COMPARISON OF SOLAR EVALUATION TOOLS: FROM LEARNING TO PRACTICE

Sophia Duluk
Department of Architecture
University of Oregon
Eugene, OR 97403
Email: sophiad6212@gmail.com

Heather Nelson
Department of Architecture
University of Oregon
Eugene, OR 97403
Email: nelson.heather.anne@gmail.com

Alison Kwok
Department of Architecture
University of Oregon
Eugene, OR 97403
Email: akwok@uoregon.edu

ABSTRACT

Solar tools and software have evolved in the last ten years to assist designers in evaluating a site for shading, solar access, daylighting design, photovoltaic placement, and passive solar heating potential. This paper presents a comparative evaluation of solar site analysis tools as base cases for evaluation. We present the results from on site measurements, software predictions, output accuracy, ease of use, design inputs needed for Passive House Planning Protocol (PHPP), and other criteria to discuss the capabilities of the tools in education and in architectural design practice. We compare six tools: Solar Transit, Solar Pathfinder + Solar Pathfinder Assistant software, Solmetric Suneye + Thermal Assistant Software, HORIcatcher + Meteonorm, and two iPhone applications. Tools differ significantly in their cost, ease of use, visualization output, and estimation/calculation of radiation. In particular, the tools vary in the types of radiation outputted as components or as global radiation.

1. INTRODUCTION

With the practice of architecture becoming more computerized, via simulations, software has become increasingly important for professionals and students to use in order to understand solar access at a particular location. Traditional, low-cost analog tools such as the solar transit provide users with an understanding of the position of, access to, and obstructions from the sun. Computer software has the advantage of automating some of the processes and calculations, while being able to factor in location specific climate data. Yet, as we have found, there are some obstacles to the use of software and a number of misunderstandings about principles and concepts of solar radiation. These can cause under- or overestimations, leading to heavy energy consequences when handling building loads and thermal comfort.

This study focuses on comparing six tools readily available to design professionals: Solar Transit (1), Solar Pathfinder (http://www.solarpathfinder.com/index), Solmetric Suneye (http://www.solmetric.com), HORIcatcher+Meteonorm (http://www.meteotest.ch/en/footernavi/solar_energy/horicatcher/) and two iPhone applications. Additionally, the study will examine shading protocols used for the Passive House Planning Package (PHPP) to see how the tools compare to the PHPP shading assumptions, and determine the importance of accounting for the various types of radiation.

2. BACKGROUND AND CONTEXT

Passive Houses and other high performance buildings must control solar radiation, while maximizing comfort and energy conservation. In passive solar design, photovoltaic placement, and Passive House design, knowing the precise amount of solar radiation at a location is critical to design optimization. Most analysis tools measure global solar radiation, but ignore the diffuse and reflected components, which do not behave in the same way as direct beam. In addition to mapping solar access, this study examines how these tools might account for diffuse and reflected radiation and the impacts on predictions for the Passive House design targets. This section provides a brief overview of the components of radiation and the issues that arise when measuring radiation.

1.1 Components of Radiation

Three main components comprise radiation: direct, diffuse, and reflected. On a clear day when the sun is high in the sky, direct beam radiation contributes up to 85% of the total solar radiation, while diffuse and reflected make up the remaining 15%. When the sun is lower in the sky, diffuse radiation can contribute up to 40% of the global solar radiation (2). This means that 40% of the solar radiation hitting the earth does not possess a specific directionality, and is not blocked by any forms of shading. The same is true on cloudy days when 100% of the radiation is diffuse.

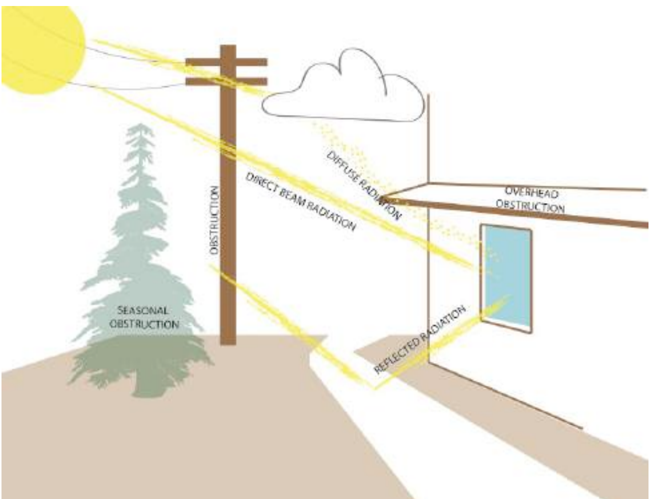

Fig. 1: Diagram of shading obstructions and radiation to a window

More specifically, direct beam radiation travels on an uninterrupted path directly from the sun to the earth's surface. This form of radiation, due to its directionality, is the only one which allows objects to cast shadows. Diffuse radiation is radiation in which the particles are scattered in the earth's atmosphere before it reaches the surface, without any directionality. Finally, reflected radiation is the radiation which is reflected off non-atmospheric objects.

Understanding the components of radiation is important to estimate proper building heat gains in order to properly size systems for heating and cooling. In Fig. 1, there are a number of questions that arise when estimating the amount of radiation that a window sees:

- Does radiation (direct and diffuse) differ for each orientation?
- At a window, how do we account for radiation bouncing off nearby objects and ground planes, in terms of reflected and diffuse radiation?
- What assumptions are made by shading tools and PHPP about radiation?
- How easy are these tools to use and how can we readily extract the information needed? How accurate is this information?

1.2 Manual Calculations

As a proof of concept, manual calculations based on the methods provided in *Renewable and Efficient Electric Power Systems* (3) were used to look at the percentages for direct, diffuse, and reflected radiation that fall on a vertical surface on a given day of the year. We wanted to verify that diffuse and reflected radiation are significant contributors to global solar radiation, and should be treated as such. In order to calculate the individual components of radiation, the following equations were used. First, the equation for direct beam:

$I_B = Ae^{-km}$
A = apparent extraterrestrial flux
$= 1160 + 75\sin[(360/365)(n-275)]$
k = optical depth dimensionless factor
$= 0.174 + 0.035\sin[(360/365)(n-100)]$
m = air mass ratio
$= 1/\sin\beta$
β = altitude of the sun

From this equation, the beam radiation reaching the collector surface, I_{BC}, in this case a vertical window, can be derived with the following equation:

$I_{BC} = I_B\cos\theta$
$\cos\theta$ = Cosine of the incidence angle
$= \cos\beta\cos(\Phi_S - \Phi_C)\sin\Sigma + \sin\beta\cos\Sigma$
Σ = angle of collector surface
Φ_C = horizontal angle from south

Next the diffuse radiation component on the collector surface, I_{DC}, can be found with the following equation:

$I_{DC} = CI_B[(1+\cos\Sigma)/2]$
C = sky diffuse factor
$= 0.095 + 0.04\sin[(360/365)(n-100)]$

The last factor, reflected radiation falling on a collector surface, I_{RC}, can be found with this equation:

$I_{RC} = \rho I_B(\sin\beta + C)((1-\cos\Sigma)/2)$
ρ = surface reflectance, 0.2 for grass in front of collector

After calculating all the components, we determined that the percent of diffuse and reflected radiation account for 12% - 33% of the total radiation at solar noon in Eugene, depending on the day of the year. Thus, reflected and diffuse radiation constitute a significant portion of global radiation and should neither be ignored nor treated as direct beam radiation, because they behave uniquely with non-directional qualities, in the field of solar analysis.

1.3 Radiation and Passive House

The impact of windows on heat losses and gains in a building is meticulously accounted for within the Passive House Planning Package (PHPP). The amount of solar radiation gained through the windows needs to be carefully calculated in Passive Houses to ensure that the house can maintain a stable temperature. However, PHPP only utilizes local global solar radiation data, and treats it as “orientation dependent radiation” (4). This means PHPP uses the numbers of global radiation and assumes that all the radiation behaves as direct-beam, and thus responds to shading. However, diffuse and reflected do not, and as we determined, they can constitute a significant portion of radiation hitting a vertical surface.

2. THE PROBLEM

We believe that most software programs assume negligible effects from diffuse and reflected radiation. Depending on the reflectivity and absorptivity of the surrounding surfaces, it cannot be assumed that all heat gain through windows will behave as direct beam radiation. However, most programs assume there are no surrounding surfaces to take into account. Most tools also ignore the effects of deciduous trees, which block direct beam radiation for only portions of the year.

During solar gain analysis, one cannot assume that blocking the direct beam radiation with a shading device reduces all solar gain, as there is up to 40% of the total radiation on a clear day, in the form of diffuse and reflected radiation (2), that may remain unblocked.

3. METHODOLOGY

3.1 Tool Comparison

We selected the solar analysis tools based on availability to professionals, ranging from manual to digital. The evaluation criteria for the tools included: 1) cost; 2) ease of use; 3) output type; 4) additional software; 5) operating system requirements; 6) global positioning satellite capabilities 7) types of radiation measured; 7) and recognized types of shading obstructions. The study focuses around how these devices account for diffuse radiation and whether they can account for a building’s overhead shading devices.

3.2 PHPP Shading Protocol

The PHPP Shading Protocol is a preliminary protocol created by the Passive House Institute United States (PHIUS) to create more specificity within the PHPP shading sheet. Currently PHPP assumes solar radiation inputs to the shading spreadsheet, based on TMY2 weather files, rather then site specific data. Their protocol utilizes a Solar Pathfinder and manual calculations to determine the amount of solar gain a window receives. Currently this protocol does not discriminate between the different types of radiation, but it is still in its preliminary stages. We will follow the PHPP Shading Protocol for a case study window and compare the results with other solar analysis tools.

3.3 Combining Tools

While examining the tools and protocol, we will be looking for possible efficiencies and overlaps between tools and programs to find the best solar analysis method.

TABLE 1: TOOL COMPARISON

Tool	Solar Transit	Solar Pathfinder	Solometric Suneye	HORIcatcher	Sun Seeker	Solmetric iPV
Cost	$10.00	$259.00	$1,995.00	$1526.00 *(1400CHF)*	$8.99	$39.99
Ease of Use	Hard	Easy	Medium	Easy	Easy	Easy
Output	Manually drawn horizon shading mask diagram	Manually drawn horizon shading mask diagram	Digital fisheye image and horizon shading mask diagram	Fisheye image- as a horizon image for Meteonorm software	Digital read of azimuth and altitude manually drawn on horizon shading mask diagram	Digital image of unwrapped horizon shading mask diagram
Software	N/A	Thermal Assistant $199.00	PV Designer Software $400	Meteonorm $710*(650 CHF)*	N/A	N/A
Operating System	Manual	PC	PC	PC	iPhone Application	iPhone Application
GPS	basic compass	basic compass	full GPS	basic compass	basic compass	basic compass
Types of Radiation Measured						
Global		✓	✓	✓		✓
Direct-Beam				✓		
Diffuse				✓		
Reflected				✓		
Recognized Types of Obstructions						
Permanent	✓	✓	✓	✓	✓	✓
Deciduous		✓				
Overhead	✓	✓	✓		✓	

4. ANALYSIS

At a glance, Table 1 shows the general differences between the tools related to cost, learning curve, outputs, inputs, software required, ability to account for obstructions, and assumptions about radiation. This section describes each tool and some of their nuances.

4.1 Solar Transit

The Solar Transit was developed as a low-cost, easy to make tool for people to learn about the sun's position in the sky and construct a horizon shading mask that would show solar access at a given location. Although difficult to use at first, once understood, the Solar Transit is not a complex tool. Shading masks are drawn onto a sunpath diagram through a series of readings off of the transit by locating the obstruction of the sun's rays to that particular location. The Transit focuses on mapping the sun and its obstructions (Fig. 2).

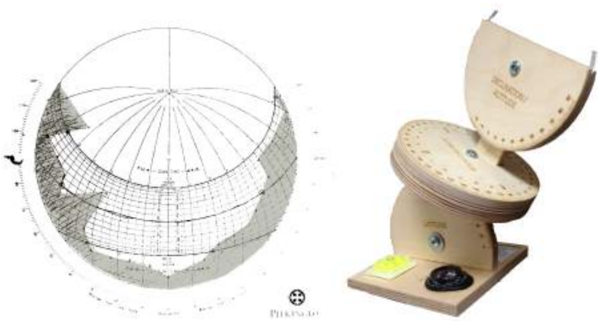

Fig. 2: Left, horizon shading mask for a location at Erb Memorial Union courtyard on the University of Oregon campus, created with the Solar Transit, shown at right.

Since all that can be done with this device is record shading obstructions, calculations to determine the amount of diffuse radiation would be difficult, although similar to the manual calculations for the Solar Pathfinder. The transit itself is made from low cost plywood, a compass, bubble level, and the equation of time. It is not useable for examining shading devices as obstructions to the window. Once learned, the transit provides the foundation for all other solar analysis tools and the rationale behind them.

4.2 Solar Pathfinder

The Solar Pathfinder is an analog tool that does many of the same things as the Solar Transit. It is quick to set up and one can see the horizon shading mask in the reflection of the polished dome of the Pathfinder. It is easy to draw the horizon shading onto the sunpath chart beneath the dome. There is a small amount of human error in drawing the shading mask because the width of a pen, or not viewing the reflection from directly above, which can vary the results. Once drawn, a camera can capture an image of the drawn shading mask or the Pathfinder from above which can then be imported into the accompanying PC-based Thermal Assistant 5.0 software.

Fig. 3: Reflected obstructions on dome intersect with sun path below (http://www.solarpathfinder.com/PF)

On the sunpath chart, there are small numbers given in half-hour increments, which show the percentage of radiation for a particular half-hour. The Thermal Assistant software can calculate radiation of any azimuth and any tilt angle, but for photovoltaic or solar hot water analysis, it requires a horizon shading mask for each corner of the array. The Thermal Assistant software is as intuitive to use at the Pathfinder itself. Once a new report is created with the proper location, the images can be brought in, and one can easily draw on the horizon line. Once the horizon is made, the user has the opportunity to draw in places of deciduous vegetation, choosing the time of year, and percentage of light allowed to pass through its branches. The output of the analysis based on the horizon conditions is given in global radiation, which does not separate out the various components of radiation. The output is given in percent of potential total radiation seen by the panels. This is useful information, however it shows that this device treats diffuse and reflected radiation the same as direct beam.

4.3 Solmetric SunEye

The Solmetric Suneye device can measure any site anywhere and run a solar analysis taking into account overhead shading devices. The SunEye has an internal global positioning satellite, which allows it to autocorrect for changes in level and orientation. Out of all the digital devices, this has the smallest learning curve. It is very simple to turn on the device, input the current location, and then capture an image. The device does the analysis on the spot, and outputs the percent of solar access on site. The images from the SunEye (Fig. 4) are also easily imported to the PC-based Solmetric SunEye software for further analysis. Both the program and the device draw their own horizon line, rather then allowing the user to draw one. Despite this, we found their horizon lines to be drawn accurately, as the computer was able to more closely outline the objects then a human hand.

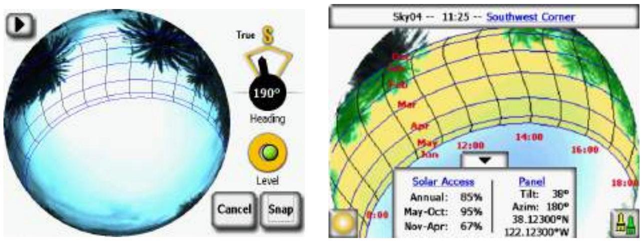

Fig. 4: Fisheye photo and sunpath diagram from the Solmetric Suneye. (http://www.solmetric.com/buy210.html)

The output from the software is given in percent of solar access available on a month by month basis. There is also no place to take deciduous vegetation into account, and it is unclear if the program recognizes a difference in objects. For photovoltaic analysis, the percent of solar access might be adequate, but the data is lacking for extracting the true amount of solar radiation at the site in order to determine solar heat gain that falls on a window.

Overall we found the software to be lacking in analysis, considering the cost and perceived complexity of the device. We found that when compared to the Solar Pathfinder each with an image taken at the same location, the percent of solar access determined by each device was similar in the spring, summer, and fall. However the winter numbers varied widely, with the SunEye having higher estimations of solar access than the Pathfinder. A good thing about the output is that the fish eye image is in jpeg form and can easily be put into another software for analysis. However, other fish eye photos cannot be inputting into the Solmetric software.

4.4 HORIcatcher

The HORIcatcher is a Swiss tool for capturing fish eye photos, designed to work in conjunction with their Meteonorm software. The HORIcatcher itself is easy to set up and capture a photo, as there is a level and compass on the device, as well as a camera included in the device set to the exact center of the fish eye lens. Once the photo is taken, it can be plugged in to the Meteonorm software under the “custom horizon” tab. Within this tab the software unwraps and orients the image, and allows the user to add a customized horizon line. The largest deficiency in the software is at this point. While drawing the horizon, it is not possible to take into account overhead obstructions such as trees and shading devices, because it only allows you to draw objects directly correlated with the ground line For a site solar analysis this may be alright if there are no large trees nearby. However, for building analysis where there is some amount of overhead shading or nearby trees, this software becomes inaccurate.

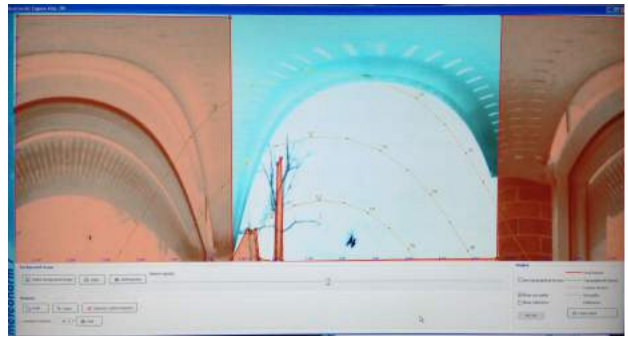
Fig 5: Drawn in horizon line (red), the lower objects are accounted for, however, the overhead shading device cannot be drawn in (screenshot from Meteonorm 7 software)

Outside of this deficiency however, the Meteonorm 7 software is the best software we came across at separating out the various parts of radiation. The software allows for a selection of the average albedo of the immediate environment, thus accounting for reflected radiation to some extent. If an angled surface, such as a window, is chosen for analysis, the outputs can be given in horizontal radiation as well as radiation on the angled surface. Also, diffuse radiation can be separated out from direct-beam radiation in analysis. This allows the designer to determine the amount of radiation landing on a window despite the shading devices that may be blocking the direct beam, and thus have more accurate solar gain calculations.

4.5 Sun Seeker

The Sun Seeker application for the iPhone is a tool comparable to the Solar Transit. It allows the user to pinpoint obstructions on the horizon utilizing augmented reality, basic GPS, and slope correction to give the exact altitude and azimuth. The solar path for the day, as well as the solstices, is also pictured in the 3D augmented reality view. This tool can be used to both locate the position of the sun in the sky at a particular date and time, as well as to locate obstructions on a manually drawn horizon shading mask diagram, similar to how the Solar Transit functions.

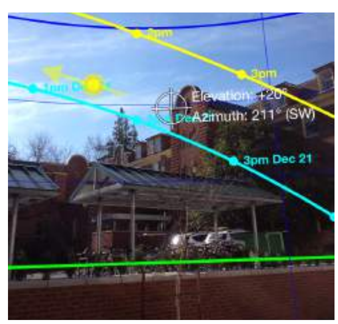

Fig. 6: 3D augmented reality obstruction locator (screenshot from iPhone)

There is also a map function to this tool that pinpoints your current location and then overlays the azimuth angles for the sun on any calendar day you select. This is helpful in determining both the hours of sun in various seasons and how much sun your site is exposed to based on the obstructions. Unfortunately, there is no digital readout associated with the application, and thus all information gathered must be manually translated to a useful diagram.

4.6 Solmetric iPV

Similar to the Sun Seeker Application, the Solmetric iPV is an iPhone application that is designed to size and determine the effectiveness of photovoltaic panels in specific locations. It also uses augmented reality to view horizon obstructions, but this application uses a crosshairs tool to allow the user to trace the edges of the skyline on the screen. This trace is then translated by the application onto an unwrapped horizon shading mask diagram, which is then used in association with local weather data to estimate the amount of solar energy, in the form of global radiation that will hit a surface. Solmetric designed this application as a substitute for their more expensive Sun Eye, but this application is less accurate and less professional than the Sun Eye.

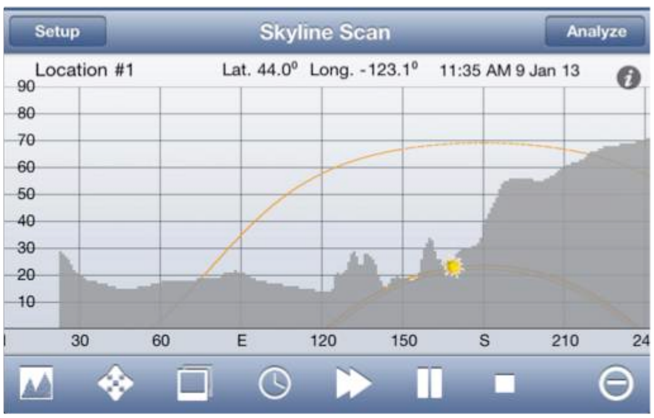

Fig. 7: Unwrapped skyline photo taken in Eugene, Oregon from Solmetric iPV application (screenshot from iPhone)

It does however, generate an informal report at the end, which includes the solar radiation data as well as the unwrapped horizon shading mask diagram, and it can be utilized as a preliminary solar study. You must select your location, as well as the type of PV panels if you want to use the data for PV analysis, to get accurate data. There is no distinction between the various components of solar radiation.

5. CASE STUDY: ALLEN HALL

In order to compare the accuracy of the tools, we chose a case study window on the South facade of Allen Hall, the new Journalism School building on the University of Oregon campus. We tested a combination of tools and softwares: the Solmetric SunEye, Suneye + Meteonorm, SunEye + PHPP Shading protocol, HORIcatcher + Meteonorm, HORIcatcher + PHPP Shading Protocol, Solar Pathfiner + Meteonorm, and the Solar Pathfinder + PHPP Shading Protocol. These tools were selected because they would give us comparable results in terms of percent of solar access available.

5. 1 Tool Outputs

Each tool outputted a fish eye photo from the same location on the case study window sill. The Solar Pathfinder gave us data in the form of a photograph from above the top polished dome, which was inputted in to Meteonorm 7 and the PHPP Shading Protocol. The Solmetric SunEye, created a digital photo with its fish eye lens which allowed us to analyze it in the Solmetric software, the Meteonorm software, and overlay a sun path chart for analysis with the PHPP shading protocol. Similarly, the HORIcatcher image is in jpeg form so we easily overlaid a sun path chart for PHPP analysis. The Solar Pathfinder and HORIcatcher images cannot be input into Solmetric software because the software only accepts images from the SunEye

The photo from each tool was put into both the Meteonorm software and the PHPP Shading Protocol. The overlaid horizon shading masks allowed the shading to be counted in accordance with the PHPP shading protocol, taking into account deciduous vegetation. From the protocol, percentages of solar radiation access are given per month, to be inserted into the original PHPP file.

Blank form, 43-49 degrees Latitude

	6		7		8		9		10		11		12		1		2		3		4		5		6		7		Site %
DEC					0	0	0	0	3	7	8	9	4.5	9	9	4	0	0	0	0	0	0							53.5
JAN					0	0	0	5	3	7	8	8	4.5	9	8	8	0	0	0	0	0	0							60.5
NOV					0	0	0	5	6	7	8	8	9	9	8	8	0	0	0	0	0	0							68
FEB				0	0	3	4	5	6	7	7	7	8	8	7	7	7	0	0	0	0	0	0						76
OCT				0	0	3	4	5	3	0	3.5	7	8	8	7	7	7	3	0	0	0	0	0						65.5
MAR			0	0	1	3	4	5	6	6	7	7	7	7	7	7	6	6	5	0	3	0	0	0					87
SEP			0	0	0	0	2	5	6	6	0	7	7	7	7	7	6	6	5	4	1.5	0	0	0					76.5
APR			0	0	1	0	0	5	6	6	7	7	7	7	7	7	6	6	5	2	0	0	0	0					79
AUG		0	1	0	2	0	0	5	6	6	6	7	7	7	7	6	6	6	5	0	0	0	0	0	0				77
MAY		0	1	2	3	1.5	0	2.5	5	6	6	7	7	7	7	6	6	5	2.5	0	0	0	0	0	0				74.5
JUL		0	0.5	2	3	3	0	0	5	6	6	7	7	7	7	6	6	5	0	0	0	0	0	0	0				70.5
JUN	0	0	0	2	2	3	0	0	5	6	6	7	7	7	7	6	6	5	0	0	0	0	0	0	0	0			69

Fig. 8 PHPP Preliminary Shading Protocol

Since only Meteonorm outputs each component of radiation we compared the tool's output of percent of solar access across the whole year and in January, since winter was the time with the most variation in result from the devices.

5.2 Analysis

The results between the programs were surprisingly varied, as shown in Table 2. In general, tools and software that used the SunEye image overestimated the amount of solar access for the case study window. It is important to note that the Meteonorm software is expected to show a slightly higher solar access because it cannot take into account the overhead shading devices. However, the overhead shading device impacted a small percentage of the solar path in January, so the addition of it is negligible for those calculations.

<u>TABLE 2: SOALR ACCESS OUTPUT OF TOOLS AND SOFTWARE FOR CASE STUDY WINDOW</u>

	Meteonorm 7	Solmetric Software	PHPP Shading Protocol
Solar Pathfinder, Annual	86.7%	n/a	71.4%
SunEye, Annual	84.0%	76.0%	81.1%
HORIcatcher, Annual	77.8%	n/a	55.3%
Solar Pathfinder, January	85.5%	n/a	66.5%
SunEye, January	93.0%	90.0%	88.5%
HORIcatcher, January	68.7%	n/a	12.0%

The main differences in the results were found in the winter months. Considering these images (Fig 9) were captured from the exact same point, we are unsure why there is a large variation. We expect the PHPP Shading Protocol to estimate a lower solar access, since it takes into account deciduous shading, while the SunEye and Meteonorm do not consider vegetation. Since these photographs were taken in winter, the SunEye and Meteonorm will overestimate solar access in summer.

One hypothesis is that the Suneye has a truncated view of the sky, cutting off lower obstructions, raising the horizon line. To verify this, we captured another image from the same location with the HORIcatcher, since the lens is more similar to that of the Solar Pathfinder then the SunEye. The HORIcatcher image, when compared to the SunEye image in the Meteonorm software, shows a lower amount of solar access, even lower solar access then calculated by the Solar Pathfinder. Upon further inspection of the tools, we realized the frame on the Solar Pathfinder might also be decreasing the amount of visible horizon, cutting the image a few degrees above the true horizon line. We believe the HORIcatcher sees the entire sky dome, even showing area slightly below the horizon.

Based on this case study and results outline above, the most accurate solar analysis is between the HORIcatcher + Meteonorm and the HORIcatcher + PHPP shading protocol. The combination of these two protocols would incorporate overhead and deciduous vegetation, while reducing the human error associated with the PHPP shading protocol.

Fig 9. From top, sun path chart from the SunEye, Solar Pathfinder, and HORIcatcher for the case study window showing a decrease in truncation of the sky from top to bottom device

6. <u>CONCLUSION</u>

Our research into components of radiation has informed us that direct-beam, diffuse, and reflected radiation behave very different from one another. Most importantly, that a lack of intuitive directionality distinguishes diffuse and reflected from direct-beam. The mathematical calculation of components of radiation has shown that diffuse and reflected radiation contribute to a significant portion of the global solar radiation, even on sunny days.

The solar tools evaluation has concluded that no one tool is yet able to address all the issues associated with measuring radiation, particularly measuring the various components of radiation and shading obstructions. Also, our research shows that there are major discrepancies between tools, so accuracy is debatable.

Our research into PHPP has shown that even amongst professionals in the field who strive for absolute accuracy of heat gain calculations, the non-directionality of diffuse and reflected radiation still remains unaddressed.

We cannot continue to ignore the impact that diffuse and reflected radiation have on our buildings, especially as we strive to become more energy efficient. More accurate calculations lead to more accurate systems, which in turn reduces wasted resources. Assuming all radiation is being blocked by a shading device can cause gross underestimations in solar heat gain. These underestimations can lead to increased interior temperature particularly in high performance buildings such as Passive Houses, causing thermal discomfort.

There is a general confusion and lack of knowledge in the profession about solar radiation, which needs to be addressed. Solar analysis tools need to provide the profession with more accurate and comprehensive data. Finally, detailed calculations related to heat gain must begin to address the unique components of radiation. No longer can diffuse and reflected radiation be ignored.

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8. REFERENCES

(1) Solar Transit: unique instrument developed by Professor Charles Benton at UC Berkeley used to determine solar access at a site by modeling the seasonal path of the sun and locating horizon obstructions.Naqi, Mahammad. Encyclopaedia of Geomorphology, Anmol Publications Pvt Ltd: Publication, 2006
(2) Masters, Gilbert. Renewable and Efficient Electric Power Systems. Hoboken: John Wiley and Sons Inc, 2004, ch 7
(3) Feist, Dr. Wolfgang. Passive House Planning Package 2007. Darmstadt: Passivhaus Institut, 2007
(4) ANSI/ASHRAE Standard 55-2010 Thermal Environmental conditions for Human Occupancy