INTEGRATED DESIGN PROCESS INCORPORATING LIGHTING
Mark B. Luther

SUMMARY OF

ACTIONS TOWARDS SUSTAINABLE OUTCOMES

Environmental Issues/Principal Impacts
- Utilize natural lighting to reduce the need for electric lighting.
- Reduce the need for excess electric lighting capital.
- Reduce greenhouse gas emissions through the implementation of daylight.
- Reduce the need for greater mechanical plant sizing due to the use of efficient daylight.

Basic Strategies
In many design situations, boundaries and constraints limit the application of cutting EDGE actions. In these circumstances, designers should at least consider the following:
- Learn to design for daylight first, establishing the zones of daylight levels.
- Size windows, skylights and clerestory openings with a balanced daylight distribution in mind.
- Study the effects of variable sky conditions and light entry into the space at various seasonal periods.
- Consider the integration of electric lighting layout in conjunction to daylight zones.
- Justify cost-effectiveness of daylighting through pre-design software.

Cutting EDGE Strategies
- Effective strategies for maximizing daylight.
- Consider the façade division into two zones; a clerestory (light directing) and a vision / view zone.
- Consider diffusing direct light before entry into the space (such as screens on skylights).
- Optimise the balance of light as well as energy efficiency through intelligent lighting control systems.

Synergies and References
- BDP Environment Design Guide note DES 21 - An Introduction to Energy Performance Software
- Integrated Design: BDP Environment Design Guide: DES 1, DES 2, DES 36, DES 49
- Lighting: BDP Environment Design Guide: GEN 61, TEC 3, TEC 9, TEC 16, DES 6, DES 7, DES 61, PRO 3, PRO 32, CAS 35
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1.0 INTRODUCTION: SUSTAINABLE LIGHTING DESIGN

This paper provides a step-by-step design and decision making process towards an energy-efficient and user acceptable lighting system. The past few decades have challenged our lighting designs in architecture, questioning whether they are environmentally and ecologically correct. Are we considering the advantages daylighting can have on the psychophysical and energy performance of our buildings? Do we even have the proper frame-of-mind to integrate daylighting into our designs?

In a recent review it was stated that: "daylighting is the use of light from the sun and sky to complement or replace electric light". The author suggests a subtle but extremely important shift from this line of thinking. Are we stating that daylight is possibly here to enhance our electric lighting systems? Perhaps we might consider, from an existentialist viewpoint that daylight was here first, and so a reversal of the above is more appropriate. An integrated lighting design might be one which begins with the onerous task of discovering how and where daylight enters our spaces.

After tedious refinements and an understanding of daylight entry there might be a discovery related to the quantity and quality of this light and how it might be controlled or supplemented. We now have a completely different paradigm where daylight zones are discovered, controlled and possibly enhanced through an electric lighting system and its associated controls. The difference in our approach is to design for and with daylight first.

As stated in a European text on daylighting in architecture there are three ways to convince designers of the advantages to be gained by improving daylighting performance on their projects (Baker et al., 1993):

- Showing possibilities through case studies.
- Providing analysis and information regarding the lessons learnt and how things can be improved.
- Making available to architects tools that can assist them in the design and analysis of daylight buildings.

Design ideas come from a stored repertoire of experienced building solutions. Those design solutions that appear to offer results are remembered and perhaps even refined and reformulated. It is useful to make reference to such architectural precedents that have provided successful solutions of lighting. Simplified design tools are usually applied after the event of design has taken place rather than in the initial design sketch. Most other evaluation tools will enter the design process in the stages of lighting design refinement. It is therefore, suggested that checklists or a reminder of 'criteria to be considered' be provided for the designer before and after this creative process.

Table 1 outlines considerations for effective lighting design. It can be used as a checklist to consider the multiple processes involved in lighting a space. The intention is to consider all the possible methods of daylight first before resorting to electric lighting which is primarily put in place to complement daylight.

2.0 HISTORIC PRECEDENCE ON INTEGRATED LIGHTING DESIGN

Natural lighting of a space has always played a dominant role in architecture. There are generally two reasons for lighting a space; first to provide visual comfort and functional illumination and second to reveal the architecture (structure) of the building (Baker et al., 1993). Interestingly enough an optimal use of daylighting occurred at a time in history when energy was cheap but when artificial lighting was just being developed. At this point in history electric lighting was used to enhance and contribute to areas with deficiencies in the level of daylight illumination.

In the late 19th and early 20th century many of the office spaces which were similar in functionality to our present offices were designed to provide daylight. Such buildings allowed for courtyards or atrium type spaces to provide access to daylight for adjacent offices. The Chile Haus in Hamburg Germany, designed in the 1930s is such an example (Figure 1). In this case, what appears to be a solid, massive building, in fact has courtyards that serve several functions; daylight, ventilation and fire access, for a multi-storey building.

3.0 ASSESSMENT OF LIGHTING INTEGRATION AT THE PROGRAMMING STAGE

The Chile Haus is a building which incorporates several environmental and service criteria through its simplified design of courtyards, creating a narrow plan design. It is essential to consider lighting design as integrated with the other services of a building. At the programming stage, an assessment on the value of daylight needs...
**Objective for Effective Lighting Design:**
- Desired illumination level on task area
- Appropriate lighting distribution and definition
- Optimised visual contrast and minimisation of glare

### DAYLIGHTING

**Room Criteria**
- Openings to daylight
- Room dimensions
- Room geometry
- Surface treatment (texture)
- Surface re-ectance level
- Surface colour

**Daylighting Conditions:**
- Sky condition
  (Clear, partly cloudy, CIE overcast)
- Season (summer and winter solstices)
- Time of Day

**Daylight Openings:**
- View capabilities
- Consider orientation
- Sidelight (window)
- Clerestory
- Skylight

**Window Treatment:**
- Shading (interior / exterior)
- Glass type (clear, tinted, reflective)
- Visible light transmittance
- Glass Shading Coefficient (SC)
- Spectral distribution

**External Factors:**
- Adjacent building orientation and location
- Surface re-ectance and colour of building
- Ground re-ectance
- Other obstructions

### ELECTRIC LIGHTING

**Light Sources and their Efficacies**
- Incandescent lamps
- Fluorescent lamp
- High pressure sodium lamp
- Metal halide lamp
- Light emitting diode (LED)

**Light Distribution:**
- Polar distribution
- Direct / Indirect sources
- Fixture design

**Light Colour:**
- Light source
- Fixture re-ector colour
- Filters

**Controls:**
- Fixture layout strategies
- Schedule strategies: timing
- Dimming
- Switching
- Adaptive control intelligence
- Machine learning

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**Table 1. Considerations towards effective lighting design**

- to be acknowledged through cost benefits and energy efficiency. It must also be appreciated that daylighting is a beneficial design strategy for other reasons including:
  - comfortable and pleasant daylight spaces increase occupant and owner satisfaction and reduce absenteeism
  - pleasant daylight spaces may lease for better-than-average rates
  - comfortable daylight spaces have lower tenant turnover rates
  - daylighting is the most cost-effective strategy for reducing associated electric lighting and cooling energy by 30-40%
  - daylighting contributes to a more sustainable design approach

(Edward Berkeley National Laboratory, *Tips for Daylighting with Windows*).

Figure 2 outlines the suggested processes at the programming or planning stage of a project. A recent inclusion into the pre-planning and programming brief stage is the environmental outcome and expectation. Before ‘starting’ the design of the project it is desirable to have feasibility studies as well as goal and target setting for the suggestions made in the brief. The feasibility, target and goal setting should be assisted as much as possible through the expertise of the quantity surveyor and evidence-based experience. Such ‘experience’ may come though pre-design simulation software and the capabilities of a consultancy team.

The objective is to provide a cost benefit and energy feasibility study at the preliminary stage in the project. It is essential that some numerate result be provided to...
establish goal and target settings for daylighting against a base case building. This process should occur prior to any design concept of the building. Goal setting and target analysis can be provided through computer programs or through simplified hand calculation methods. One of the tools familiar to the author and highly capable of providing the interactive effects of daylighting with glazing type, dimming controls, number and size of window and skylight openings, as well as the reduction of HVAC cooling loads, is ENERGY-10 (refer to EDG note DES 21 An introduction to energy performance software). This program is more than adequate at setting design targets at the programming stage of the project. Its results in terms of operational energy could be used for initial feasibility and cost-benefit analysis. It should be noted that ENERGY-10 assumes the full operational benefit of a lighting control system.

**4.0 CAPITAL GAINS, ENERGY REDUCTION AND COST BENEFITS**

The energy and cost savings derived from daylight buildings support design for daylight. A total energy process analysis perspective may further substantiate the use of daylight (Figure 3). For every two units of useful lighting to a space it takes 33 units of energy to produce it. However, the energy production, transportation, and additional cooling required to the space due to the use of lighting make it a very energy intensive process (i.e. more than 98% of the energy is lost). From an ecological and sustainable standpoint, this argument by itself may provide enough reason to pursue a daylight building design. Having stated this, it is important to be able to enumerate and estimate actual energy and cost-benefit for a particular lighting design at the pre-design stage.

Figure 4 illustrates a resulting output from the ENERGY-10 program for a particular project, a Melbourne primary school building. Illustrated is one of several analyses produced by ENERGY-10 for examining the potential running cost savings daylighting could have among several other energy efficient strategies for the building. The argument for daylighting is often paramount in such an analysis and allows the targets for operational energy savings through daylighting over that of a base case building to be set at the programming stages of a project. In Figure 4 the operational energy for the base case building is estimated at $8327. The percentage of operational energy savings for each strategy is provided in the ranking.

In the forthcoming example (Figures 5 and 6), an educational building with an east-west axis was considered, as a case was made for the implementation of daylighting integrated with shading, lighting control and mechanical system sizing. Simulation studies were performed using the ENERGY-10 program (Balcomb, 1998). Figure 5 provides a comparison of the base

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**Figure 1.** The Chile Haus in Hamburg, Germany – plan and photo (P. Parlour)

**Figure 2.** Daylight integration into a project at the programming stage
Figure 3. Life-cycle energy of electric lighting (Bradshaw, 1993)

case (non-daylit building) against an energy efficient solution. It is evident that substantial savings are provided in the 'lights' category through daylighting and that these effects are further realized in the reduction of 'Cooling' energy. The 'Heating' category is somewhat reduced, but an energy efficient lighting system produces less heat and therefore such a building may require more heating.

Figure 6 illustrates the effects external shading devices and lighting control has on the peak loads of the mechanical system. The circled values indicate the two different (north and south) zones of the building. It is noted that the values are virtually identical in peak load, implying that the mechanical system selection would be the same. This example illustrates the benefits of a total integrated design approach, involving daylighting, glazing system selection and size, dimming control, shading and mechanical system sizing, at the pre-design and programming stages of a building. These targets should become part of the goal-setting in the brief.

5.0 DESIGNING FOR DAYLIGHT

5.1 Recognition of daylight entry into the space (façade & building envelope)

The most important design aspect of lighting integration is probably the understanding of where daylight enters the space. Table 1 suggests that there are typically three distinct categories by which daylight enters a space: window, clerestory and/or skylight.

Figure 4. The ranking of several energy-efficient strategies in terms of their effectiveness
Figure 5. Total annual energy consumption of a base case against the low energy case

Each of these categories needs to be evaluated according to the type and quality of light they offer. Typically the objective is to utilize the light from the sky (skylight) and to diffuse the direct component from the sun. Once this has been accomplished it is advantageous to consider the methods of bringing this diffused light into the space.

Side-lighting or bringing diffused light in through a window is considered to be effective at 1.5 times the floor to glazing height. Through the use of higher interior floor to ceiling heights and a clerestory light-shelf or light guiding portion in the façade this 'glazing height to daylight penetration' can be extended to 2.0 and even 2.5 times the overall glazing height (Figure 6).

Some very useful design guidelines for commercial buildings are provided by the Lawrence Berkeley National Laboratory - Tips for Daylighting with Windows under the Envelope and Room Decisions section (http://windows.lbl.gov/pub/designguide/). Figure 7 suggests the division of the façade into a daylight clerestory and a vision / view portion be considered for maximizing the opportunity for daylight into the space.

Figure 6. Peak mechanical system loads for the north and south building zones

The diffusing of direct sunlight at any envelope penetration is a very important consideration for the effectiveness of daylight entry into a space. If the lighting levels are too intense then there will be potential glare problems and a rejection of daylight by the occupant, through non-performance or tampering with the daylight system. In climates with seasonal overheating within buildings, diffusing the direct solar component before it comes in contact with the building envelope is very beneficial during these cooling months. This can be accomplished through external shading and light diffusing devices. An excellent example is the placement of a metal screen above an opal translucent skylight used in the Park Ridge Primary School, Melbourne, Australia (Figure 8).

The previous examples are only a few of the many ideas used to produce diffuse daylighting for a space. Several of the listed texts and sources as provided in the reference list should be sourced for additional information and rules of thumb. EDG note DES 6 Daylighting of Buildings also contains information on daylighting strategies.

Figure 7. Concepts for considering side lighting into a space for maximising daylight
5.2 Brainstorming concepts on lighting

It is not ludicrous to consider the design process as one which is inclusive of 'daydreaming' or brainstorming. In a recently designed university building, several brainstorming ideas were considered with regard to lighting. The cross-sections shown in Figure 9 illustrate a before and after scenario with regard to implementation of daylighting concepts integrated with electric lighting design and control as well as comfort considerations. Unfortunately the 'before' case is a quite typical solution for an Australian building. Brainstorming for a pre-determined proportion and building volume occurred very early in the lighting consultation stages of the project. In hindsight and in reference to developing a 'roadmap' such tasks should be considered directly after the project brief/programming phase. At this stage there is the opportunity for the locations of window openings, daylight distribution systems, glazing material and type, etc. to be considered in conjunction with the electric lighting concept.

For the above example the brainstorming process continued through to the luminaire placement, control and design itself. A direct-indirect fluorescent lighting fixture was designed with the upward light distribution into a "browning" shape (Figure 10). Such a photometric distribution is effective at distributing the light more uniformly across the ceiling plane and avoids distinctive areas of contrast. This lighting fixture has an 80 percent light output ratio (LOR) or efficiency.

6.0 EXAMPLES AND CASE STUDIES OF INTEGRATED LIGHTING DESIGN

The following studies are examples of daylight taking on a primary role in the project brief requirements. Unlike the typical approach advocated by electric lighting consultants, each space is designed first to achieve an optimal daylighting performance. Only after achieving a daylighting scheme was the design of electric lighting considered. It was further realised that the electric lighting layout and control strategy was to be designed in terms of complementing the daylighting concept. Several benefits of this altered approach to lighting design are recognised through the case studies provided.

6.1 Electric lighting integration: working with the daylit zones

Lighting layouts for offices reliant on side lighting, will commonly provide a perimeter, centre and interior zone of daylight. Figure 11 provides an example of integration of electric light with a perimeter daylit zone. If a proper glazing system is selected which has a high visible transmittance and low shading coefficient (SC) a result as indicated in Figure 11A is achievable. The light coloured lines indicate a satisfactory daylight level above 350 lux on the work plane. The next step is to introduce a lighting luminaire and control system which is integral to this daylight performance (Luther,
1997). A perimeter row switching (or dimming) concept is presented in Figure 11B. Here upon entry to the space the interior row automatically is switched on (through the presence detector – PD) while the perimeter row (darker shaded luminaire) is left off. The interior row could also be dimmed to a set level. The user has control over the switching of the perimeter row (wall switch – S) and can switch this light on at they choose. Studies have demonstrated a 30% electric light reduction from that of a non-perimeter row switching concept (Luther, 1998).

6.2 Electric lighting strategies: the selection of the light source

The electric lighting strategy provided in Figure 10 illustrated a light source that complemented and mirrored the effects of daylight entry. Several other reasons for selecting a light source might be its ability to allow for dimming and its colour rendering capabilities.

In the next example (Figure 12) an integrated lighting layout for an open 1000m² studio space is introduced which was designed considering daylighting patterns first. This space had to meet several lighting requirements and expectations from its users. The need to separate lighting zones into corridors and studio spaces, provide on/off switching to blackout areas and dimming in daylit zones to achieve a lighting balance, demanded a flexible and adaptable lighting control system. The main reason the DALI lighting control system was useful in this case was due to the atypical mounting of the fixtures 90° to the daylight zones. DALI provided the flexibility to group individual luminaires to the perimeter zone as well as create other zones. Hence a decision was made to employ the new DALI system which permitted individual control and programming to each of the 120 plus light fittings.

Figure 12A is the daylight result under a partial cloudy sky (in winter) for the original space which only had the west facing windows. For Figures 12B & 12C a clerestory opening and interior zone skylight was introduced (Figure 13). The resulting difference with the inclusion of clerestory and skylight openings is clearly evident, in producing daylight zones.

6.3 Lighting control systems: obtaining a balance of light

Creating a lighting balance within large open spaces together with daylight can be a challenge. For a computer-dominated open office environment, daylight can become a liability when levels are too high and the light consists of direct sources upon the screen. It is recommended here that lighting designers consider the
assistance and complementary role of electric lighting systems. This advice implies that we do not design for minimum daylight factors (DF) under an overcast CIE sky, but rather obtain results under partial cloudy or average sky conditions. When considering daylight extremes it is suggested that we investigate both ends of the spectrum; a complete overcast winter as well as a clear summer sky.

The following results (Figure 14) are a very successful example for an open office with a heavy use of computers. In this case, non-direct (south facing) sky light enters the space through clerestory windows. The selection of the glazing type, location and opening size was optimized to allow for a reasonable, but not daylight dominated result. This produced a selective daylighting result which relies upon the electric light source to supplement the daylight.

7.0 CONCLUSION

This note has introduced a possible approach to integrated lighting design. It has demonstrated the need for daylight integration into our present lighting design methods. Although there are many issues to be undertaken by the designers, the strategies that reinforce and support daylight at the beginning stages of any project, are vital to ecologically sustainable design. This note has emphasized that in order for an integrated and effective lighting design to take place the following should be considered:

- Learn from the precedence of good integrated lighting examples.
- Quantify the cost and energy saving benefits at the pre-design and programming stages of a project.
- Set targets in the project brief for daylight integration and control at the pre-design and programming stage.
- Establish the daylight entry provided by the envelope: (windows, clerestory, skylight).
- Brainstorm effective and integrated lighting concepts.
- Investigate how daylight is controlled through the building envelope and interior design.
- Examine daylight patterns throughout the year for various sky conditions and periods.
- Study the appropriate light sources, distribution and layout for the space.
- Produce a flowchart for integrated lighting control strategies.

Figure 12. Daylight results for an open studio under different periods and conditions

Figure 13. Cross-section of the studio with existing and proposed envelope openings
Figure 14. Plan and section of a clerestory open office showing daylight (only) levels (BERG (Built Environment Research Group) report – Deakin University)

References
Lawrence Berkeley National Laboratory – Tips for Daylighting with Windows (http://windows.lbl.gov/pub/designaguide/).

Biography
Dr Mark Luther is a senior lecturer at Deakin University, School of Architecture and Building. He teaches in the curriculum of environmental science and building system services. He is also the consortium director of the Mobile Architecture and Built Environment Laboratory (MABEL).

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