# A single sensor system for whole building daylight linking

S. Stravoravdis
*Cardiff University, United Kingdom*

ABSTRACT

Linking artificial lighting with daylight requires the presence of controls and censors for each room. Apart from the energy saving produced though, this can have significant initial cost implications for the user. This paper presents a method for linking artificial lighting with daylight over a whole building in real time, through a single sensor system.
By placing a camera on the top of a building, it is possible to capture a digital image of the sky at regular intervals. Post processing that image can give us an accurate representation of the sky conditions at any given moment. Using that information we can reconstruct any sky condition and predict/simulate the amount of available daylight at any point within a building. By utilizing a database management system, where all the simulation information is stored, we can obtain the simulated daylight levels for each point within a building, for the current sky conditions. This is turn, allows us to control artificial light levels for all the building from a central location.

## 1. INTRODUCTION

Artificial lighting can account for a significant part of the electrical energy demand of buildings. Studies have shown more than 20% can be attributed to lighting in the case of non-domestic buildings (Li et al., 2002).

By incorporating daylight into the design of buildings, significant energy savings can be achieved (Atif et al., 2003). In order to achieve these savings though, the presence of controls is required, so that on/off switching or dimming is possible, as well as the presence of sensors that can detect the amount of daylight available and thus inform the controls through a BMS system, how much light they need to provide, if any, at any given time to supplement the available daylight.

The presence of controls is a necessity and a financial burden that cannot easily be avoided, if the integration of daylight with artificial lighting is to be achieved. The presence of photosensors though, although desirable so that daylight levels can be determined, can add a significant initial cost to the whole artificial lighting system budget of a building. This is due to the number of sensors that need to be installed so that the variation in daylight levels within every room can be accurately represented, the additional installation costs and maintenance/replacement costs. All these costs, prevent many building owners from installing photosensors even though over time there is a payback on their investment.

To this end, a method is proposed where the use of photosensors is not required to achieve dynamic daylight linking. Instead, a single sensor system is proposed where the variations in daylight availability due to changing sky conditions are accounted for and a range of other technologies are implemented to provide real-time daylight linking for a whole building.

## 2. SINGLE SENSOR SYSTEM

### *2.1 Background*

In order for the system to provide the maximum possible savings of electrical energy, it needs to be able to take account of the changing sky conditions due to clouds, time of day and day of the year. These variances in sky luminance can be minute by minute, thus significantly reducing or increasing daylight availability within buildings for that period. Photosensors can capture the resulting effects in the change of light in real time, but if they are not present, then another method is required that can do the same.

The method proposed utilizes a range of currently available technologies and puts them together in a novel way, so that the need for photosensors in eliminated, all artificial lighting demand can be controlled centrally and dynamically in real time depending on the sky conditions.

There are two main components proposed, one has to do with the method and process that needs to be used in order to predict all the desired lighting data and the other has to do with the system that needs to be implemented.

In order for the internal lighting conditions to be determined, a method was developed to predict through simulations the internal light levels for any sky condition. To achieve this, the following steps need to be undertaken:

- Generation of 3D model of building, including nearby building geometry
- Calculation of daylight lux levels within rooms for all possible sky conditions
- Storage of calculated data on a database

For the system to operate there are three main components required:

- Digital Camera, with a fisheye type of lens to capture the sky at any given moment above the building
- Computer Terminal, to receive and process the captured image, perform additional calculations and the resulting information to the control systems
- Lighting controls linked appropriately to the chosen artificial lighting luminaires

### *2.2 Daylight Availability Prediction*

In the proposed method, ECOTECT (Marsh 1996) was used as the main software for the generation of 3D geometry, exporting into RADIANCE (Ward 1994), importing the results and exporting them again to a database.

The lighting simulation engine used to predict daylighting levels within rooms, over a grid was RADIANCE. RADIANCE was also used to construct a number of different sky scenarios and simulate each one individually.

The point results obtained over the set grids, were exported to a MySQL database, a method of which can be found on Stravoravdis et al. (2005).

In order to calculate the minute by minute variances in sky luminance, some approximations were made. The sky was divided into a Perez sky model of 145 segments (Perez 1993) with each segment being able to have 4 different illuminance values (Sunny, Clear, Overcast, Partly Overcast). This, makes a total of 580 different possible skies, all of which need to be simulated over the whole year by superimposing the location of the sun on top of the sky segments. This, allows us to simulate any possible sky condition and obtain a value of natural light levels at any point within the building for any time of the year.

The method, allows for the sky to be subdivided into more segments and have more subdivisions of luminance values, but this would obviously increase dramatically the already heavy load of simulation required.

The way simulations are conducted, is to separate the process into two steps. Every segment of the sky simulated separately and then the results obtained are exported into the database. Once all the results are there, then depending on the type of sky that we want lighting results for, the relevant contribution of each segment of the sky for a particular point within the room is added. In the end, this is done for all points in the grid and thus through this post-processing a lux level value for any point can be obtained, for any possible sky condition.

Exporting results on a database and managing them through a computer can be an easy process, but when then results that need to be uploaded are excessive, processing times can become slower. To this end and method is proposed, where a unique ID is given to all possible 580 skies. The different skies and their results are pre-calculated inside the database, so when a digital image is captured and then processed to determine the luminance of each segment (based on the 4 or more ranges defined), a unique ID is given to this sky, which is then picked up by the database to provide the already calculated results much faster.

*2.3 Capturing Sky Conditions*

Changes in the sky luminance distribution can occur minute by minute, or even second by second. These changes can be insignificant, or dramatic. In any case, this effects the amount of daylight that building can receive directly from the sun and from the rest of the sky.

The amount of natural light that enters through the windows plays the most important role in determining whether the light that enters is enough, or adequate to light a space. If the light is sufficient, then the artificial lighting could be turned off, if it is partly sufficient, then certain lights might need to be turned off and others dimmed. This is the most efficient way or linking daylight with artificial lighting. First look at the supplied natural light at any moment and then supplement that light, if needed, with the appropriate intensity artificial lighting. Human response to constantly changing artificial lighting levels would not be positive, thus a BMS system is commonly used so as not to allow sudden changes in artificial light levels.

To capture these effects a digital camera is used, which is connected to a computer terminal. The camera, which has a fisheye lens constantly captures images of the sky and sends them to the PC for post processing. This, allows for a near real time capture of current sky conditions. The image in then post processed by a software, capable of separating the sky into as many desired segments and with as many desired luminance levels for each segment, then is exports it as a sky definition for RADIANCE, which is then used for simulations.

## 3. DISCUSSION

*3.1 Advantages*

There are some clear advantages to using this method, including:

- a reduction in installation and maintenance costs for sensors,
- flexibility in incorporating any sky segmentation desired,
- flexibility in calibrating the system with an additional photo sensor, if desired, or with measure results.

Takes into account of self-shading of the building and overshadowing by adjacent building, thus if an external shading device is later incorporated or a new building is constructed, which would cut down the available natural light, can be later implemented into the database with additional simulations. Even if the internal layout changes or the use of the space, all that information could be provided and with a few more extra simulations could be implanted into the updated database.

*3.2 Disadvantages*

- Current digital technology is not as fast yet to provide real time images of the sky and at the same time be able to post-process the results fast enough might be required by this application. Rapid developments in the field though, indicate that real time capturing and processing will be possible very soon.
- It is possible that such a capturing device might fail over time and in that case, there either needs to be a back-up device or there is a danger that the whole system will stop functioning.

The whole system is based on computer simulations and possible approximations through lighting simulation tools. Accuracy might be sacrificed in this case and thus lighting levels predicted could be underestimated or overestimated. In either case, there needs to be a range of values which the lights should never light below, so that such problems are minimized.

## 4. CONCLUSIONS

A new daylight linking system was described which suggested the use of a single sensor on the roof that captures the sky conditions at any given moment and through computer simulations and post processing of images and results, the light levels within buildings can be determined.

This system, promises to cut down dramatically on initial cost installation and provide the necessary information on a BMS system to provide the required supplementary artificial lighting where is needed and when its needed. In addition, the flexibility of a system which is all digital appears to be very promising, in accommodating a number of changes which might occur throughout the life of a building.

This work is currently developmental, however it is only by exploiting the technologies that are now available and putting them together that we can provide significant reductions in energy with minimum effort.

## 5. FUTURE WORK

It is hoped that more work will be undertaken to test and refine the accuracy of the system, and its real life performance.

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