Measuring the luminance and chromaticity distribution of the sky

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One of the prerequisites for the design of buildings that make good use of daylight for internal illumination is a knowledge of the daylight climate in the place where the building is to be situated. The amount of light likely to enter a building is often quantified using Daylight Factor, the ratio of internal to external illuminance, which can be measured by taking some internal and external readings with a luxmeter. A luxmeter is a photometric device that uses a photocell with V-λ and cosine correction. In other words its response is corrected so that it responds in a similar way to the human eye and accepts light from all directions from the zenith to the horizon. A typical daylight factor that might be used as a design parameter for an office space is 2-5%. Prior to the 1980s little detailed data had been gathered on the world's daylight climate and designs used an overcast sky and the daylight factor calculation to predict the amount of light reaching the inside of buildings. During the 1980s, the concept of daylight coefficients was developed by Tregenza and Waters (1983) in order to refine the process of daylight design. Use of daylight coefficients allows spatial variations in sky luminance to be taken into account in daylighting design but requires knowledge of the luminance distribution of the sky. The problem here is that the sky is constantly changing and its luminance is difficult to predict. Under the auspices of the International Commission on Illumination (CIE) a fairly long term, world-wide, programme of measurement and study was started in the early 1990s to quantify sky luminance and other parameters to produce a set of 15 Standard Skies for use by architects. The programme was known as the International Daylight Measurement Programme (IDMP). The aim was to give a basis for predicting the frequency distribution of these skies and thereby facilitate more "evidence based" daylight design. Part of the measurement programme involved the design, construction and use of specialised sky scanners. Two companies, PRC Krochmann of Germany and EKO based in Japan, produced the scanners used in the programme. These scanners were highly sophisticated and expensive items and were provided only at a small number of the IDMP stations – those designated as of "Research Class". A sky scanner typically is required to scan the entire sky vault or hemisphere, measuring the luminance in candelas per sq. m. of a series of 145 sky patches, each defined by an acceptance angle of 10 or 11 degrees. In order to avoid errors due to changes in luminance during a scan it was felt to be desirable that a scan be completed in about 1 minute.. Scans were taken at approximately 15 minute intervals over a long period (typically a year) in order to obtain data of statistical significance. It would seem that very few of these scanners are in use today and that interest in the IDMP seems to have declined since the programme came to an end in about 1997.

It was suggested to the author, by colleagues at the Low Energy Architecture Research Unit (LEARN) at London Metropolitan University, that it would be a useful aim to attempt the construction of a simple low cost sky luminance measurement system and the initial suggestion was to use light emitting diodes (LEDs) as sensors. This may seem strange since LEDs are emitters of light, but they are sensitive to light and there is documentary evidence of their use in sky measurement application. A paper by Acharya, Y.B, Jayaraman A., Ramachandran S. and Subbaraya B. H (1995) describes a recent application using LEDs as sensors. However, this was a sun photometer, where the sensor was pointed directly at the sun in order to measure the optical depth of the atmosphere and to investigate atmospheric turbidity. The sensor in such an application is subjected to very high luminance levels and does not need to be very sensitive. Light emitting diodes of different colours are sensitive to different wavelengths and the study mentioned the simultaneous use of a combination of green, yellow and red LEDs in a single optical system. The acceptance angle was approximately 10 degrees – the same as a commercial sky scanner and the system tracked the sun. In fact, early in the current project, some experiments were carried out to investigate the sensitivities of variously coloured LEDs to determine if they might be suitable for use in the project. If they had been found to have sufficient sensitivity it may have been possible to construct an economical whole sky sensor array consisting of perhaps 145 of them (matching the CIE scan pattern) because LEDs are very inexpensive compared to the more usual devices used as light sensors, photodiodes and selenium photocells. However, it would have been expensive to provide the large number of amplifiers and data acquisition channels needed, although it may have been possible to find a means of multiplexing them into a smaller number of amplifiers. Variations on such a scheme have been postulated in earlier work by Hayman (1989) and Pritchard (1992) using arrays of photodiodes. In the event, measurements indicated that LEDs would not be sensitive enough without very high gain amplifiers, which would have increased the cost very considerably. After a detailed study of the published information on sky luminance measurement, it was decided to proceed with a conventional motorised scanning system similar to those used in the IDMP. This scanner would be a simplified and low cost prototype, whose main use would be to replicate some of the original measurements as far as practicable and to carry out measurements on sky chromaticity using a new photodiode colour sensor which had become available. This new sensor uses red green and blue thin film filters applied directly to the surface of a photodiode to form a small sensor which is sensitive to each colour separately. The sensor would be mounted in a small box with a tube to define the acceptance angle for light. Scanning would be achieved by driving the sensor platform in two axes directly using stepping motors. One motor would be mounted in the base unit and would provide azimuth motion. The other would be mounted on the shaft of the first motor using an angle bracket and would provide elevation motion.

The sensors were used in the conventional photovoltaic mode with current to voltage converters to produce output voltage linearly proportional to incident light intensity on each segment of the sensor (RGB). In order to simplify the design and construction of the sensor assembly and to keep its mass to a minimum, it was decided to mount the amplifiers in the base of the instrument and connect the sensors to them via a cable with appropriate screening and grounding.

To save development time, and to ensure adequate performance, proprietary photodiode amplifier assemblies were to be used rather than a custom design. The amplifiers selected had adjustable gain so they could cope with the widely differing light levels likely to be encountered in sky measurements. To allow the use of the RGB sensor, three identical channels of amplification and data acquisition would be required. An additional channel would need to be provided in order to measure the global illuminance at the instrument position for reference purposes. It was decided to use a Universal Serial Bus (USB) data acquisition card that could be connected to and powered from a laptop computer. Financial constraints dictated the use of a low cost device with 12-bit resolution

For the prototype instrument. The data acquisition device also needed to provide digital inputs and outputs suitable for interfacing to and driving the tracking system so that it could carry out the complete interfacing function between the photocells and amplifiers, the tracking system and the controlling computer.

Given that for the original M.Res project there were tight deadlines, it was thought to be essential to use a sophisticated rapid application development (RAD) environment to develop the control and monitoring software. An obvious and available choice of system for this type of application is National Instruments Labview, which is an industry standard software development system for generating computer based (virtual) instruments. Once the decision had been taken to go down the Labview route, the design environment was more or less determined. Labview has a graphical user interface which supports programming using a proprietary visual language known as 'G'. The 'G' language allows the user to simultaneously design and test the front panel that the design will have, and the wiring diagram behind it. In essence, the designer works between these two views of the design. The front panel contains only controls and indicators and the wiring diagram contains the functionality in the form of a block diagram. Labview both supports and depends on design hierarchy to reduce the apparent complexity of the design task and to allow reuse of components in several positions in the design. The advantages of the Labview design environment over conventional text-based systems are considerable. Debugging is easier, since each item or subVI is executable on its own unlike subroutines in text based systems, which need a context in which they can be executed. However Labview, like text based programming systems, demands that the designer structure his/her designs efficiently. It is important to structure Labview programmes correctly as there is a significant effort involved in crafting each subVI and ad-hoc reworking can cause dislocations in the connectivity of hierarchical designs which are not hard to detect, but may be impossible to resolve. Another key feature of Labview, and one that makes it exceptionally powerful is its array of built in functions. Labview has functions for mathematics, logic, string handling etc. as well as file handling and many more specialised functions. Many of the functions are polymorphic depending on the signals connected to them and adjust automatically to handle single data quantities or arrays of data.

Alongside the scanning measurements, some work was done on measuring sky luminance using a digital camera fitted with a 183 degree fisheye lens.

A prototype scanner was designed, built and tested using Labview based software both to produce the required scanning behaviour and to process the digital luminance and chromaticity data that it produced.

The prototype scanner was found to be capable of carrying out a full sky scan in approximately 1 minute, taking 800 readings for a scan. In order to reduce the processing time a smaller number of results were selected from those obtained at scan time. The scanning pattern consisted of continuous 180 degree horizontal sweeps at different elevation angles, covering the entire sky in

two half hemispheres. This was due to a limitation in the scanning mechanism However it was subsequently decided to implement a more standard 145 sky patch scanning pattern in which the scanner stopped at every reading. This required a redesign of the drive system to obtain more torque in the azimuth drive system. The reason for making such a modification was to obtain more congruence with the results from previous work
Unfortunately the modifications meant that it took longer (2 minutes) to complete a scan. With the modified scanning system, luminance values were measured from the roof of the LEARN building and were compared with those from a specialised digital luminance camera fitted with a 183 degree fish eye lens. The analysis of these experiments is still in progress. It is intended to present some of these results at the time when this paper is given at the 2nd Palenc conference in September 2007.
The global illuminance channel was calibrated against a standard lux meter in the integrating sphere at the Low Energy Architecture Unit using a 500W projector lamp.
3. Chromaticity measurements were carried out, initially without calibration but with the prospect of comparison with the colour images that can be obtained from the digital camera. The acquisition of colour data from these initial experiments will allow the development of algorithms for evaluating the chromaticity of sky patches from the raw RGB data obtained.

1. RESULTS

Some preliminary results are presented here.
The graph in Figure 1 shows the variation of luminance with elevation at the four cardinal points derived from a scan taken on July 11th 2007 at approximately 12 noon. The values were obtained by interpolating from the 145 point sky luminance distribution measured with the prototype scanner. The sky conditions were overcast, with no visible sun and a global illuminance of approximately 32 klux. Global Illuminance was also recorded over the time of the experiment.

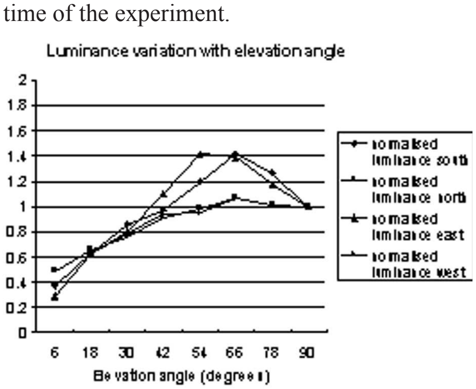

Fig.1. Luminance variation with elevation

Figure 2 shows the variation of the global illuminance over the time taken to complete the scan (approximately 2 minutes).

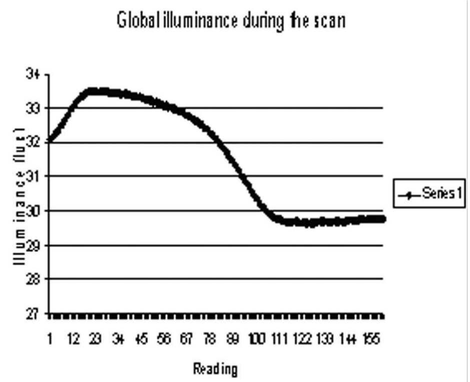

Fig. 2 Global illuminance variation

The global illuminance was found to have varied by 13% over the 2 minutes taken to complete the scan. Obviously this will have had some effect on the luminance reading, but the effect is difficult to quantify. It is again obviously desirable to complete a scan in as short a time as possible.

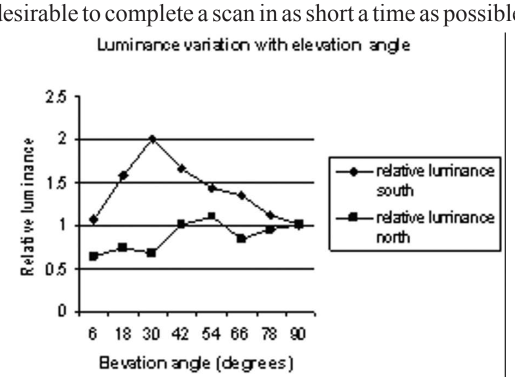

Figure 3 shows another set of data, again for an overcast sky with no visible sun.

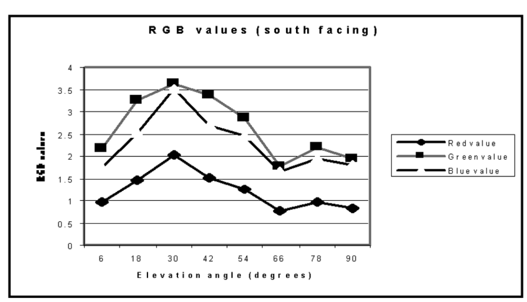

Fig. 4 shows the variation in the relative values of the measured RGB components with elevation angle, for the south facing aspect

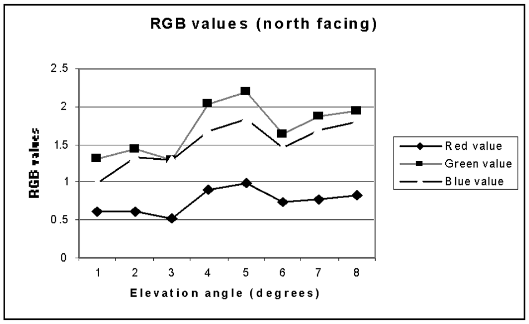

Fig. 5 show the same information for the north facing aspect.

Both figures demonstrate the ability of the system to distinguish sky colour variation. It should be possible to calibrate the response such that sky colour can actually be measured and the necessary calibration process is currently being investigated

CONCLUSIONS

1. It was generally found to be difficult to achieve satisfactory high speed scanning due to the unbalanced inertia inherent in the simple mechanism used in the prototype scanner. Work is now in progress to build a new scanner based on a commercial pan and tilt head. The new apparatus should be able to achieve faster, more accurate scanning and will be able to drive a greater payload, allowing the photocells and amplifiers to be more tightly integrated. This in turn should allow better noise performance.
2.The outputs from the scanner were found to be representative of luminance and chromaticity and the level of noise encountered was sufficiently low for accurate results to be obtained, bur more work will be required to reduce this noise (see comments above).
3. The software design was not completed to a professional standard, but did achieve the basic requirements with respect to scanning and data acquisition and storage. It is hoped to produce a more sophisticated design in which on-line processing will be used to produce sky luminance and chromaticity distributions and statistics as a direct output from the scanner, rather than having to employ external mathematical processing software.
In conclusion, it was judged that the scanner design was a success, but that it would need some redesign to achieve better scanning and noise performance. Improvements proposed include a redesigned scanner head which is better balanced and the use of more powerful drive motors to obtain a shorter scan time. Obviously, such a scanner, constructed as it was from inexpensive components could not be expected to perform to the standards achieved by its more illustrious forbears. However, the use of modern software was found to give considerable advantages in terms of flexibility and on-line data processing. It also offers the possibility of internet based connectivity and control, allowing the apparatus to be situated on a roof top and to be operated remotely. It was felt that the camera based method, which has been developed and used by other experimenters, would be a useful means of evaluating the performance of the scanner in future experiments.
All in all it was felt that the project had been worthwhile and that ample opportunities for further work on sky light measurements would follow from this project.

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