POSSIBILITIES AND CHALLENGES CREATED BY A SMART MATERIAL IN BUILDING PERFORMANCE SIMULATION

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ABSTRACT

Smart materials are predicted to ‘revolutionise’ the A/E/C industry. They are supposed to enable a building to change colour, shape, size and opacity. However, past research shows that smart materials are still not used very often in engineering applications to their full potential.

In this publication we advocate that materials should not be only chosen for simple properties such as visual, physical and insulating characteristics, but for capabilities such as being able to save/generate energy, store information, and to react to stimuli from their local environment. Therefore, this paper will research into the addition of SolaVeil to a window, its physical configuration and the possibility to model and analyse it through Building Performance simulation (BPS). This material is primarily designed to eliminate glare and redirect light. As a result it can reduce energy use caused by air conditioning and artificial lighting systems.

This paper researches into the behaviour of SolaVeil in a computer simulation using two different case studies. The first will compare how changing the width but maintaining the reflective area affects illuminance distribution, and the second will determine which physical properties of SolaVeil are most effective.

Finally, conclusions are drawn based on the case studies and it is shown that smaller width light shelves are the most suitable for an anti glare product. It is also determined that for SolaVeil to minimise glare in a room without compromising illuminance levels, it should have a light shelf angle of 40 degrees, cover between 40-60% of a window and its strips should be spaced 5mm.

Keywords: SolaVeil, smart materials, building system design, illumination.

1. INTRODUCTION

There are many problems associated with the energy consumption of a building, such as cost, material depletion and greenhouse gas emissions (West, 2001). Buildings are responsible for up to 50% of the UK’s energy consumption (HM Government, 2008), of which 30% is related to air conditioning (SolaVeil, 2010). In commercial buildings, between a third and a half is consumed by artificial lighting (Philips, 2004). If smart materials and new technologies are included in a building’s design, this energy can be saved or even more can be generated. Examples include smart windows and photovoltaics. Shading devices can also help to decrease energy consumption of a building (Philips, 2004) and (West, 2001). In terms of smart materials for buildings, smart windows and façades have had a ‘lions share of investment’ (Addington & Schodek, 2005).

Consequently, products such as SolaVeil have been developed which are used to not only reduce glare and energy consumption, but increase the natural illumination present in a buildings (SolaVeil, 2010). Physically, SolaVeil consists of micro-light shelves coupled to additional glare control panels (Miles et al., 2010) and it has been proven to reduce a building’s light energy savings up to 70% in conjunction with digital lighting controls (SolaVeil, 2010). Alternatives such as shading devices exist, but they are known to be only partially effective and tend to be expensive (Miles et al., 2010). An example is a brise soleil, which can add inadvertently to the structural load if it resists wind, and is only affective under certain sun angles.

SolaVeil is going to be modelled and modified by a lighting simulation engine, called Radiance, a process which has not been successfully accomplished before. Radiance is a backward raytracer, which is renowned for its complexity (Reinhart & Anderson, 2006). It is suitable to use for modelling SolaVeil as its calculations are physically based, which means they can model complex geometries (Ward, 1992). A program named Ecotect (Autodesk 2010) will be used as an interface and to define geometry. The results are going to be displayed in terms of illuminance, which is the amount of light falling onto an object or surface, and its unit is a lux. The illuminance in an office is recommended to be between 300-500 lux (Treganza, 1998). The next section will describe how the models used in simulations were derived.

2. METHODOLOGY

Two case studies have been performed, both consisting of a rectangular room with one south facing window. One is located in Cardiff, Wales and the other is in Ottawa, Canada. This was to show models working in different time zones. The Cardiff model was used to establish how light shelves change the light distribution in a room. The purpose of the Ottawa model was to verify the process of creating a translucent material, so it could be used to derive a material description representing SolaVeil. This was done by modelling a room that has already been validated in Radiance (Reinhart 2006), in which there is a window featuring translucent material. Once this was complete, the model was modified to include basic objects representing the light shelves and antiglare panels of SolaVeil, which could have their properties changed. For consistency, all the calculations were performed using Radiance, as it has been established in the past that Ecotect would underestimate indirect calculations (Cemesova, 2010).

2.1 Cardiff Model

The basic model of Cardiff is a 10m x 10m x 2.5m room with an 8m wide and 1.5m high window. Adaptations of this model contained various light shelves in the window, an example of the Cardiff model with SolaVeil applied to half the window is given in Figure 1. The coordinates of surfaces were entered clockwise to the normal that is being described, as Radiance deduces from this what is the internal and external surface.

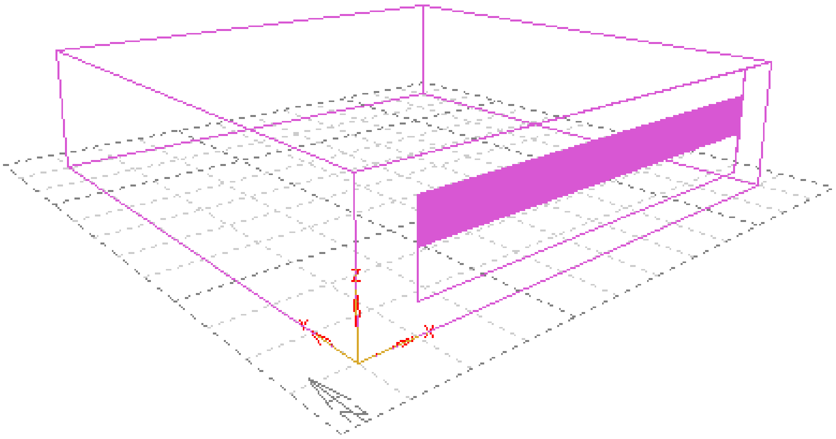

Figure 1: The Cardiff model with 50% of the window covered in SolaVeil.

The material assigned to light shelves was given the properties of 0% transmittance and the colour white for maximum reflectance to show the best case scenario. The remaining surfaces were assigned the materials shown in Table 1, which are from the Standard Element Library(Natural Frequency 2010). The CIE Overcast sky was attached, as this is most suitable sky for an area geographically near England (Muneer, 2005). The time and date, January 1st at 12:00AM, was then used by Radiance to generate a sky description.

Table 1: Materials assigned to surfaces in the Cardiff Model.

Surface Type	Wall	Floor	Ceiling	Window
Material	Brickplaster	ConcSlab_OnGround	Plaster_insulation_suspended	ClearFloat_6mm_MF

After the model was set up, ray path analysis (SRPA) was performed to visually confirm how light travels in a room, and how its path is affected by a solar light shelf. This was validated by a hand calculation which established the distance between the window and the rays reaching the ceiling. This model was then exported to Radiance, and an illumination calculation was performed at a working plane height of 0.8m. Default parameters were used, along with high model detail and model variability as modelling a light shelf is complex. The resulting light distribution was overlaid onto the SRPA. Finally, a sensitivity analysis was performed, as a previous survey showed it was regarded as important by 100% of the participants (Hopfe, 2009). This was done by changing the values of the parameters used for the Radiance simulation, but it was found that adjusting the default parameters did not have a major impact on the results.

2.2 Ottawa Model

The Ottawa model geometry, radiance simulation parameters and materials (ceiling, carpet, side walls and Trans24%) are all identical to that used by Reinhart (2006). However, the outside buildings and hedge has been omitted due to a lack of information. The model geometry was described in Ecotect, and then exported to Radiance Control Panel (RCP). This was used to edit code regarding the object material descriptions and the sky definition. The model was analysed containing a clear window, and then various configurations of SolaVeil were added to the window. Ecotect was used initially as groups of geometrically identical objects can be easily generated by the program. This was especially useful when 1000+ light shelves had to be modelled. Figure 2 contains a close view of an example configuration of SolaVeil using 'visualise' and OpenGL rendering in Ecotect. The light shelf is horizontal, both the antiglare panel and light shelf are 1mm wide and the space between strips of SolaVeil is 0.2mm.

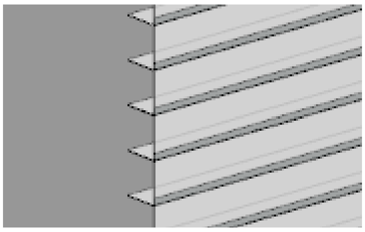

Figure 2: OpenGL render showing strips of SolaVeil antiglare panels and light shelves.

2.2.1 Sky Description.

The sky description was created using the 'gensky' generator. It was based on the latitude and longitude of 45.32 degrees N and 75.67 degrees W respectively. The data and time it is valid for is 18th March at 12:00 o'clock. The radiance code is ***'!gensky 18 3 12.00 -c -a 45.32 -o 75.67'***.As this is only a description of the sun and sky, objects that will represent the sky and sun based on the description generated by 'gensky' were added, along with a ground description. For the ground, sun and sky to be understood as a light source the material type is stated as 'glow'.

2.2.2 Calculating translucent material properties.

The Radiance material type which is most suitable to modelling a translucent material is 'trans', as it is used to model translucent materials. It has been labelled as one of 'the most confusing material entities in the Radiance repertoire' (Larson et al. 2003). It is composed of 7 arguments, labelled A1 to A7. They are calculated based on 5 measured surface properties from a real material. The 5 properties are the diffuse reflectance **Rd**, reflected specularity **Rs**, surface roughness **Sr**, diffuse transmissivity **Td** and transmitted specularity **Ts**. From a report conducted on SolaVeil (Giles 2010) the transmittance and reflectance values can be determined depending on the angle at which light is being directed at onto the surface. The closest weather file available to Ottawa was a city called Toronto. For the 18th March at 12:00 o'clock, the sun angle is 44.5 degrees to the normal. The data for SolaVeil that corresponds to this is an **Rd** value of 0.52 and a **Td** value of 0.038. The material of SolaVeil has a specular component, but to keep this example simple **Rs** was assumed as 0. The **Ts** value was assumed as 0 to give an ideal diffuser and the **Sr** was assumed as smooth, so equal to 0. The 7 arguments were worked out in the following equations 2 to 5. The parameters A1 to A3 are identical as the colour of SolaVeil is white, which is composed of an equal amount of red, green and blue.

$$A7 = Ts / (Td+Ts) = 0 \tag{1}$$
$$A6 = (Td + Ts) / (Rd + Td + Ts) = (0.038)/(0.52+0.038) = 0.0681(3sf) \tag{2}$$
$$A5 = Sr = 0 \text{ as surface was assumed as smooth.} \tag{3}$$
$$A4 = Rs = 0 \text{ as specularity was being assumed as 0.} \tag{4}$$
$$A3=A2=A1 = Rd /(1-Rs)*(1-A6) = 0.52 /(1-0)*(1-0.0681)=0.558(3sf) \tag{5}$$

In Reinhart's model, the lux levels recorded were from a data sensor placed 0.85m above ground level and 1.5m along the centre line of the room. To compare models fairly, the data for the results section was gathered at this point from the replica model, and down the centre line of the model. Consequently, a 10 x 15 grid was set up at a working plane height of 0.85m with nodes spaced 0.25m away from each other. The code generated by RCP, including all the parameters and the ambient and octree file is in (Cemesova, 2010), along with the SolaVeil material description.

3. RESULTS AND ANALYSIS

In this section, the main simulations that were carried out using the Cardiff and Ottawa model are summarised.

3.1 CARDIFF MODEL

Different sizes of light shelves were applied to the Cardiff model, and they were analysed using both Ecotect and Radiance.

3.1.1 Simulating different light shelves in Ecotect.

A SRPA overlaid with a 3D graph of illumination values is shown in Figure 3. The illumination values are imported from calculations performed by Radiance at the working plane. This is located 0.8m above the floor level. The high illuminance on the left side of the room is caused by rays crossing the working plane straight after passing through only glass. The primary dip in illuminance is due to the shelf casting a shadow onto the working plane. The second half of the room is much darker as rays have lost a lot of their energy to the surroundings. In General, the room seems to be too short to display the affects of the rays re-entering the working plane after being reflected from the ceiling.

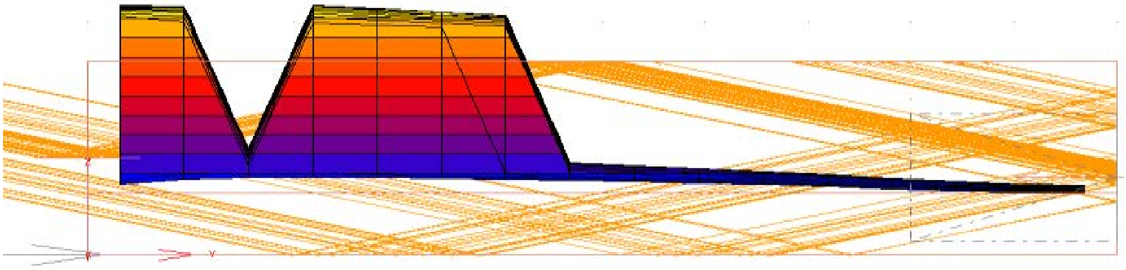

Figure 3: Cross section of a room in Cardiff, showing the illumination levels and solar ray paths.

The next factor that was examined is changing the dimensions of a light shelf whilst keeping the reflective area at $1m^2$ per meter run. Three simulations of the Cardiff model with different shelves were run, and the resulting illuminance values along the centre line are shown in Figure 3. The first simulation consisted of a model with just glass in the window. This is included as a control case. The second simulation contained a meter wide shelf located in the middle of the window. The third simulation had ten 100mm wide shelves stretching horizontally across the window, spaced 150mm apart. The last simulation had a thousand one millimetre wide horizontal shelves spread 1.5mm apart across the window.

The results show the illuminance levels in models containing shelves never exceed that of the one without, which is as expected (Moore, 1986). The meter wide light shelf causes the highest illuminance along the centre line, apart from at 937.5mm and 1562.5mm as the light shelf would throw a shadow. Also, over the length of the room, the 100mm wide shelves model is on average 1.5 lux brighter then the 1mm wide shelves model. However, the 1mm wide light shelves model gives higher lux values at the extremities of the room, although towards the back half of the room the difference between the lux levels is small. All the above light shelves have been applied internally; it is possible that if they were applied to the outer side of the glass, there would have been an increase in illuminance.

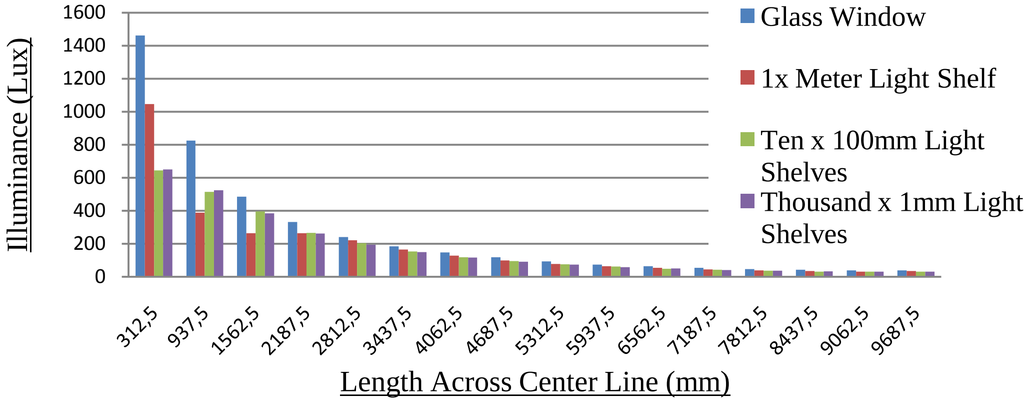

Figure 3: Illuminance across the centre line of the Cardiff model with different lighshelves.

3.2 OTTAWA MODEL

A replica of Reinhart's model of Ottawa was composed (Reinhart & Anderson, 2006), and simulations were run for 18 March at 12:00 o'clock to test if the 'trans' material had been calculated correctly. The simulations used a window containing no material, a material with 24% transmission and one whose transmission corresponds to SolaVeil, 3.8%. The calculated illuminance 1.5m along the central axis approximately matched Reinharts.

As a further check to evaluate if the 'trans' materials are transmitting accurately, the room's illuminance can be checked for both SolaVeil and Trans24%. The Trans24% material has a transmission of 24%. A model with no material in the window showed a lux level of 2430.8 lux, so a 24% transmission material should give an approximate lux level of 586 lux. A simulation using Trans24% material gave 460 lux at 12:00am and 594 lux at 9:00 am, and the calculated lux level falls into this range. Two different times were used as the path of light changes depending on the incident angle, but the first model won't be affected by this as there is no glass. Using the same theory, physical SolaVeil has a transmission of 3.8%, which should result in approximately 92.7 lux by the window. The model with SolaVeil as a sheet of 'trans' material gave a value 19 lux higher, but this is such a small amount it is negligible, especially as there is only one time available for comparison. The next steps were to apply the material to objects representing the shelves and strips of SolaVeil, and change geometrical attributes associated with it.

3.2.1 Changing the percentage of window covered.

The first SolaVeil characteristic to be changed is the percentage area of a window that is covered by SolaVeil. The percentages simulated are 60%, 40% and 20%. The calculated lux level along the central axis is shown in Figure 4. The models are modified versions of the basic Ottawa model, and the date and time has been left to 18th March at 12:00 o'clock for consistency.

The 20% model displays the highest illumination, followed by the 40%model and finally by 60% model. These three models show similar trends, but the 60% model has a steeper curve. The most efficient covering compared to a model with simply a glass window is 60%. It's simulation shows the most light redistribution and the illumination decreased up to 46%. However, the lowest lux level is 131 lux, which is below guidelines. However, by changing SolaVeil dimensions and using different skies and locations, illumination could be adjusted to rise above 200 lux. The lowest acceptable illumination is displayed by the 40% model, but it only decreases illumination up to 39%.

When SolaVeil is applied to the entire window, the trend in illuminance is very different. In comparison to a model with a glass window, the lux levels have dropped dramatically by 98% by the window, but after that remain fairly uniform. This would seem as an excellent configuration for an anti-glare device, but the actual illuminance ranges from 106 lux to 25 lux. This is insufficient for an office or school classroom.

In general, as you decrease the amount of SolaVeil, the illuminance increases in the entire room, but so does the glare. This is due to more light being let in through the clear glass, although some light redistribution must be occurring as the 60% model has a slightly different trend. It appears that the optimum percentage of a window covered by SolaVeil is between 40-60%, but further testing with a model containing objects is necessary.

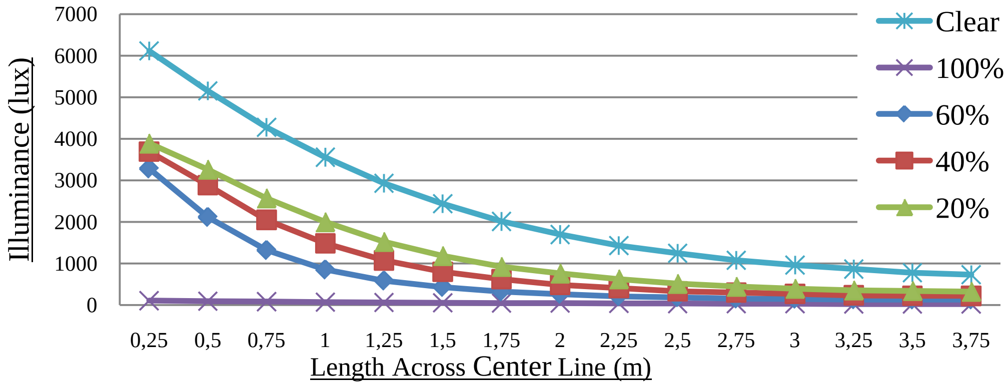

Figure 4: Illuminance across the centre line of the Ottawa model with different percentages of window covered.

3.2.2 Changing the angle of the light shelf.

The angle of the shelf was the next characteristic to be changed. The '0 degrees model' is the control model. It is the same model that was used to represent a window covered in 60% SolaVeil. It was then modified four times to give shelf angles of 10, 20, 30, and 40 degrees. The glass window has been included for reference, in the model called 'clear'. Figure 5 shows the illuminance along the centre line for the different models.

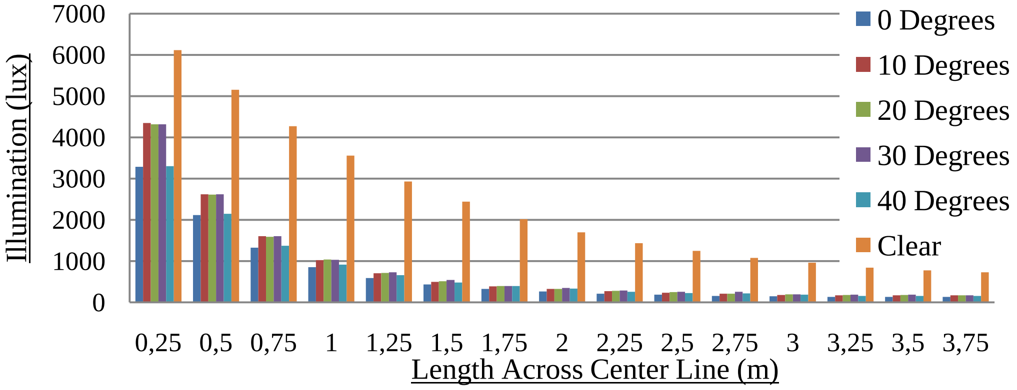

Figure 5: Illuminance across the centre line of the Ottawa model with different angles of SolaVeil shelves.

Changing the angle from 0 to 10, 20 and 30 degrees increases the illuminance in the room, but also increased glare. However, increasing the angle to 40 degrees only increased glare by 5%, whilst increasing the illumination up to 26%. This would suggest that the optimum shelf angle for SolaVeil is 40 degrees, which is logical. Sun rays come through a window at an acute angle to the horizon so the higher the angle of the shelf, the more horizontally the reflected rays will travel.

3.2.3 Changing the spacing between SolaVeil strips.

The last dimension that has been varied for SolaVeil is the spacing between the strips of SolaVeil material. The model that was used to represent 60% of the window being covered in SolaVeil is the same as the model called ‘0.2mm’. The spacing was then changed to 0.5mm, 1mm, 5mm and 10mm of clear glass, and the names change respectively. The illumination along the centre line for the different models is show in Figure 6, with the control model being ‘0.2mm’. A model called ‘clear’ which has a glass window is included for reference.

The spacing that stops the most illuminance by the window is 0.2mm, which is the spacing which is currently being used for SolaVeil in industry. As with other models, the clear model has the highest illumination values across the room. It is followed by 10mm, 5mm, 1mm, 0.5mm and 0.2mm spacing models. The 0.2mm to 1mm models have similar trends, as do the 5mm and 10mm models. The 0.2mm spacing decreases illuminance up to 46%, but the lowest illuminance is 131 lux. The lowest acceptable illuminance at the back of a room is 368 lux, and relates to the 5mm spacing model. However, this spacing only reduces glare by 42% and due to the size of spacing, could cause an uneven light distribution.

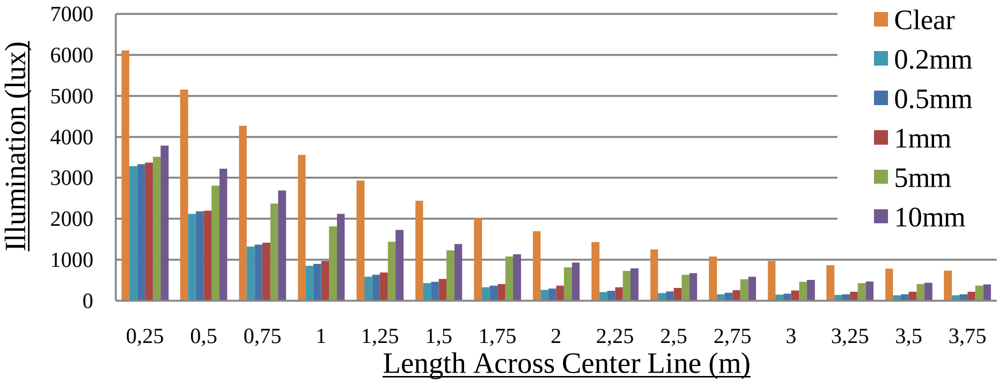

Figure 6: Illuminance across the centre line of the Ottawa model with different spacing between SolaVeil strips.

4. CONCLUSION

The research has shown varying the width of light shelves changes the interaction of light with a room. In order to simply redirect a patch of light, a large shelf is the best choice. However, small shelves are the most effective as an anti-glare product, and in some circumstances they even provide higher illuminance away from the window than wider shelves.

The addition of SolaVeil to a window was shown to dramatically change its performance. The space between strips of SolaVeil and the percentage amount of window covered by SolaVeil were shown to be the most influential characteristics. The results show that altering the light shelf angle to 40 degrees from the horizontal position, the illumination in a room can be increased up to 26% and glare is only increased by 0.5%.

In terms of spacing, 1mm gave the largest decrease in illumination that would cause glare, but the lux levels in the rest of the room were insufficient. Therefore, the 5mm spacing is the best choice.

Regarding the percentage area of a window to be covered by SolaVeil, results showed between 40-60% was most effective at reducing glare. These areas reduced the illuminance by 82%, but the illuminance values recorded at the opposite end of the room to the window were under the recommended guidelines. It must be mentioned however, all the results above are valid only for January at 12:00AM and using an Ottawa climate file.

In general, using Ecotect as an interface saves time but certain Radiance conventions have to be followed that are not stipulated by Ecotect. Using Radiance however has many advantages over Ecotect. The photorealistic rendered images can be used to show clients how their building will look once they are built. They are also useful in design team discussions as they are calculated using accurate daylight prediction, and are not just an architect's impression. However, the research also emphasises if Radiance is to output accurate values, an extensive knowledge of rendering parameters, tools and syntax is a prerequisite.

Overall, the addition of SolaVeil to a window was not shown to increase the light levels anywhere in a room. However, it does lower the illuminance by the window to a satisfactory level, so it can be said to minimise glare. It is important to remember that light shelves are meant to redirect light that would either be blocked by blinds, or absorbed by obstructions such as desks. The simulations performed did not include such obstructions, to show the worst case scenario. In real rooms, people and equipment would absorb light at working level so the redirection of light by the light shelves would be more visible in an analysis.

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