White Paper
Intel Information Technology
Computer Manufacturing
Thermal Management

Reducing Data Center Energy Consumption with Wet Side Economizers

Intel IT is using wet side economizers at two medium-size high-density data centers to achieve high levels of cooling system efficiency, reducing energy consumption and cost. Using a wet side economizer to replace chillers part of the year improved heating, venting, and air conditioning (HVAC) effectiveness—the ratio of power used for IT equipment to power used for cooling—by 85 percent, saving an estimated USD 144,000 annually. We estimate that a blade data center using a decoupled wet side economizer to complement chillers year round will improve HVAC effectiveness by 104 percent to a ratio of approximately 7.29.

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Executive Summary

Intel IT is using wet side economizers to substantially improve the efficiency of our data center cooling systems, reducing energy consumption and cooling cost. Using economizers to replace chillers from fall through early summer improved heating, venting, and air conditioning (HVAC) effectiveness—the ratio of power used for IT equipment to power used for cooling—by 85 percent to 6.19, saving an estimated USD 144,000 annually.

We estimate that using a decoupled economizer to complement chillers year round will improve HVAC effectiveness by 104 percent to 7.29.

We are using economizers at two medium-size high-density data centers to complement or replace cooling by chillers during at least part of the year. Wet side economizers use condenser water produced by cooling towers to provide "free" data center cooling, consuming less power than chillers.

Economizers can be extremely effective in data centers with higher densities of blade servers. Our analysis indicated that wet side economizers were more cost-effective for these projects than the alternative dry side economizers.

- Using an economizer to replace chillers from fall through early summer improved HVAC effectiveness by 85 percent to 6.19, saving an estimated USD 144,000 annually.
- We estimate that using a decoupled economizer to complement chillers year round will improve HVAC effectiveness by 104 percent to 7.29.

The wet side economizer is a valuable tool in our holistic design approach; we are using them to increase data center power density, improve power efficiency, and reduce cost. In the future, these efficiency techniques could be applied to other valuable uses, such as heating other buildings using the heat produced by data centers.

Contents

Executive Summary 2

Background 3

Case Study 1: Efficient Cooling for High Server Density 5

Case Study 2: A Decoupled Economizer and Blade Servers 7

HVAC Design for Blade Servers 8

Decoupled Economizer 9

Potential Future Uses 10

Conclusion 11

Authors 11

Acronyms 11

Background

Over the past five years, the power and cooling demands of servers and other IT equipment have increased rapidly. This has challenged Intel IT to develop strategies for increasing data center cooling efficiency in order to reduce energy consumption and total cost.

Economizers, which provide data center cooling using less power than standard chiller systems, can help reduce expense. If we can handle part of the data center cooling load with economizers, we can reduce the overall cooling cost.

We began investigating economizers when designing a high-performance data center with a high density of engineering compute servers. The local building code required us to use an energy-conserving HVAC design; we interpreted this as a requirement to use either a dry side or wet side air economizer system.

Initially, we looked into a dry side system. Dry side economizers are essentially modified air handlers that switch from recirculating the air inside the building to using up to 100 percent outside air. Instead of cooling the hot return air and reusing it to cool IT equipment, a dry side economizer purges the return air outside the building and draws in outside air for cooling purposes.

It becomes more economical to use a dry side economizer (rather than cooling and reusing return air) when there is a large difference between the heat content of the return air and the outside air streams. This heat content is measured and compared using an enthalpy calculation that takes into account both temperature and humidity.

At first, the dry side economizer seemed an obvious choice because the return air would be relatively warm, while the local northern climate meant that outside air would be relatively cool most of the year.

When we investigated, however, we identified a number of concerns, and the choice was not as simple as it first seemed:

- **Cost.** Economizer air handlers are larger and more expensive to purchase and operate, making it more difficult to achieve a positive ROI.
- **Air cleanliness.** Data center IT equipment is somewhat sensitive to particle contamination, and we would need additional filtration to achieve the same air cleanliness with an economizer drawing in outside air. Additional filtration also results in an increased pressure drop through the air handlers, which requires more fan power.
- **Humidity.** When the temperature of outside air is low, its water content is also low. This meant we would need a much larger humidification system. We would also need to preheat the air, either by using a hot water coil or by blending in waste heat, so the air could absorb enough water vapor to replace the water lost when purging the hot return air.

As a result of our analysis, we determined that a dry side economizer would not be as economical as we had initially anticipated.

Instead, we looked at implementing a wet side economizer system. Using a thermodynamic effect called evaporative cooling, wet side economizers typically use condenser water produced by cooling towers to cool the warmer chilled water returning from the air handlers in the data center. This "free" cooling reduces the load on the chillers, which in turn lowers power consumption, measured in kilowatts of power per ton (kW/ton) of cooling water produced.

One tradeoff with a wet side economizer is that the condenser water needs to operate at a lower temperature, requiring more water evaporation and cooling tower fan energy. Overall, however, the economizer can still produce attractive net energy savings.

Case Study 1: Efficient Cooling for High Server Density

For our high-density data center, we felt that a wet side economizer could be effective from fall through early summer because of the local northern climate. During those months, the temperature of the condenser water would be low enough to cool the chilled water, using a heat exchanger, to our required 55 degrees Fahrenheit (° F) supply temperature.

Figure 1 diagrams our wet side economizer system. The system diverts condenser water cooled by cooling towers around the chillers to a heat exchanger, where it cools down the warm return water in the chilled water system to the required supply temperature. During periods when the economizer is in operation, the chillers are turned off, saving energy. The economizer still uses power to operate the tower fans and circulation pumps. However, the savings are considerable because chillers can account for more than half the total energy consumption of the chilled water cooling system.

One common problem with wet side economizers is that it is difficult to achieve a positive ROI. Many data centers need to supply chilled water to the air handlers at 40 to 42° F in order to cool IT equipment. To produce chilled water at that temperature, we would need to produce condenser water at 35 to 37° F. This would be possible only during relatively brief periods of

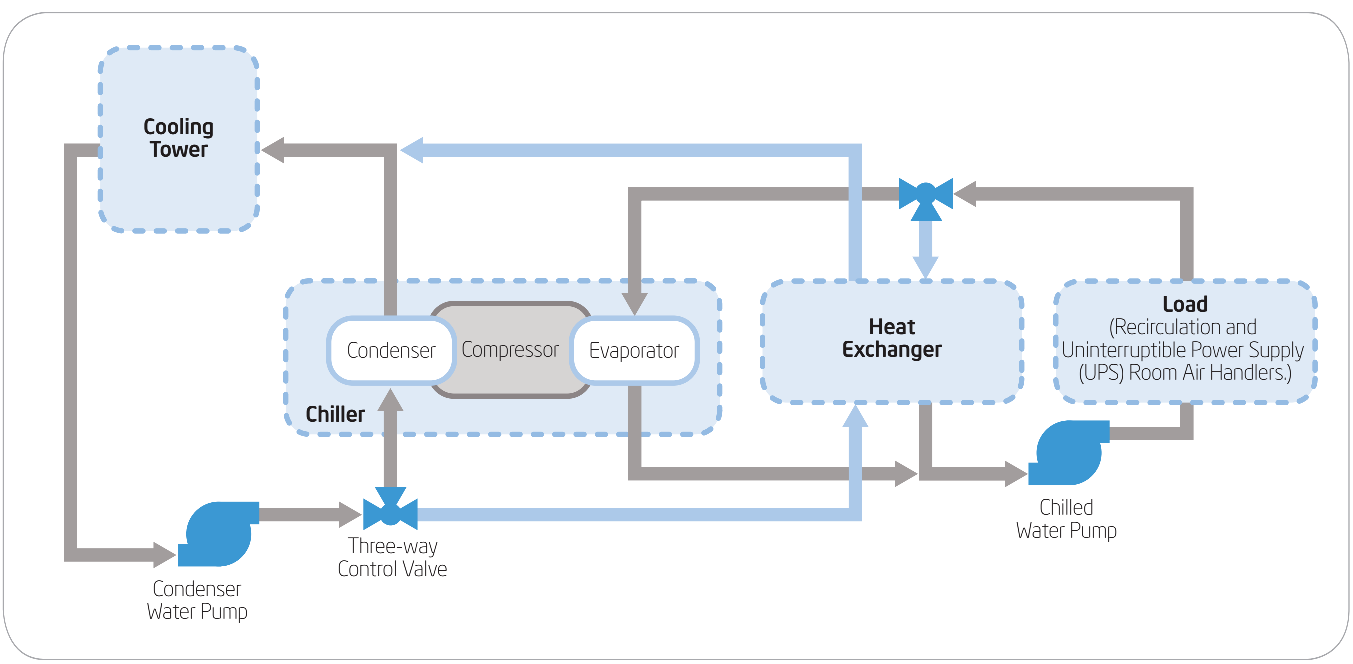

Figure 1. Wet side economizer used in a high-density data center.

Table 1. Power and Cooling Efficiency at Two Data Centers with Wet Side Economizers

	Case Study 1	Case Study 2
IT Power	5,830 kW	1,800 kW
HVAC Effectiveness without an Economizer	3.35	3.57
HVAC Effectiveness with an Economizer	6.19	7.29

Note: HVAC effectiveness is measured as the ratio of power used for IT equipment to power used for cooling (kW UPS output/kW HVAC).

Figures for Case Study 2 are estimates; this data center is currently being commissioned. IT power is UPS output to all IT equipment in the data center. KW HVAC includes the power to run the chillers, cooling tower fans, condenser pumps, chilled water pumps, and air handler fans.

Key:
HVAC heating, venting, and air conditioning
kW kilowatts
UPS uninterruptible power supply

extremely cold weather, making it hard to justify the expense of investing in an economizer. Our engineers were also concerned about this approach because the condenser water would be very close to freezing temperature, potentially icing the cooling towers.

However, we were able to use chilled water at a much warmer 55° F because we had previously implemented a more efficient approach to data center air conditioning. This approach used several techniques, including physical barriers, to stop hot return air from mixing with cool supply air before the supply air entered IT equipment cabinets and cooled the equipment. The efficient air conditioning system enabled us to use supply air at 65° to 70° F—15° to 20° F warmer than traditional HVAC supply air—and we could produce this warmer supply air with 55° F chilled water. Using a wet side economizer, we could produce chilled water at this temperature about 40 percent of the year, from fall through early summer. This positioned us to achieve a better ROI from the economizer.

Supplying warmer chilled water also improves chiller efficiency. When producing chilled water at 42° F, our nominal chiller efficiency was about 0.55 kW/ton. When producing water at 55° F, efficiency improved to 0.44 kW/ton.

Using warmer supply air and chilled water allowed us to recalculate ROI for a wet side economizer system based on our local ambient dry bulb (air) temperatures and wet bulb temperatures. Wet bulb temperatures, which vary with relative humidity as well as ambient air temperature, are important because they determine the capability of the cooling towers to produce condenser water at the required temperature.

In order for the condenser water to cool the chilled water, it must be at a lower temperature than the desired chilled water supply temperature. The difference between these is called the approach temperature. As the approach temperature gets smaller, the heat exchanger necessary to transfer heat from the chilled water to the condenser water becomes exponentially larger and more expensive. We designed our system for an approach temperature of 5° F, which meant that whenever the cooling towers could produce condenser water at 50° F or below, we could shut off the chillers and re-cool the chilled water directly with condenser water using the heat exchangers.

The economizer produced major improvements in cooling efficiency, as summarized in Table 1. We achieved excellent HVAC effectiveness, as measured by the ratio of power used for IT equipment to power used by the HVAC system for cooling that equipment. With the economizer, this ratio rose by 85 percent to 6.19, a figure better than published data from 22 other data centers reported in a benchmarking study.[1]

The increased efficiency generates substantial estimated savings. Our 5.83 megawatt (MW) data center includes two 6,000-square-foot modules, each containing a total of 220 IT equipment cabinets with an average heat density of 13.25 kilowatts (kW) per cabinet. The data center, together with the facility support areas, needs about 2400 tons of chilled water. When the economizer is not operating, the chilled water plant requires a total of 0.6 kW of power for each ton of cooling. This includes the power required for the chillers, cooling tower fans, and pumps for condenser water and chilled water.

1 "Measuring and Managing Data-center Energy Use." HPAC Engineering. March 2006.

At an electricity price of USD 0.06 per kW, the estimated cost of powering the chilled water plant continuously for a year without economizers would be approximately USD 757,382.

However, we can use the economizer an estimated average of more than 2,500 hours per year, based on wet bulb temperatures in the area. During this time, we switch off the chillers, reducing the power requirement of the chilled water plant by 0.4 kW/ton to a total of 0.2 kW/ton. This reduces the estimated average cost to approximately USD 613,382 per year, an annual savings of approximately USD 144,000. This savings is notable because even without the economizer, the chilled water system was already very efficient compared with many other data centers.

Case Study 2: A Decoupled Economizer and Blade Servers

With our next wet side economizer system, which is currently being commissioned, we expect even greater savings using a system that can increase cooling efficiency throughout the year. In our previous case study, the data center runs either on the economizer or on the chillers, but cannot use both at the same time. In our newer system, we employ a decoupled wet side economizer that is separate from the chilled water system, so each can be used independently of the other. This means we can use the economizer and chillers simultaneously, with the flexibility to distribute the load between them as necessary.

For this data center, we use two isolated condenser water systems. The wet side economizer condenser water is used to pre-cool the data center return air, as shown in Figure 2, and normally operates at a lower temperature than the condenser water used to cool the chillers. This decoupled economizer approach provides a more stable partly loaded chiller operation during spring and fall, and lets us use both systems simultaneously when the wet bulb temperature is above 50° F. This means we can save energy by using the economizer during a greater portion of the year.

HVAC Design for Blade Servers

This data center houses a high density of blade servers, and our project used a slightly different HVAC design that took advantage of the characteristics of these servers. Blades generate more heat than traditional rack-mounted 1U servers, and they draw less airflow per watt of heat absorbed by the cooling air that passes through them. This effect results in a greater difference in temperature between air entering and exiting the servers, defined as delta-T (ΔT), and it produces warmer return air.

Initially, we assumed that the high temperature of the air exiting the servers would present an engineering challenge. In reality, it delivered unexpected benefits. Blade servers provided many opportunities to increase data center power and heat density and to make the cooling system more power-efficient.

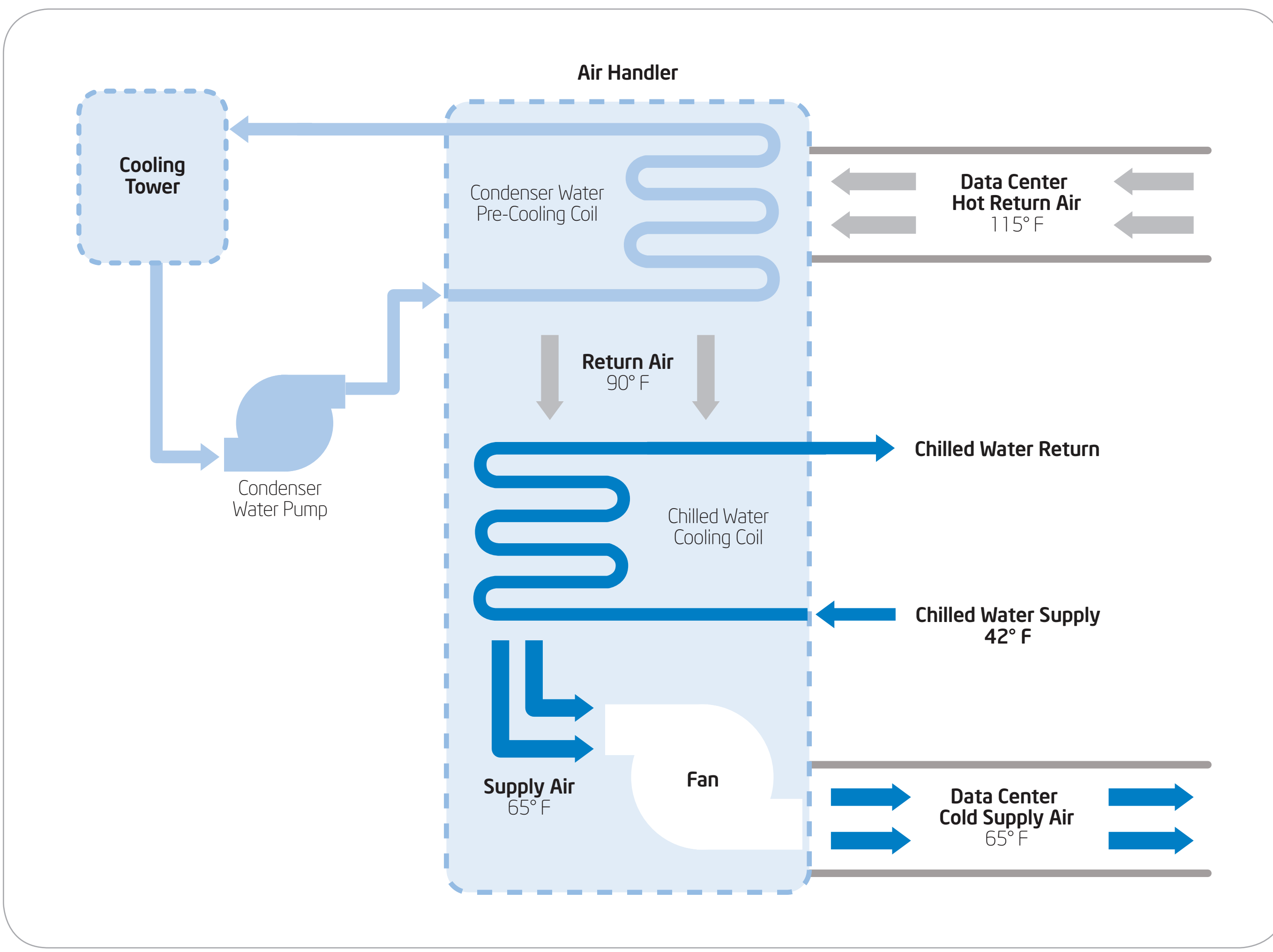

Figure 2. Decoupled wet side economizer system used with blade servers.

A true measure of data center power density is based on the total area required for both the data center IT equipment and the air handling equipment. Air handler size and footprint is proportional to airflow, so increasing the airflow to support a greater density of IT equipment requires larger air handlers, which occupy more floor space. The additional area required for this restricts our ability to increase the IT equipment power density over the total area of the data center.

However, blades can generate more than twice the ΔT of traditional 1U servers with the same kW rating. This means we can increase the power density of IT equipment without increasing the floor space dedicated to air handling equipment, resulting in a greater increase in power density over the total data center area.

In a blade data center, the total HVAC system air side ΔT can reach 50° F. For each server at peak utilization, air entering at 65° F will exit at 115 to 125° F. Because not all servers are simultaneously operating at peak utilization, and because some air may bypass the IT equipment and short-circuit back to the air handlers, return air temperature may average a slightly lower 110° F, which is still very warm compared with most data centers.

With this warmer return air, we achieve more heat transfer to the cooling coils in the air handlers, because heat transfer is proportional to the difference in temperature between the cooling water and the air entering the coil. As a result, cooling capacity of the air handling coils increases dramatically compared with data centers that have more traditional return air temperatures of 75 to 85° F.

We had to make adaptations in order to handle the hotter return air generated by blade servers. To cool this return air, we need coils capable of a larger ΔT in our custom recirculation air handlers (RAH). However, the additional cost of these coils, per kW of IT equipment, is much less than the cost of larger fans and unit casings that would be required to handle the greater airflow from traditional 1U servers. We also need less power from the uninterruptible power supply (UPS) system supplying the air handler fans, because we are using less fan power per kW of IT equipment. This lowers the initial electrical capital costs of UPS infrastructure, as well as the operating costs per kW of IT equipment.

Overall, we incur a lower capital cost for air handlers and use less fan power because we are moving less air per kW of heat. In some cases, return air at an average 110° F may be too warm for computer room air conditioning (CRAC) type air handlers, but we can manage this by deliberately tempering the return air with bypassed supply air. This lowers the return air temperature to match the maximum capability of the coils.

Decoupled Economizer

Our modified RAH units use dual coils. The first is directly supplied by the decoupled wet side economizer, which produces water that varies in temperature throughout the year, as shown in Figure 2. This coil pre-cools the very warm return air that the blade server data center produces. Because this return air is so warm, the economizer can provide partial cooling year round and nearly 100 percent of the cooling during the coolest part of the year.

After pre-cooling, the return air then enters the chilled water coil, which cools the air to our desired 65 to 70° F supply temperature.

This approach has subtle advantages that include better temperature control during transient conditions, such as when starting and stopping chillers, and more flexibility in shifting cooling loads between the economizer system and the chilled water system. This method is also highly efficient, because it uses the economizer condenser water to directly cool return air, rather than using it to cool the chilled water as in Case Study 1.

Decoupling the wet side economizer from the condenser water used to reject chiller heat to cooling towers allows more flexibility in providing optimum condenser water temperatures for the chillers. Our goal is to maximize the cooling that is performed by the economizer system at comparatively low cost, typically using the chilled water system for trim cooling. When the wet side economizer is down or requires maintenance, we can use the chilled water system to provide 100 percent cooling. This arrangement provides us with high reliability and a system hardened against cooling interruptions.

With our decoupled economizer approach, we expect even greater efficiency than in Case Study 1. We estimate that the economizer, combined with the higher air handing system ΔT and lower airflow per kW of heat, will increase the ratio of IT equipment power to cooling system power by as much as 104 percent to approximately 7.29.

Many smaller data centers are located in larger buildings with a common chilled water system. Typically, the chillers are designed for a certain water side ΔT. Operating with a smaller ΔT than this usually decreases both the usable capacity and the energy efficiency of the chilled water system. A blade data center could help correct this by sending very warm water back to the chiller plant to mix with return water at a lower than optimum temperature from the rest of the building. This mixing would raise the overall return water temperature and increase the efficiency of the cooling plant. A greater chilled water system ΔT means less water flow per ton of cooling, resulting in potential savings in power required for pumping.

Potential Future Uses

As data centers become even more prevalent and generate more heat, we see a growing potential to use these cooling efficiency techniques to deliver wider benefits.

IT equipment with high outlet temperatures, such as blade servers, opens new opportunities for energy reuse. It is now feasible to capture the heat from a data center and use it for other purposes, such as heating other buildings. The near-constant year-round heat produced by a data center would provide a reliable heating source.

A blade data center, producing return air at a temperature of 110° F or more, could capture this heat using a giant heat pumping system with a heat recovery water system operating in the 105 to 110° F range. A large data center in the downtown area of a city could sell this heating water as a utility to neighboring buildings. A factory near the data center could use it for preheating make-up air and water for industrial use.

The heat recovery chillers used in this approach are extremely effective when such a high-temperature heat source is available, especially in the winter, and they can capture heat from the pumps and chiller motors, as well as heat generated by the IT equipment.

Conclusion

Using wet side economizers, we have achieved substantial improvements in cooling system efficiency and cost at high-performance data centers. Using an economizer to replace chillers from fall through early summer improved the ratio of power used for IT equipment to power used for cooling by 85 percent to 6.19, a figure higher than published data for many other data centers. This saves USD 57.60 per hour in energy costs, resulting in an estimated USD 144,000 annual savings when operated 2,500 hours per year. We estimate that using a decoupled economizer to complement chillers with blade servers will result in an even greater improvement, increasing the ratio by up to 104 percent to approximately 7.29 and letting us use the economizer for cooling during more of the year.

Economizers are only one tool among many that we use to improve data center power efficiency, reduce cost, and increase power density. We use the expression "holistic engineering" to describe our approach, which involves spending more time in the design process in order to end up with better results over the decades-long life of a data center. We have found that spending a few extra weeks to thoroughly study the options and develop achievable project goals can position the data center for a lower operating cost and the ability for upgrades during its life.

Authors

Doug Garday is a data center engineer with Intel Information Technology.

Acronyms

CRAC	computer room air conditioning
° F	degrees Fahrenheit
ΔT	delta-T
HVAC	heating, ventilation, and air conditioning
kW	kilowatts
kW/ton	kilowatts per ton
MW	Megawatt
RAH	recirculation air handler
UPS	uninterruptible power supply

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