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Energy-saving Framework for Data Center from Reduce, Reuse and Recycle Perspectives

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ABSTRACT

Recently, there is a heightened level of awareness towards energy efficiency in high-performance data centers both to reduce environmental pollution and save cost. Such data centers consume massive amount of energy for processing huge computational requirements from users. These supercomputers demand a constant supply of electricity to be available 24/7 for both its core computing functions as well as cooling the data center. Previously, researchers had introduced various strategies for achieving energy efficiency. However, in order to achieve a truly effective energy management, factors that influence energy usages must also be taken into consideration. The failure to manage such factors leads to excessive energy consumption. In this work, we shall focus on factors relevant to running the operation of high-performance data centers. We reconstructed and analyzed such factors or attributes based on the universally accepted Reduce, Reuse and Recycle Concept (3R). We recategorized energy attributes of the existing Energy Efficient Data Center Frameworks (EEDCFs) to be aligned with 3R. Then, we developed energy-saving algorithms in response to the concept. Our framework was then measured according to the performance metrics namely power usage effectiveness (PUE), energy reuse effectiveness (ERE) and carbon usage effectiveness (CUE) against variability size of data center. The simulation results of our EEDCF showed that better energy saving is achieved in comparison to the existing EEDCFs. This signifies that the application

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of the 3R concept in energy consumption yielded a promising result as a platform for other researchers to explore more on energy renewal initiatives and embrace it for future application.

Keywords: Data center, energy efficient framework, energy management, simulation.

INTRODUCTION

Data center concept has been around since the 1940's with the invention of Electronic Numerical Integrator and Computer (ENIAC) by the U.S Army to store artillery firing codes (Haigh et al., 2016). The distinctive space with special requirement to store ENIAC is assumed to be the first known data center. The ENIAC consumed 150 kW of electricity, weighted more than 30 tons and required more than 1,800 sq. feet of space. Before 1960, the data centers were owned by the government. However, collaboration between IBM and American Airlines in developing flight reservation system known as Semi Automated Business Research Environment (SABRE), had led to the outsourcing of data centers to the private sector (Head, 2002).

Since then, energy efficiency in data centers has improved vastly with the development of current state-of-the-art data centers in which their performance are being measured by million instruction per second (MIPS) over square feet of space. To strike a comparison, the earliest data center which accommodated the enormous ENIAC machine with more than 100,000 components was only less than 0.002 MIPS. Today, a single high-end desktop with Intel Core i7 can reach more than 200,000 MIPS (Bartels, 2011; Agarkar & Barve, 2016). However, energy consumption in data centers is still growing exponentially as shown in Figure 1. It is due to more than 5 million deployment of new servers every year to meet the increasing demand to support daily online activities (Bartels, 2011). Energy

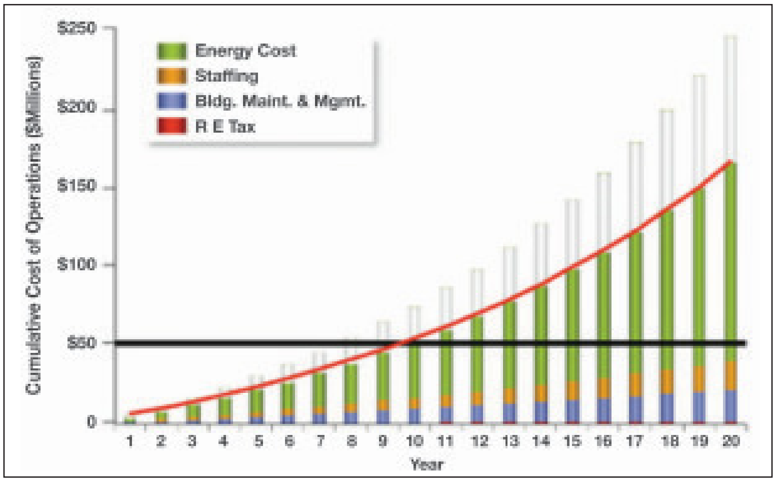


Figure 1. Cost of Data Centers Energy Consumption (Bartels, 2011)

in data centres is not only used to power up IT equipment but also to cool them down. As shown in Figure 2, an average 25% of energy consumption is being used by the Computer Room Air Conditioner (CRAC). Meanwhile another 50% of energy is required to run the servers and make sure they are available to process the users' tasks.

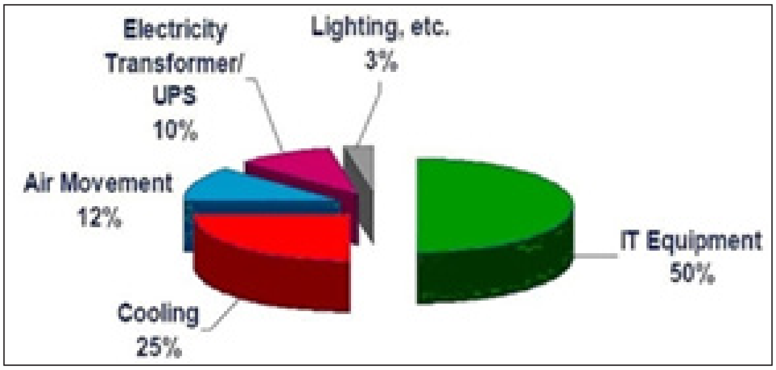


Figure 2. Energy Consumption in Data Centers (Weihl et al., 2011)

Energy efficiency in data centres is important goal for ICT industry in order to make sure the IT equipment effectively run without excessive heat as overheating leads to system degradation (Makaratzis et al., 2018; Oró et al., 2015). Therefore, it is important to ensure that energy consumption must be effectively monitored and appropriately solved. One strategy is to investigate factors/attributes that leads to energy consumption in data center. Guidelines for implementing energy efficient data center in (Oró et al., 2015) explained that quantifying electricity saving is simple. However the precise energy management decisions are still required from the top management. The author claimed that there is simple and no cost effort in planning data center utilization where it could save 20% to 50% of electrical bill while utilizing up to 90% resource availability. For example, in Information technology (IT) section, it can concentrate on software aspect for improving energy efficiency through several policies such as virtualization, consolidation, measurement and verification technology as well as enables servers sleep modes attributes. It further emphasized on analyzing and predicting an optimum return on investment (RoI) such as capacity management and right sizing, data center zoning, service level and availability management etc. Hence, investigating energy factors/attributes to create a better energy consumption in data center is the core issue; which is to be properly addressed far ahead before proposing the technical solution.

Extensive efforts have been dedicated for various frameworks that facilitate the development of high-quality green data centers. In this work, we studied the energy attributes for bringing new opportunity into efficient energy management. The results obtained show that the Reduce Reuse and Recycle (3R) approach towards green data center can achieve better energy efficiency for various sizes of data center. The remainder of this paper is organized as follows: Section 2 describes related work on existing energy efficiency frameworks and summarizes their attributes; Section 3 details the Reduce Reuse and Recycle (3R) concept used in the paper; our new energy efficient framework is presented in Section 4; Experimental settings and results are presented in Section 5; and Finally, Section 6 concludes the paper.

STUDY BACKGROUND

Data center's expert from government, industry and education sectors developed various energy frameworks for data center to decrease its negative impact to the environment and their finance while increasing energy resource availability. Various Energy Efficient Data Center Frameworks (EEDCFs) have been developed in order to reduce energy consumption. Those frameworks comprehensively cover a wide area of energy efficiency components. Some significant and openly available energy efficient data center frameworks are as follows:

- Data center energy efficiency framework (DCEEF) (Green Data Center Alliance, 2010),
- Guidelines for energy-efficient datacenters (The Green Grid, 2007),
- The EU code of conduct on data centers by European Commission (Newcombe et al., 2014),
- Best practices guide for energy-efficient data center design (VanGeet, 2011) and
- Green data center practices (Office of Government Chief of Information Officer, 2016)

We studied their framework in order to determine the essential energy attributes for better energy management. Note that some energy frameworks are a bit older but their works are still reliable and cited by many recent papers (Wan et al., 2018; Makaratzis et al., 2018; Constante-Flores & Illindala, 2019). The data center energy efficient framework (DCEEF) (Green Data Center Alliance, 2010) by Green Data Center Alliance (GDCA) is by far the most comprehensive framework for data centers. It covers five major principles particularly facility design & engineering, information technology, process, governance and finance. As an additional strength, the framework provides value for each attribute to represent their energy efficiency ranking in regards to their importance. However, this framework does not incorporate human resource factor as part of its blueprints.

Meanwhile, energy-efficient data centers guidelines by The Green Grid (The Green Grid, 2007) provides a brief presentation on promoting the importance of energy conservation thus convincing key stakeholders in adopting energy efficiency in data centers. The guideline is formed in a simple manner therefore suitable for top management for understanding the gist of energy efficiency in data center. The EU code of conduct on data centers by European Commission (Newcombe et al., 2014) is another comprehensive energy efficient data center framework being applied by developers. One of its major strength is the categorization of attributes into five different approaches i.e. entire data center, new software, new IT equipment, newly build or retrofit and optional practices. The categorization approach allows the framework to be adopted by existing non-energy efficient or newly built data center, further it facilitates data center developer in applying it. For clearer guidance, the framework also provides value for each attribute to represent level of energy efficiency and priority.

The best practices guide for energy-efficient data center design by U.S Department of Energy (USDE) (VanGeet, 2011) emphasized more on electrical factors since this is the source of the energy consumption. The framework best feature is the green metrics to benchmark data center level of energy efficiency. A formula designed to calculate the metrics is given together with the data center energy efficiency benchmark and status of achievement either standard, good or better. The benchmark could assist data center stakeholders in understanding their data center condition in term of current energy consumption and possibilities for reducing operational cost in the future.

In July 2016, Hong Kong Government Chief Information Office (CIO) had released green data center practices version 3.0 (Office of Government Chief of Information Officer, 2016). The data center practice is documented based on project lifecycle phases; design, procurement, operation and disposal. It is a well-defined framework hence easy for data center's stakeholders to execute it. However, energy efficient attribute is not explained in depth. Based on the existing EEDCFs, some of the energy attributes can be enhanced to improve energy efficiency. We did a thorough study of the energy efficiency framework and summarized energy attributes from existing EEDCFs (The Green Grid, 2007; Green Data Center Alliance, 2010; VanGeet, 2011; Newcombe et al., 2014; Office of Government Chief of Information Officer, 2016) as shown in Table 1. Note that there are only eight (8) out of 34 energy attributes that are established by all the frameworks i.e., attribute number 2, 7, 10, 12, 13, 14, 17 and 19. These attributes become the significant factor in the existing EEDCFs since 2007 to 2016; hence, we analyzed the attributes to be matched into our 3R concept in contributing towards energy efficiency. It also shows comparable list of energy attributes between Green Data Center Alliance (GDCA) frameworks and Hong Kong Green Data Centre version 3.0. Note that the GDCA is the most complete framework that complies with most of the energy attributes and follows by the framework from Hong Kong Government CIO Office as the second framework with complete energy attributes.

Table 1
Summarization of Energy Attributes

No	Attributes	A	B	C	D	E	Total
1	System Design	Y	Y	Y			3
2	Energy Efficient Lighting	Y	Y	Y	Y	Y	5
3	Dedicated Cooling Plant			Y	Y	Y	3
4	Thermal Imaging Camera	Y				Y	2
5	Temperature and Humidity Range			Y	Y	Y	3
6	Blanking Panels	Y	Y	Y		Y	4
7	Cable Management	Y	Y	Y	Y	Y	4
8	Tile Perforation Placement	Y	Y	Y		Y	4
9	Floor Cutout Seals	Y				Y	2
10	Equipment Placement & Orientation	Y	Y	Y	Y	Y	5
11	Thermal set point	Y		Y	Y	Y	4
12	Containment Solution (Cold or Hot Aisle)	Y	Y	Y	Y	Y	5
13	CRAC Intake Placement	Y	Y	Y	Y	Y	5
14	Energy Efficient UPS	Y	Y	Y	Y	Y	4
15	Variable Frequency Drives/Fan	Y		Y		Y	3
16	High Efficiency Thermal Insulation and Roofing	Y					1
17	Consolidation	Y	Y	Y	Y	Y	4
18	Measurement & Verification of Reporting	Y		Y		Y	3
19	Virtualization	Y	Y	Y	Y	Y	5
20	Enable Server Sleep Modes	Y	Y	Y		Y	3
21	Data Center Zoning	Y		Y		Y	3
22	Configuration Management & Orphaned Servers	Y	Y			Y	3
23	Capacity Management & Right Sizing	Y	Y			Y	3
24	Service Level & Availability Management	Y		Y			2
25	Training & Awareness	Y	Y				2
26	Energy Efficiency Role Defined	Y					1
27	Continuous Improvement Program	Y				Y	2
28	Establish & Track Performance Against Targets	Y				Y	2
29	Performance Pay	Y					1
30	Rationalize Operational Risk	Y					1
31	Energy Efficient IT Procurement	Y	Y	Y		Y	4
32	Asset Refresh Rationalization	Y	Y	Y		Y	4
33	Customer Charge Back	Y					1
34	External Air Cooling and Heat Reuse	Y		Y	Y		3
	Total	32	17	22	12	25	

Legend:
A = Green Data Center Alliance;
B = Green Grid;
C = European Commission (EUCC);
D = U.S Department of Energy; and
E = Hong Kong Government CIO Office.

REDUCE, REUSE AND RECYCLE (3R) PERSPECTIVE FOR GREEN DATA CENTER

Reduce, Reuse and Recycle; or widely referred as the 3R concept is being applied in our work as the main principle in environmental conservation and provide basic procedures in executing it. The idea of reducing, reusing and recycling has been around in our daily life for years, and it is a successful shift to the environment (Ramesh et al., 2010). In this work, we embraced the essence of 3R to improve energy efficiency in data center. The 3R concept could be associated with significant data centers energy efficient metrics: power usage effectiveness (PUE), energy reuse effectiveness (ERE) and carbon usage effectiveness (CUE) (Murugesan, 2008; Singh & Vara, 2009; Guo et al., 2014) respectively. We represent the PUE with reduce approach because it measures the efficiency of electricity usage towards data centers' productivity (De Courchelle et al., 2019). The ERE is associated with reuse approach because it measures the level of energy reuse in data centers. While the CUE is associated with recycle approach by measuring how much a data center could decrease carbon footprint by using renewal energy. Thus, the 3R concept with the respective metrics is able to observe the gaps that could be addressed by the energy efficiency attributes.

Based on study from Table 1, we matched and mapped the attributes according to the 3R concept. In preliminary study, we have analyzed the existing EEDCFs (The Green Grid, 2007; Green Data Center Alliance, 2010; VanGeet, 2011; Newcombe et al., 2014; Office of Government Chief of Information Officer, 2016) by studying and understanding their energy attributes. The process of analyzing is based on the data centers energy efficient metrics that was mentioned previously (i.e., PUE, ERE, CUE). Specifically, we matched the attributes with the factor used in the metrics. The output from our preliminary study as shown in Table 2 proves that most of the energy attributes are related to reduce factor with only one attribute belonging to the reuse aspect. There is no attribute that could be associated with recycle approach. Such output then helps us in designing the EEDCF with 3R concept as described in the following Table 2.

Table 2
Energy Attributes maps 3R Concept

No.	Attributes	Approach
1	System Design	Reduce
2	Energy Efficient Lighting	Reduce
3	Cooling Plant	Reduce
4	Data Center Building	Reduce
5	Infrastructure, power and performance monitoring	Reduce
6	Blanking Panels	Reduce
7	Cable Management	Reduce
8	Tile Perforation Placement	Reduce
9	Floor Cutout Seals	Reduce

Table 2 *(continue)*

No.	Attributes	Approach
10	Equipment Placement & Orientation	Reduce
11	Thermal set point	Reduce
12	Containment Solution (Cold or Hot Aisle)	Reduce
13	CRAC Intake Placement	Reduce
14	Energy Efficient UPS	Reduce
15	Variable Frequency Drives/Fan	Reduce
16	High Efficiency Thermal Insulation and Roofing	Reduce
17	Consolidation	Reduce
18	Measurement & Verification Technology	Reduce
19	Virtualization	Reduce
20	Enable Server Sleep Modes	Reduce
21	Data Center Zoning	Reduce
22	Configuration Management & Orphaned Servers	Reduce
23	Capacity Management & Right Sizing	Reduce
24	Service Level & Availability Management	Reduce
25	Training & Awareness	Reduce
26	Energy Efficiency Role Defined	Reduce
27	Continuous Improvement Program	Reduce
28	Establish & Track Performance Against Targets	Reduce
29	Performance Pay	Reduce
30	Rationalize Operational Risk	Reduce
31	Energy Efficient IT Procurement	Reduce
32	Asset Refresh Rationalization	Reduce
33	Customer Charge Back	Reduce
34	External Air Cooling and Heat Reuse	Reuse

Reducing CRACs Energy Consumption

Based on Electronics Cooling Magazine (Iyengar & Schmidt, 2010), Computer Room Air Conditioner (CRAC) on average consumes more than 25% from data center's total energy consumption. Therefore, it is expected that by emphasizing on reducing CRACs energy consumption enables for achieving efficient energy management. In this work, the reduced aspect would benefits CRACs where normally high electrical energy is consumed for cooling purposes. In this work, we propose *Energy Reduce* as part of energy attribute in our framework. The reduced aspect relied on the range in thermal setting point that referring to ASHREA guideline (David & Schmidt, 2014). It aims to exploit data center's current processing burden in order to efficiently regulate the CRACs operation. Thorough description on *Energy Reduce* attribute is provided in the next section.

Reusing Waste Heat

Based on Table 2, there is lack of reuse component in the existing EEDCFs. Only attribute number 34; *External Air Cooling and Heat Reuse* has mentioned in Green Data Center Alliance (GDCA) (Green Data Center Alliance, 2010) for heat reusing. In their work, the attribute is highlighted to utilize the existing external air cooling and heat for reusing the waste heat in energy management. Such attribute is only beneficial for energy management system when the data center allocated in countries with temperate climate. It is because they able to exploit the waste heat during cold weather days. Meanwhile, for data centers located in other regions, the heat reuse attribute is impractical. Therefore, we propose the application of *Energy Reuse* attribute to convert waste heat into electricity all year long throughout the world.

Recycling Resource by Harvesting Renewal Energy

The initiation of recycle aspect into energy efficient data center can lead to harvesting renewal energy for data center's operation. There are several prominent organizations such as Google (Google, 2014; Google, 2016), Facebook (Park, 2011) and Microsoft (Smith, 2016) that have successfully harvested renewal energy for their data centers' usage. The impact to their budget and reputation is so encouraging that some of these organizations have targeted to be 100% renewal energy dependable. However, in the existing EEDCFs there is no energy recycle attribute. In our work, we propose *Energy Recycle* as a new attribute in the EEDCF. The recycle attribute utilizes solar and wind energy for data centers usage as further elaborated in next section.

THE APPLICATION OF 3R CONCEPT IN ENERGY EFFICIENT DATA CENTER FRAMEWORK

We introduced three groups of energy attributes for data center that in previous section i.e., *Energy Reduce*, *Energy Reuse* and *Energy Recycle*. In this section, we shall thoroughly explain features of each attribute and on how it is applied to be factored into the energy efficient data center framework.

Our EEDFC algorithm; as shown in Figure 3 consists of three models that represent 3R attributes through Pre-CRC model, H2E model and SW2E model. Specifically, the EEDFC algorithm consists of three different models that represent the concept of reduce, reuse and recycle. The significant input for the algorithm is data-center temperature reading and air conditioner saving. Both inputs are collected through prior designed functions, called as thermal setting point and heat reuse. Once, the input is collected, the algorithm then started to execute the sub-algorithm to represent 3R model, where it is started in sequence. Firstly, Pre-CRC model, secondly, H2E model and lastly, SW2E model. Details of each models are presented in Section 4.1, 4.2 and 4.3, respectively. The EEDFC algorithm is sequentially executed due to it mainly aims for reducing the energy consumption. It then follows by reusing the wasted energy that released from the Pre-CRC model. In the last model, our solution aims for reutilizing the external energy by recycling it and used in the data center. The models are embedded together into EEDFC algorithm where in prior those models are independently operated. We run the simulation for different type of data center (i.e., small, medium and large) according to simulation setting (detail in Section 5).

1: Require: Data center workload dataset
2: Ensure: The randomization of data center workload dataset is within maximum and minimum bound.
3: **For** small data center **To** large data center
4: **For** the first hour **To** the 24th hour
5; Calculate total data center energy consumption based on simulation setting
6: Calculate energy consumption of CRAC based on preset data center temperature. (Function: ThermalSetPoint)
7: Calculate the energy saving from office air conditioner (Function: HeatReuse)
8: Calculate precise energy consumption of CRAC based on the PreCRC Simulation.
9: Calculate generated electricity from waste heat based on the H2E Simulation.
10: Calculate generated electricity from renewal energy based on the SW2E Simulation.
11: **Next** hour
12: **Next** data center size
13: **Return** simulation result (PUE, ERE, CUE and energy saving)

Function: ThermalSetPoint
1: Require: Data center workload dataset
2: Ensure: The randomization of data center workload dataset is within maximum and minimum bound.
3: **For** 1R EEDCF **To** 3R EEDCF
4: Calculate the energy consumption of CRAC based on thermal set point (highest allowable temperature)
5; Get ccumulated CRAC energy consumption
6: **Next** EEDCF type
7: Get the difference between Accumulated normal practice CRAC energy consumption and accumulated thermal set point CRAC energy consumption
8: **Return** simulation result (energy saving)

Function: HeatReuse
1: Require: Data center workload and outside temperature datasets
2: Ensure: The randomization of data center workload dataset is within maximum and minimum bound.
3: Calculate the energy saving from office air conditioner since excess heat from data center is used to warm the office area. (only applicable in cold days)
4: Get accumulated office air conditioners saving.
5: **Return** simulation result (energy saving)

Figure 3. EEDFC algorithm

Energy Reduce – Pre-CRC Model

The *Energy Reduce* attribute focuses on improving data centers energy efficiency by reducing CRACs energy consumption. It is based on the 11th attribute (Table 2) which is thermal set point. The purpose of thermal set point is to adjust the data center's temperature to the highest limit but still within the allowable range established by ASHREA guideline (David & Schmidt, 2014).

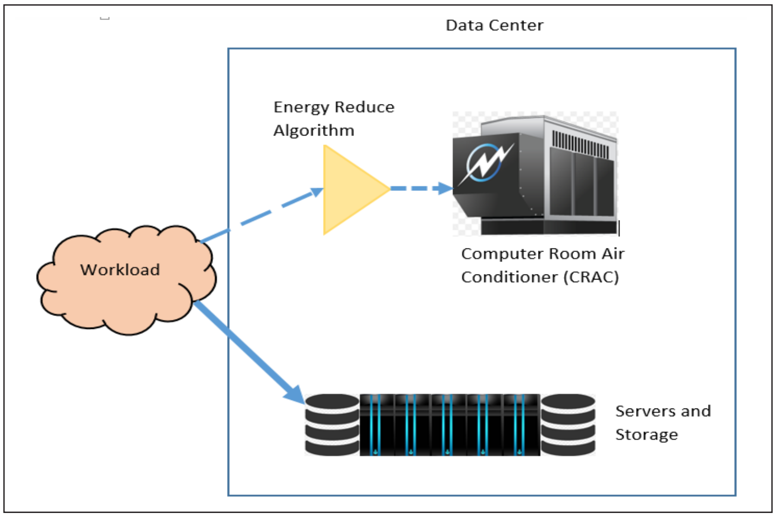


Figure 4. Precise cooling requirement for CRACs (Pre-CRC) Model

We propose Precise Cooling for CRACs (Pre-CRC) model as shown in Figure 4 by utilizing the data center's current processing burden as a parameter/threshold that regulates the CRACs temperature controller. The data center information is represented by the number of running servers. The temperature controller is then dynamically monitored and adjusted based on the limit processing threshold. It aims to ensure the cooling temperature reached is at the most suitable degree for running IT equipment.

The number of servers is stated in experiment setting where it depends on the size of the data center. Specifically, at a peak processing time, when most of the servers are busy executing, the CRACs cooling temperature will be minimized. In low or medium processing states, the CRACs temperature are then adjusted accordingly. By getting accurate cooling temperature supplied, the Pre-CRC model does not only reduce the CRACs energy consumption, but also prolong the IT equipment lifecycle by not being overheated. In our model, the processing threshold needs to be preprogrammed prior to match with the CRACs' temperature controller.

Energy Reuse – H2E Model

The *Energy Reuse* attribute in our framework is developed based on the 34th attribute in Table 2; *External air cooling* and *heat reuse* attribute. There are couple of ways for converting heat into electricity, such as by using thermoelectric (Ward et al., 2012) and steam turbine (Esmaeili et al., 2017). Basically, electricity generated in thermoelectric generator moves electrons from hot to cold area. For the best result and achieved high

Carnot efficiency (Mongia & Abdelmoneum, 2010), the hot plate needs to be extremely hot and the cold plate needs to be very cold. However, in the data center its waste heat is low thus it is inefficient for the CRAC to produce excessive cold air. In other technique, the steam turbine reuses the waste heat by converting water into steam which in turn, moves the turbine generator to produce electricity. However, the same problem with the thermoelectric approach arises when the waste heat is low thus it could not boil the water to steam (Yongbing et al., 2012; Newcombe et al., 2014; Paulides et al., 2015).

Hence, we invent a model called as a Heat-to-Electricity (H2E) strategy as shown in Figure 4. It aims to increase the heat intensity until it could boil the water and turn it into steam. The H2E strategy will estimate the amount of electricity that the data center could generate. The total heat is then calculated from all data center equipment. In order to solve the low-grade energy issue, we utilize the heat pump once the heat temperature reaches 110^{o}C. According to the authors in (Yongbing et al., 2012) the best suitable degree to start pumping the turbine is when it reached 100 to 120^{o}C. Only after that it could be manipulated to drive the steam turbine to generate electricity. It is where the high-pressure steam is channelled through nozzles to the turbine for spinning the blades. The spinning blades in the turbine connected to the generator, thus it generates electricity. Such connection is expected to occur for every type of data center from day one until the last day in a year for producing net electricity.

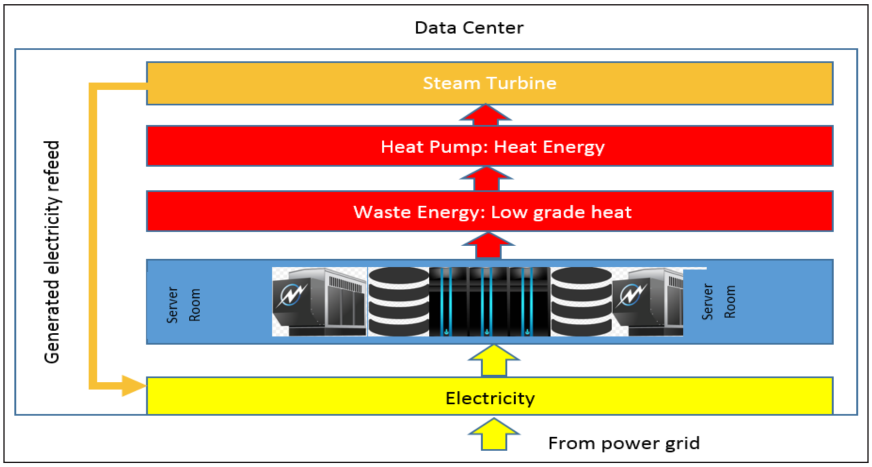


Figure 5. Heat to Electricity (H2E) Model

Energy Recycle – SW2E Model

Solar and wind are the two most common renewable energy harvested for commercial and home usage after hydroelectric (Agarkar & Barve, 2016; Kalla et al., 2018). They are recycled into electricity then form a hybrid of renewal energy for data centers. The advantage about hybrid renewal energy is that they are able to complement each other in ensuring a continuous power supply to data centers. Hence, we invent Solar & Wind to Electricity (SW2E) model where solar or photovoltaic cell is to be used to convert sunlight into electricity while micro turbine transforming wind into electricity as shown in Figure 6. The generated electricity is then re-feed into the data centers electrical supply together with the commercial electrical grid. It is assumed that sunlight is available for 12 hours a day and wind is available intermittently for 24 hours throughout the year.

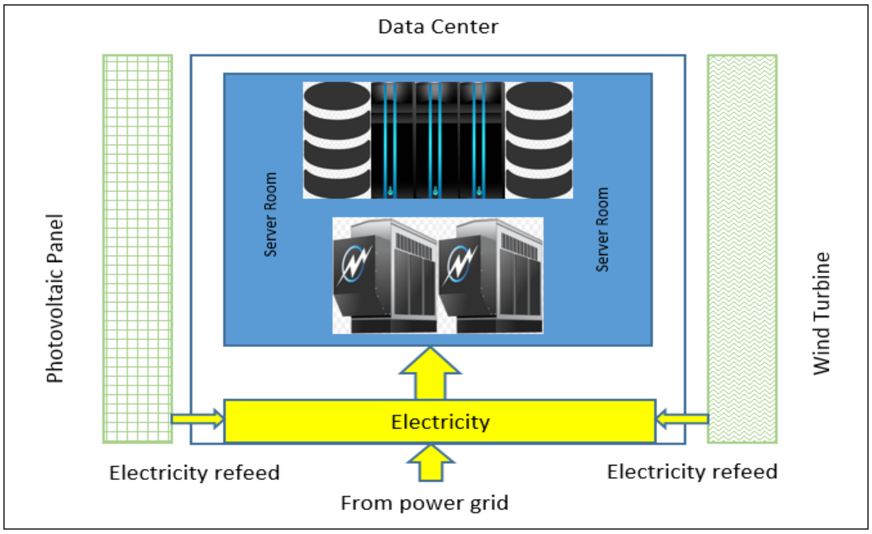


Figure 6. Solar and Wind to Electricity (SW2E) Model

EXPERIMENT SETTING

We conducted simulations using a diverse set of data center infrastructures to evaluate the performance of 3R concept towards energy efficiency. These simulations were carried out as part of our comparative study between 3R EEDCF and other frameworks; where the description are shown in Table 3. The 1R EEDCF represents only one energy attribute (*Reduce attribute*) similar with the Green Data Center Practices by Hong Kong Government Chief Information Office (CIO) that considered merely reduce attribute. The 2R EEDCF represents EEDCFs with *Reduce* and *Reuse* attributes such as from Green Data Center Alliance, Green Grid, EUCC and USDE. For fair experiment setting, there is only attribute number 1 which is thermal set point chosen to exemplify the 1R EEDCF. The 2R EEDCF on the other hand is demonstrated by attribute number 11 (thermal set point) and 34 (heat reuse). The 3R EEDCF include thermal set point, heat reuse and hybrid renewal components; as shown in Table 3.

Table 3
Energy Efficient Data Center framework simulation

	Energy Efficient Data Center Framework (EEDCFs) Benchmarking Architecture		
	1R EEDCF	2R EEDCF	3R EEDCF
Attributes	1. Existing Reduce Attribute: No. 11- Thermal Set Point	1. Existing Reduce Attribute: No. 11- Thermal Set Point 2. Existing Reuse Attribute: No. 34-Heat Reuse	1. New Recycle Attribute 2. New Reduce Attribute 3. New Reuse Attribute 4. Existing Reduce Attribute: No. 11-Thermal Set Point

Characteristic and setting of each data center size (Table 4) is determined by number of servers that hosted in (Patterson et al., 2010). In particular, the quantity of servers leads to amount of required Computer Room Air Conditioner (CRAC). It is because a total cooling capacity of the CRACs is equal or slightly more than total heat emission by the servers (Patterson et al., 2010). Other hardware quantity such as switches, uninterruptible power supply (UPS) and power distribution unit (PDU). in each data center size are also determined by the number of servers. The simulation hardware works on an ordinary core i5, 4G RAM desktop.

Table 4
Simulation setting for Energy Efficient Data Center benchmark

Data Center Equipment	Data Center Size/Equipment Energy Usage					
	Small		Medium		Large	
	Unit	Watt	Unit	Watt	Unit	Watt
Servers	32	750	192	750	515	750
Storage	1	2300	1	4300	1	7300
Core Switch	2	2500	2	4000	2	8700
Rack Switch	6	278	26	278	70	278
Router	2	200	2	200	2	200
Server Rack	3	0	13	0	35	0
CRAC	2	15000	9	15000	23	15000
UPS	6	100	26	100	70	100
PDU	6	10	26	10	70	10
Lighting	10	15	40	15	106	15

Our simulation system evaluates energy usage according to power usage effectiveness (PUE), energy reuse effectiveness (ERE), carbon usage effectiveness (CUE) that been used in (Jaureguialzo, 2011; Moore et al., 2016)**,** as given below:

$$\text{Power usage of effectiveness (PUE)} = \frac{\text{Total data center energy consumption}}{\text{Total IT equipment energy consumption}} \quad (1)$$

$$\text{ERE} = \frac{\text{Total DC energy consumption} - \text{Reuse energy}}{\text{Total IT equipment energy consumption}} \quad (2)$$

$$\text{CUE} = \frac{\text{Total CO2 emissions caused by total DC energy consumption}}{\text{Total IT equipment energy consumption}} \quad (3)$$

RESULT AND ANALYSIS

The simulation results are presented and analyzed in the following sections. We analyzed the energy consumption into two different motivates towards better energy saving which are energy attributes and size of data center.

Impact of Energy Saving Attributes

From Figure 7 the PUE, ERE and CUE is plotted with respect to different frameworks (i.e., 1R, 2R and 3R EEDCFs). Remarkably, the 3R EEDCF shows significant operational expenditure reduction through energy saving of more than 8% compared to 1R EEDCF or nearly twice the energy saving of 2R EEDCF. It is due to the 3R EEDCF utilized recycle attribute that consumed less dependability on direct electricity grid. Moreover, the 3R EEDCF presents the lowest CUE which means the least amount of carbon emission to

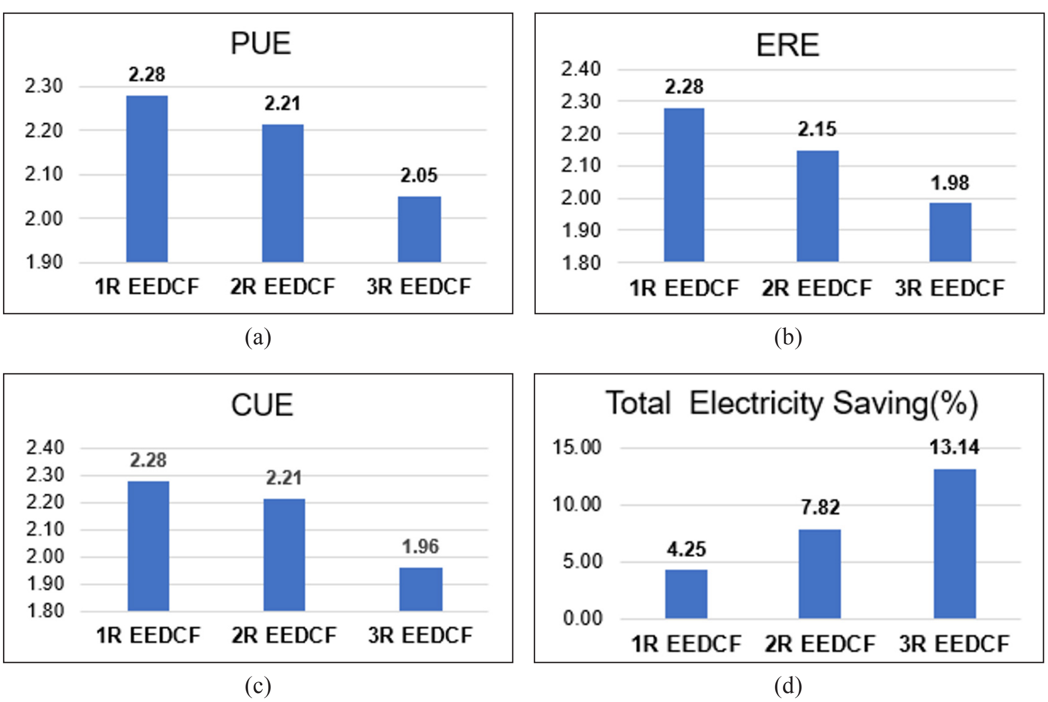
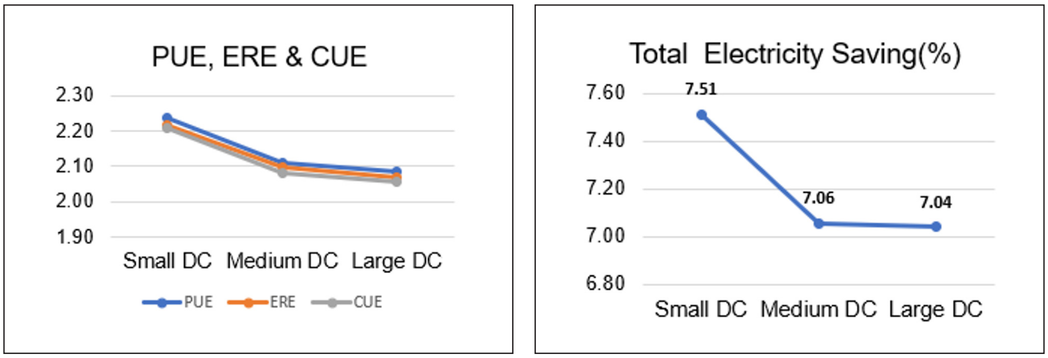


Figure 7. Average of simulation result

operate data center compared to 2R EEDCF and 1R EEDCF. It is concluded that the additional 3R concept in EEDCF reveals a good point since most of the energy spent in the data centers contributes to the system performances and productivity.

Impact of Data Center Sizes

Results shown in Figure 8 indicate that PUE, ERE, CUE and energy saving performance are reducing from the small data center to the large data center. It is surprising that the big data centers are more energy efficient compared to small data centers through 3R EEDCF. The reason behind this could be because it is easier to control energy consumption of larger data centers compared to smaller one. It is expected that there are low percentages of utilization in small data center due to many equipment are idle. Hence, it consumed more energy for sake of IT equipment availability with the cooling system staying active. In other word, the 3R EEDCF can be effectively applied for large-scale data center to achieve better energy saving.



(a) (b)

Figure 8. Simulation result for different sizes of Data Center

CONCLUSION

Energy efficient data center framework is essential in promoting green awareness to conserve the environment and reduce operation cost. There are existing Energy Efficient Data Center Frameworks (EEDCFs) that concern on cutting-edge attributes in embracing green concept in the data centers. Furthermore, thorough deliberating of energy attributes in energy management offers potential enhancement in energy saving. In this work, we utilized the concept of reduce, reuse and recycle (3R) in the energy attributes for better energy saving. Specifically, the 3R attributes (i.e., *Energy Reduce*, *Energy Reuse* and *Energy Recycle*) are incorporated into the energy saving algorithms (i.e., PreCRC model, H2E model and SW2E model) to form 3R EEDCF. The simulation analysis shows that the 3R EEDCF gains more energy efficient compared to 1R and 2R EEDCFs. Optimistically, there are other opportunities to further enhance energy-saving by considering other energy extent qualities such as cabling, lighting, processing loads etc. into energy management.

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