Institution: University of Liverpool

Unit of Assessment: 16 - Architecture, Built Environment and Planning

Title of case study: The impact of lighting research into provision of user control and alternative daylight sources

1. Summary of the impact

The Lighting Group has been involved in the formulation of national and international design guidance, with impacts on the practices of the UK and international lighting industry.

This guidance offers designers the tools to create optimum visual conditions in energy efficient buildings while reducing electric lighting usage. This involves three areas:

1. The development of lighting design in interiors to take account of room contents;
2. Involvement of the occupant in the control of light levels and electricity usage; and
3. The replacement of electric lighting with guided daylight systems.

The main impact of the work is its influence on the body of professional practice relating to interior lighting design. This guidance advocates the creation of user friendly visual conditions, low electricity usage and natural light in areas remote from windows.

2. Underpinning research

The Lighting Group, led by Dr David Carter, focuses on the study of lighting as part of the building system. The approach has been to use field measurement and computer simulation to investigate the effect of innovative concepts and devices on interior lighting. In addition, a range of post-occupancy evaluation techniques have been developed to establish human reaction to these innovations. A combination of the two approaches has enabled design guidances to be framed, which have been trialled by cooperating industrial partners, before forming national and international design guidance documents, now used worldwide.

The first theme investigated is lighting design in complex and obstructed spaces (1993 – 2002). Conventional calculation methods assume an empty room as the main condition, but in real interiors, illuminance is affected by room contents such as furniture and machinery. The research has yielded generalised predictions of losses in real interiors such as offices. This was extended into design guidance on selection and positioning of luminaires for minimum light loss and hence minimum electric usage. Key outputs include 1 and 2 cited in the next section.

The second theme (1998 – 2008) is the manner in which employees use individual lighting control systems to create a satisfactory visual environment in offices. The research demonstrated that users with individual control select lower light levels than those specified in codes and the resulting lower electricity usage is beneficial for the environment. A parallel study of user reaction to the systems led to design guidance, to take advantage of the large energy savings obtained by the use of this technique. Key outputs include 3 cited in the next section.

The third theme is remote source lighting, where source and output devices are separated by a guidance system. This has three strands. The initial research on electric source guidance developed both methods of analysis of photometric performance and methods of extraction and redirection of delivered light. This was followed by research on daylight source systems (1997 – 2001). Research on the influence of system configuration on illuminance and visual quality of passive tubular daylight guidance systems was undertaken by a combination of field measurement and assessment of human response, and the integration of the passive light output devices with conventional interior electric lighting was also addressed (2001- 2012).

The third theme, on remote source systems, concerns hybrid systems (2006 -2012), which simultaneously deliver daylight and electric light. The research examines light delivery and potential energy savings for commercial buildings. The results established usage patterns (the proportions of daylight, electric and hybrid lighting) for combinations of building configuration, geographic location and types of daylight delivery system. The significant variation in performance with system type, geographic location, and building geometry, has confirmed that choice of appropriate light guidance system is strongly influenced by building location. Key outputs include 4, 5, 6 and 7 cited in the next section.

Key researchers:

Academic Staff Dr D J Carter (1980 – present)

Research Staff: Dr Q Ning (1996), Dr T Moore (1997-2001), Dr M Hadwan (1998-2005), Dr M Mayhoub (2007-2011)

3. References to the research

Key outputs from the research

1. A S M Leung, M J Lupton and D J Carter (1994) Standard obstructions for lighting calculations, Lighting Research and Technology, 26 (3), 161-165
2. D J Carter (2005) Lighting design for obstructed interiors, Technical Report CIE161:2004, Commission International de l'Eclairage, Vienna 35p ISBN 3 901 906 32 0
3. T A Moore, D J Carter and A I Slater (2003), Long-term patterns of use of occupant controlled office lighting, Lighting Research and Technology, 35 (1) 43-59
Awarded the Society of Light and Lighting Leon-Gastner Medal for this paper.
4. D J Carter and M Al Marwaee (2009), User attitudes toward tubular daylight guidance systems, Lighting Research and Technology, 41 (1) 71-88
5. D J Carter (2006) Tubular daylight guidance systems, Technical Report CIE173:2006, Commission International de l'Eclairage, Vienna 64p ISBN 3 901 906 49 5
6. M S Mayhoub and D J Carter (2011), The costs and benefits of using daylight guidance to light office buildings, Building and Environment, 46 (3) 698-710
7. M S Mayhoub and D J Carter (2012), A feasibility study for hybrid lighting systems, Building and Environment, 53 (1) 83-94

Key research grants

1. 1992 - 1995 "Design of electric lighting for obstructed spaces" Science and Engineering Research Council. £77,610
2. 1992 - 1995 "Modelling of light losses in real interiors" Toshiba Lighting and Technology Corporation. *4 Million Japanese Yen* (£21,000)
3. 1992 - 1995 "Remote source artificial lighting systems" Science and Engineering Research Council CASE/Simplex Lighting Ltd £21,450
4. 1996 - 1999 "Lighting quality and quantity in offices with variable control systems"
EMC 96-52, Building Research Establishment, Department of the Environment £66,727
5. 1998 - 2000 "Design of passive solar light pipes" Monodraught Ltd. £21,000

All above grants were exclusively held at Liverpool. The PI in all cases was Dr D J Carter

4. Details of the impact

Research by the Liverpool School of Architecture Lighting Group has made a significant and active contribution to the formulation of national and international design guidance, and hence on the design practice of the UK and international lighting industry. In addition the methods developed during the research were taken up in the R&D test protocols for the lighting industry.

The development of lighting design for interiors to take account of room contents

Research on lighting of building interiors, which are obstructed by room contents, commenced in 1983 and early work on light loss assessment and luminaire layouts led to the effects of obstruction being included in lighting design for the first time, with results from the research being incorporated into the 2009 and subsequent Society of Light and Lighting Code for Interior Lighting. The significance of this is that internal obstructions account for approximately 10% light loss. Although lighting designers know of this effect they traditionally over-design the system in compensation, with resultant unnecessary energy use and costs. The research permits that over-design to be eliminated. Active collaboration with Thorn Lighting in the UK and Toshiba Lighting and Technology Corporation, Japan, extended the design methods to take account of a wide range of building types and lighting equipment. Both companies used the results to inform their lighting design procedures.

The report *Lighting design for obstructed interiors* from the Commission International de l'Eclairage (CIE) Technical Committee TC 3-31, Chaired by Carter, drew heavily on the Liverpool work and the report continues to act as specialist reference for national and international design codes.

Of particular significance to this case study is the related research on obstructed interiors, which has led to the development of methods used for field measurement of task and planar illuminance in occupied interiors. This work is incorporated into the current (2012) Society of Light and Lighting Code for Interior Lighting (used in the UK), and also into the CIE/ISO Interior Code (Lighting of work places Part 1: Indoor 2001) which remains the main code world-wide.

Involvement of the occupant in the control of light levels and electricity usage

The research on lighting control investigated the manner in which people use individual systems to create a satisfactory visual environment. The research demonstrated that users with individual control select lower light levels than those specified in codes and the resulting lower electricity usage is beneficial for the environment. This research was funded by, and in collaboration with, the Building Research Establishment and supported by ECS Lighting Control and the results were incorporated into the lighting control element of the current revision (2010) of Part L of the UK Building Regulations.

The replacement of electric lighting with guided daylight systems

The initial Liverpool research on electric source guidance was supported by Simplex Lighting, a manufacturer of luminaires for industrial applications. It developed both methods of analysis of the photometric performance of these devices and methods of extraction and redirection of delivered light, both of which were applied to the development of the Conductalite luminaire, marketed by Simplex. This research was the basis for a study of tubular daylight guidance systems – devices which collect, transport and distribute daylight deep into buildings – undertaken with the two UK market leaders, Monodraught and Solatube. The impact of the work has been threefold:

- The results formed the scientific basis both for understanding the photometry of the devices and their relationship with the building they light, and for the design procedures used by the manufacturers and installers.

- Dr Carter was appointed Chair of Commission International de l'Eclairage Technical Committee TC 3-38, concerned with tubular daylight guidance systems.

- Dr Carter was co-author of the present UK guidance document on fibre optic and remote source lighting, produced jointly by the Institution of Lighting Engineers and the Society of Light & Lighting.

In addition, current research on hybrid lighting systems, undertaken in cooperation with two companies, Parans Solar Lighting and Limitless, continues to inform the design procedures for hybrid systems of both companies.

5. Sources to corroborate the impact

1. The Research Officer at the National Research Council Canada can be contacted to corroborate all claims, particularly those relating to obstructed interiors and lighting control.

2. This source is a consultant at Aston: Lighting & Control, after retiring from Philips Lighting Ltd. He is an acknowledged authority on lighting control systems and can be contacted to corroborate claims made here about the Liverpool contribution to the use of individual lighting control systems in offices.

3. The Managing Director of Parans Solar Lighting (Sweden) can be contacted to corroborate claims made relating to hybrid daylight guidance systems. This company is the worldwide market leader in the manufacture and development of hybrid daylight guidance and could be expected to comment on the Liverpool contribution to the understanding of their integration into buildings technology.

4. The Managing Director of Solatube UK Ltd. can be contacted to corroborate claims made about tubular daylight guidance systems in buildings. Solatube is one of the worldwide market leaders in the manufacture and development of tubular daylight guidance technology.

5. This source from Lighting Research & Technology has a worldwide reputation as a lighting researcher and author. He is the Technical Editor of Lighting Research and Technology which is recognised as the world's premier refereed journal in this field. He can be contacted to corroborate the claims on obstructed interiors and lighting control.