International Journal of Computer Information Systems and Industrial Management Applications.
ISSN 2150-7988 Volume 7 (2015) pp. 094-105

Green Data Center Frameworks and Guidelines Review

Norhashimi Bin Mohd Nor[1] and Mohd Hasan Bin Selamat[2]

Faculty of Computer Science & Info. Technology
Universiti Putra Malaysia, 43400 Serdang, Malaysia
[1] *norhashimimohdnor@yahoo.com*
[2]*mhasan@upm.edu.my*

***Abstract*: Our world today are getting more attach to the technology especially IT. Behind every superb applications that we rely on everyday are data centers where all the processing activities reside. Data centers as the heart of computing gained its magnitude and vitality through the emergence of internet services. The intense workload of data centers in order to fulfill customers need indirectly contributed to world pollution through massive usage of electricity. Thus an energy efficient framework for steering the data centers design and management is needed. Besides the green factor, the framework should take into consideration total cost of ownership (TCO) as one of the key components to make it budget friendly and feasible to all kind of budget. To achieve this, a comparison on 10 existing energy efficient data center frameworks and guidelines was performed. The comparison deduced that the frameworks have the opportunities for improvement in term of components, attributes, energy efficient metrics and implementation methodology. Free of charge (FOC) green initiatives extracted from the existing frameworks and guidelines could shed some light on green embracement by every data center regarding of their size, capability and fund allocation. Categorization of attributes based on return on investment (ROI) and energy efficiency level in one of the frameworks that allows it to be implemented in phases is a sensible and practical approach. Propositions and novel ideas from industry leaders such as Google and Facebook are also gathered to provide diverse views on energy efficiency approaches and opportunities in data centers.**

Keywords: energy efficient; green data center; framework comparison; IT equipment; return on investment (ROI)

I. Introduction

Our world is depending more and more on technology especially IT. A couple of decades ago only a small bunch of people would complaint if the internet was out of service. However nowadays, an hour of inaccessibility to the internet in most organizations would create chaos and paralyze their operations.

Communications, financials, online businesses, broadcastings, researches and all other fields rely on applications hosted in data centers that run 24/7. The applications need to be available and accessible at all time, throughout the year even though nobody is accessing them. This situation contributes to the massive energy consumption by data centers as reported by Data Center Journal [1]. In their article, Industry Outlook: Data Center Energy Efficiency, data centers energy consumption is up to 3% from total global energy production. The number 3% will grow bigger in the future if no comprehensive measures are undertaken. The consequences are not merely to organizations financial but worse to the environment through carbon footprint. Alliance Trust Investments projected that by 2020 carbon footprint contributed by data centers will double up from 2015's amount as shown in Fig.1 [2]. The forecast contradicts with White House aspiration to cut down carbon dioxide pollution by 30%[3].

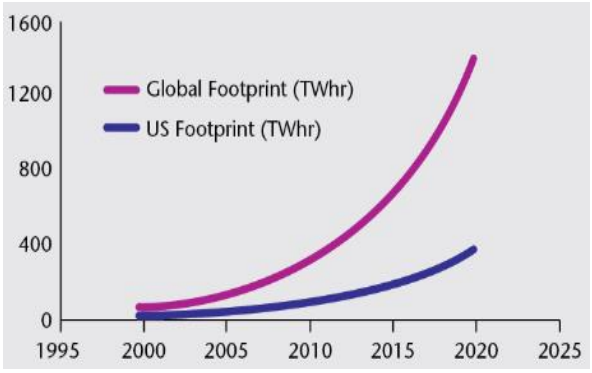


Figure 1: Projection of Data Center Carbon Footprint[2]

Frameworks, models or guidelines are terminologies used to represent a structured method of developing, managing and maintaining dense systems like green data center. There are many structured methods in achieving green data centers focused on different aspects, motivations and obstructions. All these multiplicity have their pros and cons as well as strengths and weaknesses that could be extracted and molded into new and agile structured method for the demanding future.

In this paper we compared 10 frameworks and guidelines side by side in order to obtain a bigger picture about green data center. By listing the green initiatives from each frameworks and guidelines we realize that they complement each other in every aspects. Another essence that we would like to present in this paper is the other side of green perspective in data centers. Green initiatives in data centers are always associated with complex deployment together with high capital

expenditure (CAPEX). The idea is partially untrue and also a misperception created by fancy advertisements to attract obsess and devoted IT green peace with abundant fund. The green initiatives are portrayed in exclusive as well as expensive designs, materials, software, hardware and expert human resources. This misperception is one of the reasons that keeps most data center owners and managers from embracing the green initiatives in their data centers. But the truth is green initiatives can be embraced progressively, starting with simple and free of charge measures. Setting air conditioners in data center at acceptable lower level, enabling servers sleep mode, arranging server racks accordingly and much more are simple and FOC measures that could be implemented in any data centers by anybody without any cost.

The first and foremost step in solving any problems is to thoroughly comprehend the problem itself. In reducing energy consumption in data center, the energy deployment must be measured accurately to identify each and every components in the data center that contribute to the electricity bill such as information technology (IT) equipment, mechanical and electrical (M&E) infrastructure and ventilating/cooling infrastructure [4]. Precise measuring that relates cost of operating data centers with actual business outcome could create genuine conscious on energy saving. Power costs per transaction, transactions per kWh, revenue per server, server utilization levels and the cost of idle versus busy servers [5] could be an eye opener to business owners on the actual impact of their business decisions. The enlightenment possibly will help business owner to be more cautious and green literate in making any business decisions in the future. Some decisions seem unrelated to energy efficiency in data centers such as increasing data backup retention period from two to five in order to enhance information availability. On the contrary, this small decision would grow the need for more storage facility, increasing retrieving and backup time, complicating data management and maintenance thus increasing energy consumption through additional processing time.

Based on Uptime Institute estimation, 20% of servers in data centers are obsolete while nearly half of the data centers do not have scheduled exercise to identify and remove unused servers. Additionally more than half of senior executives in data centers believe that less than 5% of their servers are comatose[6]. The obsolete, comatose and unused servers decrease the energy efficiency in data center because of their low or nil productivity compared to energy consumption. The unfit servers are just a part of the issues that decreases the data center energy efficiency, besides substandard of facilities design, IT resources management, process, governance and finance [7]. All these issues need to be tackled holistically from the data center design until the daily operation and refurbishment to ensure the data center energy efficiency is in place.

Knowledge management is another potential area that can be explored in order to increase energy efficiency in data center. Metadata on users browsing or accessing pattern can be used to develop energy efficient task and resource scheduling algorithm in virtualization system. The scheduling algorithm could manage IT resources e.g. processing core, memory, storage, bandwidth and etc. efficiently through precise heuristic prediction. The algorithm furthermore could enhance the virtual machines (VM) migration within physical servers to maximize servers utilization while shutting down underutilize servers [8], [9]. Intangible knowledge on green data center management by different data center managers is hard to be captured, combined, enhanced and shared. The intangible knowledge includes various skills in planning, managing, trouble shooting, forecasting, calibrating and fine-tuning. Currently most of these intangible skills acquired through experience are not documented and passed on randomly and manually. However with structured KM system the precise and efficient result could be repeated and enhanced.

Therefore a complete and feasible green data center framework is needed to assist the data center stakeholders to perform their role in conserving the environment.

II. Literature Review

A. Green data center

Almost every medium to big organizations has their own data centers while small to medium organizations acquire their data center services from third party providers. Owning a data center require quite an investment to the organizations as for the high initial investment, resource intensive (IT resources, electricity and human resources), low second hand value of the equipment and rapid changing of the IT technology that forces new equipment procurement [10]. The conventional or traditional data centers do not emphasize on energy saving either by the IT devices or the infrastructure equipment. This type of data center focuses only on IT services performance or meeting service level agreement (SLA) as promised to the users.

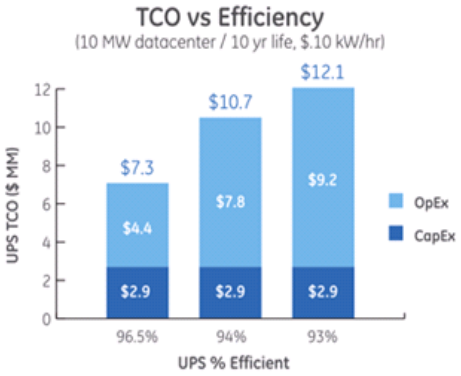
Key performance indicators (KPIs) for green data centers are the SLA and most importantly reduction of total energy consumption by the data center. Therefore the advantages of green data center are not limited to reduction on data center energy cost, but also improves equipment lifetime, reduces maintenance cost, preserves the environment, lessen the electricity grid strain and etc. [11]. These effects do not require intense or total implementation of the green initiatives, some simple and no-cost steps at the design phase could promote 20% to 50% saving on electrical bill [12].

B. Total cost of ownership (TCO) vs energy efficiency equals return on investment (ROI)

Total cost of ownership (TCO) is one of the vital variables that influence data center stakeholders in deciding the degree of energy efficiency when designing their data centers. The TCO comprises of capital expenditures (CapEx) and operational expenditures (OpEx). Unfortunately CapEx always overshadow its fraternal twin OpEx in representing TCO. The perception about energy efficiency data center caused higher TCO is misleading as the OpEx is not precisely calculated. The comparison on both TCO components is illustrated in Fig1, where even the same CapEx can produce lower OpEx, thus reduce the overall TCO[13].

Implementing energy efficiency in data center should be started with the simplest thing, or “start with low hanging

fruits" as mentioned by Mamane[14]. It is a very practical approach for existing data centers or new data centers with minimal development fund. The low hanging fruits are initiatives with low or medium TCO but produced high energy efficiency as shown in Tab.1. Initiatives that could produce such result are setting air conditioners to acceptable high temperature, enable server sleep mode, precise placement of perforated tiles and much more. These initiatives will not cause us a single cent, but will surely reduce data centers' energy consumption. Moreover those initiatives can be done easily by anybody in a split second.



UPS % Efficient	96.5%	94%	93%
CapEx	$2.9	$2.9	$2.9
OpEx	$4.4	$7.8	$9.2
TCO Total	$7.3	$10.7	$12.1

Figure 2: TCO vs Efficiency[13]

Table 1: ROI vs TCO vs Efficiency

ROI	TCO	Efficiency	Advantages
HIGH	Low	High	• Zero or minimum CapEx • Zero or minimum effort (in term of human resource) • High energy efficiency • High reduction on OpEx • Immediate impact
	Medium	High	
	Low	Medium	
MEDIUM	High	High	• Medium CapEx • Medium effort • Medium energy efficiency • Medium reduction on OpEx.
	Medium	Medium	
	Low	Low	
LOW	High	Medium	• NIL
	High	Low	
	Medium	Low	

C. *Performance vs energy efficiency*

Performance determines productivity of data centers thus affects the service level agreement (SLA) with customers. The performance of IT equipment and data center infrastructure plays an important role in data center design and governance. However data center productivity performance is associated inversely proportional with energy efficiency in conventional understanding [15]. In other words, data center stakeholders need to sacrifice productivity performance in order to be green. This is not always true since Meisner & Wenish [15] proved that in general high-power servers are more energy efficient than low-power servers.

D. *Redundancy vs energy efficiency*

Tradeoff between cost and redundancy is a crucial decision when designing a data center. While ensuring data center's continuity, redundancy burden data center owner with CapEx and OpEx costs. The OpEx will be literally doubled without any impact to productivity if for tier 4 data centers that have 99.995% availability. The near 100% availability on all IT services is every business owner dream, however it is not compulsory. Business owners need to sincerely evaluate their business needs, whether their applications truly require 24/7 accessibility. The needs have to be matched up with their capital to ensure the worthwhile of their investment. The investment must be lower than the total expected losses including cash revenue, shares in stock exchange and business reputation in market if the redundancy is not on hand [16][17]. Disaster recovery (DR) and business continuity (BC) are major type of redundancy that would boost the CapEx and OpEx in order to preserve business availability. Both DR and BC plans need to be treated as a part of the whole data center strategy rather than a separate 'just-in-case' strategy to reduce cost and improve agility [18]. Rather than 'on-standby', DR and BC facilities need to be fully exploited in a load balancing manner to maximize the investment and at the same time ensuring its operability.

E. *Mentality vs energy efficiency*

People's attitude and mentality are shaped by society's values and state. Ignorance in public evolves from over-comfortable situation or lack of exposure in community[10][11]. The energy efficiency awareness should be nurtured since the very beginning in a person life to avert ignorance thus generating a conservational society. People should be educated to conserve energy whenever, wherever and whatever possible means even in switching lights. Another factor that contributes to the energy wasting is the 'buy more pay less' doctrine in people's sub-conscious mind [21]. We are so used to the idea of paying less while getting more in the hypermarket that we unintentionally practice it in electricity consumption.

F. *Big Data & High Performance Computing*

Growth of data center is closely related to the service level agreement (SLA) between data center owners and business owners. The data center owners have to expand and maintain their facilities and services to accommodate users need as agreed in the SLA. Business owners on the other hand have to tailor their plans based on the market and users' needs. More demands from the market mean more applications need to be developed and more data need to be catered. In addition to big

data, high performance computing (HPC) or parallel computing are among the challenging issues faced by data center owners. Both big data and HPC need extremely large processing capability thus requires massive servers, storages, connectivity and etc. These vast requirements could not be avoided in order to survive in our rapidly evolving world today and certainly increase the energy consumption in data centers. However, one of the measures that can be done to reduce the impact is to increase the processing efficiency so that every watt of electricity used will generate equivalent or extra value.

III. Comparison of frameworks

Ten frameworks were compared to observe their strengths and weaknesses, thus to understand green data center framework in detail. The frameworks are Data Center Energy Efficiency Framework (DCEEF) by the Green Data Center Alliance[7], Guidelines for Energy-Efficient Datacenters by The Green Grid[12], The 4 Pillar Framework for energy efficient HPC datacenters by T. Wilde et al.[22], The EU Code of Conduct on Data Centers by European Commission [23], Best Practices Guide for Energy-Efficient Data Center Design by U.S Department of Energy[24], Green IT Framework for Energy Efficient Data Center Using Virtualization by Uddin et al.[25], Implementing Energy Efficient Data Center by APC[26], 12 Ways to Save Energy in Data Center by Energy Star[27], Google Data Center by Google Inc.[28]. and Facebook Data Center by Facebook Inc.[29].

A. Data Center Energy Efficient Framework (DCEEF)

The DCEEF by Green Data Center Alliance (GDCA)[7] comprises of five domains or components i.e. Facility Design & Engineering, Information Technology, Process, Governance and Finance. The components are followed by 30 requirements or attributes as in Fig 2. The framework is comprehensive that it covers almost every aspect in data center. In order to make the framework practical and applicable to all type and range of data centers, the framework categorized the 30 attributes into three levels I, II and III based on energy efficiency fundamental element in data center and return on investment (ROI).

Level I is meant for basic attributes in green data center that have high impact on energy efficiency with minimal investment. Level II consists of attributes that need more investment in term of cost, time and difficulty with equal impact on energy efficiency. Level III is the ultimate stage of implementing energy efficiency in this framework where high investment is needed with long term impact on the energy efficiency. The DCEEF is very feasible and handy to data center designer and manager to design and build green data center since it provides different levels or phases for different requirements and budgets.

Although the DCEEF touch various aspects in data center development and management, only the fundamental energy metrics are considered in this framework. Furthermore this framework emphasized more on the micro issues, thus some of the macro issues were left out such as location of the data center, building features where the data center (server room) resides, applications that run in the data center etc. Additionally, the levels are formed from ROI or Cost-Benefits calculation value, with the intention that attributes with higher value are grouped in Level I and lower value attributes in Level II and III accordingly. However, that was not the case since some higher value attributes resided in Level III while some lower value attributes were placed in Level I. Method of calculating the value should be refined in order to get a more accurate and sensible framework deployment approach.

B. Guidelines for Energy-Efficient Datacenters

Guidelines for Energy-Efficient Datacenters by The Green Grid[12] on the other hand provide a brief framework on implementing green data center from designing until staffing as shown in Fig.3. The framework offers loose guiding principle in developing green data center as it is represented only by attributes without components categorization and with no precedence among the attributes. The unsorted attributes make it harder for budget-restricted data center architect and manager to determine the priorities in designing and building green data center.

ID	Requirement	Value	Level I	Level II	Level III
Facility Design & Engineering (FA)					
FA-1	Blanking Panels	4.0	√	√	√
FA-2	Cable Management	3.9	√	√	√
FA-3	Tile Perforation Placement	4.2	√	√	√
FA-4	Floor Cutout Seals	4.0	√	√	√
FA-5	Equipment Placement & Orientation	4.3	√	√	√
FA-6	Thermal set point	4.5	√	√	√
FA-7	Containment Solution (Cold or Hot Aisle)	4.2		√	√
FA-8	CRAC Intake Placement	3.3			√
FA-9	Air or Water Side Economizers	4.4			√
FA-10	Energy Efficient UPS	3.4			√
FA-11	Variable Frequency Drives	3.7			√
FA-12	High Efficiency Thermal Insulation and Roofing	3.3			√
Information Technology (IT)					
IT-1	Consolidation	4.9	√	√	√
IT-2	Measurement & Verification Technology	3.9		√	√
IT-3	Virtualization	4.1		√	√
IT-4	Enable Server Sleep Modes	4.2		√	√
Process (PR)					
PR-1	Data Center Zoning	4.0	√	√	√
PR-2	Configuration Management & Orphaned Servers	3.8		√	√
PR-3	Capacity Management &Right Sizing	3.4		√	√
PR-4	Service Level & Availability Management	3.9		√	√
PR-5	Training & Awareness	3.9			√
Governance (GO)					
GO-1	Energy Efficiency Role Defined	3.6	√	√	√
GO-2	Continuous Improvement Program	4.1		√	√
GO-3	Energy\CSR Policy	3.9		√	√
GO-4	Establish & Track Performance Against Targets	3.9			√
GO-5	Performance Pay	3.5			√
GO-6	Rationalize Operational Risk	3.8			√
Finance (FI)					
FI-1	Energy Efficient IT Procurement	3.4	√	√	√
FI-2	Asset Refresh Rationalization	3.4		√	√
FI-3	Customer Charge Back	3.4			√

Figure 3: GDCA Framework[7]

However the energy metrics are explained in details from various aspects in other documents published by The Green

Grid. As a prominent organization in promoting green IT with myriad of information and resources, it would be excellent if all the knowledge could be assembled in a comprehensive framework that covers the entire components of energy efficient data center horizontally as well as explores them vertically in depth. However this guideline is best suitable for non-IT top management exposure to green initiatives as for its simplicity, understandability and catchy arrangement.

C. *The 4 Pillar Framework*

The third framework evaluated in this paper is The 4 Pillar Framework for energy efficient HPC datacenters by T. Wilde et al.[22] comprises of four pillars/components i.e. building infrastructure, system infrastructure, system software and applications. This framework only focus on four components that makes it incomplete for developing green data center. Human resource is organization's most precious asset and it should be incorporated from the planning and designing phases until the operational and maintenance phases. Besides the attributes in some of the components are not thoroughly covered and explained. The building infrastructure component for example could include the basic air contamination attributes such as perforated tiles placement, floor cutout seal, hot and cold isle and etc to enhance it.

Nevertheless the 4 Pillar Framework emphasizes more on correlation and interaction among the components to achieve energy efficiency in data center as shown in Fig.4. The collaboration method is a unique quality that distinct this framework from others. In addition the framework as claimed by the author could evaluate current data center's energy efficiency hence discovering potential focus areas to be enhanced.

D. *EU Code of Conduct on Data Centers*

The EU Code of Conduct (EUCC) on Data Centers by European Commission[23] represents its framework in seven components i.e. physical building, data center management (utilization & planning), IT equipment & services, cooling, data center power equipment, non-data center equipment and monitoring. The EUCC categorized attributes of the components into five different approaches i.e. entire data center (applicable to all existing components in data center), new software (in case of new software installation or upgrades), new IT equipment (in case of new hardware procurement or replacement), new build or retrofit (suitable for data center built or majorly renovated from 2010 onwards) and optional practices (depends on the particular data center applicability and suitability due to special circumstances) as in Fig.5. In this way every data center whether it is existing non-energy efficient or newly built is eligible to adopt this framework.

Additionally, data center stakeholders that are interested in applying this framework can ascertain which attributes are appropriate and applicable for them. Another strength of this framework is that it clearly defines roles of data center's stakeholders. This approach could facilitate in outlining each party responsibilities and rights thus improving the implementation.

Check-off Box	Efficiency Best Practice	Date Executed
	Itemized datacenter electric bill in hand	
	Optimization of datacenter design	
	Optimization of data equipment floor layout	
	Proper location of vented floor tiles	
	Rightsizing of UPS	
	Installation of "green" power equipment	
	Installation of a close-coupled cooling architecture	
	Deployment of server virtualization	
	Installation of energy-efficient lighting	
	Installation of blanking panels	
	Installation of efficient plumbing	
	Efficient server consolidation practices	
	Utilization of air conditioner economizer modes	
	Coordination of air conditioners	
	Proper configuration of server software	
	Proper alignment of datacenter staff	

Figure 4: Green Grid Guideline[12]

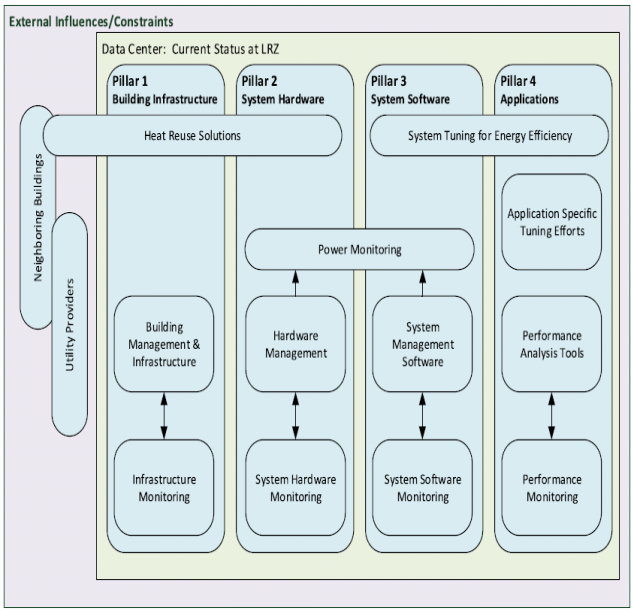


Figure 5: 4 Pillars Framework[22]

E. *Best Practices Guide for Energy-Efficient Data Center Design*

Best Practices Guide for Energy-Efficient Data Center Design by U.S Department of Energy (USDE)[24] proposed five components of data center that can be enhanced to improve energy efficiency i.e. information technology (IT) system, air management, cooling system, electrical system and other opportunities of green design. USDE emphasized more on electrical factors since this is the source of the energy efficiency. Small increment of 10% in efficiency by using external high-efficiency instead of internal rack-mounted alternating current – direct current (AC-DC) power supplies could lead to $2,000 to $6,000 saving per rack per annum [24]. Fig.6 illustrates the difference between legacy or internal rack-mounted power supplies and external high-efficiency power supplies.

The framework best feature is the green metrics to benchmark data center level of energy efficiency. Formulas to calculate the metrics are given together with the data center energy efficiency benchmark achievement of 'standard', 'good' and 'better'. The benchmark could assist data center stakeholders in understanding their data center state in term of energy consumption and possibilities for reducing operational cost. However similar to the 4 Pillar Framework, human resource as the most highly invested capital is not included in this framework and this is an excellent opportunity for improvement.

Category	Description
Entire Data Centre	Expected to be applied to all existing IT, Mechanical and Electrical equipment within the data centre
New Software	Expected during any new software install or upgrade
New IT Equipment	Expected for new or replacement IT equipment
New build or retrofit	Expected for any data centre built or undergoing a significant refit of the M&E equipment from 2010 onwards
Optional practices	Practices without a background colour are optional for participants

Figure 6: EU Code of Conduct[23]

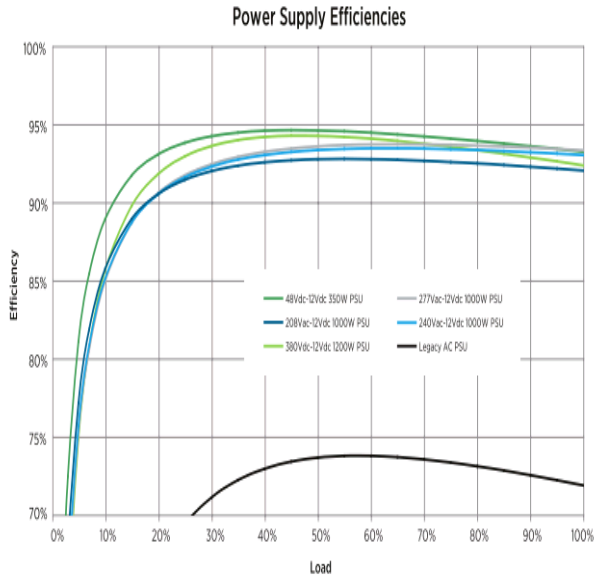


Figure 7: U.S Department of Energy Best Practice[24]

	Temporary Consumption Avoidance	Structural Consumption Avoidance	Comment
Method of savings	Power Management Load shedding Economizer	High Efficiency Servers High Efficiency UPS Right-sizing	
1yr electrical savings	**$960**	**$960**	Assuming $0.12 per kW hr
10yr electrical savings (IT)	**$9,600**	**$9,600**	Typical design life of data center
10yr electrical savings (NCPI)	**$960**	**$13,760**	Structural avoidance allows reduction in capacity-related electrical consumption
NCPI CapEx Savings	**$0**	**$13,300**	Structural avoidance allows reduction in equipment capacity
NCPI OpEx Savings	**$0**	**$6,600**	Reduction in equipment reduces operating expenses such as maintenance
Total 10yr Savings per kW	**$10,560**	**$43,260**	

Figure 8: APC- Implementing Energy Efficient Data Center[26]

F. Implementing Energy Efficient Data Center

Guidelines in implementing energy efficient data center by N. Rasmussen on behalf of APC[26] is more to management point of view rather than technical. It explains energy efficiency in data center in a simple and practical manner through quantifying electricity saving. Therefore precise and prompt decisions could be made by top management without any hesitations. The author believes that simple and no cost effort during data center planning and design phases could save 20% to 50% of electrical bill while systematic efforts could reach up to 90% saving, which is quite high.

N. Rasmussen furthermore questions the appropriateness of efficiency as a metric in measuring electrical power consumption reduction and suggested direct metrics such as kW/h and price of electricity as alternatives as shown in Fig. 8. Data center could be separated into at least five components in energy efficiency initiatives, however this guideline involves only the design and equipment of the data center. The guideline could be expended by exploring other components since it captures saving estimation for each attributes which is very helpful and rare.

G. Energy Star Guidelines

Energy Star as a program voluntary program by Environmental Protection Agency (EPA) was dedicated in committing many green initiatives since 1992, especially in buildings and electric appliances. As for data center, Energy Star listed 12 ways in making a data center energy efficient. The 12 steps are categorized into 3 main components i.e. IT opportunities (especially virtualization as in Fig.9), air flow management strategies and HVAC adjustment[30]. Although they only covered some portions of the components in data center energy efficiency, but they did it very well. All the ways/attributes were thoroughly defined and explained in their website.

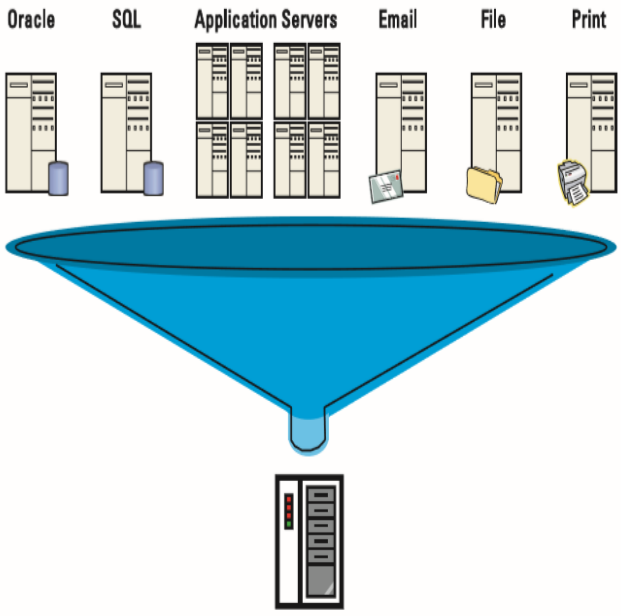


Figure 9: Energy Star Guidelines[27]

H. Google Data Center

Google as one of the leaders in IT world has a big responsibility in establishing high benchmark for green computing. One of the areas that demands for green initiatives is its data center which is the heart of google. Google commitment in data center energy efficiency started at the beginning of the new millennium when they designed their own custom made energy efficient servers [28]. Their endeavor continued with designing energy efficient data center and by 2007 their data centers are 50% more efficient than average data centers at that time. They also started to utilize renewable energy in their data centers to diversify their green initiatives. As a recognition for all their efforts and determination, they are the first company in US to obtain energy management certification.

Google emphasizes on six cores i.e. measuring efficiency, servers, temperature control, water cooling (that is why some of their data centers were built near water resource as in Fig.10), recycling and renewal energy in making their data centers energy efficient. One of the excellent initiative that distinguished Google approach from the others is recycling. Since they produce their own servers, they are capable of recycling the old servers and salvage anything usable. This initiative or capability is actually very beneficial since an obsolete or broke down servers have working and functional parts that still could be utilized. Their latest implementation on energy efficiency is the intelligent efficiency which could intelligently predict the energy usage pattern.

I. Facebook Data Center

With active users more than 1.35 billion by fourth quarter of 2014, Facebook managed to double the figure from 2011 to 2014[31]. This amount of active users definitely require multi data centers working together fulfilling their users demand. Having that amount of users together with tremendous growth rate, definitely Facebook has their strategy in keeping their data centers as efficient as possible. Their energy efficient data center in Prineville was constructed around these initiatives, increasing electrical efficiency, DC backup power, custom reactor power panel and airflow innovation. This approach is a successful with 1.07 (at full load) of power usage effectiveness (PUE) and 0.31 liters/kWH of water use effectiveness (WUE)[29]. Fig.11 shows one of Facebook data centers located in Prineville, Oregon.

Figure 10: Google Data Center[28]

Figure 11: Facebook Data Center[29]

J. Green IT Framework for Energy Efficient Data Center Using Virtualization

This framework by Uddin et al. [25] focused on virtualization technology which is among the most effective measures[26], [27], [32] in enhancing data center energy efficiency. Although virtualization is one of the utmost ways to reduce power consumption in data center, the application is not straight forward. Design and configuration of the virtualization will determine the degree of energy efficiency of a data center. Uddin et al. provide complete steps in implementing virtualization that comprises of these five phases:[25]

1) Create green data centers plan.
2) Classify data center into measureable components.
3) Identify and set benchmark for green metrics.
4) Identify and apply virtualization type.
5) Evaluate performance.

Besides providing structured method of implementation, the framework had been tested and proven feasible on five significant data centers in Pakistan. However since scope of the framework had been specified within virtualization domain, this framework could be categorized as a micro framework. This micro framework might be a perfect complement to a more comprehensive energy efficient data center framework.

IV. Discussion

Comparison of the 10 frameworks and guidelines is summarized in the Table1, which is an extended version of energy efficient data center frameworks comparison in Review on Green Data Center Frameworks by Nor and Selamat [33]. The table apparently proves that Green Data Center Alliance (GDCA) has the most complete framework which covers facility design and engineering, information technology (IT), process, governance and finance. However there are improvements that could be done to the framework by changing some of the component names to really represent them e.g. information technology (IT) into IT equipment technology, process into IT management best practice and finance into asset management.

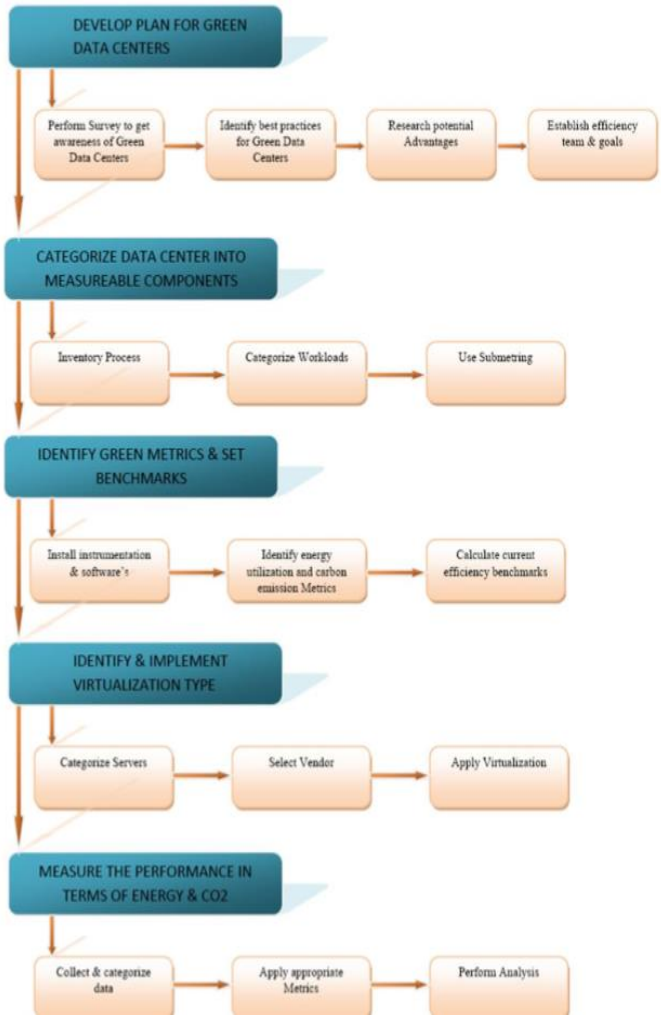


Figure 12: Energy Efficient Data Center Framework Using Virtualization[25]

Besides that, addition of components e.g. building design, systems or applications design, monitoring tools would complement the framework. Several misclassifications of requirements or attributes into inappropriate domains or components should be amended e.g. data center zoning in process should be placed in facility design and engineering and customer charge back in finance should be shifted in governance.

The EUCC indicates the impact level of each attributes by assigning value ranging from 1 (lowest impact) to 5 (highest impact), however this value is qualitative rather than quantitative thus that it cannot be manipulated mathematically. This framework could be more beneficial if the value could be converted into quantitative purposes hence the value could be manipulated to generate better findings and conclusions.

Three of the reviewed frameworks i.e. by GDCA, EUCC and USDE proposed used of outside air to cool the data center and simultaneously using heat from IT equipment to warm up other working space during winter. The environment provides free of charge cooling resource, unfortunately this attribute is only applicable for data centers resided in four seasons regions. However, data center stakeholders could consider highlands or skyscrapers for one season regions.

1 = Green Data Center Alliance;
2 = Green Grid;
3 = 4 Pillar Framework (T. Wilde et al.);
4 = European Commission (EUCC);
5 = U.S Department of Energy
6 = APC
7 = Energy Star
8 = Google
9 = Facebook
10 = Energy Efficient Data Center Using Virtualization (Uddin et al.)

Table 2: Comparison of Green Data Center Frameworks and Guidelines

No	Attributes	1	2	3	4	5	6	7	8	9	10
1	System Design		Y		Y			Y			
2	Energy Efficient Lighting		Y		Y	Y	Y	Y			
3	Cooling Plant				Y	Y			Y		
4	Building Infrastructure			Y	Y						
5	Infrastructure, power and Performance Monitoring			Y	Y					Y	
6	Blanking Panels	Y	Y		Y		Y	Y	Y		
7	Cable Management	Y			Y	Y		Y			
8	Tile Perforation Placement	Y	Y		Y		Y				
9	Floor Cutout Seals	Y						Y			
10	Equipment Placement & Orientation	Y	Y		Y	Y	Y		Y		
11	Thermal set point	Y			Y	Y		Y	Y		
12	Containment Solution (Cold or Hot Aisle)	Y	Y		Y	Y	Y	Y		Y	
13	CRAC Intake Placement	Y	Y		Y	Y	Y		Y		
14	Air or Water Side Economizers	Y	Y		Y		Y	Y			
15	Energy Efficient UPS	Y			Y	Y	Y	Y	Y		
16	Variable Frequency Drives/Fan	Y			Y			Y			
17	High Efficiency Thermal Insulation and Roofing	Y									
18	Consolidation	Y			Y	Y		Y			
19	Measurement & Verification Technology	Y		Y	Y						
20	Virtualization	Y	Y	Y	Y	Y	Y	Y			Y
21	Enable Server Sleep Modes	Y			Y						

22	Data Center Zoning	Y			Y						
23	Configuration Management & Orphaned Servers	Y	Y	Y				Y			
24	Capacity Management & Right Sizing	Y	Y	Y			Y				
25	Service Level & Availability Management	Y			Y						
26	Training & Awareness	Y	Y								
27	Energy Efficiency Role Defined	Y									
28	Continuous Improvement Program	Y									
29	Energy\CSR Policy	Y			Y						
30	Establish & Track Performance Against Targets	Y									
31	Performance Pay	Y									
32	Rationalize Operational Risk	Y									
33	Energy Efficient IT Procurement	Y	Y		Y			Y	Y		
34	Asset Refresh Rationalization	Y	Y		Y						
35	Customer Charge Back	Y									
36	External Air Cooling and Heat Reuse	Y			Y	Y			Y	Y	
37	Energy Efficiency Logging and Reporting				Y						
38	Rain Utilization for cooling				Y						
39	Modular type equipment for power and cooling						Y				
40	Row Cooling						Y				
41	Contain Server Racks (e.g. flex strip curtain)							Y	Y		
42	Measuring Efficiency (e.g. PUE)								Y		
43	Water Cooling (e.g. cooling tower, cold sea water)								Y		
44	Local UPS and PDU (not centralized)									Y	
45	Custom Reactor Power Panel									Y	

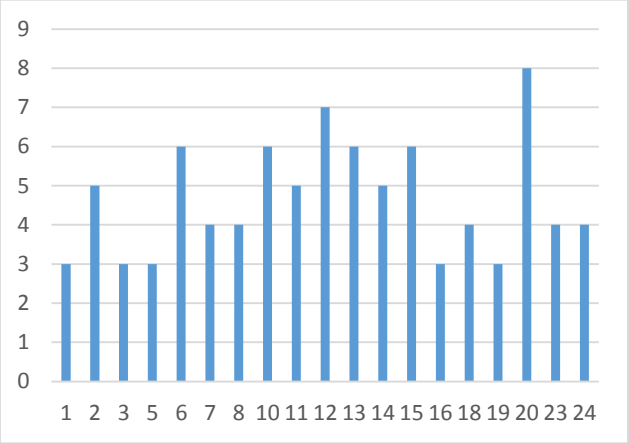


Figure 13: Most Accepted Energy Efficient Attributes

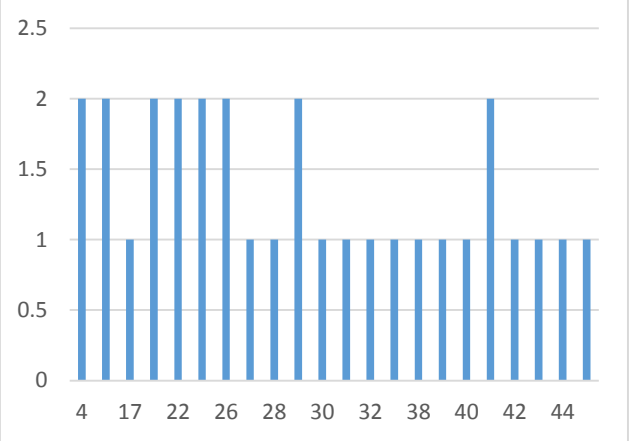


Figure 14: Most Uncommon Energy Efficient Attributes

Table 3: Free of Charge (FOC) Green Initiatives in Data Center

Free of Charge (FOC) Energy Efficient Data Centre initiatives	For New DC	For Existing DC
Enable Server Sleep Modes	Yes	Yes
Thermal set point	Yes	Yes
Tile Perforation Placement	Yes	Yes
Contain Server Racks (e.g. flex strip curtain)	Yes	Yes
Blanking Panels	Yes	No
Cable Management	Yes	No
Floor Cutout Seals	Yes	No
Equipment Placement & Orientation	Yes	No
CRAC Intake Placement	Yes	No
Data Center Zoning	Yes	No
Energy Efficient IT Procurement	Yes	No
Consolidation	Yes	No

Although Google and Facebook possess high recognition in energy efficiency within IT world, but their score in the comparison table do not reflect their reputation. With state-of-the-art data centers all around the world they are the "living proof" of what energy efficient data center should be, thus they should performed better. The reason behind this confusion is that we believe Google and Facebook only highlight the important and new initiatives that they adopt. Thus other energy efficient initiatives that are common to them are not emphasize in their website.

The most accepted and renowned energy efficient data center attributes as shown in Fig.13 is virtualization. This technology could reduce energy consumption in data center up to 40% but it must be planned, designed and configured properly. Otherwise this technology is just a "white elephant" in data center as for its high price. Fig.14 shows that more than a quarter of the total attributes only exist in one of the framework or guideline. There are two reasons for this matter, it is either the attributes have low impact to energy efficiency or the attributes are novel hence uncommon to general public.

Free of charge (FOC) green initiatives in data centers are highlighted in Tab.2. This list of initiatives is hopefully could motivate and assist every data center owners and managers in embracing green within their data centers. For existing data centers four initiatives could be immediately implemented without any cost in order to reduce energy consumption. Whereas new small and medium size data center owners and managers that would like to adopt green initiatives could implement these 12 initiatives without tampering their initial budget allocation.

Continuous Improvement (CI) in all components using Deming Cycle, Six Sigma or other methodologies as proposed only in GDCA is a vital attribute in this framework to ensure data center energy efficiency sustainable enhancement in the future. Among the aspects that should be focused are consolidation and rationalization [18]. Constant consolidation and rationalization on IT equipment and applications could optimize available resources, eluding needs for new one and the foremost achievement is shutting down of 'unprofitable' data center.

Another opportunity that could be taken into consideration in green data center framework for one season region is photovoltaic energy. This initiative needs quite an amount of CapEx but assure very minimal OpEx especially for the solar panel maintenance. Although the all year round sun assures free energy, data center owners unwillingness in adopting it as a secondary source of energy is an interesting issue to study.

Data center infrastructure management system (DCIM) is highlighted in [4] [18] as one of the solutions for problems in data center. Data center owners don't have to manage different systems for every infrastructure on site. The DCIM overseeing all the necessary components of the data center no matter of their vendor proprietary or silos issues through storing information, monitoring and generating reports.

Another technology that could be emphasized in reducing energy consumption is data compression and archiving [34]. Better compression and archiving technology could enhance data storing method by reducing the stored data size thus lessen the need for new storage despite the data growing trend. The compression and archiving on the other hand should take into account the processing time issue of the compressed and archived data otherwise the outcome will be back to square one.

Some of the attributes in improving energy efficiency in data centers demand for huge investment either in money or time. Unfortunately not every organization has the luxury of fund and time, therefore low cost version of green data center framework is needed. Despite minimal investment, the low cost type of framework should not compromise energy consumption reduction thus increasing the ROI. Optimistically the framework could be the foundation for every newly built data center because being efficient does not only impact the data centers stakeholders' pockets but also the environment.

V. Conclusion

This paper presents review of frameworks and guidelines that facilitate in building and governing green data centers. Excellent frameworks could provide data center stakeholders with decent green data center regardless of their budget. The frameworks should also cover all related aspects and components of data centers in achieving holistic impact. The green data center could be considered from low cost point of perspective. Small investment does not necessarily produced minimal impact, since some of the green attributes require less or even zero capital but could create relatively huge reduction in energy consumption thus increasing the return on investment (ROI). Works focusing on developing higher ROI attributes will definitely contribute in building more energy efficient and greener data center in the future. Besides that, study should also be conducted to find the 20% attributes that contributed to the 80% impact on energy efficiency in data centers. Several notable companies established excellent examples in greening their data centers thus setting high benchmark for the rest of us.

References

[1] A. Rallo, "Industry Outlook: Data Center Energy Efficiency." [Online]. Available: http://www.datacenterjournal.com/it/industry-outlook-data-center-energy-efficiency/.

[2] H. Parker, "Energy efficient data centres," *Alliance Trust Investments*, 2013. [Online]. Available: http://www.alliancetrustinvestments.com/sri-hub/posts/Energy-efficient-data-centres. [Accessed: 01-Jan-2015].

[3] P. Thibodeau, "EPA urges efficiency, many data centers still far from it," *Computer World*, 2014. [Online]. Available: http://www.computerworld.com/article/2490158/data-center-epa-urges-efficiency-many-data-centers-still-far-from-it.html. [Accessed: 01-Jan-2015].

[4] S. ONYSHKEVYCH, "Top Five Data Center Issues: DCIM To the Rescue," *Data Center Knowledge*, 2013. [Online]. Available: http://www.datacenterknowledge.com/archives/2013/01/08/top-five-data-center-issues-dcim-to-the-rescue/.

[5] "Industry Outlook: Data Center Energy Efficiency," *The Datacenter Journal*, 2014. [Online]. Available: http://www.datacenterjournal.com/it/industry-outlook-data-center-energy-efficiency/.

[6] "2014 Data Center Industry Survey," *Uptime Institute*, 2014. [Online]. Available: http://journal.uptimeinstitute.com/2014-data-center-industry-survey/. [Accessed: 01-Jan-2015].

[7] Green Data Center Alliance, "Data Center Energy Efficiency Framework," *New York State Energy Research & Development Authority*, 2010.

[8] Y. H. Said, S. Bergeon, S. Ploix, Q. H. Giap, and I. Dumitru, "Towards a global energy management within a data center," *11th International Conference on Electrical Power Quality and Utilization*, pp. 1–8, Oct. 2011.

[9] L. Wang, F. Zhang, J. A. Aroca, A. V. Vasilakos, K. Zheng, C. Hou, D. Li, and Z. Liu, "GreenDCN: A general framework for achieving energy efficiency in data center networks," *IEEE Journal on Selected Areas in Communications*, vol. 32, no. 1, pp. 4–15, 2014.

[10] "5 Reasons Why Building Your Own Data Center is a Terrible Idea.", Mosaic Network. [Online]. Available: http://mosaicnetworx.com/blog/5-reasons-why-building-a-datacenter-is-a-terrible-idea/.

[11] M. Uddin and A. A. Rahman, "Energy efficiency and low carbon enabler green IT framework for data centers considering green metrics," *Renew. Sustain. Energy Rev.*, vol. 16, no. 6, pp. 4078–4094, Aug. 2012.

[12] The Green Grid, "Guidelines for Energy-efficient Datacenters," *Green Grid White Paper*, 2007.

[13] "Using a Total Cost of Ownership (TCO) Model for Your Data Center," *Data Center Knowledge*. [Online]. Available: http://www.datacenterknowledge.com/archives/2013/10/01/using-a-total-cost-of-ownership-tco-model-for-your-data-center/.

[14] A. Mamane, "ReEngineering to a 'Green' Data Center, with Measurable ROI," *42 U Data Center. Solution.*, 2009.

[15] D. Meisner, T. F. Wenisch, and P. W. Peak, "Does Low-Power Design Imply Energy Efficiency for Data Centers ?," Proceedings of the 17th IEEE/ACM international symposium on Low-power electronics and design, 2011.

[16] J. Clark, "The Price for Datacenter Availability," *The Datacenter Journal*, 2011. [Online]. Available: http://www.datacenterjournal.com/design/the-price-of-data-center-availability/.

[17] "All You Need To Know About Tier Classification," *Lifeline Datacenters*, 2013. [Online]. Available: http://www.lifelinedatacenters.com/n1-data-center-redundancy/.

[18] "Gartner Outlines Eight Critical Forces to Shape Data Center Strategy," *Gartner Inc.*, 2013. [Online]. Available: http://www.gartner.com/newsroom/id/2629015.

[19] L. Lundstrom, "Everybody's doing it! Energy Efficiency and Herd Mentality," *Public Power*, 2011. [Online]. Available: http://www.publicpower.org/Media/magazine/ArticleDetail.cfm?ItemNumber=33046.

[20] M. Gunther, "How a Kindergarten Mentality Can Drive Energy Efficiency," *GreenBiz*, 2010. [Online]. Available: http://www.greenbiz.com/podcast/2010/01/20/how-kindergarten-mentality-can-drive-widespread-energy-efficiency?page=0,0.

[21] W. Nissen, "Fighting The Wallmart Mentality in Energy Use," *Minnesota 2020 Hindsight*, 2012. [Online]. Available: http://mn2020hindsight.org/view/fighting-the-walmart-mentality-of-energy-use.

[22] T. Wilde, A. Auweter, and H. Shoukourian, "The 4 Pillar Framework for energy efficient HPC data centers," *Computer Science Research & Development*, vol. 29, no. 3–4, pp. 241–251, Jul. 2013.

[23] L. Newcombe, "2014 Best Practices The EU Code of Conduct on Data Centers," *European Commission*, 2014.

[24] W. Lintner and B. Tschudi, "Best Practices Guide for Energy-Efficient Data Center Design," *U.S. Department of Energy*, 2011.

[25] Mueen Uddin, "Green Information Technology (IT) framework for energy efficient data centers using virtualization," *Int. J. Phys. Sci.*, vol. 7, no. 13, pp. 2052–2065, 2012.

[26] B. N. Rasmussen, "Implementing Energy Efficient Data Centers," *American Power Conversion*, 2006.

[27] "Top 12 Ways to Decrease Energy Consumption in Your Data Center," *Energy Star*, 2011.

[28] "Google Data Center," *Google Inc.*, 2014. [Online]. Available: http://www.google.com/about/datacenters/. [Accessed: 01-Jan-2015].

[29] J. Park, "Designing a Very Efficient Data Center," *Facebook Inc.*, 2011. [Online]. Available: https://www.facebook.com/notes/facebook-engineering/designing-a-very-efficient-data-center/10150148003778920. [Accessed: 01-Jan-2015].

[30] "12 Ways to Save Energy in the Data Center," *Energy Star*, 2014. [Online]. Available: http://www.energystar.gov/index.cfm?c=power_mgt.datacenter_efficiency. [Accessed: 20-Mar-2015].

[31] "Number of monthly active Facebook users worldwide as of 4th quarter 2014," *Statista*, 2014. [Online]. Available: http://www.statista.com/statistics/264810/number-of-monthly-active-facebook-users-worldwide/. [Accessed: 01-Jan-2015].

[32] "Energy Efficiency Best Practices," *42 U Data Center Solutions*, 2007. [Online]. Available: http://www.42u.com/efficiency/data-center-best-practices.htm. [Accessed: 01-Jan-2015].

[33] N. Mohd Nor and M. H. Selamat, "Review on Green Data Center Frameworks," *4Th World Congress on Information and Communication Technologies*, WICT, pg.338-343, 2014.

[34] "Data Center Management: Trends and Challenges," *Seagate:Tech Insight*. [Online]. Available: http://www.seagate.com/tech-insights/data-center-management-master-ti/.

Author Biographies

Norhashimi Mohd Nor is currently a PHD student at Department of Computer Science, Faculty of Computer Science & Information Technology, University Putra Malaysia. He received his Master degree in Computer Science (Software Engineering) from University Putra Malaysia in 2009. He published several papers on knowledge management, energy efficient scheduling and energy efficient data center. His research interest includes energy efficient data center, energy efficient scheduling and green cloud computing.

Associate Prof. Mohd Hasan Selamat works at The Department of Computer Science, University Putra Malaysia since 1979. He had published many research journal papers and had presented many more papers at regional and international conferences. He had authored several books and own patents. He was trained as software engineers but now his research interest include information system and computer security