SKYVISION: A SOFTWARE TOOL TO CALCULATE THE OPTICAL CHARACTERISTICS AND DAYLIGHTING PERFORMANCE OF SKYLIGHTS

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ABSTRACT

Skylights can offer useful benefits in reducing building energy consumption and improving building occupants satisfaction. Skylights may also offer interesting features which increase a building's market value by conveying an aesthetic look to buildings, admitting natural light indoors and connecting building occupants to the outside world. While skylight features are fully exploited, their benefits are still not fully understood and accounted for in currently available computer tools. In fact, research has shown that skylights may result in high-energy consumption if not properly designed. The SkyVision software aims to assist skylight manufacturers and building designers in developing appropriate skylight designs for given buildings and daylighting applications. The software analyses the optical characteristics of various types and shapes of skylights, and calculates their daylighting and energy performance. This paper presents a description of the software and its capabilities along with some preliminary software comparison studies. SkyVision predictions of indoor illuminance compared very well with the ADELINE 3 suite of programs (RADIANCE and SUPERLITE).

INTRODUCTION

Skylights can offer useful benefits in reducing building energy consumption, and improving building occupants satisfaction. Skylights can also offer interesting features in increasing building market values by giving aesthetic look to buildings, admitting natural light indoors and connecting building occupants to the outside world. While skylight features are fully exploited, their benefits are still not fully understood and accounted for in currently available computer tools. In fact, research has shown that skylights may result in high-energy consumption if not properly designed. Skylight manufacturers lack design tools that would allow them to determine the suitability of skylight products in meeting given design requirements. Furthermore, the great variety of the many types of skylight shapes and sizes found today in the marketplace makes the skylight selection a very difficult task. In addition, fenestration simulation software such as FRAMEplus5.1 (CANMET, 2003) and WINDOW5.1 (LBL, 2003a) deal with only planar and transparent geometry, such as windows and flat skylights. Sophisticated lighting simulation software such as RADIANCE (LBL, 2003b), LUMEN MICRO (Lighting Technologies, 2003) and SUPERLITE (IEA SHC Task 21, 2000), are not only cumbersome to use, but they do not provide any output related to the skylight optical characteristics, which are useful for skylight product rating and selection. Specialized skylight software are very rare and limited. For example, the SkyCalc (HMG, 2003) program is limited to some USA climate regions, and handles only flat translucent skylights.

The SkyVision software aims to assist skylight manufacturers and building designers to come up with an appropriate skylight design for a given building and use. The tool analyses the optical characteristics of skylights of various shapes and types, and calculates their daylighting and energy performance. The benefits of skylights may be maximized by accounting for the skylight shape and glazing, lighting and shading controls, curb/well geometry, building location and orientation, and prevailing climate.

The specific objectives of this paper are:

- To describe the software tool and its capabilities;
- To conduct a comparison study between SkyVision and available daylighting simulation software.

ABOUT SKYVISION

SkyVision is an easy-to-use, Microsoft Windows™-based computer program developed by the Institute for Research in Construction (IRC) of the National Research Council of Canada, in partnership with Natural Resources of Canada and Public Works and Government Services Canada. The software calculates for a given design day, the overall optical characteristics of various types of skylights, performance indicators of skylight/room interfaces, indoor daylight availability and lighting energy savings. It is intended for use by skylight and curb manufacturers, building designers, architects, engineers, fenestration councils, and research and educational institutions.

Figure 1 shows the main screen of the software. The main screen is composed of three sections. The left section includes the tools to specify the inputs (which can also be accessed from the main menu), the middle section displays the optical characteristics of the skylight for the beam and diffuse radiation, and the right section displays the daylighting and energy performance of the skylight.

CALCULATION ENGINE

SkyVision's calculation engine is composed of four sets of modules:

Glazing optics modules that compute the optical characteristics of a composite glazing pane (substrate with/without coating) and glazing assembly (set of composite panes separated by an air/gas space) at a given incidence angle. The monolithic model (Rubin et al. 1998) is currently used for this purpose.

Skylight optics modules that compute the overall skylight optical characteristics. Ray-tracing based models are used to compute the optical characteristics of representative skylight shapes. A newly developed concept of the *Shape Parameter* (Laouadi and Atif, 2001a) is used to convert any skylight shape to the representative one. This approach makes SkyVision's evaluation potential for any skylight shape almost limitless.

Daylighting modules that compute the indoor illuminance distribution and related variables. A newly developed zonal model (Laouadi and Atif, 2001b), in which the space below the skylight is divided into a number of vertical, four-surface (floor, walls, ceiling and opening) zones, is used to calculate the diffuse and inter-reflected components of surface fluxes. Indoor surfaces are assumed to be perfectly diffuse. A ray-tracing based method is used to compute the direct components of surface fluxes when the skylight is transparent. This approach provides results as accurate as detailed methods implemented in currently available software.

Sky models that compute the sky luminance distribution. CIE/IES standard sky conditions and the climate-based (Perez et al. 1990, 1993) models are implemented.

SOFTWARE INPUTS

To evaluate a skylight using SkyVision, the user simply inputs information in a number of fields, choosing to work in either the Imperial (IP) or International (SI) unit system. Inputs include:

Site Location

The user specifies the site latitude, longitude, and time zone (or, choose from a database of major Canadian and US cities).

Sky Conditions

Two types of sky conditions can be selected: Standard skies that are site-independent, or dynamic (real) skies that change with daytime (for example, clear in the morning, partly-cloudy in the afternoon and cloudy in late afternoon). Standard skies include: (1) uniform overcast sky that corresponds to dark thick clouds; (2) CIE overcast sky (CIE, 1995) that corresponds to thin clouds; (3) CIE average intermediate sky; (4) IES partly cloudy sky (IESNA, 2000); (5) CIE clear sky for industrial areas (with high air pollution); and (6) CIE clear sky for rural areas (with low air pollution). Dynamic skies use weather data to determine the sky condition (Perez et al., 1990, 1993).

Skylight Shape and Glazing

The user may specify various skylight shapes found in today's marketplace. Skylight shapes are classified in five categories: dome-like, cone-like, vault-like, light pipe and flat. Under each shape category, a number of shapes can be simulated. For example, for dome-like skylights, one can simulate circular domes, segmented domes, square-based bubbles, or any other similar shape. Skylight glazing may be multi-pane transparent or translucent (diffuse). An attached glass database allows users to build skylight products from certified manufacturer glass products. The user may also add new glass products to the database.

Indoor Space Geometry and Surface Characteristics

The user specifies the dimensions of the curb (space between the skylight and roof), well (space between the roof and ceiling), and room (space below the ceiling), the indoor surface reflectance values, the building orientation, and the skylight position layouts.

Lighting and Shading Controls

The user specifies the lighting control strategy (on/off auto, or continuous dimming), the type and position of the shading devices (fixed or movable), and the shading control strategy (time clock, on/off auto, or adaptive).

SOFTWARE OUTPUTS

In return for these inputs, SkyVision calculates:

- The skylight overall optical characteristics (transmittance, absorptance, reflectance and Solar Heat Gain Coefficient) as a function of the incidence angle and daytime hour. The hemispherical values of the skylight optical characteristics are also calculated under a given sky luminance distribution pattern.

- The daylight factor at floor, ceiling and wall surfaces for a given sky condition.
- Total illuminance from sun beam and sky diffuse light at floor, ceiling and wall surfaces.
- The well efficiency and coefficient of utilization.
- Percent of daily lighting energy savings.

In addition, SkyVision automatically tracks changes in the design inputs and compares corresponding design output performance based on some built-in criteria. Results can be read in a graphical or table format, which can then be used as an input for third-party software, such as building thermal simulation software.

Figure 2 shows typical outputs of skylight product comparison, and illuminance distribution on indoor surfaces.

COMPARISON STUDY

A preliminary comparison study between SkyVision and the ADELINE 3 suite of programs (IEA SHC Task 21, 2000) was conducted to predict the indoor illuminance levels of an indoor space. The ADELINE software package uses two well known programs, SUPERLITE and RADIANCE, to predict the behavior of daylighting and electric lighting in a space. The dimensions of the simulated indoor space were fixed at: length = width = height = 4m. Two cases were considered: (1) an open space (100% glazed roof) without a light well, and (2) an indoor space with a cubic light well of dimension 1m each, placed in the middle of the roof. The reflectance values of the floor, wall and ceiling surfaces of the indoor space were fixed at 30%, 50% and 80%, respectively. The well reflectance was fixed at 80%. The roof opening was glazed with two types of skylights: a translucent skylight with perfectly diffusing glazing and a transparent skylight. The skylight transmittance was 100%. The computer simulations were carried out for two sky conditions: uniform overcast sky and clear sky with/without sun. The results of the ADELINE programs were obtained using a grid of 20x20 nodes on the work plane. For the clear sky condition, SkyVision uses the standard CIE model with an illuminance turbidity of 2.45 (CIE, 1995). However, the SUPERLITE program uses a model based on the Ångström's turbidity coefficient (β) and the atmospheric moisture content (w). The values for these two parameters that generated approximate results with SkyVision were $\beta = 0.07$ and w = 1.9 cm. The sky luminance patterns were generated for a typical summer day (June 21st) in Ottawa, Ontario, Canada (latitude 45° north, longitude 75° west).

For the considered sky conditions, SkyVision and SUPERLITE generated close results of the outdoor and indoor illuminances (Laouadi et al. 2003). However, RADIANCE generated about 30% lower illuminance values, which made the illuminance comparison criterion not relevant for the present study. The average Daylight Factor (DF) approach was then used. The average DF (in terms of %) is defined here as the ratio of the floor total illuminance from the sky diffuse and sun beam light to the outdoor global horizontal illuminance.

Figures 3 to 5 show a comparison of the average Daylight Factor (DF) at floor level of the indoor space of case 1 (100% glazed roof without a light well) under uniform overcast sky and clear sky with/without sun conditions. Under the uniform overcast sky condition, both SUPERLITE and SkyVision predicted very closely the DF values for the translucent skylight, which are about 6% higher than RADIANCE. For the transparent skylight, the three programs generated almost identical results. Under the clear sky with/without sun condition, the agreement among the three programs is very well.

Figures 6 to 8 show a comparison of the average Daylight Factor (DF) at floor level of the indoor space of case 2 (6.25% glazed roof with a light well) under uniform overcast and clear sky conditions. Under the uniform overcast sky condition, both SUPERLITE and SkyVision predicted very closely the DF values for the translucent skylight, which are about 8% higher than RADIANCE. For the transparent skylight, SkyVision and SUPERLITE results were about 6% higher and 15% lower than RADIANCE, respectively. These differences among the programs were expected for such low DF values, since they are comparable to the model accuracy of each individual program due to parameter settings (e.g., grid nodes for SUPERLITE, and the many numbers of RADIANCE parameters). The same trend happened under the clear sky without sun condition, where SkyVision and SUPERLITE predicted the DF values up to 23% higher and 24% lower than RADIANCE, respectively, especially at sun rise/set times. However, under the clear sky with sun condition, SkyVision results were up to 36% lower than RADIANCE, especially when the sun first hit the floor surface (10AM to 11AM).

BETA RELEASE

The first beta version of the software has just been released for testing and evaluation by end-users. It can be downloaded free of charge from the web site: ***http://irc.nrc-cnrc.gc.ca/ie/light/skyvision.***

Comments and suggestions are appreciated, and may be directed to Dr. A. Laouadi.

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CONCLUSION

A brief description the SkyVision software tool was presented. SkyVision calculates in details the optical and daylighting performance of various types of skylights. SkyVision accounts for the skylight shape and glazing, lighting and shading control, curb/well geometry, building location and orientation, and the prevailing climate The software is a useful tool whether you are a building designer or architect, skylight manufacturer or educator.

Two features of SkyVision are particularly unique: the newly developed S*hape* P*arameter* concept and the *zonal* model.

The *shape parameter* can take any skylight shape, convert it to a representative shape, and calculate the optical and energy performance of that new shape. This tool makes SkyVision's evaluation potential for any skylight shape almost limitless.

The *zonal model* divides the indoor space into a number of vertical four-surface zones—floor, walls, ceiling and opening—then calculates the diffuse and inter-reflected components of surface fluxes for each zone and reassembles them for a complete picture of the space.

Preliminary comparison studies between SkyVision and the ADELINE 3 suite of programs (SPERLITE and RADIANCE) showed very good agreement.

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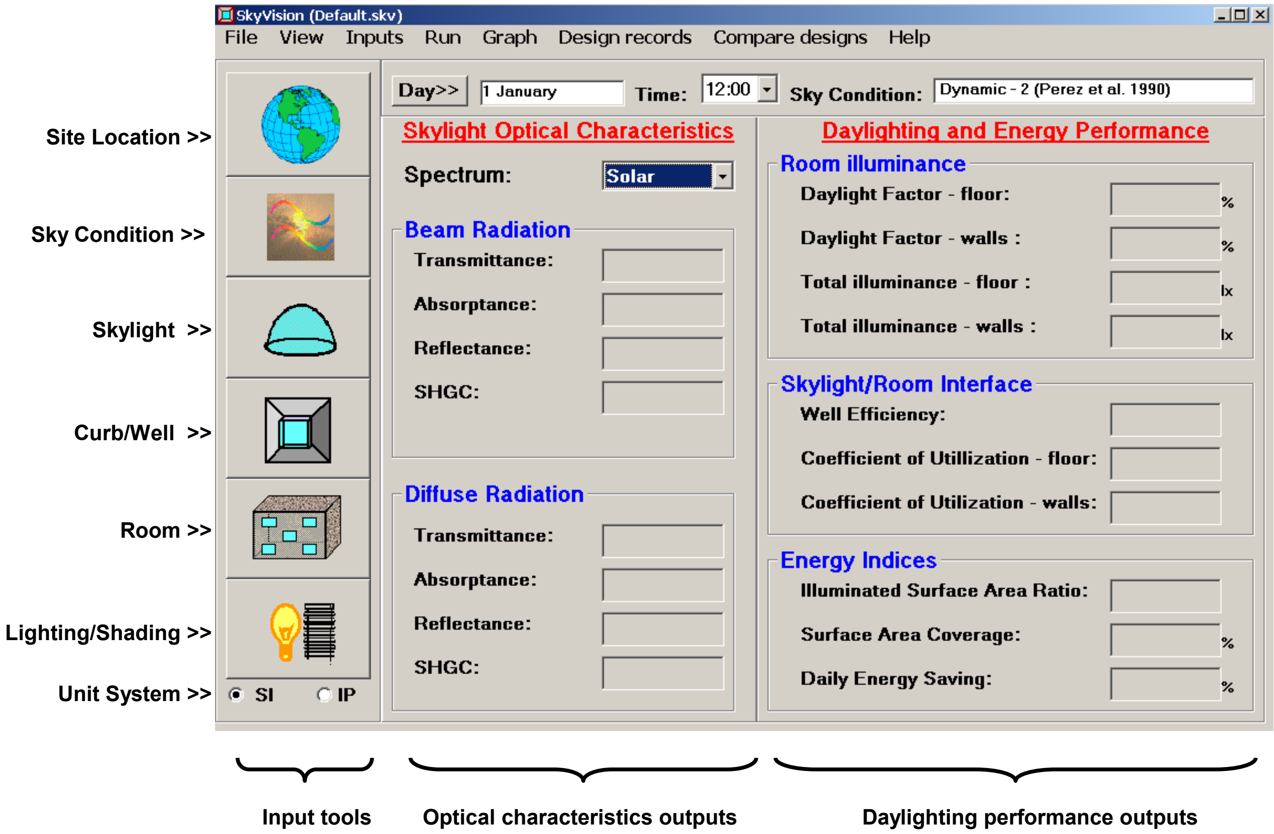

Figure 1: Main screen of the SkyVision software

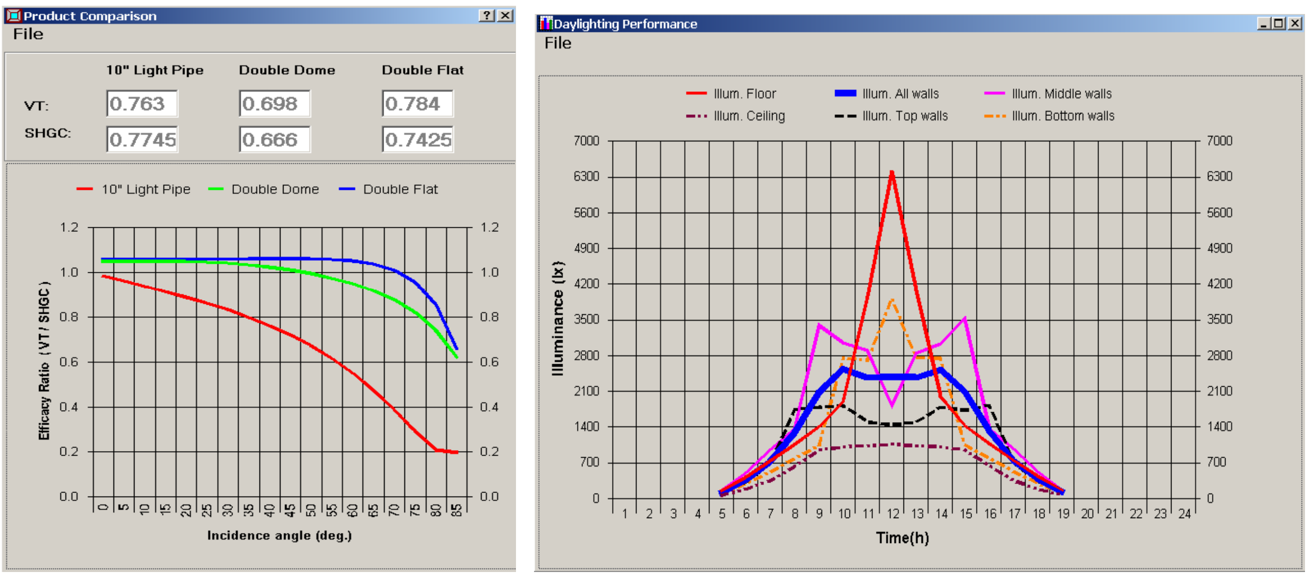

Figure 2: Typical output results: Skylight optical characteristics comparison and illuminance distribution on indoor surfaces

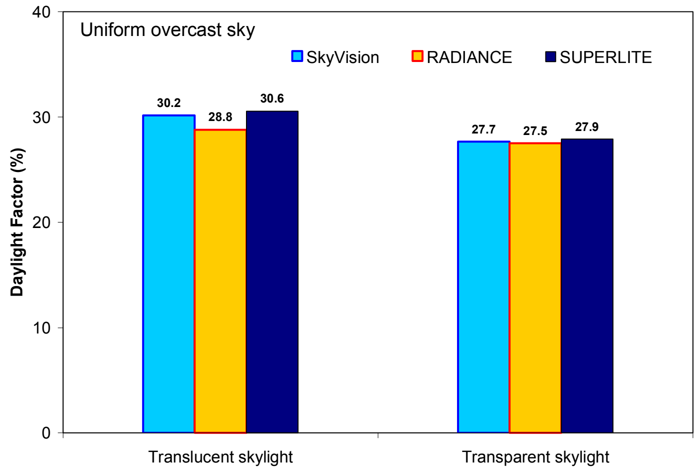

Figure 3: Comparison of the average Daylight Factor at floor level under a uniform overcast sky – case 1 (indoor space with 100% glazed roof and without a light well)

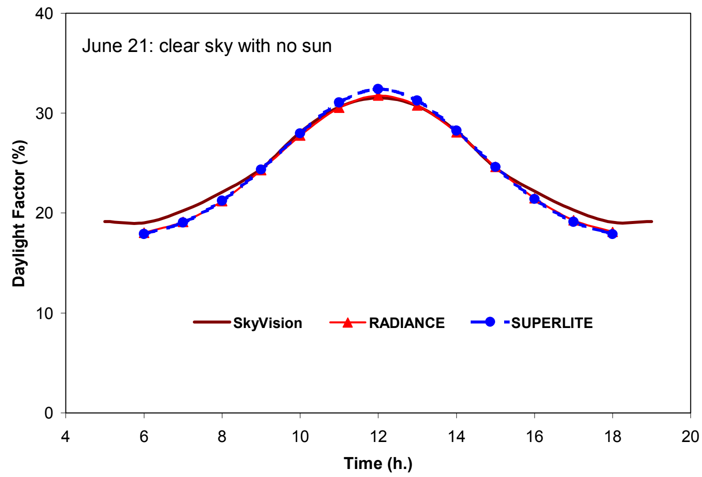

Figure 4: Comparison of the average Daylight Factor at floor level under a clear sky without sun– case 1 (indoor space with 100% glazed roof and without a light well)

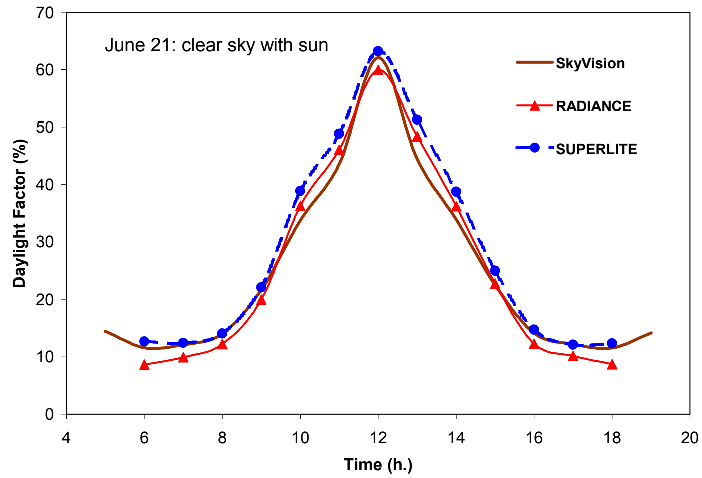

Figure 5: Comparison of the average Daylight Factor at floor level under a clear sky with sun – case 1 (indoor space with 100% glazed roof and without a light well).

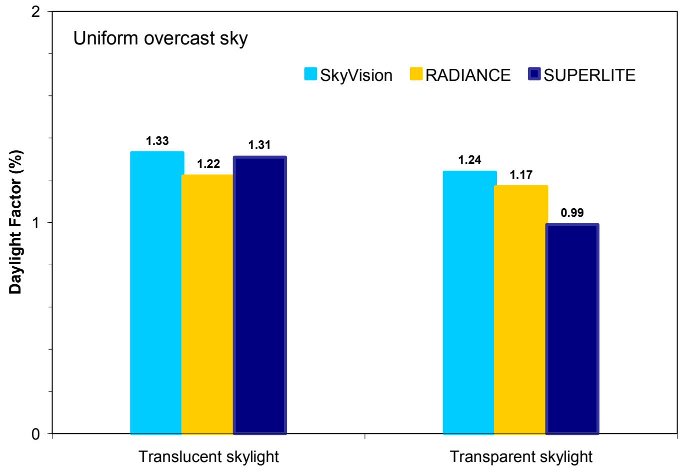

Figure 6: Comparison of the average Daylight Factor at floor level under a uniform overcast sky condition – case 2 (indoor space with 6.25% glazed roof and a light well)

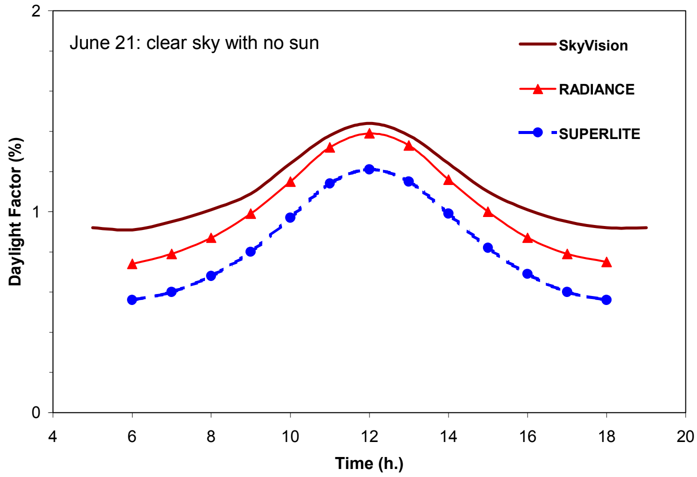

Figure 7: Comparison of the average Daylight Factor at floor level under a clear sky without sun condition– case 2 (indoor space with 6.25% glazed roof and a light well)

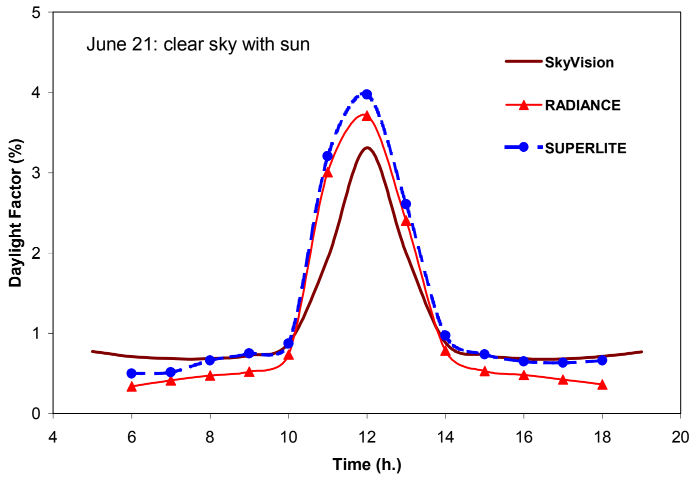

Figure 8: Comparison of the average Daylight Factor at floor level under a clear sky with sun condition – case 2 (indoor space with 6.25% glazed roof and a light well).