Data Center Energy Optimization Strategy for Standby Generation

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Introduction

Access to power supply now governs a site's ability to host graphics processing units (GPU) for computing within a data center [1]. The question is not how much power the data center needs at a given site, but how much power a given site can garner from the electrical grid. With a given power supply allocation at a site, non-compute electrical load represents not only an operational cost (via electrical rates paid to the utility) but also an unrecognized revenue. The fundamental value proposition for a data center site is to convert electricity (MW) into IT compute capacity (bits). For every electron required for non-compute electrical site load, one less electron can be converted into bits. Energy efficiency for non-compute electrical loads is therefore critical to the business value of a data center site.

> The use of more efficient heating technologies for engine preheating represents an opportunity to improve power usage effectiveness (PUE) of a data center site, thereby freeing up more site power supply capacity for powering GPU.

One such non-compute electrical load is the engine preheater on standby generation systems - required equipment to keep standby generation systems at an optimal temperature so that they can accept full nameplate generator rating in the event of a grid-side outage, as required by NFPA 110, the Standard for Emergency and Standby Power Systems.

The use of more efficient heating technologies for engine preheating represents an opportunity to improve power usage effectiveness (PUE) of a data center site, thereby freeing up more site power supply capacity for powering IT.

Power Usage Effectiveness (PUE)

The Importance of PUE for Data Centers

Power usage effectiveness (PUE) for a data center site is defined as the total power use coming into the facility (MW or MWt) divided by the power use of the IT equipment (MWu). It is a useful metric for understanding the relative power demand required for non-compute electrical load at the site compared to the electrical load used for IT.

$$PUE = \frac{Total\ Site\ Power\ Demand}{IT\ Compute\ Power\ Demand}$$

Efforts to improve the energy efficiency of non-compute electrical load can therefore be classified as a PUE reduction measure. PUE reduction can be considered in two lights; it can be considered as a cost reduction measure or IT compute capacity increase (Figure 1).

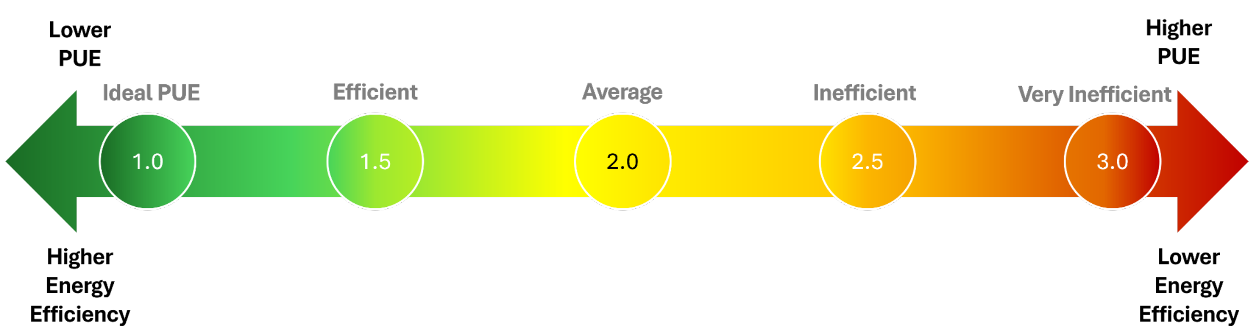

Figure 1

Reduction in Electric Power Cost

Reduction in PUE could be characterized as a reduction in electric power cost, since at any given IT compute capacity, a lower PUE would represent a lower power demand on the electric grid. For a given amount of IT compute capacity at a site, the total site power demand is equivalent to the IT compute demand multiplied by PUE.

For example, if a site has 100MW of IT compute demand (100MWu), and if PUE is equal to 1.35, then the total site power demand is 135MW. If, through energy efficiency measures, the PUE is reduced to 1.32, then the total site demand would drop from 135MW to 132MW. This would represent cost savings based on electrical rates paid to the utility for power usage.

Augmented IT Compute Capacity

Reduction in PUE could also be characterized as an increase in IT compute capacity for a given data center facility, since at any given power draw from the electric grid a reduction in PUE would correspond to greater power available for IT compute. The amount of power available for IT compute (revenue generating capacity) is the power supply divided by PUE. Thus, a lowering of PUE represents an increase in the amount of power available for powering IT and generating revenue.

For example, if the same site has a power supply capacity of 135MW and if PUE is equal to 1.35, then the power available for IT compute functions is 100MWu. If PUE is reduced from 1.35 to 1.32, then the IT compute capacity increases from 100MWu to 102.3MWu, which represents added revenue potential for a site.

Standby Power Generation System Heating

Exploring Efficient Engine Preheater Technologies

Reliability requirements of the standby power generation system necessitate the thermal regulation of the water jacket coolant such that the generators may be started quickly and accept full generator load when backup power is required.

> Standby power generation is critical to data center operations in case of power outage.

The coolant system temperature is maintained by circulating heated coolant through the engine block. The simplest is convective coolant heating, where the coolant heated by the electric resistance element rises to the top of the engine, causing the cold coolant from the bottom of the engine to enter the heater, creating a small “convective” coolant circulation through the engine. This utilizes the most energy to maintain the temperature of the engine since the coolant is being heated to nearly 100°C(212°F) to create the flow, much higher than required to maintain startability of the engine. This also means the engine loses more heat to the environment.

The alternate method adds a pump to the electric resistance coolant heater which circulates the heated coolant through the engine, maintaining the engine block at a uniform engine starting temperature, and using less energy than the convective coolant heating system.

Energy consumption of these heating technologies can exceed 50,000 kWh annually for each standby generator in cold ambient environments due to the limited thermal insulation of an outdoor genset enclosure, and in concrete basement genset rooms where the room temperature is modulated by the ground temperature.

In consideration of PUE reduction, more energy-efficient methods of heating standby generators should be examined, including air-to-liquid heat pumps, liquid-to-liquid heat pumps, and liquid-liquid heat exchangers.

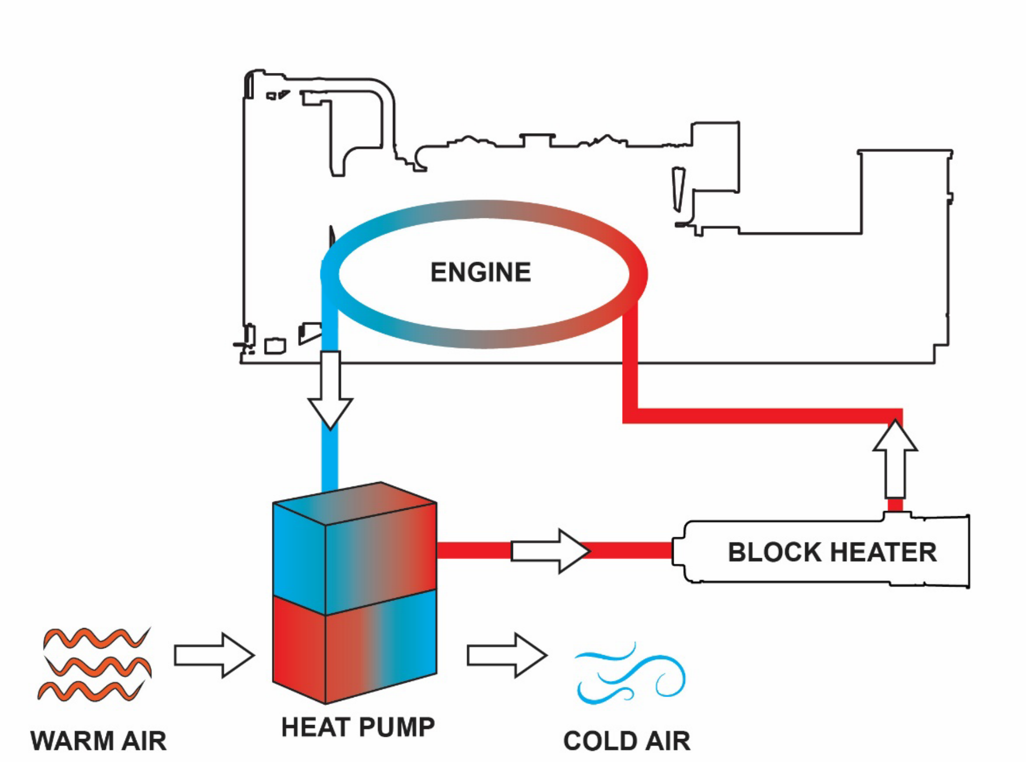

Figure 2

Air-source heat pumps capture the heat from surrounding air by passing the air through the evaporator with a fan. The cold refrigerant in the evaporator is heated by the air, the refrigerant is then compressed, raising its temperature further, and then transferring that heat into the engine coolant, returning to the evaporator as a fluid to be heated by the air again (Figure 2). The variable speed compressor allows for precision heating by responding to ambient temperature changes and avoids overheating or underheating the engine by dynamically adjusting heat delivery to match the current heat losses from the engine.

Heat pump effectiveness is measured as coefficient of performance (COP) which is the ratio of energy output of the heat pump relative to the power consumed by the heat pump. The COP for an air-source heat pump is dependent on the air temperature; at lower ambient temperatures, there is less heat to pull out of the air to transfer to the engine coolant at over 38ºC (100ºF), so the COP will be lower, but still better than an electric resistance heater. An electric resistance heater operates with a COP of 1; every watt of electricity consumed by the heating element is converted directly into heat. For every 1 watt consumed by the heat pump, between 2W (cold air temperatures) to 7W (warm air temperatures) are transferred to the engine coolant.

Energy savings of 65-80% over electric resistance engine heaters have been realized, with outliers both above and below depending on installation optimization (Figure 5; Table 1).

Air-source heat pumps can be installed in series with the existing electric resistance engine preheater: the heat pump becomes the primary engine heater, and the electric resistance heater provides supplemental heat in low ambient conditions. Since the air source heat pump has an integral coolant pump, it can be used with both pump-driven and the simple "convective" style electric resistance engine heaters.

The air source heat pump may be located inside of a genset enclosure or outside of a genset enclosure for "skin-tight" enclosures where installation of the heat pump within the enclosure would significantly impact engine maintenance activities. When installed inside the genset enclosure, the heat pump essentially recycles the energy the engine has lost into the air around the engine back into the engine, gaining efficiency through the higher air temperatures within an enclosure than outside an enclosure.

Liquid-to-Liquid Heat Pumps

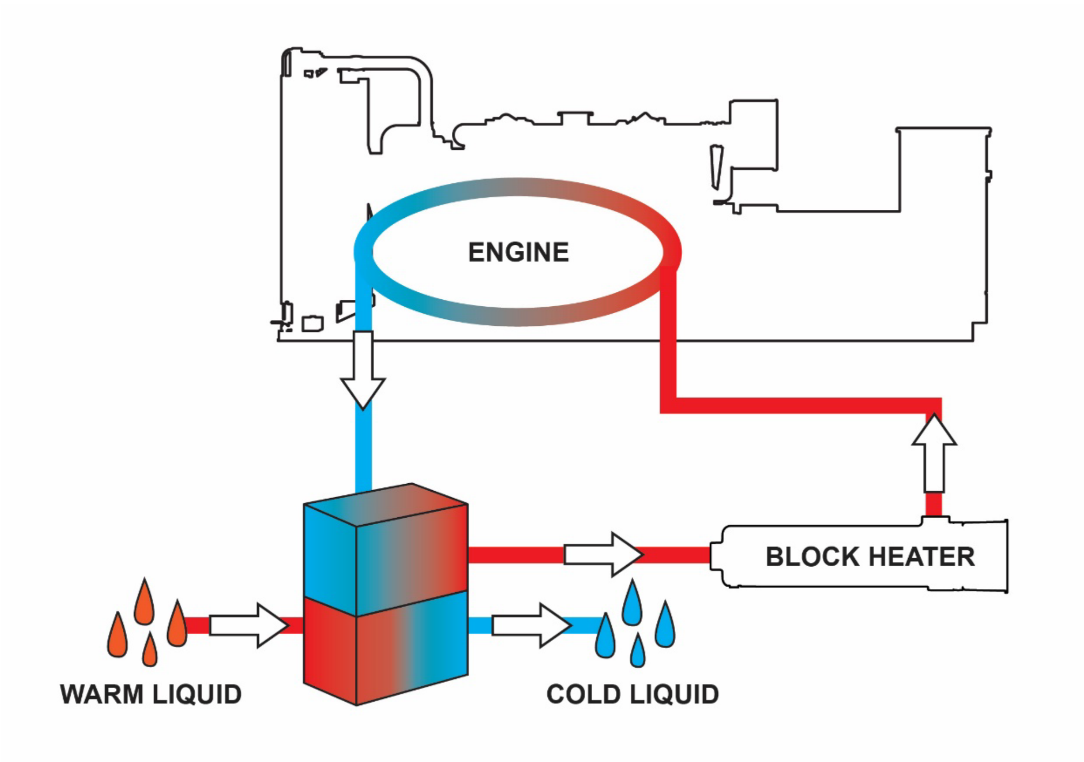

Figure 3

Liquid-to-liquid heat pumps can be used to recover some of the waste heat from data centers which utilize liquid cooling. The operation of the heat pump is the same, except instead of pulling heat out of the air, the heat pump uses a different heat exchanger to pull heat out of the data center cooling loop (Figure 3).

Liquid-to-liquid heat pumps used as engine preheaters require planned infrastructure design to closely locate the waste heat fluid near the backup generators. Due to the average temperature of the waste heat fluid over a year being generally higher than ambient air temperature over a year, heating from fluid increases the liquid-to-liquid heat pump COP over the air-to-liquid heat pump COP, allowing the liquid-to-liquid heat pump to operate at a higher COP and therefore more efficiently.

Liquid-Liquid Heat Exchangers

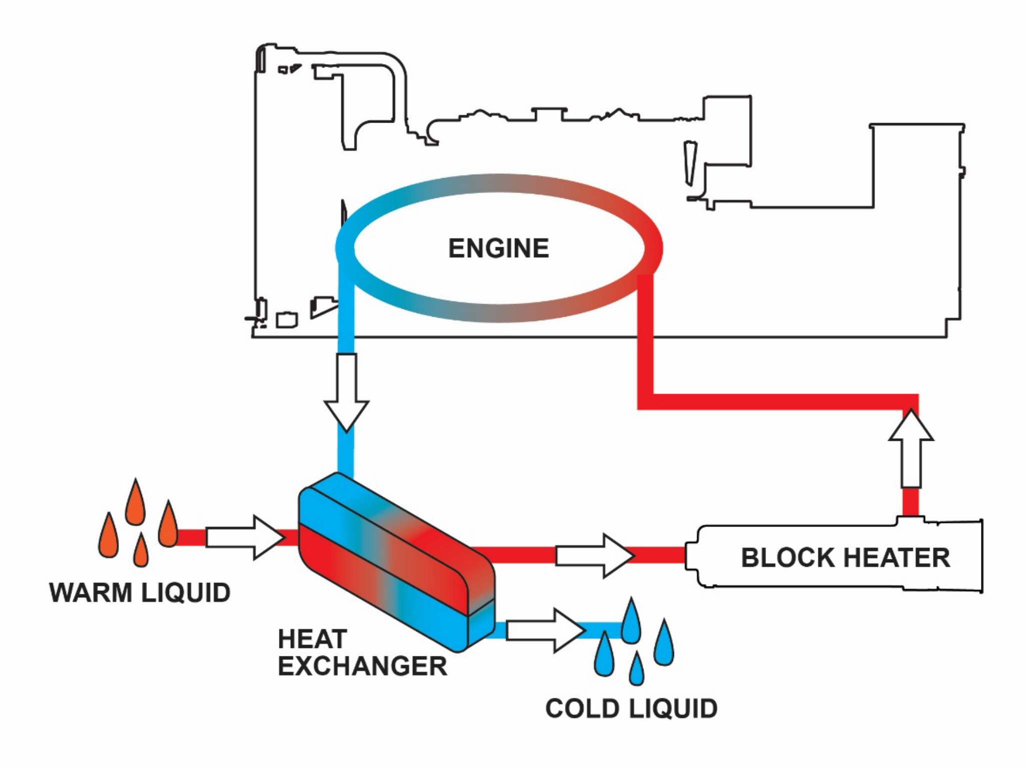

Figure 4

For waste heat fluid temperatures over 120°F (49°C), a simple liquid-liquid heat exchanger may be utilized in series with the electric resistance preheater, a pump, and thermally activated shut off valves for each genset to heat the engine coolant, further reducing backup generator heating energy usage (Figure 4). Annual energy usage consisting only of fluid pumps and controls could be below 3,500 kWh annually per genset. However, if waste heat fluid temperatures drop below 120°F (49°C), the electric resistance block heater will take over, resulting in higher energy usage.

Annual energy usage for various engine preheater technologies for standby generators is illustrated below. The most notable comparison is between utilization of an air-source heat pump (yellow) and the energy requirement for convective coolant heating (blue) or forced circulation coolant heating (orange). Utilization of an air-source heat pump is a reliable and well-established technology for new installations or retrofits.

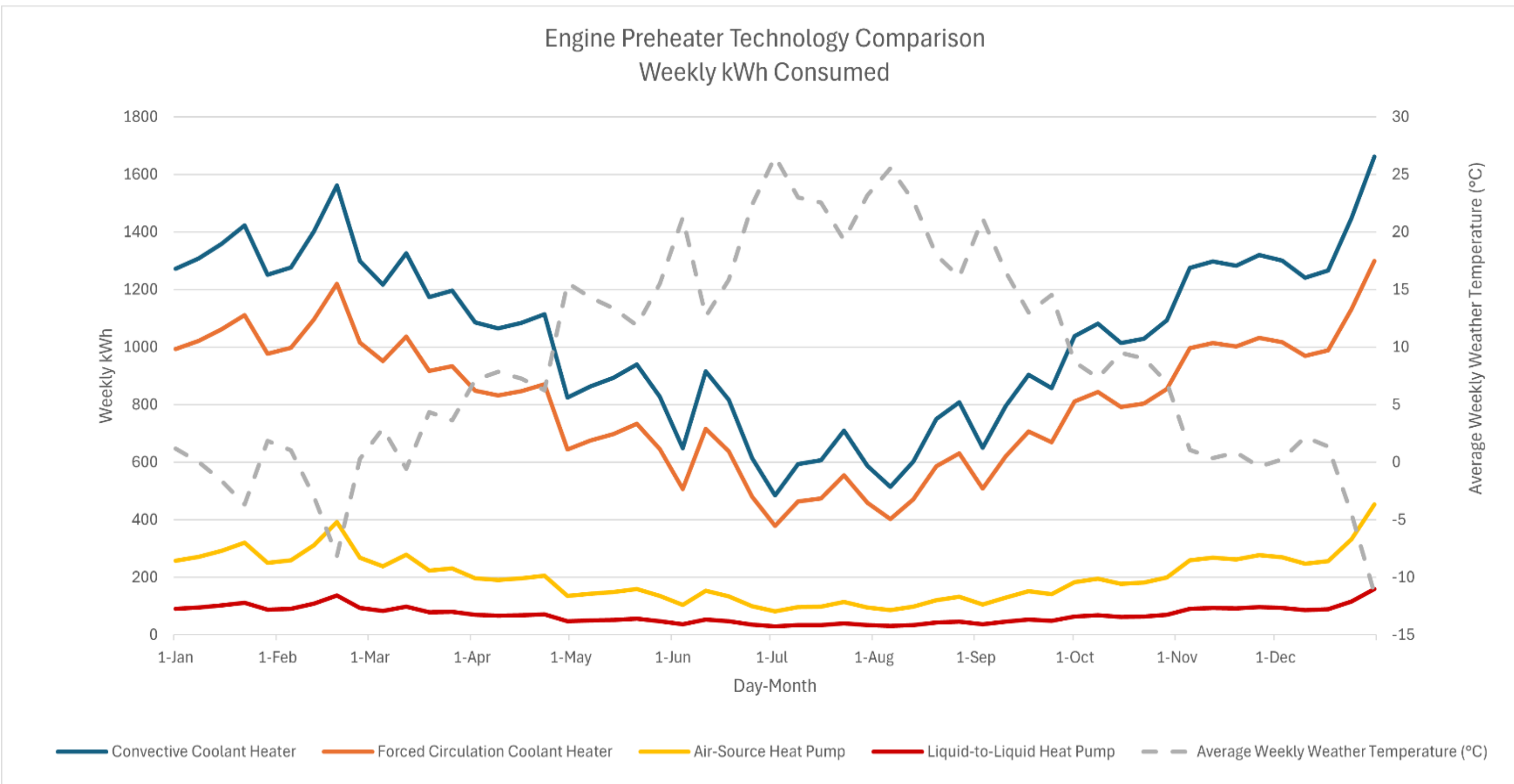

Figure 5: Comparison of engine preheater technologies' weekly energy usage relative to Typical Meteorological Year Data for Spokane, WA, 2023

Heater Technology	% Energy Usage Relative to Convective Heater	Approximate Annual kWh per Genset
Convective Heater	—	53,000 kWh
Forced Circulation Heater	72%	42,000 kWh
Air Source Heat Pump	**24%**	**10,000 kWh**
Liquid Source Heat Pump (55°F source fluid temp)	15%	8,000 kWh
Liquid Source Heat Pump (65°F source fluid temp)	11%	6,000 kWh
Liquid Source Heat Pump (80°F source fluid temp)	8%	4,000 kWh

Table 1: Energy usage per genset for engine heating using Typical Meteorological Year Data for Spokane, WA 2023

Strategy for Energy Efficient Preheaters to Reduce PUE

Utilizing energy efficient heating systems on standby generators for data centers has potential to further reduce PUE. As discussed above, this would result either in lower power consumption cost or augmented IT compute capacity.

Parameter	Small Scale DC	Med Scale DC	Hyperscale DC
Data Center Size (MW)	10	40	200
Average Energy Use (MWh/yr)	55,326	221,305	1,106,526
Number of Generators	5	19	91
Energy Savings per Generator (kWh/yr)	40,000	40,000	40,000
Total Energy Savings (MWh/yr)	200	760	3,640
Additional Racks @ 10kW per Rack Density	2.3	8.7	41.6

Table 2: Effect on PUE with energy efficient standby generator heating systems

While the power savings are marginal relative to overall site demand, the efficiency measures represent a one-for-one trade on power utilization for IT compute capacity.

Cost Benefit Analysis

Realizing PUE Improvements via Engine Pre-Heating Efficiency

When considering avoided power cost alone, implementation of energy efficient block heater systems can achieve project payback as soon as one year. Further cost offset is often available via energy efficiency incentive programs from the regional utility. If energy reduction is viewed as a PUE reduction to free up IT compute capacity, the payback on block heater systems is likely on the order of weeks to months.

Cost Benefit Tabulation

The project implementation costs and avoided energy costs are tabulated below.

Shorter payback periods can be realized by taking advantage of utility incentive programs. One example is through an industry leading incentive program from Energy Trust of Oregon [3], optimizing payback time by covering equipment and installation costs for $12,000 to $22,000 per unit.

Parameter	Small Scale DC	Med Scale DC	Hyperscale DC
Data Center Size (MW)	10	40	200
Number of Generators	5	19	91
Energy Savings (kWh/yr)	200,000	760,000	3,640,000
Project Cost	$110,000	$418,000	$2,002,000
Electrical Cost Savings per year $.082 per kWh [4]	($16,520)	($62,776)	($300,664)
Maintenance Savings $500 per generator	($2,500)	($9,500)	($45,500)
Estimated Payback Period	5.8 years	5.8 years	5.8 years
Utility Incentive $12,000 per heat pump example	($60,000)	($228,00)	($1,092,200)
Estimated Payback Period	20 months	20 months	20 months

Table 3: Cost Benefit Tabulations

PUE Reduction Cost Efficiency

The PUE reduction measures outlined for standby generation heating may also be expressed in terms of cost per point of PUE reduction, to compare to other PUE reduction strategies. This represents a PUE reduction cost efficiency metric – it describes the relative efficiency of dollars spent on PUE reduction.

In this case, assuming a mid-sized data center with a nameplate of 40 MW implements air source heat pump technology, the site would garner about 760,000 kWh per year of energy savings (refer to Table 3). Expressed as a rate, energy saved is 86.8 kW. Assuming an initial PUE of 1.350, the IT compute nameplate would be 29.63 MW. The PUE reduction measure results in a decreased PUE of 1.347 (reduction of 0.003 points, or 30 basis points). At a project cost of $437,000, the PUE reduction cost efficiency works out to be about $15,000 per basis point of PUE reduction.

Benefit of Augmented Compute

In the case of augmented compute capacity, the estimated benefit is highly variable and depends on the rental rate for GPU racks at a given facility. As an example, Nvidia's H100 XSM GPU can garner about $2.10 per hour as a rental rate and utilizes about 700 watts of power [5, 6]. Assuming a rack density of 10kW, one rack can generate about $237,000 per year.

Parameter	Small Scale DC	Med Scale DC	Hyperscale DC
Data Center Size (MW)	10	40	200
Additional Racks @ 10kW per Rack Density	1.7	6.5	31.2
Added Revenue from Augmented IT Compute	$406,000	$1,542,000	$7,385,000

Table 4: Increased Revenue Potential from Augmented IT Compute Capacity

Co-Benefits of Energy-Efficient Engine Pre-Heating

In addition to reduced energy consumption, avoided power cost, and resulting PUE improvements, utilizing alternative methods to heat backup generators results in additional benefits of redundancy, reliability, carbon reduction, and avoided maintenance costs.

Redundancy and Reliability

While the main benefit of the air-source heat pump on the backup generator is the annual energy savings realized, the heat pump also provides an additional level of redundancy in ensuring the backup generator is ready in case of a utility power outage. The heat pump system design provides a failover mechanism where if the heat pump is unable to provide adequate heat to the coolant to maintain engine temperature (such as at low very low ambient temperatures), the internal controls will switch back to the electric resistance heating system. In cases where there is an electrical failure within the heat pump, the control of the electric resistance heat is via normally closed contactor, so functional heat pump controls are not required for a failsafe reverting to the backup resistance heating.

CO2 Reduction

PUE Reduction has co-benefits associated with CO2 reduction due to reduced demand, depending on the electrical utility resource mix.

From the example above, if a site has 100MW of IT compute demand (100MWu), and if PUE is equal to 1.35, then the total site power demand is 135MW. If, through energy efficiency measures, the PUE is reduced to 1.32, then the total site demand would drop from 135MW to 132MW; a 3MW reduction.

In one of the top data center markets in the world, Data Center Alley' in Northern Virginia [7], this can be equated to a CO2 reduction of 2.1 tons [8].

Avoided Maintenance Costs

The Standard Operation Procedure (SOP) and maintenance intervals are greatly simplified and reduced by upgrading generator heaters to more efficient technology.

Maintenance strategies vary with site owners; however, existing electric resistance engine preheaters have electrical wear components such as thermostats and contactors which require replacement every one to three years depending on the usage and risk assessment of the facility. Convective coolant heaters tend to overheat hoses, requiring frequent replacement.

Installation of a heat pump in series with the existing electric resistance heater reduces the electrical cycling to approximately 25% of its historical usage, increasing the service interval by a factor of 4. Due to the integrated pump in the heat pump, convective coolant heaters no longer overheat the outlet hose.

As compared to the recommended maintenance procedure for a heat pump, this can reduce average annual service costs in parts and labor by $500 per year per genset.

Conclusion

Alternative standby power generator heating systems can be used to reduce overall site power consumption and reduce power usage effectiveness (PUE) at data center facilities. Application of air-source heat pumps for generator heating can decrease overall power use by about 40,000 kWh annually per genset. At a mid-sized data center facility with air chillers and a PUE of 1.350, implementation of high efficiency generator heating would decrease overall site PUE by about 30 basis points (0.003) at a cost of around $15,000 per basis point.

As PUE garners more scrutiny in both Europe and the Americas, standby generation systems are one area to investigate for scalable energy reductions.

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