# RADIANCE ANALYSIS AND ITS APPLICATION TO REAL TIME DYNAMIC LIGHTING CONTROL

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## ABSTRACT

There is a great deal of research being conducted on the use of LED lighting systems in buildings. Their potential benefits derive from both the high levels of control they offer and increased energy efficiency as the technology develops. Rather than cluster many LEDs into large light sources as a replication of existing technologies, some of this research is looking at more distributive models where multiple LEDs are embedded into each ceiling tile and distributed more evenly over large office spaces.

From a daylight-linked perspective, such lighting systems offer unprecedented levels of control, with the potential to maximise both comfort and energy savings. However, the ability to accurately and efficiently control such a multitude of individual light sources is significantly limited by existing sensor technologies required for dynamic feedback within such a system.

This paper proposes that, instead of relying on real-time measurements from in-room sensors, the control system could be based on the results of a large number of pre-computed lighting simulations using daylight and fixture coefficients for multiple control points over each floor in a building. This would involve generating reasonably accurate geometric computer models of those areas of the building to be subject to this level of lighting control and using an application such as Radiance to perform the analysis.

## KEYWORDS

RADIANCE, LEDs, Lighting Control, Daylight Linking, Light Simulation

## INTRODUCTION

With developments in the Radiance *Rtcontib* program, it is possible to calculate and store the relative contribution of different parts of the sky dome to daylight levels at points within a room or over an entire building. By dividing the sky into discrete segments and then varying the radiant distribution of each segment to simulate changing sky conditions, it is possible to quickly calculate illuminance levels for almost any type of sky or weather condition. This technique is already widely used within the industry (Reinhart et. al. 2006).

Real-time analysis of the radiant distribution of the sky is becoming much easier with the use of digital cameras, fish-eye lenses and fast computer image processing. Feeding this information from an unobstructed area on the roof (or a nearby tall building) into the sky segment model, it is possible to generate daylight illuminance levels in close to real time. The resulting images can then be easily processed to determine areas of low light level that need supplementation by the installed artificial lighting system.

As a parallel database, the same *Rtcontrib* program can be used to calculate the relative contribution of each light source at any point within a room or building. A simple algorithm can then be used to calculate the required power level for each light fixture to meet the supplementary demand.

As sudden changes in perceived artificial light levels are generally undesirable in a workspace, these databases and calculations can easily be handled by a single computer acting also as the lighting controller. This central controller could also be programmed to introduce other subtle seasonal or diurnal variations, such as to simulate circadian rhythms for example. It is also possible to integrate room occupancy sensors and apply this information to moderate the supplementary demand in different parts of the building at different times of the day.

The use of LEDs embedded within ceiling panels offers designers an unprecedented level of control over the lighting distribution within large spaces. Potentially the output of each panel can be individually controlled, allowing for a wide range of lighting patterns to be produced by a single system. Whilst it can be expensive to wire up individual controls to each fixture, this can potentially be offset by savings to be had from being able to link with daylight systems and providing only supplementary lighting when and where required during the day.

LEDs can offer characteristics in lighting that are found in existing lighting technology, such as a high level of controllability, an efficacy curve which can be almost linear at lower currents (compared to fluorescents where there is a big drop in efficacy at lower currents), longer life, thus making them suitable for lighting applications and systems that were not possible in the past. One of such systems is the one discussed here in this paper, where a number of technologies are put together, in order provide a daylight linking system.

*Figure 1 – An example of an LED embedded ceiling light panel*

**An LED-Based Daylight Linked Control System**

Using a digital camera with a fish-eye lens, it is possible to capture unobstructed images of the entire sky dome at regular intervals – as often as every few seconds. From each image the luminance distribution of the sky can be determined and, using previously calculated daylight coefficients from detailed computer simulations, it is possible to calculate daylight levels at any number of control points within a building. Feeding these levels into a control system able to regulate individual LED ceiling panels, it is then possible to determine the optimum output of each panel to meet pre-defined lighting levels at each point with minimum wastage of energy.

A series of steps would be required in this control system in order to achieve the desired outcome. These steps are as follows:

1. Determine control point positions over each floor.
2. Calculate daylight coefficients at each control point.
3. Determine LED output characteristics.
4. Calculate LED coefficients at each control point.

The dynamic control of the system involves periodically:

1. Recording sky segment luminances.
2. Calculating daylight levels at each control point.
3. Determining the lighting deficit at each control point.
4. Calculating optimum LED power levels.

## SETTING UP THE SYSTEM

**Distributing Control Points**

The first step in setting up such a lighting system is to determine the location of control points over the floor being controlled. Control points define those areas which have a particular lighting requirement and where each daylight and artificial lighting analysis will be performed. Each control point is assigned both a preferred and a minimum allowable lighting level which is intended to be met by the combination of daylight and ceiling LED output.

The exact number and distribution of these points will depend on the nature and layout of each space. Whilst it is possible to tailor the distribution of control points to closely match a particular occupancy pattern, for maximum flexibility in space use, a relatively regular grid is recommended. This way changes in function or usage can be accommodated by simply editing the required light levels at each point.

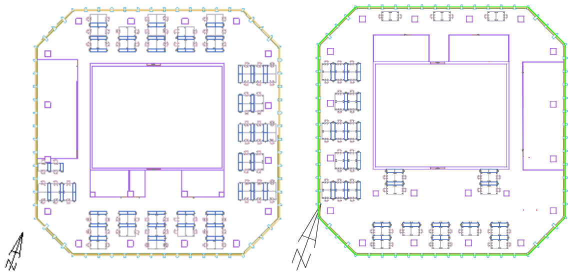

*Figure 2 – Different configurations of lighting requirements in the same building, for offices located at different floors*

Because changing the required light levels is a simple matter of updating entries in a data array, it can be done close to instantaneously and, if required, on a schedule to reflect diurnal or seasonal changes within the building.

**Calculating Daylight Coefficients**

With recent developments in the Radiance *Rtcontrib* program, it is possible to divide the sky dome into a series of discrete segments and then calculate and store the relative contribution of each to daylight levels at each control point. These stored values are known as daylight coefficients and allow actual daylight levels to be quickly determined even under changing sky conditions.

There are many methods for generating sky subdivisions and they have been widely published (Tregenza, 1995, White, et. al. 1998 and Wenninger, 1999). However, a standard 145 segment equal area method has been shown by Tregenza to be sufficiently accurate for use in (Tregenza, 1995)

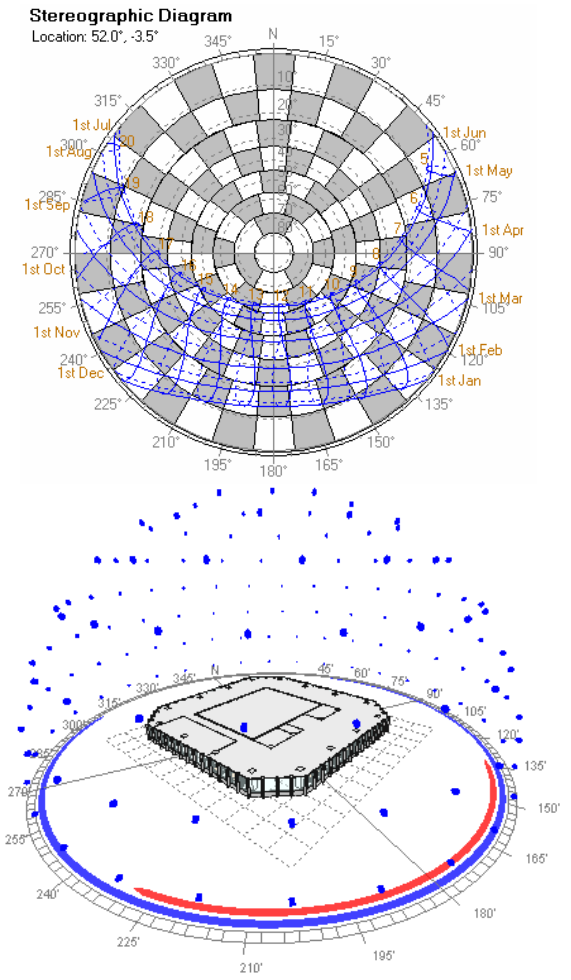


*Figure 3 – The 145 segment equal area sky subdivision method proposed by Tregenza.*

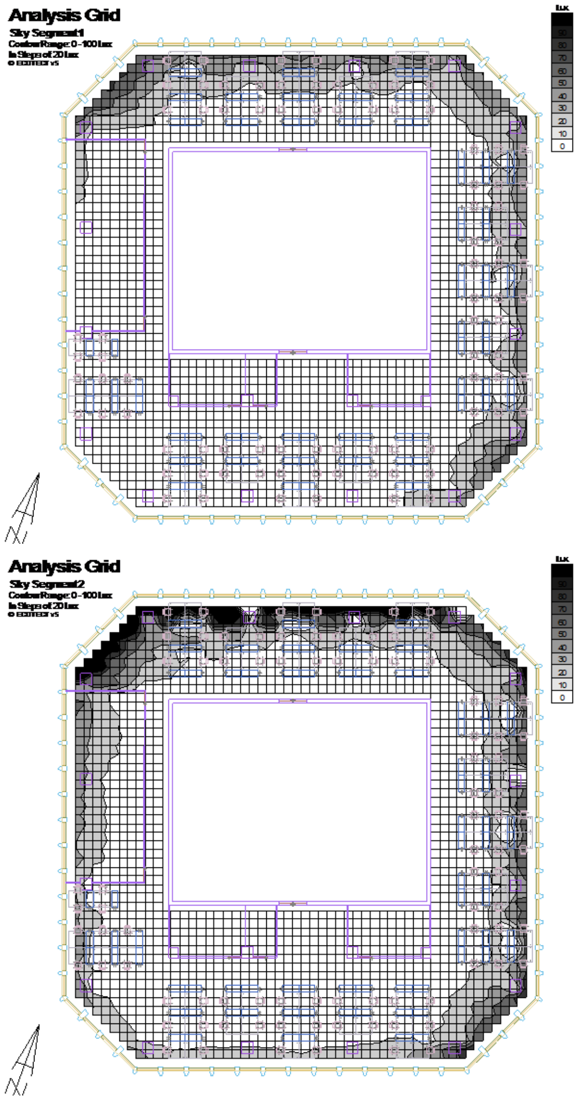


*Figure 4 – The contribution of two different sky segments to internal daylight levels.*

Whilst the *Rtcontib* program simplifies and speeds the process considerably, the underlying method is best explained through the calculation of a series of illuminance images in which only a single sky segment provides the luminance. With the total luminance of each segment being the same fixed value, the amount of illuminance reaching each control point in the model is stored for each sky segment in an array. The total illuminance is found by simply summing the contributions of each sky segment. The calculation of actual daylight levels is then simply a process of multiplying the actual luminance of each sky segment by the relative daylight coefficient of that segment and summing the modified results.

Examples of this can be found in figure 4, where the effect of two different sky segments has been simulated. What is clear, is the big different between the two sky segments in terms of their contribution to daylight levels in the space.

The real benefit of using Radiance with this method is that it fully accounts for and includes the effects for diffuse inter-reflection, glazing transmission and external overshadowing.

### Determining LED Output

The accuracy of the system very much depends on being able to characterise the output distribution of each LED fixture used in the ceiling lighting system. Most manufacturers provide the output distributions of their products in electronic form, typically as an IES file or similar photometric data set that describes output lumens at a range of three-dimensional angles from the directional axis of the fixture. The output distribution significantly affects each LED's individual contribution to each control point.

If this information cannot be obtained from the manufacturer, then there are commercial laboratories that can measure this directly from a sample set of panels.

As a last resort, by manually controlling individual LED fixtures, it is possible to physically measure the contribution of individual LED fixtures at each control point using an illuminance meter at night, however this is likely to be extremely laborious.

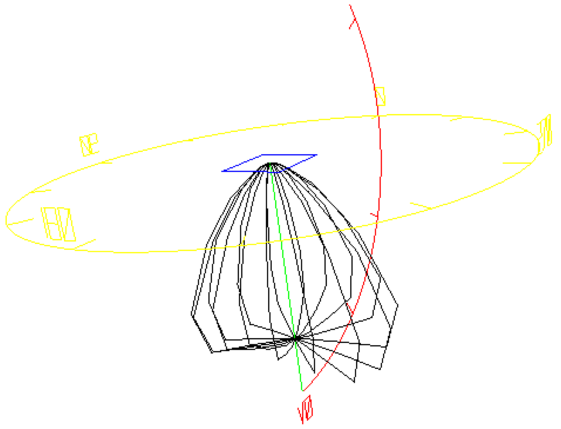

*Figure 5 – An example manufacturers data on LED output profile.*

**Calculating LED Lighting Coefficients**

Once the output distributions are known, the same technique of determining the relative contribution of each sky segment can be used to determine the relative contribution of each LED to illuminances at the control points. A series of illuminance images are produced in which only a single LED provides the luminance. With each LED set to a known output (derived from a calibrated power input), the amount of illuminance reaching each control point is stored for each LED in a separate array.

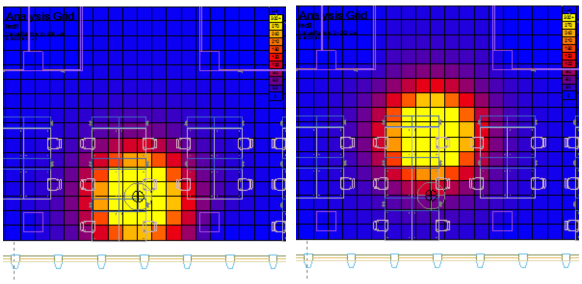

*Figure 6 – The individual contributions of two different LED ceiling fixtures.*

Here too, the total artificial illuminance level at each point can be found by simply summing the contributions of each LED in the array. However, the output of each LED can be precisely controlled, making it possible to produce almost any pattern of illuminance over the floor area.

## DYNAMIC PROCESSING

Once the characteristics of the system have been established and all the Radiance runs completed, the control system can begin providing the supplementary artificial lighting dynamically. As discussed earlier, this process involves periodically recording the sky luminance distribution, determining the total luminance over each sky segment and using this to calculate the daylight level at each control point. The resulting daylight levels are then compared to the preferred light levels for each point to generate a deficit map showing the amount and distribution of supplementary lighting required over the floor area.

**Recording Sky Luminance Distributions**

Work in this area is ongoing, but what is actually needed is a capturing device that is able to record sky conditions over the whole dome, at each moment. Current lens systems allow for this, but still there could be issues with distortion of the image close to the horizon.

A single sky capturing system at the top of a building in this case, could be enough to serve the whole building. Issues, such as reliability of the system would ofcourse have to be tested before implementation.

Another issue that is important to address is the location of such a system. Preferably at the top of the building. Overshading from other buildings near by can be taken into account in this system.

In addition, such a system could also in theory be positioned at the top of the tallest building in a city block and serve as the real-time database for all buildings nearby.

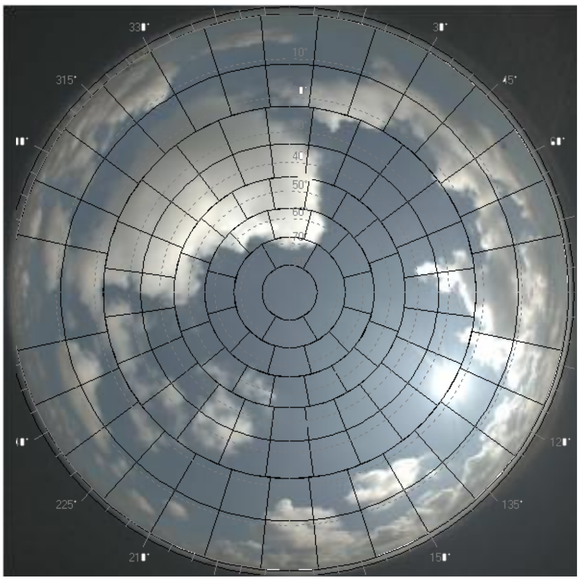

*Figure 7 – An example of a digital camera fitted with hemispheric lens.*

**Constructing a Deficit Map**

The amount of supplementary lighting required at each control point is calculated by subtracting their calculated daylight levels from their preferred lighting levels. Negative results are ignored as these indicate a surplus. The resulting array of required artificial lighting levels is then passed to the LED control system in order to determine the optimum output for each fixture.

In future research, a surplus map may be used to control shading systems or electro-chromic glazing in an attempt to minimise potential glare problems.

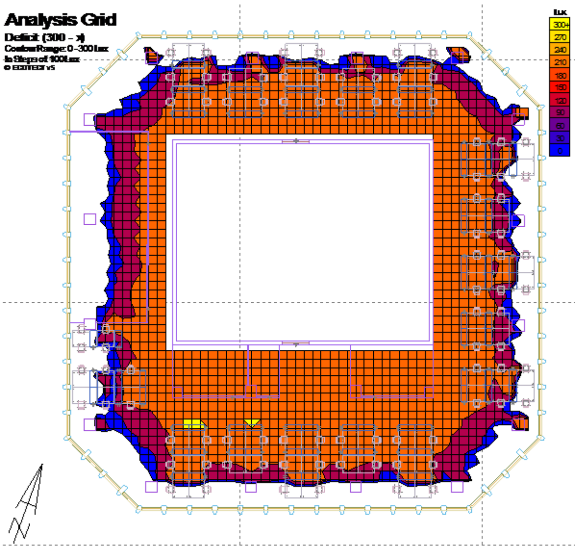


*Figure 8 – The construction of a deficit map from lighting requirements and daylight levels.*

### Optimising LED Output

Properties of LED fixtures can be inputted here, like lumen output, output profile, efficacy curve and colour. Other performance factors can also be taken into account, like the effect of age, current and room and LED junction temperature on the efficacy of LEDs. All these properties can be inputted for each individual fixture, thus allowing for individual customised control.

Apart from daylight linking, there are other not as obvious applications. Some of these include:

- Providing supplementary light from nearby light sources to compensate for a fixture that is not working properly any more.
- Taking into account all the properties of a replacement luminaire (whether this is new, used, or of a different technology alltogether)
- Providing a rough estimate/warning on individual light fixtures that will need replacement, based on personalised cummulative usage profiles.
- Providing the desired light levels and lighting effect, for a new internal layout or function. Whether that is a temporary change (i.e. an event taking place), or more permanent (i.e. a different use to the building alltogether).
- Providing the desired light levels, when a renovation on the skin of a building takes place, where opening, glazing properties, or shading could change, thus affecting natural lighting distribution. This would also apply for cases where other buildings are built nearby, which would affect overshading and reflected light.
- Integrating movement sensor information into the system, to adjust light levels depending on occupied areas.

## CONCLUSION

The method proposed in this paper is not limited to LED lighting system, but can also be applied to existing lighting technologies.

The use of Radiance and especially the Rtcontrib command is instrumental for the calculation of daylight and artificial lighting contributions.

Research in this area in ongoing and it hoped that the system will soon be in a position to be used in a real application.


## ACKNOWLEDGMENT

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