RayTrace:
A Simplified Ray Tracing Software for use in AutoCad

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Abstract
A design aid tool for testing and development of daylighting systems was developed. A simplified ray tracing software was programmed in Lisp for AutoCad. Only fully specularly reflective, fully transparent and fully absorbant surfaces can be defined in the software. The software is therefore best suited to evaluation of light transmission through specularly reflective daylighting systems. A graphic and numeric display of arrays for each incident angle aids the user in the ray tracing analysis. The results are automatically written to a text file for easy import and analysis in a spreadsheet.

Introduction
Ray tracing simulations require many computations and my be very time consuming. As the name indictates, ray tracing simulations track the path of each ray as it bounces between the surfaces in the model. For detailed models with millions of ray bounces the computational time can be substantial. Moreover, many ray tracing software like Radiance will not show the ray tracing path even though it could be useful for analysis and further development of the simulated lighting or daylighting system. A simplified and quick raytracing software was therefore been developed as a design aid tool for (day)lighting systems.

Overview of RayTrace
As many buiding designers work in AutoCad, the software RayTrace was programmed in Lisp, which can be loaded and run directly in AutoCad. The software only works for 2-dimensional models, for example a vertical cut of a building model. All the components of the model must be in the same plane. The RayTrace software is best for evaluation of the light transmission efficiency and light distribution of specular reflective (day)lighting systems, because the software has the following limitations:

1. Reflective surfaces can only be defined as fully specular
2. Transparent surfaces can only be defined as fully transparent
3. Opaque surfaces can only be defined as fully absorbant
4. Light rays can only be emitted in parallel and from a flat straight line, which can be pivoted step-wise within a user-defined angle and with user-defined steps

A limitation of maximum 100 reflections pr. ray is enforced, so rays bouncing between specular surfaces would otherwise never come to a stop.

The Raytrace software and user-guide can be downloaded from www.ien.dk under ”downloads”. In order best to illustrate the use of the RayTrace software a case study is given in the following.

RayTrace Case Study

In this case study the light deflecting properties of two different blinds are compared. The first blind is the so-called RetroLux O blind and the other blind is an ordinary slightly curved blind. Both blinds have the same specularly reflective surface properties. According to the RetroLux O manufacturer this blind design ejects direct solar radiation at high incident angles (summer situation in temperate climate) and accepts direct solar radiation at low incident angles (winter situation in temperate climate) by acting as a light shelf and reflecting the light onto the ceiling (Köster, 2004). The advantages of the RetroLux O to an ordinary blind are threefold. Firstly, it reflects the unwanted solar radiation back out instead of absorbing it. Secondly, it reflects light deeper into the room than a ordinary blind and thus yielding a better indoor daylight distribution. And lastly, it blocks the sun entry efficiently while still providing a visual contact with the outdoors. The RayTrace software is used to evaluated the validity of these claims as well as providing an analysis for possible improvement of the blind design.

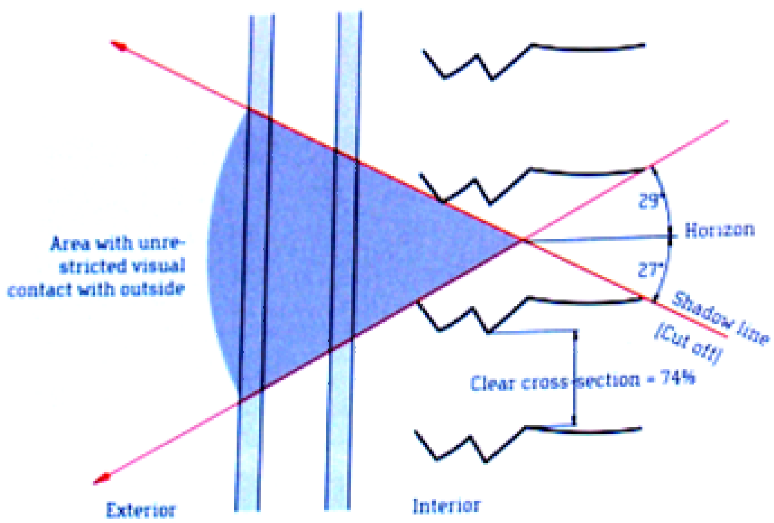


Figure 1: Cross-section of blind RetroLux O. The clear cross section is 74% and the area of unrestricted visual contact to outdoors is 29° and 27° below and above the horizon, respectively (Köster, 2004).

AutoCad Model

The two blinds were constructed in AutoCad: The RetroLux O blind (Figure 1) and the ordinary slightly curved blind (Figure 2). The ordinary blind was tilted upwards until the clear cross section matched the 74% of the RetroLux O blind. Both blinds were defined as being perfectly specular reflective.

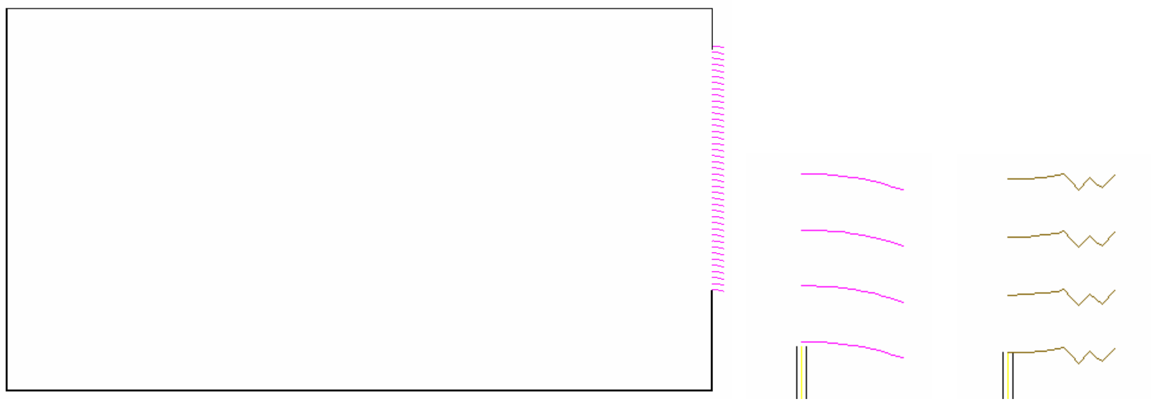


Figure 2: AutoCad models of the 2-dimensional room (left), of the ordinary blind (middle) and of the RetroLux O blind (right). Both blinds have the same clear cross section of 74%.

Both blinds were inserted into 2-dimensional room model. The room depth is 7 meters. The floor to ceiling height is 3.8 meters. The parapet wall below the window is 1 meter, and the window fitted with a full-height blind runs from 1 to 3.4 meters above the floor, as illustrated in Figure 2. The window pane is omitted for this simulation.

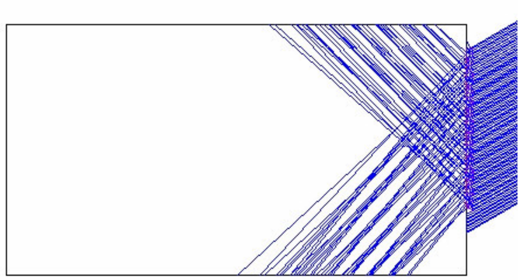
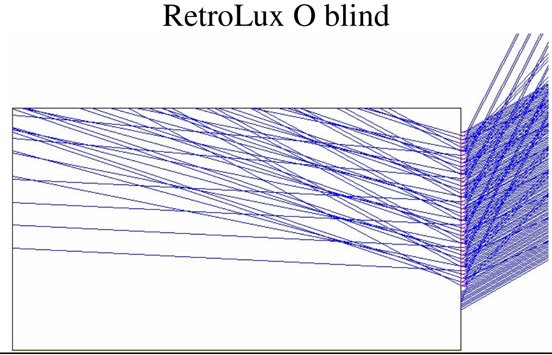
Test Variables and Results

Both blinds are positioned in the vertical window opening. The blinds receive sky radiation from incident angles ranging from 0° (horizontal) and up until 90° (vertical). Reflected light from the ground is omitted. For a comprehensive ray tracing analysis the following parameters are therefore chosen as input:

Start angle of incident radiation:	0°
End angle of incident radiation:	90°
Step angle interval:	5°
No. of rays pr. interval:	100

Figure 3: Input to RayTrace

The visual ray tracing result of the 100 rays is displayed for each step angle interval; insofar the user chooses this option. Some screen-dumps of this visual analysis are inserted below:

	Ordinary blind	RetroLux O blind
30°		

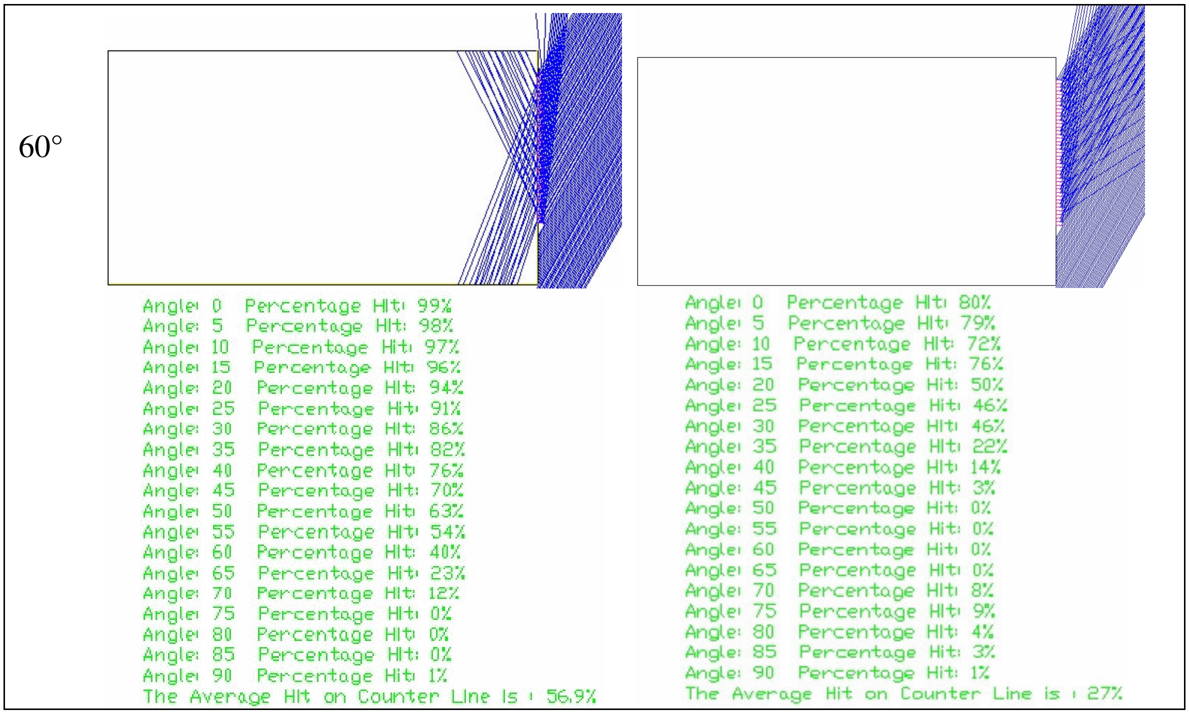


Figure 4: Ray tracing analysis for the two blind systems. 100 parallel and equally spaced rays were emitted onto the window facade for each rotation of 5° in the interval 0 – 90°. The percentage of rays being transmitted into the room is automatically calculated at is written on the drawing as well as in a text file. The predicament that the RetroLux O blind would eject solar rays at high angles of incidence is correct in the interval 45 – 90° where less than 10% of the rays enter the room. For the ordinary blind the solar entry is much higher in this interval.

From Figure 4 it can be seen that rays of incident angles 50 – 65° are entirely blocked by the RetroLux O blind. For rays of higher incidence, however, some rays are allowed to pass through. The numbers in Figure 4 refer to the percentage of the 100 rays that make it into the room. However, as the emitted rays are projected from a straight line, which is rotated at 5° steps around the top hinge of the window and increasing amount of rays fall on the outside of the parapet wall or on the ground. In order to determine the actual light transmission efficiency of the blind system for each incident angle a reference ray tracing run is undertaken for the window opening without any blind system installed. The light transmission efficiency therefore becomes

$$Light\ transmission\ efficiency = \frac{rays\ transmitted\ indoors\ with\ the\ blind\ system\ installed}{rays\ transmitted\ indoors\ without\ any\ blind\ system\ installed}$$

Applying the above formula yields the following graph:

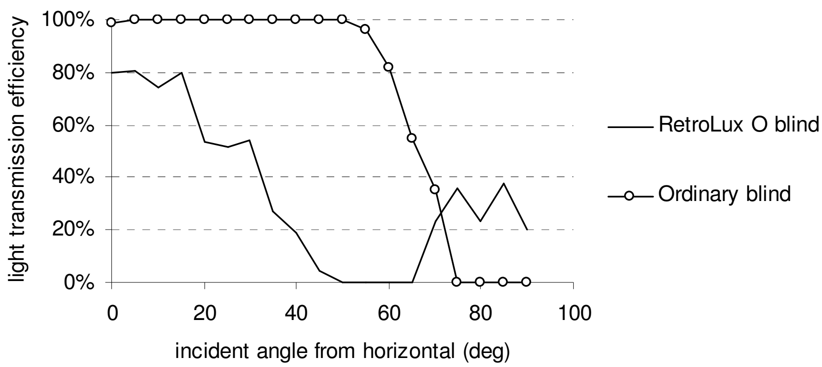


Figure 5: Light is transmitted much more efficiently to the indoor environment for the ordinary blind than for the RetroLux O blind, which completely blocks rays in the interval 50-65°.

In a tropical context the incident angle of direct sunlight often surpass 65° from horizontal. For the RetroLux O blind it is therefore unfortunate that light slips through at these high angles of incidence (Figure 5). Using RayTrace to zoom in on the light bounces at the blinds reveals how light enters:

60° 75°

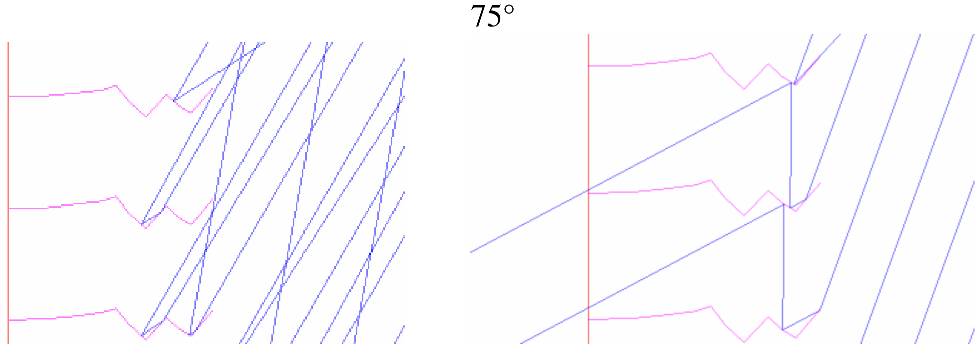


Figure 6: Incident light at RetroLux O blind and 60° and 75°, respectively. The latter enters the room.

The RayTrace analysis shows that inter-reflection in the RetroLux O blind for incident light surpassing 60° from horizontal may enter the interior. Judging from Figure 6 the problem of undesired reflection to the interior can be solved by changing the tip of the blind to a non-reflective material. As it can be seen from Figure 7 this solves the problem.

Another difference between the RetroLux O blind and the ordinary blind is their ability to reflect light deep into the ceiling. This is analysed by limiting the light ray counting surface to the ceiling surface beyond 2 meters from the facade denoted as “ ceiling > 2m from facade” in Figure 7. Light falling on the rear wall above 1.8 meters from the floor is also counted as hitting the ceiling. Similarly, it is also computed how much of the light hits the ceiling including the first 2 meters from the facade; this is denoted as “ceiling” in Figure 7.

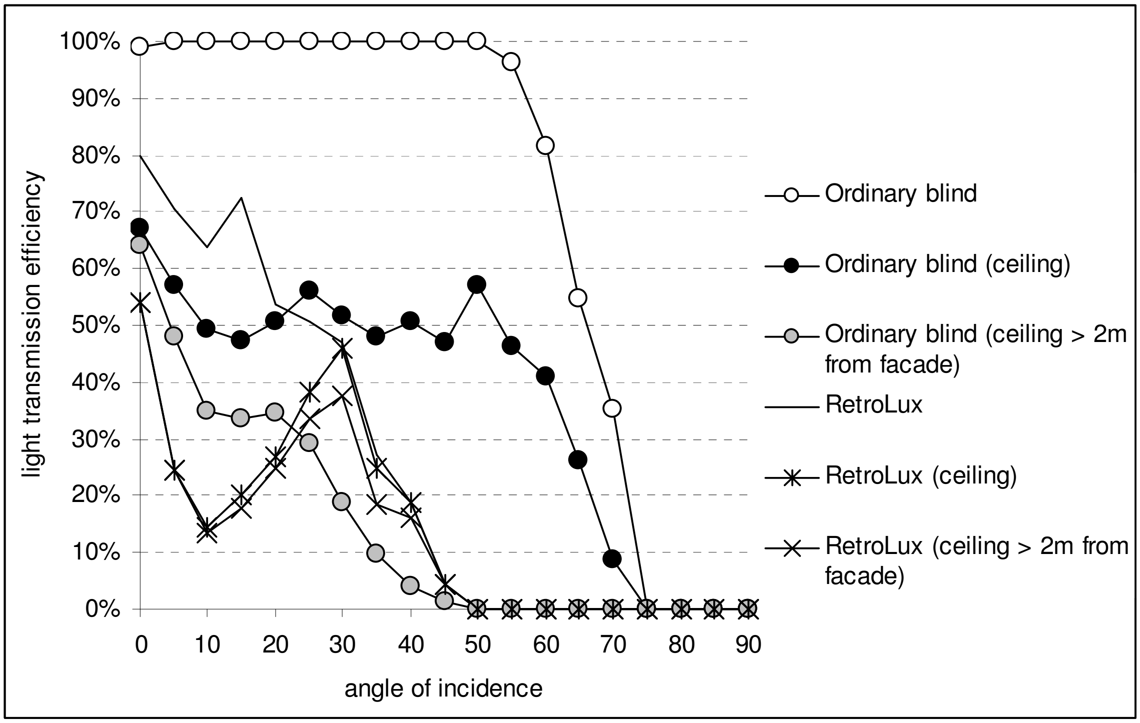


Figure 7: Light transmission efficiency for the modified RetroLux O blind and the ordinary blind. The faction of light falling onto the ceiling is also shown.

The modified RetroLux O blind with a non-reflective outer surface solves the problem of light admittance at high incident angles. Figure 7 also shows that the RetroLux O blind is superior to the ordinary blind in deflecting light deep into the room for angles of incidence higher than 25° hence yielding a more evenly distribution of daylight in the room.

Conclusion

The case study has shown that the simplified ray tracing software RayTrace is well suited for a quick analysis in AutoCad of different daylighting systems both when it comes to their light transmission efficiencies at different angles of incidence and when it comes to a visual analysis of the ray tracing pathways. The quick analysis offered by RayTrace is useful for analysis and development of daylighting designs in the early stages. The main limitations of the software are that it is 2-dimensional and treats all reflective surfaces as perfect mirrors. Download of the RayTrace software is free at www.ien.dk.