U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

FEDERAL ENERGY MANAGEMENT PROGRAM

# Improving Data Center Efficiency with Rack or Row Cooling Devices:

## Results of "Chill-Off 2" Comparative Testing

## Introduction

In new data center designs, capacity provisioning for ever-higher power densities puts into question whether conventional room-conditioning systems can manage future information technology (IT) loads. Within existing data centers, computing capacity typically increases over time as it requirements increase resulting in increased power and cooling requirements. Data center operators are challenged to provide adequate support infrastructure that is provisioned, or adapts accordingly, to achieve future it mission requirements while minimizing energy use. To examine modular cooling solutions, Lawrence Berkeley National Laboratory (LBNL) in partnership with the Silicon Valley Leadership Group organized a comparison demonstration which became known as "Chill-Off 2."

### Evolving Data Center Cooling

As IT computing servers and devices continue to evolve, producing increasing amounts of heat, effective and efficient removal of this heat will need to increase. One approach to improving this efficiency is to locate the removal device closer to the heat generating source. New rack- and row-mounted cooling devices are designed to be installed on or near the server rack that are referred to "close-coupled" cooling devices. These devices could be used in addition to, or instead of, standard room-conditioning units. Therefore, data center operators could reduce overall data center energy consumption by using modular, close-coupled cooling devices.

### At a Glance

- Rack- and row-mounted, close-coupled cooling devices are more efficient than computer room cooling devices.
- Rack- and row-mounted devices are appropriate for legacy data center retrofit upgrades as well as for new data centers.
- Row- and rack-mounted devices are suitable for higher "allowable" server inlet air temperatures, per ASHRAE guidelines.
- During testing as server inlet air temperature is increased above 75°F, server fan energy generally increased.
- Rear-door, passive cooling devices have higher heat-removal efficiency than row and rack close-coupled devices, but rely on server fans to operate.

### Challenging conventional cooling systems

Rack/row-mounted cooling devices can replace or supplement conventional cooling systems and result in energy savings. Conventional data center cooling is achieved with computer room air conditioners (CRACs) or computer room air handlers (CRAHs). These CRAC and CRAH units are typically installed in data centers on top of raised-floors that are used for cooling air distribution. Such under-floor air distribution is not required by the new rack/row-mounted devices. Consequently, the vagaries of under-floor airflow pathways for room conditioning are avoided. Importantly, close-coupled devices may be better suited for installation in legacy data centers where under-floor air distribution pathways are already cluttered and restricted. In a new data center, the cost of a raised floor can be eliminated.

### Comparing rack/row-mounted devices to conventional cooling

Comparisons were made between room cooling units and rack/row-mounted devices that account for all conditioning energy used to maintain a set point temperature in a data center. In July 2009, a series of energy-efficiency tests were hosted by Oracle (previously SUN Microsystems) in Santa Clara, California to evaluate eleven rack/row-mounted cooling devices. The test project, called Chill-Off 2, was completed in March 2010. Complete results are available in a report to the California Energy Commission titled "Demonstration of Rack-Mounted Computer Equipment Cooling Solutions." This report presents the evaluation methods and results of the testing of these cooling devices.

### Industry Participation

Promoters of the comparison testing project successfully engaged multiple participants from the data center cooling industry. This allowed comparison of the newest close-coupled devices to typical room cooling/conditioning systems. The devices, which were provided by the original equipment manufacturers included varying design features but all could be described as close-coupled cooling solutions. In addition, other industry contributors provided support during the testing. A wireless sensing company contributed a system for monitoring temperature, humidity, fluid flow, electrical current and power, and operational status. Another industry partner contributed a robust data collection and reduction software suite that was invaluable during data reduction efforts.

## Performance Results

As noted above, the eleven close-coupled computer rack cooling devices tested were either rack-level or aisle-containment type. Energy efficiency comparison metrics developed specifically for this

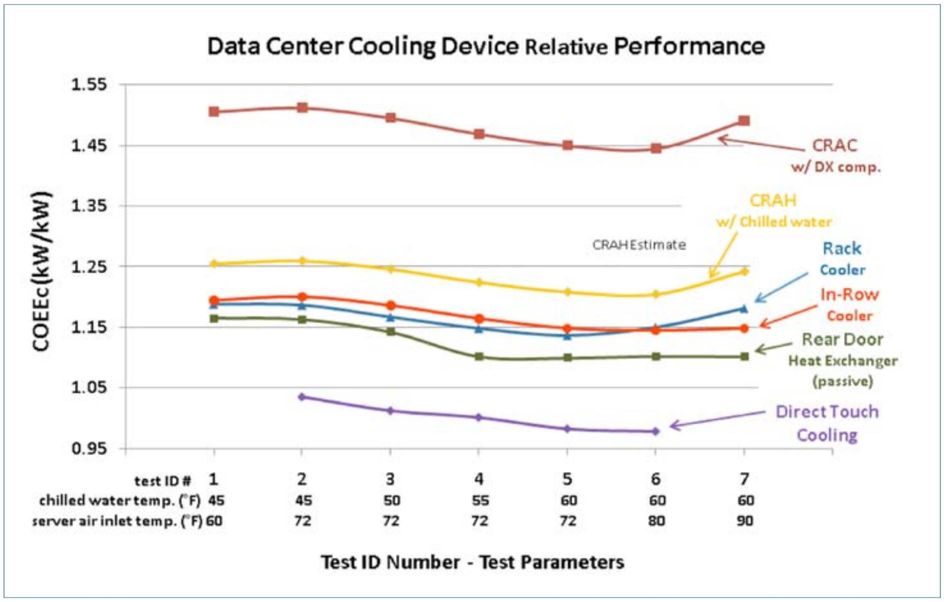

Figure 1: Data Center Cooling Device Relative Performance.

project results showed that all eleven devices tested can provide adequate cooling of rack mounted it equipment; see Figure 1. All devices performed within a narrow band of energy consumption. The total power use span, from low to high, was approximately thirteen percent for the complete set of test runs. Within one set of test conditions, the span between power use varied even less. For example, the test run with 55°F (12.7°C) chilled water and 72°F (22.2°C) server air inlet temperatures, the performance range from highest to lowest device was 8 percent.

### More efficient than conventional room cooling

Chill-Off 2 project results showed that the tested devices are more energy-efficient than conventional data center room cooling designs, which uses CRAC and CRAH units with under-floor cold air supply distribution. In support of the project, calculations were completed to estimate the energy-efficiency performance for a conventional data center cooling approach using CRAH units. Performance information for the conventional cooling design was obtained from a CRAH/CRAC device manufacturer.

### Passive rear-door cooler efficiency

Some of the rack-mounted cooling devices tested do not have internal fans; they rely on server fans to move rejected hot air over their heat exchange surfaces. These "rear-door" devices are more energy efficient than the other devices tested for a number of reasons including not using power for fans. Even though the rear-door devices impose a restriction to airflow that is overcome by the IT equipment fans, no energy efficiency reduction or other negative impact was noted as a result of this airflow restriction. A companion bulletin on the rear-door coolers is available at: *http://hightech.lbl.gov/documents/data_centers/rdhx-doe-femp.pdf*.

### Improving efficiency using warmer chilled water

During test runs, a significant improvement in cooling energy efficiency was recorded as the temperature of the chilled water increased. In the test runs, chilled water supply ranged from 45°F (7.2°C) to 60f (15.5°C) and server air inlet temperature ranged from 60F (15.5°C) to 90f (32.2°C). For example, for all devices total energy savings of 5.3 percent was achieved by raising the chilled water temperature from 45°F (7.2°C) to 60°F (15.5°C) while the server air inlet temperature was held constant at 72°F (22.2°C). Combining higher chilled water temperatures with higher server air inlet temperatures allows increased use of free cooling to achieve even greater energy efficiency in data centers.

## Devices Tested

The rack/row-mounted computer equipment cooling devices tested were evaluated and compared based on their cooling effectiveness and energy consumption. The close-coupled systems were of various designs but all transferred server heat to the building's chilled water system. Cooling devices tested were: rack coolers with air-to-water heat exchanger, row-type rack cooler with air-to-refrigerant or air-to-water heat exchanger, and rack rear-door "passive" cooler with air-to-refrigerant or air-to-water heat exchanger. In addition, a prototype direct-touch cooling system design, which conducts heat to a specially designed heat transfer plate in a specially designed rack using refrigerant as the heat transfer fluid. Also, a design consisting of a container-type enclosure cooled with chilled water were also tested for comparison, but not covered this bulletin.

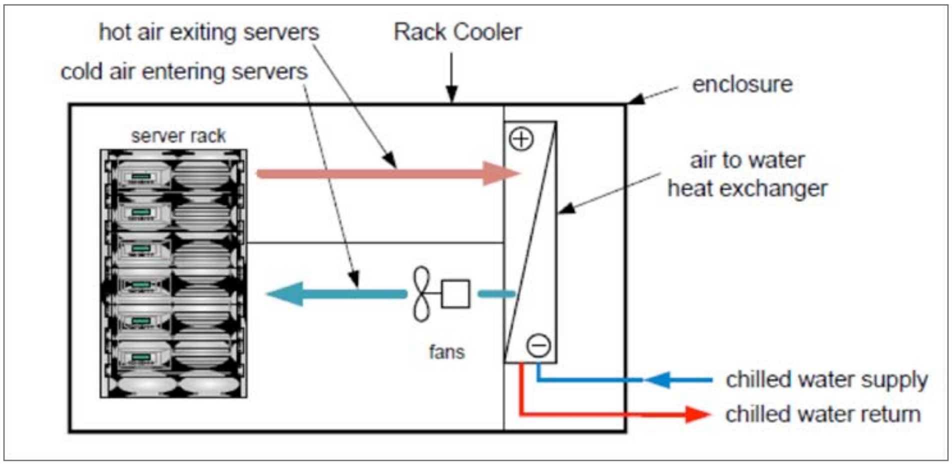

Figure 2: Rack cooler.

### Rack Coolers

A *rack cooler* is defined herein as a device that includes an enclosure system for a small number of racks, typically one or two. Heated server exhaust air is recirculated within the enclosure and is thus prevented from entering the computer room. This device contains heat exchangers that cool the recirculated air and return the cooled air to the server air inlet. Rack coolers contain fans or blowers that provide the flow needed to overcome the pressure drop through the enclosure and across the heat exchanger. Figure 2 shows the thermal schematic for these devices.

### Row Coolers

A *row cooler* is defined herein as a device that is placed directly adjacent to computer racks either within the row between two server racks or above the racks. The row cooler gathers warmed server exhaust air from the "rear" of the rack. The warm air is then drawn into this device and cooled using an air-to-water or air-to-refrigerant heat exchanger. The cooled air is supplied near the server air inlet. Some manufactures install this type of device in conjunction with additional containment structures that reduce mixing of hot exhaust and cold supply air streams. All devices of this type were tested using optional containment structures. Figure 3 shows the thermal schematic for these devices.

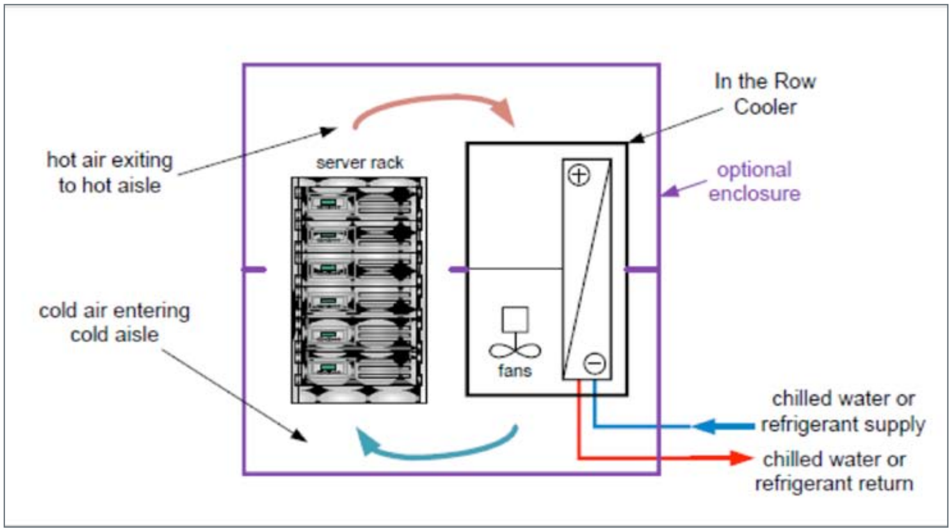

Figure 3: Row cooler

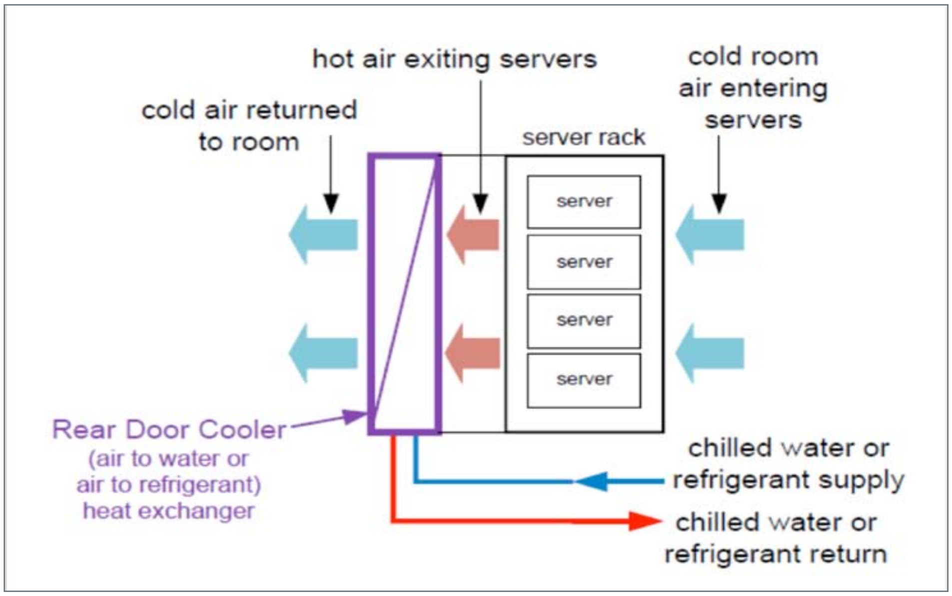

Figure 4: Passive rear-door rack cooler.

### Rear-Door Coolers

A *rear-door cooler* is defined herein as a device that cools hot air exiting the it server rack. The rear-door cooler device, which resembles an automobile radiator, is placed in the airflow outlet of a sever rack. Subsequently, the rear-door device removes heat from the air being forced through the rack by the server fans. Generally, a rear-door device exchanges this heat to circulating water from a chiller or cooling tower. This reduces the temperature of the resulting server-rack outlet air before it is discharged into the data center. Heat exchange is performed by either air-to-water or air-to-refrigerant designs. The tests of two water-based rear-door devices showed very little efficiency impact caused by different server air inlet temperatures. Figure 4 shows the thermal schematic for these devices.

### Direct-touch Cooler

An example of a prototype device was demonstrated for comparison. Defined as a *direct-touch cooler*, the device cools hot electronic components located inside IT equipment directly, using conduction to refrigerant for heat removal. This design is unique because it uses custom modified servers with server chassis level fans removed thereby providing reduced power consumption for a given amount of computing. The efficiency results for this design are included in a separate report. Figure 5 shows the thermal schematic for these devices.

## Evaluation Method

The primary objective of this study was to investigate how the energy efficiency and performance of rack/row-mounted devices compared with conventional data center cooling solutions. An additional feature of the test regime was to study the energy impact of varying chilled water supply temperature and server air inlet temperature. Seven different combinations of chilled water supply and server air inlet temperatures were developed, to investigate how each device would perform under varying conditions.

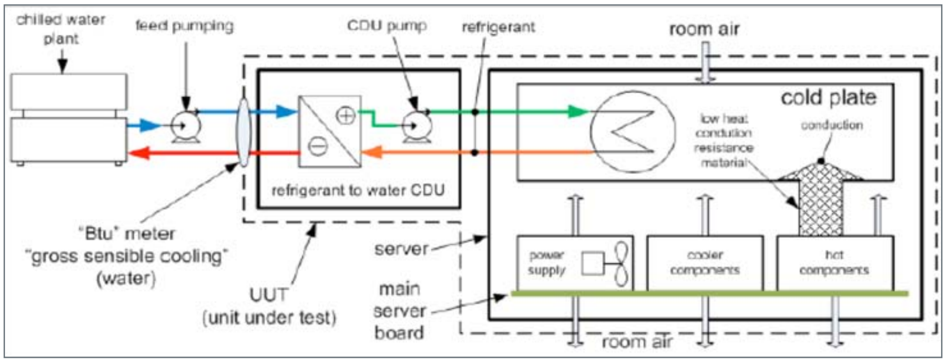

Figure 5: Direct-touch cooler.

### Testing Approach

A comparative evaluation of cooling-device technologies required the following considerations:

- Develop a simplified test process that is easily repeated.
- Structure a "level playing field" of stipulated constraints.
- Produce data sets that are verifiable.
- Delineate goals that are clearly revealed when achieved.

### Testing Goals

- Develop a controlled test environment to enable equal, comparative testing between different solutions.
- Test each system in an identical manner to produce comparative, unbiased data and share these data with the industry.
- Evaluate current cooling technology efficiencies with realistic compute loads.
- Compare cooling device performance with various server air inlet and cooling water temperatures with a varying work load.

### Testing Methodology

#### Test Area

- Tests were conducted in an isolated area to minimize external influences. The test area had dedicated electrical power and chilled water for cooling devices & fan-coil unit.

#### Data Collection

- Record power and thermal collection points in functioning cooling devices and server racks every 30 seconds. All other data were recorded at 1 minute intervals.
- Monitor temperature and cooling water flow data with wireless instrumentation.
- Store and present data gathered through dedicated software collection system.

#### Workload Simulation

- Simulate varying compute-load by combing customized scripts "wrapped" into one executable file provided by supporters.

### Test Runs

#### Stabilization period

- Ensured server-rack temperature steady with compute load
- Measured energy-balance comparing input electrical power to removed thermal-cooling.
- Monitored stability of exiting temperature from the server.

#### Test period: a four-hour compute-load test-run

- Varied chilled water supply temperature (CWST) and server inlet air temperature (SIAT):
- Completed seven test-runs for each cooling device per the following table:

| Test Run # | Chilled water supply temperature (CWST) | Server air inlet temperature (SIAT) |
|---|---|---|
| 1 | 45°F CWST | 60°F SIAT |
| 2 | 45°F CWST | 72°F SIAT |
| 3 | 50°F CWST | 72°F SIAT |
| 4 | 55°F CWST | 72°F SIAT |
| 5 | 60°F CWST | 72°F SIAT |
| 6 | 60°F CWST | 80.6°F SIAT |
| 7 | 60°F CWST | 90°F SIAT |

### Initial observations

- Clearly observed increased server energy at higher SIATs.
- Existing internal server fan controls (algorithm routines) not accommodating ASHRAE recommended inlet air temperature range.
- Server fan speed will increase due to supply air temp, not actual onboard component temps.
- Server energy at "idle" 75% to 80% of full-compute energy.
- No power management enabled.

## Metrics Developed

A number of energy-efficiency metrics and test parameters were developed and used for comparing relative cooling device performance. The energy efficiency metrics follow industry standard methods with some modifications. Three new metrics were used to calculate and compare energy efficiency that uses an algorithm for the quantity of cooling provided divided by the electrical power needed. Another metric includes the power required for the rack mounted electronic equipment thus providing a metric for total power required, which is compared to the quantity of cooling provided. See full report for additional information and explanations.

## Efficiency Impacts

All devices tested within the group were comparable in energy efficiency performance considering the total power required including the computer equipment power and the power needed to provide the cooling. The following characteristics impacted energy efficiency:

### IT server fan energy use

Server fan operation is a function of server inlet air temperature that directly relates to and significantly varies by server make, model, and other features. At some point as server inlet air temperature is increased, the server fans will respond to cool the server. The amount of power used by these fans usually increases as the inlet air temperature increases due to server fans speeding up; see Figure 6. The average server power increased by 6.2 percent for tests that increased server inlet air from 72°F (22.2°C) to 80°F (26.6°C). In addition, if the chilled water temperature is increased, then it could lead to higher server air inlet temperatures causing an increase in it fan- power use. Therefore, when elevating chilled water temperature, an analysis of total power used may be warranted.

### Rack and row cooler observations

During test runs, some in-row and rack cooling devices exhibited a significant increase in their fan power when server air inlet temperatures were raised from 72°F (22.2°C) to 80°F (26.6°C) and 90°F (32.2°C). These devices may benefit from a review and modification of their fan speed control to reduce unnecessary air flow at high server inlet temperatures when data center operator elects to use a higher server inlet air temperature set point.

For water cooled in-row and rack devices, a water-to-water cooling distribution unit (CDU) may not be needed when higher temperature chilled water is used. Omitting a CDU will increase overall energy efficiency and lower system first cost.

### Rear-door device performance

Four rear-door devices were tested in two general categories: 1) water cooled and 2) refrigerant cooled. The water cooled type can perform slightly better than the refrigerant passive doors when a water-to-water CDU is not included. When a CDU is included as part of the design, some refrigerant devices perform better than the water cooled rear-door devices.

## Lessons Learned

The largest consumer of power, in relation to the amount of IT power cooled, is the power needed to make the chilled water. Small increases in the chilled water temperature supply set point can provide large energy savings. Additional information is provided below.

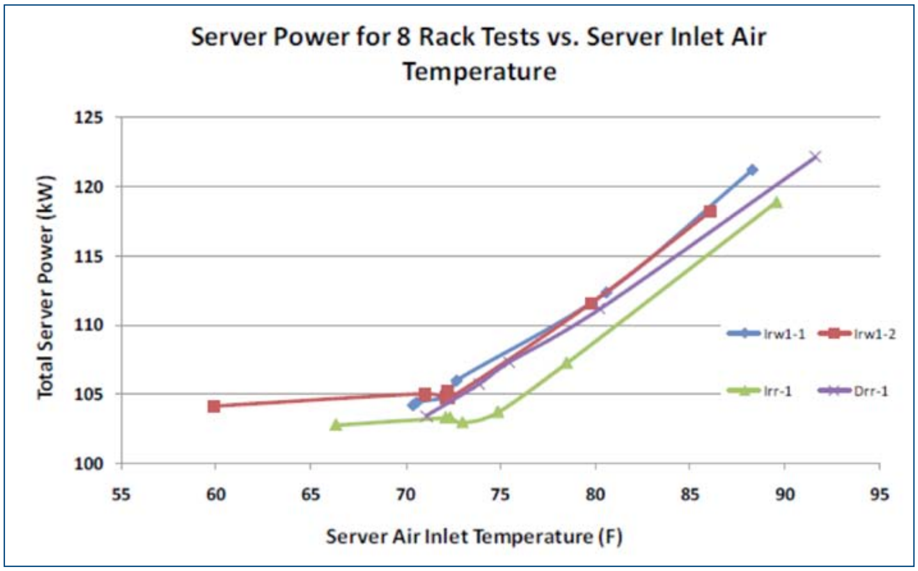

Figure 6: Passive rear-door rack cooler.

### Chiller plant energy impact

As stated, the major power-use component was the electrical power needed to make the chilled water. Chiller plant operating efficiencies vary greatly, and this should be considered when reviewing the results of this bulletin.

Calculations resulting from the Chill-Off 2 project indicated that the power needed to make chilled water averaged 4 times greater than the power required for all other cooling-power-related components combined, e.g., device, CDU, and pump power. The total power required for cooling can be reduced 15–20 percent, in some cases, by raising the chilled water temperature from 49°F (9.4°C) to 54°F (12.2°C).

### Chilled water distribution energy savings

Depending upon system design, the chilled water distribution pump power is not a large component of overall energy efficiency. Savings can be achieved easily when the water supply pressure is reduced to the lowest required level that optimally balances flow throughout the system, usually with a variable speed drive. In addition, careful planning of chilled water distribution systems using variable speed equipment and two-way modulating valves can: yield energy savings with existing equipment; improve energy efficiency; and stabilize operations.

### Heat removal with water or refrigerant

All of the devices used chilled water for the final heat transfer, but some rack/row-mounted devices used refrigerant as a primary heat transfer fluid, which was circulated using a low pressure drop system. The water-cooled, passive, rear-door heat exchangers had the best energy efficiency when installed without a water-to-water cooling distribution unit (CDU). When a water-to-water CDU was added to the water cooled devices, the refrigerant cooled passive devices had slightly higher energy efficiency compared to the water-cooled passive devices. The energy efficiency for refrigerant devices can be maximized by carefully matching the server heat load to the capability of the refrigerant to water CDU.

## Acknowledgments

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