HVAC considerations for lamp and laser projectors in cinema – 2021 update

How cool!

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AUTHOR **Goran Stojmenovik** | Product Management - Projection | goran.stojmenovik@barco.com

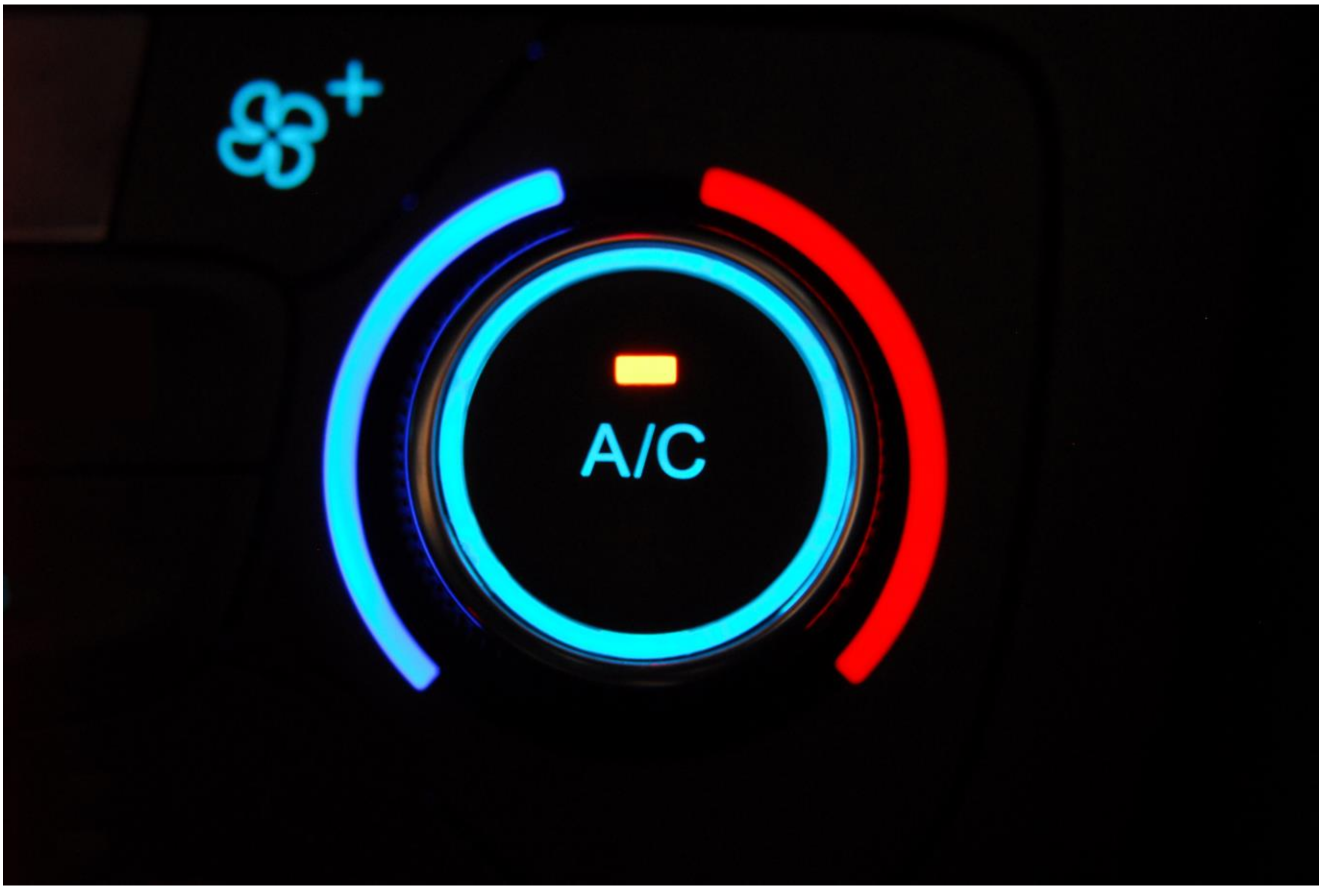


Table of contents

Introduction

Laser projection in cinema has come a long way. Even before the pandemic, at least half of the cinema projectors sold worldwide were based on laser technology.

Since the first version of this white paper in 2018, Barco has introduced a whole new line-up of Series 4 laser projectors. This whitepaper has been rewritten with this in mind.

One of the main and obvious benefits of laser technology is that it's 'green': laser projectors generate much less waste (no lamps!) and typically produce the same amount of light as lamp-based projectors, but with much less electricity.

The reason for using less electricity is that laser diodes are more efficient in converting current to light, but also the light generated by the laser diodes is much more directed and more easily captured. With lamps, the light shines in all directions and it needs to be collected before it's directed toward the lens.

The 'green' aspects related to lamps and electricity savings are very relevant in themselves, and steadily increasing in importance too. But laser projectors also offer great possibilities in cutting operational expenses related to heating, ventilation and air conditioning (or HVAC to use an industry acronym). With laser, things that were impossible before are now straightforward.

This white paper introduces some basic concepts from the HVAC world, describes the differences between laser and lamp-based projectors with regard to electrical and HVAC considerations, provides the benefits of laser technology, and gives recommendations on how best to install and operate cinema booths with laser projectors.

For the nostalgic ones: cinema booths with lamp projectors

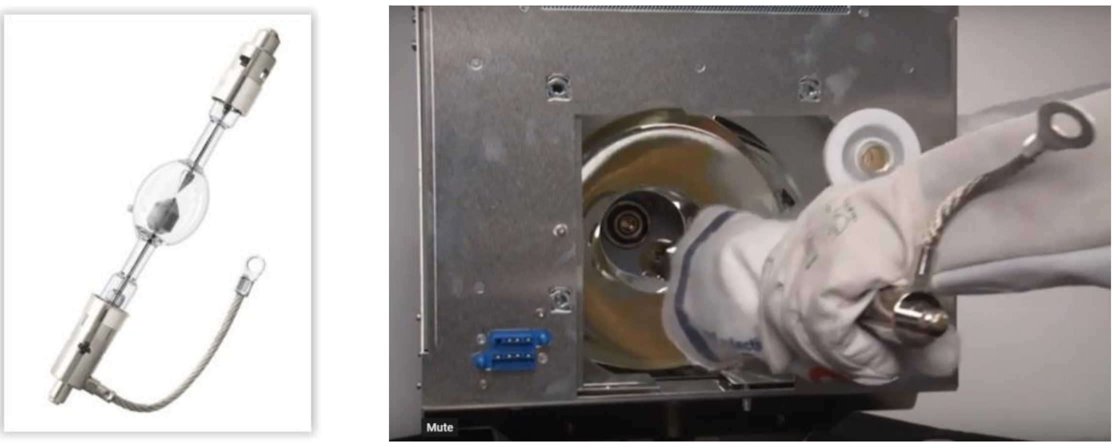


Figure 1. A typical Xenon cinema lamp and changing the lamp in a Barco reflector housing

In Figure 1 to the left, you can see a typical cinema Xenon arc lamp. The cathode and anode (the two sharp metal points in the center of the lamp) are located in a pressurized glass bulb, filled with Xenon gas. The light in this lamp is made from a discharge arc between the cathode and anode: it creates a very bright – and very hot – spot, and from this point all the light (and heat!) spreads out in all directions around it.

To capture as much of this light as possible, lamp-based projectors employ a reflector that focuses the light toward the projector optics (Figure 1, right). But by the time it passes the lens, only about *a tenth* of the produced Xenon light is left: all the rest is lost as heat!

So what happens to the heat?

The light that is not captured by the projector optics and lens heats up the internal projector optics (reflectors, mirrors, lenses, metal components). Part of this heat is transferred to the air in the lamp compartment, and part is eventually radiated out of the projector into the projector booth.

The other heat generated inside the lamp promptly spreads to the Xenon gas, the glass lamp enclosure, and to the ambient air inside the lamp housing. That hot air needs to be removed from the lamp compartment and replaced by fresh, cooler air. Typically the temperature of the hot air is between 100-140°F (40-60°C).

To prevent this hot air from heating up the booth, cinemas deploy an 'exhaust system': a duct system with a fan above the projector, which pulls the air out of the lamp compartment and pushes it out of the cinema booth (either outside the building, or to some sort of heat recovery system).

Figure 2. A projector booth with a digital and a film projector and top exhaust systems

So, we've captured all of the projector's heat in this way?

You wish. First, the lamp power supplies (LPS) are not 100% efficient, so they generate some heat right there in the projector. Second, the exhaust system only takes away the air from inside the lamp house – but there is quite a lot of lamp heat conducted and radiated in the metal case around the lamp house and in the projector optics. Lastly, the projector electronics, fans, etc. produce heat as well (since they consume energy), and that is transferred to the projection booth.

Stubborn heat: air conditioning of cinema booths with lamp projectors

In order to *quantify* the heat management of cinema projection booths, we will start applying some basic engineering principles by means of realistic projector values, in a step-by-step approach, until we have painted a complete picture of HVAC management in a cinema complex.

STEP #1 (Energy and Heat)

According to the principle of energy conservation, all of the electrical energy the projector consumes is transformed into *heat* and *light*. (The mechanical energy (noise) that is produced is actually very negligible!) The total amount of light + thermal energy equals the total amount of consumed electrical energy. But how much of which do we have in any given case?

Let's start from the power plug. The projector Lamp Power Supplies (LPS) typically have an efficiency of around 90%, so for each 1 kW the lamp requires, you need to draw about 1/0.9 = 1.1 kW from the wall plug. This difference becomes heat in the LPS compartment.

Next, Xenon lamps are big heat generators. Only about 30% of the energy they use is converted to light, which means that 70% of the rated lamp power immediately becomes heat.

In addition, of the entire light created in the arc, only about 10% is captured and transmitted through the projector and finally through the lens: the remaining light is lost in the lamp house, in coupling to the integrator rod, and in projector optics and mechanics and becomes… heat. So in fact, only about 3% of the used lamp power becomes light aimed for the screen!

Additionally, the projector electronics consume around 0.4-0.6 kW of power, which is transformed into… heat.

Adding these components together, we obtain the total picture of projector energy consumption. Table 1 lists the electricity consumed and the energy produced for several Barco projector models using Xenon lamps. For produced energy we also list the BTU/h values rounded to the nearest hundred.

Table 1. Energy breakdown of electricity consumed and thermal and optical energy produced by projectors

All values in kW		CONSUMED ENERGY			PRODUCED ENERGY			
		ELECTRICAL (kW)			OPTICAL (kW)	THERMAL (kW or BTU/h)		TOTAL (kW)
Projector	Lamp Power	LPS	Projector Electronics	Total Consumed	Light	Extractable Heat	Radiated to Booth	Total Produced
32B	6.5	7.3	0.6	*7.9*	0.18	4.8/16500	2.9/9800	*7.9*
23B	4.2	4.7	0.6	*5.3*	0.14	3.1/10500	2.1/7200	*5.3*
15C	3.0	3.4	0.5	*3.9*	0.08	2.2/7600	1.6/5300	*3.9*
10S	2.2	2.5	0.4	*2.9*	0.05	1.7/5700	1.1/3900	*2.9*

The 'Produced Energy' section shows what happens to the electrical energy. Most of it is converted to heat, since the light coming out of the lens carries away only about 0.05-0.18 kW.

Moreover, one can see that a significant percentage of the heat remains in the booth, as only a part can be extracted directly through the lamp's exhaust system.

STEP #2 (Airflow)

The concept of ***airflow*** is important in understanding the heat extraction system for lamp projectors. The definition of airflow is the *volume of air* transferred per *unit of time*. Alternatively, you can think of airflow as the *air speed X the area* it passes through. Typically, we use units like cubic feet per minute (CFM), liters per second (L/s), or cubic meters per hour (m^3/h) depending on the geographical region or the engineer's preference.

Recommended airflow values for a cinema projector exhaust system are between 240 CFM (113 L/s) for a projector using a 3-4.2 kW lamp to 360 CFM (170 L/s) for a 6.5 kW lamp projector. Some regulations mandate minimum airflows of 300 CFM for Xenon projectors, and in practice the exhaust rate per projector can go up to 600 CFM.

In order to maintain a neutrally pressurized booth, any air extracted from the booth needs to be replenished by an equal amount. This sounds trivial; however this exact behavior can be the reason for many headaches related to dust and unconditioned air in the projection booth.

In Figure 3, we consider a cinema projection booth containing a lamp projector with an exhaust rate of 360 CFM (170 L/s), and an open door as the only air entry. The projector's exhausted air is collected by a main exhaust duct and is removed from the building. This air is replaced by 360 CFM of air coming through the door into the projection booth.

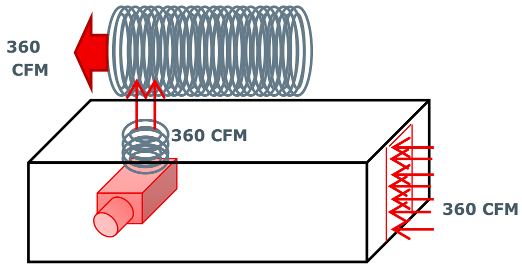


Figure 3. Extracting air from the projector booth means you need to replenish it from elsewhere

STEP #3 (Return Air and Humidity Management)

Remember, any air extracted from the booth needs to be replenished by an equal amount. The next step is to think about conditioning the air you return to the booth. What can happen if the return air is not conditioned?

Actually, quite a lot:

- Outside air is dusty – so you are potentially pulling lots of dust into the booth;
- Outside air can be hotter than the booth target temperature, so you might be warming the booth while in fact you should be cooling it;
- Outside air can also be quite cold – which can be fine as a means of cooling, but cold air can also induce condensation (and mold) in the booth near the air's entry point.

So, for all you know, you can be doing more harm than good. Extracting air from the projection booth and bringing in unconditioned outside air definitely doesn't sound like good booth management.

The solution? The return air in the booth must be filtered for dust and air-conditioned for temperature and humidity, as illustrated in Figure 4.

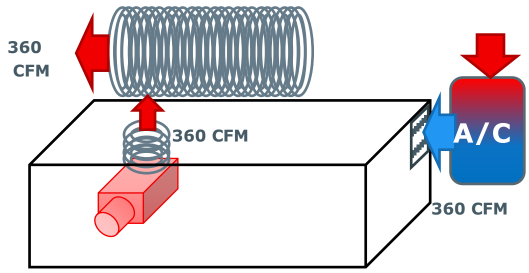


Figure 4. Replacing extracted air by conditioned outside air

(You might think of another option, in which the exhausted air is 'recycled' – that is, cooled down and returned back to the booth. However, this option is prohibited by the International Mechanical Code in case of Xenon projectors due to hazardous substances potentially present in this air: so, although it might actually be occurring in some countries, we will not consider it here.)

STEP #4 (Remaining Heat)

The projectors (and the audio processors, amplifiers, automation, etc.) act as heat generators. Some heat can be extracted as in Steps #2-3, but some heat stays in the booth, as per Table 1. This remaining heat will increase the booth's temperature until it might be too high for your equipment to still operate in, so supplemental air conditioning is required to keep the temperature conditions in the booth acceptable.

The best way to reduce this heat is to use a local air-conditioning system that constantly cycles and cools the booth's air (see the A/C to the left in Figure 5).

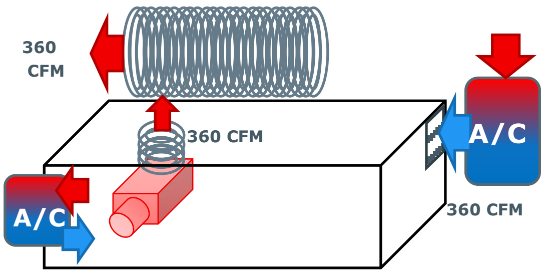


Figure 5. Illustration of a typical air management system in a projection booth with lamp projectors

It is crucial to note the difference between electrical energy and heat energy when it comes to air-conditioning: while, with a projector, the entire used electrical energy is converted to mostly heat and some light, A/C systems can manage higher thermal energy with using much less electricity. This is because they use the electrical energy to transfer the heat energy from one place to the other (e.g. moving the heat out of the room into the environment – hence, cooling the air in the room).

A key factor here is the Coefficient of Performance (COP), which gives the amount of heat energy that can be managed with an A/C system per electric Watt used. Typically, A/C systems have a COP of around 3-4, which means that, in order to cool a heat load of 3-4 kW, the system will use only 1 kW of electricity.

Example 1 – HVAC calculation for a booth with Lamp projectors

Using the figures in Table 1, and doing some engineering calculations on the cases described above, we can summarize the thermal (cooling or heating) power needed for a booth with *one* 6.5kW-lamp projector.

A typical auditorium will play both 2D and 3D movies. With lamp projectors, for 3D screenings, the lamp is always driven at close to 100% of power to maximize 3D brightness (knowing that the lamp brightness decays quickly); 2D screenings are initially done at minimum power (60%), but towards the end of its lifetime the lamp is driven to maximum for 2D as well. So the average lamp power consumption in cinemas is around 85%.

Table 2 is structured in the same way as Table 1, but the values are recalculated to reflect an 85% lamp drive level instead of 100%.

Table 2. Energy breakdown of electricity consumed and thermal and optical energy produced by projectors run at an average of 85% lamp power

All values in kW		CONSUMED ENERGY			PRODUCED ENERGY			
		ELECTRICAL (kW)			OPTICAL (kW)	THERMAL (kW or BTU/h)		TOTAL (kW)
Projector	Lamp Power @85%	LPS	Projector Electronics	Total Consumed	Light	Extractable Heat	Radiated to Booth	Total Produced
32B	5.5	6.2	0.6	*6.8*	0.15	4.1/14000	2.5/8700	*6.8*
23B	3.6	4.0	0.6	*4.6*	0.12	2.6/8900	1.9/6400	*4.6*
15C	2.6	2.9	0.5	*3.4*	0.07	1.9/6500	1.4/4800	*3.4*
10S	1.9	2.1	0.4	*2.5*	0.04	1.4/4800	1.0/3500	*2.5*

As mentioned in Step #3, any outside air returned to the booth needs to be brought to the booth's temperature and dehumidified. This happens irrespective of the lamp's power – it only depends on the exhaust capacity and outdoor conditions.

At this point, we'll apply a bit of 'magic' – calculating the managed thermal power when conditioning outside air. This involves a pretty complicated calculation – so we'll gladly spare you the details and only show the result.

Thus, Table 3 summarizes the thermal power the A/C needs to manage in the booth and for outside air (for two different climatic conditions), and the resulting A/C electrical consumption.

Table 3. Summary of A/C thermal power needed for conditioning the booth PER PROJECTOR for different outside air conditions and for a 6.5kW lamp projector

6.5kW lamp projector 360 CFM exhaust system A/C system with COP=3.5	**Case 1: Cold outside air**	**Case 2: Hot and humid outside air**
Outside air temperature/relative humidity	5°C/41°F / 70% RH	35°C/95°F / 60% RH
Return air target temperature/humidity	25°C/77°F / 20% RH	25°C/77°F / 50% RH
A/C thermal power for return air	3.8 kW/13000 BTU/h	5.1 kW/17400 BTU/h
A/C thermal power for booth, @85% lamp power	2.5 kW/8500 BTU/h	2.5 kW/8500 BTU/h
Total A/C electrical consumption (managed heat/COP)	1.8 kW	2.2 kW/7500 BTU/h

The main lessons from this example are:

- Cinema booths with a lamp projector need an exhaust system to extract the hot air from the lamp compartment. This air should be removed from the building according to international regulations.
- The same amount of air needs to be returned to the booth from outside. This air needs to be air-conditioned for dust, temperature and humidity before it enters the cinema booth. This conditioning requires quite some energy – but it's needed to keep the booth clean and the equipment healthy.
- In addition, a local A/C system needs to be able to manage the projector's heat that remains in the booth, to avoid overheating (and possible damage to) the equipment.

So to conclude… while you might rub your hands and say "There you go, I have an extract, so I got rid of my lamp heat!" – in fact, the problem has just shifted to a much larger scale: ***air-conditioning of the whole cinema complex!***

Enter laser projection

Laser projectors use laser diodes that use electricity to produce light. The laser diodes are small elements that emit light in one direction, can be stacked for the light power output that's required, and do not need reflectors to capture stray light. This by itself makes a laser light source much more efficient than lamps. Of course, the energy that is not transformed into light becomes heat. The lasers are typically encapsulated in a conductive metal that conducts most of the heat from the laser by the help of **liquid cooling** (see Figure 6). Other types of encapsulation also exist.

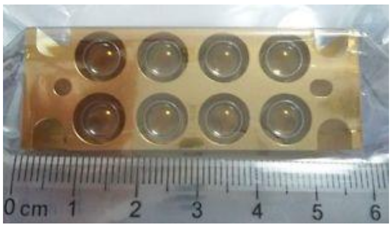


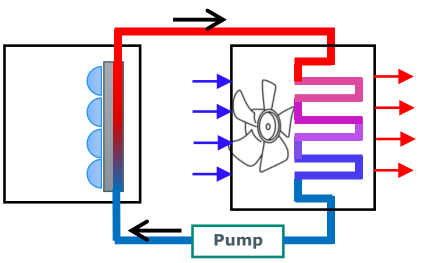
Figure 6. An example of a 'laser bank' – encapsulation of 8 laser diodes inside a metal container

There are two types of cooling methods for laser projectors that have an impact on the actual coolant (and laser) temperature:

- Radiator cooling
- Chiller cooling

Figure 7 Left shows a ***radiator cooling*** system. The lasers (to the left) are cooled by running liquid, and the liquid is cooled by radiators (to the right) and fans blowing ambient air onto them. The liquid used to cool the lasers is at room temperature at best (as it cannot be cooled below ambient temperature merely by radiators and fans). The liquid is only heated up by a few degrees when passing through the lasers, and then the radiators and fans need to cool it down to ambient temperature levels. The radiator can be within the projector, or external, depending on the projector design and cooling need.

Figure 7 Right shows a ***chiller cooling*** system. A chiller uses refrigeration technology to cool the liquid to a low temperature (as cold as 50°F/10°C) in order to cool the lasers better. The refrigeration system is more complex than a radiator cooling system, and involves elements such as an expansion valve, condenser, compressors, etc., which we won’t draw for the sake of simplicity. In simple terms, a chiller has one circuit for creating cold liquid with a controlled temperature going toward the lasers, and another circuit that is responsible for absorbing the heat from the liquid and rejecting it via a condensing unit into the air.



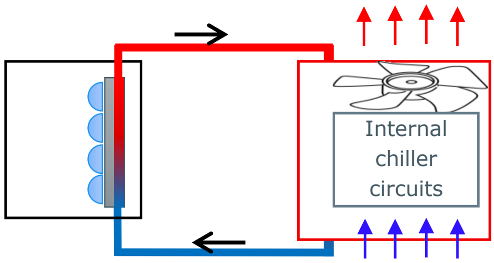


Figure 7 Left: a radiator cooling system for laser projection. Figure 7 Right: a chiller cooling system for laser projection.

Table 4 compares the performance characteristics and benefits of each type of laser cooling system. In Barco Series 4 projectors, we have decidedly chosen for a radiator cooling, integrated in the projector.

Table 4. Overview of features and benefits of radiator and chiller cooling for laser projectors

	Radiator cooling	**Chiller cooling**
Size	Smaller	Larger
Cost	Lower	Higher
Liquid temperature	Few degrees above ambient	Controlled, low temperature
Laser lifetime	Normal	Extended
Airflow	Constant	Depending on ambient temperature

Air conditioning of cinema projector booths with laser projectors

While lamp projectors typically require a higher lamp drive level in order to compensate for the drastic brightness decrease, Barco **Series 4** Smart cinema projectors can be set at a lower average level and still keep the brightness constant over a longer period of time. So, while for a lamp projector we calculated an average power level of 85% in a mix of 2D and 3D usage, for a laser projector this is closer to 75% for the same brightness performance over time.

Table 5 shows the differences between Xenon lamp projectors and Barco **SP2K** and **SP4K** Laser projectors when it comes to energy consumption and heat production. Note that the total consumed energy of a Barco Laser projector is on average *50% lower* than the energy of Xenon lamp projectors for a similar use case. In addition, the heat radiated to the booth is also much lower with Laser projectors compared to lamp projectors. This plays a big role in reducing HVAC costs in a multiplex, as we will see below.

Table 5. Comparison of consumed and produced energy for Barco laser projectors vs. Xenon projectors

LAMP PROJECTORS (85% power)				*LASER PROJECTORS (75% power)*			
Lamp Projector	Total Consumed	Extractable Heat	Radiated to Booth	Laser Projector	Total Consumed	Extractable Heat	Radiated to Booth
	kW	kW / BTU/h	kW / BTU/h		kW	kW / BTU/h	kW / BTU/h
32B	*6.8*	4.1/14000	2.5/8700	SP4K-35	*2.4*	1.6/5500	0.7/2400
23B	*4.6*	2.6/8900	1.9/6400	SP4K-25	*1.9*	1.3/4300	0.5/1800
15C	*3.4*	1.9/6500	1.4/4800	SP2K-15	*1.2*	0.8/2800	0.4/1200
10S	*2.5*	1.4/4800	1.0/3500	SP2K-9	*0.9*	0.6/1900	0.3/1000

Now let’s take a look at Table 6, which summarizes the airflows produced by the radiator coolers for the respective Barco laser projectors. The given values assume the nominal fan speed that is sufficient for most cases.

Table 6. Overview of typical airflow produced by the radiator cooler of Barco Smart Projectors at nominal fan speed values and 25°C ambient temperature

Barco Projector	**Produced Cooler Airflow (CFM)**	**Produced Cooler Airflow (L/s)**
SP4K-35	615	290
SP4K-25	400	189
SP2K-15	250	118
SP2K-9	190	90

Example 2 – Electricity and HVAC cost savings with Barco Series 4 Projectors

How does this knowledge translate to the needed booth conditioning and airflow management in the building when transitioning from lamp to laser projectors? We have everything at hand to make the right conclusions, so, as before, let's consider our options:

Option I: use the existing exhaust systems and booth A/C

Option II: reduce the existing exhaust airflow

Option III: shut down the exhaust duct system (keep only at minimum for ventilation) and completely cool the projector heat with a local A/C.

Let's calculate the three options for a bright Series 4 projector (SP4K-35) and compare them with the example we had for a Xenon projector (6.5 kW lamp). At the same time, we will calculate the difference in running cost for the HVAC installation when moving to laser projection.

Consider the case of a cinema auditorium that runs (on average) **4200 hours** per year at an electricity cost of **$0.15/kWh** or 0.15€/kWh.

The calculation for the lamp projector and the three options is given in Table 7.

In **Option I**, nothing has changed. We still extract 360 CFM which is less than the air produced by the SP4K coolers. In addition, because laser projectors are much cooler, our booth A/C will need to manage less heat (1.36kW (4600 BTU/h) instead of 2.5kW (8700 BTU/h)). The excess capacity can be used to lower the booth temperature if wanted or needed.

In **Option II**, we lower the existing exhaust duct capacity to 240 CFM (113 L/s), which can still remove almost 40% of the hot air produced by the cooler. Remaining in the booth: the projector heat plus a bit more of the non-extracted cooler heat portion, or in total 1.7 kW (5800 BTU/h) which is significantly lower than the 2.5kW remaining in the booth for the lamp projector case.

In **Option III**, we remove the exhaust altogether, and thus remove the need to manage external air returning to the booth. But we need to cool down the entire heat generated by the projector and coolers in the booth, which amounts to 2.3 kW (7850 BTU/h), **8% lower** than in the lamp case.

Summarizing the above values in Table 7, we can readily visualize the electricity and HVAC cost savings when going from lamp to laser projection for different options of the booth HVAC.

Table 7. Summary of A/C thermal power needed for booth condition PER PROJECTOR for a 6.5kW lamp projector, and a SP4K-35 laser projector in three different cases of extraction

	6.5kW lamp projector **A/C COP=3.5**	***Lamp projector***	***OPTION #1***	***OPTION #2***	***OPTION #3***
Exhaust	Total exhaust capacity	360 CFM	360 CFM	240 CFM	/
Thermal	Return air heat load	3.8 -5.1 kW	3.8-5.1 kW	2.5-3.4 kW	/
	Booth heat load	2.5 kW	1.36 kW	1.7 kW	2.3 kW
	Total A/C thermal power	*6.3-7.6 kW* *21.6-26.1 kBTU/h*	*5.2-6.5 kW* *17.6-22.1 kBTU/h*	*4.2-5.1 kW* *14.4-17.3 kBTU/h*	*2.3 kW* *7.9 kBTU/h*
Electric	Exhaust fan power	0.25 kW	0.25 kW	0.17 kW	/
	Average projector electric consumption	6.8 kW	2.4 kW	2.4 kW	2.4 kW
	A/C electric consumption	1.8-2.2 kW	1.5-1.8 kW	1.2-1.5 kW	0.7 kW
	Total electric power	***8.9-9.2 kW***	***4.2-4.5 kW***	***3.8-4.1 kW***	***3.1 kW***
Cost per year	Projector power consumption	**$4290**	**$1540**	**$1540**	**$1540**
	A/C and fan electricity	**$1300-$1530**	**$1090-$1320**	**$860-$1020**	**$415**
Savings per year (rounded)	***Projector electricity savings***	***/***	***$2750***	***$2750***	***$2750***
	A/C energy savings	***/***	***$210***	***$430-$510***	***$890-$1120***
	Total savings over Xenon (per year)	***/***	***$2970***	***$3190-$3270***	***$3640-$3870***

How should we approach replacing a Xenon projector by a Barco Series 4 Laser projector?

1. **Preferably reduce the exhaust airflow!** This would either significantly decrease the dust entering the booth if the return air is not managed, or decrease the load on the A/C system managing the outside air. ***Recommended for existing cinemas.***
2. **Removing the exhaust** altogether is recommended for new builds: This lowers the risk of dust entering the booth, but requires a higher local A/C. The total savings on construction and electricity more than warrants the cost of a new A/C split unit in the booth. ***Recommended for new build cinemas***. Note that basic ventilation is still necessary.

Summary

Laser projectors in cinemas have the benefits of ***reducing electrical consumption*** by up to 50%, as well as greatly reducing lamp and other operating costs. In addition, laser projectors can also help ***reduce air-conditioning and ventilation costs***, and also ***reduce the impact of dust*** and humidity inside the booths and projectors.

When a Xenon projector is replaced by a Series 4 laser projector, the exhibitor can choose between the following HVAC options:

- Remove all extraction (but retain booth ventilation), which reduces the requirement to condition the outside air and reduces the risk of dust entry. This might require increasing the A/C power in the booth to keep the temperatures to the same level as for a Xenon projector (or lower), by either reusing auditorium cooling via plenum return, or investing in a stronger booth A/C. However, on a global scale, this is the most cost-effective way.

- Reduce the exhaust system airflow while reusing the existing infrastructure as for the lamp projector. This requires a lower local A/C power in the booth that can be used to lower the booth temperature if wanted, AND reduces the dust and humidity intake into the booth, due to lower airflows. In any case, you still reduce the electrical cost associated with the projector, local A/C and external A/C.

With a **new-built** cinema, the verdict is clear: ***build the cinema without booth exhaust***!

This saves all of the costs of installing the extract ducts, the fans, and the external heat management system. The projector should then be cooled with the general auditorium ventilation system. Since the laser projectors are much more efficient than lamp projectors, the reduction in heat load reduces the cost of the cinema HVAC system and provides significant electrical energy savings per auditorium per year.

Key messages
• Barco SP2K and SP4K Cinema Laser projectors use up to 50% less electricity than Xenon lamp projectors, saving money on both electricity and cinema cooling/ventilation management. • Installing a Barco Series 4 Smart Projector instead of a lamp system gives the opportunity to lower, or entirely remove the exhaust system with less dust and humidity as a result • For a typical case, if done properly, replacing a lamp projector with Barco SP4K projector can save around $3700 per auditorium per year.