflict with any regulations that specified a maximum load (W/m^2) for each type of interior space.

The actual energy efficiency achieved by task-ambient lighting depends on both the opportunities to selectively switch off or dim the ambient component and the frequency with which occupants would switch off the task component under their control. One reported trial (Alexander et al. 1983) over a period of a year with a task-ambient installed load that was 26% less than that of a uniformly lit control area showed an overall energy saving of 85%, which was attributed to differences in the switching patterns. Nevertheless, the greater initial capital cost of a task-ambient installation is a strong deterrent to its adoption. To overcome this resistance, either the energy savings could be made even more attractive or the economic considerations could be presented in a broader context. Techniques for further enhancing the energy savings by encouraging greater switching activity will be discussed shortly.

The alternative context for considering the energy savings of alternative lighting strategies is to go beyond consideration of lighting costs to look at the running costs of the building as a whole. This latter consideration goes way beyond taking account of, say, the impact of a reduced lighting load on the loading of cooling or air conditioning plant. The enhanced quality of the interior lighting that is likely to accompany non-uniform horizontal illuminance can generate other paybacks related to the satisfaction of the building occupants. Microeconomic theory might caution us that the anticipated energy savings might not be realised if the occupants choose to ”spend” some of these savings on making the lit appearance of the interior space even more satisfying. (Indeed, this was found in surveys of energy savings gained by insulating houses, where occupants chose to spend some of the savings to heat their homes to a higher temperature or to heat more rooms in the home than previously had been affordable (Bakke et al. 1975; Fisk 1977). The additional benefits from this enhanced lit appearance might nevertheless generate economic paybacks of a broader kind.

An analysis of the economic use of lighting would quite properly ask what outcome from the provision of lighting should be compared with the energy input – the production of light by the equipment or the production of activity-based outcomes by the building occupants? These latter outcomes can include work performance, but that idea can be generalised to cover also such diverse activities as performance at indoor sports (including spectator satisfaction with their own visual performance as well as with the level of game achieved by the players), and viewer satisfaction at an art gallery. Clearly the latter is very difficult to quantify in economic terms (and it may be unnecessary and inappropriate to do so).

One of the more readily quantifiable situations is work performance in an office building. From an economics perspective, we can include the occupants in the running costs of the building as a whole. Indeed, through their wages or salaries they represent the most significant component of the total running costs. A study undertaken in Auckland, New Zealand, of 22 office buildings looked at the dollar outlay over a typical 40 year life cycle of the buildings and found that personnel costs (salaries and direct benefits) constituted 80–87% of the annual running costs (Robertson 1990). Similar studies in the United States of America have produced figures in the range 90–92% (Wineman 1986), and a recent report has estimated that for office-type buildings in the UK, staff salaries account for 85% of the sum of building capital cost and the total operating cost for the first ten years (Loe and Davidson 1997). In the Auckland study, energy constituted 0·3–2·2% of the annual running costs. While this was not broken down further into lighting, heating, etc, the comparison with personnel costs is striking for the disparity in size. (The percentage of annual running costs in other categories was: leasing or capital replacement: 1·5–8%; plant maintenance: 0–5·5%; lifts: 3–4%; cleaning: 2–5%; building maintenance: 0·5–2·5%; and miscellaneous (including office equipment, communications, rates, insurance, security): 1·5–8·5%.)

On the basis of these figures, the most telling argument that could be put to a building owner or tenant is one that maximises the return from the investment in the employment costs of staff. In the context of lighting design, this return relates to two aspects: increased visual performance and enhanced satisfaction with the lit appearance of the office (or equivalent workplace). The significance of the latter is the more positive approach to work that might be expected to follow and a reduction in absenteeism. The extension of the idea of energy-efficient lighting to embrace energy-efficient support for human activities is a very telling one. It is only in those circumstances which optimise the work performance of a building's occupants that we can be assured that the energy consumed is being used in the least wasteful way. Whether the enhanced occupant satisfaction with the lit appearance of the workplace is regarded as an integral part of work performance or as a bonus does not affect the validity of the argument.

ENERGY EFFICIENCY IN LIGHTING CONTROLS

To return to the consideration of potential increased energy savings from the design of lighting controls in a task-ambient installation, the ambient component will be considered first. By allowing people to retain control of task lighting, and by providing sufficient control for that component to enable those people to fine-tune the lighting of their personal workplace to their own requirements and satisfaction, the ambient component can be made subject to automatic control. One of the commonest controls would be a time switch, but its use will become increasingly constrained by the flexibility of working hours employed, and sometimes encouraged, in many workplaces. An alternative is an occupancy detector which can switch off lights in rooms that remain unoccupied for a preset time. Neither of these devices presents a problem if the switching action occurs in the absence of room occupants. It is those control actions that occur in occupied rooms that need to be carefully considered.

A photocell can be employed to switch or dim lamps close to windows when the available daylight increases or vice versa. This can generate an immediate dissatisfaction among the people occupying a space if the control action is not one that they would have taken under the same circumstances. The main origin of such differences is the immediacy of the control action by the photocell compared to the delay that is likely in human control actions. This delay is the result of a combination of adaptation to the changing luminances in the room, distraction by activities of higher priority or greater interest, forgetfulness, laziness and the like. The problem is that a photocell (and similar sensors) reacts to the state of a single variable, to attain a preset goal through a single available course of action. The control actions that are (or could) be taken by people display a vicarious mediation of many aspects of the environment, will display varying degrees of information processing based on past experience or current mood, and may be selfconscious or unselfconscious. It is possible to build this complexity of control decision-making into an automatic device.

Fuzzy theory has been employed for over 20 years to drive industrial process controllers in ways that replicate the actions of human experts (King and Mamdani 1977; Gupta 1979). While architectural applications have been proposed, particularly for the computer modelling of the way people interact with buildings and the assessing of the energy effectiveness of various environmental control strategies with which people are permitted to interact (Willey 1979; Willey 1982), they have been restricted so far to fuzzy logic control of elevators (Sangalli 1992) and fuzzy-aided security and smoke detection systems (So and Chan 1994). Fuzzy logic control flourished in industrial settings with fuzzy control algorithms replicating the imprecise control protocols of human operators because the experience of the human operators was seen as a more effective basis for control than any previous automatic system. On the other hand, there has so far been little interest in fuzzy modelling of human environmental control actions because it has been believed that people generally control buildings in an energy-inefficient manner and, in any case, are being written out of services systems control scripts as buildings become progressively more automated.

There is evidence that this situation is changing (Willey 1996) as a consequence of the sick building syndrome (SBS). SBS studies continue to show that restrictions on occupant control of the environment in buildings is an ongoing cause for complaint and one of many contributory causes of the syndrome (Potter 1988; Rowe 1994). Included among the findings are a perceived need for occupant access to light switches (or at least those for a task component of the lighting system) (de Dear and Auliciems 1988; Rowe 1996).

There are two possible ways of reintroducing a more human-orientated control system for lighting: either direct control actions by occupants are permitted or a simulation of expert human control actions is introduced as the strategy underlying automatic control (as in industrial process control). The latter technique lends itself well to control of the ambient component of a two-tier lighting system. The need to ensure that the control actions to be simulated are "expert" ones is to ensure the elimination of such facets of normal human actions as making mistakes, forgetfulness and choosing inefficient alternative actions. The appropriate algorithms, in short, are not those that model all aspects of human control but rather to display certain powerful characteristics of human perception and decision-making. Further aspects of human control of the environment, especially differences between human environmental control and industrial process control, have been discussed elsewhere (Willey 1996).

Such a model of an ambient lighting control system would also provide a suitable basis for interactive control in which a computerised control centre was able to interpret and respond to imprecise (or fuzzy) requests relayed to it from the occupants of a building. However, almost all current occupant control of lighting involves direct access to switches or dimmers (and/or to curtains, blinds, awnings, etc). In this case, the available control actions can be judged in terms of three general criteria: anticipated reponse time, anticipated satisfaction to be gained, and efficiency (of the person's action, not the energy efficiency of the lighting). The first criterion is largely irrelevant to lighting where the response will be immediate (unlike control of air temperature). Anticipated satisfaction should relate to both the lighting itself and the effect of the control action on energy efficiency. The feedback on the first is direct and obvious but the second factor is much more difficult to provide feedback on. People can be educated to know the likely consequences of their control actions and to value any action that saves energy, but it would be good to have some visual feedback on energy performance of the lighting built into the controls.

The third criterion, the efficiency of the control action itself, depends on the location and design of the switch or dimmer, be it toggle, pull-cord, slide, rotating knob or a TV-like remote control with "up" and "down" buttons. Ergonomic research would help to ensure that people were encouraged to use the control actions available to them and to do so with clear feedback as to the consequences, as part of the strategy to optimise the energy efficiency with which their activities were lit.

THEORETICAL SUPPORT FOR A BROAD DEFINITION OF ENERGY EFFICIENCY

A theoretical model for environmental control has been developed in detail (Willey 1978) and an updated version presented elsewhere (Willey 1992). This model is founded on cybernetic principles and includes the integrative way in which people sense environmental variables. This vicarious mediation of the environment permits richer control objectives and corresponding actions than can be achieved by conventional automatic controls, resulting in a potentially more stimulating environment. Both the provision for user input and the resulting environmental character can enhance people's satisfaction with their environment.

The model enables the focus of consideration for energy efficiency to become environmental quality rather than the simplistic quantitative parameters now employed. Economic analysis of control strategy options can be correspondingly broadened. The development of this analysis and detailed investigation of the strategy options has yet to be undertaken. However, the implementation of a design approach to energy efficient lighting based on an intended outcome of providing support for human activities could be undertaken immediately and with confidence.

CONCLUDING REMARKS

In a similar way to that in which luminaire manufacturers have concentrated on lighting the working plane as efficiently as possible, to the potential detriment of the lit appearance of the space, so too has energy efficiency had a single-minded goal that has neglected other criteria by which we could evaluate a lighting installation. These include the effect of the resulting lit appearance on the occupants and the closely-related economic impact of a poor working environment on worker performance. That the economic consequences of the latter far outweigh the economic gains of small improvements in energy efficiency in the production of light shows how bereft the single-minded approach is of any logic or, indeed, humanity.

While the difficulty of quantifying the energy efficiency with which a lighting installation supports human activities means inevitably that energy efficiency will continue to be discussed in terms of lumens per watt, we must never lose sight of the purpose of lighting and we must remain aware that the efficiency with which we use energy must ultimately depend on how wisely and effectively we employ it to support human activities. ●

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