

2016 TOP 10 CLOUD VENDOR BENCHMARK

EUROPE REPORT

Price-Performance Analysis of the Top 10 Public IaaS Vendors

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INTRODUCTION

A public cloud service provider (CSP) offers instantaneous, scalable virtual infrastructure with utility billing. While the public cloud IaaS industry streamlines IT through these advantages, a lack of standardization in performance can lead to businesses overspending in order to obtain the necessary performance requirements for their applications.

Cloud Spectator set out to test 25 of the largest, most well-known public cloud providers with data centers in Europe. For various reasons, Cloud Spectator was only able to test 19 of the providers on the original list with reasonable effort. The report measures and ranks CSPs using a comprehensive performance and price-performance methodology designed by Cloud Spectator specifically for the purpose of measuring cloud environments. The study documented in this report examines the performance of vCPU, memory, and block storage as well as the value (the CloudSpecs™ Score) as defined by the relationship between price and performance.

In conjunction with a proper process for cloud vendor selection, this report serves to assist in the purchasing decision by assessing performance and price-performance in a holistic, industry view. The report is specifically designed to educate readers on the variation in performance and price-performance value across public cloud providers. Performance is a critical and often overlooked component when making a cloud purchase decision, but can have substantial impact on annual operating costs.

WHY IS THIS INFORMATION NECESSARY?

A lack of transparency in the public cloud IaaS marketplace for performance often leads to misinformation or false assumptions. Users and potential users may be led to view cloud computing as a commodity, differentiated mostly by services. The reality of performance in cloud computing, though, impacts the user differently from CSP to CSP, involving everything from the physical hardware (e.g., Intel or AMD, SSD or spinning disk), to the cost of the virtualized resources. By identifying environments based on performance rather than resource count, users are able to maximize value in the cloud.

MISCONCEPTIONS ABOUT PERFORMANCE IN CLOUD

1. VM performance is pretty much the same from CSP to CSP.

While CSPs often use the same terms to label resources (i.e., vCPUs, RAM or memory, and block storage), differences in the underlying hardware, architecture, and performance tuning lead to entirely different results from the same terms such as vCPUs. For example, on VM performance alone (the virtual processor and memory), the Top 10 IaaS providers in this report exhibited a difference of 3.4x. With block storage performance, differences exceeded 10x.

2. For performance, you get what you pay for.

When it comes to additional services such as support, security, geographical location, and managed services on CSPs, this may be true; however, regarding performance, this study found no correlation between price and performance. The study demonstrated the best-value CSPs in this report (defined as the ratio of price and performance as ranked by the CloudSpecs Score™) offer virtualized resources at the lowest prices. Similarly sized VMs within the Top 10 IaaS

providers displayed a spectrum of prices with a 5x difference between the least and most expensive CSPs.

3. Resource contention, known colloquially as the Noisy Neighbor Effect, is not a concern with most providers.

A public cloud environment offers multi-tenant physical hosts, which means a business may share the same physical resources with different users on the same hardware. With a lack of understanding of other users' activities, resource-hogging applications can affect the performance of other VMs on the host machine. While resource contention has been addressed by many of the largest providers in an attempt to stabilize VM performance, the block storage offerings still exhibit high levels of performance fluctuations, with almost a 25X difference in IOPS output over the 24-hour test period of this study, which may be related to other activity on the same physical host as Cloud Spectator's test VMs. The fluctuation in performance evidenced in some CSPs can significantly affect hosted applications within those environments.

3a. If Noisy Neighbor is a concern, then performance is too unpredictable.

In public cloud environments, some providers, especially major ones such as Google Compute Engine and Amazon Web Services, employ performance throttling among other strategies to deliver a consistent user experience regardless of the actual user load on the physical machine. This means that, while performance may be artificially low for the VM, the user will not see much change over time. See Performance by VM Size to view the performance variation of different CSPs over the 24-hour period of the study (on disk performance in particular, Google Compute Engine, one of the Top 10 IaaS Providers in this study, demonstrated very stable performance).



EXECUTIVE SUMMARY

INTRODUCTION

This report examines the results of a study measuring and comparing the price-performance value of 25 CSPs within the European region. While the CSPs included in the study did not have to be headquartered in Europe, they must have at least one data center located within the European continent (see [Methodology](#) page 11). Among the 25, only 19 were successfully tested for various reasons including but not limited to: bugs, provisioning issues, and resource limitations. Six CSPs out of the original 25 could not complete testing for those and other reasons, stressing the importance of testing before selecting a CSP.

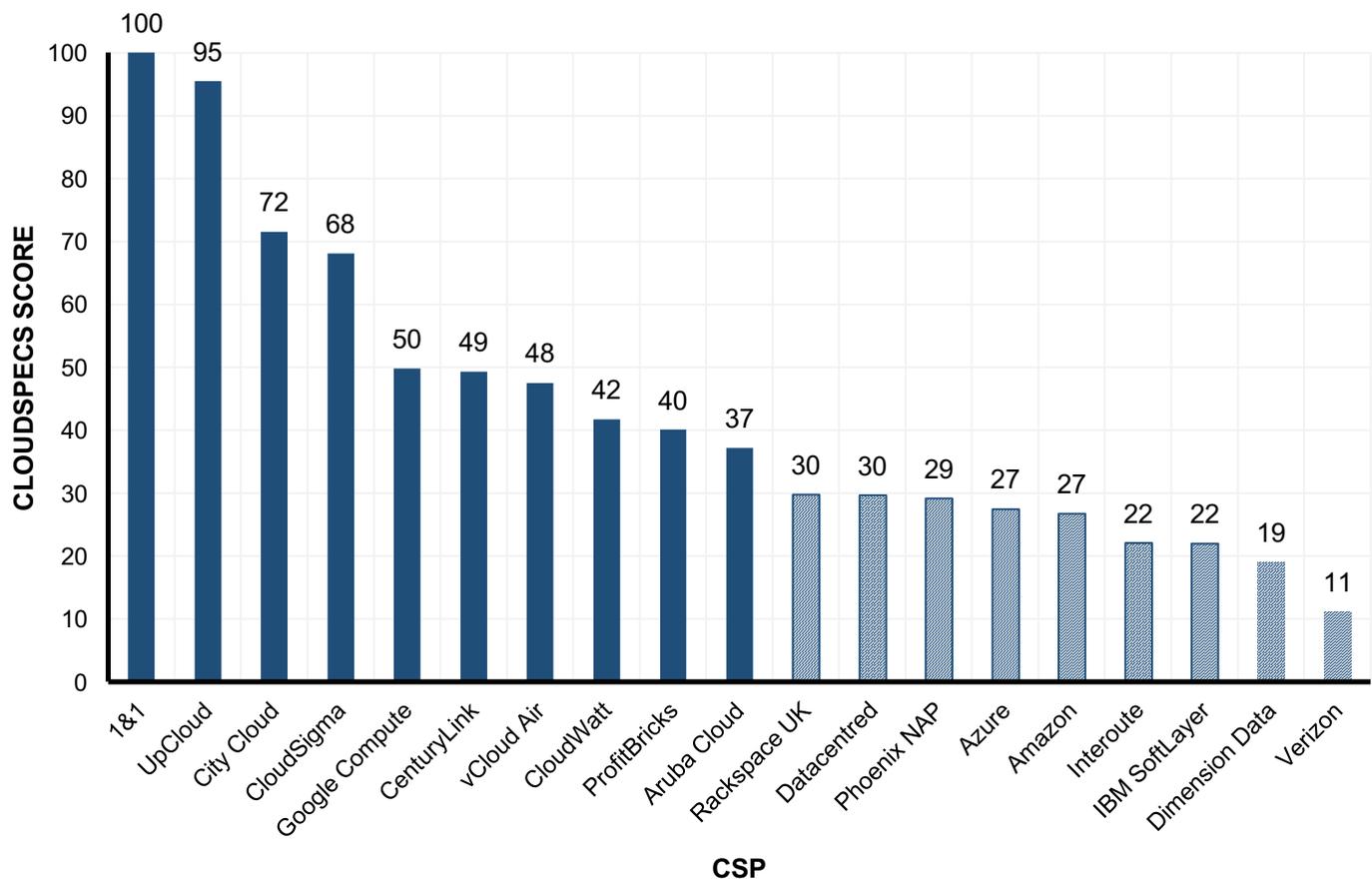
The list of 25 CSPs included major providers like Amazon AWS, Google Compute Engine, Microsoft Azure, and IBM SoftLayer. When comparing price-performance against other CSPs though, some of the major providers did not rank in the final Top 10. Smaller CSPs, some of which specialize in high performance and aggressive pricing, can achieve higher CloudSpecs Scores™ as a result.

NOTES

- Verizon recently announced its exit from the public cloud space, after the completion of the study; therefore, its performance results are recorded and published within this report.
- Pricing may have changed on providers after the release of this report, thus price-performance values and pricing tables are accurate only as of 2/23/2016.

PRICE-PERFORMANCE KEY FINDINGS

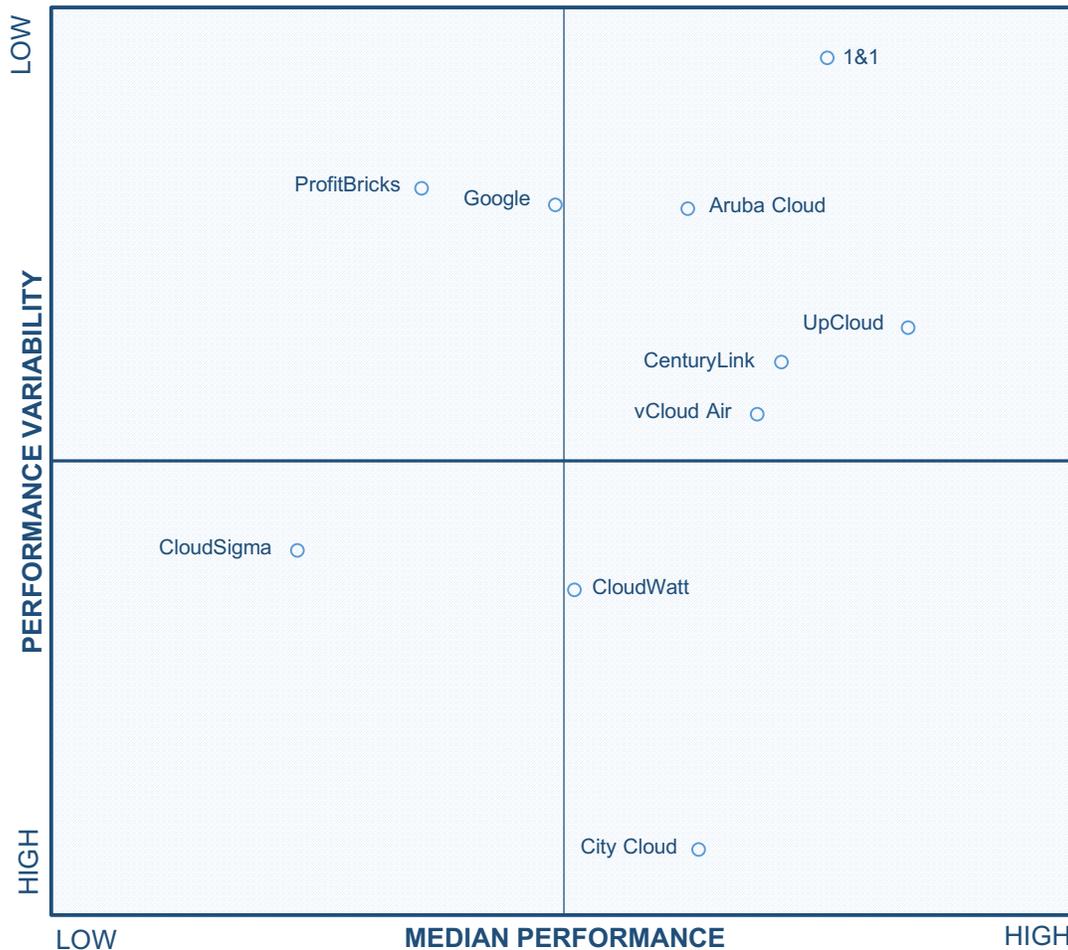
Chart 2.1: Overall CloudSpecs Ranking



- Value, defined as the ratio of price and performance (see [Methodology](#) page 16) varies by 2.7x when comparing the Top 10 CSPs and 9.1x when comparing all tested CSPs.
- 1&1 achieves the highest CloudSpecs Score™ in the Top 10 cloud IaaS providers ranking. This is largely due to high VM performance and the most inexpensive packaged pricing found in the study.
- While certain providers such as CenturyLink may have achieved above-average performance for VM environments, the price-performance value achieved by those types of providers were lower due to higher costs.
- Amazon, which scores higher in VM (defined as vCPU and memory) performance than CloudSigma, CloudWatt, Google and ProfitBricks, does not rank within the Top 10 due to lower relative disk performance and higher monthly costs.
- CloudSigma achieved the highest performance in one of the storage tests; however, lower than average VM performance resulted in a lower overall score.

VCPU & MEMORY PERFORMANCE KEY FINDINGS

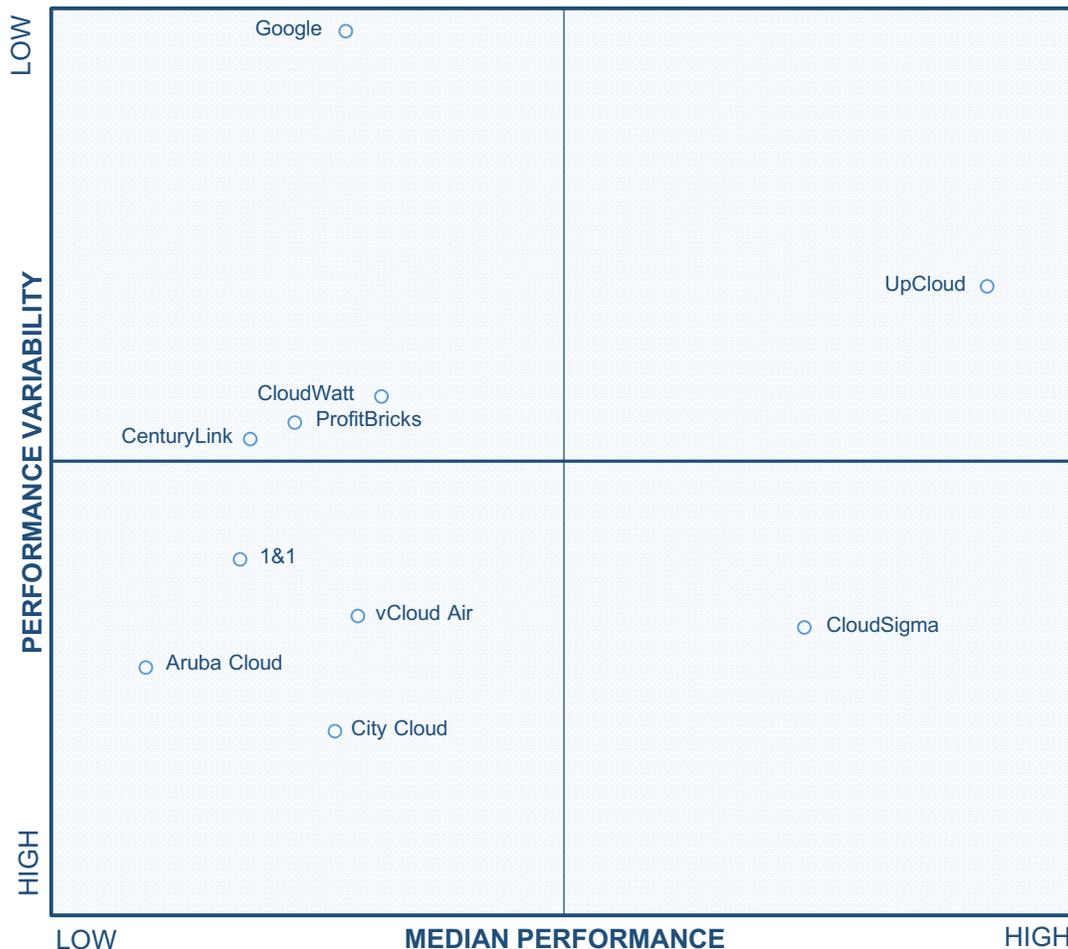
Chart 2.2: vCPU & Memory Performance and Variability Over 24 Hours



- The Top 10 ranked providers exhibited a difference of more than 3.4x in CPU & memory performance, emphasizing the need for performance testing to understand value.
- The differences in performance across the Top 10 providers demonstrates a strong mismatch of VM sizing and standardization in public cloud IaaS; e.g., UpCloud's Small VM outperforms CloudSigma's Large VM on vCPU and memory performance, allowing a user the possibility to utilize fewer resources and lower expenses for certain applications.
- 1&1, Aruba Cloud and UpCloud achieved the best combination of low variability to high performance over the 24-hour test period, contributing to high value and predictable performance.
- The average VM variability between the Top 1-5 and Top 6-10 for VM performance is relatively similar, with average CVs of 5.2% and 4.5% respectively.
- The five providers with lowest variability (Upcloud, 1&1, Aruba Cloud, Google and ProfitBricks) have a higher average CPU/Memory score of 73, compared to the remaining five providers who average 67 in CPU/Memory score.

BLOCK STORAGE PERFORMANCE KEY FINDINGS

Chart 2.3: Block Storage Performance and Variability Over 24 Hours



- While disk performance variability exceeded 40% with some providers, Google demonstrated stable performance over the test period with variability of less than 3%, likely due to throttling to avoid resource contention.
- UpCloud block storage sustains higher overall IOPS than all other CSPs. CloudSigma sustains higher IOPS, though, on Type 2 block storage testing, indicating better performance for applications running larger block sizes.
- Differences in IOPS performance across CSPs exceed 10x in some categories of block storage testing (see [Performance by VM Size](#) on page 32).
- UpCloud and CloudSigma offer the highest overall disk performance measured in the study with scores of 82 and 66 respectively, however performance variability between the two providers differs by over 2x. UpCloud's performance variability measures at 18% while CloudSigma measures at 41%.
- The five providers with highest disk performance (UpCloud, CloudSigma, CloudWatt, vCloud Air, Google) had lower variability compared to the remaining five providers, with average CVs of 25% compared to 37% respectively.

Table 2.1: Performance and Variability of CSPs Over 24 Hours

	vCPU & Memory		Block Disk	
	Performance Index	Variability	Performance Index	Variability
1&1	91	1%	17	36%
Aruba Cloud	74	3%	8	44%
Century Link	85	5%	17	28%
City Cloud	76	11%	25	48%
CloudSigma	29	7%	66	41%
CloudWatt	61	8%	29	26%
Google Compute	59	3%	26	2%
ProfitBricks	43	2%	21	27%
UpCloud	100	4%	82	18%
vCloud Air	82	5%	27	40%

Table 2.1 lists the indexed performance scores and variability percentages by CSP. These numbers are used in generating Charts 2.2 and 2.3.

The Performance Index is calculated by indexing the individual performance scores achieved by each VM category (categorized as Small, Medium, Large and Extra Large; see [Methodology](#) for more information) on a scale of 0-100 with 100 as the top score. An average across all VM categories is calculated to represent the Performance Index for each provider.

Variability is calculated as the average coefficient of variation (CV) that is the standard deviation expressed as a percentage of the mean performance for the VM categories of each CSP. Higher CV correlates to more fluctuation in performance (i.e., higher performance variability) over the test period.



METHODOLOGY

The Cloud Spectator team designed this methodology to measure the performance of various public cloud infrastructure services. These results will provide a general insight into the public cloud industry; however, businesses have varying needs when defining performance requirements, so businesses should apply testing methodologies relevant to their business and technical use cases to yield more relevant results.

THE CRITERIA

In order to be considered and tested as one of the IaaS providers in this report, a CSP must deliver the following as part of its IaaS offering:

1. The CSP must have at least one data center located within the European continent. The CSP does not need to be headquartered in Europe.
2. Self sign-up: a user must be able to sign up for a CSP's services online, rather than reaching out to a sales representative. Contact forms that request users to message the CSP for sign-up are not considered self sign-up.
3. Self-service: a user must be able to log into a portal that allows the user to provision, manage, and terminate virtual machines and other cloud-related services.
4. Hourly billing intervals: the CSP must provide billing by the hour or less. Some CSPs offer billing by the minute.
5. Only providers with persistent block storage offerings are included in this study. Cloud Spectator measured disk performance by running performance tests on block storage.

THE SETUP

The team set up anonymous accounts on all cloud service providers. No accounts were credited, and no CSPs provided the team an account to provision Linux virtual machines. For all VMs, Ubuntu 14.04 images were operating systems of choice. In cases when Ubuntu 14.04 was not available, 12.04 was used; if no Ubuntu images were available, Debian was used. Virtual machines were tested according to four separate categories: Small, Medium, Large and Extra-Large. Each category contained a prerequisite allocation of VM resources.

Table 4A: VM Sizing

SIZE	vCPU COUNT	RAM COUNT (GB)	DISK COUNT (GB)
Small	2	4	100
Medium	4	8	150
Large	8	16	200
Extra Large	16	32	500

CSPs were segmented into two categories: (1) Packaged Offering CSPs and (2) Customizable Offering CSPs. Packaged Offering CSPs include providers such as Amazon Web Services (AWS) and Microsoft Azure, which deliver VMs based on pre-packaged sizes; for example, a customer can purchase an Instance size of c4.xlarge on AWS. Customizable Offering CSPs allow users to define custom VM sizes by setting resources such as vCPUs, RAM, and disk space. Only block storage was tested for disk because of its durability and persistence. This meant that CSPs such as DigitalOcean, which only offer local storage, were not included in the report. Only a single block storage size was paired and tested with each VM size. For other CSPs such as Amazon, which offers local and persistent block storage, the local storage was not measured and did not affect the performance or price-performance ranking of the CSP beyond the potential effect on pricing if local storage is included in packaged VM prices.

For Packaged Offering CSPs, the team selected VMs that most closely corresponded to the four categories of sizes. For Customizable Offering CSPs, the team provisioned servers designed to the exact requirements of the four categories of sizes when possible.

For each CSP, the team provisioned three copies of VMs for each size; i.e., three Small, three Medium, three Large, and three Extra-Large VMs were provisioned. All VMs were provisioned and tested simultaneously for 24 hours. This means that, for each CSP, twelve various-sized VMs were running from the account on the corresponding provider for 24 hours.

Please note that some CSPs do not offer any VMs with resource allocations that would qualify for the Extra Large size.

SIMULTANEOUS TESTING OVER TIME

Three resources were examined to compare performance: vCPU, memory, and storage. Performance tests were run in continuous, iterative sequence according to the following order: vCPU tests and memory tests followed by block storage tests. Each complete sequence of testing comprised a single cycle, and cycles repeated without pause for the duration of 24 hours. Different providers completed varying numbers of cycles within the 24-hour time limit, and the number of cycles completed was impacted by the performance levels of the resources tested (higher performance allows each test to be completed faster).

Testing over several iterations impacted the ranking of performance for CSPs. In an uncontrollable multi-tenant environment, VM performance can be affected by issues that arise with neighboring VMs. While these issues may be mitigated with resource planning as a responsibility of the CSP, sometimes performance levels cannot be guaranteed or sustained in the public cloud; therefore, measuring to examine sustainable performance is just as important on a public cloud as measuring to

examine achieved performance. This is why the Cloud Spectator team chose to test over a period of 24 hours.

Three VMs of each category size were tested in parallel. Single-VM performance may not necessarily be reflective of the potential performance a CSP's VMs can achieve if the provisioned VM is faulty for any number of reasons. Measuring more than a singular VM of each size mitigates the possibility that the performance may be an unusual outlier due to a VM provisioning issue, so results are a more accurate reflection of a VM type's potential performance.

At other times, the physical host itself may experience issues, affecting all VMs residing on it. By provisioning all VMs simultaneously, Cloud Spectator may increase the possibility of measuring on multiple physical hosts with different users and resource contention issues, which would be more representative of a VM size's performance. While all of these processes are implemented to increase the accuracy of the measurements, it should be noted that these practices cannot guarantee 100% accuracy. Even by provision three of the same VMs of each category, the VMs still have the possibility of residing on the same physical host depending on the provider's capacity.

DATA COLLECTION

Throughout the 24-hour period of testing across all qualified and tested providers in this report, a total of 1,937,088 vCPU and memory performance data points and 1,631,232 block storage performance data points were collected, for a total of 3,568,320 data points collected to measure and compare performance variation. Testing was conducted in December 2015.

The list of CSPs ranked in the Top 10 was produced based on the CloudSpecs Score™, which is a price-performance ratio of the cost and median performance output of the VM. Each VM size

category received a VM CloudSpecs Score™ and block storage CloudSpecs Score™, which were averaged to calculate a CloudSpecs Score™ for the VM. The 10 CSPs with the highest average CloudSpecs Scores™ across all VMs were selected and ranked as the Top 10 CSPs. All 19 tested CSPs were ranked according to price-performance; the report details the findings of the top 10.

TESTING USED

Table 4B: Testing Tools

TEST	TOOL	TASKS
vCPU Testing	Geekbench 3	Integer and Floating Point
Memory	Geekbench 3 (using STREAM)	Reads and writes
Block Disk	Fio	Reads and writes

vCPU and Memory

vCPU performance was measured with integer and floating point tasks from the Geekbench 3 benchmark suite. The Geekbench 3 benchmark suite was also used in collecting memory bandwidth data, which was used to measure the performance of the system memory (RAM).

Table 4C: Testing Specifics

CATEGORY	TYPE 1	TYPE 2
Block Size	4KB	128KB
File Size	5GB	128MB

Table 4D: Total Files Used in Block Storage Testing

SIZE	TYPE 1	TYPE 2
Small	1	2
Medium	2	4
Large	4	8
Extra Large	8	16

Storage

Storage performance was measured using fio. Two storage scenarios were run to capture performance data: Type 1 and Type 2. In both scenarios, random and sequential IOPS were recorded as the indicator of performance over a test period of 60 seconds. Type 1 used a large file size with a small block size, while Type 2 used a small file size with a large block size. The total number of files used in testing varied with the category of VM.

RANKING CALCULATION

The list of Top 10 CSPs were determined by calculating the median performance of both vCPU-memory and storage with the monthly cost corresponding to each VM size for two price-performance scores per VM size (one for vCPU-memory and one for storage). The resulting ratios were normalized in relation to the highest-value provider for each resource, which receives a score of 100. Then the two price-performance scores for each VM size were averaged together to get one score per VM size. The providers were then ordered based on their value across all each VM size, and then their scores were averaged for all VM sizes to come up with a final score. The providers that sustained higher ratios across all VM categories ranked in the Top 10.

PRICE-PERFORMANCE VALUE (THE CLOUDSPECS SCORE)

Cloud Spectator's price-performance calculation, the CloudSpecs Score™, provides information on how much performance the user receives for each unit of cost. The CloudSpecs Score™ is an indexed, comparable score ranging from 0-100 indicative of value based on a combination of cost and performance. The calculation of the CloudSpecs Score™ is:

$$\text{price-performance_value} = [\text{VM performance score}] / [\text{VM cost}]$$

$$\text{best_VM_value} = \max\{\text{price-performance_values}\}$$

$$\text{CloudSpecs Score}^{\text{TM}} = 100 * \text{price-performance_value} / \text{best_VM_value}$$

CPU and Memory

Cloud Spectator used the median Geekbench 3 performance scores as the [VM performance score] to calculate each machine's CPU and memory CloudSpecs Score™.

Block Storage

For both storage scenarios, median sequential r/w and median random r/w IOPS are used as the [VM performance score] to calculate each machine's Type 1 and Type 2 storage CloudSpecs Score™. Type 1 and Type 2 scores were averaged to calculate a single block storage CloudSpecs Score™.

Overall

Overall storage CloudSpecs Score™ was calculated by averaging block storage and vCPU-memory price-performance scores together so that they have equal weight for each VM size. Then, all resulting VM size scores were averaged together. For block storage performance, the normalized sequential and random CloudSpecs Scores™ were averaged together. Then, the Type 1 and Type 2 CloudSpecs Scores™ were averaged together to create a single storage CloudSpecs Score™ per VM size. Then, the overall CPU, memory and storage CloudSpecs Scores™ were calculated by averaging the CPU and memory CloudSpecs Score™ and overall storage CloudSpecs Score™ for each VM size. All VM size scores were then averaged for each provider and normalized to get the final scores on the scale from 1 to 100.

VARIABILITY

Variability is calculated by taking the coefficient of variation (CV) of each VM size's individual performance data points. The CVs are averaged for all VM sizes per CSP. The coefficient of variation is the standard deviation expressed as a percentage of the mean.

CONSIDERATIONS

Limitations within the Methodology

The IaaS industry lacks a standard methodology for evaluating CSPs. While the most effective methodology for measuring value of a CSP varies among use cases, the methodology developed by Cloud Spectator for this study was designed to capture performance statistics based on synthetic

performance uniquely adopted for cloud infrastructure, which requires steps including extended testing over a period of time and running multiple VMs in parallel.

VM Sizes

The performance data in this report only applies to the tested VM and block sizes. Larger VMs may yield better results with both VM scores and block storage scores. Larger block sizes may also yield better block storage performance scores. Not all CSPs offered the Extra Large size (see Methodology page 12) for testing. In those cases, the CloudSpecs Score™ was calculated by averaging the three available sizes.

Pricing Calculations and Discounts

In this report, Cloud Spectator used monthly pricing to calculate the cost of VMs on providers. Some providers offer sustained-use discounts based on a monthly interval, while others discount for monthly commitments. Certain providers offer similar discounts on an annual basis or longer; these longer-term discounts were not factored into the analysis. Where available, monthly discounting was factored into the pricing calculations; therefore, for longer or shorter time commitments, the rankings may change.

The Ranking System

The Top 10 providers ranked in this report were chosen based on a calculation that considers both performance and cost of the environments. The performance results of vCPU, memory, and block storage are all included in the calculation. While some providers may exhibit high performance on vCPU, memory, and/or block storage, those CSPs may not necessarily rank high in the Top 10 or even rank within the Top 10 depending on the cost of their environments as compared to their competitors.

Additional Features and Costs

Only the VM, block storage, and costs of those two components were examined in this study.

Additional features, such as support costs (where applicable), public and private networks, traffic, and other services that may increase the overall cost of a CSP's offering, were not examined in the report.

Depending on the types of use cases, the features not examined may impact the overall rankings.

However, if a user can select between different base infrastructure options that have a difference in performance (e.g. SSD vs. magnetic storage), the options yielding higher performance outputs were chosen.

DATA CENTER LOCATIONS

All VMs were provisioned in the European data centers of each CSP. For providers with more than one European data center, the most location with lower pricing was chosen. If all locations were priced equally, the location closest to the regional HQ was chosen. Specific locations, as described by each CSP, are listed in Table 4E.

Table 4E: Data Center Locations

Provider	Data Center Location
1&1	Germany
Aruba Cloud	FR1
Amazon	EU (Ireland)
Azure	Northern Europe
CenturyLink	GB1
City Cloud	Karlskrona
CloudSigma	Zurich
CloudWatt	France
Datacentred	UK
Dimension Data	Amsterdam
Google Compute	Europe-West1
IBM SoftLayer	AMS01
Interoute	London
Phoenix NAP	EU West
ProfitBricks	Karlsruhe
Rackspace UK	London
UpCloud	Helsinki
vCloud Air	Europe UK 1
Verizon	EU North

PRICE- PERFORMANCE VALUE

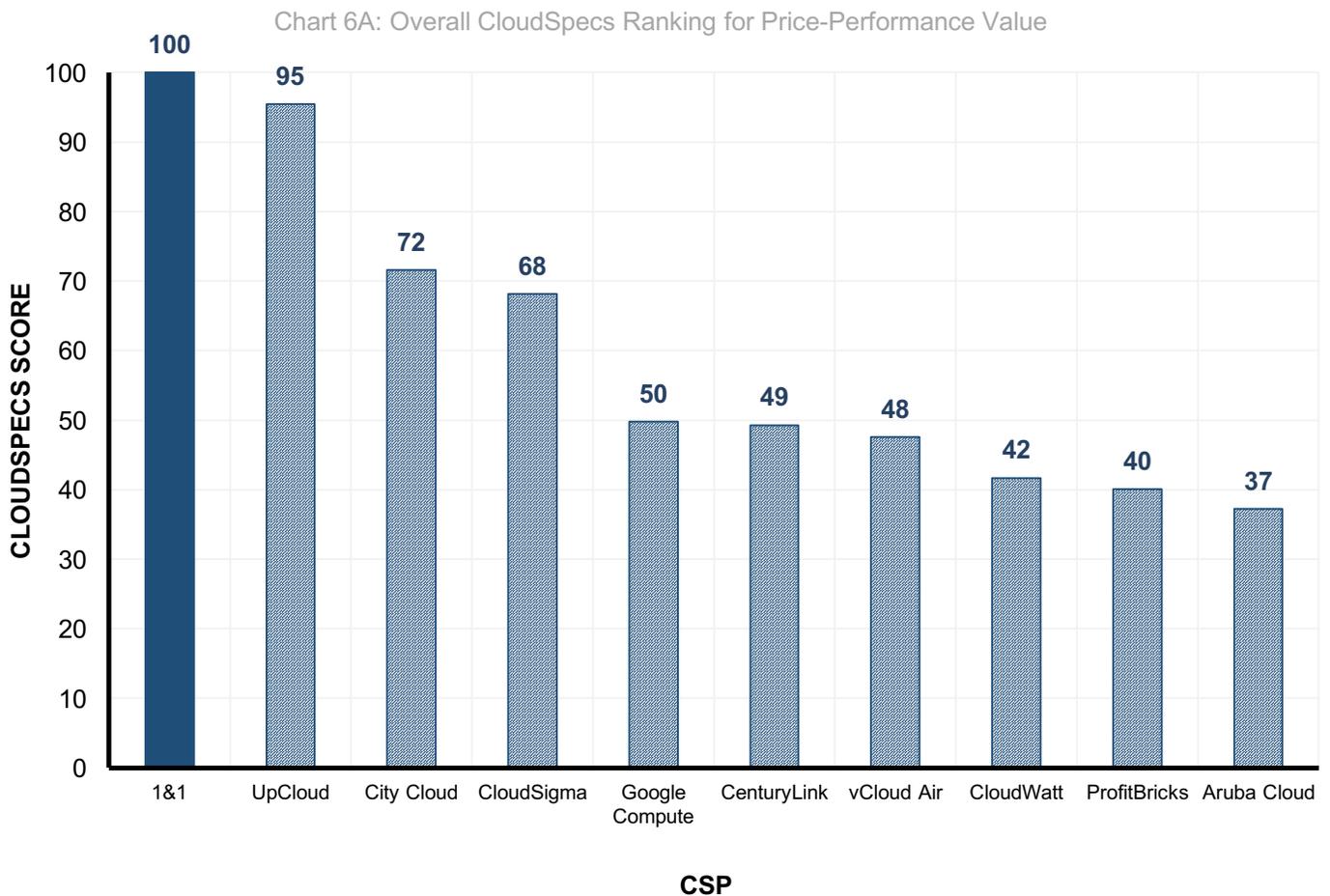
This section examines the price-performance value (i.e., the CloudSpecs Score™) of the Top 10 IaaS providers, which is used in determining each CSP's ranking in this report. The CloudSpecs Score™ is calculated as the ratio between the price, defined as the monthly cost of the VM and block storage, and median performance of the VM and block storage. For more information on the calculation of the CloudSpecs Score™, please see the [Methodology](#).

1&1's Cloud Server achieves the highest CloudSpecs Score™ in this study (a CloudSpecs Score™ of 100). CSPs such as CenturyLink, which achieved high performance scores in the previous section, ranked lower overall due to higher costs of infrastructure.

OVERALL CLOUDSPECS RANKING

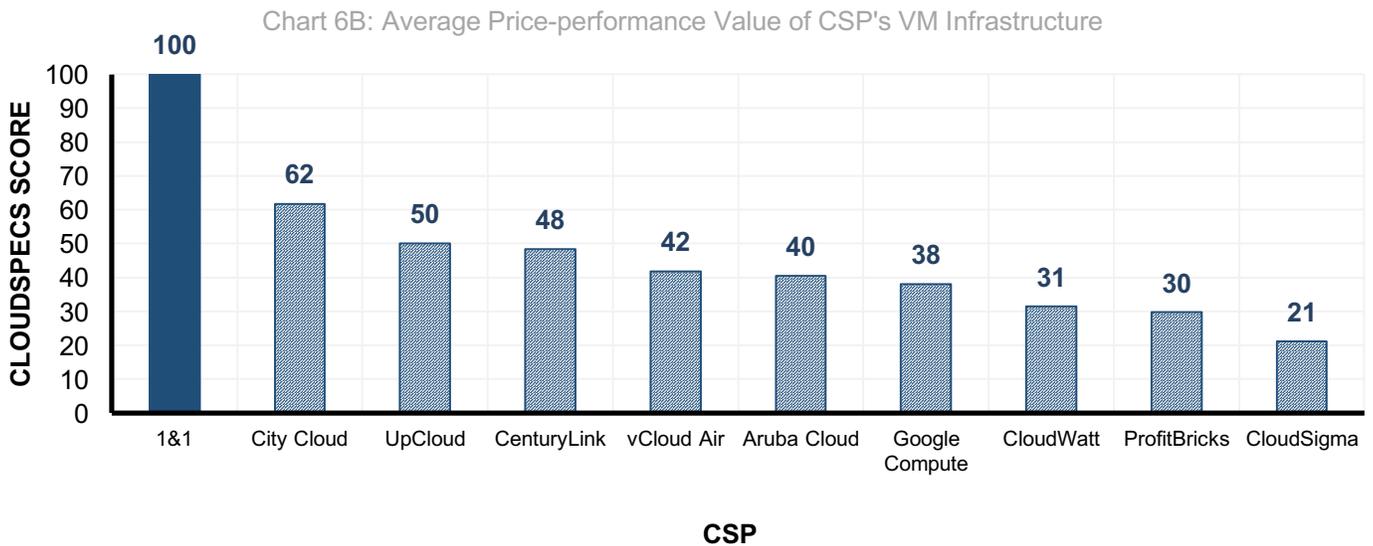
The ranking of the Top 10 CSPs based on CloudSpecs Score™ is displayed in Chart 6A.

Value based on price-performance in this study is ranked in relation to the highest-value CSP, 1&1. A difference in value of 2.7x exists between 1&1, the highest-ranked CSP, and Aruba Cloud, the lowest-ranked CSP in the Top 10.

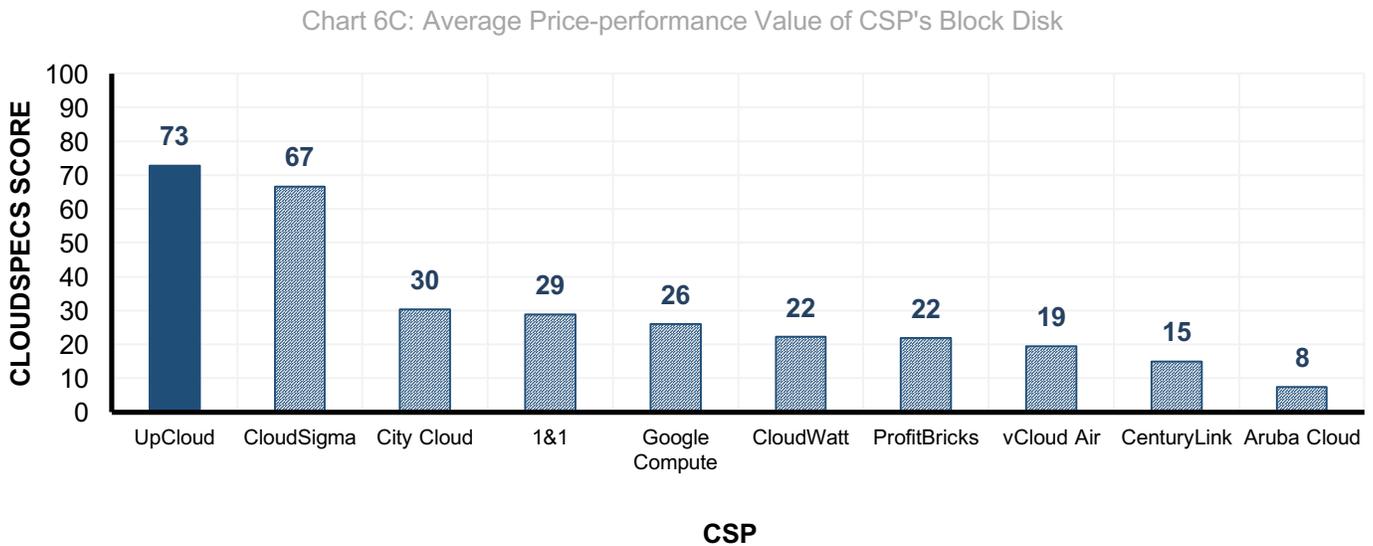


The following sections (vCPU and Memory Value and Block Storage Value) illustrate the individual Value scores segregated by section, which are the scores used to calculate the overall CloudSpecs™ ranking. 1&1 achieves the highest CloudSpecs™ ranking in the vCPU and Memory Value category, while UpCloud achieves the highest CloudSpecs™ ranking in the Block Storage Value category. 1&1 scores highest overall.

VCPU AND MEMORY VALUE



BLOCK STORAGE VALUE



PERFORMANCE

This section examines the performance of the Top 10 IaaS providers ranked in this report. This section does not use the CloudSpecs Score™, which is used to rank providers and can be found in the Price-Performance section of the report.

The period of 24-hour testing across 3 parallel machines for each category of VMs demonstrated much higher overall stability of performance in the vCPU and memory components for all providers, as compared to block storage performance over the same period. Performance differences are more noticeable as VMs scale up in size (e.g., the XL size), although a noticeable difference exists in the small VM category as well.

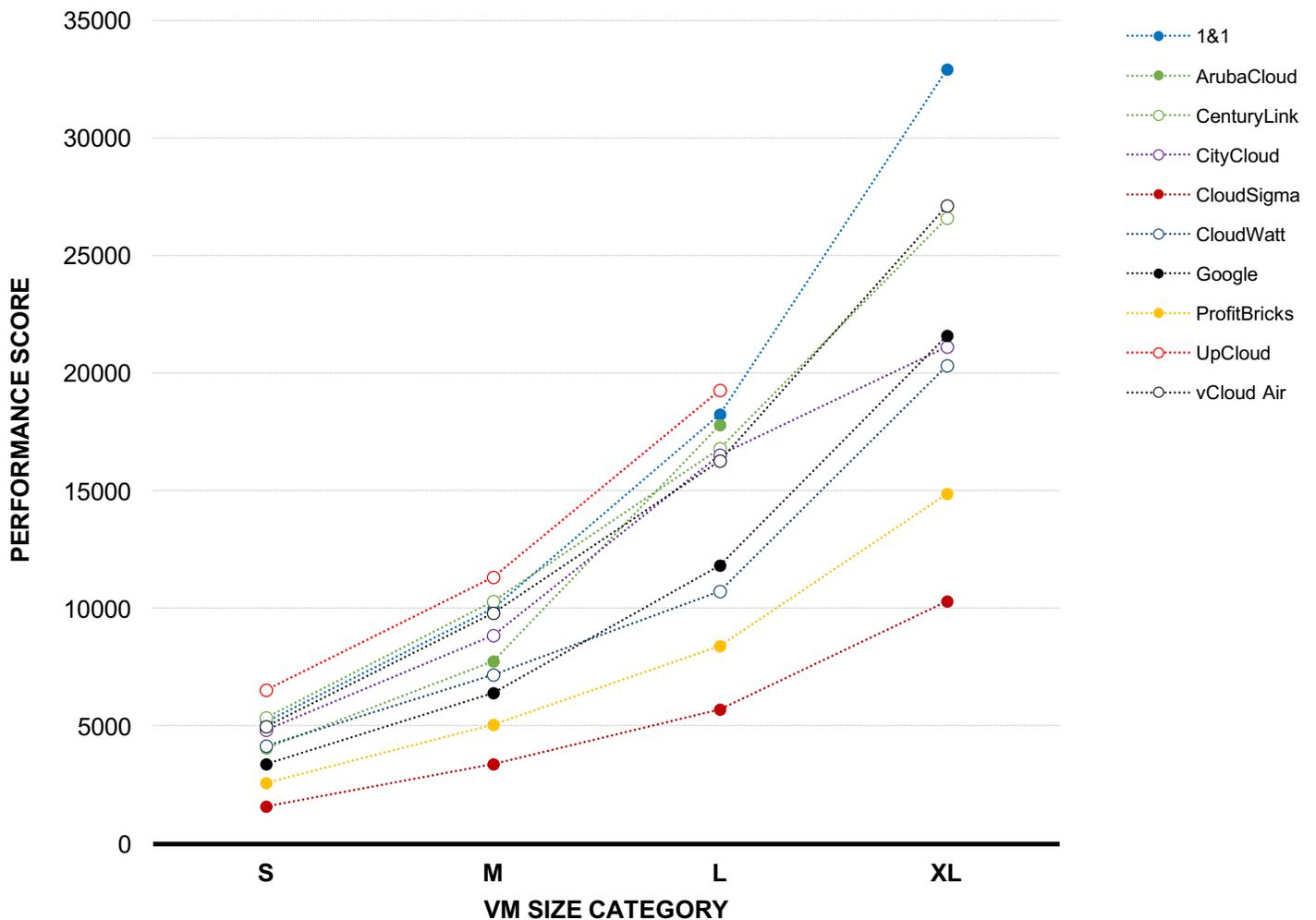
For detailed information on performance scores by VM size, see [Performance by VM Size](#) on page 32.

VCPU AND MEMORY PERFORMANCE

Performance values between CSPs on vCPU and memory increase with the size of the VM. The chart below illustrates the vCPU and memory performance across the Small, Medium, Large and Extra-Large VMs:

- The Small VM category exhibits a difference of 4.1x between the highest and lowest-performing CSP VMs; The Extra Large VM category exhibits a difference of 3.2x between the highest and lowest-performing CSP VMs.
- The providers scale on average 1.8x as they increase to the next higher VM size. Aruba Cloud scales the most between sizes at an average rate of 2.1x, while CityCloud is the lowest at 1.66x.

Chart 5A: vCPU and Memory Performance (Median Scores Displayed)



BLOCK STORAGE PERFORMANCE

Because the relationship in performance between providers remained similar with both the random and sequential operations, only results from the sequential tests are displayed in this section.

Detailed results and random results can be found in the [Performance by VM Size](#) on page 32. Each varying disk size corresponded with a VM category (see [Methodology](#) page 12). Two disk scenarios were measured: Type 1 and Type 2. More information on the two scenarios can be found in the [Methodology](#) (page 11).

- Block storage is not standard across CSPs in regards to hardware, architecture, or performance. A difference of more than 10x exists between highest and lowest-performing block storage offerings across CSPs.
- In disk scenario Type 1, certain CSPs exhibit a noticeable scale in performance as the size of the disk is increased (along with the disk size, the number of files are increased as well). In Type 2, the scale is unnoticeable for the majority of providers (CloudSigma being the exception), despite the increase in size of the disk and the number of files created on the disk. This may be due to factors such as throttled performance of the VM, and the amount of IOPS a certain VM size can access, or the larger 128K block size.

Chart 5B: Scenario Type 1 - Sequential Performance (Median Scores Displayed)

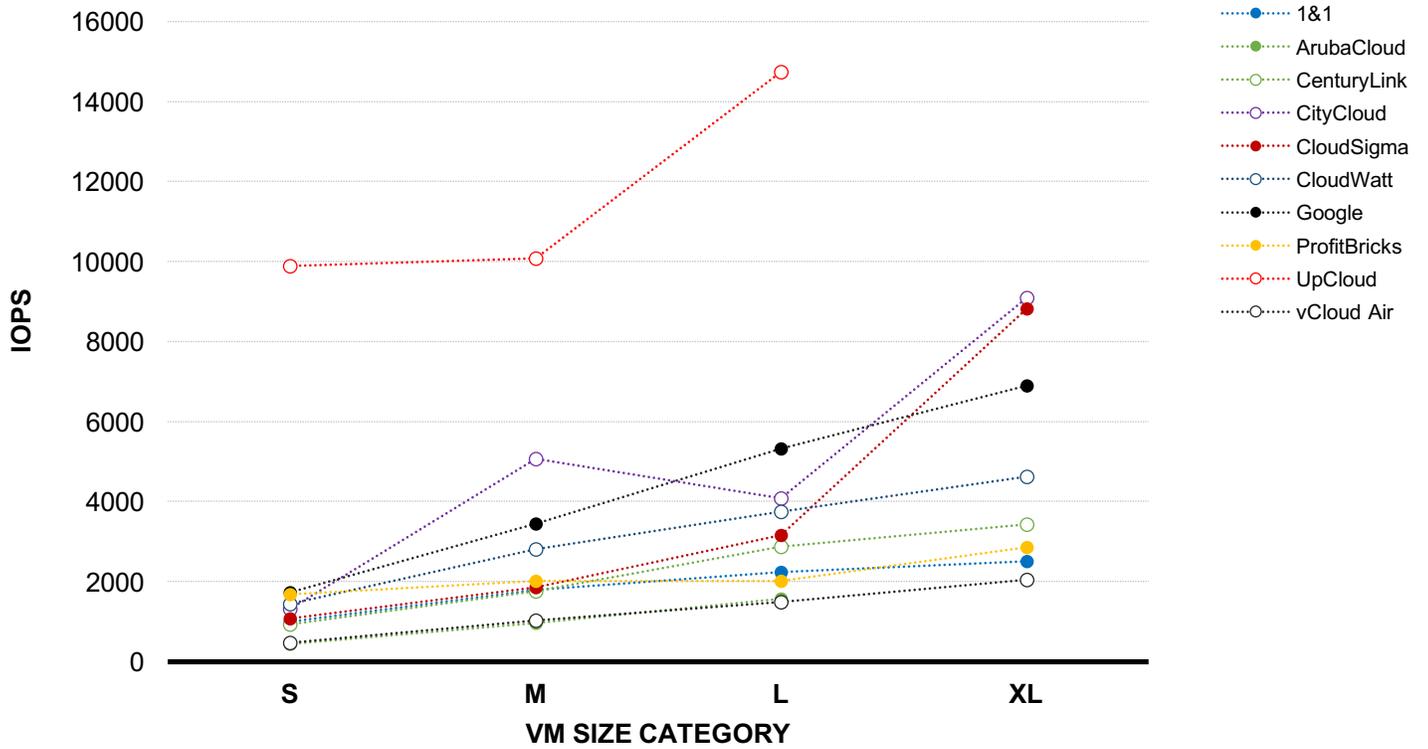
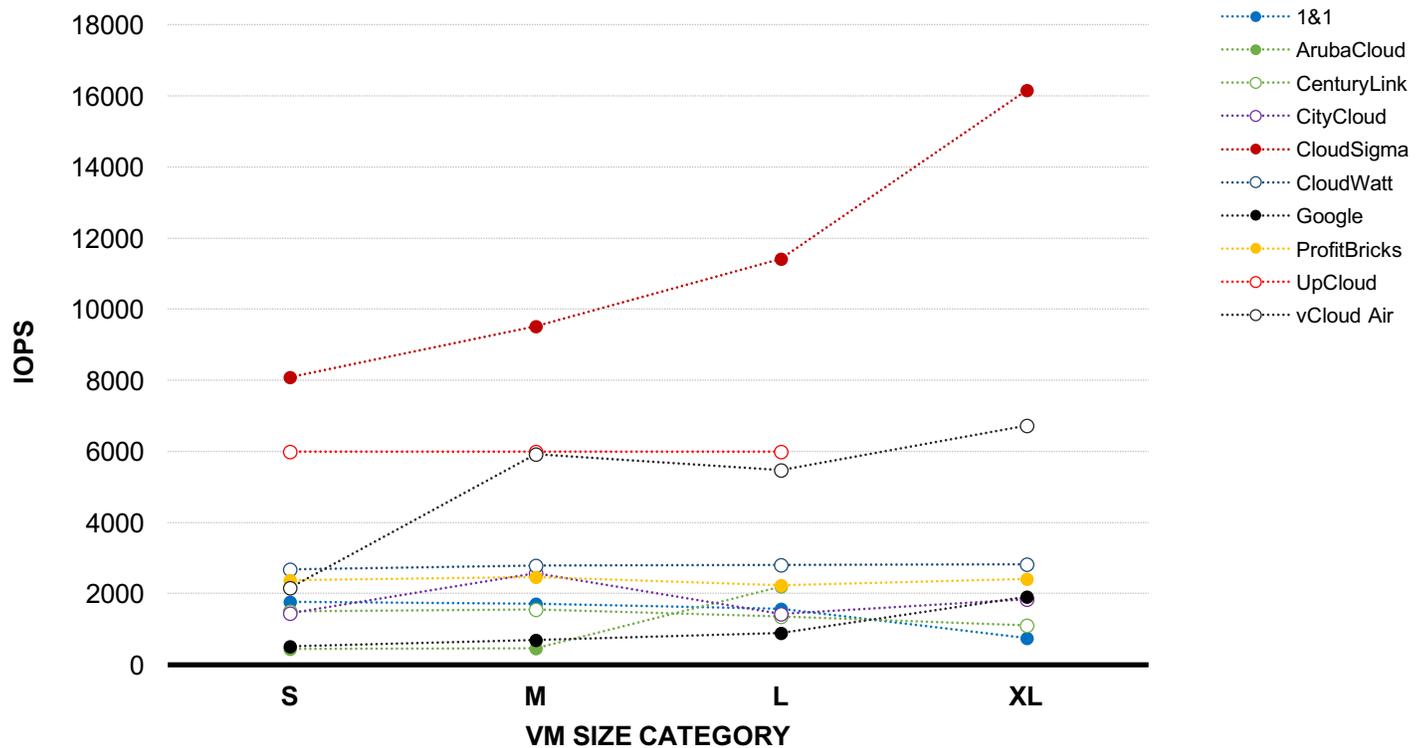


Chart 5C: Scenario Type 2 - Sequential Performance (Median Scores Displayed)



PRICING

This section outlines the cost of the VMs and block storage for each size examined in the study across all CSPs. Additional services, unless required (such as vCloud Air support), are not included in the final cost of the VMs. Only the cost of the VM and tested block storage were factored into the final cost. Keep in mind that some providers may charge for add-on services such as support, while other providers include it into the cost of the VMs.

A separate section on traffic costs across CSPs is included as well to highlight the impact of additional considerations that may be involved in pricing, which can impact the final cost of CSP infrastructure.

Pricing for the report updated on 2.23.2016

OVERALL PRICING

The final monthly cost of each VM category for each CSP is calculated as the cost of the VM and the cost of the attached block storage. The six least-expensive providers demonstrate consistent, low pricing across all VM sizes.

Chart 7A: Monthly Cost of VMs Across CSPs

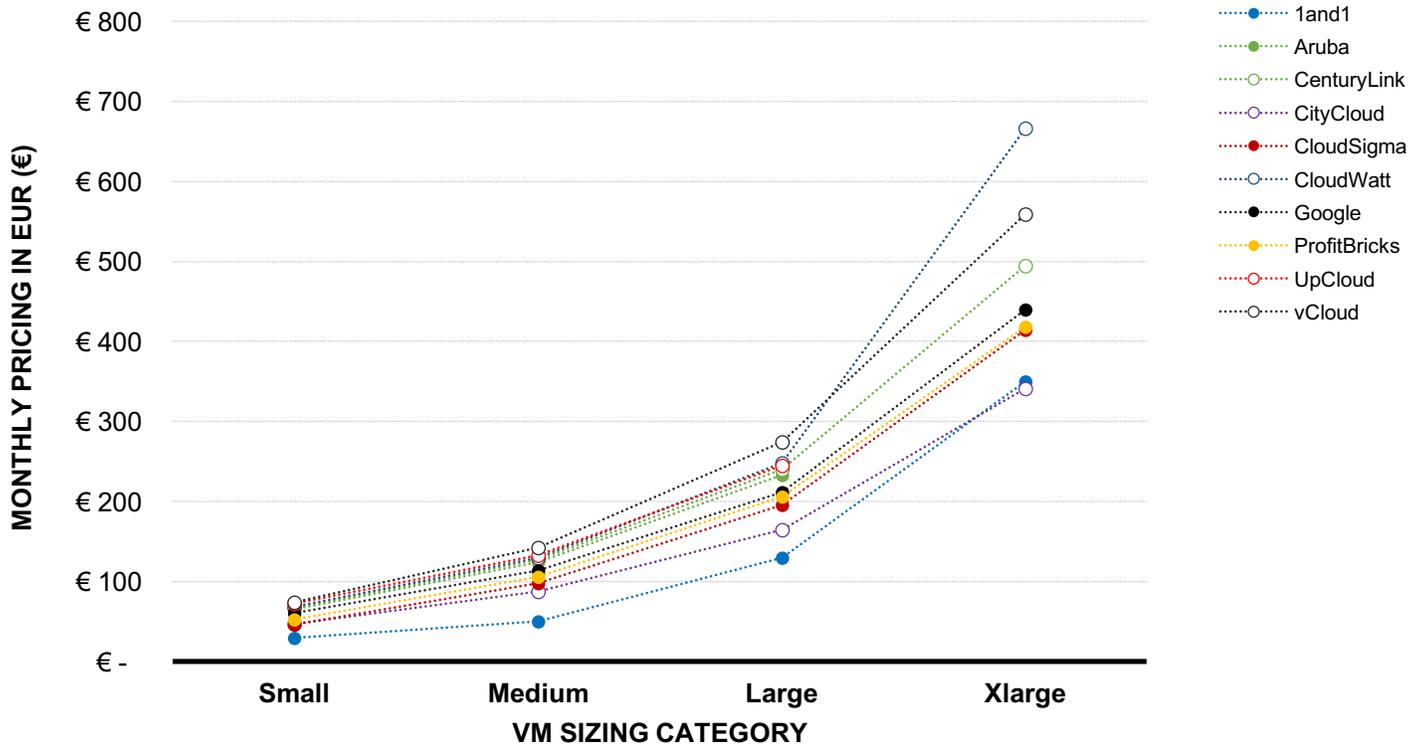


Table 7A: Monthly Cost of VMs Across CSPs

	Small	Medium	Large	Extra Large
1and1	€ 30	€ 50	€ 130	€ 350
Aruba Cloud	€ 66	€ 124	€ 234	€ 495
CenturyLink	€ 67	€ 127	€ 240	€ 495
City Cloud	€ 47	€ 88	€ 165	€ 341
CloudSigma	€ 46	€ 98	€ 196	€ 415
CloudWatt	€ 69	€ 130	€ 248	€ 667
Google Compute	€ 61	€ 114	€ 212	€ 440
ProfitBricks	€ 53	€ 106	€ 206	€ 419
UpCloud	€ 73	€ 133	€ 245	€ 559
vCloud Air	€ 74	€ 142	€ 274	€ 559

PRICING BY VM CATEGORY

Costs of servers remain fairly linear as VM categories scale larger in size. The singular exception occurs in the transition from a Large VM to an XLarge VM, where the 1&1 VM category's monthly cost exceeds the City Cloud VM category's monthly cost. Among the Top 10 CSPs, CloudWatt, UpCloud, and vCloud Air are the most expensive, while 1&1, City Cloud, and ProfitBricks are the least expensive.

Chart 7B: Monthly Cost of Small VMs

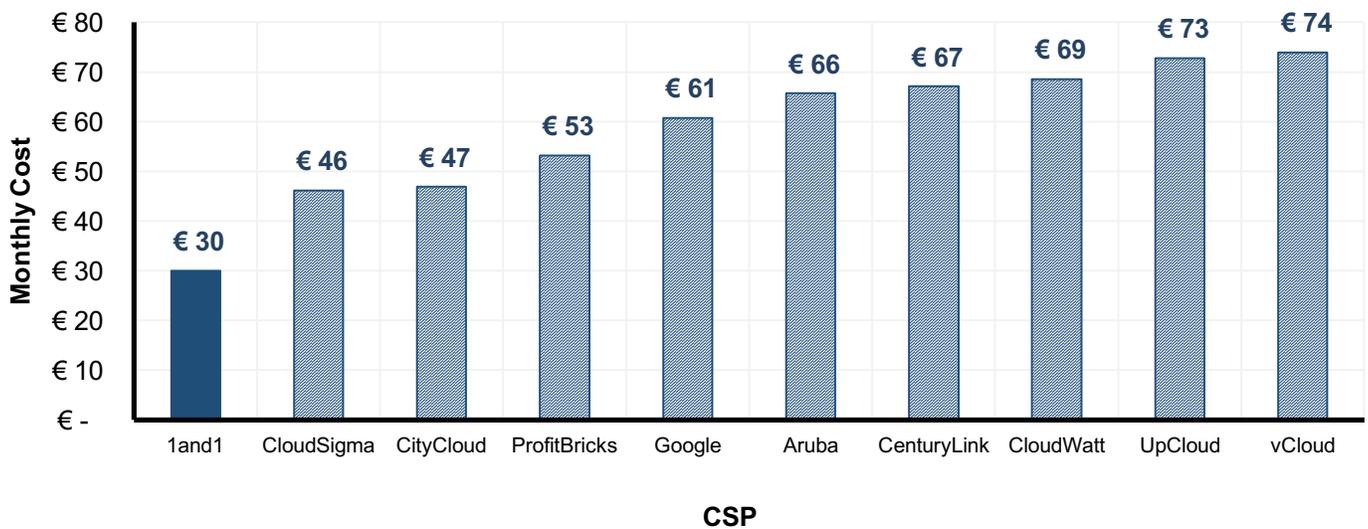


Chart 7C: Monthly Cost of Medium VMs

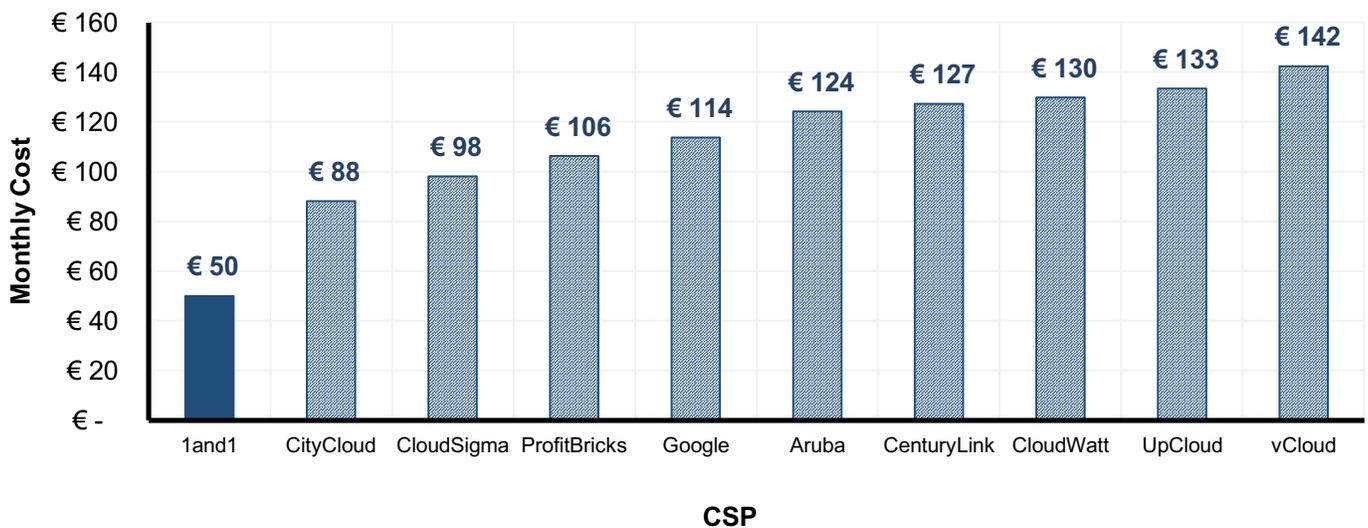


Chart 7D: Monthly Cost of Large VMs

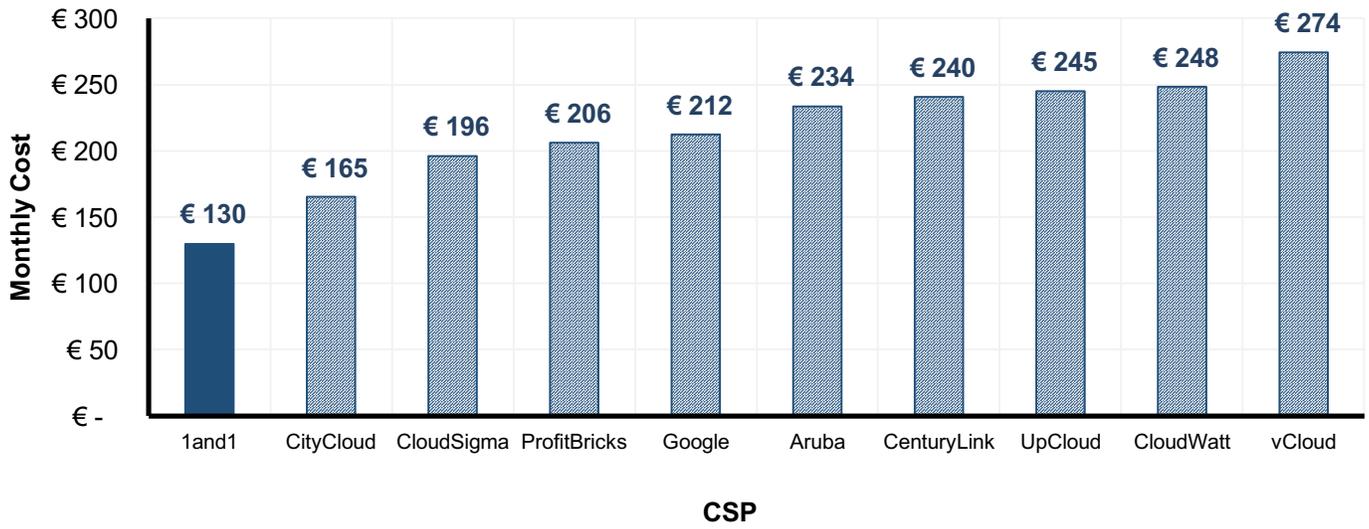
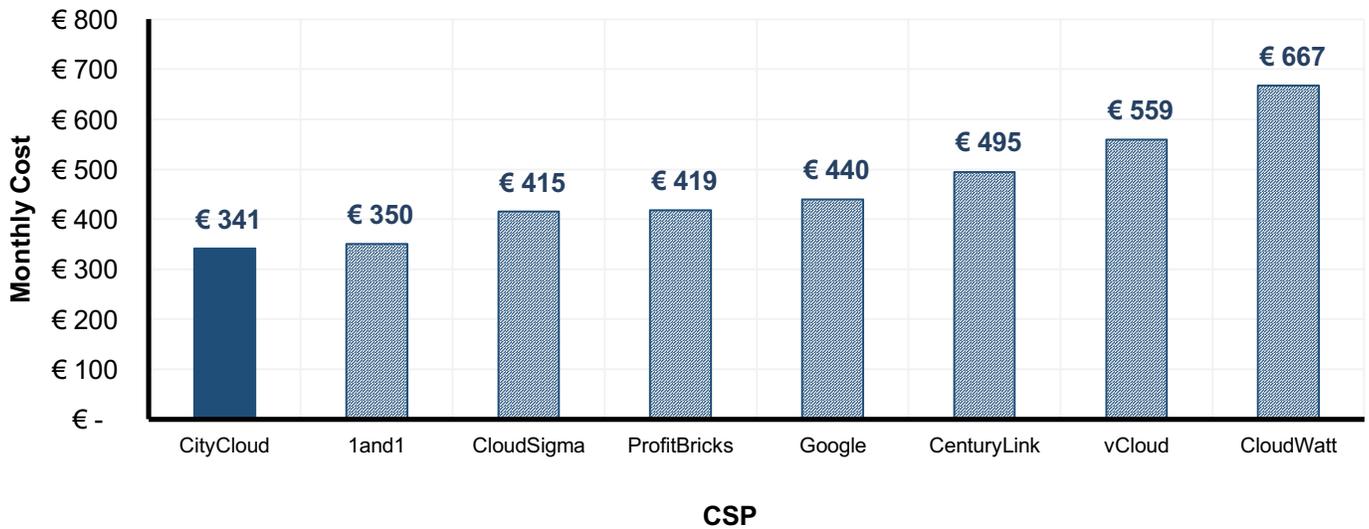


Chart 7E: Monthly Cost of Extra Large VMs



TRAFFIC COSTS

Table 7B illustrates bandwidth pricing for egress traffic by GB, which varies depending on the CSP. All providers in the table offer free ingress traffic. For use cases heavily involving egress traffic, readjusting price-performance value to calculate for the increased traffic may alter the results of the Top 10 rankings within this report.

Table 7B: Egress Traffic Costs Across CSPs (per GB)

	First 1 GB	First 5GB	Up to 1TB	1 to 5 TB	5 to 10 TB	Next 40 TB	Next 100 TB	Next 50 TB	Next 300 TB
1&1	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00
Aruba Cloud	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00
CenturyLink	€ 0.04	€ 0.04	€ 0.04	€ 0.04	€ 0.04	€ 0.04	€ 0.04	€ 0.04	€ 0.04
City Cloud	€ 0.00	€ 0.00	€ 0.00	€ 0.02	€ 0.02	€ 0.02	€ 0.02	€ 0.02	€ 0.02
CloudSigma	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.04	€ 0.04	€ 0.04	€ 0.04	€ 0.04
CloudWatt ¹	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00	n/a	n/a	n/a	n/a
Google	€ 0.12	€ 0.12	€ 0.12	€ 0.11	€ 0.11	€ 0.08	€ 0.08	€ 0.08	€ 0.08
ProfitBricks	€ 0.06	€ 0.06	€ 0.06	€ 0.06	€ 0.06	€ 0.06	€ 0.06	€ 0.06	€ 0.06
UpCloud	€ 0.05	€ 0.05	€ 0.05	€ 0.05	€ 0.05	€ 0.05	€ 0.05	€ 0.05	€ 0.05
vCloud Air ²	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00

¹ Contact CloudWatt for data transfer – egress more than 10TB

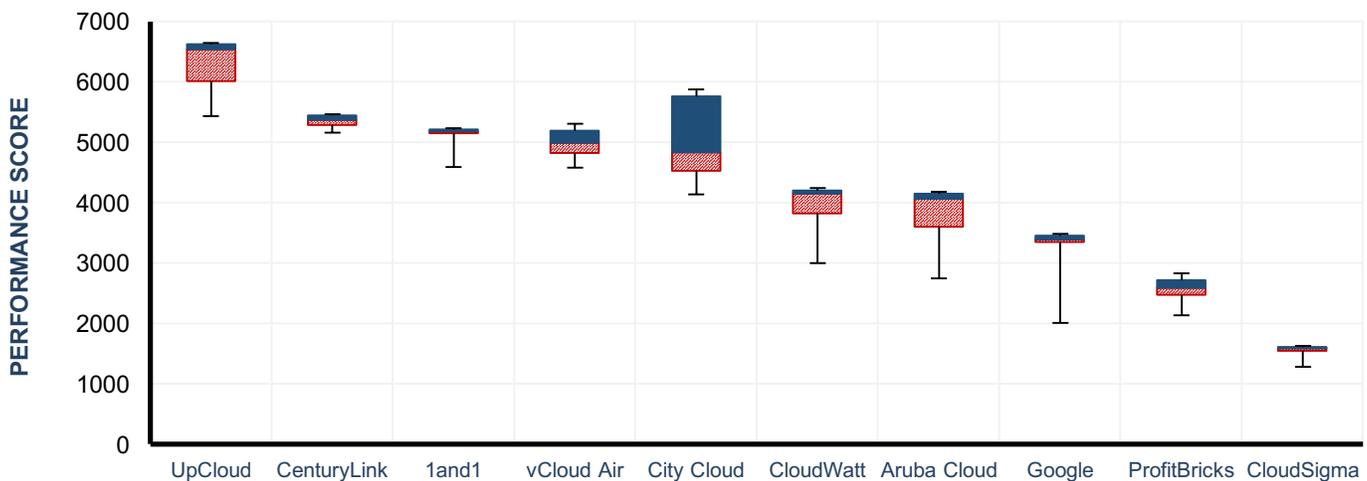
² vCloud Air On Demand is offering free data in/out as part of a limited time promotion (no indication of promotion end date)

PERFORMANCE BY VM SIZE

UNDERSTANDING THE CHARTS

VM performance is illustrated using percentile scores retrieved from all data points collected. 5th percentile and 95th percentile scores are often used instead of minimum and maximum scores in order to exclude potential outliers. Median scores are used instead of mean to avoid values being skewed by outliers. The information has been integrated into percentile graphs and value tables designed to visualize performance variation captured while testing over time. An example of the performance percentile graph along with a corresponding value table is displayed in Chart 8:

Chart 8: Sample Graph



-
- A diagram of a box plot with labels for its components. The box is divided into a red bottom half and a blue top half. Whiskers extend from the top and bottom of the box. A legend on the right explains each part:
- **Maximum (MAX):** The highest performance score(s) achieved on the VM over the course of the study.
 - **95TH Percentile (95TH):** 95% of all scores on the VM achieved this performance score or lower.
 - **Median (MED):** The number separating the higher and lower half of scores. If the median is closer to the 95TH percentile, then more high performance scores were observed than low performance scores (and vice versa).
 - **5TH Percentile (5TH):** 5% of all scores on the VM achieved this performance score or lower.
 - **Minimum (MIN):** The lowest performance score(s) achieved on the VM over the course of the study.

SMALL VMs

Chart 8A.1: vCPU & Memory Performance (Small VMs)

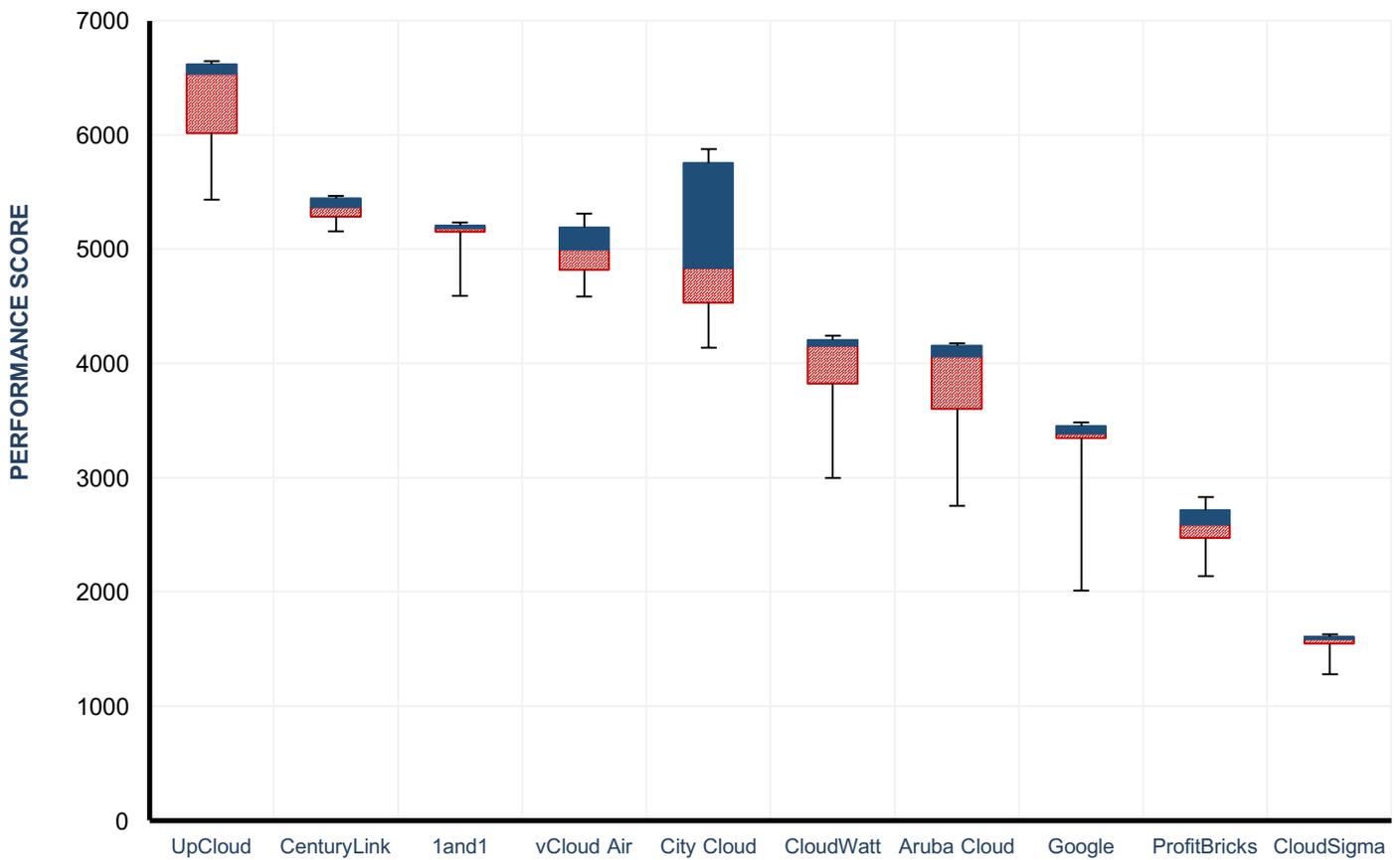


Table 8A.1: vCPU & Memory Performance (Small VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	4590	5149	5184	5209	5232	28	1%
Aruba Cloud	2752	3599	4059	4153	4179	187	5%
CenturyLink	5157	5282	5368	5442	5466	50	1%
City Cloud	4137	4529	4837	5756	5874	437	9%
CloudSigma	1284	1549	1585	1611	1631	26	2%
CloudWatt	3000	3821	4153	4204	4241	146	4%
Google	2014	3346	3388	3451	3484	80	2%
ProfitBricks	2140	2470	2588	2716	2832	86	3%
UpCloud	5436	6014	6535	6620	6647	205	3%
vCloud Air	4584	4818	4995	5192	5309	121	2%

Chart 8A.2: Sequential Block Disk Performance Type 1 (Small VMs)

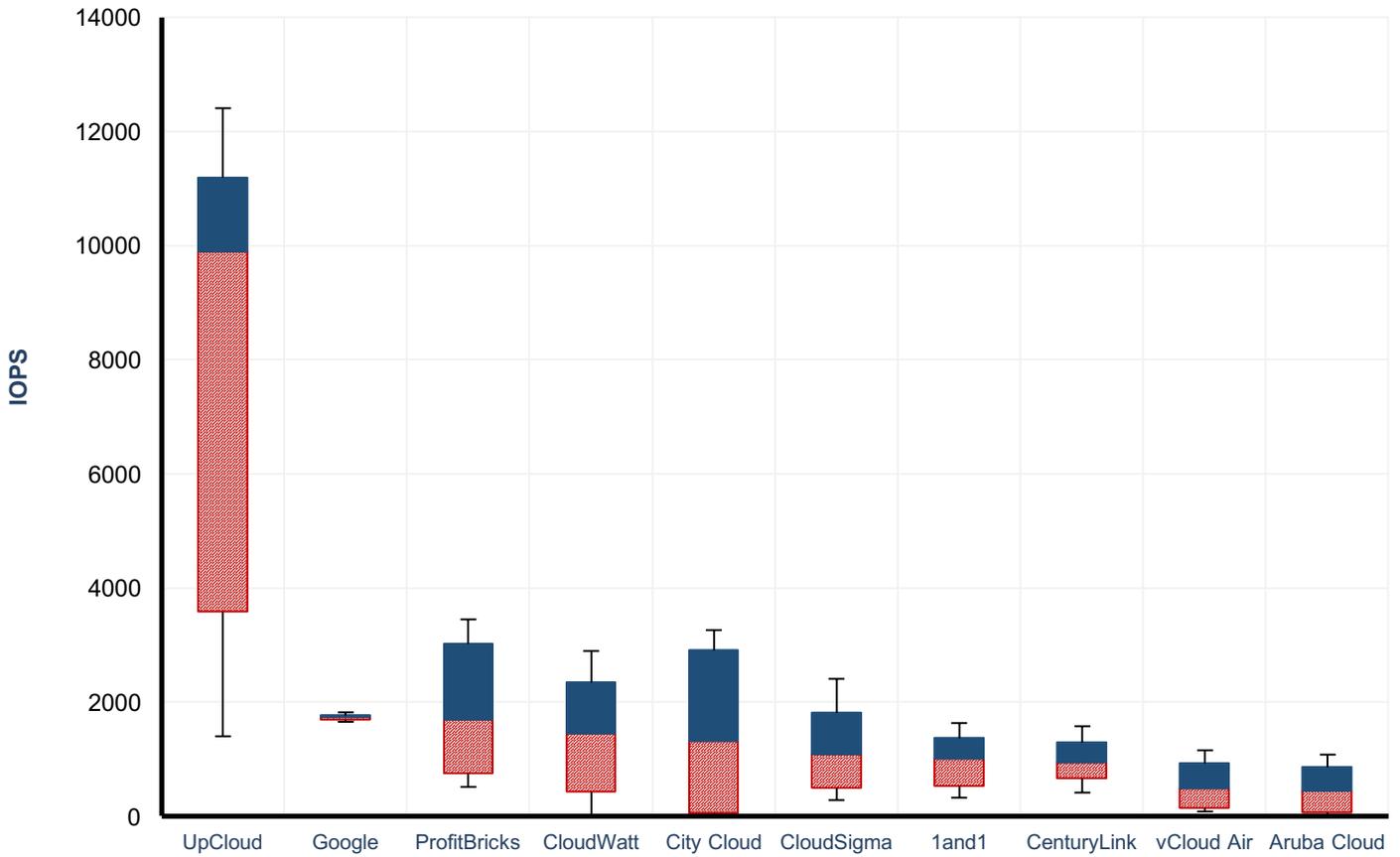


Table 8A.2: Sequential Block Disk Performance Type 1 (Small VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	333	529	1008	1374	1636	258	26%
Aruba Cloud	15	67	438	865	1084	239	53%
CenturyLink	422	664	939	1293	1580	189	20%
City Cloud	23	56	1316	2910	3265	934	68%
CloudSigma	284	494	1084	1812	2409	400	36%
CloudWatt	6	434	1444	2342	2898	569	40%
Google	1664	1690	1741	1773	1821	25	1%
ProfitBricks	521	748	1688	3019	3454	706	40%
UpCloud	1405	3583	9895	11192	12409	2573	30%
vCloud Air	93	146	482	930	1158	245	49%

Chart 8A.3: Random Block Disk Performance Type 1 (Small VMs)

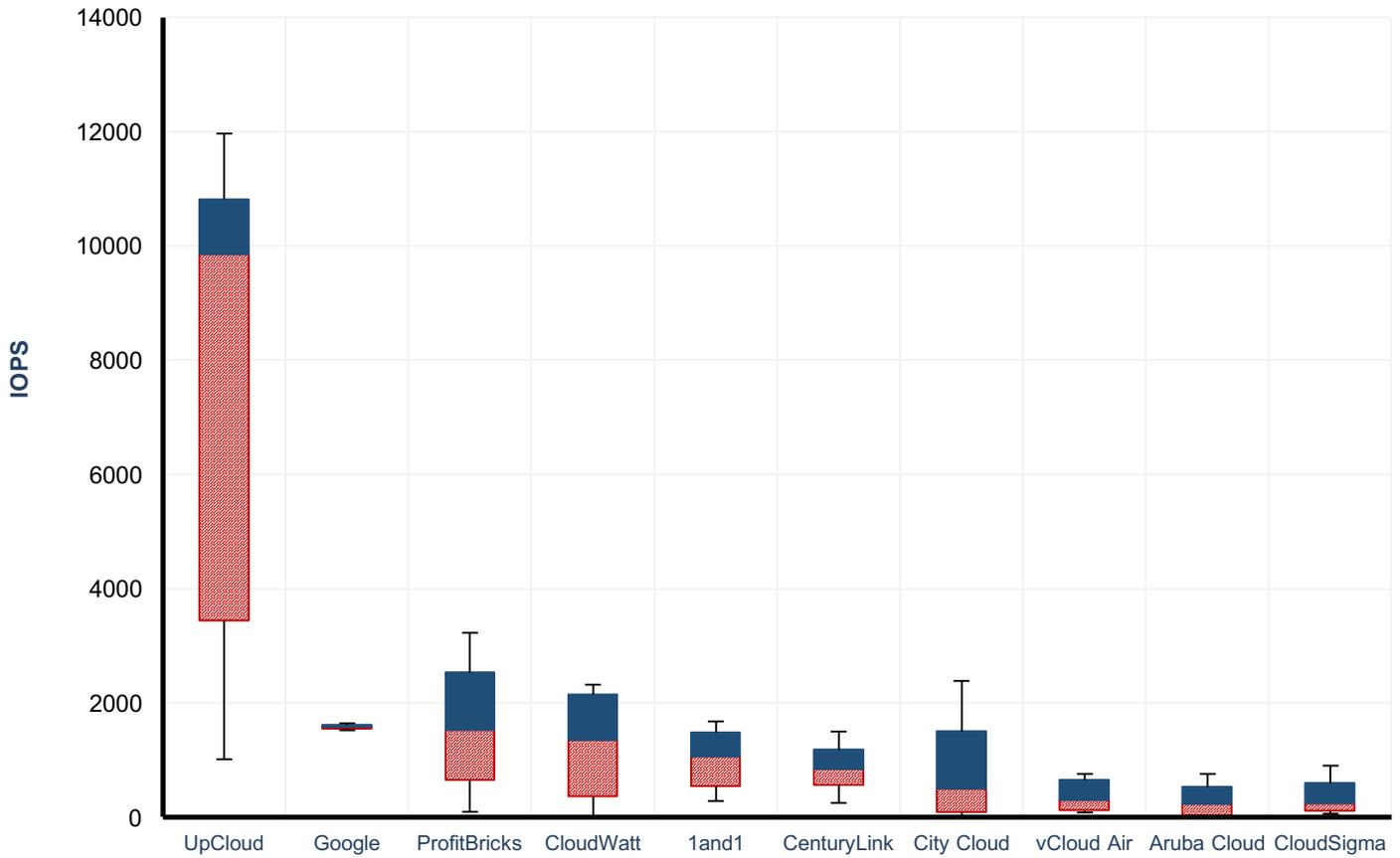


Table 8A.3: Random Block Disk Performance Type 1 (Small VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	290	543	1058	1480	1682	289	28%
Aruba Cloud	4	35	230	526	758	164	63%
CenturyLink	256	560	843	1183	1502	189	22%
City Cloud	19	91	495	1502	2391	454	75%
CloudSigma	70	105	238	597	908	158	57%
CloudWatt	9	359	1349	2152	2325	521	40%
Google	1526	1546	1586	1616	1649	22	1%
ProfitBricks	101	651	1528	2540	3233	565	37%
UpCloud	1018	3437	9855	10818	11972	2595	31%
vCloud Air	83	119	303	650	768	169	50%

Chart 8A.4: Sequential Block Disk Performance Type 2 (Small VMs)

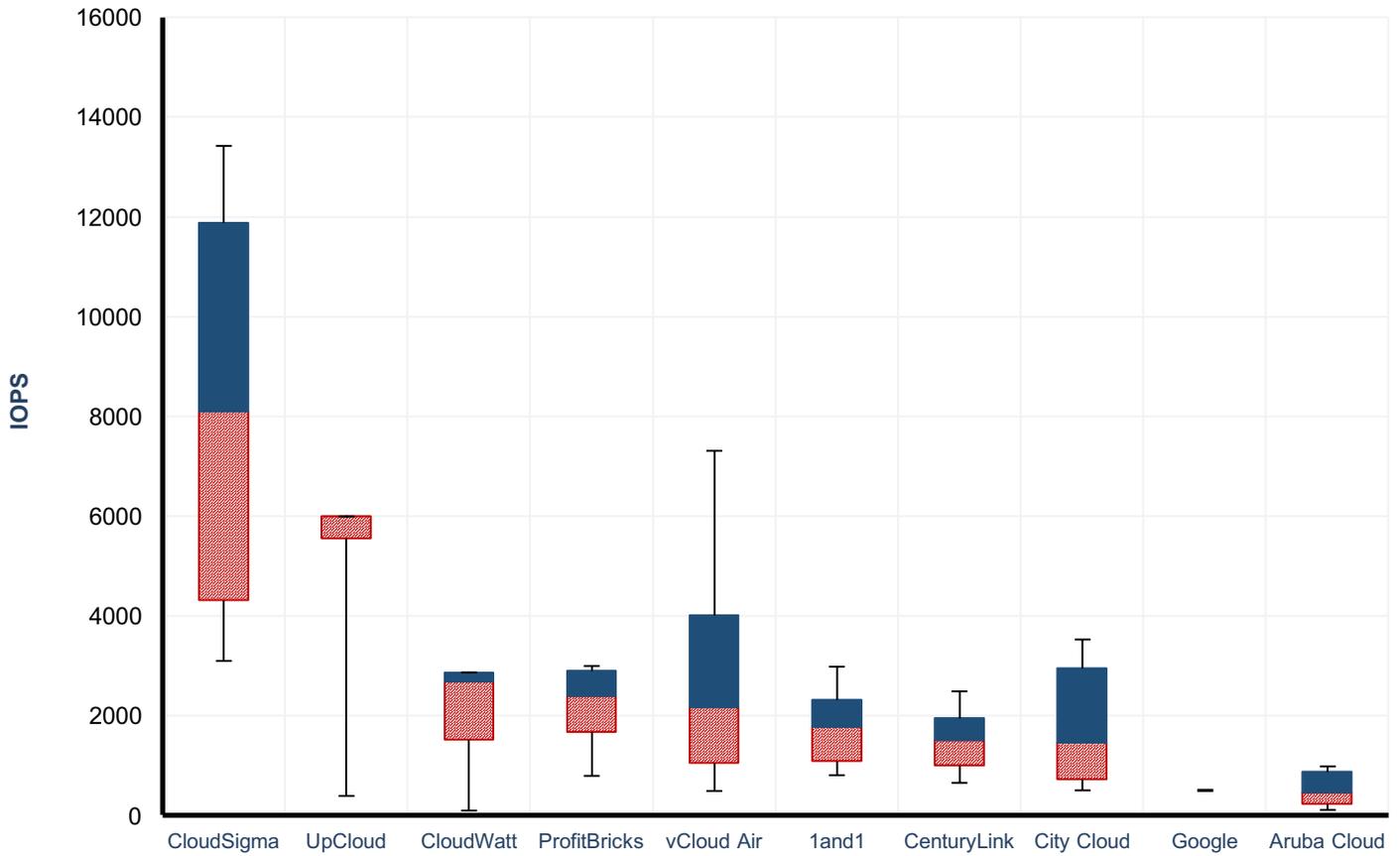


Table 8A.4: Sequential Block Disk Performance Type 2 (Small VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	806	1089	1769	2320	2989	394	23%
Aruba Cloud	108	227	460	870	981	204	41%
CenturyLink	656	998	1500	1944	2488	266	18%
City Cloud	505	714	1457	2953	3531	718	43%
CloudSigma	3104	4316	8098	11884	13424	2257	28%
CloudWatt	99	1513	2681	2860	2866	467	19%
Google	497	519	519	519	519	1	0%
ProfitBricks	797	1669	2386	2898	2997	378	16%
UpCloud	390	5552	6001	6001	6002	266	4%
vCloud Air	493	1046	2161	4009	7318	960	42%

Chart 8A.5: Random Block Disk Performance Type 2 (Small VMs)

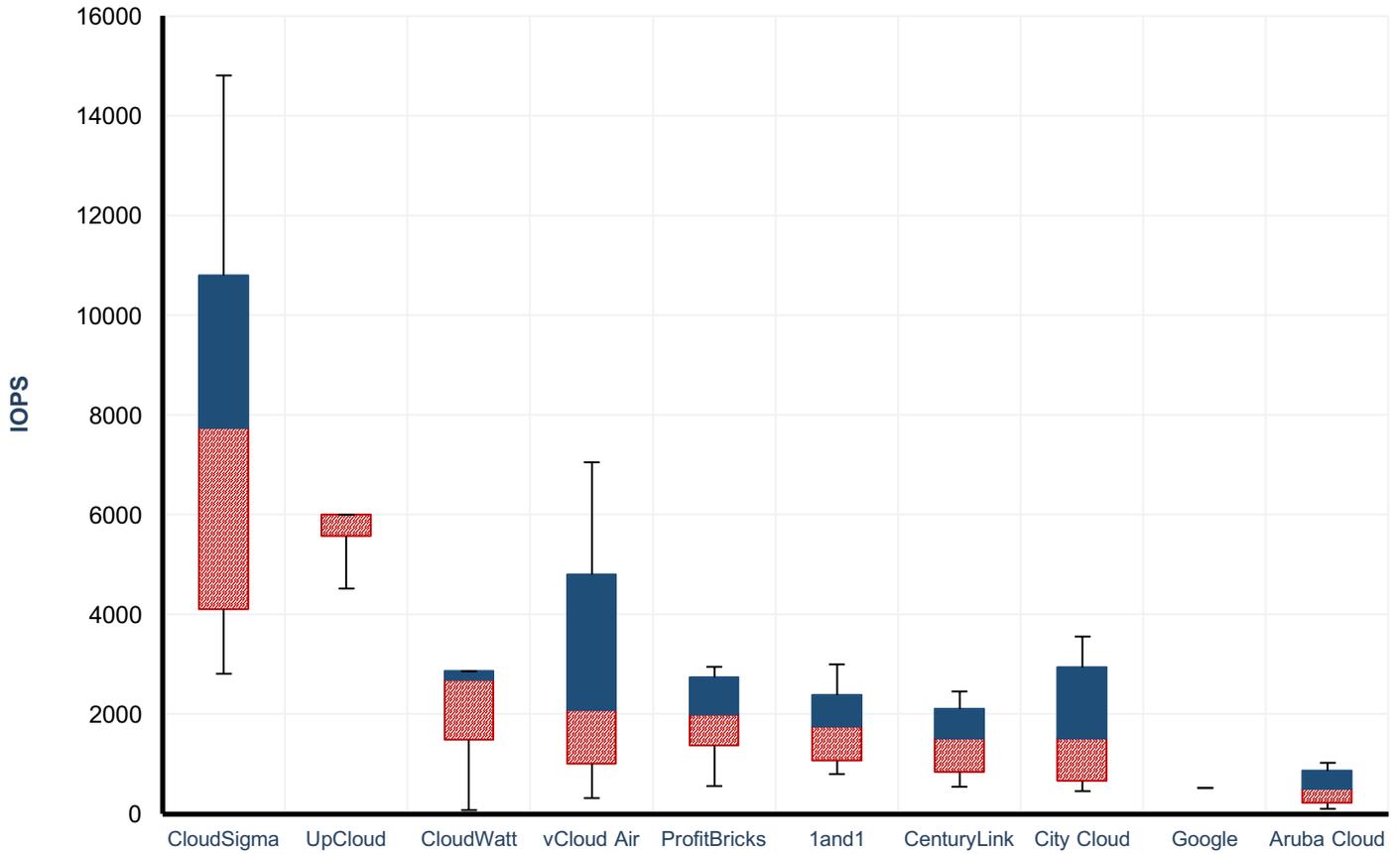


Table 8A.5: Random Block Disk Performance Type 2 (Small VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	805	1069	1746	2378	2999	408	24%
Aruba Cloud	105	223	499	864	1024	206	40%
CenturyLink	553	836	1506	2112	2464	348	23%
City Cloud	459	663	1509	2937	3565	726	43%
CloudSigma	2813	4107	7740	10793	14814	2057	27%
CloudWatt	86	1491	2683	2860	2866	465	19%
Google	518	518	518	518	518	0	0%
ProfitBricks	562	1371	1986	2735	2958	423	21%
UpCloud	4523	5575	6001	6001	6002	184	3%
vCloud Air	319	1008	2075	4796	7050	1153	49%

MEDIUM VMs

Chart 8B.1: vCPU & Memory Performance (Medium VMs)

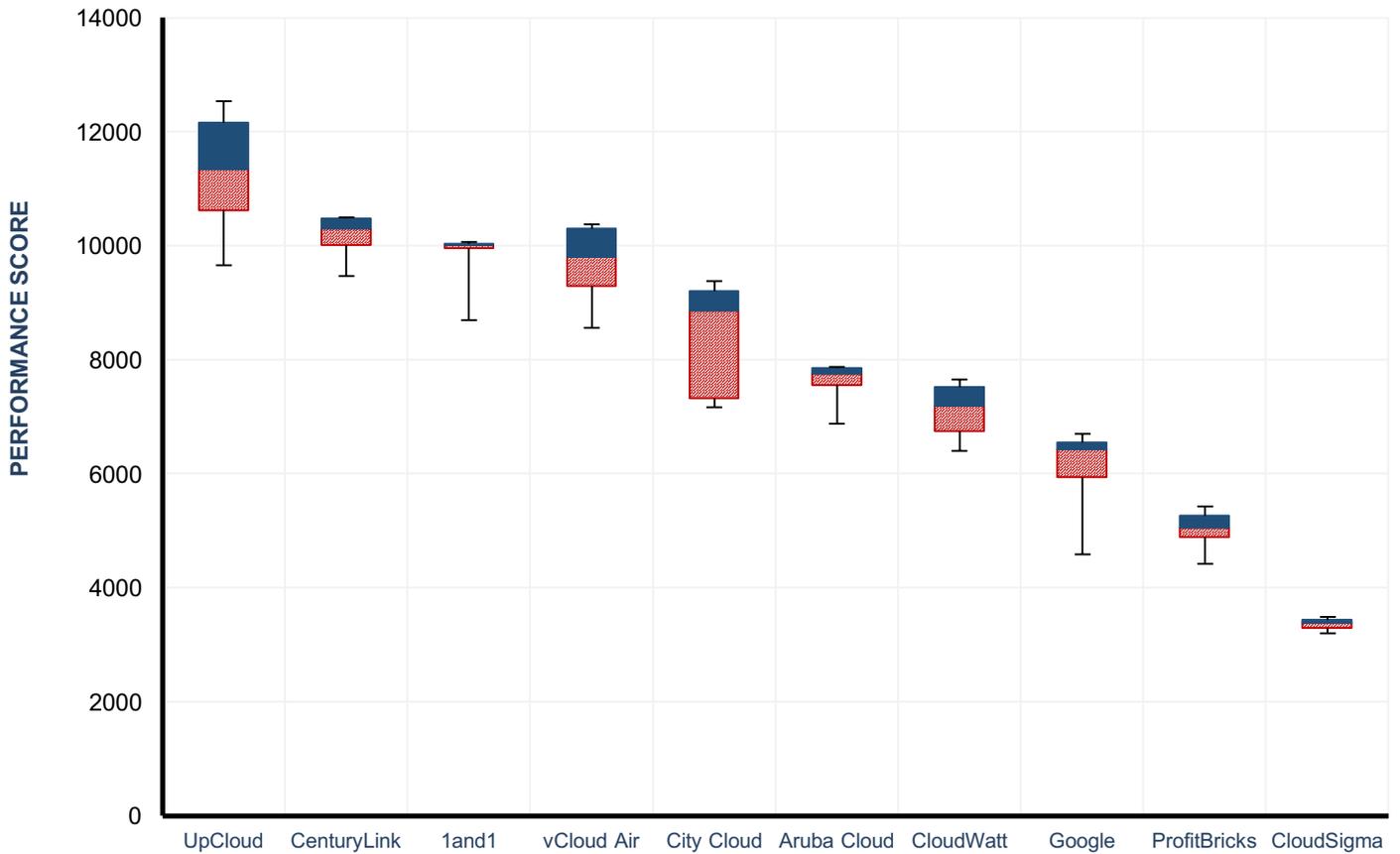


Table 8B.1: vCPU & Memory Performance (Medium VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	8695	9957	10008	10031	10070	55	1%
Aruba Cloud	6873	7551	7753	7852	7877	106	1%
CenturyLink	9466	10009	10298	10473	10502	157	2%
City Cloud	7168	7325	8865	9199	9380	754	9%
CloudSigma	3198	3295	3375	3430	3495	42	1%
CloudWatt	6407	6746	7188	7523	7656	233	3%
Google	4591	5936	6422	6547	6699	253	4%
ProfitBricks	4420	4885	5050	5260	5429	117	2%
UpCloud	9658	10622	11336	12155	12540	434	4%
vCloud Air	8561	9290	9801	10295	10378	326	3%

Chart 8B.2: Sequential Block Disk Performance Type 1 (Medium VMs)

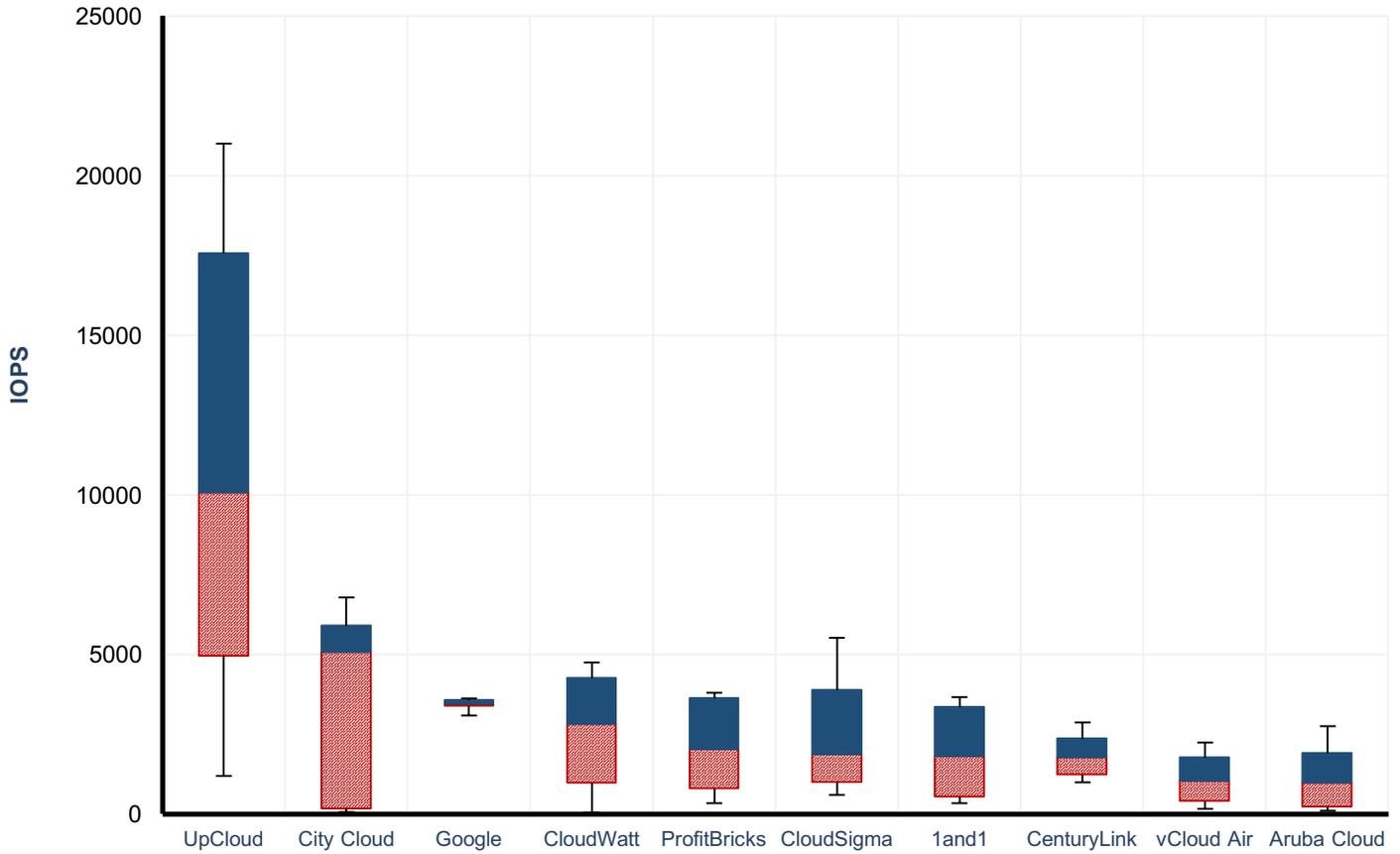


Table 8B.2: Sequential Block Disk Performance Type 1 (Medium VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	352	546	1804	3348	3663	848	46%
Aruba Cloud	100	230	972	1896	2764	502	50%
CenturyLink	1006	1228	1768	2352	2869	361	20%
City Cloud	70	175	5074	5893	6790	1974	49%
CloudSigma	604	990	1859	3883	5531	888	43%
CloudWatt	47	976	2823	4256	4759	999	37%
Google	3092	3392	3455	3564	3618	58	2%
ProfitBricks	336	798	2020	3634	3798	893	42%
UpCloud	1192	4950	10079	17569	21008	3661	35%
vCloud Air	167	403	1031	1766	2238	426	41%

Chart 8B.3: Random Block Disk Performance Type 1 (Medium VMs)

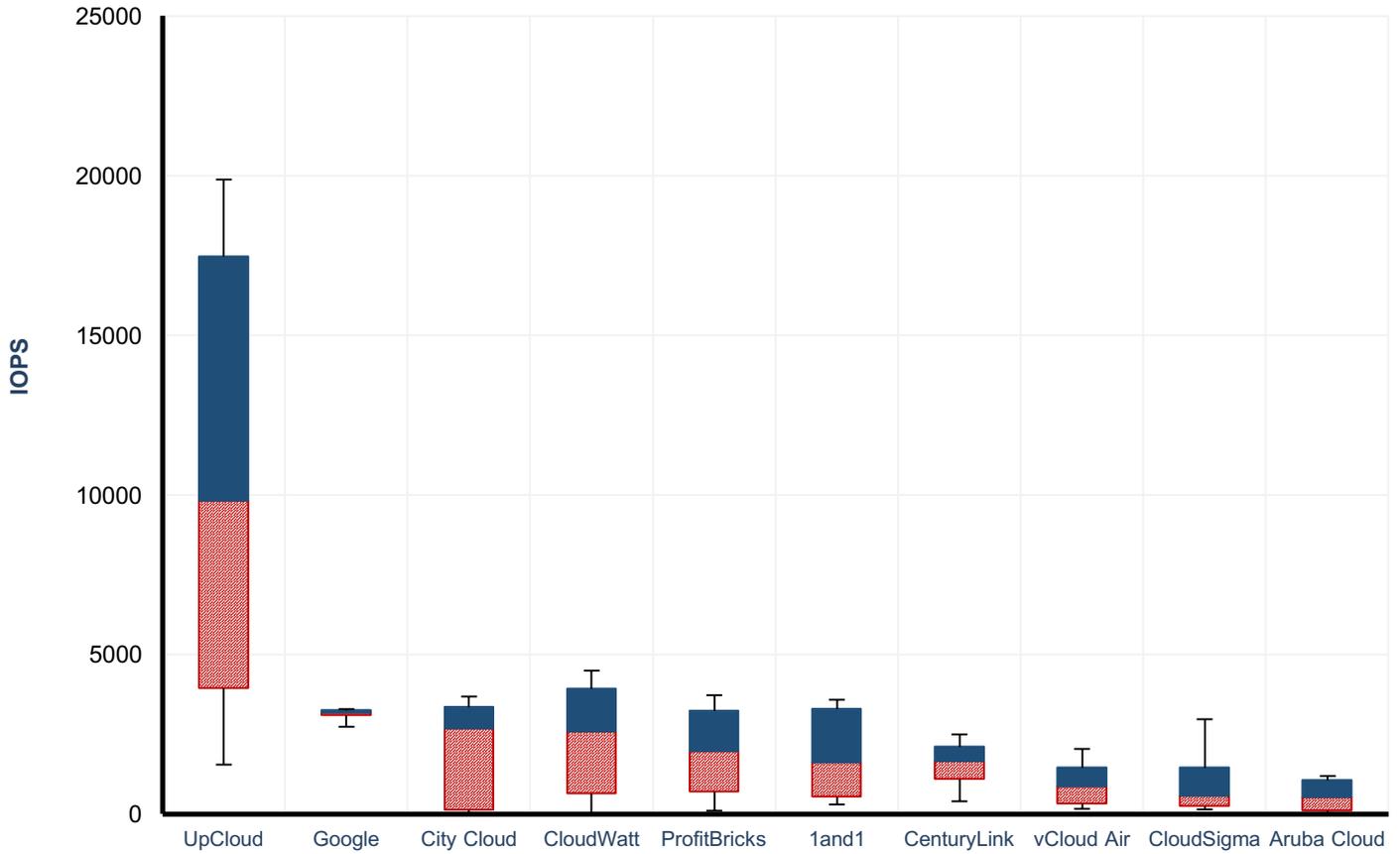


Table 8B.3: Random Block Disk Performance Type 1 (Medium VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	308	551	1600	3290	3587	840	48%
Aruba Cloud	19	109	519	1051	1193	290	53%
CenturyLink	397	1097	1650	2103	2504	322	20%
City Cloud	24	133	2685	3341	3688	1218	63%
CloudSigma	139	238	552	1452	2966	410	64%
CloudWatt	7	635	2579	3914	4496	1035	42%
Google	2734	3099	3162	3249	3299	51	2%
ProfitBricks	101	698	1964	3222	3724	743	37%
UpCloud	1554	3936	9807	17463	19886	3649	37%
vCloud Air	176	330	857	1451	2049	360	42%

Chart 8B.4: Sequential Block Disk Performance Type 2 (Medium VMs)

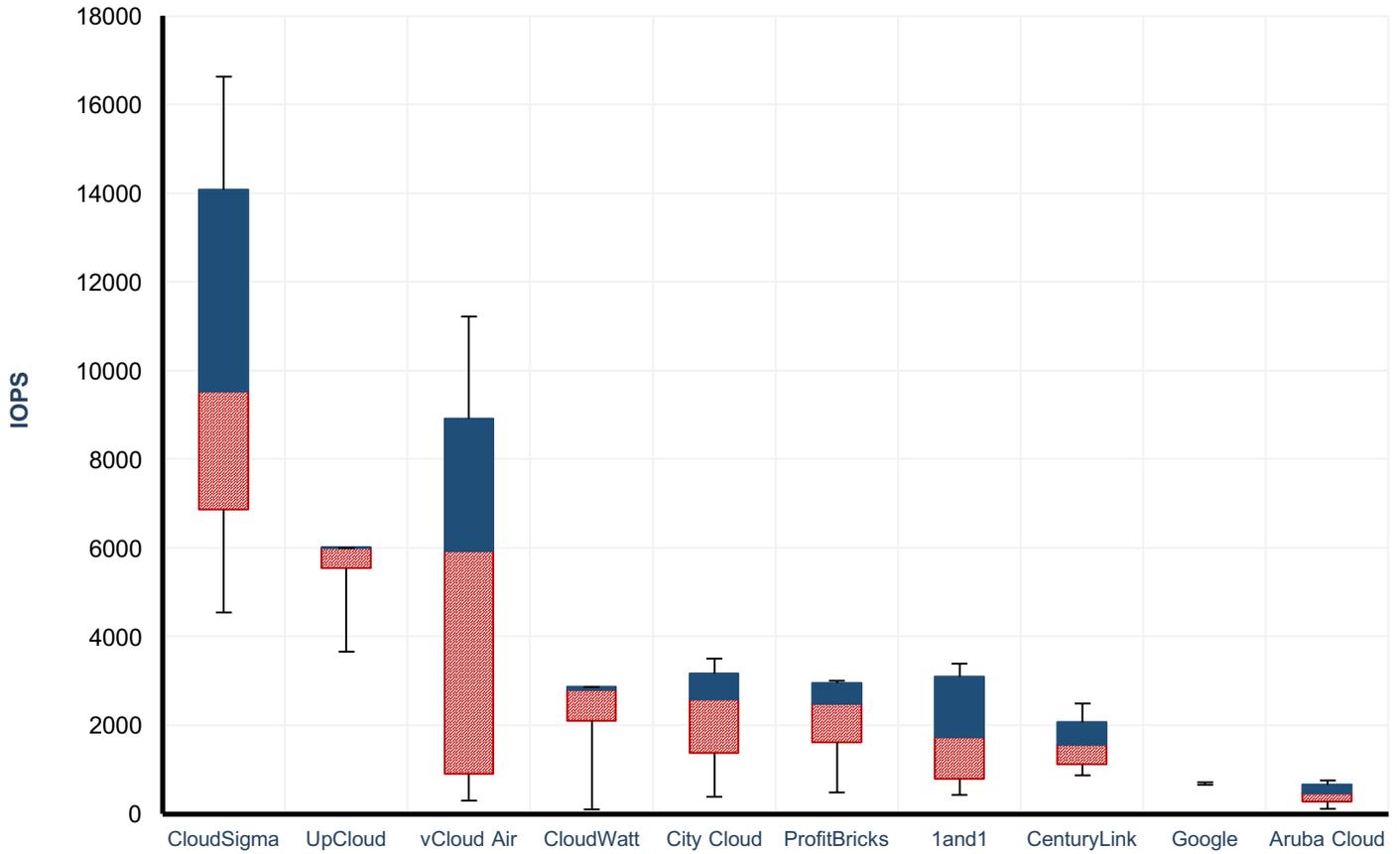


Table 8B.4: Sequential Block Disk Performance Type 2 (Medium VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	437	782	1727	3093	3393	660	37%
Aruba Cloud	118	274	463	657	754	115	25%
CenturyLink	872	1114	1562	2075	2490	298	19%
City Cloud	392	1377	2582	3166	3511	513	21%
CloudSigma	4548	6860	9530	14084	16635	2218	23%
CloudWatt	101	2104	2794	2864	2866	340	13%
Google	664	711	711	711	711	2	0%
ProfitBricks	487	1613	2481	2950	3008	415	17%
UpCloud	3665	5547	6001	6003	6003	217	4%
vCloud Air	300	896	5927	8913	11218	2340	42%

Chart 8B.5: Random Block Disk Performance Type 2 (Medium VMs)

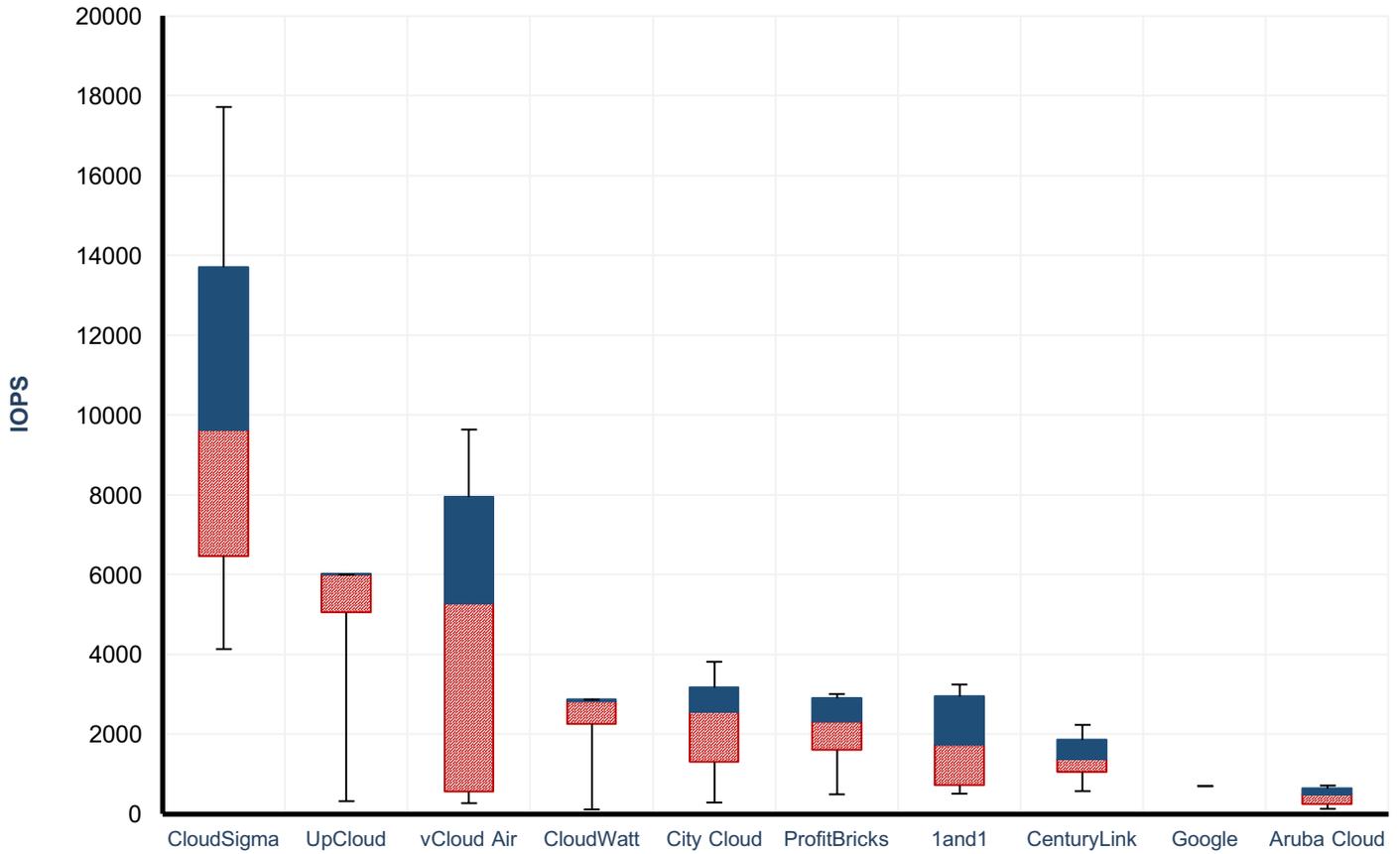


Table 8B.5: Random Block Disk Performance Type 2 (Medium VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	516	712	1736	2943	3248	653	37%
Aruba Cloud	138	244	481	643	723	120	26%
CenturyLink	572	1044	1362	1850	2237	247	18%
City Cloud	298	1309	2560	3164	3816	546	22%
CloudSigma	4139	6461	9621	13702	17727	2174	22%
CloudWatt	120	2248	2817	2864	2866	324	12%
Google	709	709	709	709	709	0	0%
ProfitBricks	503	1604	2311	2897	3008	420	18%
UpCloud	317	5054	6000	6003	6004	374	6%
vCloud Air	268	558	5268	7948	9638	2213	45%

LARGE VMs

Chart 8C.1: vCPU & Memory Performance (Large VMs)

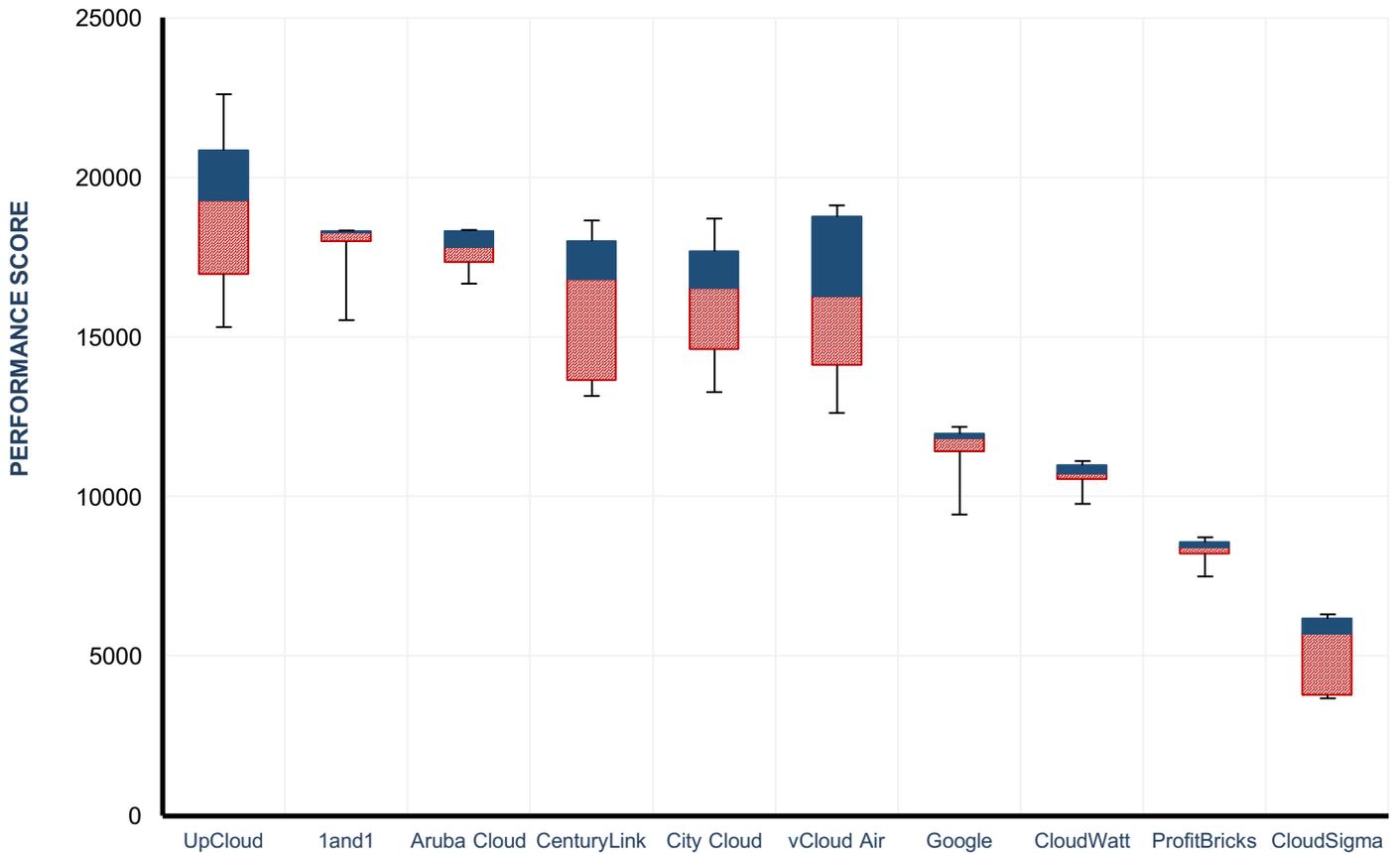


Table 8C.1: vCPU & Memory Performance (Large VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	15534	17999	18269	18307	18338	137	1%
Aruba Cloud	16671	17337	17811	18315	18362	346	2%
CenturyLink	13146	13657	16807	18007	18648	1422	9%
City Cloud	13281	14617	16537	17689	18701	944	6%
CloudSigma	3676	3789	5700	6176	6307	950	18%
CloudWatt	9779	10546	10727	10982	11124	149	1%
Google	9437	11422	11830	11976	12182	216	2%
ProfitBricks	7508	8205	8402	8571	8715	127	2%
UpCloud	15314	16961	19273	20839	22603	1092	6%
vCloud Air	12613	14123	16280	18773	19121	1511	9%

Chart 8C.2: Sequential Block Disk Performance Type 1 (Large VMs)

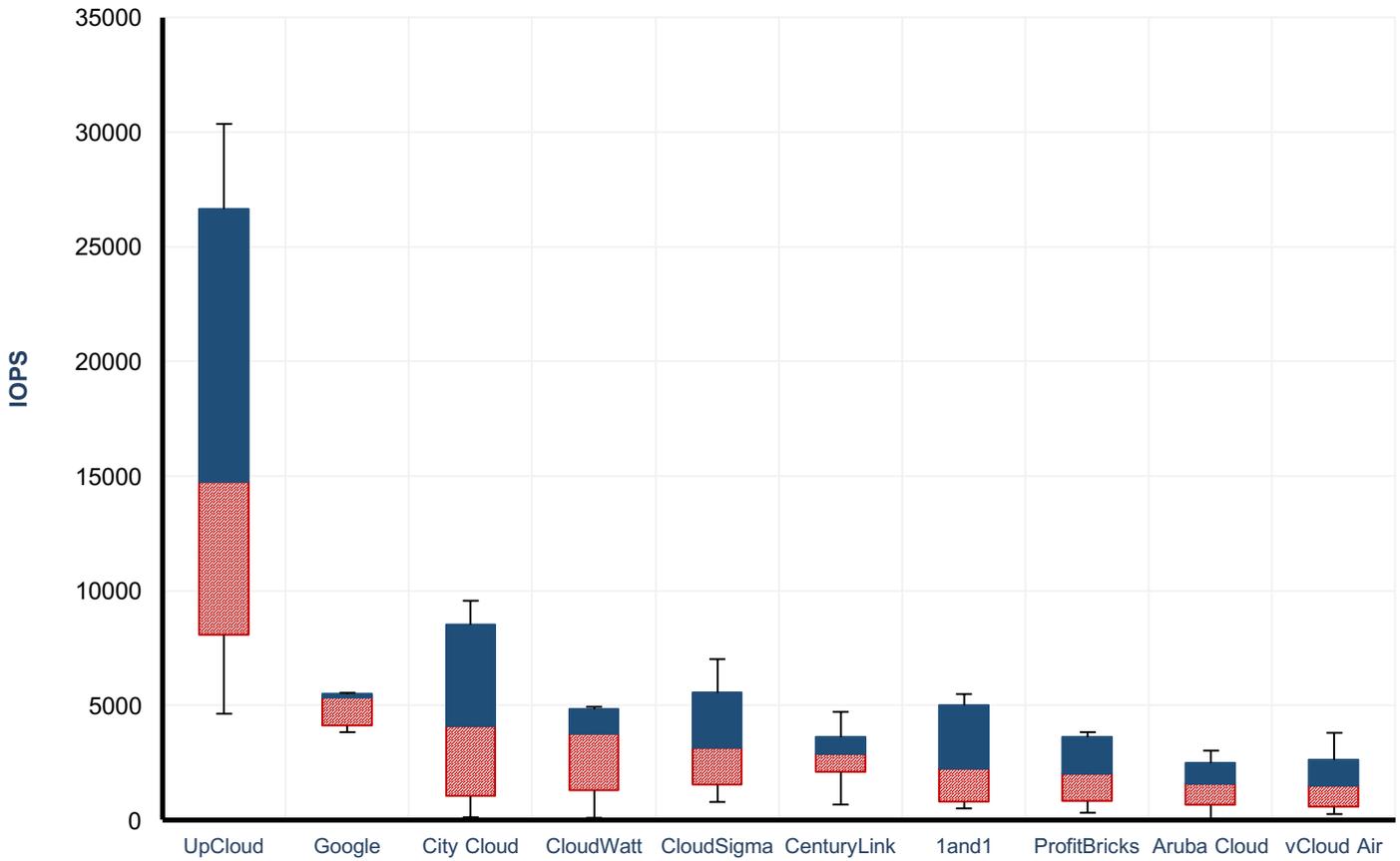


Table 8C.2: Sequential Block Disk Performance Type 1 (Large VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	527	808	2236	5016	5500	1272	50%
Aruba Cloud	66	673	1581	2485	3038	545	34%
CenturyLink	680	2092	2875	3614	4741	481	17%
City Cloud	147	1042	4089	8516	9567	2540	59%
CloudSigma	798	1555	3160	5568	7023	1225	37%
CloudWatt	98	1295	3756	4848	4943	1153	33%
Google	3852	4110	5329	5517	5571	345	7%
ProfitBricks	329	836	2024	3630	3845	863	41%
UpCloud	4638	8081	14750	26642	30370	5032	33%
vCloud Air	273	579	1497	2623	3825	656	42%

Chart 8C.3: Random Block Disk Performance Type 1 (Large VMs)

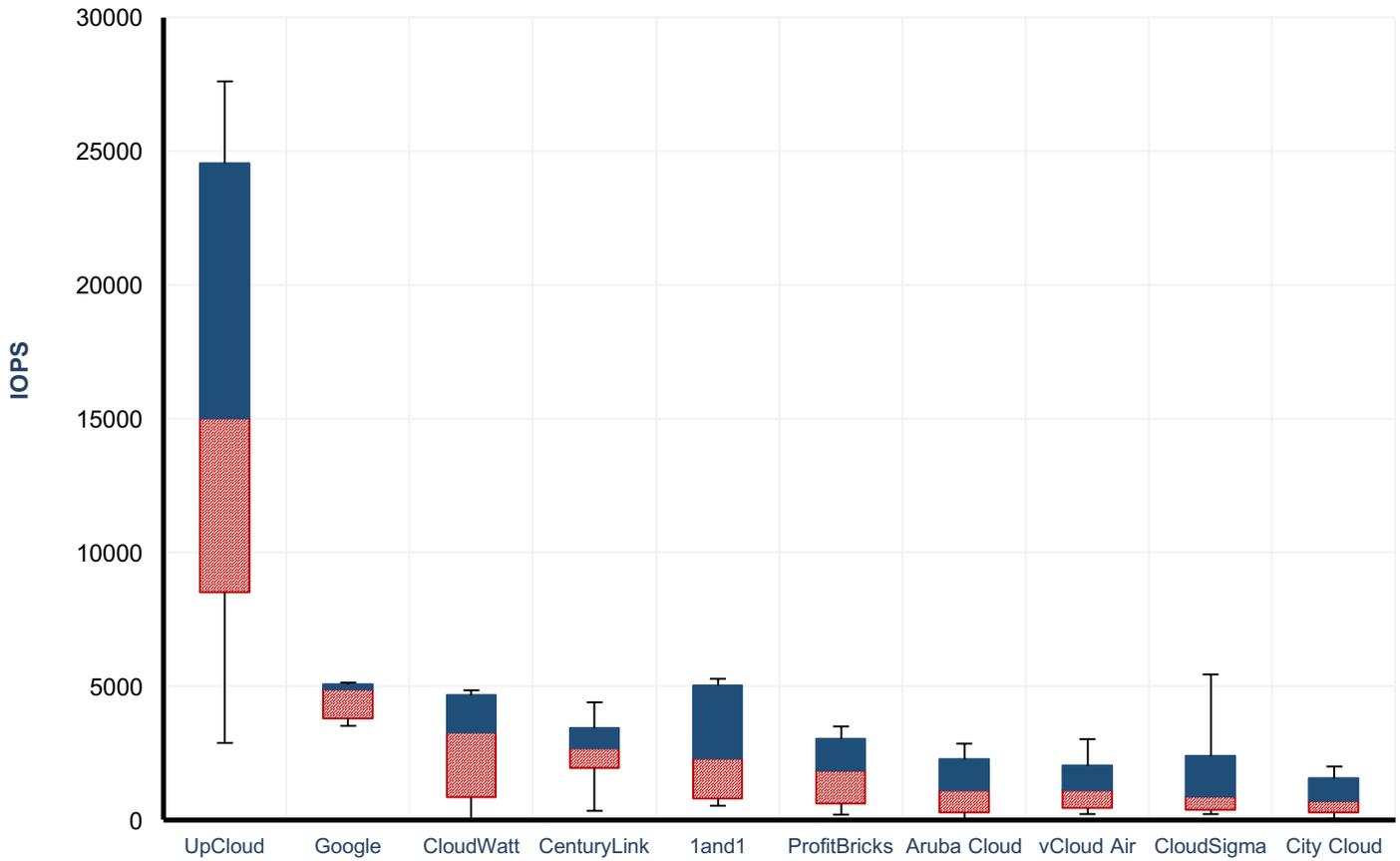


Table 8C.3: Random Block Disk Performance Type 1 (Large VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	540	793	2289	5023	5293	1272	50%
Aruba Cloud	25	274	1102	2284	2864	606	52%
CenturyLink	360	1950	2673	3443	4405	514	19%
City Cloud	71	292	713	1567	2020	381	49%
CloudSigma	231	368	866	2386	5449	694	67%
CloudWatt	12	855	3269	4682	4861	1228	40%
Google	3541	3794	4876	5064	5155	315	7%
ProfitBricks	208	620	1860	3044	3511	733	39%
UpCloud	2884	8509	15018	24544	27602	4420	29%
vCloud Air	238	452	1118	2046	3046	512	44%

Chart 8C.4: Sequential Block Disk Performance Type 2 (Large VMs)

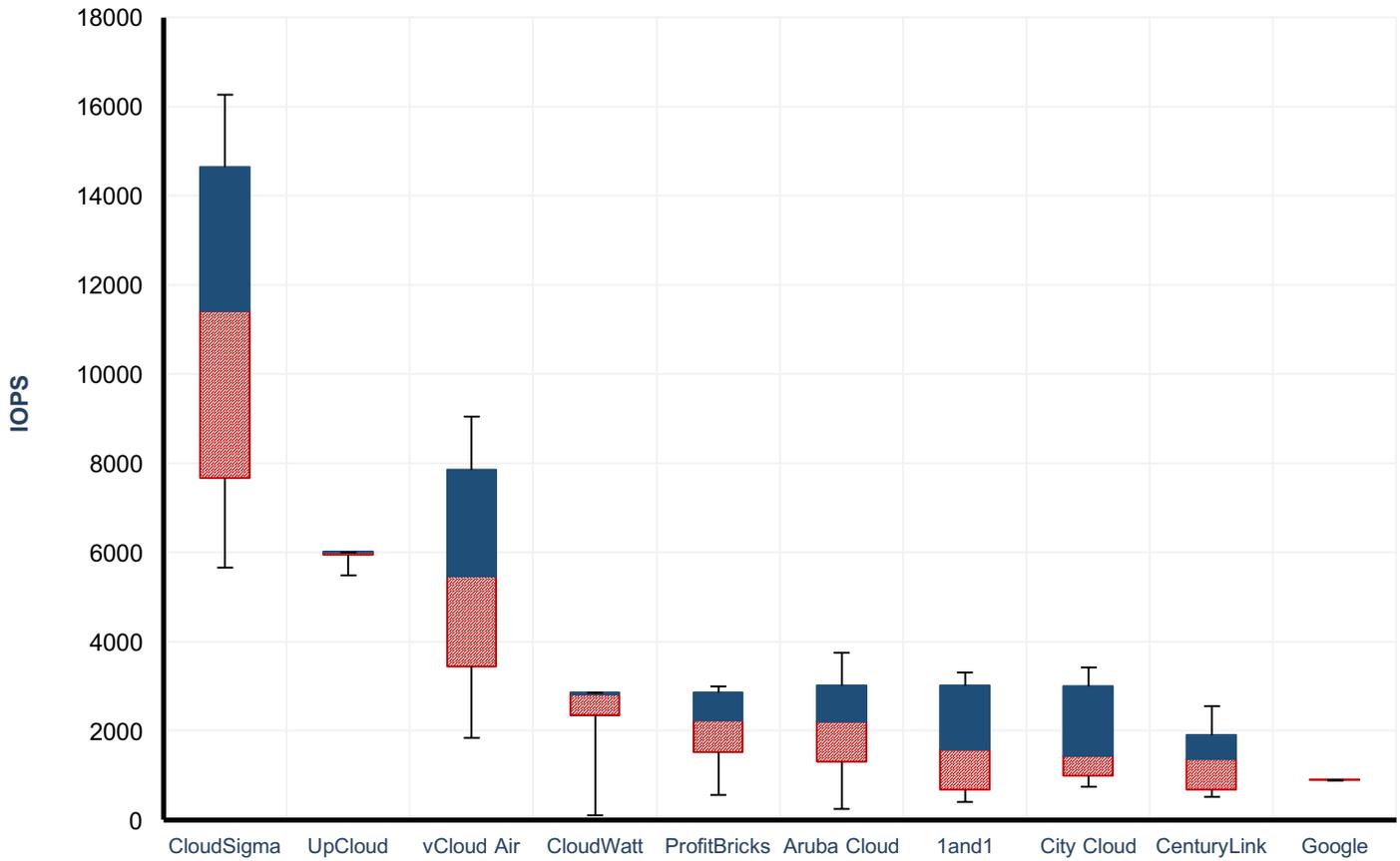


Table 8C.4: Sequential Block Disk Performance Type 2 (Large VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	414	678	1582	3016	3309	691	41%
Aruba Cloud	248	1309	2207	3023	3758	555	25%
CenturyLink	523	685	1362	1912	2557	386	29%
City Cloud	759	999	1441	3006	3432	673	39%
CloudSigma	5660	7673	11416	14654	16264	2141	19%
CloudWatt	108	2353	2813	2865	2866	315	12%
Google	902	902	903	903	903	0	0%
ProfitBricks	564	1527	2233	2866	3006	423	19%
UpCloud	5487	5950	6001	6003	6005	49	1%
vCloud Air	1846	3445	5471	7850	9053	1351	24%

Chart 8C.5: Random Block Disk Performance Type 2 (Large VMs)

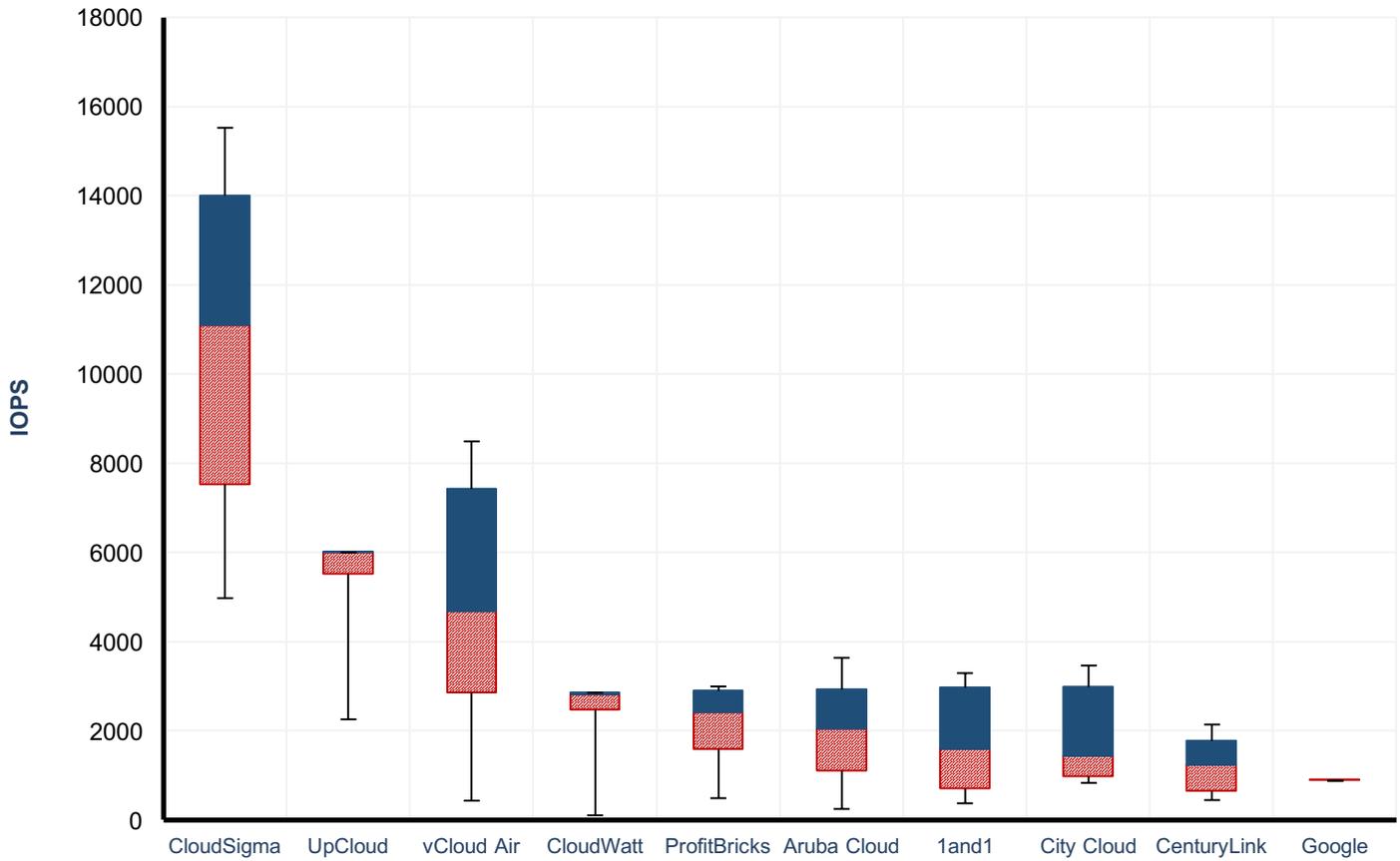


Table 8C.5: Random Block Disk Performance Type 2 (Large VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	386	709	1587	2977	3304	665	40%
Aruba Cloud	257	1105	2043	2924	3639	566	28%
CenturyLink	448	654	1234	1782	2142	338	28%
City Cloud	840	983	1432	2994	3468	674	40%
CloudSigma	4986	7522	11104	14012	15527	1998	18%
CloudWatt	118	2474	2823	2865	2866	319	12%
Google	883	895	901	901	902	2	0%
ProfitBricks	496	1593	2424	2908	3003	407	17%
UpCloud	2258	5525	6001	6003	6005	241	4%
vCloud Air	444	2867	4686	7433	8490	1352	28%

EXTRA LARGE VMs

Chart 8D.1: vCPU & Memory Performance (XLarge VMs)

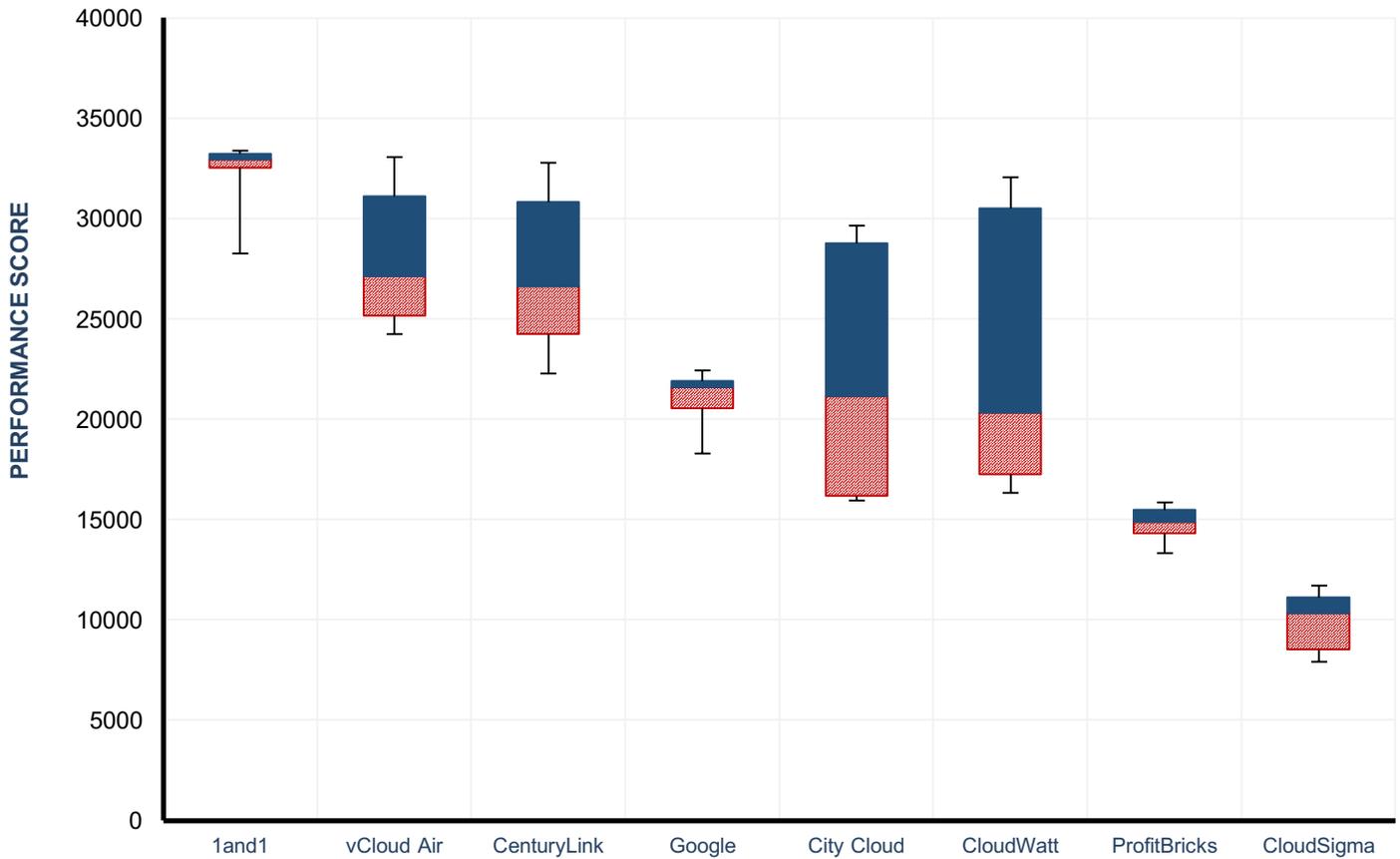


Table 8D.1: vCPU & Memory Performance (Extra Large VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	28269	32532	32931	33232	33380	275	1%
CenturyLink	22286	24225	26603	30825	32765	2048	8%
City Cloud	15956	16167	21137	28760	29648	4629	21%
CloudSigma	7927	8508	10316	11121	11700	783	8%
CloudWatt	16329	17235	20328	30499	32047	5189	23%
Google	18296	20538	21594	21901	22448	477	2%
ProfitBricks	13319	14309	14885	15463	15867	358	2%
vCloud Air	24251	25169	27133	31098	33073	1792	6%

Chart 8D.2: Sequential Block Disk Performance Type 1 (Xlarge VMs)

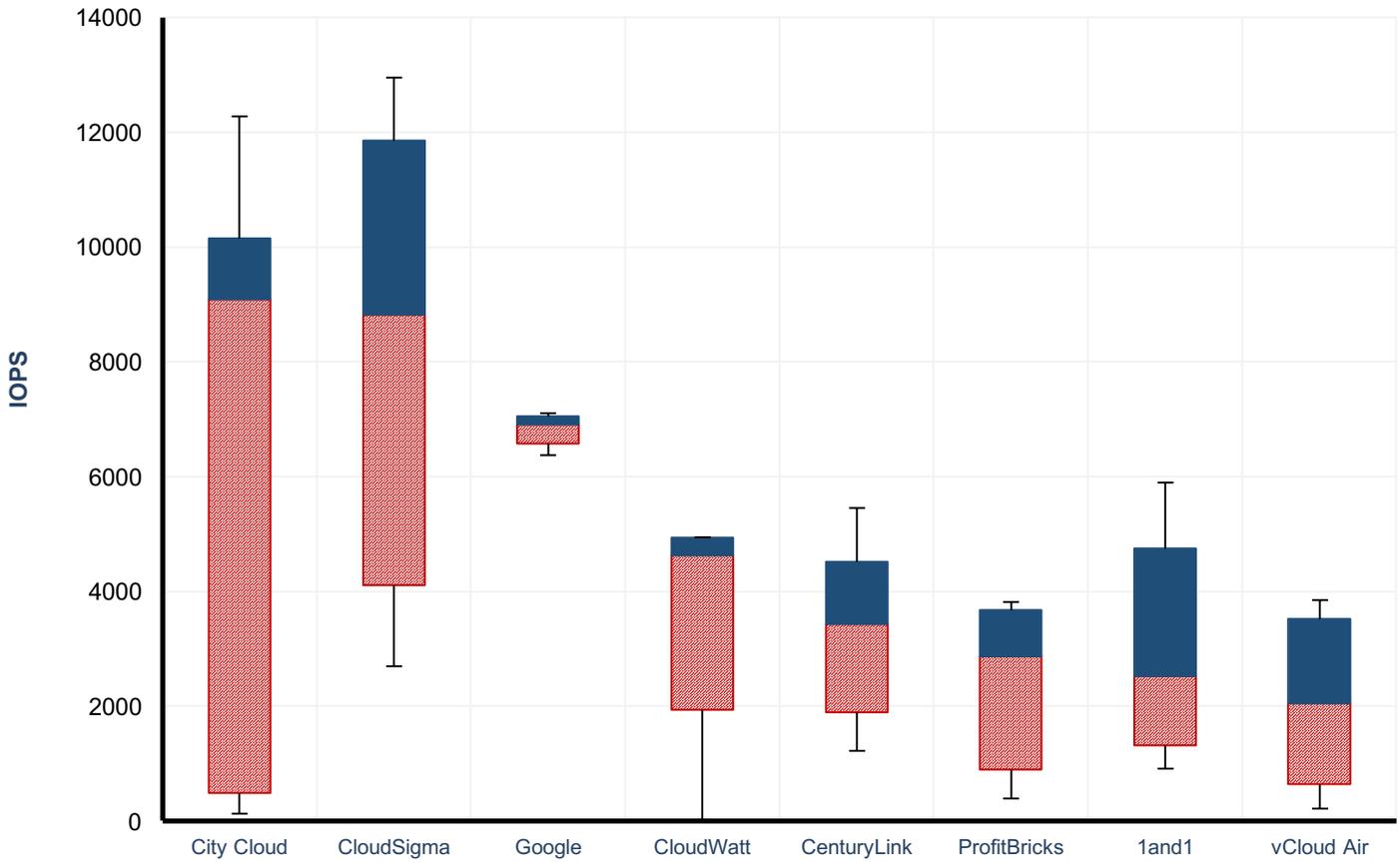


Table 8D.2: Sequential Block Disk Performance Type 1 (Extra Large VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	919	1321	2520	4748	5902	1076	40%
CenturyLink	1223	1897	3433	4514	5458	786	24%
City Cloud	129	484	9092	10157	12275	3280	45%
CloudSigma	2700	4101	8819	11852	12955	2487	30%
CloudWatt	23	1938	4628	4932	4951	1055	26%
Google	6379	6578	6908	7055	7112	148	2%
ProfitBricks	397	892	2866	3676	3817	980	38%
vCloud Air	220	637	2048	3523	3849	880	42%

Chart 8D.3: Random Block Disk Performance Type 1 (Xlarge VMs)

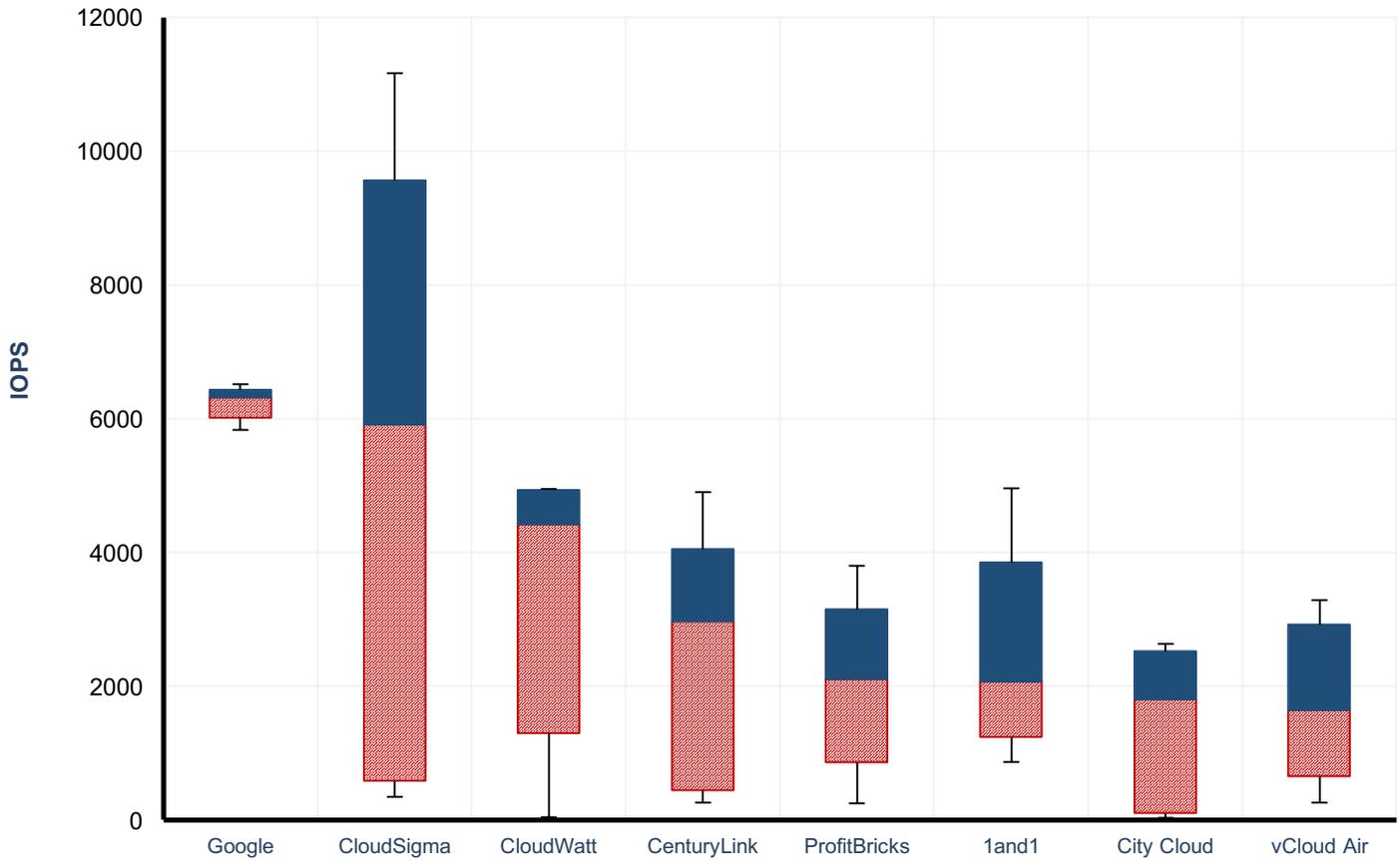


Table 8D.3: Random Block Disk Performance Type 1 (Extra Large VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	869	1241	2064	3853	4963	826	37%
CenturyLink	267	450	2967	4053	4902	1389	59%
City Cloud	39	101	1806	2519	2642	868	59%
CloudSigma	349	590	5911	9561	11171	3259	63%
CloudWatt	50	1301	4422	4932	4950	1213	31%
Google	5834	6012	6316	6437	6522	133	2%
ProfitBricks	254	867	2105	3146	3800	692	34%
vCloud Air	261	650	1637	2924	3293	649	39%

Chart 8D.4: Sequential Block Disk Performance Type 2 (Xlarge VMs)

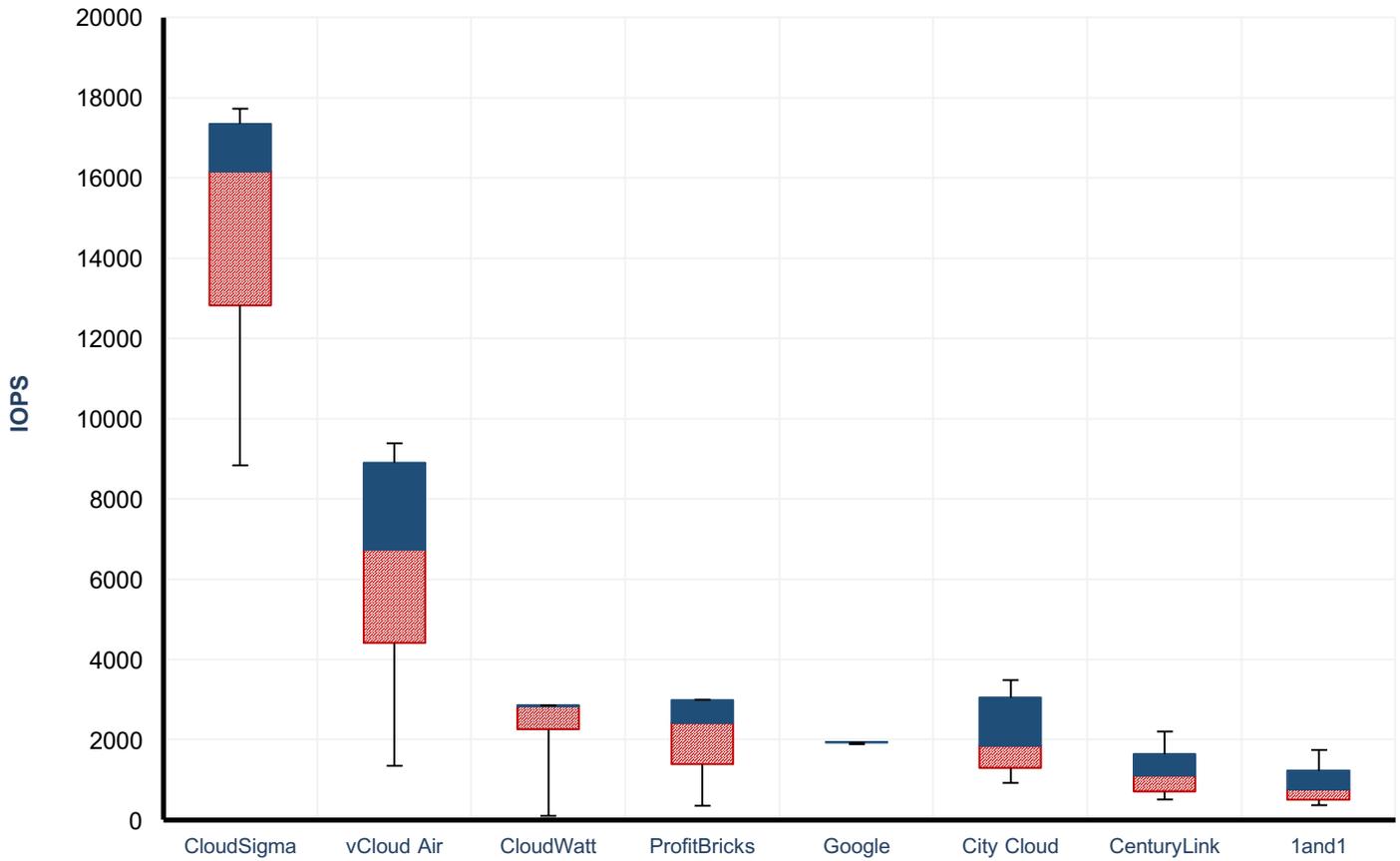


Table 8D.4: Sequential Block Disk Performance Type 2 (Extra Large VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	381	510	763	1227	1761	220	28%
CenturyLink	522	706	1113	1646	2211	300	27%
City Cloud	936	1297	1856	3050	3495	645	31%
CloudSigma	8841	12825	16160	17347	17729	1509	10%
CloudWatt	111	2260	2835	2864	2867	316	12%
Google	1898	1921	1921	1922	1922	2	0%
ProfitBricks	365	1398	2414	2994	3006	538	23%
vCloud Air	1363	4409	6736	8909	9393	1506	22%

Chart 8D.5: Random Block Disk Performance Type 2 (Xlarge VMs)

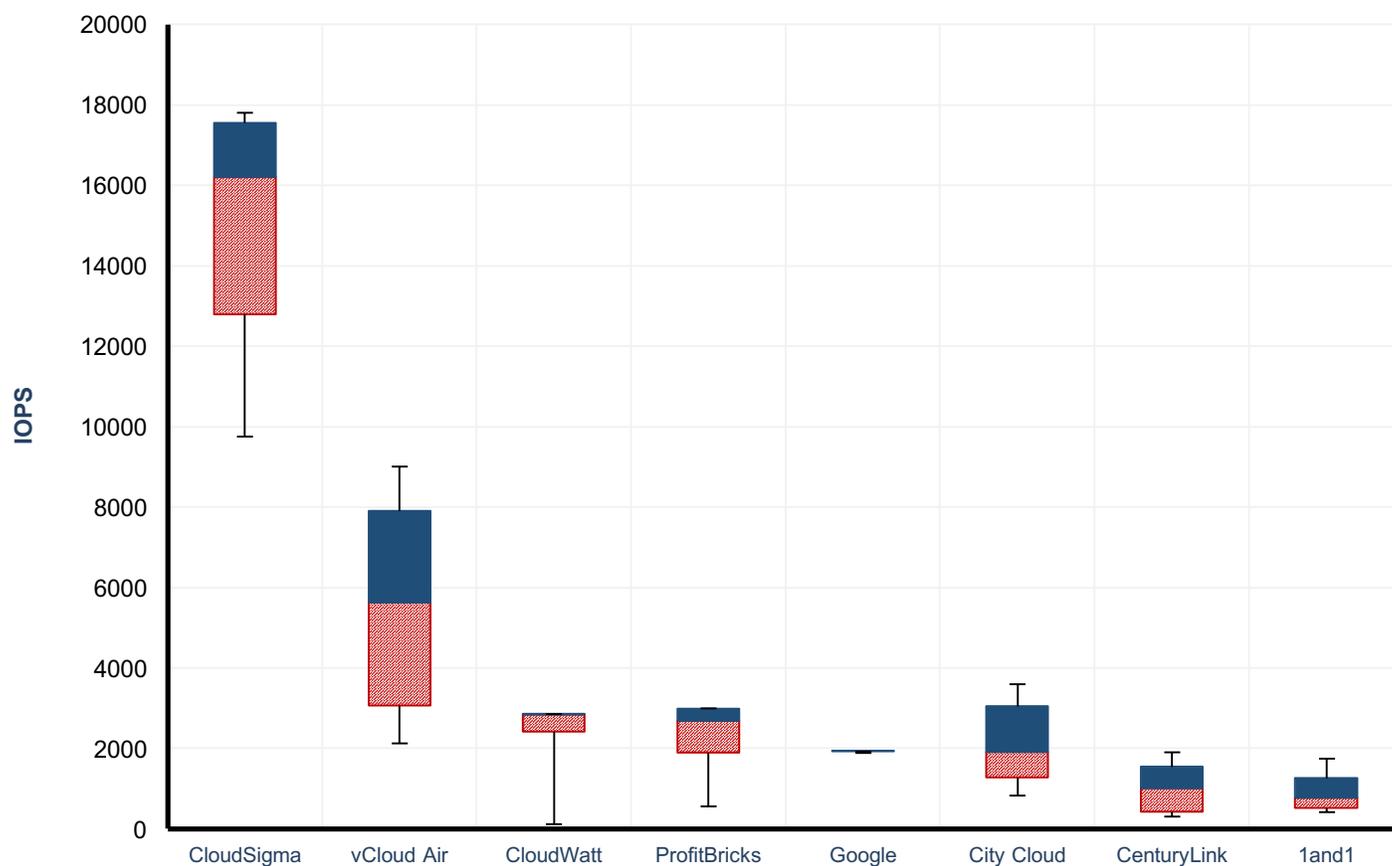


Table 8D.5: Random Block Disk Performance Type 2 (Extra Large VMs)

PROVIDER	MIN	5TH	MEDIAN	95TH	MAX	STDEV	CV
1and1	423	516	767	1261	1752	226	28%
CenturyLink	314	420	1009	1547	1913	369	39%
City Cloud	838	1288	1911	3049	3608	656	31%
CloudSigma	9763	12794	16209	17561	17801	1519	10%
CloudWatt	121	2423	2845	2864	2866	266	10%
Google	1896	1921	1921	1922	1922	2	0%
ProfitBricks	562	1901	2687	2994	3006	385	15%
vCloud Air	2127	3060	5634	7910	9007	1449	26%

ABOUT CLOUD SPECTATOR

Cloud Spectator is a cloud benchmarking and consulting agency focused on cloud Infrastructure-as-a-Service (IaaS) performance. The company actively monitors several of the largest IaaS providers in the world, comparing VM performance (i.e., CPU, RAM, disk, internal network, and workloads) and pricing to achieve transparency in the cloud market. The company helps cloud providers understand their market position and helps business make intelligent decisions in selecting cloud providers and lowering total cost of ownership. The firm was founded in early 2011 and is located in Boston, MA.

For questions about this report, to request a custom report, or if you have general inquiries about our products and services, please contact Cloud Spectator (www.cloudspectator.com) at +1 (617) 300-0711 or contact@cloudspectator.com.



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