Title:	The Lowdown on UV LED Energy Savings
Event:	OMET Networking Event, Label Expo
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Revision Date:	Thursday, September 6, 2018
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As converters increasingly consider purchasing new printing presses equipped with UV LED curing as well as retrofitting existing assets, one of the questions commonly raised is *what are the energy savings*? Typical responses from many press and LED suppliers in the industry are generally *it depends* as well as the non-descript estimate of *up to 50% or more in savings* when compared to a conventional UV system. While generally correct, these very generic responses are far from the data backed answer that converters need to confidently conduct an ROI calculation and sufficiently justify a UV LED purchase to management.

When it comes to UV LED energy savings, the reality is that with better performing and higher speed LED presses as well as older presses upgraded to LED for greater throughput, the more powerful, liquid-cooled, UV LED installation can sometimes consume a comparable amount of total system power as a conventional arc installation when all related energy consuming elements of the press and UV system are taken into account. In other cases, particularly for equally high powered air-cooled UV LED systems as well as lower powered LED devices, the energy consumption can be considerably less than a conventional mercury installation. So, unfortunately, the answer really is *it depends*.

The reason behind the typically vague responses is that there is considerable variability in the UV output and corresponding energy consumption of all the different UV LED products available on the market. When it comes to engineering a UV LED head, there is much more freedom and flexibility in the design than there is with conventional mercury systems. Conventional UV lamps are fundamentally limited by the physics of vaporized mercury inside a sealed quartz tube. The building blocks of a UV LED system, on the other hand, are much more discrete. As a result, UV LED offerings can be configured in an unlimited number of arrangements based on the type of diode used, the quantity of diodes used, the packaging of the diodes, the length of the UV source, the method and effectiveness of the cooling mechanism, and the maximum emitted peak irradiance (W/cm^2) and energy density (J/cm^2). The result is that each UV LED design or model is unique, emits a different UV output correlated to its total engineered power load, and consumes a variable amount of energy based on its power setting.

It is due to this freedom in design that UV LED systems have the ability to be optimized to the needs of each individual application. This makes their use in manufacturing processes much more efficient than conventional curing units as long as the LED systems are properly matched to the process requirements. Without this, the end result is an integration where the LED system is either over engineered (delivers more UV than necessary) or under engineered (delivers less UV than necessary) for the press capabilities, installation, or application. Installing lower powered UV LED systems will always limit press speed and reduce cure. Consequently, in order to provide a valid and relevant statement on energy consumption, it is necessary to first understand web width, number of curing stations, press speed, LED cooling method, formulations, and the general nature of the products being printed, cured, and converted.

Until the UV LED system is matched to the particular press needs, it's rather difficult to provide an accurate numerical value that applies in all circumstances; hence the generic *catch-all percentage savings* responses from many industry suppliers. Fortunately, once one knows the type of UV LED system required for a given press and application, it's relatively easy to calculate energy consumption for comparison to the present curing technology. By arming oneself with specific questions to ask the UV LED or press suppliers or knowing where to find the data on a supplier spec sheet, integrators and end users can collect the necessary information and quickly calculate the energy consumption and cost of operation themselves.

Energy Consuming Components

The two energy consuming components in a UV LED curing system are the UV LED head(s) and the cooling mechanism. The cooling mechanism consists of either air blown across fins of a heat sink or liquid circulation through the manifold of a heat sink. In the case of air-cooled UV LEDs, small electronics fans are typically mounted on the LED head assembly to positively cool the device (i.e. air is blown into the head and vented out the side or ends). Ozone is not a factor with UV LED as longer UVA spectral output does not generate ozone. This eliminates the need for an external air ventilation system; freeing up space on the factory floor, eliminating roof penetration, and further reducing energy consumption.

An air-cooling method commonly used with arc lamps entails ducting each lamp head on a press to either an individual exhaust blower or a larger common exhaust blower that negatively pulls air, heat, and ozone out of the lamp heads and extracts it from the building. These exhaust systems are one of the main noise contributors on conventional printing presses and are the reason that facility make-up air is required to maintain positive pressure inside the building. By comparison, liquid-cooled UV LED systems and some air-cooled LED systems are significantly quieter.

The electrically generated heat within the UV LED curing head must be removed to keep the diodes within their specified operating temperature range. When LEDs are run above their maximum allowable temperature rating less UV output is emitted, the LEDs have significantly shortened life span, and they ultimately succumb to catastrophic failure due to prolonged thermal stress. As a result, a properly engineered and maintained cooling system is critical to both the performance and life of a UV LED curing system. This is one of the key differentiators across all the UV LED curing systems currently available on the market. Only the better engineered cooling systems will actually provide long UV LED life.

If the UV LED heads are air-cooled and a chiller is not needed for ancillary items such as a chilled drum, rollers, or plates, then the only energy component is the power required for the UV LED heads as the fans are typically driven off the lamp supply power. LED systems that emit greater total UV output (irradiance and energy density), span wider webs, and include more curing stations will consume proportionally more energy and require larger chillers when liquid-cooling is used, but then this is also the case with conventional mercury systems.

How and Where to Source Energy Data

The UV LED or OEM press supplier should be able to confirm some or all of the following for the exact press scenario being considered:

- Maximum DC wattage per UV LED head
- Total maximum system DC wattage for all heads on press
- Rating plate wattage of the electrical cabinet or PSUs to power the heads

- Maximum liquid cooling capacity required per UV LED head
- Total maximum liquid cooling capacity required for all heads on press
- Rating plate AC wattage of the chiller

If you know the individual DC power or cooling capacity required for each size UV LED head running at full power, it is possible to multiply the common value by the number of stations or add dissimilar values if mixed heads are used in order to obtain the total DC press power or chiller requirement. It should be noted that the actual wattage of the DC power supplies should always provide a value higher than what is required by the heads. As a result, to be conservative in calculations, use the total available wattage of the actual power supplies or the rating plate wattage on the electrical cabinet. If this is not noted in watts, then for single phase power, this can be calculated by multiplying the AC supply voltage and the stated maximum AC current load. The electrical cabinet also includes the power needed for low voltage controls but this is minimal compared to that required by the UV LED heads. Since chiller sizes are factory driven, the actual wattage of the chiller will also be higher than the cumulative cooling capacity required by all the heads on the press. To be conservative in calculations, use the total wattage of the actual chiller as opposed to the combined requirements of all the heads. If the chiller wattage or actual DC power supply wattages are unknown, the requirements for the heads will be close enough.

For conventional mercury arc UV systems, the two main energy consuming components are the lamp head(s) and the extraction blower. A third energy component is the make-up air required to offset the extraction of lamp generated heat and ozone to outside the facility. For non-climate controlled buildings, this is simply the wattage (or portion of wattage) of the large fan or blower mounted in the wall or on the roof. For climate controlled facilities, there is the additional energy cost of heating the make-up air in the winter and cooling it in the summer. In conventional lamp systems where water cooling or water filtration is employed, the power consumption of the chiller must also be taken into account. It should be noted that while water cooled and water filtered arc lamps are not typically utilized in narrow web flexo, they are used in other types of printing presses, and the respective chiller energy draw should be factored into those calculations.

Since UV LED systems do not emit ozone and do not use large blowers for cooling the assemblies, all HVAC costs are eliminated from the energy calculations. Any UV LED savings in make-up air and climate control, however, are specific to the installation location and not something that can be accounted for by the UV LED system or press supplier. It should be noted that the more presses a plant converts to UV LED, the greater the savings that can be achieved from reduced air-handling. For new UV LED press installations, there is the added benefit of not needing to cut a hole in the roof or wall for extraction of heat and ozone.

The UV lamp head or OEM press supplier should be able to confirm some or all of the following for the exact press scenario being considered:

- Nominal bulb or lamp head spec in W/cm or W/in
- Maximum AC wattage required per lamp head
- Total maximum system AC wattage for all heads on press
- Rating plate AC wattage of the electrical cabinet
- Rating plate AC wattage of the extraction blower(s)
- Rating plate AC wattage of the chiller if using liquid-cooled or liquid-filtered lamp heads

Note that the mercury bulb length can be multiplied by the nominal Watts/inch or Watts/centimeter rating to calculate the total lamp head wattage. To be conservative in calculations, use the total wattage listed on the rating plate of the UV electrical cabinet, blowers, and any chillers as opposed to the calculated value.

Which UV LED System Configuration is Right for my Application?

In terms of UV output, all UV curing sources including LED and mercury arc can be characterized according to spectral wavelength (nm), peak irradiance or intensity (Watts/cm^2), and energy density or dose (Joules/cm^2). These three characteristics should be matched to the needs of the press and print product portfolio in order to deliver the most effective solution and meet performance targets. UV LED system suppliers and OEM press manufactures can guide converters through this process. In many cases, the optimal UV LED system will have already been determined by the supplier for a particular press or category of printing.

While commercial UV LED systems are marketed at peak irradiances of up to 20 W/cm^2 for air-cooled and up to 50 W/cm^2 for liquid-cooled, the viable flexo irradiance range for most applications is between 12 and 20 W/cm^2 with faster press speeds and improved cure ultimately driven further by increasing the delivered energy density (J/cm^2) and not the irradiance (W/cm^2). It should be emphasized that the specified peak irradiance (W/cm^2) provides absolutely NO insight into the delivered energy density (J/cm^2). Furthermore, high peak irradiance does NOT guarantee a high energy density; not all 16 W/cm^2 UV LED systems on the market deliver the same energy density, and in many cases, the emitted values are not even close. LED systems at the lower end of output will struggle to cure at faster press speeds.

Converters should do their due diligence and make sure that the UV LED system they are considering can indeed cure the necessary formulations at the desired press speeds. A lower wattage UV system is not more efficient in its electrical conversion. It is simply emitting less UV output and consuming less power in the process.

UV LED systems are between 30 to 40% efficient at converting electrical energy into ultraviolet energy. The conversion loss is dissipated as electrical waste energy in the form of heat. While most systems currently sold into the flexo market use liquid-cooling to remove this heat, there is a strong shift toward air-cooling. Air-cooled systems eliminate the need for a refrigerated chiller and its corresponding energy consumption. As long as the UV LED head is engineered and integrated correctly, similarly designed products will emit the same UV output regardless of whether they are cooled by air or liquid. That said, not all systems on the market claiming to offer an identical irradiance (W/cm^2) provide the same UV output, performance, and life. The choice of an air-cooled or liquid-cooled UV LED system ultimately comes down to desired energy savings, UV output, personal preference, for factor, integration, and the environment in which the system is operating.

Calculating Energy Consumption for UV LED Systems

The amount of energy consumed by the system components varies by UV LED supplier, UV LED model, length of head, number of heads, UV output, and cooling method. As an example, consider a 17" web on an eight station press, running at press speeds of 1,000 fpm (300 mpm). The two high dose Phoseon products listed in Table 1 with their corresponding technical specifications have been proven to cure sufficiently at this speed across a wide range of formulations and web materials.

Table 1: UV LED Systems for Narrow Web up to 1,000 fpm

Specifications	System One	System Two
Supplier	Phoseon	Phoseon
Model	FJ605	FP601
Wavelength	395 nm (UVA)	395 nm (UVA)
Cooling Method	Positive Forced Air (Ambient)	Liquid Circulation (25 to 30°C)
UVA Irradiance	20 Watts/cm^2	20 Watts/cm^2
Emitting Window	450 mm (17.7") x 20 mm (0.8")	450 mm (17.7") x 20 mm (0.8")
DC Power Per Head	4,474 Watts	4,176 Watts
DC Power for 8 Heads	35,792 Watts	33,408 Watts
Plated DC Power for Heads	36 KW	36 KW
Cooling Power Per Head	None	3,424 Watts
Cooling Power for 8 Heads	None	27,392 Watts
Chiller Model	None	OptiTemp OTC-10A
Chiller Cooling Capacity	None	35 KW
Total Energy Consumption	36KW*	71KW

**Excludes energy costs associated with facility make-up air and environmental conditioning.*

The total electrical cabinet plated energy consumption of the air-cooled system with the UV LED heads running at full power is 36 KW. The total energy consumption of the liquid-cooled system with the UV LED heads and chiller running at full power is 36 KW plus 35 KW for a total of 71 KW.

There is a special case that should be noted with regard to the liquid-cooled system. If a plant chilled water system is already installed at the converter's facility and is equipped with sufficient capacity to cool the UV LED systems with no additional or minimal outlay in energy, then the energy component for the dedicated chiller goes away. In that case, the liquid-cooled and air-cooled systems highlighted in this example are almost identical in total energy consumption. The small difference in head wattage is strictly due to the power required for the integrated cooling fans and UV output optimization for the air-cooling.

It should be noted that UV LED systems are instant ON/OFF and only draw power when they are running. Mercury systems, by comparison, must be shuttered at low power to avoid cool-down and start-up cycles that can last several minutes each as well as spike inrush currents and wear away the electrodes in the bulbs with each start-up. UV LEDs are also infinitely adjustable in output from 10% to 100%; whereas, mercury lamps have a much higher, low power setting. As a result, less power will be consumed whenever the LED systems are turned OFF for press adjustments and operator breaks and when the lamps are run at lower power settings for slower web speeds and easier to cure formulations. For the purposes of this paper, all systems are assumed to operate continuously at 100% power.

Calculating Energy Consumption for Mercury UV Systems

While conventional UV system suppliers will always site the efficiencies and advantages of their product over competitors', mercury lamps are much more similar to each other in terms of power consumption than UV LED systems are to each other. For mercury lamps, only so much output is possible, short bulb life is a foregone certainty, and heat management on substrate or construction is always a challenge. Only so much creative engineering can be done to alleviate these issues.

Mercury systems are generally specified by the nominal W/cm or W/in rating. This is effectively the wattage of the supply power supply divided by the additive lengths of all the bulbs. As a result, if one does not know the total wattage of the system, it is possible to work backwards by multiplying the length of the bulb (inch) by the nominal power rating (W/inch) by the number of stations to get a total wattage value. Alternatively, one can also read the total wattage off the rating plate located on the electrical cabinet.

For a non-specific mercury lamp comparison to the LED products in Table 1, consider once again a 17" web on an eight station press, running at a press speed of 1,000 fpm (300 mpm). Table 2 provides the corresponding technical specifications for a typical mercury lamp proven to cure sufficiently in a high speed press scenario across a wide range of formulations.

Table 2: Mercury Arc System for Narrow Web up to 1,000 fpm

Specifications	System Three
Supplier	Non-Specific
Model	Non-Specific
Wavelength	Broad Band (UVA, UVB, UVC, UVV, Infrared)
Cooling Method	Blower with Negative Air Extraction
UVA Irradiance	3 $Watts/cm^2$
Nominal Power	400 Watts/in
Bulb Length	18 in
AC Power Per Head	7,200 Watts
AC Power for 8 Heads	57,600 Watts
Plated AC Power for Heads	60 KW
Cooling Capacity Per Head	100 cfm
Capacity of Blower for 8 Heads	5,750 cfm @ 6 in S.P.
Blower Model	Cincinnati
Plated AC Power for Blower	8 KW
Total Energy Consumption	68KW*

** Excludes energy costs associated with facility make-up air and environmental conditioning.*

The total energy consumption of this particular air-cooled mercury system with the heads running at full power is 60 KW for the lamp heads and 8 KW for the blower resulting in a total of 68 KW. If the blower is powered off the UV electrical cabinet, its power draw would already be captured in the power rating plate and not added separately. An additional energy component not reflected in Table 2 is the portion of power necessary to run the facility's make-up air system for this particular press. This particular value will vary based on each facility's particular HVAC infrastructure and should be added to the 68 KW total.

Interpreting Energy Consumption for UV LED and Mercury Arc Systems

The key specifications and energy components for each of the three systems is summarized in Table 3. Please note the highlighted cells.

Table 3: Energy Consumption Comparison for 1,000 fpm, 8 Station Press

Specifications	System One	System Two	System Three
Supplier	Phoseon	Phoseon	Non-Specific
Model	FJ605	FP601	Non-Specific
Wavelength	395 nm (UVA)	395 nm (UVA)	Broad Band
Cooling Method	Positive Forced Air	Liquid Circulation	Negative Air Extraction
UVA Irradiance	20 Watts/cm^2	20 Watts/cm^2	3 Watts/cm^2
Length	17.7”	17.7”	18”
Power for Heads	36 KW	36 KW	60 KW
Power for Cooling	0 KW	35 KW	8 KW
Total Operating Wattage	36 KW*	71 KW	68 KW*

**Excludes energy costs associated with facility make-up air and environmental conditioning.*

The important revelations that can be gleaned from the analysis are:

- A high powered, liquid-cooled UV LED curing system capable of curing on a narrow web press at 1,000 fpm consumes a comparable amount of energy to a mercury system of similar cure performance when a dedicated chiller is used and any additional energy savings from the make-up air system is excluded.
- In the high powered UV LED category, significant energy savings is achieved by using an air-cooled system or cooling liquid UV LEDs via a plant chilled water system that is already installed and has sufficient capacity. It should be noted that for high powered, air-cooled systems, the heat that is vented from the lamp is dissipated throughout the room. Plants with multiple air-cooled LED heads may require additional air-conditioning for climate control.
- Energy savings based on consumed power may not always be significant enough on its own to justify the adoption of UV LED curing. Other UV LED benefits and regional utility billing factors should also be considered.

It should be emphasized that not all flexo presses run 1,000 fpm (300 mpm) and require 100% UV output power. In cases where the press speed is slower and the UV output can be reduced accordingly, the operating energy comparison to conventional UV is significantly better. In addition, if one was to account for the percentage of press downtime, the UV LED energy consumption is decreased further as the UV LED system is turned OFF when not needed. By comparison, the mercury system typically remains ON in a low powered, shuttered state when not needed for short periods.

Caution should be used when UV LED system manufactures state generic high percentage claims of energy savings without actually providing the energy consumption values or the context for comparison. In many cases, suppliers are only referring to the power consumption of the UV LED head and are omitting any discussion of the power consumed by the liquid circulation chiller. In other cases, the energy consumed by the UV LED system and the chiller may in fact be less than the conventional mercury system, but this could also be a case where the UV LED system is undersized for the job at hand. It doesn’t do a converter any good to save money on an investment and / or energy consumption if the print jobs cannot be completed or run at target press speed due to insufficient UV output. In these cases, converters may be saving money on operating costs, but they are also shipping less product and generating less revenue. In all cases, due diligence requires the converter to work with the UV LED supplier, press OEM, and formulator to ensure that the UV LED system is optimized to the needs of the press and the application before conducting energy comparisons.

Translating Energy Consumption into Cost of Electricity

Once the total energy consumption in watts or kilowatts is known, it is possible to calculate the electrical operating costs per day. For more precise values, the required power consumption should be divided by the plant's power factor (PF). If this is unknown, a value of 0.9 is reasonable. The system power required per day by is calculated by dividing the total operating wattage values in Table 3 by the plant's power factor and multiplying the result by the number of hours the mercury lamp or LED is ON for the day. For LED, this ON time is known as the emitted time or emitted hours. In both cases, the result is reported in watt-hours (W-HR) or kilowatt-hours (KW-HR).

If the UV LED head is turning ON and OFF for periods of time due to other activity on the press, then only the ON time duration should be used. For the mercury system, it will always be ON; however, it will be shuttered at a lower power level when not in use. To be conservative, assume the systems are always ON at 100% power for the duration of the shift.

Dividing the number of watt-hours by 1,000 converts the values to kilowatt-hours. It is then possible to multiply the result by the plant's electricity rate in $/KW-HR to get the electrical cost of operation per day.

Operating Energy Cost = ((Total Operating Watts/PF) / (1000 Watts/1 KW)) x Hours per Day x Electricity Rate

This formula was applied to each of the three systems in Table 3 using a power factor of 0.9 and an electricity rate of $0.08 / KW-HR. It was assumed that each system ran eight hours of continuous operation per day at a 100% output power level. The resulting electricity costs are provided in Table 4.

Table 4: Energy Cost Comparison

Specifications	Total Operating Wattage	KW-HR	Electricity Cost Per 8 Hours*
Air Cooled UV LED System	36,000	40	$25.60
Liquid cooled UV LED system utilizing previously installed plant cooling system	36,000	40	$25.60
Liquid cooled UV LED system with dedicated chiller	71,000	79	$50.25
Typical mercury arc system with exhaust blower	68,000	76	$48.64

**Assumes 1,000 fpm (300 mpm) press with 8 stations operating at 100% power across an eight hour shift with a facility electricity rate of $0.08 / KW-HR*.

For this specific scenario, based on the calculations, the biggest daily energy savings between a conventional arc system ($48.64) and a UV LED system ($25.60) over an eight hour shift is $23.04. Assuming a single shift running five days a week for 50 weeks, the total annual energy savings to a converter using the air-cooled LED instead of the arc lamp is $5,760. Alternatively, the liquid-cooled LED in this example works out to $402.50 more per year than the arc lamp system; however, the make-up air costs required for the arc lamp were not included and would easily offset this difference with LED ultimately consuming less energy than the arc system.

The scenarios in this paper are based on the most powerful commercially available UV LED systems on the market running at full power for 100% of the time over an eight hour shift. As a result, these are worst case examples based on ***mathematically calculated energy consumption values (Watts)***. What converters are observing in practice, however, is that there are indeed additional energy savings being realized on monthly utility bills that are not being captured by these calculations. Utility bill rate charges are incredibly complicated and vary by regional utility as well as state and country. It is not entirely clear how the energy consumption of the LED system and its actual usage is translating to additional energy savings. As a result, there is a need for further energy usage studies based on actual data collected from LED presses for comparison to arc lamp presses in the same facility. This is currently being investigated and will be the subject of a future paper.

For now, the main revelation of this paper is that actual energy savings based solely on calculated power consumption is difficult to estimate prior to installation, does not tell the full story, and should not be used as the main decision criteria in UV LED justification. What should be used instead to justify the adoption of UV LED curing has everything to do with established improvements to process control, reduced maintenance, and ease of operator use.

UV LEDs are much more consistent in performance, much more repeatable, and much more reliable over time than conventional mercury arc lamps. Integrating UV LED systems onto a press enables converters to immediately be more productive by increasing press speeds, reducing scrap, reducing downtime, and achieving repeatable and consistent print quality. Greater yields and operators free to focus on other aspects of the printing process and press ultimately affect the converter's bottom line more than then *calculated* UV LED energy costs that are not a very good indicator of utility bill savings. Ultimately, the real lowdown is that process improvement is the real driver for UV LED conversion as it presents a valuable economic proposition for converters that should seriously be considered today; any additional financial savings that appears on a facility's utility bill is simply another upside to those who convert to UV LED.