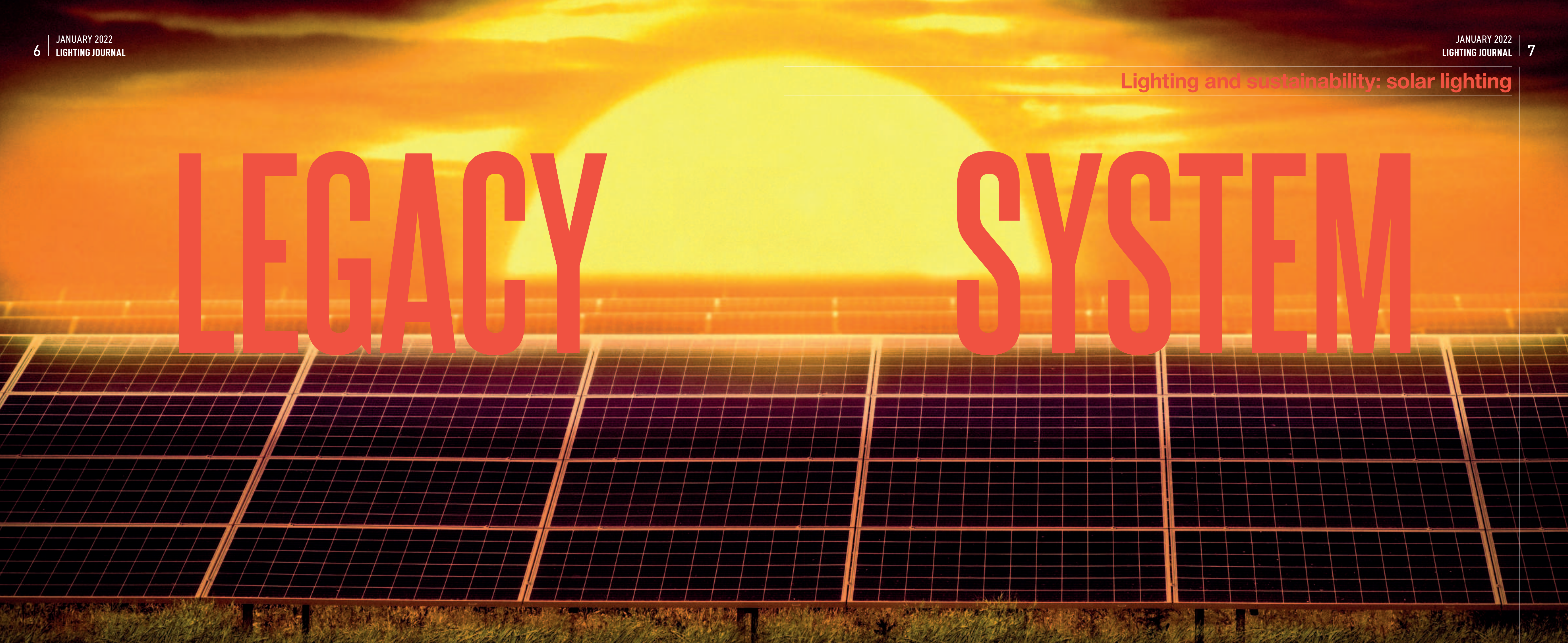


LEGACY SYSTEM

As we reflect on November's COP26, solar lighting is going to be at the heart of lighting's future sustainability conversations. However, to maximise the benefit from solar and leave a positive legacy for future generations, lighting professionals will need to be bringing together the technologies and science in a coherent way

By Mark Hopkins

November's COP26 summit in Glasgow has reaffirmed the need to find zero or low carbon solutions for all areas of the built environment. So, it comes as no surprise that solar lighting continues to be of interest to the street lighting community.

However, the need to bring together the different technologies and science in a coherent way is vital for the industry if, in the future, we are to stand by the decisions made today in the design, manufacture and installation of solar luminaires.

SOLAR STREET LIGHTING COMING OF AGE

Delving into the current theory and practice around solar lighting will help the lighting industry make informed decisions about what questions to ask. Although the application of solar street lighting is not new, and there are a range of options currently available, the need to embrace the science and understand the different parameters that make up a successful installation is key to success.

The following article is, I emphasise, by no means definitive, not least because technology changes are advancing rapidly in both energy conversion and energy storage. Yet, in the temperate regions of the world that have a limited number of days throughout the winter months to harvest this energy, there are a number of important considerations.

THE SUN

It all begins, of course, with the sun and, as we all know, in the UK this is a variable input. The actual energy to be harvested from this resource depends on many factors, some in our control and some not.

The measurement for the energy received from the sun over a given area is known as the 'insolation' and is measured in Watts/m^2. The reduction in insolation for a temperate region is shown in figure 1 below.

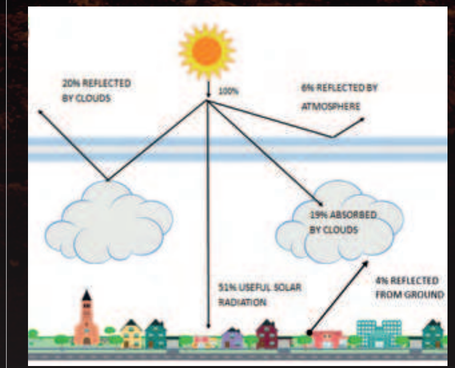


Figure 1. An illustration of the reduction in insolation for a temperate region

Figures for different regions of the world have been compiled for many years and, courtesy of NASA, these figures for any specific location are be recorded and freely available.

As an example, figure 2 to the right shows the values for Rugby in the UK – home of course to the ILP – and illustrates the sun's input without considering the effects of clouds and atmosphere. Then figure 3 shows the actual insolation reaching a potential solar panel.

Measuring kWhr/m^2/day, the variances even during the summer months are significant. Throughout the year, the lowest value = 0.2 whereas by comparison the highest value = 8.41.

The path of the sun as it changes throughout the year can be presented in sun path diagrams; these show the angle of the sun for the summer and winter equinox at a specific location.

This information is critical to maximise the harvested energy from a solar panel tilted and aimed in the correct direction. There are, handily, smartphone apps available that produce fairly accurate

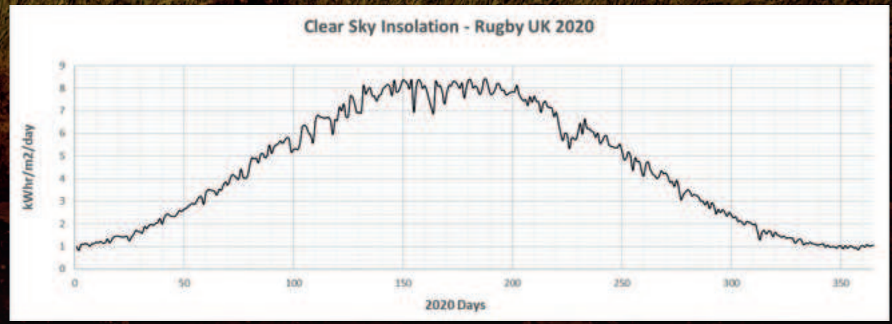


Figure 2. Clear sky insolation figures for 2020 for Rugby

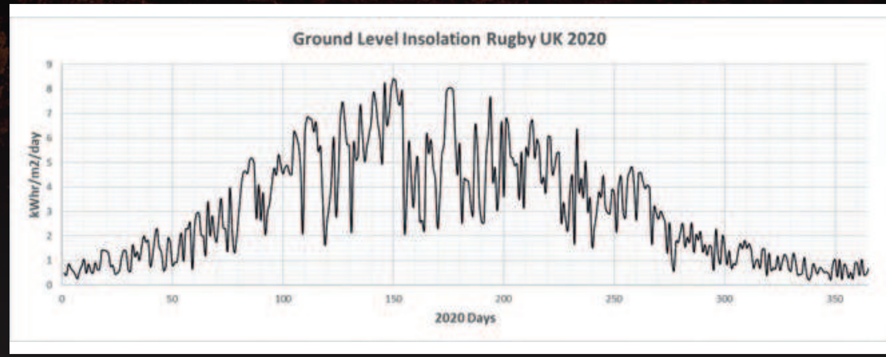


Figure 3. An illustration of the actual insolation reaching a ground-level solar panel, again for Rugby during 2020

→

positioning information and which can be used on site to optimise the orientation. An example of this is shown in figure 4.

The winter sun, for obvious reasons, is taken as the datum for system design purposes and, as you travel south to north, the point at which the sun is lowest in the sky changes from 18° at Land's End down to just 11° in Glasgow.

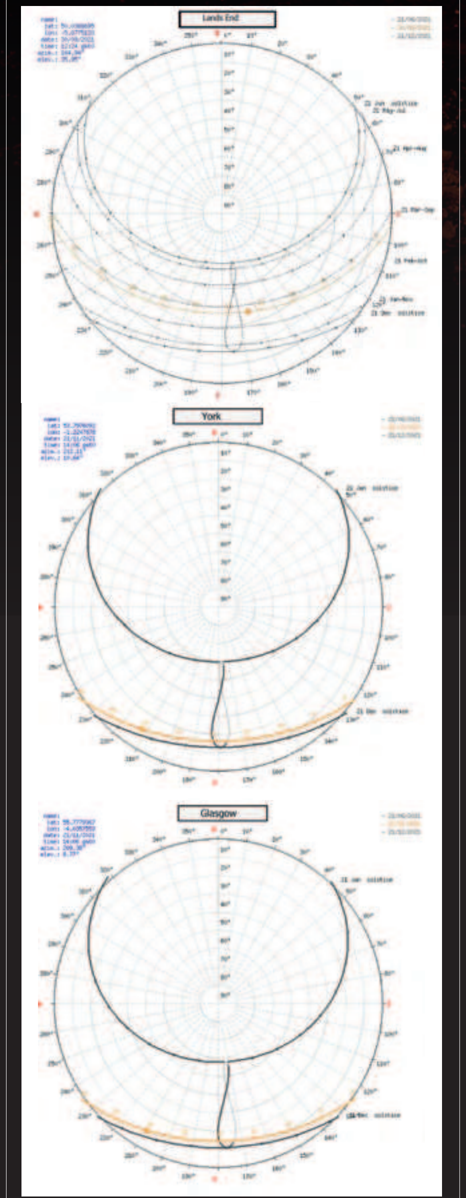
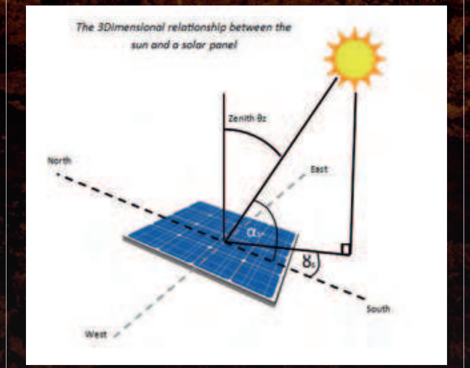
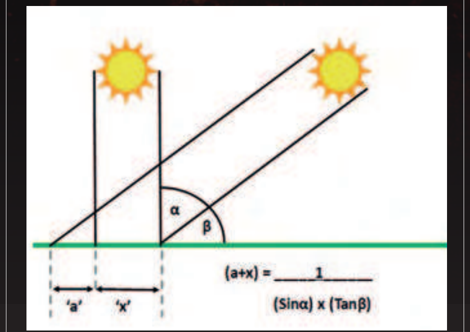


Figure 4. Three sun path diagrams, showing the angle of the sun for the summer and winter equinox at a specific location

Having established the quantity of the sun's energy we can expect to harvest, and the need to have the solar panel facing south at an angle certainly greater than 45°, it is worth noting what the effect is of *not* mounting the solar panel in this orientation.

The three-dimensional representation of the sun's angles is illustrated in figures 5 and 6. These show the effective energy loss from the increase in surface area and also the array incidence loss as the angle changes throughout the day.





Figures 5 (top) and 6. These show three-dimensional representations of the sun's angles, illustrating the relationship between the angle of the sun and a solar panel and (figure 6) the impact of array incidence loss

This transition is also illustrated in figures 7 and 8, which show how, as the panel angle reduces, the efficiency drops away.

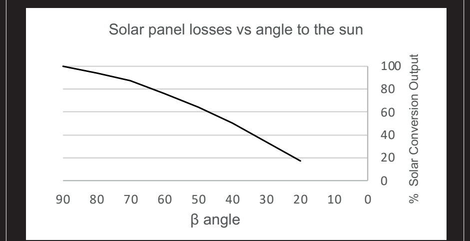


Figure 7. The reduction in power as the sun's incidence angle β decreases

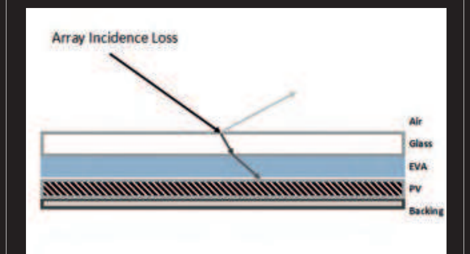


Figure 8. This shows array incidence loss, with reflection and refraction through the solar panel glass

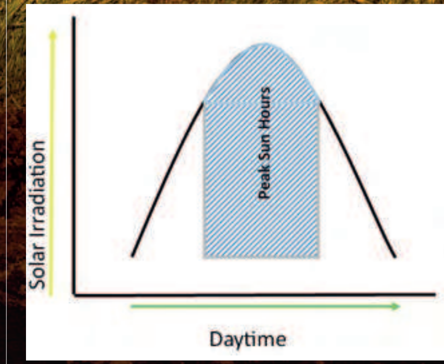


Figure 9. An illustration of solar irradiation during peak sun hours. This is a result of the sun's angle and array incidence losses

The result of these losses gives us figure 9. This shows the peak sun hours graph for each day, which is the base line for the possible energy harvested through the day.

Perhaps the best way to demonstrate these losses is by running through a number of different scenarios, which in turn can enable us to generate a more accurate way to specify a solar luminaire. The reason for the choice of 5 November is that is when the sun is at a maximum of 23° in the sky at midday and two hours each side of midday ranges between 17° and 23°.

SCENARIO 1

- Location: London UK – latitude 51°
- Solar panel facing south: angled at 60° to the horizontal
- No local shading: maximum output possible 60 Watts.
- Date of observation: 5 November, 2021

In this scenario, the average range of angles of the sun on this panel over this four-hour period from two hours either side of midday is 20°.

The actual effectiveness of the sun on this panel over this period therefore ranges from 17° to 23°, applying the formula:

$$(a+x) = \frac{1}{(\sin\alpha) \times (\tan\beta)}$$

The reduction in output is therefore 1.5%.

SCENARIO 2

- Location: London UK – latitude 51°
- Solar panel facing south: angled at 30° to the horizontal
- No local shading: maximum output possible 60 Watts
- Date: 5 November, 2021

In this second scenario, the average range of angles of the sun on this panel over the same four-hour period is, again, 20°.

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The actual effectiveness of the sun on this panel over this period, also again, ranges from 17° to 23° applying the formula:

$$(a+x) = \frac{1}{(\sin\alpha) \times (\tan\beta)}$$

However, this time, the reduction in output is 30.5%. The difference of 29% between scenario one and two is purely contributed by the angle of the solar panel, assuming of course that it is facing south.

THE EFFECTS OF SHADING

A simplified description of a solar panel is of a set of solar cells connected in series, and to work as intended each solar cell requires an equal energy input from the sun.

If any one of these cells receives less input than the others, then this cell's effective internal resistance increases and restricts the current flow. Therefore, the shading of a solar panel should be limited as much as possible.

This is where site surveying can be very important; a solar streetlight situated close to a north-facing building, for example, can significantly restrict the sunlight hitting the panel, as illustrated in figure 10.

Siting the unit on the opposite side of the road is an obvious and simple solution. However, not doing it will severely restrict the charge potential of any solar streetlight during the winter months

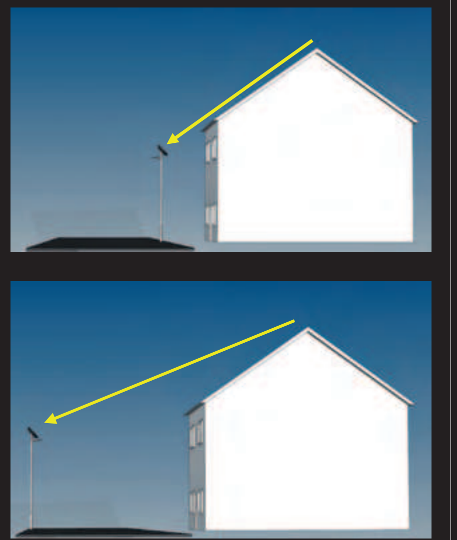

Figure 10. A north-facing building (top) can obstruct the sunlight. However, this can easily be remedied by siting the unit on the opposite side of the road (bottom)

SOLAR PV EFFICIENCY POTENTIAL

Silicon is the predominant material for solar cell production and, with the rapid increase in adoption of very large-scale solar farms, the cost has reduced considerably.

However, the solar irradiation spectrum exhibits a broad energy distribution, while the semi-conductor material can only absorb a portion of photons with an energy layer larger than the bandgap.

There is a maximum efficiency potential called the S-Q limit (Shockley-Queisser) of a single junction solar cell, which is around 30%. The majority of solar panels used today are 'passive emitter rear cell' (PERC) construction and have an efficiency of around 20%-23%. The mechanical construction of these also requires consideration if a 25-year life expectancy is required.

Halide perovskite (PVSK) is an alternative solar cell material with a different bandgap. Development has been ramping up to combine these two materials, silicon and PVSK, to increase the combined efficiency to over 45% utilising a greater energy spectrum.

One of the key advantages of perovskite is that it works well under low-light conditions. Currently this material is not in commercial production yet, however the UK is leading with this new technology and the first megawatt of production is well under way.

OTHER SOLAR CELL TECHNOLOGY DEVELOPMENTS

Another development and innovation in solar cell technology is 'thin film': either cadmium telluride (CdTe) or copper indium gallium selenide (CIGS), both of which materials are used for flexible cells.

The 'next generation' when it comes to solar cell technology is very much quantum dots.

Nano-structured semiconductors, amorphous silicon, and printable solar panels are from a broad group of technologies and very much in their development stage. The advantages of these technologies lie in their potential for low-cost production and novel new applications, but life expectancy will play a key role in their early adoption.

A WORD ON ENERGY STORAGE

Battery technology has come a long way in the last 10 years and will clearly continue to develop. Each technology has its own merits and, as with most systems, there is a trade-off between technology, performance cost and recycling potential.

Solar installations have been using a mix of two primary technologies for the past five years: lead acid and lithium ion, in different forms.

The predominant lead acid type (PbA) has been a sealed gel mat configuration, which is maintenance free and has a life expectancy of around five years for a street lighting application.

A fairly recent adaptation of PbA technology is lead crystal, which uses an electrolyte that crystalises when charged/discharged.

This new type of technology (non-corrosive SiO2 acid) combined with the use of high-quality plates (high-purity lead calcium selenium) considerably improves battery performance.

With only slightly higher-energy density than Pb gel mat and similar weight, these new batteries are still a very cost-effective solution for street lighting applications, giving an expected life of between seven to ten years.

Lithium ion, on the other hand, has much higher energy density and lower weight, with life expectancy of ten years+. However, it has a well-documented downside for long-term application in cold conditions.

Below 0°C, the charging of lithium ion cells becomes a problem, as a phenomenon known as 'lithium plating' occurs.

This is the formation of metallic lithium around the anode during charging.

Without going into the science behind this, in broad terms it is necessary very carefully to control the charge rates of lithium cells at temperatures ranging between 10°C to 0°C, and to stop charging when the battery temperature reaches a point of 0°C or lower.

Other battery technologies that are currently in early stages of adoption or still in the prototype phase are:

- **Sodium ion**. The use of such an abundant material as sodium is the driving force behind this technology. With rapidly improving energy densities aiming at the lithium ion specification, this has great potential for a low-cost long-life battery solution.
- **Cobalt-free lithium ion**. This technology has a similar specification to existing lithium ion but with much lower manufacturing cost and slightly shorter life.
- **Silicon anode lithium ion**. This has a longer life with less environmental impact.
- **Others**. We don't have the space to go into detail on these, but other battery technologies that either have been under development for several years or are a complete rethink of the way energy can be stored are as follows: aluminium/air; lithium/air; super capacitors; copper/foam; dual carbon; vertically aligned carbon nanotubes (VACNT) batteries.

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The different technologies also have very different parameters for the rates and voltages of charge and discharge, limiting many installations to using a single battery type and size for the full life of the installation.

The different technical characteristics of each battery technology restricts the use of changing the battery type part-way through installation life, including:

- Float charge voltage.
- Cycling charge voltage.
- Internal resistance.
- Discharge current and cut-off voltage.
- Pre-charge rates when the battery level falls below a critical value.
- Trickle charge characteristics when the battery is near full capacity.
- Charge temperature range.

Unless the controller used in the installation can be reprogrammed on site to adopt these different values and charge characteristic algorithms, an installation today will not be able to benefit from the new battery technologies in the future.

END-OF-LIFE CONSIDERATIONS

All battery technologies come up with the sustainability question of how to deal with them in their end-of-life condition.

If we consider this as an essential part of a specification from day one then we will be building a sustainable future. Here are a few statistics that provide some food for thought.

- 74% of the lead that is used to manufacture batteries in Europe comes from recycled stock.
- 5% of lithium ion batteries in Europe are currently recycled.
- 38% of waste fires in the UK are caused by lithium ion batteries.

There are presently no major lithium-ion battery recycling operations in the UK. These facts are not meant to overly criticise a technology that has become a ubiquitous part of our everyday lives but simply to ask questions now so the industry can push to find sustainable solutions.

CONCLUSIONS

The primary aim of any streetlight is to provide a reliable, safe environment for the public, whether we are talking about pedestrians, cyclists or motorists. Therefore, as lighting professionals, we are aiming to provide light throughout the night-time, with sensible caveats around comfort, safety and environmental impact.

The previous paragraphs have indicated how much power we have available throughout the year to achieve this. Therefore, to design a system that will comply with current standards it is necessary to consider how these different technologies can be combined to operate as a balanced system.

One key area within this is the control system. The control system used in a solar installation has to, firstly, convert as much of the available power from the solar panel into the correct charge regime for the specific battery.

Second, it has to record the power harvested for further use in the charge algorithm, and then to monitor sunrise and sunset. Once the sunset point is reached, the controller must turn on the lighting, and manage the level of stored power.

The most efficient controllers in use for low-power applications such as street lighting are maximum power point tracking devices (MPPT).

This technology takes current and voltage available from the solar panel and converts it into the required charge characteristics for the battery. It is the early mornings and early evenings, when the sun's power is lowest, that the MPPT controller can maintain a charge input to the battery even when the solar panel voltage has dropped below the battery threshold.

This algorithm can add a potential 25% increase in charge capacity during the winter months, over a PWM (pulse-width modulation) controller that can only charge the battery when the solar panel voltage is above the battery voltage. Once the battery has been charged and dusk detected, the light source should be triggered.

By recording of the data from the charge/discharge cycles throughout the year the battery life can be better managed. This is through reduction in the LED power output at predetermined periods during the night and eventually by indicating when the battery is nearing the end of life. The addition of LED driver circuits a PIR (passive infrared) or radar detector circuit and a serial interface port for programming and data management are the final building blocks for this control circuitry.

Wireless communication with the adoption of smart city technology can be added but with the caveat that the system size may need increasing to accommodate the additional power consumed by the unit.

A well-balanced system will have each of these control elements matched perfectly to minimise losses that can be critical in a solar installation operating in the UK. Ideally, they will be supplied as a single unit with simple programmable capability to future-proof the installation when component upgrades become available.

Finally, I need to include a brief word on the subject of hybrid solar, as my first hybrid system was installed in 2008. This is an excellent solution for commercial developments, where a UMSUG (unmetered supply user group) coding is not required, and where the solar element is an addition to the energy mix not the primary.

This type of system could be a good compromise for main road and motorway lighting, with metering using wireless technology.

Solar streetlights come in all shapes and sizes, from traditional Victorian-themed units to modern contemporary designs. But the fundamental principles are the same and I am keen to make sure we are leaving a legacy for our children that will not be the subject of criticism, whether for technological or environmental reasons.

COP26 in Glasgow. The climate change summit focused attention on alternative energy and alternative light sources

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