The New Age of Lighting and Heating

Reptile lighting is constantly evolving. Whilst today's keepers have always considered reptiles to be ecto-thermic and reliant on heat, the methods with which we provide such heat and light have changed drastically over the last 50 years. Now, we strive to replicate the sun's radiation as closely as possible and newer products allow us to replicate the major wavelength groups. Whilst we can measure ultra violet light (UVi), visible light (Lux), measuring the strength of infrared radiation (power density) has not been in the herpetologists' tool box. Hitherto measuring heat has been the proxy for sunlight strength; here we explain why solar irradiance has our attention.

The Basics

The sunlight spectrum (280nm – 3000nm) can be broken into three wavelength groups; ultraviolet light (280nm-400nm), visible light (400nm-700nm) and near infrared light (700nm-3000nm).

The shortest wavelength group ultraviolet, includes UVb, an important facilitator for Vitamin D3, calcium and management of the immune system, but can, in excess also cause cancer. UVa is also used by our reptiles and is recognised as facilitating vision at wavelengths that we humans cannot see.

Bright visible light is the only part of the solar spectrum we can see, it offers vision, triggers the circadian cycle and hormonal balance, thus improving mood. Visible light photons carry the greatest energy and contribute to heating of the skin surface.

The longest wavelengths are infrared and have sub-groups, IRa, IRb, and IRc, also called Near Infrared and Far Infrared. The most physiologically important wavelengths centered around 1000nm, are near infrared and in the IRa band specifically.

Near IR is physiologically important because it is able to penetrate into the dermis, and heat it internally. Near IR is a healer; it helps the production of nitric oxide and research has shown that nitric oxide helps functions in the nervous system such as digestion. It may also encourage the release of hormones, including growth hormones and insulin. Nitric oxide also acts as a vasodilator, meaning it helps open blood vessels to improve blood flow. How better to circulate heat than with warming blood?

A body operating at Far IR temperatures, (say 300^{0}c) sheds most of its energy through conduction and convection rather than radiation. It is generally sensed physically by touch, (like a heat mat). Far IR is not a constituent of sunlight irradiation.

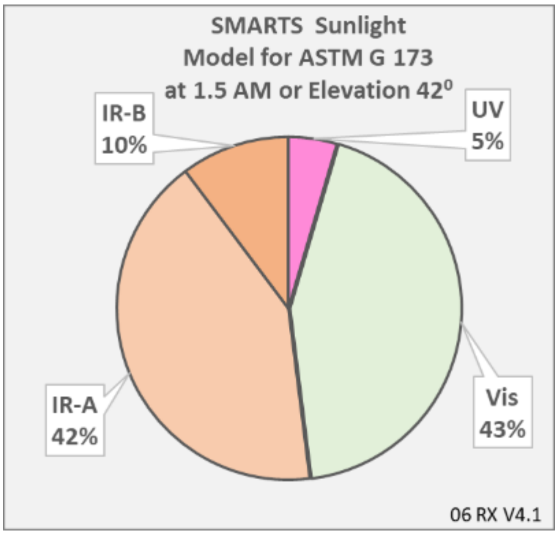
Irradiating wavelengths, spanning the full solar spectrum from 280nm to 3000nm work together to provide full spectrum benefits. Thus, all wavelengths must be represented to simulate the sun. Whilst there are no single products that perfectly replicate the complete solar spectrum, hobbyists will typically use a combination of lamps in the best vivarium set-ups.

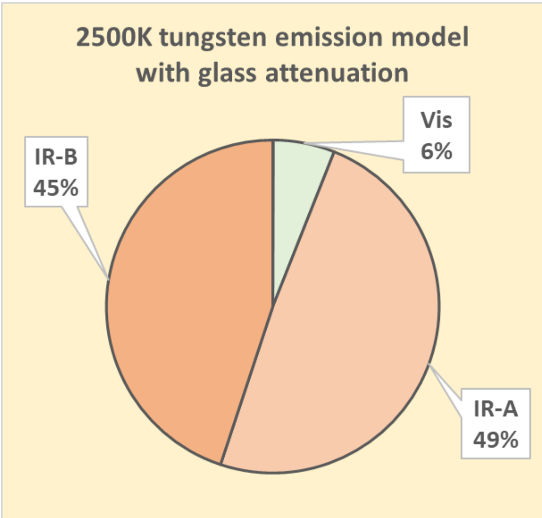
These are
1) for ultraviolet D3 provision, usually a tube such as an HO-T5 D3;
2) for visible light an LED spot light or an HID halide lamp;
3) for Near Infrared a tungsten/halogen/incandescent lamp.

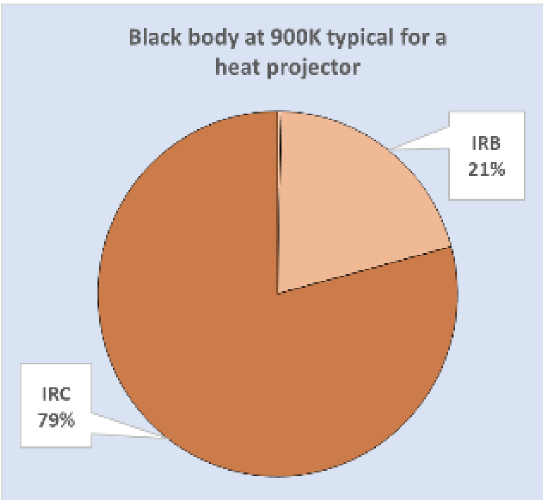
In October 2019 "Exotic Keeper Magazine" published an article "The Next Level Heating" which has since been referenced by hobbyists frequently. It's now five years later, herpetology has evolved and we are able to update some of the information then presented. One of the changes is to include and recognise that there is an international standard for sunlight that was developed for the Solar Power industry. It is ASTM 173-G defined at an Air Mass (AM) of 1.5 (or a solar elevation of 42 degrees) it is entirely appropriate to use this standard for herpetology as the wavelengths used by basking reptiles are the same as those used by solar panels. Furthermore, there is a public domain data set called SMARTS which enables sunlight modeling for different times of the day.

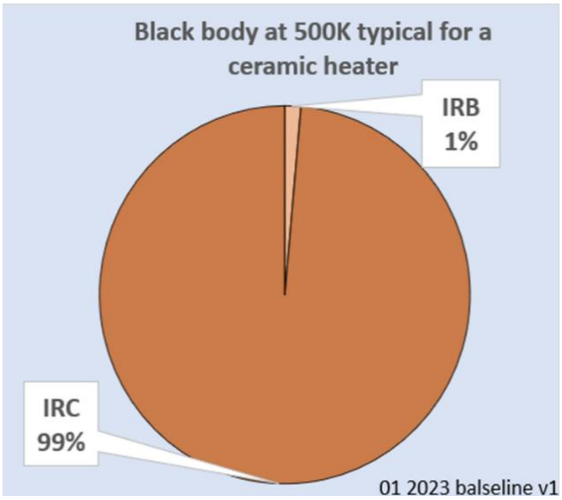
In this note, the black body radiators, the heat projectors, ceramic emitters and heat mats are depicted by pie charts as before, but a better approximation for their operating temperature has been used.

In the last 2 years Quentin Dishman has taken the original model for tungsten lamps and significantly improved it by adding tungsten emissivity to the model. The charts below reflect the best science we have currently.









The Experiment – "What light would a reptile choose if given a choice?"

Over the course of three years Roman Muryn has studied the usage of basking spots for various different species of reptiles. He used dozens of bulbs; MVB *Mercury Vapour Bulb* (3 sizes, 2 brands), *Tungsten halogen* (1 crate of assorted Powers, Kelvins and shapes), *HID Halide* (Several brands and powers including UVB producers), *Carbon filament heat projectors* (4 items tested, 3 brands). Taking 1000s of photographs, he recorded the frequency that a basking spot was visited by the following species: Bosc monitor (*Varanus exanthematicus*), Bearded Dragon (*Pogona vitticeps*), Painted Agama (*Laudakia stellio*), Collared lizard

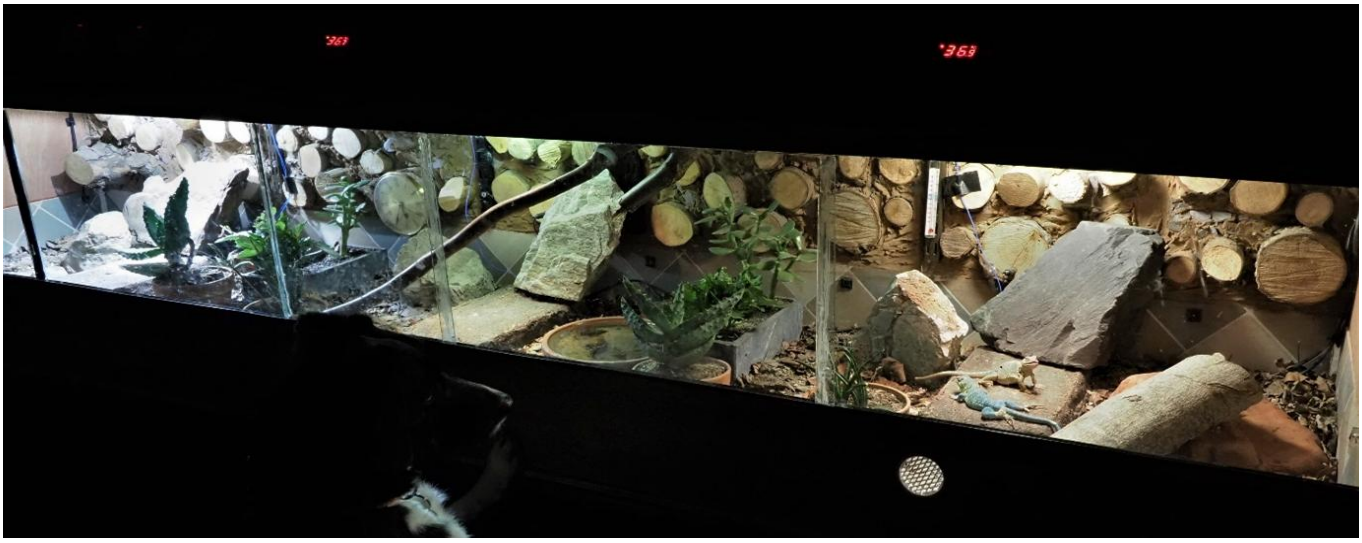
(*Crotaphytus collaris*), Desert iguana (*Dipsosaurus dorsalis*), Italian wall Lizard (*Podarcis sicula campestris*), Ackie dwarf monitor (*Varanus acanthurus*).

The experiment involved a purpose-built, 8-foot vivarium, offering three identical basking positions. Each position had a UVb tube (T5 HO 12%), a visible light provision (E27 LEDs, Halides and MVBs) and a Near IR provision (E27, many forms of tungsten/halogen and incandescent bulb). Each basking spot, a "concrete slab" had exactly the same colour, mass and material, each slab was thermostatically controlled.

Each basking area had similar furniture and air flow.

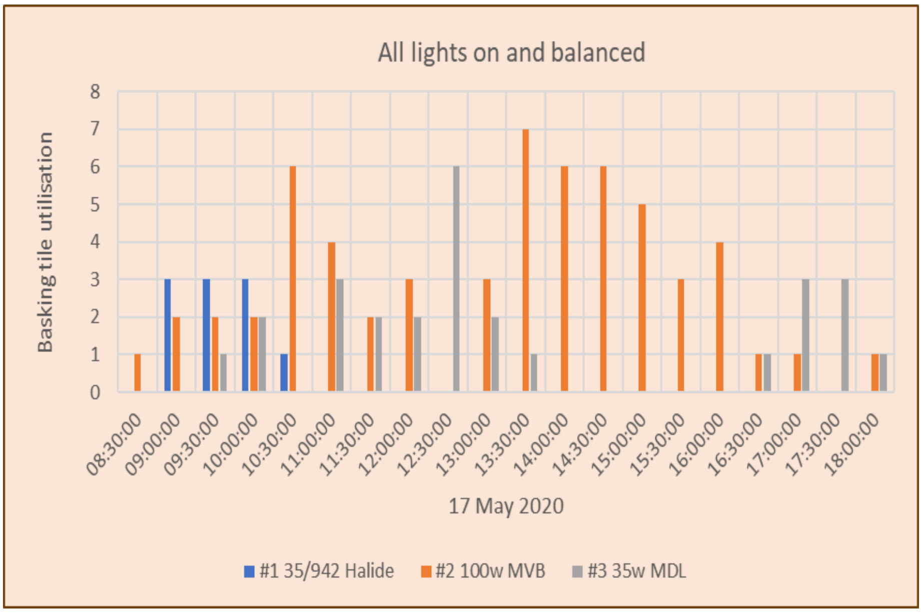
A clock was used to co-ordinate activity, location, with the thermal data logger and video.

The working temperature for the basking area was chosen to be 40c.

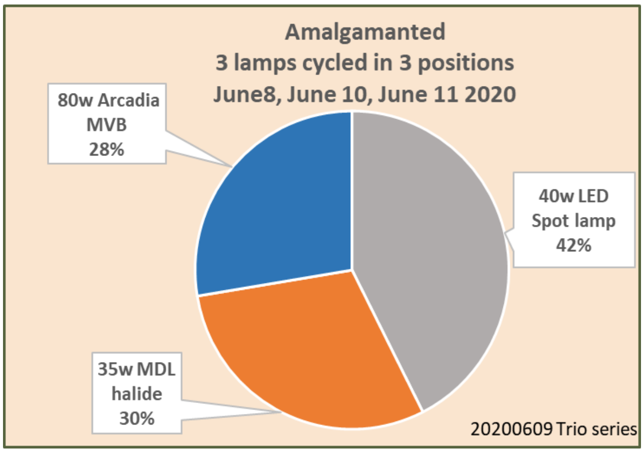


Many combinations of lamps, temperatures and powers were evaluated. The earliest results were baffling and not what had been expected. Here an example to demonstrate the problem. The balanced temperatures were 40c on the basking spot. HID halide lamps are favourites for lighting enclosures especially in Europe, so 2 different lamps were being assessed, the third lamp was a mercury vapour lamp (MVB) lamp.

The MVB was by far the most visited basking spot by the lizards; a surprise. Note that activity dropped off at midday, just as it does in nature. Why was the MVB preferred?



Eventually a combination of lamps and powers was established where all the lamps were visited with equal frequency. Tests included switching lamp positions to reduce the favourite spot and other preferential effects.



It was about that time that Roman was having his solar panels checked. The engineer was using a meter to measure actual solar power; the sunlight specification for the panels was noted and it quoted the AM1.5 solar standard. It seemed that the use of this meter would enable actual lamp power to be measured directly during the vivarium experiment.

Tungsten halogen lamps are “black Body” light emitters through incandescence just as the sun is!

An RS Pro ISM 400 solar power meter was obtained and measurements were taken. Units of solar power are in watts per square metre, a standard engineering metric. (w/m^2) and defined as Power Density (PD).

Note that LEDs lamps, Halide lamps and MVB lamps are not “black body” emitters of light, and readings taken with the ISM 400 have yet to be calibrated.

Then there was the “light bulb” moment.

The balanced lamp set up noted above in the pie chart, gave the results as shown in the table using the new meter. The power readings were the discriminator! Later test showed that the halide lamps in the test were avoided simply because they were too intense at the distances used during testing.

Power density with RS ISM 4010 Distance about 33cm			
		50w tungsten alone	Just visible light
35w MDL HID	w/m^2	240	60
40w LED spot	w/m^2	240	86
100w MVB	w/m^2	224	75

It was not the temperature of the basking spot that mattered to the animals, it was the intensity of the lamp that they were responding to. PD mattered and PD could now be measured.

Later work showed that whilst the ISM 400 meter was designed and calibrated to measure sunlight at ASTM 173-G, AM=1.5 standard, it was actually also quite satisfactory for measuring Near IR radiated from tungsten halogen lamps, provided the lamps were measured stand alone.

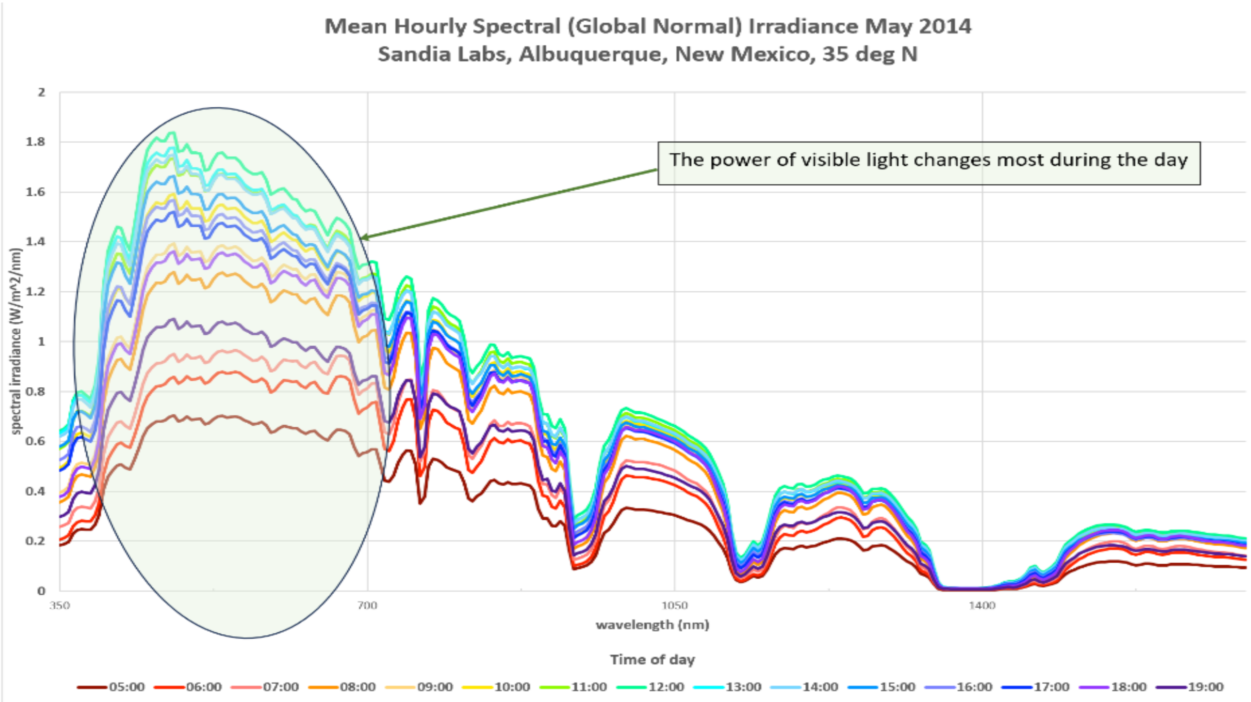
A paper by Piazena which examined the effects of PD on skin (human context) was revisited, with a pleasant surprise, in that the PD values that Piazena offered, matched Romans results.

> **Helmut Piazena and Debra K. Kelleher**
> *Effects of Infrared-A Irradiation on Skin: Discrepancies in Published Data Highlight the Need for an exact Consideration of Physical and Photobiological Laws and Appropriate Experimental Settings*
>
> “(approximately 250–300 W m)2 in the tropics and approximately 200 W m)2 in the mid-latitudes)”

As an exploration of Piazena’s statement, a number of people were asked to identify at which point they could feel a tungsten lamp warming their skin. It will not be a surprise that the first gentle warmth could be felt at about 200 w/m^2 what is more, people were quite consistent.

Changes in sunlight

The sun comes to visit us every day, it arrives at dawn and completes its tasks at dusk. In the morning it is on the horizon and its light has the longest path to travel. (This is the air mass AM referred in the sunlight specification). As day progresses so its light has a shorter path; it is closest to us at midday. The distance the suns light has to travel changes considerably. Consider that the atmosphere is not pure, it has dust, particles of pollution, Ozone and water vapour. All of these molecules act upon the light in different ways, the shorter the wavelength (bluer) then the more blocking or reflecting it receives. So, at sunrise and sunset when the suns light has its longest path, for the shortest wavelengths it also has the greatest impediment. That is why light in the morning and evening has more red content. What we don't see, is that early sunlight also has as a bigger proportion of infrared. At midday when the sun is overhead it has the shortest path to earth and so the greatest energy is received, ie visible light and UV are at their strongest, the most intense.



Global normal spectral irradiance in Albuquerque: a one-year open dataset for PV research

Anton Driesse1 and Joshua S. Stein

The graph shows that visible light fluctuates significantly over the day, but infrared remains comparatively more stable. This means that the sunlight a reptile is exposed to at 7am is very different in its makeup to the sunlight the reptile may be exposed to (or actively avoid) at mid-day. Most diurnal reptiles are active in early mornings and late evenings, when the animal can receive the maximal IR without the strongest UV and visible light energy being present.

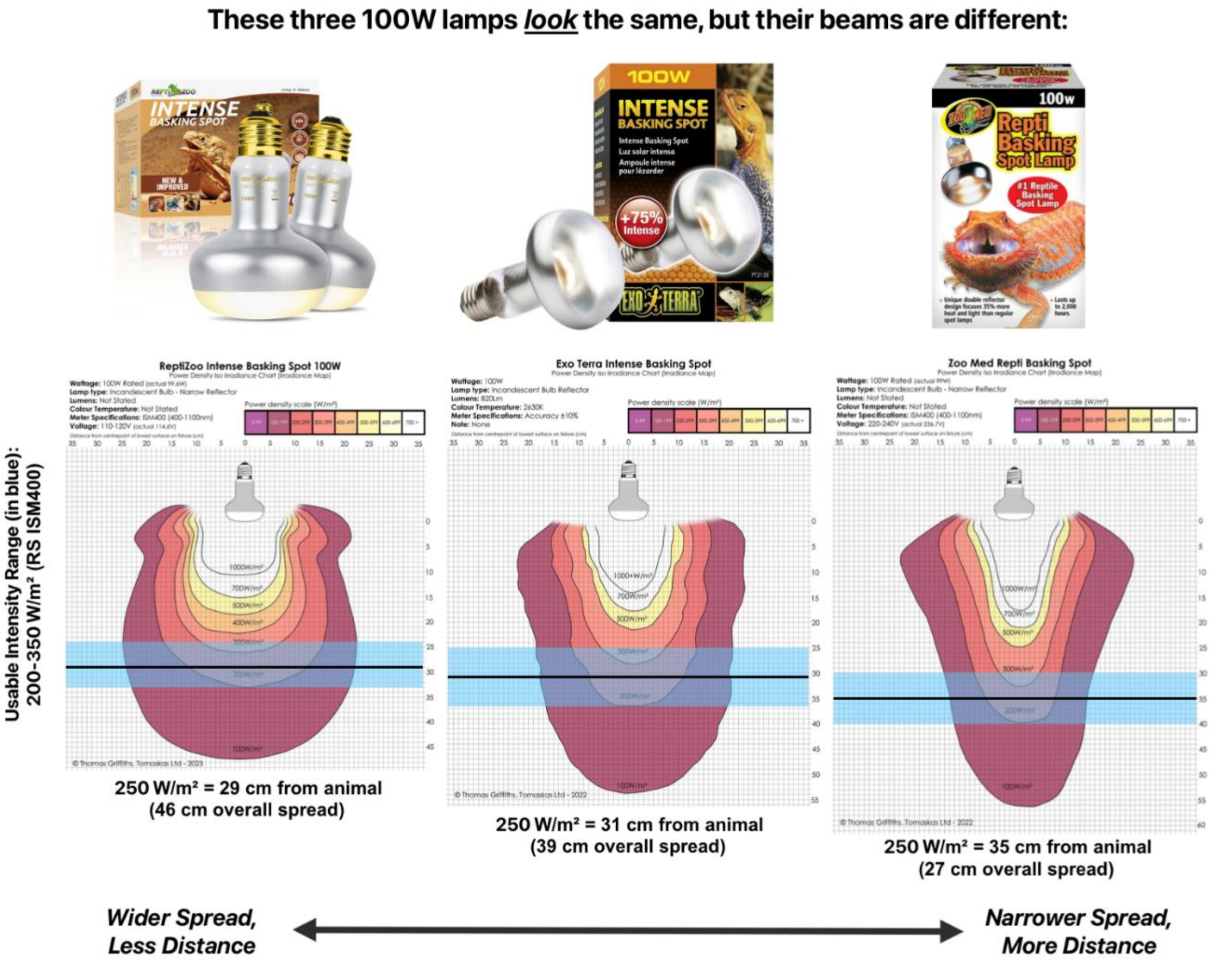
It is now possible to weave the threads of the above dialogue together. We have learned from the experiment that using the temperature of a basking spot does not help establish the best basking criteria but that knowing how strong the irradiation from a lamp is, gives better husbandry guidance. The experiment settled on about 250 w/m^2 as a preferred PD for Near IR. Piazena also identified a similar magnitude in his paper. The question now arises; what about real life? How does this information fit in practice?

The story then has nearly finished its tale, after some 3 years of experimentation, it was realised that the intensity of the light; its power, was important. An instrument was selected that could measure sunlight power; the RS Pro ISM 400, (it can also measure Near IR from tungsten lamps).

Experimentally 250w/m^2 for Near IR as emitted by a tungsten halogen was found to be about right. This also aligned with medical papers noted by Piazena and others. Meteorological data and physics told us how sunlight changed during the day. Field work informed that the best herping is in the morning when the sun was less intense. The numbers aligned!

Lamp timing and power

Interestingly, if the keeper can achieve the correct power density from their light, they will also likely achieve the correct temperature. The Reptile Lighting FB group has developed irradiance charts that depict how the light power (PD) is irradiated by a lamp. The example charts below show the spread of Near infra-red from various commercially-available lamps. The black/blue line shows where the power density matches that of recommended PD levels. Different lamps can reach this power density at different distances.



The above chart was produced by Quentin Dishman and the irradiance charts and measurements were produced by Thomas Griffiths.

It is hoped that data like this will be printed on the side of lamp packaging.

Using meteorological data, Roman and Quentin, along with various other herpetologists across the world, are already identifying power density for different regions. A methodology is being developed for recommending power densities, and has so far, been promising.

The experiment used timing as below, and thiswould be applicable to most cases. Variation for season should be applied.

For UV light
Turn on the UV lamps from 9.00 till 15.00.
Set power levels measured by the SM 6.5 as recommended by Ferguson zones.

For visible light
Turn on visible lamps from 8.30 till 19.00
Sunlight reaches over 100,000 Lux and that's not possible, not necessary, nor practicable in the vivarium. For the basking spot provide a lamp as bright as possible preferably over 20,000 Lux. The experimental vivarium had 40w LED spot lamps producing over 40,000 Lux. Provide background light also, strip light LEDs work fine.

For Near IR light
Turn on tungsten/halogen infrared lamps from 8.00 till 21.00
PD recommendation is about 200 w/m^2 for northerly cool climate animals and 350 w/m^2 for bright sunlight, midday desert animals. It is important to remember that basking strengths when we encounter animals are often lower than that normally quoted for midday sunlight power.

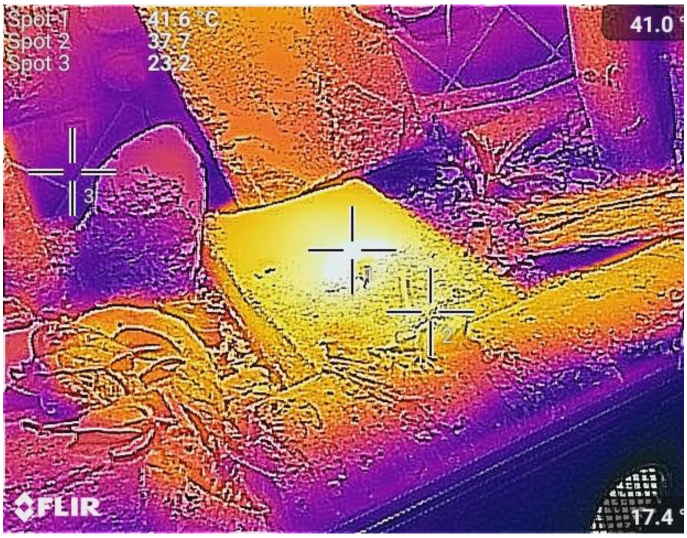
Whilst the light doses are now outlined, the other part of the vivarium set up-up should provide shade, substrate, humidity, ventilation, retreat and security.

A simple summary of just a few of the benefits each wavelength group brings.

UV wavelengths 290 – 400nm	Visible light wavelengths 400 – 700nm	Near Infrared wavelengths 700 – 3000nm
• D3 synthesis through UVb • Immune system management • Fungal and bacterial infections • Signalling • Egg development	• Warmth • Drying and heating to aid in shedding • Fungal and bacterial infections • Raise temperature to manage viral infections • Parietal eye stimulus • Melanopsin control • Hormone management and production –raises serotonin and dopamine levels. • Circadian cycle • Communication	• Sub-cellular Melatonin • Digesting food • Drying and heating to aid in shedding • Raise temperature to manage viral infections • Healing • Pineal gland stimulus • Egg and foetus incubation. • Protection against UV • Nitric Oxide. • IRa also stimulates ATP production in mitochondria

Temperature control

Once the lamp power is established and provided that the enclosure volume is appropriate then the basking spot temperature should follow through. However, a simple on/off thermostat is still required. The sensor is placed in the cool spot, one which offers the necessary thermal gradient, out of the direct light. This would be set such that if for some reason there is an overheating problem and the cool spot gets too hot, then the thermostat kills the heat lamp(s).



A typical infrared image of a basking spot, here you can see that the basking temperature actually covered the basking rock quite well. Note that the cool spot at the back is much lower in temperature.

In the experimental vivarium, the summer brought extra heat and a thermostatically controlled fan was used to suck in fresh cool air from outside, the inlet vent can be seen at the front in the IR image.

Summary

- Reptiles perceive light differently to humans, do not assume that what you see is what your reptiles sees.
- To mimic sunlight, the keeper should provide a source of ultraviolet light, a source of visible light and a source of infrared light in the right doses.
- Actual sunlight changes very little across the world for the same latitude, it is the local environment that influences temperatures.
- UV and visible light change the most throughout a day, infrared remains relatively stable. This can be mimicked in a terrarium.
- Providing the correct power density is just as important as providing the correct light spectrum. It is just like medicine; dose is important and dose varies from patient to patient.
- It is possible to provide the correct power density with lighting that already exists on the market. However, the keeper must select the wattage of each lamp to balance them effectively, dimming is not really required.

Roman Muryn C.Eng.

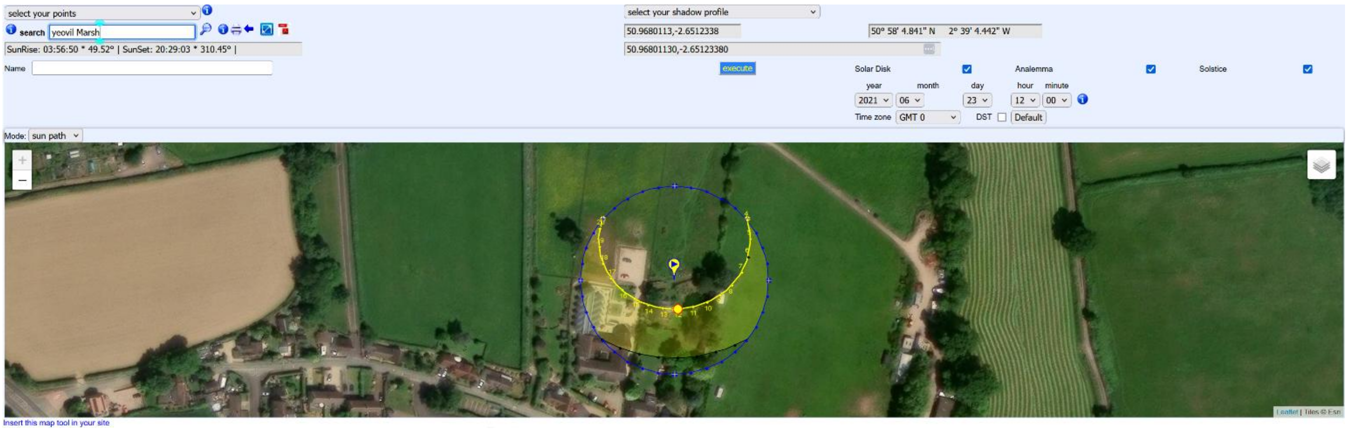
Addendum

The purpose of this addendum is to work though the practical element of this note. I will use a location in Somerset UK for the example. Its close enough to adders and other reptiles to be valid as an example, I have slow worms and grass snakes on site as well. Turtles in my pond also serve as a basking indicator.

First let us determine where the sun is whilst measuring outdoor power density.

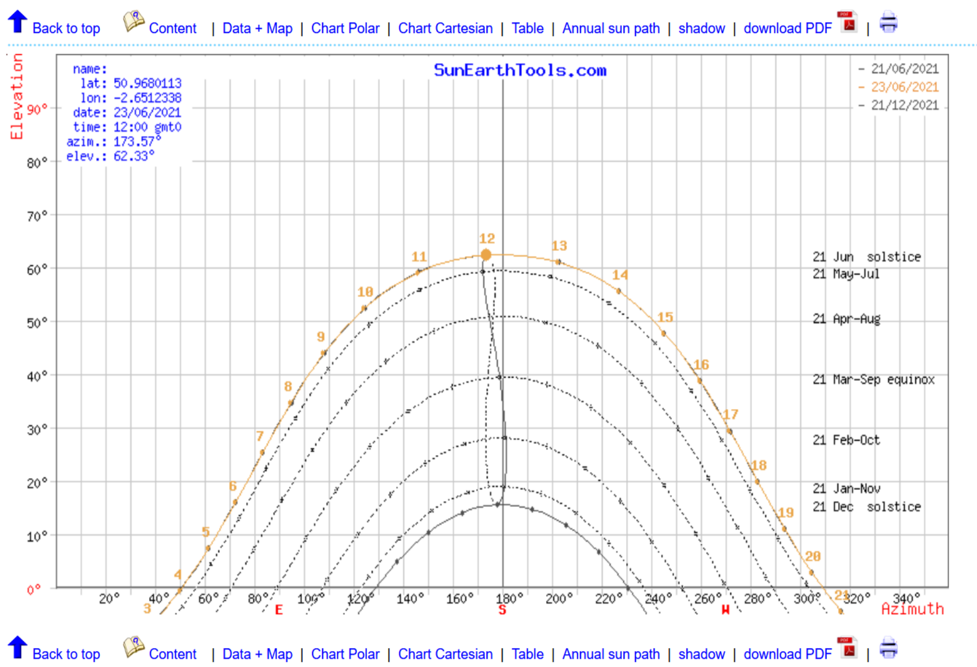
The tool I use is SunEarthtools https://www.sunearthtools.com/dp/tools/pos_sun.php#top

Start by *home>solar tools>sun position* Then select the time and location. I chose the time when my readings were taken. Then execute.



Scroll down to under the map and find graphs.

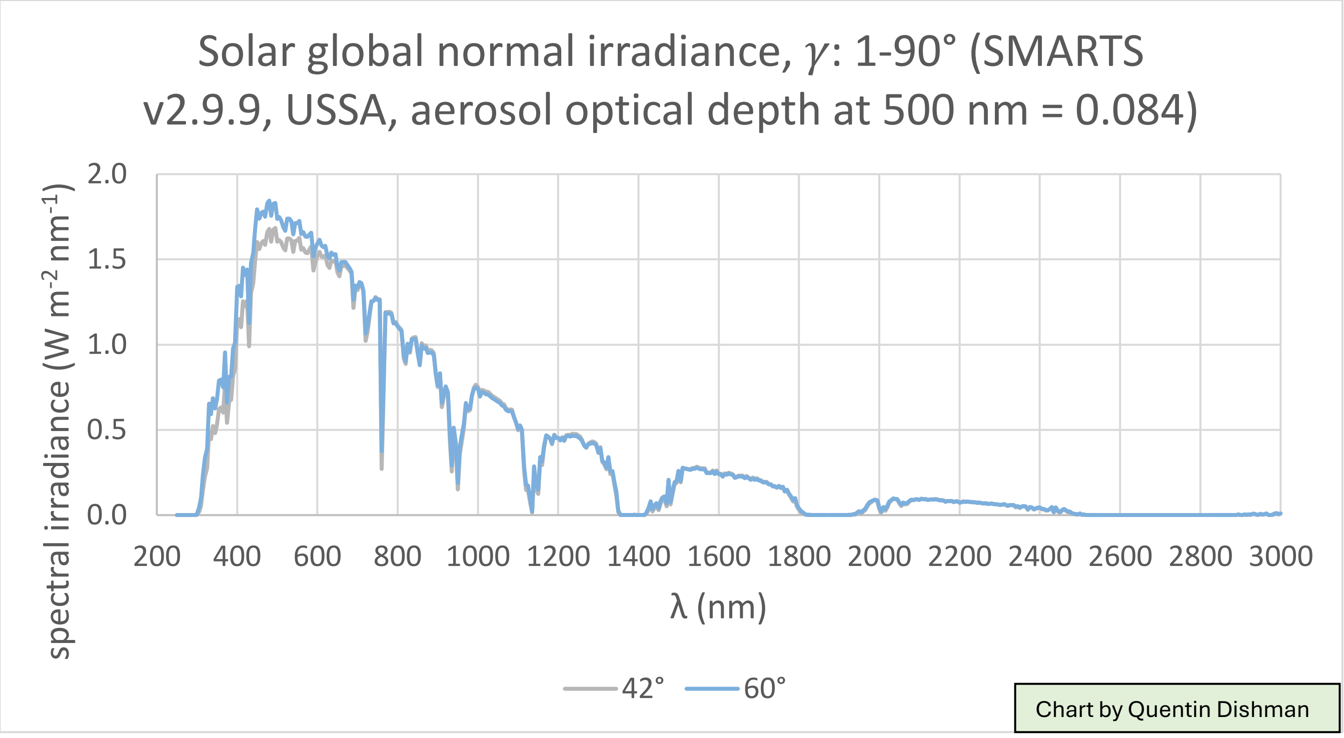
Date:	23/06/2021 | GMT0	
coordinates:	50.9680113, -2.6512338	
location:	50.96801130,-2.65123380	
hour	Elevation	Azimuth
03:56:50	-0.833°	49.52°
4:00:00	-0.46°	50.14°
5:00:00	7.35°	61.5°
6:00:00	16.03°	72.41°
7:00:00	25.25°	83.34°
8:00:00	34.67°	94.93°
9:00:00	43.91°	108.16°
10:00:00	52.37°	124.51°
11:00:00	59.04°	146.05°
12:00:00	62.33°	173.57°
13:00:00	60.98°	202.66°
14:00:00	55.56°	226.91°
15:00:00	47.72°	245.25°
16:00:00	38.72°	259.61°
17:00:00	29.32°	271.76°
18:00:00	19.97°	282.89°
19:00:00	11.01°	293.74°
20:00:00	2.79°	304.86°
20:29:03	-0.833°	310.45°



From the data (orange line) we can see that at the location at midday, the highest elevation for me will be 62^0 Lat. The 42^0 (1.5 Air Mass) point comes at about 8:30 and 15:45. This data point links to the ASTM 173 pie chart. Readings taken here will have the ratios as in the pie chart.

The SMARTS Model

I have selected from the SMARTS model, two elevation points, 42^0 and 60^0.



The spectrum using the SMARTS model looks like this for the 42^0, and 60^0 solar elevations. You can see that by 8:30 the solar power curve was very similar to the maximum midday values, and any significant variability would likely be due to atmospheric or local air quality effects.

From the SMARTS tool we get these numbers.

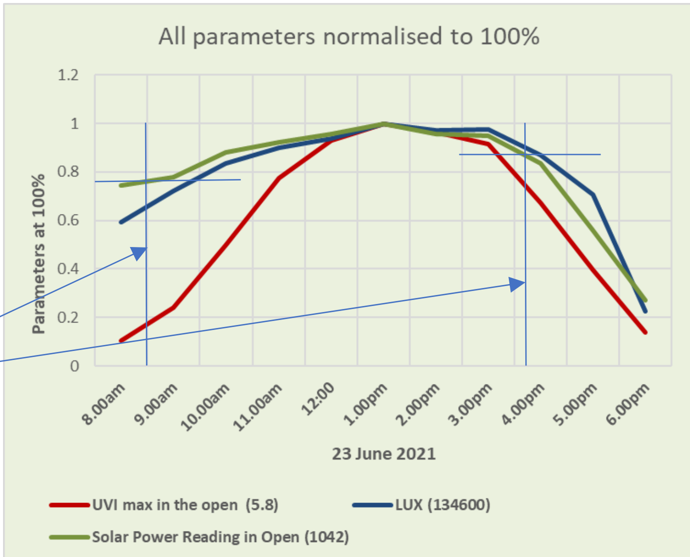
Elevation	42°		60°		90°	
total Value	1024.9		1074.4		1101.7	
UV	46.9	5%	59.6	6%	67.1	6%
Visible	445.1	43%	477.0	44%	494.8	45%
IR-A	427.9	42%	430.8	40%	432.6	39%
IR-B	104.9	10%	107.0	10%	107.2	10%

In 2021 June 23, I recorded these parameters. It looked a cloudless day.

From graphs you can see that the maximum elevation was 62^0 and PD was 1042w/m^2. The prediction from the SMARTS tool is 1074 w/m^2
The two values are really very close (3%).

The reference 42^0 elevation is encountered twice during the day, at 8:30am and 15:45 pm

At 8:30 we are at about 75% of max value PD Ie. 782w/m^2
At 15:45 we are at about 85% max PD Ie.886 w/m^2.



The 1.5 AM/42^0 value measured is quite different to the SMARTS model. The SMARTS model takes into consideration standard atmospheric effects that were defined some 50 years ago. Atmospheric content today is different, certainly for CO_2. Atmospheric effects can be considerable and not always apparent. We have two values for the same elevation, with the same meter at the same location; the difference is due to variation of atmospheric conditions during the day. Basking animals are used to such variation.

The Near IR content at 8:30 would have been 52% of 782 w/m^2= 407 w/m^2 , and at 15:45=461 w/m^2 , about an 11% variation and is perfectly acceptable.

By 8:30 the infrared content had achieved a stable value and at that point the animals were receiving maximum IR irradiation. It will be remembered that their basking started much earlier at a lower PD value.

The emerging recommendation when setting up the incandescent basking lamp is to "aim lower" for the working power density than the theory: this moves toward lower morning/evening levels of IR, which reptiles expose themselves to, more regularly.

The sun produces no IRc but the tungsten lamp does. The lamp produced IRc is blocked from escape by glass attenuation and its energy absorbed. It's about 10% of total power, so a 100w lamp will produce 10w of power that is captured and then dissipated by the glass and base fittings as heat. This lamp sourced heat can build up has to be managed. Enclosures do not behave as does nature outdoors, vivaria are nearly always covered, there is no sky to reradiate excess heat into, no night cooling, and we know that top mesh has a blocking effect. There is no cooling breeze, there is no humidity or evaporative cooling, very rarely is there a cool burrow from which heat relief is available. A lower lamp irradiation value helps mitigate this effect.

Given that a value here would be nominally 400 w/m^2 over much of the day, an incandescent lamp reading should be shooting lower, somewhere within the 200-300 w/m^2 range would be appropriate. Experimentally a value of 250 w/m^2 was found to work well.

I am grateful to Quentin Dishman for helping me massage the words and principles ideas into shape, a team effort here.