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Re-examining HPC Energy Efficiency Dashboard Elements

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***Abstract*—With increasing high performance computing (HPC) energy consumption and the rising cost of energy, it has become important to be able to monitor and manage energy and power consumption. Dashboards will monitor and display energy and power consumption of various physical data center components in or near real time as well as trend data. The dashboard will display monitored, measured, and calculated parameters. A survey of the major United States Department of Energy (DOE) National Laboratory HPC data centers was completed in early 2012. Only a few DOE labs reported having energy performance dashboards and those were described as partial, piecemeal and under construction. As a result of the 2012 survey, the Energy Efficient HPC Working Group published recommendations for energy and power elements of an HPC data center dashboard. Another survey was recently completed as part of a 'Birds of Feather' Session at SC15. This survey tested the relevance of the recommendations. This paper provides an update on recommendations to help select or tailor the energy and power elements or parameters of an HPC data center dashboard.**

Keywords—energy; management; dashboard; data center

I. Introduction and Motivation

The objective of this paper is to provide an update on general recommendations to help select or tailor the energy elements or parameters of an HPC data center infrastructure dashboard [1]. This is a very timely topic, since energy efficiency has become of paramount importance to the HPC community as the race towards exascale computing accelerates. The most powerful supercomputers today (of petaflop scale) have power consumption in the order of megawatts (MW). TITAN, the fastest supercomputer in the United States located at Oak Ridge National Laboratory (27 petaflop), consumes 9 MW of power. The goal of the exascale initiative is to reach a thousand time increase in performance (1 exaflop or 1000 petaflop) with an energy budget of 20 MW. In addition to the technological advances needed to build such an energy efficient supercomputer, the data center facilities also need to make available energy efficient infrastructures to house and operate these machines. As such, it is necessary for the HPC community to reach consensus on easy to measure metrics and energy efficiency elements. It is also necessary to select the most pertinent elements for data center dashboards for situational awareness of the various stakeholders in a datacenter.

A dashboard is a display that is used to provide critical feedback to the users. Dashboards can also be configured to run historical reports that can be used to identify trends in a facility or to benchmark against other facilities. It is also very useful to show the facility users the impact of certain decisions on energy usage. For example, if an HPC workload is determined to be power hungry then it can be scheduled to run during off peak hours to reduce operating cost.

Carefully selecting the elements to be displayed on the energy dashboard is important, as energy management is a shared responsibility of all stakeholders: operations managers, facilities managers, and system administrators. The selection of these elements will also guide the development of appropriated monitoring and profiling tools, as we cannot display something that we cannot measure. This is why the recommendations made in this paper are important.

II. Backround and Prior Work

Dashboards have been used by data centers to quickly grasp the current operating state of the data center components. In the past the information displayed in these dashboards has been mostly computer performance oriented. Given the rising importance of energy efficiency, data centers have started to include energy related information into dashboards. For example, eBay's Digital Service Efficiency dashboard (http://tech.ebay.com/dashboard) [2] contains both business performance indicators and infrastructure metrics such as total power and power usage effectiveness (PUE). Yet what energy related information must be displayed in a dashboard for effective energy management remains unclear for the HPC community in general. The lack of consensus slows down the rate of improvement in data center energy efficiency.

Observing the issue, the Energy Efficient HPC Working Group (EE HPC WG) [3] formed a team to draft a guideline of general recommendations for selecting energy efficiency

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elements of HPC data center dashboards. The guideline is based on the analysis of a survey, conducted in early 2012, of the major United States Department of Energy (DOE) leadership computing facilities. The guideline has been broadly reviewed since September 2012, and its executive summary [1] was presented in a workshop in 2013 [1]. In 2014, the U.S. Federal Energy Management Program published its dashboard guide (https://datacenters.lbl.gov/resources/femp-dashboard-guide) [4] that is based on the work done by the EE HPC WG.

In the 2012 guideline, the energy efficiency elements are prioritized with respect to three different target stakeholders: Director, Facility Manager, and Information Technology (IT) Manager. For Director, 11 metrics are identified, and 6 of them are deemed as high priority. For Facility Manager, 34 metrics are identified, 12 of which are considered high priority. For IT Manager, 9 metrics are identified with 8 labelled high priority.

According to the guideline, all the three stakeholders are concerned with total power, total energy, and PUE (i.e., data center energy overhead) for power and energy. Director and IT Manager are also concerned about energy cost and average IT utilization. In contrast, Facility Manager is more concerned about cooling energy use, its efficiency, the electricity distribution network, the thermal picture of the data center, and the CRAC units.

The overall goal is to use the suggested lists of energy efficiency metrics as a starting point in designing a dashboard for a specific site. As HPC data centers begin to more actively deploy and use energy management dashboards, potential uses of the information collected are vast. Some possibilities include longitudinal data analysis, cross-site comparison and six-sigma continuous improvement.

III. Survey Results and Comparision

At a Birds of Feather (BoF) Session [5] during the 2015 International Conference for High Performance Computing, Networking, Storage and Analysis (SC15), attendees were asked to complete a survey to help update recommendations developed by the EE HPC WG on energy efficiency elements of dashboards for high performance computing centers. The survey participants were asked to rate as high, medium or low priority a list of energy efficiency elements from the perspective of the Operations Manager, the Facilities Manager and the System Administrator or System Manager. Section A below describes the results of the SC15 BoF Survey.

The list of elements assessed in the SC15 BoF survey were based on prior recommendations developed by the EE HPC WG. These elements were of high or medium priority (not low priority) according to the EE HPC WG. An analysis comparing the SC15 BoF survey results with the EE HPC WG recommendations is described below in Section B.

This update was significant primarily because it extended the community of contributors defining relevant HPC energy efficiency dashboard elements. In addition, the original work was done in 2012, so the community has several more yea rs experience. The EE HPC WG members were primarily from United States Department of Energy National Laboratories. There were less than 10 active participants. Although it wasn't tracked, the SC15 BoF respondents probably reflected a broader community. Furthermore, there were 28 attendees of the BoF who completed and submitted the survey. This comprised at least one third of the total attendees.

A. SC15 BoF Survey Results

The SC15 BoF survey respondents were asked to "assess the priority" of a list of "energy efficiency measures and metrics" for each of three stakeholders. Table 1 shows the survey respondent's prioritization for the Operations Manager. The survey had 12 elements listed for the Operations Manager that are listed on the left-most column of Table 1. The other three columns show the number of respondents for a choice of high, medium or low priority. For example, Total energy (kWh) of the HPC center was evaluated as a high priority by 22 respondents, a medium priority by 5 respondents, and a low priority by one respondent whereas maximum power (kW) of the HPC center was evaluated as a high priority by 19 respondents, a medium priority by 8 respondents, and a low priority by one respondent. The elements are ranked from high to low by the high priority column.

These elements are intended to provide recommendations for a dashboard that initiates drill-down which might lead to improved data center power and/or energy efficiency. The relative position of these elements will be greatly influenced by site specifics. For example, a site with a penalty for power peaks may be more interested in Maximum power of the HPC center whereas another site with a flate rate energy charge may be more interested in Total energy of the HPC center. The list is intended to show 'best practices' from which a site can pick and choose those elements that are most relevant to the site specific situation.

Most of the elements for the operations manager dashboard were assessed as high or medium priority. The last three elements were assessed as a medium or low priority.

TABLE 1. Operations Manager Priorities

	# Respondents		
Energy Efficiency Dashboard Elements	High priority	Medium priority	Low priority
Total energy (kWh) of the HPC center	22	5	1
Energy cost ($) of the HPC center	21	6	1
Maximum power (kW) of the HPC center	19	8	1
Total Cost of Ownership ($)	18	8	2
HPC compute system utilization (%)	18	8	2
Total energy (kWh) of the IT systems	17	9	2
Power usage effectiveness (index)	15	11	2
IT efficiency where workload is site defined (workload output/W)	13	9	6
Maximum power (kW) of the IT systems	12	14	2
Carbon emission (tons)	4	12	11
Carbon usage effectiveness (kg/KWh)	4	12	12
Energy cost per square foot ($/sq ft)	3	9	16

Table 2 shows the results for the Facilities Manager. The survey had 36 elements listed for the Facilities Manager. All of the elements were considered either a high or medium priority by the majority of the respondents. Lighting power, IT fan power, and subfloor/duct pressure had the highest response for low priority.

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TABLE 2. Facilities Manager Priorities

Energy Efficiency Dashboard Elements	# Respondents High priority	Medium priority	Low priority
Maximum power (kW) of the HPC center	23	3	0
Cooling energy (kWh)	22	4	0
Total energy (kWh) of the HPC center	20	6	0
Cooling efficiency (kW/ton)	18	7	1
Maximum IT power (kW)	15	9	2
Water usage effectiveness (L/kWh)	15	6	3
Water cooling plant efficiency (kW/ton)	14	10	0
Water cooling plant load (btuh or ton)	14	9	1
Chiller power (kW) and energy (kWh)	13	11	0
Total IT energy (kWh)	13	10	2
Water cooling supply water temperature (degrees F or C)	12	12	0
Power usage effectiveness (index)	12	12	2
UPS input / output maximum power (kW)	12	12	2
Transformer input/output power (kW) and energy (kWh)	12	10	1
Temperature map (degrees F or C)	11	14	1
Data center IT equipment cooling diagram (degrees F or C)	10	14	2
UPS input / output energy (kWh)	10	12	2
PDU input/output power (kW) and energy (kWh)	10	9	6
Power factor (percent)	10	8	5
Chiller plant load (btuh or ton)	9	15	0
Total CRAC Compressor power (kW) and energy (kWh)	9	12	2
Average use of renewable energy (kWh percent)	9	11	5
IT efficiency where workload is site defined (workload output/W)	9	11	6
Total CRAC/CRAH/AHU fan power (kW) and energy (kWh)	9	10	4
Outdoor drybulb and wetbulb temperatures (degrees F or C)	8	11	5
Total CRAC/CRAH/AHU Humidifier power (kW) and energy (kWh)	8	11	4
District cooling energy use (kWh)	7	12	4
Subfloor/duct pressure map (in-wc)	7	11	8
Avg, min, max CRAC/CRAH/AHU return air temperature (degrees F or C)	6	15	5
Humidity map dewpoint (degrees F or C)	6	15	5
Total CRAC/CRAH/AHU Reheat power (kW) and energy (kWh)	6	12	5
Pie chart of energy end use HPC vs other IT vs site (percent)	6	11	6
Avg, min, max CRAC/CRAH/AHU supply air temperature (degrees F or C)	5	15	6
IT fan power (kW) and energy (kWh)	4	13	8
Lighting power (kW) and energy (kWh)	4	11	9
Rack cooling index (RCI)Hi	3	13	6

Table 3 shows the results for the System Administrator. The survey had 14 elements listed for the System Administrator. Almost all elements listed were assessed as high or medium priority by the majority of the respondents, with the exception of UPS input/output maximum power (kW) and energy (kWh). Maximum power of the HPC center is an example of a different priority for different stakeholders.

TABLE 3. System Administrator Priorities

Energy Efficiency Dashboard Elements	# Respondents High priority	Medium priority	Low priority
HPC compute system utilization (%)	24	1	0
Server virtualization (percent)	14	6	5
IT systems (e.g., compute, storage, network) power (kW) and energy (kWh)	11	9	5
IT efficiency where workload is site defined (workload output/W)	11	8	6
Energy cost per workload unit of measure (kWh per unit, e.g., kWh/Flop)	11	7	7
Maximum IT power (kW)	11	5	8
Total IT energy (kWh)	10	6	9
Total energy (kWh) of the HPC center	9	11	5
Maximum power (kW) of the HPC center	8	13	4
Data center electrical distribution diagram	7	12	6
Temperature map (degrees F or C)	7	11	7
Power usage effectiveness (index)	6	10	9
PDU input / output maximum power (kW) and energy (kWh)	3	12	10
UPS input / output maximum power (kW) and energy (kWh)	6	9	10

B. EE HPC WG Recommendation Comparison

The results of the SC15 BoF Survey largely supported the recommendations of the EE HPC WG. Most of the elements considered high priority by the EE HPC WG were also assessed as high priority by the majority of the survey respondents. There were some elements that were new to the SC15 BoF survey, so a comparison cannot be made for new elements. For the sake of brevity, this analysis will only detail the elements that change as well as the new elements.

Table 4 compares the elements that changed and new elements for the Operations Manager. The first four elements had not been part of the EE HPC WG recommendations and were new to the SC15 BoF Survey. In the Change column (left-most) of Table 4, they are marked as new. The first three were assessed as a high priority by the majority of the Survey respondents. These are Maximum power (kW) of the HPC center, Total Cost of Ownership ($), and Total energy (kWh) of the IT systems. Carbon usage effectiveness (kg/KWh) straddled medium and low priority assessments. The last element, Energy cost per square foot ($/sq ft), dropped from a medium priority (per the EE HPC WG) to a low priority (per the Survey results).

TABLE 4. Operations Manager Element Changes

Change	Energy Efficiency Dashboard Elements	# Responderts High priority	Medium priority	Low priority
new	Maximum power (kW) of the HPC center	19	8	1
new	Total Cost of Ownership ($)	18	8	2
new	Total energy (kWh) of the IT systems	17	9	2
new	Carbon usage effectiveness (kg/KWh)	4	12	12
lower	Energy cost per square foot ($/sq ft)	3	9	16

Table 5 compares the elements that changed and new elements for the Facilities Manager. There was only one new element, Water usage effectiveness, which was assessed as a high priority for the majority of respondents. Six elements had been medium priority for the EE HPC WG, but were assessed as high priority by the SC15 BoF respondents. These are Water cooling plant efficiency (kW/ton) and load (btuh or ton), Chiller power (kW) and energy (kWh), and Transformer input/output power (kW) and energy (kWh), PDU input/output power (kW) and energy (kWh), and power factor (percent). There were also four elements that had been a high priority for the EE HPC WG, but were assessed as a medium priority by the SC15 BoF repondents. These are Temperature map (degrees F or C), Data center IT equipment cooling diagram (degrees F or C), avg, min, max CRAC/CRAH/AHU supply air temperature (degrees F or C), and IT fan power (kW) and energy (kWh).

TABLE 5: Facilities Manager Element Changes

Change	Energy Efficiency Dashboard Elements	High priority	Medium priority	Low priority
new	Water usage effectiveness (L/kWh)	15	6	3
higher	Water cooling plant efficiency (kW/ton)	14	10	0
higher	Water cooling plant load (btuh or ton)	14	9	1
higher	Chiller power (kW) and energy (kWh)	13	11	0
higher	Transformer input/output power (kW) and energy (kWh)	12	10	1
lower	Temperature map (degrees F or C)	11	14	1
lower	Data center IT equipment cooling diagram (degrees F or C)	10	14	2
higher	PDU input/output power (kW) and energy (kWh)	10	9	6
higher	Power factor (percent)	10	8	5
lower	Avg, min, max CRAC/CRAH/AHU supply air temperature (degrees F or C)	5	15	6
lower	IT fan power (kW) and energy (kWh)	4	13	8

Table 6 compares the elements that are new and those that have changed for the System Administrator. Server virtualization was considered a medium priority for the EE HPC WG, but shows anassessment as a high priority by a large number of the survey respondents. Maximum IT power (kW) and Maximum power (kW) of the HPC center were both new to the SC15 BoF survey. UPS input/output maximum power (kW) and energy (kWh) dropped from medium to low priority, but with only one respondent difference (9 reported medium priority and 10 reported low priority).

TABLE 6: System Administrator Element Changes

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			# Respondents	
Change	Energy Efficiency Dashboard Elements	High priority	Medium priority	Low priority
higher	Server virtualization (percent)	14	6	5
new	Maximum IT power (kW)	11	5	8
new	Maximum power (kW) of the HPC center	8	13	4
lower	UPS input / output maximum power (kW) and energy (kWh)	6	9	10

IV. CONCLUSION

The design of an energy performance dashboard is a combination of two tasks. One task is what elements to present (purpose driven), and the other task is how to present the selected elements. Different stakeholders have different requirements for both tasks. This paper provided an update for the most important dashboard elements for three HPC data center stakeholders: the Operations Manager, the Facility Manager, and the HPC System Administrator. The updated and new recommendations based on both surveys will help to define IT system and data center measurement capabilities and can provide guidelines for needed analytic capabilities based on identified Key Performance Indicators.

This study provides the following insights:

- Dashboard elements are different for each stakeholder and their importance might change over time.
- Some elements (like Energy cost per workload unit of measure) are more difficult to measure.
- Some elements (like Total Cost of Ownership) are more difficult to measure in 'real-time.'
- Some elements (like IT utilization) might be individual to each system

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