



Data Centre Energy Efficiency Benchmarking

Final Report

**Benchmarking summary, findings, and final
conclusions of audited data centres
submitted to**

National Environment Agency (NEA)

September 2012

I. Management Summary

Overview

The benchmarking study was commissioned by the National Environment Agency (NEA) and supported by the Infocomm Development Authority of Singapore (IDA). It is an initiative of the Energy Efficiency Programme office (E2PO), which seeks to establish an understanding of the local landscape of DCs by assessing the energy performance of selected DCs as well as surveying DC operations and manpower capabilities. The study covered the 3 main components of energy consumption in a DC, namely IT load, electrical load, mechanical and auxiliary load. It discusses about the main causes of inefficiencies, as well as recommends improvement actions and best practices to minimize overall energy consumption. In addition, the study provides guidelines on the achievable Power Usage Effectiveness (PUE) figure for Singapore.

The benchmarking study work began in June 2010 with the development of an Energy Assessment Framework (EAF) for the data centre buildings in Singapore. The EAF consists of methodologies and processes for data centre operators in Singapore to evaluate their data centres from an energy and sustainability perspective. The EAF presents globally harmonised and accepted metrics to evaluate the data centre efficiency. These metrics include energy utilization metrics such as the PUE, mechanical PUE, electrical PUE, percentage of cooling system energy use, percentage of UPS energy loss, Carbon Usage Effectiveness (CUE) and air management metrics such as bypass, recirculation air flow ratios and others.

Energy assessments were conducted at 23 data centre sites in Singapore. The energy assessments covered the key components of energy use in a data centre (IT loads, electrical loads and mechanical and auxiliary loads), operation and maintenance practices, manpower capability in terms of energy management, and recommendation of actions or strategies for improvement.

Following the established procedures in the energy assessment framework, the benchmarking of the 23 data centre sites in Singapore was done, as well as the benchmarking to similar data centres in other parts of the world. A list of energy efficiency best practices for design and operation was also generated for data centres in Singapore.

This report presents a summary of the findings from this benchmarking study.

Singapore Data Centres' Energy Usage

It is estimated that the total electrical energy usage of data centres in Singapore for the year 2010 is 3.6% of Singapore's total electrical energy consumption. This is a significant percentage of the country's total consumption and will continue to increase over the coming years. Furthermore, the energy consumption demand of data centre buildings is estimated to grow to 2,260 GWh by 2015, which is a 51% increase over 5 years from 2010's consumption. More details on these figures can be found on this report, page 11 of Section 1.

Benchmarking Results and Findings

Power Usage Effectiveness (PUE)

A sample of 23 data centres was selected to cover a range of characteristics such as type of industry, public and private, governmental and institutional facilities, various Uptime Institute Tier levels, various cooling and power infrastructure topologies, various sizes and ages.

Average PUE

Benchmarked to date, Singapore data centres have an average PUE of 2.07, which is considered consistent compared to those in the United States (PUE=2.2, average of 75 sites) and the European Union (PUE=2.02, average of 25 sites). This finding indicates that although Singapore data centres are located in a hot and moist climate, they are operating at a similar efficiency level compared to data centres located in cooler climates.

Electrical PUE

The electrical PUE for the sites ranged from a low 1.15 to a high 1.64 with an average of 1.26 for all sites. The average electrical PUE is comparable to EMEA (Europe Middle East Africa – 1.28) and the United States (1.32).

Mechanical PUE

The average mechanical PUE value across the 23 sites is 0.80, which is slightly higher than European counterparts (0.74) and lower than the United States (0.88).

Equipment and Capacity Utilisation

There is tendency for both mechanical and electrical systems to be either oversized or under loaded versus their intended designed capacity. Factors that attributed to this condition were over buffering of designed capacity, lack of both strategic roadmap and accurate forecasting model to determine IT growth over time, as well as the effect of business and strategic direction changes.

Mechanical Equipment – Cooling

The study found that all the sites employed refrigerant-based mechanical cooling systems for heat removal from the data centre room. 65% of the sites employed air cooled direct expansion type computer room air conditioning (CRAC) units, 22% uses water cooled chillers and the remaining 13% uses air-cooled chillers.

The findings showed that the primary cause of a higher mechanical PUE level was due to under loading and poor operating practices, regardless of the type of cooling system the site adopted.

Sites using water-cooled chillers were found to have the lowest average mechanical PUE, followed by CRAC and air-cooled chillers.

Electrical Equipment – Uninterrupted Power Supply (UPS) Systems

The primary factor that influences the electrical PUE value is UPS efficiency, which is highly dependent on its utilisation factor and optimum operating efficiency. On the average, UPS losses accounted for around 53% of the electrical system loss, while distribution and transformer losses accounted for around 37% and lighting accounted for the remaining 10% of the electrical system losses.

The study found that the average UPS utilisation for all sites is 27.4% (utilisation range: lowest at 5% and highest at 89%) with an average UPS efficiency of 87.6% (efficiency range: lowest at 76.5% and highest at 94.5%). For higher UPS utilisation rate of 50% or more, it is possible for the UPS efficiency to be 95% or higher.

It was also found that the average Information and Communication Technology (ICT) power load density is 0.37 kW/m², which is much lower than the average designed load density of 1.01 kW/m². This indicates that most of the data centres have oversized UPS systems or an excess of capacity as compared to their actual ICT load.

Air Management

Based on 37 data halls/rooms assessed in the study, the average air mixing bypass and recirculation flow ratios are 0.38 and 0.35 respectively. Data centre owners should aim for a ratio value below 0.25, which can be achieved through the adoption of air management, design and operation best practices.

This indicates that there is a tremendous opportunity to minimize the mixture of the hot air and the cold air. A few data centres with lower air mixing were observed to have CRAHs located in galleries outside the data centre with a ceiling air return plenum, a comprehensive implementation of blanking panels and cable brushes, high ceiling, and a servers' intake temperatures of above 21°C. In general, these centres have most of the best practices implemented. All the sites in the study used raised floor plenums as a primary method of cold air delivery to the IT equipment.

Most of the site owners are aware of the issues coming from the lack of good air management practices. However, there is still a lack of determined effort to correct them. The owners' lack of action to correct these air management issues can be attributed to the following:

- Difficulty in tracking and verifying the changes in the environment (air temperature).
- Concerns of upsetting the existing balance being achieved in air temperature stability.

Please refer to Section 3.3 of this report for more details on air management practices and recommendations.

Staffing and Capability to Implement Energy Management Programs

Majority of the sites (77%) have in-house personnel who are aware and have some technical proficiency with regards to the implementation of energy management programs for their facilities. Close to 20% of the sites have full capability to initiate and implement energy management and reduction programs while slightly over 50% of the sites can initiate and implement programmes with assistance from 3rd party consultants.

The remaining data centres have no capability at all and are reliant on third party assistance to assess, initiate and implement the programs. However, with some training and knowledge transfer, their staff members should be able to take on some form of energy management activities to track and implement energy usage reduction programs.

In terms of ability to measure and track energy usage, only 23% of the sites are capable of tracking the sites energy usage and PUE. 45% of the sites use digital power and demand meters in their electrical systems but will require additional upgrading to enable the ability to record the demand and track their PUE.

The remaining 30% of the sites do not have the ability to track energy demand due to the design of their electrical systems, which made very little, if not no use of digital power meters. These sites will require intensive upgrading in order to have some form of rudimentary ability to track the overall PUE.

Any form of energy management program requires the tracking of energy usage, hence the lack of the means to track energy usage will derail all such programs. There is an urgent need for data centres to address this lack of energy metering. The installation of power monitoring and recording devices should have an increased priority, similar to the priority level applied to the energy reduction measures implemented on the cooling or electrical systems.

Economics of Energy Usage Reduction Programs

The 23 data centres were grouped into three categories based on their sizes. For small data centres (up to 300m²), reduction of the PUE from 2.18 to 1.94 would require a small investment of about S\$45,750, which on average, would be paid back in about 1.75 years and result in an annual abatement of 69 tons of carbon dioxide (CO₂). Please refer to the tables in Section 9 for more details.

Medium data centres (301 to 1000 m²) would require an average investment of \$81,000 for a reduction of PUE from 2.06 to 1.81, and annual abatement of 132 tons of CO₂. The payback period is 1.68 years. On the other hand, large data centres (>1000 m²) would require an average investment of \$1,881,000 for a reduction of PUE from 2.07 to 1.73, and annual abatement of 758 tons of CO₂. The payback period is 4.2 years.

The main areas of investment for all the data centres are in the air management accessories and air conditioning systems upgrades.

Achievable PUE level for Singapore

Existing Data Centres

The study found that on average, existing data centres would be able to reduce their energy consumption by 10%. This will result in an average PUE of 1.94 for small data centres, 1.81 for medium sized data centres, and 1.73 for large sized data centres.

New Data Centres

New data centres of any size using conventional air delivery approach (CRAHs/CRACs) would be able to achieve a PUE of 1.69 or better at full load. Furthermore, it is possible for Singapore data centres to achieve a PUE of 1.33, using non-conventional air delivery approach in combination with water cooled chillers (Refer to Section 9.2)

Conclusion

This study found that most of the shortcomings of Singapore data centres in energy usage were primarily caused by the lack of good air management practices, leading to higher energy demand from the cooling systems. The other attributing factor is the under loading and poor operating practices of the equipment such as the chiller and UPS systems, which significantly reduced the energy efficiency of these equipments.

The average PUE level of the data centres in Singapore can undoubtedly be further improved in the future with the rightsizing of equipment to closely match the IT power and cooling load of the data centre. Good design techniques and the use of highly efficient equipment will also help to improve the PUE levels.

However, the far more important factor that has a great impact on energy usage is operating practices. The adherence and implementation of good operational practices in air management, accompanied with the willingness to operate in the upper range of the recommended temperature and humidity level, and the operation of data centre with just the required reliability configuration that matches business availability requirements, are needed in order to achieve the highest level of performance in the data centre.

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Key Contributors

Department	Role	Name
HP CFS	Consultant	Munther Salim, Ph.D.
HP CFS	Consultant	Robert Pe

Approval / Verification

Role	Date	Name
Global Energy & Sustainability Practice Leader	09/06/2012	Munther Salim, Ph.D.

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1. Introduction

1.1. Data Centre Energy Usage in Singapore

Data Centres consume an immense amount of power to perform functions reliably and effectively. The electrical costs in data centres typically accounts for 40-60% of the total operating costs. Improving energy efficiency of a data centre is extremely beneficial - it reduces the costs of operation and at the same time, lowers the environmental impact of the facility.

There was no official survey or study conducted by government or any private organisation in Singapore to determine the energy demand and usage of data centres in Singapore. Hence, the energy demand of Singapore data centres is estimated by using the Singapore average IT load density, the total area of data centre in Singapore, average PUE value and assuming data centres operate 8760 hours a year, to get the total annual energy usage in kWh.

The estimated data centre space in Singapore for the year 2010 is 222,829 square meters. This is based on a survey done by Broadgroup on 29 data centre commercial space vendors operating 50 major data centres in Singapore. This is projected to grow to 336,900 square meters by the year 2015. Although the Broadgroup study only counted the data centre colocation or hosting space companies, the mix of data centre tenants in these colocation sites is however similar to the representation of the companies and organisations that were assessed in this study. They would have similar characteristics such as IT load density and designed capacity.

The total electrical energy consumption from the year 2006 to 2010, extracted from the Energy Market Authority's Historical Yearly Electricity Consumption Record for Singapore, is shown in Table 1.1. The table shows an average 3.5% year to year increase in the total electrical consumption over the five year period. The columns shows the breakdown across the 3 sectors, with "domestic" representing residential and housing demand, "manufacturing" and "other industries" which include all other sectors such as commercial and office buildings, retail and others inclusive of purpose built data centre buildings and data centres residing in office buildings.

Year	Domestic	Manufacturing	Other Industries	Total
2006	6,764.30	15,041.50	14,116.00	35,921.80
2007	6,820.80	15,261.60	14,977.90	37,420.30
2008	6,784.50	15,482.60	15,709.20	37,940.30
2009	7,084.90	13,628.00	17,261.00	37,974.00
2010	7,304.50	16,693.00	17,202.30	41,199.80

Table 1.1 Singapore's electrical energy consumption from 2006 to 2010 in GWh (extracted from Singapore's Energy Market Authority's Historical Records of Annual Electrical Consumption)

The electrical energy demand and usage of the data centres in Singapore can thus be calculated using the following formula:

Where:

A = 222,829 square meters = area of data centre space in Singapore

D = 0.37 kW/m² = Average IT load density of data centres in Singapore

PUE = 2.07 = Singapore average PUE value

t = 8760 hrs/ year = No. of hours in 1 year

Total Annual Energy Demand = $A \times D \times PUE \times t = 222,829 \times 0.37 \times 2.07 \times 8760$

Total Annual Energy Demand = 1,495,023,044 kWh = 1,495.023 GWh

The estimated total electrical energy usage of data centres in Singapore for the year 2010 expressed in percentage of Singapore's total electrical energy consumption is 3.6%. This is a significant percentage of the country's total consumption and would continue to increase over the years to come.

Based on the commercial data centre area growth projection by Broadcom, the total area would increase to 336,900 square meters by the year 2015. Assuming that the IT load density and PUE value of 2.07 remains the same; the projected energy consumption would increase to 2,260 GWh by the year 2015. This is a 51% increase over 5 years from the year 2010's consumption.

Note that the 2015 projection did not take into account the future increase in IT load density resulting from the pressure on organisations to reduce the physical footprint of their data centres, and the increased use of blade servers in the data centre.

However, improved energy efficiency of data centres in Singapore should slow down the increase in energy demand over the upcoming years. For example, a reduction of the PUE from 2.07 to 1.8 would translate to an annual energy consumption reduction of 195 GWh; equivalent to 97,890 metric tons of CO₂ emission in the 2010 data centre energy usage estimate

Need for Action

In an era of constrained budgets, limited resources, increased corporate social responsibility and potential regulations, the data centre's high energy bills are uncomfortably in the spotlight. Presently, many changes are taking place that affect data centre operations: energy costs are rising; government organizations such as the U.S. EPA and DOE are working to implement new legislations that will regulate and tax massive energy consumers. In Europe, the European Union finally released the EU Data Centre Code of Conduct, which is voluntarily at this point, yet appealing to many data centres in the continent. In Singapore, the government is working actively to understand the energy usage in data centres for the establishment of shared best design practices for the whole community. "Singapore Standard for green data centres– Energy and environmental management systems" was released, constituting the first step towards greening the information and communication technology (ICT) sector. Together with IDA, the Building & Construction Authority (BCA) has developed Green Mark rating certification for data centres, which is similar to what is implemented for commercial buildings in Singapore.

1.2. Energy Saving Opportunities

Lessons learned from over 100 data centre energy audits indicate that improving energy efficiency is possible in nearly any data centre, often beginning with simple no-cost or low-cost measures.

Establishing an energy-efficient data centre begins with an energy audit to baseline the energy usage by the various components and systems in a data centre. The energy audit report provides a detailed look on the usage of energy as well as potential energy conservation measures that can be implemented. The report also contains financial metrics that accompany any potential investment, and an identification of the most cost effective energy efficiency (EE) enhancement measures.

Simple no-cost or low-cost energy saving opportunities include adjustments of the temperature and humidity set point of the air handling units in the data centres; elimination or minimization of poor controls. Other recommendations with reasonable payback includes retrofitting constant volume flow air handling units with variable speed fan motor drives; upgrading of the chiller plant equipment with variable flow drives whenever fully analysed and justified, and upgrading of the lighting systems.

IT decision makers in mature countries opt to extend the life of existing data centres, or reduce the data centre physical footprint by utilizing virtualization technologies. Server virtualisation is the primary step to reducing data centre energy usage as it has a cascading effect on the site's energy usage (reduced UPS and cooling load). For a site with a PUE of 2.0, a reduction of 10 kW in IT load from virtualisation would lead to an overall reduction close to 20 kW in energy demand.

Similarly, IT decision makers are also looking for ways to reduce the costs of running data centres by increasing asset utilization. There is an emerging trend whereby IT decision makers increasingly place greater priority on IT infrastructure energy management and energy usage when expanding existing facilities or building new data centres.

In the near future, companies will be placing greater emphasis on energy efficiency across the organizations' operations. Industry analysts' reports from Gartner, IDC and many others reinforced the need for technology providers to continue to focus on aligning virtualization with improved energy efficiency, and also increasing the focus on the benefits of improved asset utilization.

Although business continuity, availability, user service levels and infrastructure consolidation will continue to be the most important drivers of strategic change across most enterprises (refer to Section 8 for discussion of IT initiatives to reduce energy usage), green initiatives and focuses on sustainability will drive many enterprises to implement a variety of IT and facility technology projects that may include some of the following:

- Server and storage virtualization – consolidation of discrete servers to blade platform or storage area network, which reduces server sprawl, cooling load and power consumption. It also reduces the number of network switches and associated cabling.
- Migration to blade servers to reduce power consumption
- Energy efficient network infrastructure – increase use of equipment compliant to IEEE P802.3az Energy Efficient Ethernet (EEE) can lead to 25% reduction in power consumption in the Ethernet network infrastructure.
- Implementation of IT and facilities infrastructure energy management tools such as cooling management software and implementation of combined cooling, heat and power monitoring and management tools.

1.3. NEA Data Centre Energy Benchmarking Study

This benchmarking study was commissioned by the National Environment Agency (NEA) and supported by the Infocomm Development Authority of Singapore (IDA). It is an initiative of the Energy Efficiency Programme office (E2PO), and will ascertain the energy usage patterns and operating conditions of local data centre buildings, evaluate current industry metrics, and other data centre sustainability issues.

HP Critical Facilities Service (CFS) consultants worked closely with Singapore's IDA workgroup committee to develop the elements of green data centre standard which later became SS 564. The NEA benchmarking study work began in June 2010 when CFS consultants developed an Energy Assessment Framework (EAF) for the data centre buildings in Singapore. The EAF consists of methodologies and processes for data centre operators in Singapore to evaluate their data centres from the energy and sustainability perspective. The EAF presents globally harmonised and accepted metrics to evaluate the data centre efficiency. Those metrics include energy utilization metrics such as the Power Usage Effectiveness (PUE), mechanical PUE, electrical PUE, percentage of cooling system energy use, percentage of UPS energy loss, Carbon Usage Effectiveness (CUE) and air management metrics such as bypass, recirculation air flow ratios, and others.

In addition, energy use of data centre buildings in Singapore was benchmarked. The benchmarking was based on 23 data centres' comprehensive assessment covering energy usage by the various equipments and systems, readiness for certification, staff technical skills, staff appetite to implement green practices and general operational practices. Refer to Annex C on the approach and process used in conducting the assessments.

The sample of 23 data centres was selected to cover various elements such as type of industry, enterprise, governmental and institutional facilities, various Uptime Institute Tier class levels, various cooling and power infrastructure topologies, various sizes and ages. This report presents a summary of the energy audits across these data centres as part of this benchmarking effort.

The benchmarking study also identified technical and operational factors affecting the energy efficiency performance of data centres, as well as recommended actions to address them.

1.4. Recommended Environmental Operating Conditions

The recommended operating environment specifications are generally based on the reliability aspects of the electronic hardware. Specifically:

- High Humidity (RH) levels have been shown to affect failure rates of electronic components. Examples of failure modes exacerbated by high relative humidity include conductive anodic failures, hygroscopic dust failures, tape media errors and excessive wear and corrosion. The recommended upper RH limit is set to limit this effect.
- Electronic devices are susceptible to damage by electrostatic discharge, while tape products and media may have excessive errors in rooms that have low relative humidity. The recommended lower RH limit is set to limit this effect.
- High temperature will affect the reliability and lifespan of the electronic equipment. The recommended upper ambient temperature limit is set to limit these temperature-related reliability effects.
- The lower the room temperature, the more energy is required by the HVAC equipment. The recommended lower ambient temperature limit is set to limit these energy requirements.

Prolonged exposure of operating equipment to conditions outside the recommended range, especially approaching the extremes of the allowable operating environment, can result in decreased equipment reliability and lifespan. Exposure of operating equipment to conditions outside its allowable operating environment risks catastrophic equipment failure.

The first environmental operating condition guidelines for data centres was published by ASHRAE in 2004. This was amended in 2008 with the release of an expanded recommended operating range. The difference between the two versions is shown in Table 1.2.

	2004 Version	2008 Version
Low End Temperature	20 °C	18 °C
High End Temperature	25 °C	27 °C
Low End Moisture	40% RH	5.5 °C DP
High End Moisture	55% RH	60% RH & 15 °C DP

Table 1.2 ASHRAE 2008 vs. 2004 environmental standards

The Thermal Guidelines in 2008 ASHRAE TC 9.9 expanded the environmental range for data centres so that an increasing number of locations throughout the world will be able to operate with more hours of economizer usage. The humidity range was amended to include the dew point (DP) temperature limits (refer to Annex B for discussion on Climate).

Most recently, ASHRAE's 2011 Thermal Guidelines for Data Processing Environments include an expanded data centre classes and usage guidance. The new guidelines were developed with a focus on providing as much information as possible to the data center operators to allow them to operate in the most energy efficient mode and still achieve the reliability necessary as required by their business.


Classes (a)	Equipment Environmental Specifications							
	Product Operations (b)(c)					Product Power Off (c) (d)		
	Dry-Bulb Temperature (°C) (e) (g)	Humidity Range, non-Condensing (h) (i)	Maximum Dew Point (°C)	Maximum Elevation (m)	Maximum Rate of Change(°C/hr) (f)	Dry-Bulb Temperature (°C)	Relative Humidity (%)	Maximum Dew Point (°C)
Recommended (applies to all A classes; evaluate ITE metrics in this paper for conditions outside this range)								
A1 to A4	18 to 27	5.5°C DP to 60% RH and 15°C DP						
Allowable								
A1	15 to 32	20% to 80% RH	17	3050	5/20	5 to 45	8 to 80	27
A2	10 to 35	20% to 80% RH	21	3050	5/20	5 to 45	8 to 80	27
A3	5 to 40	-12°C DP & 8% RH to 85% RH	24	3050	5/20	5 to 45	8 to 85	27
A4	5 to 45	-12°C DP & 8% RH to 90% RH	24	3050	5/20	5 to 45	8 to 90	27
B	5 to 35	8% RH to 80% RH	28	3050	NA	5 to 45	8 to 80	29
C	5 to 40	8% RH to 80% RH	28	3050	NA	5 to 45	8 to 80	29

Table 1.3 ASHRAE 2011 environmental guidelines

The recommended envelope is identical to that published in the 2008 version. The revised ASHRAE guidelines incorporated additional sub-classes in Class A to provide guidance on a wider set of environmental operating parameters that may be used for less critical or non-critical IT equipment to operate on, with the overriding purpose of reducing energy usage rather than reliability and availability.

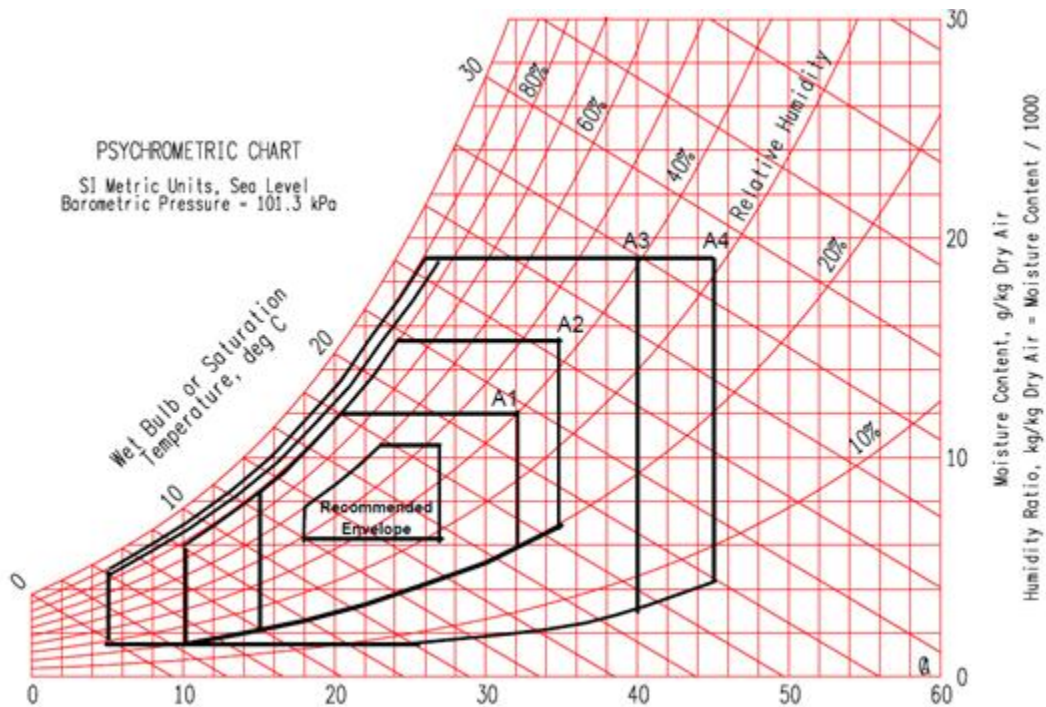


Figure 1.1 ASHRAE 2011 extended guidelines at computer equipment air intakes

(Courtesy of ASHRAE)

The different sub-classes A1 to A4 have a progressively wider allowable temperature and relative humidity range. In the context of energy efficiency purposes, the room may operate without any cooling system and use filtered outside air with minor treatment of the humidity.

Majority of enterprise class of data centres that support business operations and functions of a company operate in Class A1. The recommended environmental operating condition for Singapore data centres shall follow the ASHRAE recommended range of Class A1 with the upper part of the range (21°C to 27°C) preferred for energy efficient operation.

Recommendation:

Temperature Range: 18°C to 27°C

Preferred Range for Energy Efficient Operation: 21°C to 27°C

Humidity Range: 5.5°C DP to 60% RH and 15°C DP as the upper limit for humidity.

DP refers to dew point, which is the temperature below which the water vapour in a volume of humid air at a constant barometric pressure will condense into liquid water.

The upper RH limit for a supply air temperature of 27°C will be 47.8% RH. For supply air temperature of 25°C, the RH level limit will be 55%.

2. Benchmarking Data and Results

2.1 Energy Breakdown in Data Centres

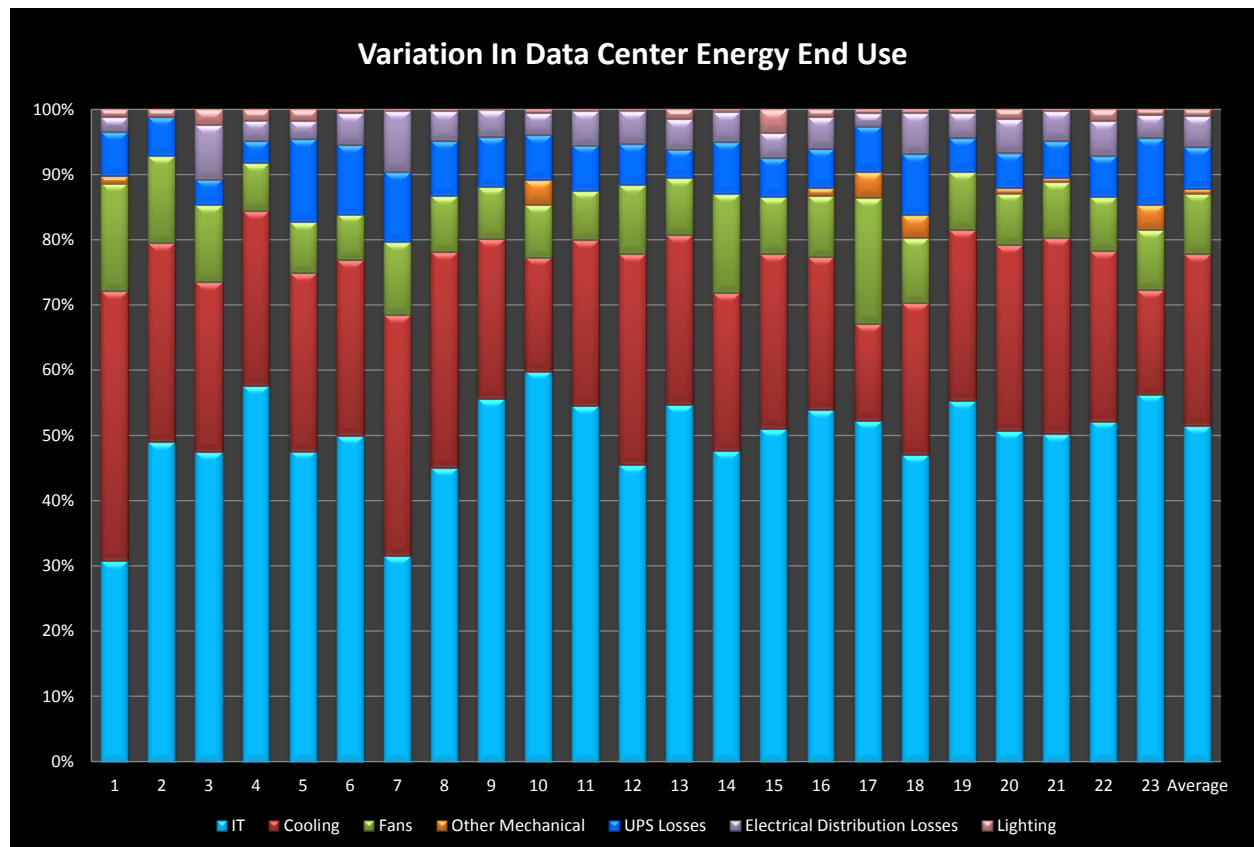


Figure 2.1 Breakdown of energy usage in the data centre

Figure 2.1 show the breakdown of energy use between the IT load, mechanical systems and electrical loads. On average IT load accounts for around 51% of the total electrical demand, mechanical systems (fans, cooling, other mechanical) account for 37% and electrical loads (lighting, UPS and distribution losses) for the remaining 12%. The mechanical systems are broken down into sub-systems; cooling (compressor energy usage), fans and other mechanical. Note that "other mechanical" includes pumps, cooling towers and ventilation/exhaust fans, while "Fans" in the graph are AHU fans within the data centre rooms itself (fans for moving cold air to the IT equipment). These allow further inspection as to how much the sub-system or components contribute to the total energy usage. Figure 2.2 shows the overall breakdown of energy usage from the IT, mechanical and electrical systems.

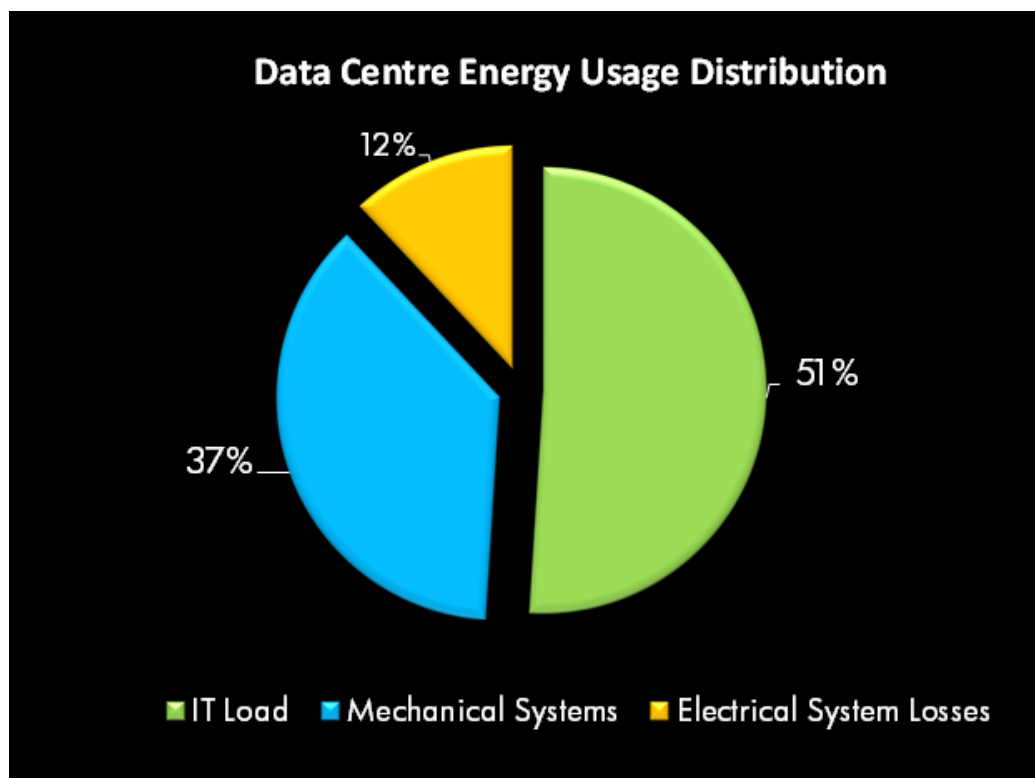


Figure 2.2 Breakdown of energy usage by systems

2.2 Annual Average PUE

It can be seen from figure 2.3 that the PUE for Singapore data centres ranges from 1.67 to 3.31 with an average of 2.07 based on 23 sites. The age of the data centre in the study ranges from 0.5 year to 15 years old with an average age of 8.3 years. The data centres that were assessed in this report comes from a variety of industries spanning across financial, education, government, institutional, telecommunication, services and manufacturing sectors as well as data centre space providers (co-location facilities). The differing sectors provide a comprehensive representation of Singapore data centres. The study comprises 20 data centres assessed over a period of 14 months, from October 2010 to December 2011, and three other sites that were assessed between 2008 and 2009.

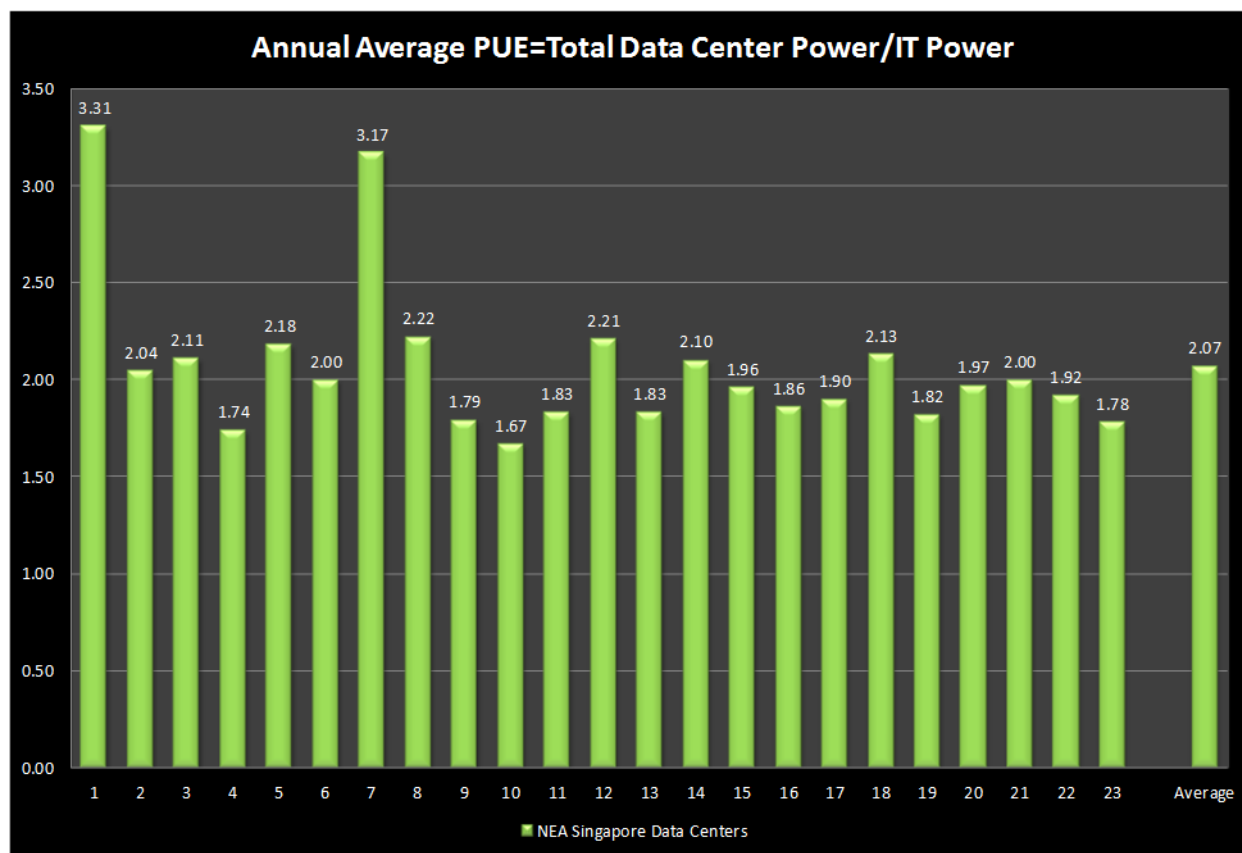


Figure 2.3 Singapore Annual Average PUE benchmarking

There are two notably high PUE value in the graph above, with one of the sites operating only for a few months and the other site being supported by an aged (>10 years old) under-utilised air cooled chiller system. These two sites seem to be deviants from the other sites and if excluded, the average PUE value is 1.96. However these two sites were included in the calculation of the average PUE for Singapore as they are representative of both new and old data centre sites with highly under-utilised capacity in space, cooling and UPS systems.

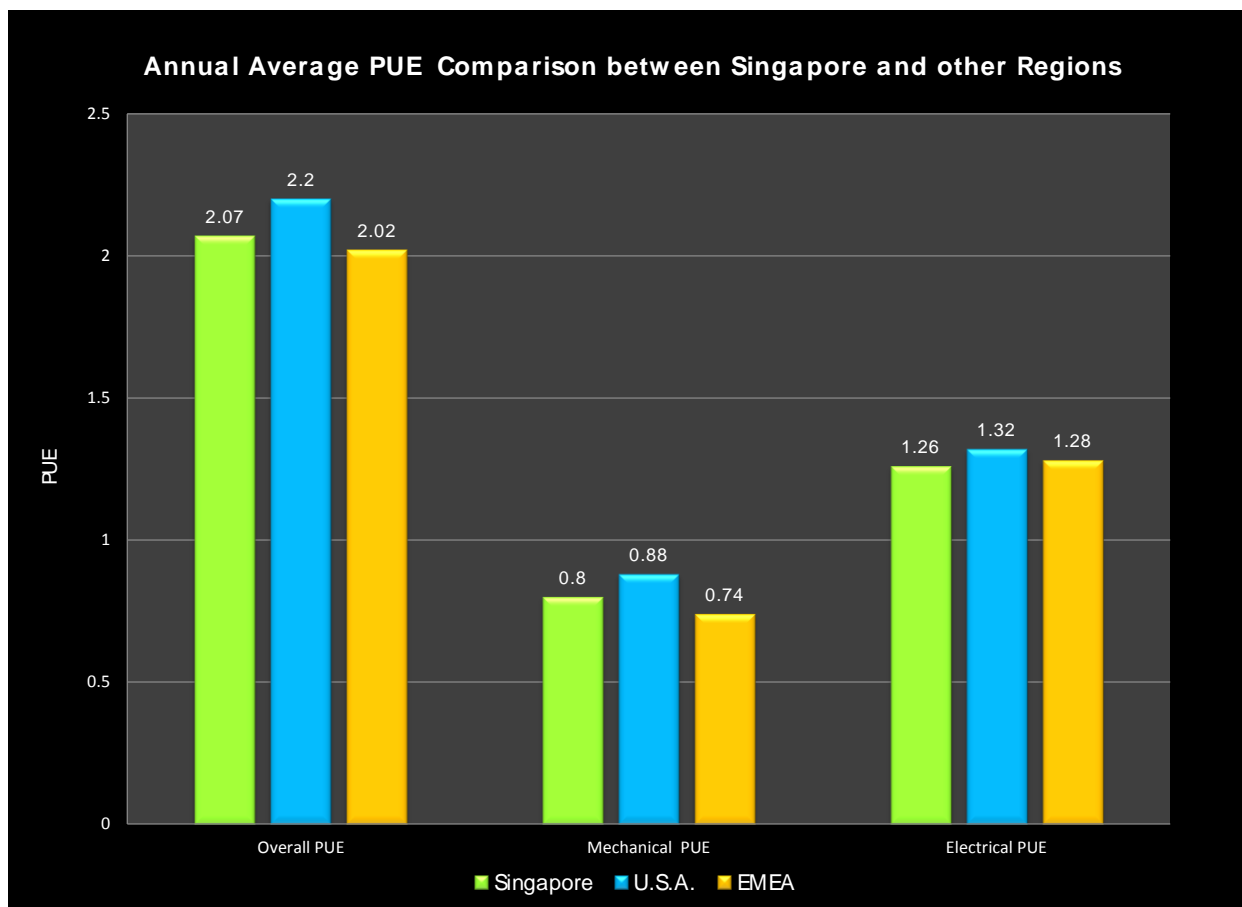


Figure 2.4 Annual Average PUE Comparison between Singapore and other regions

Singapore data centres' annual average PUE is consistent with PUE reporting from other regions as seen in Figure 2.4. It should be noted that the value for the U.S. was derived from over 75 sites whereas for Europe the results were derived from 25 sites. The breakdown of the overall PUE into the mechanical and electrical component is also shown in the graph.

Average PUE

Singapore data centres, benchmarked to date, have an average Power Usage Effectiveness (PUE) of 2.07. This is considered consistent compared to those in the United States (PUE=2.2, average of 75 sites) and European Union (PUE=2.02, average of 25 sites). This finding indicates that although Singapore data centres are located in a hot and moist climate, they are operating at similar efficiency levels compared to data centres located in cooler climates.

Electrical PUE

The electrical PUE for the sites ranged from a low 1.15 to a high 1.64 with an average of 1.26 for all sites. The average electrical PUE is comparable to EMEA (Europe Middle East Africa – 1.28) and the United States (1.32).

Mechanical PUE

The average mechanical PUE value across 23 sites is 0.80, which is slightly higher than European counterparts (0.74) and lower than the United States (0.88).

Relationship between Size and PUE

The 23 data centre sites analysed in the study was further classified based on area and listed in Table 2.1 below. This classification will allow further analysis and comparison of the average PUE between each class based on size.

Site Class	Area Range	No of Sites	PUE
Small (S)	Up to 300 m ²	6	2.18
Medium (M)	301 to 1000 m ²	11	2.06
Large (L)	>1000 m ²	6	1.96

Table 2.1 Data centre classification by area and their average PUE

Site Class	Average UPS Designed Load Utilisation	Average Mech. PUE	Average Elect. PUE	Average Age
Small	34%	0.83	1.36	5.33
Medium	61%	0.82	1.23	10.55
Large	47%	0.73	1.23	10.83

Table 2.2 Data centre classification by area and their average PUE

It was observed that the PUE value decreased as the size of the data centre area increased as shown Table 2.2. Primary observations made on this trend are as follow:

1. The mechanical PUE of larger sites is lower than the small and medium sites.
2. Some of the medium and most of the large sites have dedicated onsite operations support personnel which may have lead to more checks and corrective actions being conducted on the data centre operating state.

The corresponding site DC class ID, PUE and age are listed below in Table 2.3. There is no defined relationship between the ages of the sites and their PUE values. A probable reason for this is that data centres undergo some form of upgrades or enhancement during its lifespan which may result in an improved energy usage performance. Figure 2.5 shows that there is no definite trend to relate the site's PUE to its age.

Site ID #	DC Class	PUE	Age in Years
1	M	3.31	15
2	M	2.04	8
3	M	2.11	6
4	S	1.74	0.5
5	S	2.18	10
6	S	2.00	7
7	S	3.17	0.5
8	S	2.22	3
9	M	1.79	5
10	M	1.67	15
11	M	1.83	10
12	M	2.21	7
13	M	1.83	15
14	M	2.10	15
15	M	1.96	10
16	M	1.86	10
17	L	1.90	8
18	L	2.13	10
19	L	1.82	10
20	L	1.97	10
21	L	2.00	15
22	L	1.92	12
23	S	1.78	11

Table 2.3 Data centre listing and their size classification

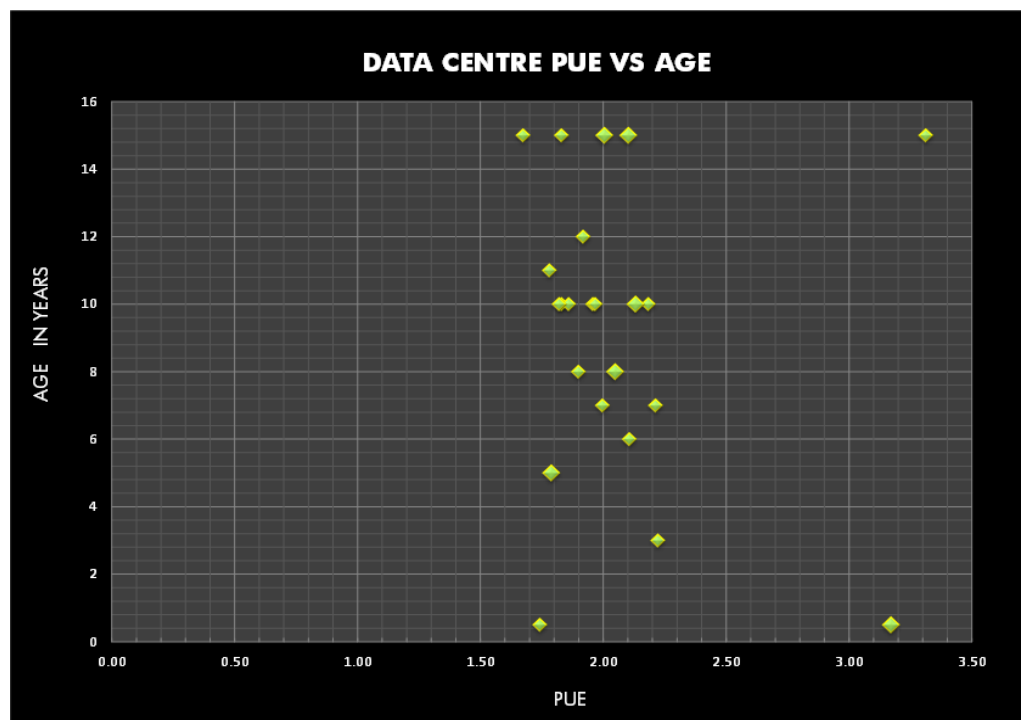


Figure 2.5 Data Centre Age versus PUE Relationship

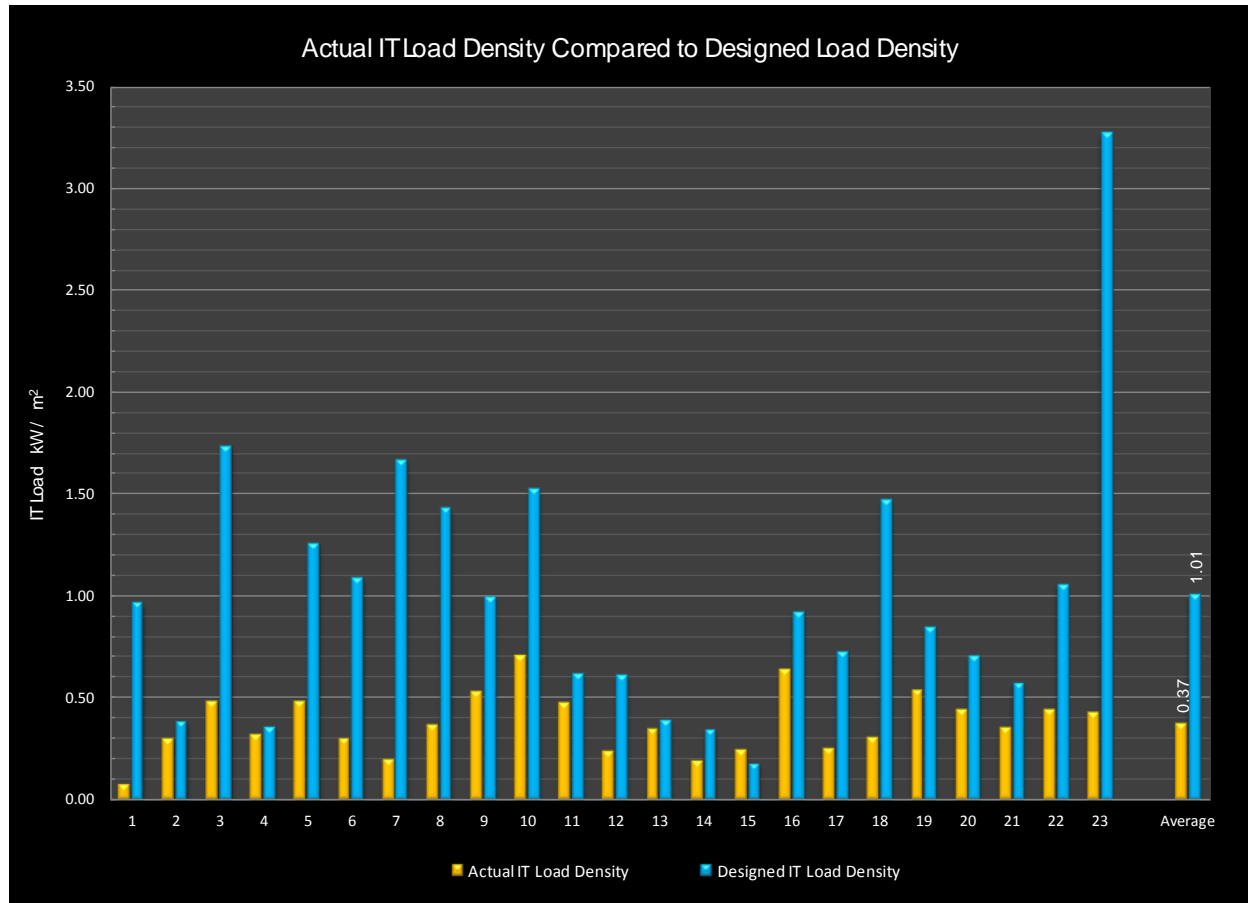


Figure 2.6 Data centre IT load density and average for Singapore, kW/m2

Impact of UPS Utilisation on PUE

The IT load density for Singapore data centres is shown in Figure 2.6. The IT load density is the IT equipment electrical load in the data centre in kilowatts divided by the area of the data centre in square meters. The average IT load density is only 0.37 kW per square meters versus the average designed load density of 1.01 kW per square meter. The graph implies that most of the data centres have oversized UPS systems or have an excess capacity as compared to their actual load. Several factors may attribute to the over sizing of the UPS systems. These are:

- Use of IT equipment nameplate rating to estimate load without considering historical equipment utilisation levels.
- Over buffering of capacity.
- Lack of strategic roadmap and good forecasting model to determine IT equipment growth over time.
- Changes in business and strategic direction.
- Consolidation and virtualisation of server, leading to a reduction of IT equipment in an existing data centre.

It was observed that the UPS utilisation levels in small data centres were lower as compared to the medium and large data centres. Small data centres were characterised by lower UPS utilisation levels averaging 33% (9.3% to 87.5%) as compared to its designed capacity. This contributed to the previous finding that smaller data centres have higher PUE values than medium and larger ones.

The medium sized data centres had an average UPS utilisation of 59.3% (20.6% to 93.9%) while the large data centres had an average UPS utilisation of 47.7% (20.5% to 62.6%).

The level of UPS utilisation has a direct impact on the cooling systems. The designed capacities of the cooling systems are typically matched with the design UPS capacity.

All the sites assessed in Singapore used refrigerant based mechanical cooling system for heat removal from the data centre rooms. Most of the refrigerant based cooling system efficiency is highly dependent on load of the system, and optimum efficiency is reached when cooling load is around 70% to 90% of its rated capacity. Thus UPS utilisation affects not just electrical efficiency but also the efficiency of the mechanical systems.

Furthermore, data centre cooling systems are always designed with significantly higher capacities (at least 25% more) than the projected cooling load to compensate for losses and inefficiencies in the air delivery system. During operation, redundancy requirements adds more cooling capacity to this buffer, which results in operating cooling capacity that can be 200% more than the actual cooling load in the room. This reduces the overall efficiency of the cooling systems by subjecting them to low part load conditions, resulting in an increased energy usage per unit of heat removed from the room.

2.3 Annual Average CUE

Carbon Usage Effectiveness (CUE) measures the carbon footprint of the data centre and is defined as the total CO₂ emissions from the data centre energy use divided by the IT equipment energy. CUE depends on the amount and source of energy a data centre is using. An ideal value of CUE is 0, where the power is totally derived from a source that has no carbon emissions. The annual average CUE of Singapore data centres is shown below.

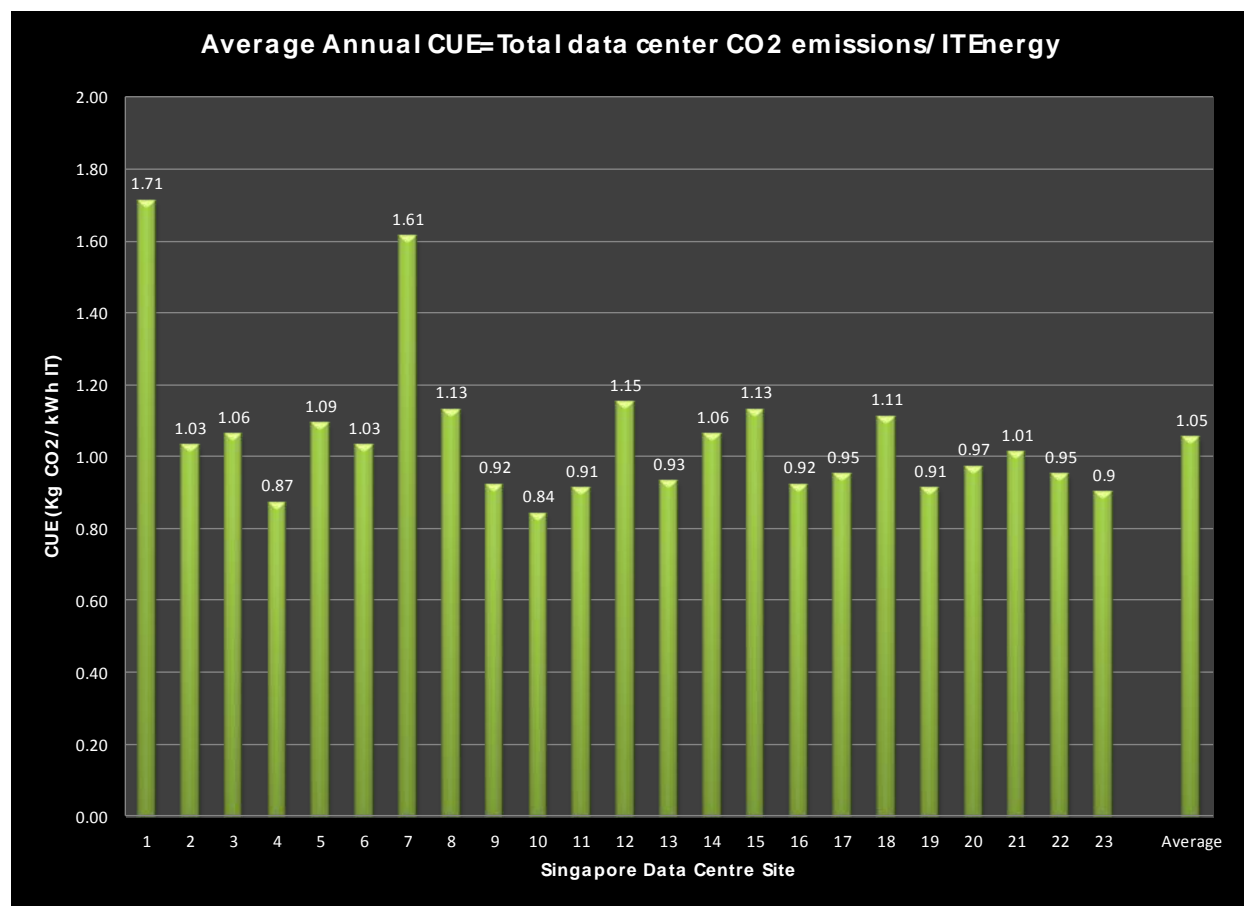


Figure 2.7 Average Annual CUE of Singapore data centres

The average annual CUE chart in Figure 2.7 shows that majority of the data centres are below 1.2 with the lowest value at 0.87. The electricity grid carbon emission factor used in this report is based on year 2008 value, at 0.5016 kg per kWh.

3. Mechanical PUE – Findings and Recommendations

Singapore's climate zone 1A is hot and humid all year round. Some form of mechanical cooling is required to remove the heat from equipment and facilities, especially in data centres which generate large amounts of heat. The study found that all the sites employed refrigerant based mechanical cooling systems for heat removal. The average mechanical PUE value of 23 sites is 0.80 (see Figure 3.1), which is comparable to the European (0.74) and United States (0.88) counterparts. Generally, it is anticipated that the cooler European climate results in lower cooling demands and hence, lower mechanical PUE than those in Singapore.

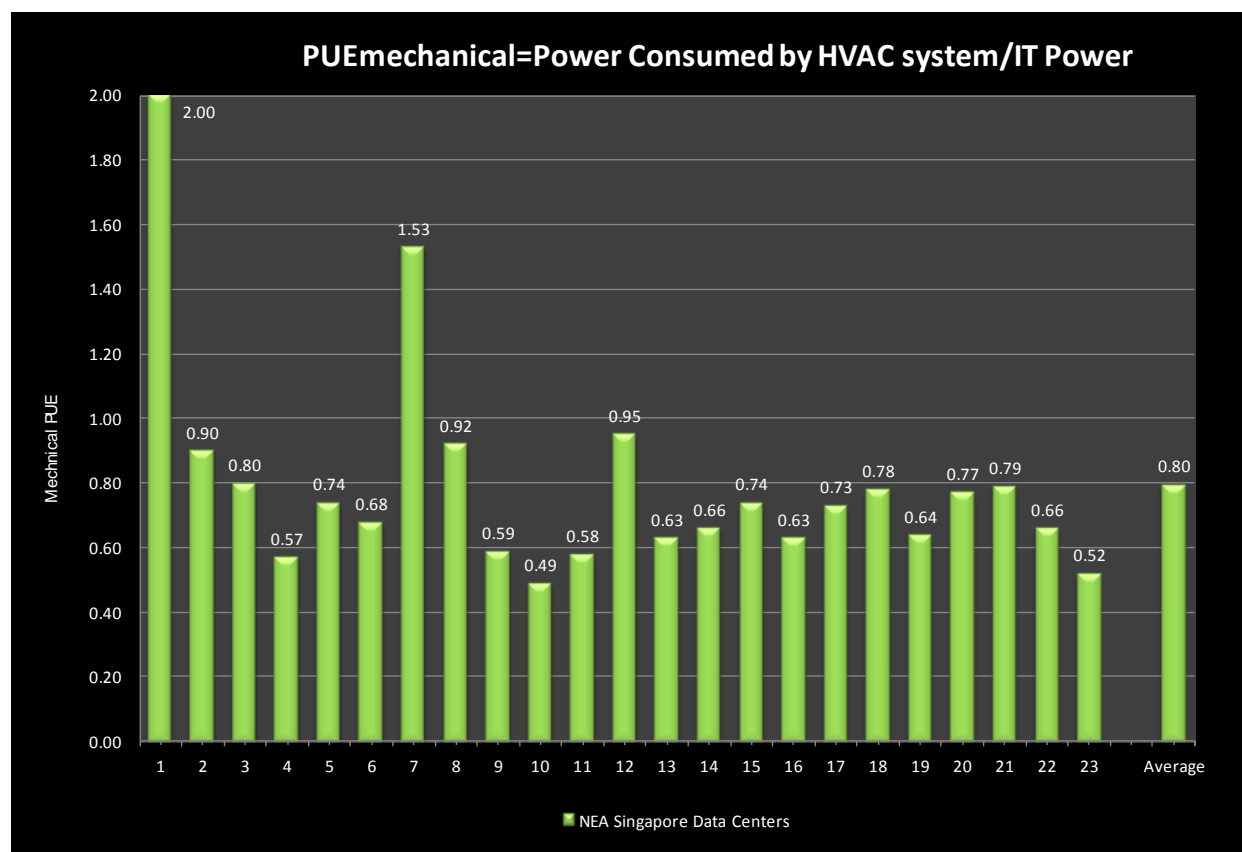


Figure 3.1 Annual average mechanical PUE site assessments

3.1. Type of Cooling System and Mechanical PUE

Cooling System Type

Table 3.1 shows the breakdown of sites by the type of cooling plant used. It was noted that majority (15 out of 23) of Singapore data centre facilities surveyed employ air cooled direct expansion unitary systems, which are commonly known as computer room air conditioning (CRAC) units.

8 sites used chillers where water cooled chillers are used in 5 sites and air cooled chillers in 3 sites. For the sites that used water cooled chillers, only 1 had dedicated chillers for the data centre. The other 4 sites drew their chilled water supply from a shared central chilled water plant.

For the sites that used air cooled chillers, 2 had dedicated chillers for the data centres while the remaining site was supplied from a shared central chilled water plant.

It was also noted that 4 of the sites that used chillers (3 WCC and 1 ACC) also employed CRAC units as a back-up in case of failure in the chillers, running them in parallel with the chillers to cool the data centre rooms.

Site Classification by Type of Primary Cooling System	No. of Sites	% of Total
Site using Air cooled /water cooled DX Units (CRAC)	15	65 %
Sites using Air cooled chiller (w/ CRAH)	3	13 %
Sites using Water cooled chiller (w/CRAH)	5	22 %
Total number of sites	23	100%

Table 3.1 Primary System Cooling Type by Site

Type of Cooling	No. of Sites	Mechanical PUE Normalised Average	Value Range
CRAC	14	0.71	0.59 to 0.95
Air Cooled Chillers	2	0.78	0.77 to 0.79
Water Cooled Chillers	5	0.64	0.49 to 0.78

Table 3.2 above shows the normalised average mechanical PUE between the different types of cooling system.

Link between Cooling System Type and Mechanical PUE

The two sites with very high mechanical PUE values (2.00 and 1.53) shown in Figure 3.1 were excluded to normalise the average values. The table shows that data centres using water cooled chillers achieved the best mechanical PUE among the 3 types of cooling. The least efficient cooling system was air cooled chillers.

In this study, it was found that sites were not achieving their full potential due to under loading and poor operating practices.

Some of the under loaded sites using chillers were also found to be using constant speed systems. This resulted in having a disproportionate amount of pump and cooling tower fan power being used versus the actual cooling load, leading to a higher mechanical PUE.

In Singapore, large and purpose built data centre complexes tend to employ water cooled chilled water plants for their primary cooling requirements.

Water cooled chillers is the preferred design approach as long as site space constraints allow. There are exceptions wherein large data centres use air cooled DX systems for primary cooling. These are typically located in shared building complexes that were partly converted into data centres and where building constraints do not allow the installation of chiller systems.

It was noted that the primary issues that is preventing the wider adoption of water-cooled chiller systems to cool data centres are as follow:

- Site constraints – data centres located in a multi-tenanted building usually face space and service riser issues to install the equipment and run the piping needed for chilled water systems.
- Operational constraints – most of the small and medium sites do not maintain full time operations and maintenance support personnel to monitor and attend to the facility infrastructure. Chilled water systems will require full time support personnel to operate and maintain the systems. Most of the small and medium sites rely mainly on remote third party operation and maintenance support with a 2 hour onsite response time.
- Chiller systems also require a lot more monitoring and maintenance efforts (water treatment, periodic cleaning of cooling towers and chiller water tubes) compared to ACDX/CRAC systems. Other provisions like back-up water storages for cooling towers (part of availability requirement for most enterprise data centres) especially for Tier 3 and higher classed data centres, is required as well.
- Availability requirements would require a redundant chiller unit be operated at all times, unless some form of thermal energy storage (TES) capability is provided as a buffer to cater for the chiller start-up period (TES would require space). The TES are typically designed with a 5 to 10 minute buffer period, depending whether a "quick start" (~300 seconds) or "normal start" chiller (~8 to 10 minutes) is installed. For example, a 500 RT or 1,757 kW cooling load would require a 46 cubic metre volume tank for a 10 minutes back-up with a 5.5°C difference between supply and return chilled water temperature.
- Shared chiller systems in commercial or office buildings typically do not meet the service level and availability requirements of most data centre owners.

The above reasons are the main obstacles towards the usage of a chilled water system in small to medium sites, limiting the usage to large sites and purpose built data centre buildings if there is an economic benefit in doing so (cost of purchased chilled water is lower than electrical power consumption of ACDX CRAC units).

Recommendations

- For medium and large sites, water cooled chiller systems would provide the most energy efficient operation as long as the utilisation levels are kept within the optimum operating range of the cooling systems' installed capacity.
- Cooling systems including water cooled chillers should be sized and designed properly to ensure that the cooling load profile of the site falls in the "sweet spot" of the chiller system or has the necessary features to allow high efficiency part load operation, such as the use of variable speed driven water pumps and cooling tower fans.
- For small and medium data centre sites that are not able to use water cooled chiller systems, the new generation of air-cooled DX systems with variable speed driven fans and variable capacity compressors should be able to provide energy efficient operation. This would include the use of in-row, rear door or overhead heat exchanger units. Sites that have an unpredictable IT load growth or a very slow growth pattern would benefit from the modularity in this type of cooling systems.

Water Cooled Chiller Systems

- Use of variable speed driven pump and cooling tower motor fans significantly reduces energy consumption. However, implementation will require tighter temperature controls for condenser and chilled water loops.
- Use of efficient chiller system with a performance of 0.6 kW/RT or better.
- Use of a lower approach or greater range in cooling tower design may reduce overall energy consumption. The analysis and technique to do this is beyond the scope of this document but may be explored by the HVAC systems design engineer during the design stage.
- Use of variable speed chiller units or staging of chiller units to better handle part load conditions should be explored where feasible.

Recommendations applicable for both water-cooled and air-cooled chiller plants:

- Use of premium efficiency motors for fans and pumps.
- Operating at a higher chilled water leaving temperature increases chiller efficiency by reducing the compressor power usage.

(Note this is recommended for dedicated chillers for data centres only. Shared chillers supporting both data centre and offices should have provisions for humidity control in the offices if a higher leaving temperature is used. Furthermore, the impact to the performance of AHUs' cooling capacity should be assessed. Additional AHUs may be required to be turned on to compensate for the loss in cooling capacity, which would increase overall fan power consumption and negating the savings in the chillers.)

- Reduce pump head loss in headers and piping system by use of gradual bends in pipes and use of low resistance valves throughout the system where applicable.
- Periodic maintenance and calibration of internal sensors such as temperature and flow meters to ensure that the system is operating within its designed range.
- Extensive use of chilled water energy meters to monitor and trend system performance as well as energy usage across the data centre facility.
- Use of smaller capacity chillers together with larger ones to cater for part load conditions and maintain utilisation levels of chillers within the optimum load range.

3.2. Design and Operating Practices and Mechanical PUE

This section discusses other design and operating practices that influence the mechanical PUE, providing some recommendations on design and operating practices.

Air Handling Units in Operation

It was noted that the data centres in the study typically have 200% or more operating cooling capacity, compared to the IT cooling load requirements in the data centre (See Figure 3.2). Operating cooling capacity is the available cooling capacity of all the air handling units (CRACs and CRAHs) that are operating inside the data centre at any point of time. It does not include units on standby mode which fans are turned off.

It was also noted that majority of the sites (19 out of 23) used constant speed motors on the air handling units. This led to a higher than needed energy demand from the AHU fans, leading to a higher mechanical PUE value. (AHU fans and CRAC compressor motors also generate heat that added to the cooling load of the room).

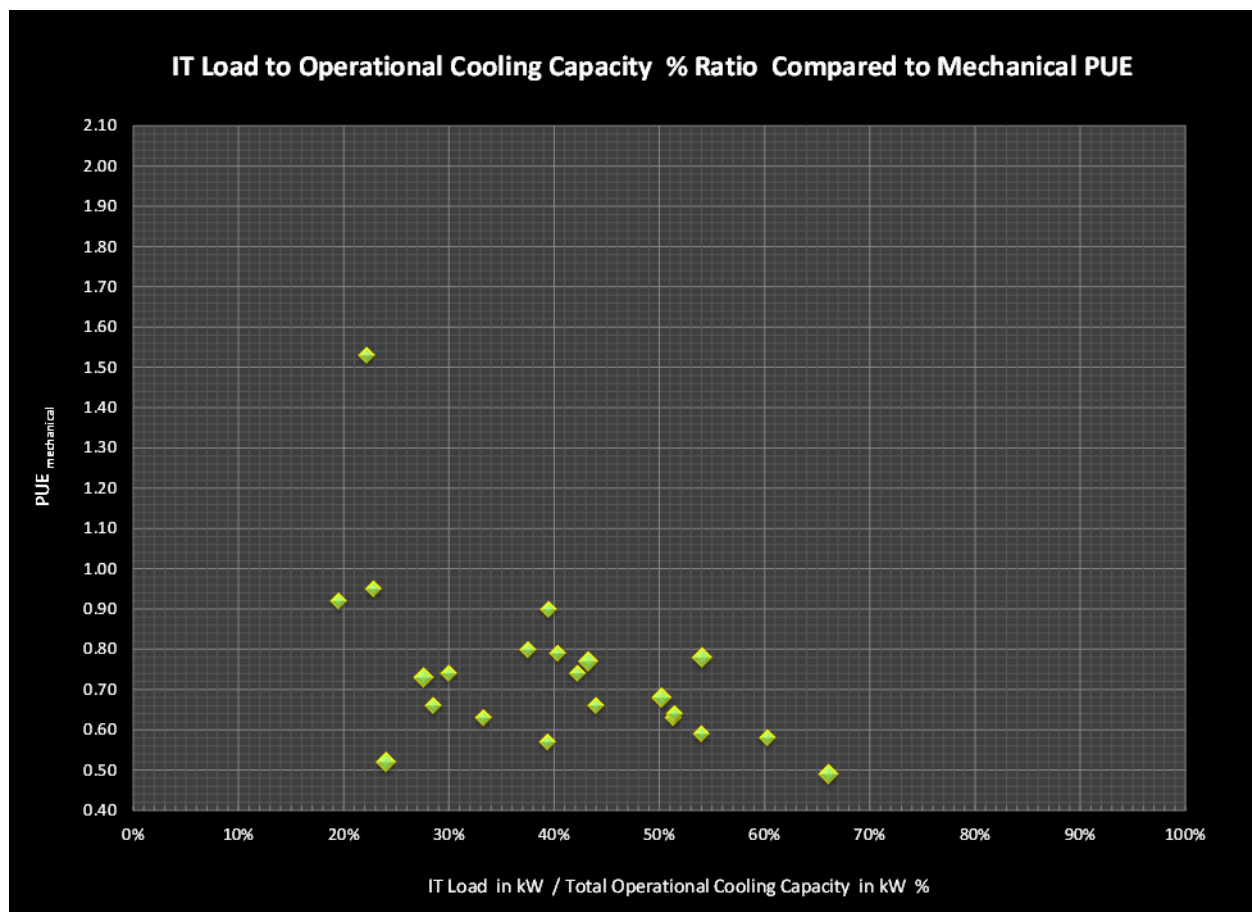


Figure 3.2 IT load to operational AHU cooling capacity ratio distribution

Aside from the need for redundancy (elaborated below), the other cause of this overcapacity is poor air management practices (refer to section 3.3) that led to "hot spots". The subsequent remedial action by the owner to address the issue is by turning on additional air handling units to cool down the hot spots.

Availability Requirements and Redundancy

The data centres in the study were all enterprise data centres that have higher availability requirements for both IT systems and supporting facility infrastructure. This requirement resulted in the use of redundant configuration in most aspects of design. Typically, air handling units are always configured to run with an extra unit or with a minimum capacity buffer that is able to take over the cooling capacity loss if one unit fail. In some of the larger rooms, there is a redundant unit operating for each defined section of the room.

This also applies to chilled water systems wherein at least two chiller units with their corresponding pumps and cooling towers are always operating. This resulted in the chiller units operating at low part load condition of 50% or less of rated capacity of the system. Unless the data centre site has some form of thermal storage that can continue to supply chilled water to the air handling units in the data halls or has chiller units designed for quick restart (ordinary chiller restart period is between 5 to 10 minutes), availability requirements will dictate that an extra chiller has to be kept running to cater for a failure of a single unit. Although this practice is wasteful in terms of energy usage; most site owners accept this in order to meet service level requirements and will pay the premium on energy consumption costs.

Recommendation:

- Operating cooling systems capacity should closely match the cooling load.
- Redundant units should be turned off at all times when in normal condition.
- Use of monitoring and control systems to detect abnormal or failure in the cooling system to turn on the redundant units instead of running them continuously.

Room Location and Extraneous Heat Gain

The impact of solar heat and heat gain from walls was observed to be insignificant on majority (17 out of 23) of the data centres in the study. This has been reduced to a large extent by the following design practices and choice of room location within the building:

- Sealed windows or rooms without windows – windows are sealed with dry wall partition mainly due to security reasons with added benefit of reducing heat transmission through glass.
- Room location within building – data centre rooms are located in mid-level floors where the air conditioned areas above and below the room provided a buffer against external heat gains to a great extent.
- Reduced external facing walls – most of the rooms are having only one exterior facing walls or facade of the building which limits solar heat gains. Some has no exterior facing wall at all and are surrounded by air conditioned space such as office or factory areas.
- Insulated partition walls – most of the sites are constructed with fire rated partition and are also insulated internally with rock wool sheets with aluminium foil backing that form a vapour barrier. This reduces the heat transfer across the partition from the adjoining space into the data centre.

Note that most of the practices listed are primarily dictated by security requirements with the added benefit of reducing the heat gain from solar radiation or from a warmer environment.

Recommendation:

It is recommended that the data centre room location within the building is located in an area that has minimal or no exposure to the external environment to reduce heat gain from solar radiation or from a warmer environment. The data centre rooms should preferably have windows sealed and insulated, or designed with no windows at all.

Chilled Water Supply Temperature Set point

Only one site used a higher temperature set point of 8°C and intends to raise it further. This site has a dedicated chilled water plant system solely for data centre use only.

The chilled water supply temperature set points for majority of the sites using chiller systems are in the range of 6.8°C to 7.2°C. However, raising the chilled water set point for these sites is not possible as the chilled water plants are being shared with the building complex.

Recommendation:

Increasing the chilled water leaving temperature setpoint leads to a reduction in energy consumption of the chiller's compressor to a certain extent (~1 to 1.5% per °C increase for constant speed chillers).

However, due diligence should be conducted prior to any increase of setpoint temperature. It should be noted that the cooling coils of the air handling units are designed for a specific chilled water supply temperature range and increasing beyond this range would lead to reduction in cooling capacity.

The reduction in cooling capacity may in turn require additional air handling units to be turned on, causing inefficiency of the AHU. This could possibly result in an increased fan power consumption, which would overall negate the energy savings in the chiller or even result in a higher power consumption.

Provision of Fresh Air and Dehumidification

Most of the data centres (77%) assessed do not have dedicated fresh air supply and uses the air exchange that occurs when doors are opened and closed, drawing in air from the common corridors of the building. The building common space and corridors are provided with centralised air conditioning and are designed with the necessary volume of fresh air to comply with the code requirements.

For the remaining data centres (23%) with dedicated fresh air provision, fresh air is primarily provided to pressurise the room to prevent infiltration of air from other areas of the building or untreated outside air into the data centre space (reducing contamination). A typical approach is to use a constant air volume fan and a heat exchanger (chilled water or DX fan coil unit) with particulate filters at the intake. The air is pre-cooled and dehumidified to some extent before it goes to the data centre. None of the data centres that were provisioned with dedicated fresh air supply used desiccant based dehumidifiers.

The notable issue on the supply of fresh air is that the air diffuser openings are directed right over the CRAC/CRAH units instead of dispersing this across the room to mix it with the return air. Relative humidity (RH) measurements showed that the RH level of the treated air supply is in the range of 60% to 70%, while the RH set point of their CRAC/CRAH units is at 50%.

The return air RH sensors of these units sense the higher humidity level of the air from these ducts. The CRAC/CRAH units then go into the dehumidification mode. During this mode, the units go into 100% cooling state to lower the off coil air temperature (10°C to 12°C) well below the dew point level of the incoming air to condense the perceived “excess” moisture. The CRAC/CRAH unit then reheats the air using electrical resistance heating coils to increase the air temperature up to 16°C to 18°C , depending on the control algorithm program of the unit. In some of the sites surveyed, the unit subjected to this condition will continue to run in the dehumidification mode as long as the fresh air supply is on. This dehumidification process is wasteful in terms of energy usage in both cooling and heating.

Recommendations

HVAC designers should take note of the placement and location of the fresh air supply diffusers within the data centre. For existing data centres, a review of the placement should be undertaken and corrections made to avoid this issue. The fresh air diffusers or vents should be located over the hot aisles where the incoming air can be dispersed and mixed with the warm low humidity air coming from the servers.

Designers should also look at other techniques such as demand control ventilation and air locks when designing provisions for air exchange and pressurisation purposes. Data centre owners should increase the RH level set point to 55% or to the ASHRAE allowed limits. Likewise, depending on the size of the room, the number of CRAH/CRACs fitted with dehumidification function should be limited to as few as possible just enough to remove the moisture intake based on calculated fresh air intake and infiltration.

For new data centres, standalone dehumidification units can be installed instead of using CRAH or CRACs for the function.

Latent Cooling Load

Observations noted that the RH levels inside the data centres tend to go lower as IT load levels increase in the room. As cooling load increases, there is a corresponding increase in the “cooling” mode duty cycle period of CRAC/CRAH units in the room. The temperatures in the cooling coil of these units typically fall below the dew point, resulting in constant moisture removal from the air passing through the coils. A point of equilibrium is reached if the existing moisture intake to the room remains constant. It was noted that the CRAC/CRAH units still produced condensate water from the cooling coils though there is no observable source of moisture in the room. It can be assumed that the primary source of moisture at this point is either from the walls, floors and ceilings, or the infiltration of higher humidity air from other areas when doors to the data centre are opened or there is human activity within the room. For data centres at this state, it was observed that the CRAC/CRAH units no longer go into a dehumidification mode of operation. Reheat coils no longer activate as well and this function is being disabled by the data centre facility team in majority of the sites that were assessed.

Recommendations

It is recommended that vapour barriers and sealants are incorporated into the design of the data centre room structure to reduce the introduction of moisture from adjacent areas bordering the data centre room.

Do note that too much moisture removal leading to relative humidity levels below 35% in the room is also detrimental to IT equipment due to the build-up of static electricity in certain materials and clothing of personnel. This can lead to electrostatic discharge that damages electronic equipment.

Humidity levels in the room should be maintained within the ASHRAE recommended range for Class A1 room. In cases where moisture levels falls too low in the room, ultrasonic humidifiers can be installed to provide humidification function.

UPS and Battery Room Cooling

It was noted that data centre sites using static UPS systems locate them (UPS modules and batteries) in rooms provisioned with either CRAH/CRAC or fan coil units. The room temperature is typically maintained at 20°C to 22°C.

The primary reason for this approach is to maintain reliability of the valve regulated lead acid (VRLA) batteries used in the UPS system. The reliability and lifespan of the batteries reduce drastically once the internal temperature goes beyond 28°C.

On the other hand, some models of the UPS modules are designed to continuously operate at environmental temperatures of up to 35°C and up to 40°C. They do not require the low temperature environment as the batteries.

Recommendations

The UPS power modules should be separated from the batteries and located in their own room where feasible. They can then be operated at a higher environmental temperature of 28°C to 30°C without degradation of reliability. This may also allow the use of filtered outside air using ventilation fans to cool the UPS systems instead of using refrigerant based systems.

The batteries on their own do not have much cooling demand as they have very little heat dissipation and thus, can be provisioned with a smaller air conditioning unit to maintain room temperature of up to 25°C (for VRLA batteries). By separating these two components into separate rooms and applying different environmental parameters, additional energy savings can be achieved in the data centre.

3.3. Air Management Practices and Mechanical PUE

Air management is the most important area that data centre owners can take advantage of to greatly reduce their energy demand due to its direct impact on energy use by the cooling system. Proper design of the data centre and planning of the layout, including placement of equipment and a continuous proactive operational approach, are required for it to be effective.

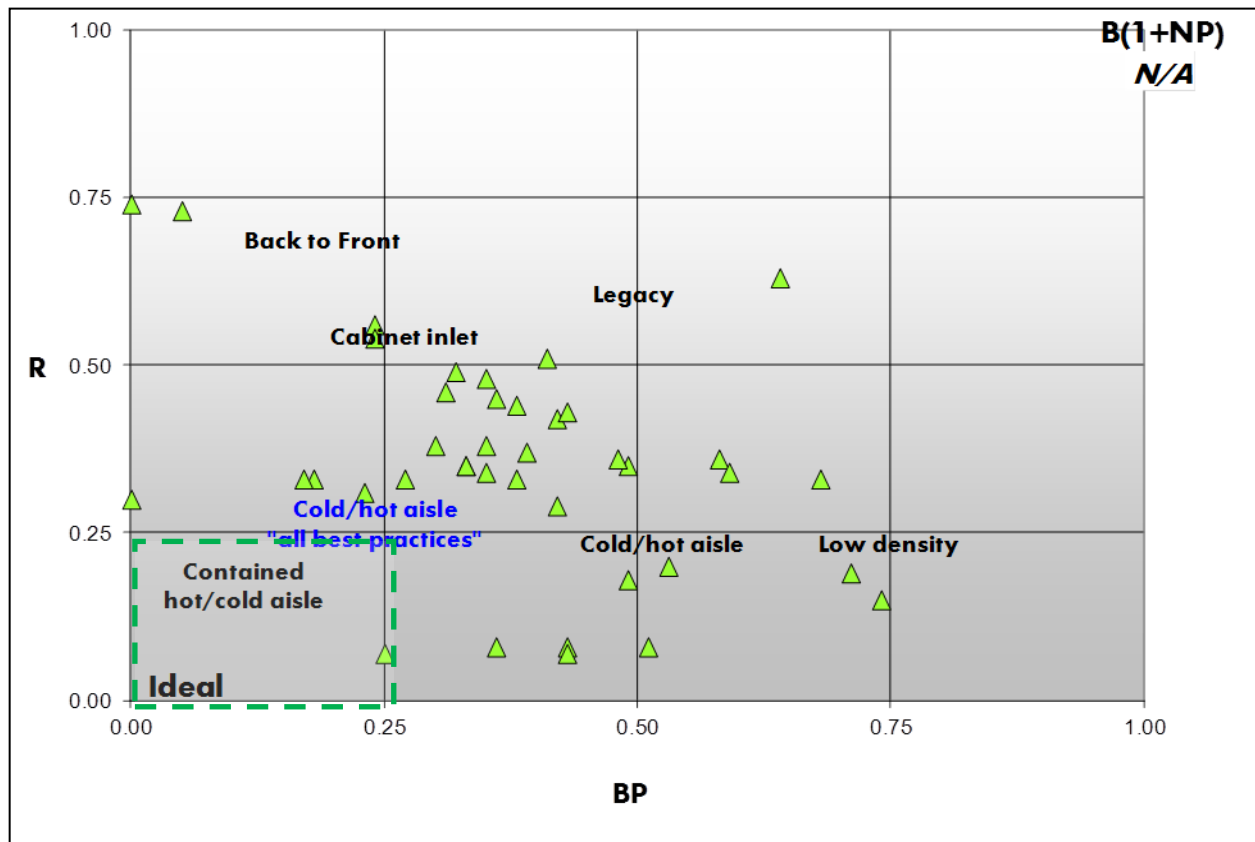


Figure 3.3 Air management benchmarking

The average of all of the data halls' bypass and recirculation flow ratios are 0.38 and 0.35 respectively, based on 36 data halls/rooms across 23 data centre sites in the study. The two ratio values for the rooms are represented by the green triangles in Figure 3.3. (Refer to NEA's Common Assessment Framework document on how the metrics are derived and the formulas and methods in deriving the data)

Data centre owners should target to have bypass and recirculation values below 0.25. A few data centres with lower bypass and recirculation were found. Those were observed to have CRAHs located in galleries outside the data centre with a ceiling air return plenum, comprehensive implementation of blanking panels and cable brushes, high ceiling, servers' intake temperatures above 21°C, and generally have most of the best practices implemented. In general, figure 3.3 shows there is still a lot of room for improvement for most of the data centres (Ideal: R=0, BP=0). See Figure 3.4 for diagram showing the airflow within the room.

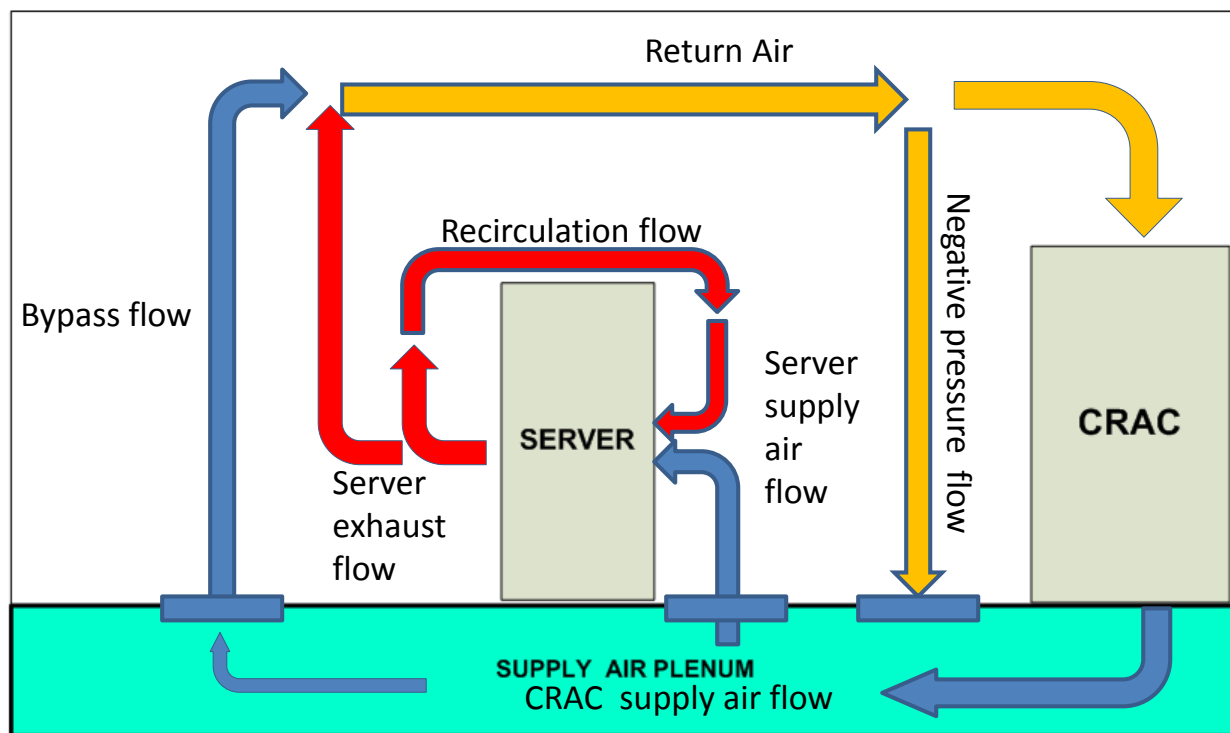


Figure 3.4 Diagram illustrating the various type of airflow occurring in a room

Significance of Bypass Value

The bypass value of 0.38 indicates that a significant amount of cold supply air flowing from the CRAH/CRAC units into the data centre do not pass through the IT equipment, and may not do any significant work to cool the IT equipment, leading to higher overall fan power consumption. This may be due to the following:

- Excess CRAC/CRAH units in operation, causing the cooling air to exceed demand from the IT equipment (refer to Section 3.2 discussion on air handling units in operation).
- Openings in the supply air plenum that are not directed at the intakes of the IT equipment which allows cold supply air to bypass the IT equipment and return to the air handling units (CRAHs/CRACs).

However, bypass air cannot be eliminated altogether especially for conventional air handling units due to the design of their heat exchanger coils. Conventional AHU cooling coils are designed to have a temperature delta across the coils of around 10°C to 11°C between entering and leaving air (off coil temperature). On the other hand, IT equipments are designed with highly efficient heat sinks, and the delta temperature rise of air across the equipment ranges from 10°K to 25°K. This reduces the volume of air needed to dissipate the heat from the IT equipment. (Temperature units are in absolute temperature scale).

For example, a CRAH unit with a specific cooling capacity can cool down 1,000 cubic meters of air per hour on a designed delta T of 10°C from an entering air 24°C to 14°C at the CRAH discharge. The CRAH supply air is then supplied to a group of IT equipment that generates an equivalent amount of cooling load with respect to the CRAH cooling capacity but has a designed temperature delta of 20°C. Therefore, the volume of air that the IT equipment requires in order to dissipate the heat generated is only half of what the CRAH unit discharges into the room. The remaining volume of air from the CRAH unit that has not passed through the IT equipment mixes with the hot air before it returns to the CRAH unit intake, lowering the temperature in the process to the designed return air set point at 24°C. This balance is needed in order to prevent the CRAH discharge air temperature from progressively rising over time. In this example, 50% of the air produced by the CRAH unit has bypassed the IT equipment.

Therefore, there is a limit to how much bypass air can be reduced unless the cooling unit's design can match the delta temperature across the IT equipment. Do note that this is a simplistic description of the thermodynamic process involved without going through the mass flow balance and enthalpy equations. In the preceding example, the cooling load is equal to the CRAH cooling capacity.

Bypass values should be reviewed together with the sum of the cooling capacity of all units operating in the room versus the cooling load. A difference of more than 25% between cooling load and total cooling capacity of operating CRAH/CRACs in conjunction with a high bypass value signifies inefficient airflow in the data centre room.

Recommendations

- Locate floor air grills so that they supply to the inlet of servers, i.e. no floor air grills in hot aisles
- Ensure air velocities from floor grills are not too high and do not overshoot the cabinet height
- Seal air gaps in the raised floor with "cable brushes/pillows"
- Consider air isolation of CRAC units with dampers since CRAC units not in operation are a source of bypass air
- Ensure that the combined cooling capacity of AHUs in operation closely match the cooling load in the room
- Use aisle containment systems
- Combined cooling capacity of CRAH/CRAC in operation should not be more than 125% of the cooling load

There are supplemental spot coolers from specific vendors with a higher designed delta temperature across them as compared to conventional AHUs. These typically use chilled water as a cooling medium and are designed to act as a passive heat exchanger (using the IT equipment cooling to move the air through the heat exchanger) or with small multiple variable speed fans. These units typically have very little bypass air especially the passive cooling units. Refer to Annex A.2 for more recommendations on Air Management Practices.

Significance of Recirculation Value

It was found that occurrence of air recirculation is prevalent in Singapore data centres. The notable factors that caused this is the lack of blanking panels in racks, mixed row arrangement (racks in a row are not arranged in a single defined direction), as well as legacy front to back row arrangement (Refer to Figure 3.5).

High recirculation value can also be attributed to the lack of cooling air supply in a given section of the data centre where the IT equipment air intake volume exceeds the volume of cooling air supply from the perforated floor panels or supply air grilles. This results in the IT equipment drawing in the warm exhaust air from the equipment's outlet into the intake (See Figure 3.4). Most of the time, the shortage of cooling air supply is caused by the lack of static pressure in the floor plenum due to excessive openings in the floor from unsealed cable cut-outs behind and under the racks. The other noted cause is the congestion in the raised floor plenum from the large amount of data cabling blocking air flow from the AHUs leading to a reduced airflow volume in certain sections of the data centre.

"Hot spots" is the term used in the industry to describe these sections of the data centre with elevated temperature from recirculation. Data centre owners typically resolve hotspot issues by either lowering the temperature set points of the CRAC/CRAH units, or by adding/turning on more CRAC/CRAH units to increase air flow in the room. In some cases, a combination of both "remedy" is used by owners.

Whatever the causes, the common "remedy" adopted by the data centre owner drives up energy demand by operating more CRAC/CRAH units than needed with some having 300% more cooling capacity in operation versus load.

Recommendations

- Consider return air plenum and ductwork for the CRAC units or "raising height of CRAC returns"
- Remove obstructions under the floor that restrict cooling air supply to the server inlets
- Ensure as best as possible adequate cooling air supply to the server inlets
- Ensure air velocities and flows from floor grilles are sufficient to reach the top of cabinet servers
- Fit blanking plates in cabinets where servers are not installed
- Close gaps between cabinets (where warm air can make its way to the server inlet)
- Avoid installing highly loaded servers at the end of cabinet row or at the top where recirculation is more likely to occur
- Ensure that cables/wires are routed properly in the rear of IT cabinets
- Ensure that return air grills are over hot aisles if applicable
- Consider means to physically isolate the supply (cold) and return (hot) air streams using containment systems
- Consider continuous rows of IT equipment not individual racks

Observations of Air Management Practices (Singapore Data Centres)

If air management best practices are implemented studiously, it can effectively bring down energy usage of data centres by increasing the efficiency of air delivery to the IT equipment. The number of AHU units in operation can then closely match the cooling load in the room, reducing excess fan power consumption.

Poor air management is the primary cause of energy wastage in a data centre, where close to 50% of Singapore data owners are neglecting as shown in Table 3.3 below.

In the table, operational best practices are identified with the “BP” enclosed in parentheses while design best practices are identified with the “DBP” enclosed in parentheses as well. The ideal percentage value of certain practices is also provided in the table where 100% means full implementation. The BP and DBP are further elaborated in the succeeding paragraph.

Design best practices (DBP) are typically decided prior to the construction and easily implemented when a new data centre room is being built or the entire room is being renovated. They can be implemented on existing sites but are disruptive to operations most of the time. Also note that raised floor plenum is not labelled either BP or DBP as this is more of a design preference depending on the site constraints.

Air Management Practice	No. of Sites	% of Total
<u>Row Arrangement</u>		
Hot Aisle Cold Aisle (DBP)	10	45.4%
Legacy Front to Back	3	13.6%
Mixed Legacy and Hot Aisle Cold Aisle	9	41.0%
<u>Method of Air Delivery</u>		
Raised Floor plenum with perforated tiles/grilles	22	100%
Others – ducted , direct room throw	0	0%
<u>Method of Air Return</u>		
Ceiling Plenum (DBP)	5	22.7%
Room Return - No Extended ducts	14	63.7%
Room Return Extended Ducts (DBP)	3	13.6%
<u>Sealing of cable cut-out and Un-needed Openings (Ideal BP=100%)</u>		
From 75% to 100%	10	45.4%
From 25% to 75%	4	18.2%
Less than 25%	8	36.4%
<u>Use of Blanking Panels in racks (Ideal BP = 100%)</u>		
From 75% to 100%	8	36.4%
From 25% to 75%	5	22.7%
Less than 25%	9	40.9%
<u>Use of Overhead Trays for Data Cabling (DBP)</u>		
Yes	9	41%
No	12	54.5%
Mixed	1	4.5%
<u>Supplemental Spot Cooling (DBP/BP)</u>		
In-row coolers	2	9%
Others – rear door, overhead	0	0%
<u>Aisle Containment System (DBP/BP)</u>		
Fully Enclosed Cold Aisle or Hot Aisle	0	0%
Partially Enclosed Cold Aisle or Hot Aisle	2	9%
Rack Enclosure with built in cooling	0	0%

Table 3.3 Air management practices profile findings

Row Arrangement

Air management practices listed in the above table shows that 45% of the sites are using segregated aisle for warm exhaust and cold supply air (Hot Aisle –Cold Aisle) and that a further 41% of the sites are in the process of adoption as well. This practice (Hot Aisle –Cold Aisle) is already the accepted standard for all new data centres in Singapore (See Figure 3.5). In the diagram, the blue arrows signify cold supply air from the floor plenum while red arrows signify warm exhaust air from IT equipment. The yellow orange arrows signify mixed air flow consisting of warm exhaust and cold supply air.

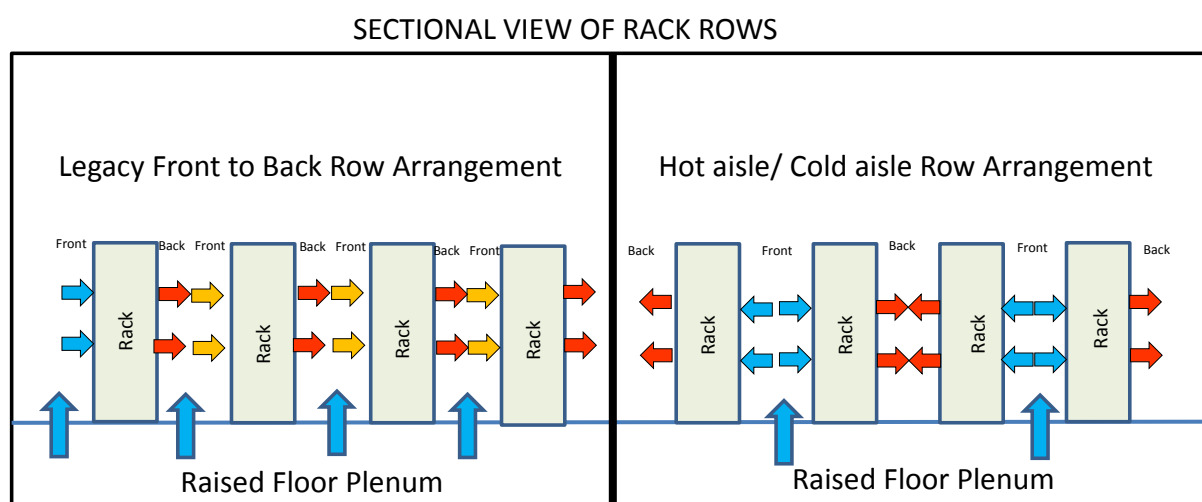


Figure 3.5 Diagram showing two type of row arrangement illustration

Air Delivery Approach

The preferred method by Singapore data centres for cooling air delivery is still the raised floor plenum with all surveyed sites using this method. None of the sites use direct top discharge of supply air from the AHUs.

Use of supplemental spot cooling such as in-row, rear door or overhead to support high density is gaining ground and can be found in the newer sites as well existing sites that has been upgraded or renovated. Two of the sites have adopted this approach.

Air Return Approach

Around 77% of the sites still use a room return approach for their data centres with only a small fraction of them using extended return ducts for their air handling units. Only 23% used a ceiling plenum approach. The primary factor that limits the sites from using extended return ducts or a ceiling plenum return approach is the limited floor to floor (slab to slab) height available in most of the buildings. However, majority of the site owners are aware of the advantage and would implement either approach on new sites, as well as look for new data centre space that allows these features to be designed (See Figure 3.6 for the ceiling plenum return concept).

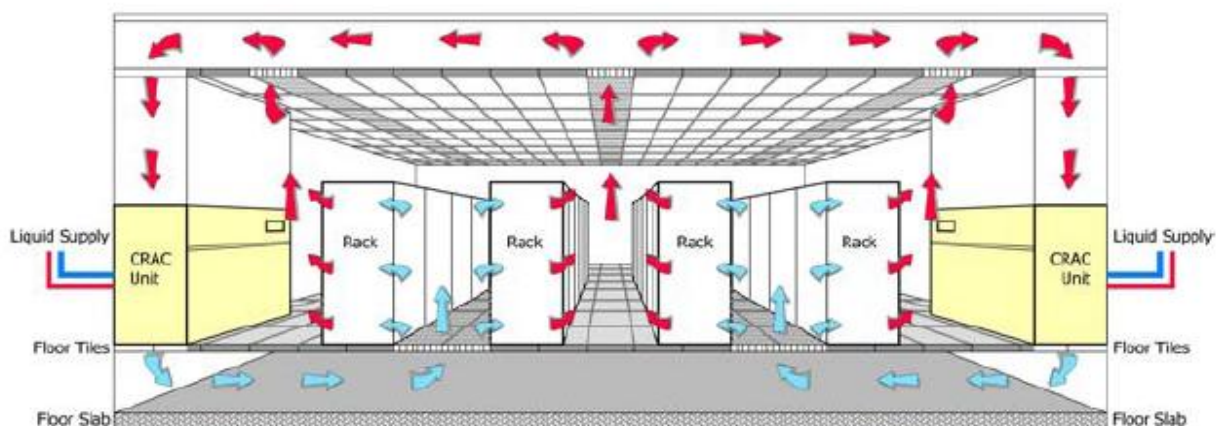


Figure 3.6 Ceiling plenum return concept (Illustration from ASHRAE)

Sealing of Cable Cut-outs and Unnecessary Floor Openings

Sealing of cable cut-outs and un-needed floor panel openings is a major concern. The loss of static pressure from these openings directly translates to higher energy demand by having to run more AHUs to compensate for the air static pressure loss. Only 45% of the sites have intensively implemented or strictly adhere to the practice of sealing the openings that are not used to support IT equipment. Majority of the owners are aware of the impact of unsealed openings but around 55% of the sites are showing partial implementation or no implementation of this practice. This can easily be implemented without any disruptive impact to operation but it is not being done on a much broader scale (refer to Annex A.2 Air Management and Environmental Controls).

Use of Blanking Panels in Racks

Close to 41% of the sites still do not use blanking panels to seal the unused space of their racks. The few blanking panels that are used in these sites are mainly found on cabinets that were part of supply package for IT systems that comes with their racks from the IT vendor. There is no proactive practice to seal the un-used rack space within existing cabinets. Only 36% of the sites have fully or proactively practised the sealing of unused rack space with blanking panels. The rest of the sites have partially implemented blanking panels or are limited by the rack type. Lack of blanking panels may not be an issue with lightly loaded racks having IT load of 1 to 2 kW, however as load density goes beyond 3 kW or more, it is a must to seal the unused space in between servers in these racks otherwise recirculation issues will occur (refer to Annex A.2 Air Management and Environmental Controls).

Use of Overhead Trays for Data Cabling

It is well known that the primary obstruction in the raised floor plenum is caused by the growth of data cabling over time, which blocks air from the AHUs from flowing across to other sections of the data centre. The assessment shows that the use of overhead trays for data cabling, which is a design best practice, is more prevalent with at least 41% fully adopting the practice. The other 54% that has data cabling running under the raised floor are mainly limited by the height constraints in the building but would prefer overhead cabling for their new sites in the future. Some of the sites that plan to renovate their existing sites indicated that they would use overhead trays for data cabling for the renovated sites. Data centre sites that used overhead cable trays are typically located in industrial type of buildings whereas those that do not are located in buildings that were designed for office space. It is recommended that new data centres have a minimum clear height of 4.2 metres between the top of the floor slab and

the underside of beams in order to implement most of the best design practices that increases air delivery efficiency.

Supplemental Spot Cooling

The use of supplemental spot cooling is still not prevalent, with only 2 sites adopting this approach to mitigate the impact of high density racks within a conventionally designed data centre (See Figure 3.7).

SPOT COOLING CONCEPT

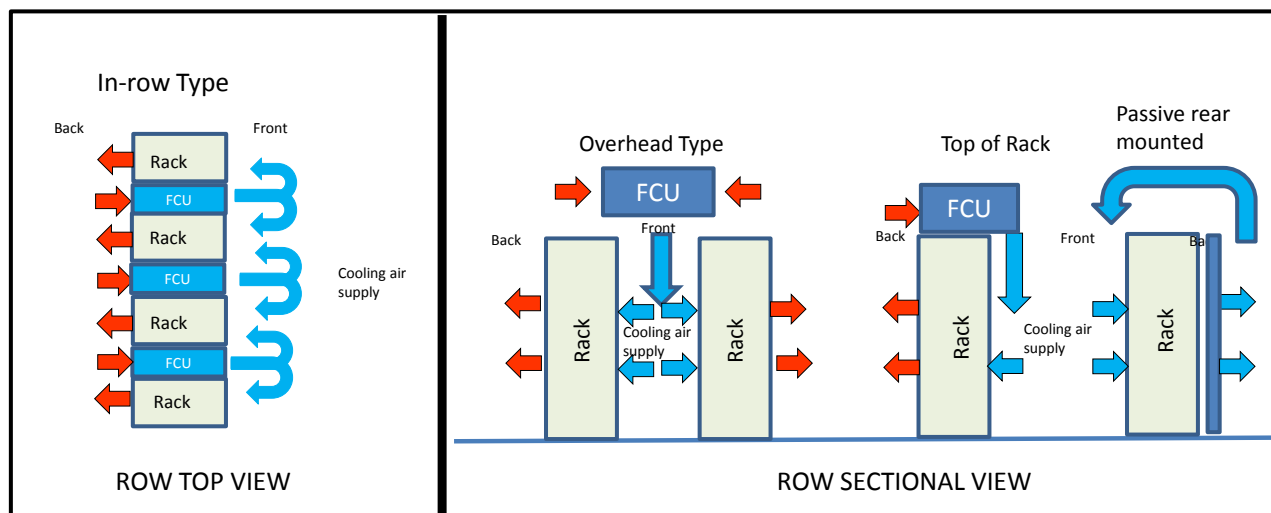


Figure 3.7 Spot cooling concept

The use of supplemental spot cooling is more energy efficient as this greatly reduces the energy demand required to deliver the cooling air to the equipment, and also to minimise the inefficiencies from the air delivery system compared to the conventional approach of using CRAHs or CRACs with a raised floor plenum for air delivery. These inefficiencies come from the resistance losses incurred by the air flow through the raised floor plenum, raised floor panel openings and other obstructions along the way that impedes the air from having a direct path to the IT equipment and back to the air handling unit. This results in an increased fan power requirement to move the air around the data centre as opposed to having the cooling unit right next to the IT equipment itself.

Spot cooling units are typically fitted with variable speed fan motors. This approach was originally intended for cooling medium (~5 kW/rack load) to high density rack row (>6 kW load). The system allows for higher air intake temperature by using a supply air control algorithm to regulate the supply of cooling air to the IT equipment. Using a supply air temperature control approach would make it easier for data centres to operate at optimum cooling supply air temperature range of 24°C to 27°C at the IT equipment air intake.

They are designed for sensible heat removal only, and have no latent heat removal capacity allowing them to operate at higher air temperature across the heat exchanger coil.

We may see more widespread adoption of this method as equipment costs decrease over time with more manufacturers coming into the market. Conventional computer room air handling or conditioning units can primarily function as humidity control equipment for the room or be completely replaced with desiccant type dehumidifiers in new data centres. Desiccant type dehumidifiers use moisture absorbent materials similar to silica gels and can be recharged to expel moisture out of the material for reuse. It uses less energy for moisture removal as it does not condense water out from air, which requires large amount of energy during the process of condensation (latent heat removal due to phase change from vapour to liquid).

Aisle Containment System

The study conducted shows that 2 sites have implemented this method using partial containment on sections of their existing data centres, using flame retardant PVC strips to close off the ends of the cold aisle. Aisle containment system, whether it is used in the hot or cold aisle is considered the most effective method to segregate warm from cold air inside the data centre.

There are two approaches to this method with one completely enclosing the aisle and the other partially blocking the aisle, either by putting plastic strips or door frames and door at each aisle ends. The adoption and use of this approach will become more prevalent once the issues related to fire protection are resolved. This method can be used in conjunction with either conventional CRAC/CRAH or spot cooling systems (See Figure 3.8).

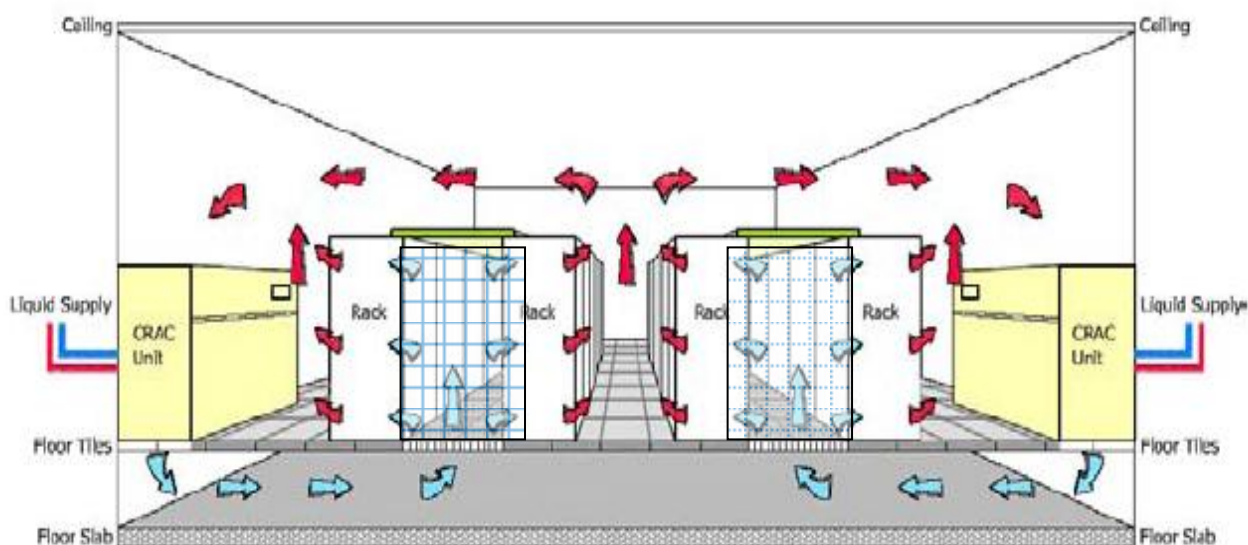


Figure 3.8 Cold aisle containment concept (Illustration from ASHRAE)

3.4. Environment Temperature Control

Since the release of the ASHRAE Thermal Guidelines for Data Processing Environment in 2004 which was updated in 2008 with the ASHRAE Environmental Guidelines for Datacom Equipment, data centre owners have adopted it as the defacto standard for their data centre environment. In 2011, it released an updated guideline which is shown in Section 1 Table 1.3 of this document. The guideline recommends an equipment air intake temperature range of 18°C to 27°C. The intake air temperature measurements and profile shown is based on the recommended operating range for Class A1, which most data centres adhere to or base their operating environment range on. Do note that the primary purpose of the ASHRAE recommended range is to address reliability issues of IT equipment rather than energy efficiency issues.

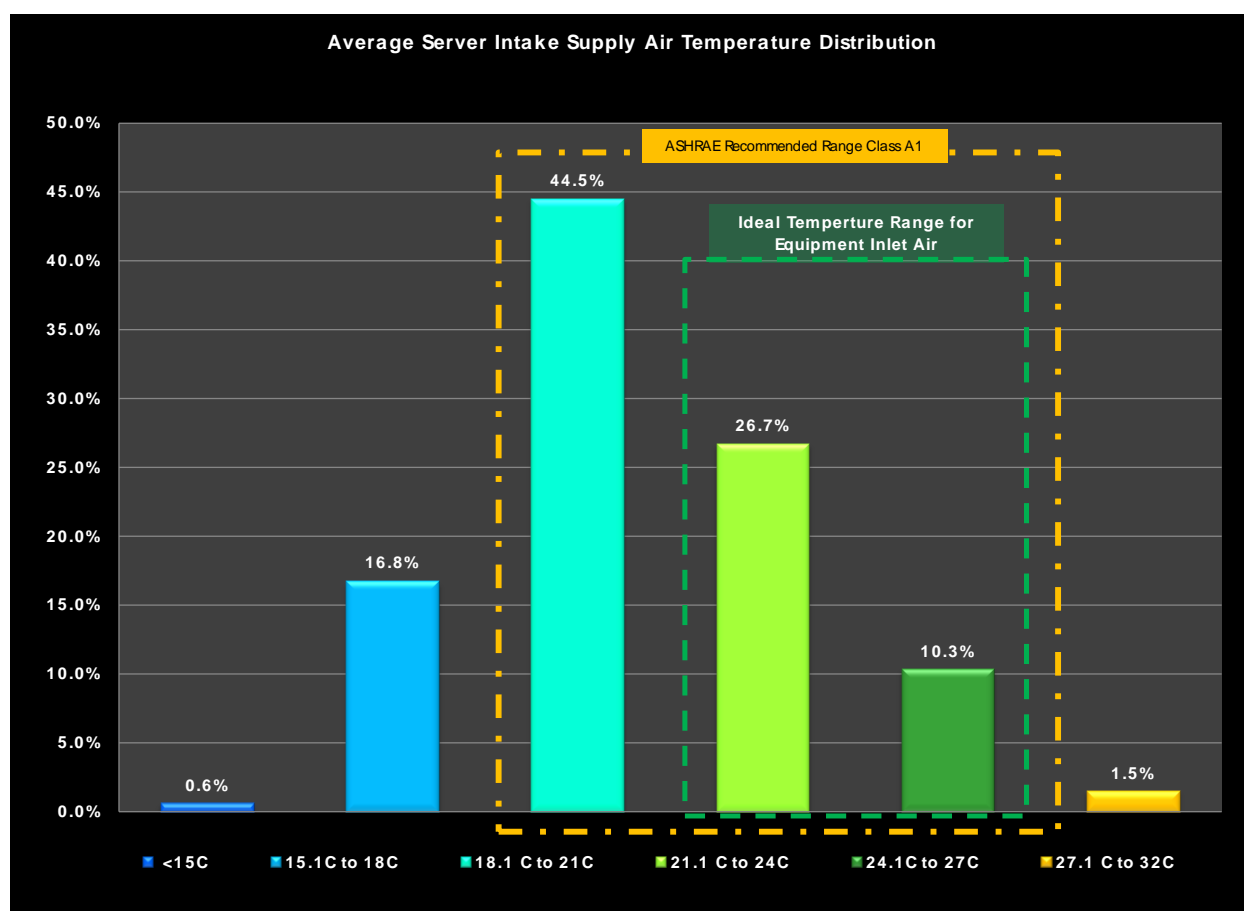


Figure 3.9 Singapore data centres average inlet air temperature

The average measured server inlet air temperature across the sites is shown in Figure 3.9. The result shows that 81.7% of the equipment inlet temperatures sampled is within the ASHRAE recommended range. However 44.5% of the total falls in the lower band (18.1°C to 21°C) of the ASHRAE recommended range and a further 17.8% of the total falling below 18°C. This shows that Singapore data centres are being operated far colder than necessary and there is opportunity to reduce energy demand from cooling by raising the inlet air temperature to the middle band (21.1°C to 23°C) and upper band (23.1°C to 27°C) of the ASHRAE recommended range. Raising the computer room air handling or conditioning units' temperature set point reduces the workload on the refrigerant compressors.

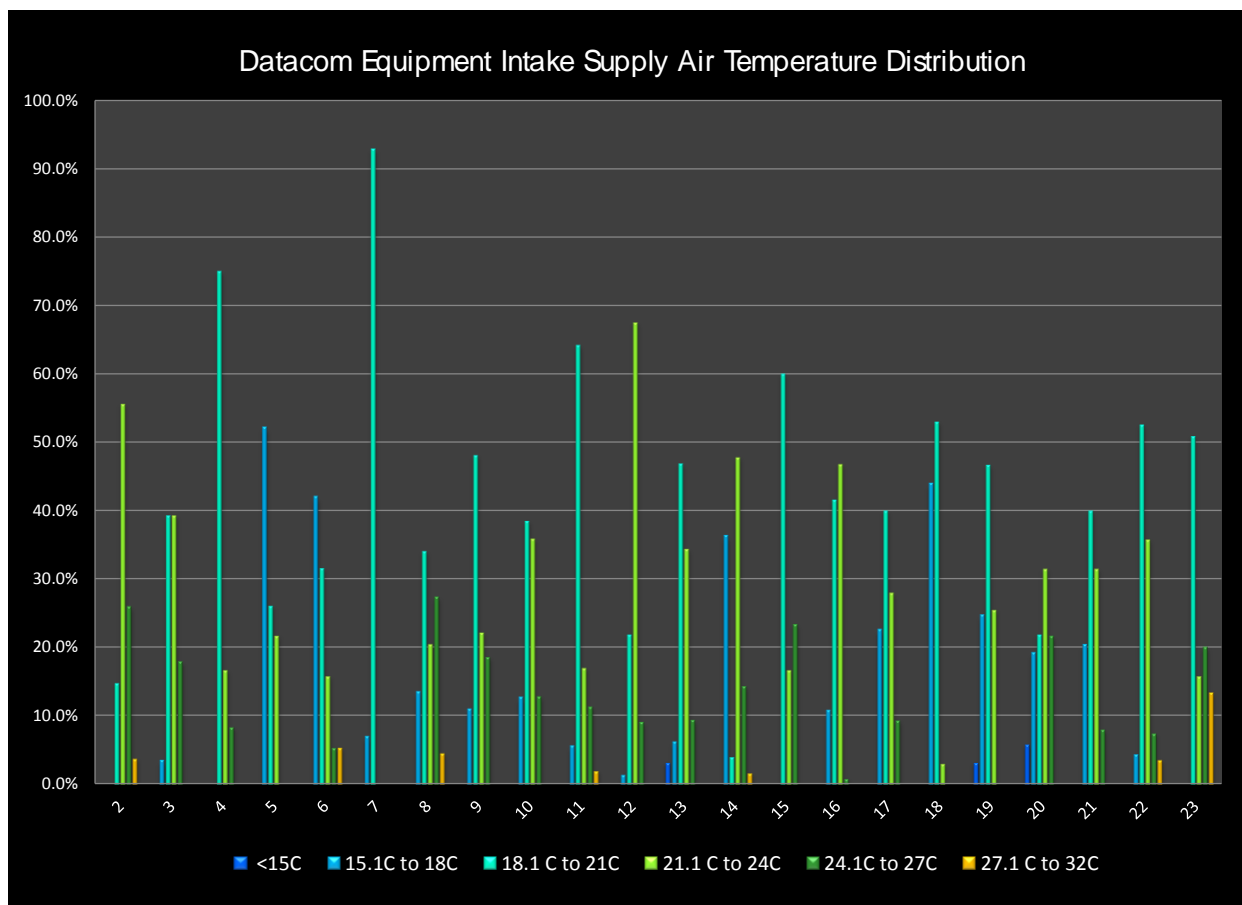


Figure 3.10 Datacom equipment intake air temperature profile across the sites

The average server intake air temperature profile for each site is shown in Figure 3.10. Only one site (#15) managed to have all of the measured points within the ASHRAE recommended range. However, 60% of these measured points still fall in the lower band of the recommended range. (Note: Data for site #1 is unavailable)

Temperature set point of CRAH/CRAC units across the sites varies and ranges from 17 °C to 25 ° C. The predominant temperature set point range is between 20°C to 22°C which accounts for 50% of the site assessed. In addition some of the sites vary the set point between adjacent units or units across the room such that the set point ranges from 19°C to 22°C (3 sites). 8 of the sites have temperature set point in the range between 22.5°C to 25°C.

The primary factors that prevent most sites from operating on a higher air temperature are as follow:

- Legacy control of air handling units and uneven air distribution – 100% of the sites use return air temperature control approach which results in differing supply air temperature from the AHUs as well as differing air return temperature to the units.

Example of uneven load and air distribution impact on cooling systems energy usage

This phenomenon is caused by the non-uniform air temperature returning to the AHU units and the effect of “area of influence” of each AHU. This is a common occurrence in data centres that have CRAC/CRAH units using a room return approach or having far more units in operation than what is required. As illustrated in Figure 3.11, CRAC 2 senses the higher return air temperature from the heavily loaded racks even though it does not have an influence in that particular row of racks, resulting in CRAC 2 running at 100%.

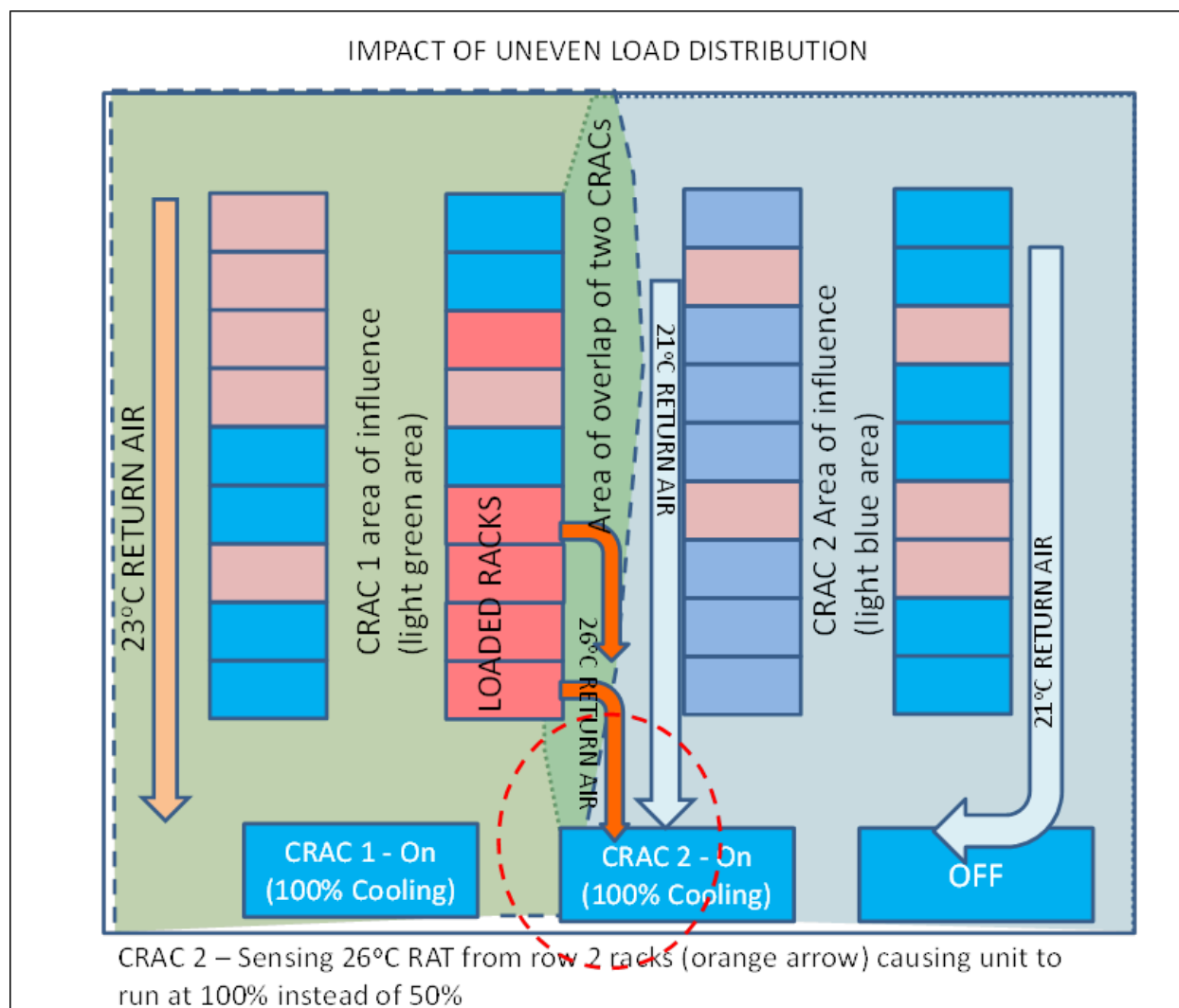


Figure 3.11 Impact of uneven load distribution on cooling systems

- Mind-set – a number of data centre owners as well as IT equipment owners (for hosting/co-location sites) are still uncomfortable with adopting a higher operating temperature that is similar to an “office temperature” level. There is also a belief among them that having a lower room temperature provides a “buffer” that prevents the room from heating up rapidly.

- Service level agreement (SLA) requirements - Service level agreements imposed by a collocating tenant typically have very narrow temperature and humidity band (e.g. 22°C +/-1°C; RH 50% +/- 5%). This prevents the site owner from adjusting the temperature set points higher in the room and allowing a wider operating temperature band due to concerns in meeting contractual obligations to the tenant.
- Legacy Room Design and Under floor Obstructions - Legacy room design with data cabling laid under the raised floor plenum which over the years has created air "dams". This greatly reduces the ability of the data centre to operate on an elevated air temperature range (as in the upper range of the ASHRAE recommendations) as any adjustments in set points greatly increases the likelihood of "hot spots" in certain sections of the room, with temperatures that may exceed the upper limit of the ASHRAE recommended range.
- Best Practices Implementation – There is still a lacksaidal attitude towards the implementation of best practices such as sealing of cable cut-outs and unnecessary floor openings, and use of blanking panels (refer to Air Management Practices in Section 3.3).

Recommendations:

Raising the operating environmental temperature in the data centre would require a combination of the following inter-related actions:

- Temperature settings should be matched to equipment specifications operating range to allow wider tolerance to operating temperature variance within the data centre (but keeping within ASHARE recommended range)
- Obstruction under the raised floor plenum should be minimised to allow free flow of air across the room
- Implementation of good air management practices such as sealing of cable cut-outs and rack blanking panels and others.
- Use of computational fluid dynamics (CFD) simulation tool to determine airflow pattern in the room for both existing and new sites (during design stage).
- Periodic CFD analysis at least once a year should be conducted for sites with frequent addition of IT equipment or before a major intake of IT equipment into the data centre.

3.5. Summary of Recommendations to Improve Mechanical PUE

Assisting Data Centre Owner

While mechanical systems is the second biggest energy consumer after the IT equipment in the data centre, it is the area where most data centre owners have the most difficulties in understanding and predicting the impact when trying to implement an improvement on the cooling system of the data centre.

The lack of in-depth technical knowledge and tools resulted in owners' hesitation and subsequent difficulty of getting the budget from their management. The data centre owners should be encouraged to engage professional help from specialist consultants to address their data centre cooling issues.

Pre-planning and Forecasting

The lack of a good forecast and roadmap of the IT equipment growth, power and space requirement usually results in a data centre that is oversized and under-utilised. It is rare to find a data centre that has been undersized. It is of great importance that data centre owners develop this roadmap for their data centre prior to starting the design. Forecasting the IT equipment technology and growth against the organisation's business plans and requirements, enhances the ability to right size the data centre, such as having modularity designed into the data centre infrastructure.

Planning and Design Phase

It is recommended that data centre designers be fully aware of air management practices and have a good understanding of IT equipment characteristics and requirements. Proper planning of the layout and placement of equipment as well as the use of computational fluid dynamic analysis tools should be done during the design stage. This enables the best possible layout and placement of equipment to be made prior to the actual construction of the room.

Data centre owners should engage engineering consultants that are experienced and knowledgeable in data centre design best practices. During operation, the data centre owner should diligently implement air management best practices, which then allow for higher operating environmental parameters to be implemented in the data centre.

For new data centres, the room should be designed for optimum operating temperature and incorporate newer generation of air conditioning equipment and techniques. This includes the use of some of the techniques and technology as discussed earlier in this section.

Redundancy configuration should be designed to match availability requirements.

Cooling System Type Selection

For medium and large sites, water cooled chiller systems would provide the most energy efficient operation as long as the utilisation levels are kept within the optimum operating range of the cooling systems' installed capacity.

Cooling systems should be sized and designed properly to ensure that the cooling load profile of the site falls in the "sweet spot" of the chiller system, or has the necessary features to allow high efficiency part load operation such as the use variable speed driven water pumps and cooling tower fans.

Chiller System

Air-cooled Chiller Systems

- Use of high efficiency chiller model instead of standard models, can reduce chiller power consumption by around 2% to 3%.
- Each Centigrade degree reduction of condenser entering air temperature reduces chiller compressor power consumption by 0.8% to 1.3%. This can be achieved through use of water mist sprayers to reduce the entering air temperature. Do note that water mist systems require periodic maintenance to maintain optimum performance of the nozzles.
- Condenser fins have to be periodically cleaned as dirty fins significantly reduce performance of condenser unit, leading to higher energy consumption.
- Ensure that adequate space between walls and chiller units are provided to avoid coil starvation or short circuiting of warm exhaust air back into the condenser.

Water Cooled Chiller Systems

- Use of variable frequency driven pump and cooling tower motor fans significantly reduces energy consumption.
- Use of chiller system with performance of 0.6 kW/RT or better.
- Use of a lower approach or greater range in cooling tower design may reduce overall energy consumption.
- Use of variable speed chiller units or staging of chiller units to better handle part load conditions should be explored where feasible.

Recommendations applicable for both water-cooled and air-cooled chiller plants:

- Periodic cleaning of heat exchangers' water side tubes as well as regular chemical treatment to reduce carbonate and sludge coating on surfaces.
- Use of premium efficiency motors for fans and pumps.
- Operating at a higher chilled water leaving temperature increases chiller efficiency by reducing compressor power usage. *(Note this is recommended for dedicated chillers for data centres only. Shared chillers supporting both data centre and offices should have provisions for humidity control in the offices if a higher leaving temperature is used. Furthermore the impact to the performance of AHUs' cooling capacity should be assessed. Additional AHUs may be required to be turned on to compensate for the loss in cooling capacity which would increase overall fan power consumption and negating the savings in the chillers.)*
- Reduce pump head loss in headers and piping system by use of gradual bends in pipes and use of low resistance valves throughout the system where applicable.
- Periodic maintenance and calibration of sensors such as temperature and flow meters to ensure that the system is operating within its designed range.
- Extensive use of chilled water energy meters to monitor and trend system performance as well as energy usage across the data centre facility.
- Use of smaller capacity chillers together with larger ones to cater for part load conditions and maintain utilisation levels of chillers within the optimum load range.

Operating Practices

Room Location and Extraneous Heat Gain

- Minimum or no exposure to the external environment to reduce heat gain from solar radiation and heat transfer from a warmer to a colder environment.

- Data centre rooms should have windows sealed and insulated, or designed with no windows at all

Fresh Air supply and Humidity Control

- Proper placement and location of the fresh air supply diffusers within the data centre to ensure that the air is diffused and mixed with the room air prior to entering CRAH/CRAC units.
- The fresh air diffusers or vents should be located over the hot aisles where the incoming air can be dispersed and mixed with the warm low humidity air coming from the servers.
- Use of demand control ventilation and air locks when designing provisions for air exchange and pressurisation purposes.
- Increase the RH level set point to 55% or to the ASHRAE allowed limits.
- Depending on the size of the room the number of CRAH/CRACs fitted with dehumidification function should be limited to as few as possible; just enough to remove the moisture intake based on calculated fresh air intake and infiltration calculations.
- For new data centres standalone dehumidification units can be installed instead of using CRAH or CRACs for the dehumidification function.

Static UPS and Battery Room Cooling

- Static UPS power modules can be separated from the batteries and located in their own room where feasible. They can then be operated at a higher environmental temperature of 28°C to 30°C without degradation of reliability. This may also allow the use of filtered outside air using ventilation fans to cool the UPS systems instead of using refrigerant based systems. Refrigerant based cooling can then be turned on during certain conditions such as high ambient air temperature or very high humidity conditions.
- The batteries on their own do not have much cooling demand as they have very little heat dissipation and can thus, be provisioned with a smaller air conditioning unit to maintain room temperature of up to 25°C (for VRLA batteries).

By separating these two components into separate rooms and applying different environment parameters, additional energy savings can be achieved in the data centre.

Air Management Practices

Refer to Section 3.3 and Annex A.2 for further details on air management practices.

Reducing Bypass

- Locate floor air grills so that they supply to the inlet of servers, i.e. no floor air grills in hot aisles
- Ensure air velocities from floor grills are not too high and do not overshoot the cabinet height
- Seal air gaps in the raised floor "cable brushes/pillows"
- CRAC units turned off are a source of air bypass (consider air isolation with dampers)
- Ensure that the combined cooling capacity of AHUs in operation closely match the cooling load in the room
- Use aisle containment systems
- Use supplemental spot coolers. These units typically have very little bypass air as they are installed close to the load

Reducing Recirculation

- Consider return air plenum and ductwork for the CRAC units or "raising height of CRAC returns"
- Remove obstructions under the floor that restrict cold air to supply the server inlets
- Ensure as best as possible the adequate supply of cold air to the server inlets
- Ensure air velocities and flows from floor grills are sufficient to reach the top of cabinet servers

- Fit blanking plates in cabinets where servers are not installed
- Close gaps between cabinets (where warm air can make its way to the server inlet)
- Avoid installing highly loaded servers at the end of cabinet row or at the top where recirculation is more likely to occur
- Ensure that cables/wires are routed properly "in the rear of IT cabinets"
- Ensure that return air grills are over hot aisles "if applicable"
- Consider means to physically isolate the supply (cold) and return (hot) air streams using "containment systems"

Operating in the ASHRAE Recommended Range

Raising the operating environmental temperature in the data centre would require a combination of actions that are inter-related to each other. These are the following:

- Temperature settings should be matched to equipment specifications operating range to allow wider tolerance to operating temperature variance within the data centre (but keeping within ASHARE recommended range)
- Obstruction under the raised floor plenum should be minimised to allow free flow of air across the room
- Implementation of good air management practices is a must
- Use of computational fluid dynamics (CFD) simulation tool to determine airflow pattern in the room for both existing and new sites (during design stage).
- Periodic CFD analysis at least once a year should be conducted for sites with frequent addition of IT equipment or before a major intake of IT equipment into the data centre.

4. Electrical PUE – Findings and Recommendations

The average electrical PUE for individual data centre sites as well as the average is shown in Figure 4.1. The electrical PUE for the sites ranged from 1.15 to 1.64 with an average of 1.26. The average electrical PUE is comparable to EMEA (Europe Middle East Africa – 1.28) and the United States (1.32).

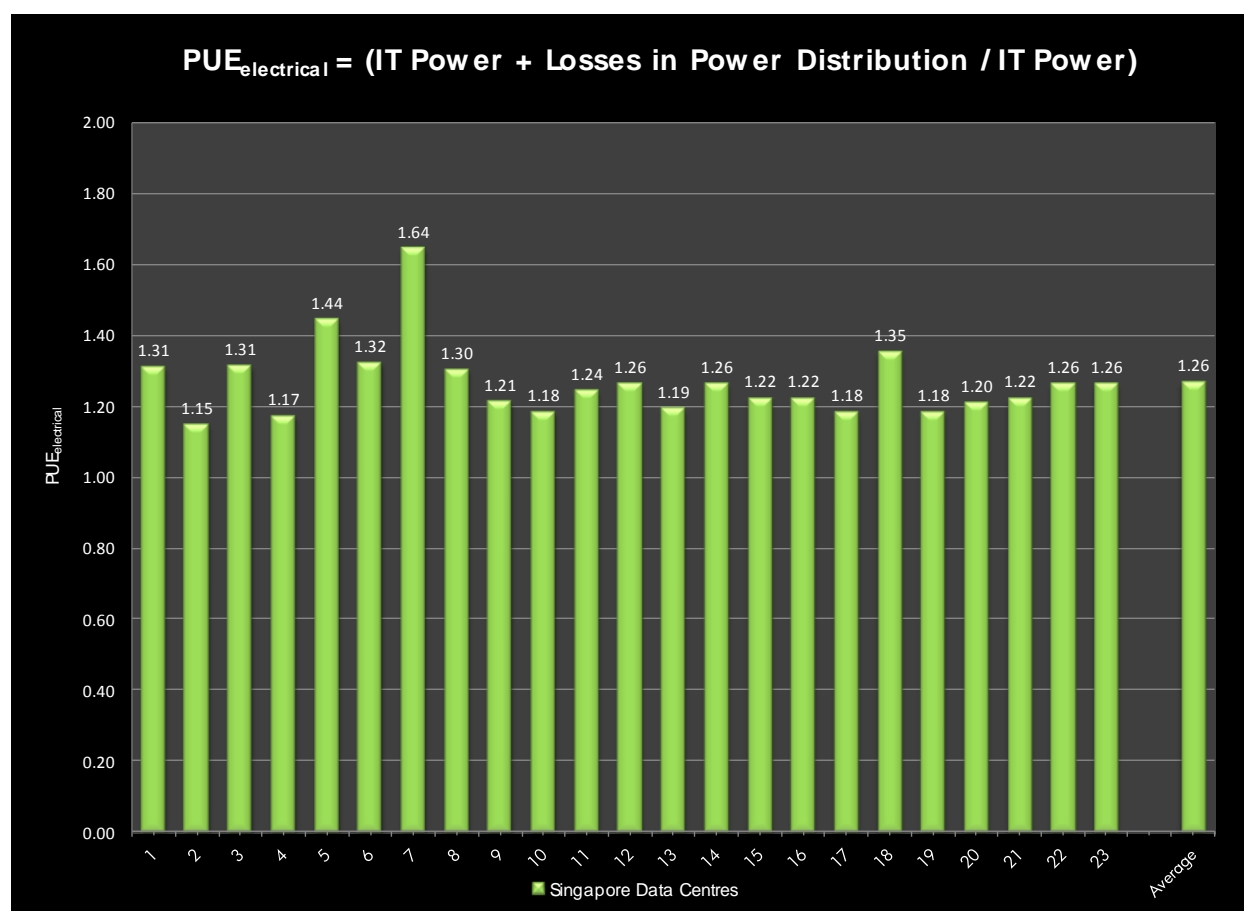


Figure 4.1 Singapore Annual average Electrical PUE

4.1. Design, Equipment and Operating Practices and Electrical PUE

Designed Load Utilisation and Electrical PUE

Figure 4.2 shows the electrical PUE plotted against the percentage of utilisation of designed UPS capacity. Generally, the higher the design load utilisation, the lower the electrical PUE.

The electrical PUE ranges from 1.15 for efficient facilities with high UPS utilisation factor to 1.64 for facilities with high redundancy and low UPS load factor which resulted in high UPS losses.

Majority of the data centres (~61%) benchmarked below were characterised by moderate to high UPS utilisation, with a few approaching the designed load resulting in lower losses and better electrical PUE. The trend shows that the electrical PUE goes below 1.3 once utilisation is beyond 40%. However, it was noted that none of the sites went below 1.15 and this may correspond to the lower limit for electrical PUE is when either static or Dynamic Rotary Uninterruptible Power Supply (DRUPS) systems are being used.

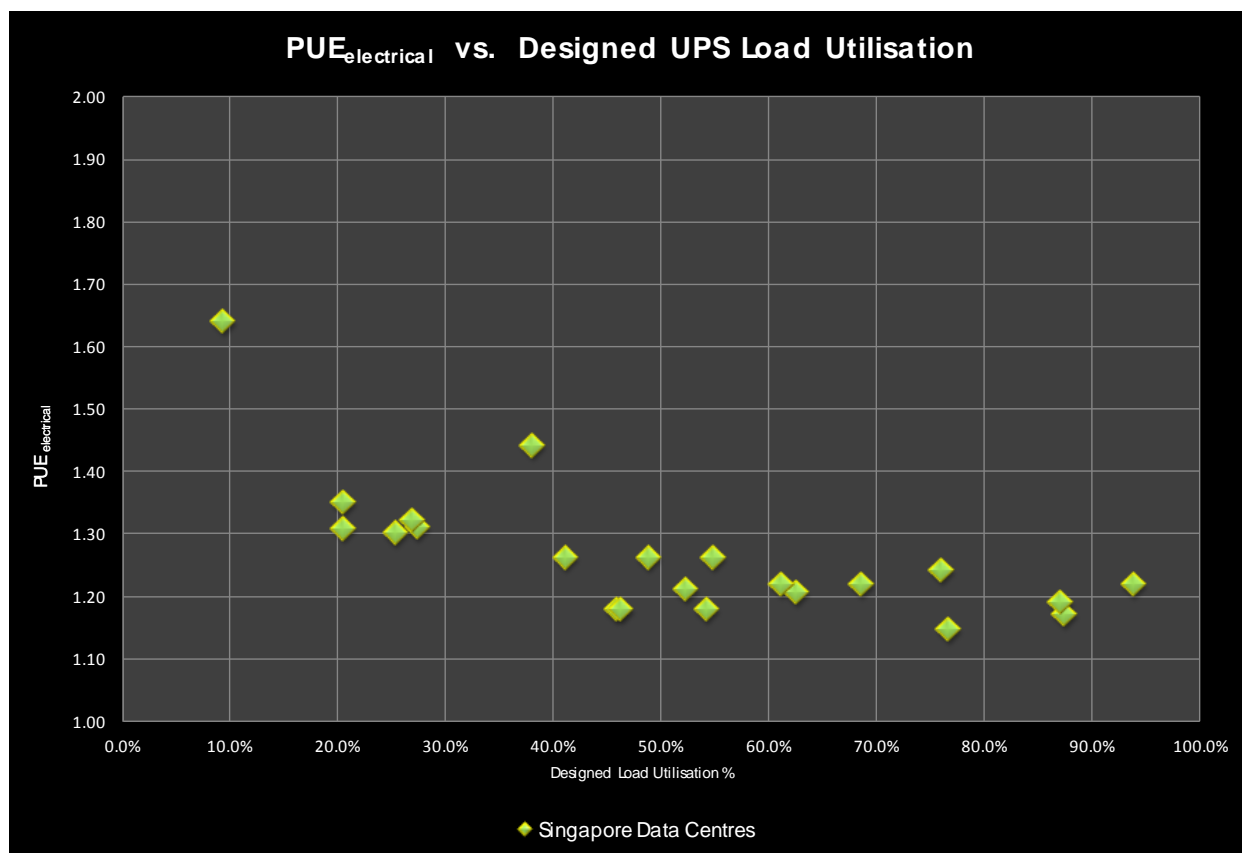


Figure 4.2 Annual average Electrical PUE against designed UPS load utilisation

The highest value recorded for a site was 1.64. This was primarily attributed to an under-utilised large capacity UPS system (<10% load) and the system was just commissioned few months prior to the assessment. Another site with a PUE of 1.44 had under-utilised UPS systems due to a change of business direction, leading to a reduction of IT equipment in the data centre (with one of the N+1 UPS system operating at less than 3% load).

The average UPS utilisation for all sites is 27.4% with an average UPS efficiency of 87.6%. The primary factor that influences the electrical PUE value is UPS efficiency, which is highly dependent on its utilisation factor.

UPS losses accounted for around 53% of the electrical system losses on average. The electrical distribution system (including transformers) accounted for 37% while lighting accounted for the remaining 10%.

Distribution losses, which accounts for around 37% of the average losses in the electrical system may also be reduced but not as significantly as the UPS system. This is due to the inherent physical characteristics of electrical conductors (cabling) and step down transformers that are used to convert medium voltage to low voltage. Reducing the distance between the main transformers and the data centres will reduce the conductance losses. Likewise, use of low loss transformers will also reduce the losses across the transformers.

Recommendations

- Proper selection and use of high efficiency UPS system is needed to keep the electrical PUE low. UPS efficiency levels should be higher than 90% or better at 25% load utilisation.
- Use of modularity in the design allows for higher utilisation factors in the UPS system.
- Redundancy configuration should be matched to business availability requirements and should not exceed the minimum required level.
- Distribution losses should be minimised by keeping power transmission distances short, use of high efficiency transformers and proper sizing of conductors.
- Installation of energy monitoring systems or power demand meters allows owners to identify areas of high energy usage and enable analysis and identification of issues and subsequent corrective actions to be undertaken.

Equipment and Design Configuration and Electrical PUE

The predominant type of UPS system used in the sites is the static UPS (basically consist of AC to DC to AC converter module with batteries providing the energy storage for the ride through) which is used in 21 of the 23 sites. Average efficiency for static UPS systems is 87.2% with an average utilisation rate of 28%.

2 of the 23 sites used dynamic rotary UPS (DRUPS), which is primarily a diesel engine coupled to a rotating flywheel (serving as an energy storage) and an alternator set. Average DRUPS system efficiency is 91.5% with an average utilisation of 20%. The DRUPS used for IT equipment were fitted with filtering circuits which accounted for the efficiency at the lower ninetieth percentile range. One of the sites that used DRUPS as a back-up for the mechanical systems was noted to have efficiency levels of 97% and was not fitted with any filtering circuits which accounted for the higher efficiency.

The primary advantage of DRUPS system in terms of energy performance is that it is housed in a non-air conditioned room and requires only ventilation fans for cooling whereas for a static UPS system, its batteries has to be housed in an air conditioned room (i.e. battery reliability is affected by elevated temperature). Thus, energy demand for cooling the DRUPS is less than that of equivalent capacity static UPS systems. The disadvantages of DRUPS are operational in nature which limits its widespread acceptance (i.e. short ride through period in seconds, long maintenance period requirement during bearing changes).

No. of Sites	% of Sites	Design Configuration	Utilisation	UPS Efficiency	Electrical PUE	UPS Age
14	61%	2N (Static)	28.1%	88.4%	1.27	5.8
6	26%	N+1 (Static)	28.7%	85.1%	1.28	6.6
1	4%	N (Static)	24.0%	83.6%	1.18	8.0
2	9%	2N (DRUPS)	20.0%	91.5%	1.23	2.5

Table 4.1 Summary of UPS system for Singapore Data Centres

Table 4.1 shows the average electrical PUE of the sites in relation to the average UPS utilisation rate, efficiency, age and design configuration. There is a dominance of 2N configured UPS (70%) over all other configuration in Singapore data centres.

2N vs. N+1 Configuration (Static UPS)

For sites with static UPS systems, sites with 2N configuration have a slightly higher UPS efficiency values as compared to an N+1 configured UPS systems at almost equal utilisation (See Figure 4.3). This does not suggest that 2N configured UPS are more efficient than N+1 configured UPS systems. The small difference between the two can be attributed to the following:

- It was observed that the number of UPS modules (2) used in sites having N+1 configured UPS was similar to those used in sites with 2N configured UPS.
- N+1 UPS systems have lower efficiency – For sites using N+1(static) configuration, 4 out of 6 sites have UPS systems that are 7 years and above in age. For sites with 2N (static) configuration, 8 out of 14 sites have 2N configured systems that are 5 years and below in age. The newer generation of UPS modules typically have better efficiency as compared to older systems (aged 5 years and above) mainly due to the increased use of Insulated Gate Bipolar Transistors (IGBT) in the power conversion circuits whereas the older generation uses Silicon Controlled Rectifiers (SCR) or thyristors. In addition, the newer generation of UPS systems uses a transformer-less design which removed the losses coming from the transformer.
- For N+1 configured UPS system modules, the number of modules directly affects the maximum level of utilisation that each individual module can attain. Figure 4.4 shows the impact on utilisation level as the number of modules is increased. Note that this can be applied to modular UPS systems as well.

2N Configuration (Static vs. DRUPS)

It was noted that the individual system efficiency of DRUPS is higher than static UPS systems at lower load (<20%). The sites with DRUPS systems use 2N configuration.

N Configuration (Static)

There is only 1 site with an N configured UPS system in the study. The electrical PUE for the lone site is lower than either sites with 2N or N+1 configured UPS systems as expected due to the lower UPS losses.

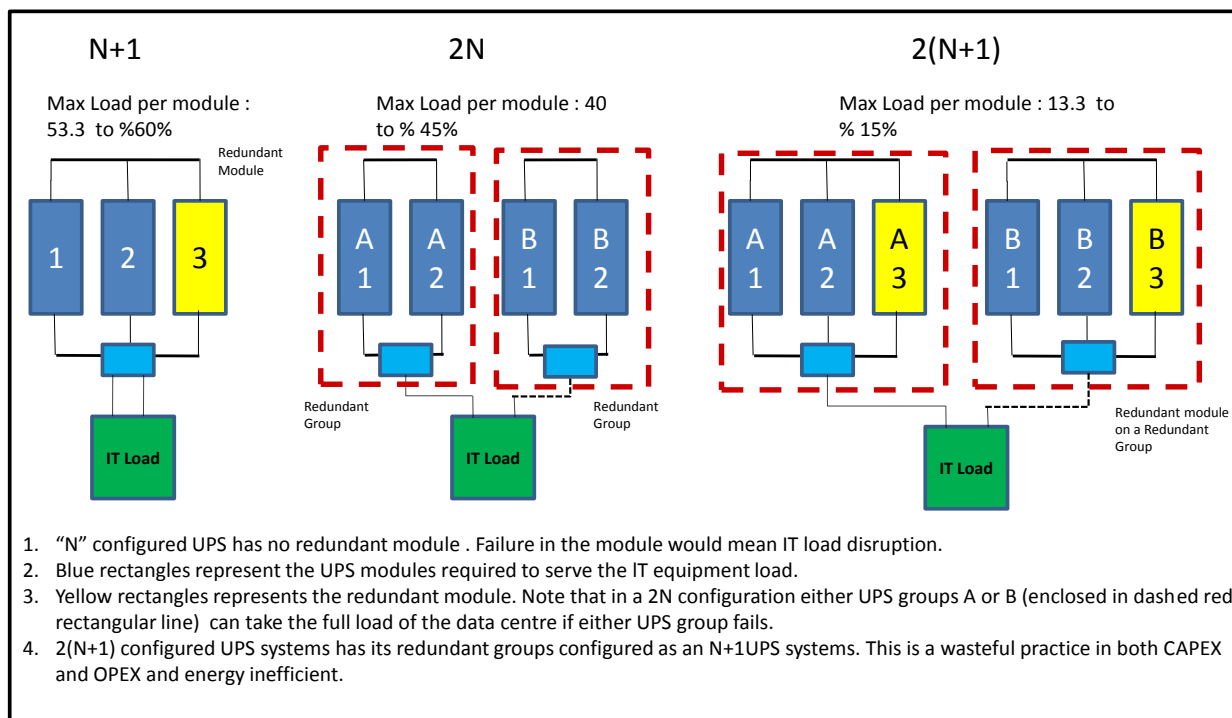


Figure 4.3 Diagram showing 3 types of redundancy configuration for UPS systems.

Example of how number of modules affects module load utilisation percentage on an N+1 configured UPS systems by using smaller capacity modules as the load increases.

Assume a data centre designed IT load of 500 kW :

Option A : N+1 with 2 UPS Module of 550 kW

Normal operation utilisation where total number of modules is 2.

% Utilisation = $500 / (2 \times 550) \times 100\% = 45.4\%$

Module failure operation % Utilisation 90.8%*

Option B : N+1 with 3 UPS Module of 300 kW

Normal operation utilisation where total number of modules is 3.

% Utilisation = $500 / (3 \times 300) \times 100\% = 55.5\%$

Module failure operation % Utilisation = 83.3%*

Option C : N+1 with 4 UPS Module of 200 kW

Normal operation utilisation where total number of modules is 4.

% Utilisation = $500 / (4 \times 200) \times 100\% = 62.5\%$

Module failure operation % Utilisation = 83.3%*

* Note:

Designers tend to avoid load utilisation over 90% of rating. Typical designed maximum load utilisation is between 80% to 90% of UPS module rating. Between the 3 options option C would be the choice for a site with a low initial IT load and slow growth. Modular sizing allows for higher UPS load utilisation levels.

Figure 4.4 Example of how the number of modules affects utilisation on an N+1 UPS configuration.

4.2. Recommendations to Improve Electrical PUE

The electrical power distribution system, in general, other than the UPS systems and lighting, provides the least opportunity for any significant power savings once the data centre is built and operational. Any upgrading work will result in disruption to some part of the data centre. Thus it is crucial that the electrical system is designed correctly from the start.

Utilisation

Proper IT load forecast (refer to Preplanning and Forecasting in Section 3.5) over the lifecycle of the data centre is the determining factor to right size as well as set the stage for capacity upgrades over the lifespan. The UPS systems account for around 53% of the total electrical losses in the data centre and as such, this should be the area of focus in the design to ensure that utilisation is always kept high so as to enable the UPS to operate at the optimum level of efficiency.

UPS Design and Configuration

Design configuration of UPS systems should also match business availability requirements. In one of the sites, the UPS system was designed with a 2(N+1) configuration. This configuration did not add much to the reliability but did add significantly to the electrical losses as well as the cooling demand.

- Proper selection and use of high efficiency UPS system is needed to keep the electrical PUE low.
- UPS efficiency levels should be higher than 90% or better at 25% load utilisation.
- Use of modularity in the design allows for higher utilisation factors in the UPS system.
- Redundancy configuration should be matched to business availability requirements.

Transformers and Distribution System

High efficiency transformers should also be selected for use in the data centre. Locating the data centre closer to the transformers and main switch rooms can reduce conductor resistance losses, as well as reduce capital investment costs (i.e. instead of using bigger conductors to reduce the resistance). However, sufficient separation distance should be provided between the transformer rooms/main switch rooms and the data centre to mitigate electromagnetic interference coming from the transformers and high current power transmission conductors. Use of static transfer switches should be avoided unless it is really necessary due to losses across the electronic switching circuits.

Energy and Power Monitoring System

The other important feature that is often left out or be given the lowest priority during the design and construction of a new data centre is an integrated power monitoring system. Power monitoring system typically has power quality monitoring features as well. This offers the best functionality to monitor the entire power infrastructure. On a more modest scale when budget do not allow for an integrated power monitoring system, all electrical distribution panels should at least be fitted with digital power meters to allow energy usage and demand monitoring of individual systems such as HVAC systems, lighting, IT load and UPS system. These can be connected and monitored by the building automation system (BAS) or building monitoring system (BMS), allowing trending and remote monitoring. For smaller data centres with no BAS/BMS, periodic manual recording from each meter can be done.

The ability to track and monitor individual power consumption of systems, provide the basis for any energy reduction and management program and should be the foundation for an energy efficient data centre.

It should be noted that although these recommendations are more appropriate in the design and construction stage of a new data centre, they can also be used to improve an existing data centre to a certain extent as long as operational issues, costs and return on investment are taken into consideration.

5. Staffing and Operation – Findings and Recommendations

5.1. Staff Capability on Energy Management

The following observations and findings were also made on the site's ability to track and record energy consumption, as well as staff knowledge and ability to implement energy efficiency related measures or programmes. The results are represented in table 5.1 (Information for one site is not available).

Staff Capability	No. of Sites	% of Total
In-house operations/facility support personnel are technically proficient in energy management and can implement programmes	5	22%
In-house operations/facility support personnel are aware of energy management best practices with some technical proficiency to implement energy management programs with 3rd party assistance	12	55%
In-house operations/facility support personnel are not technically proficient and totally reliant on 3rd party for assistance to implement energy management programs	5	23%

Table 5.1 Staff capability findings

Majority of the sites in the study have in-house personnel who are aware and have some technical proficiency to implement energy management program for their facilities. About 1 out of 5 sites has full capability to initiate and manage energy management and reduction programs while slightly over 1 out of 2 can initiate and implement with some assistance from 3rd party consultants and contractors.

The remaining data centres have no capability at all and are reliant on 3rd party assistance to assess, initiate or implement any program. However, with some training and knowledge transfer, their staff should be able to take on some form of energy management activities to track and implement energy usage reduction programs in their data centre facilities.

Recommendations

Data centre owners should increase awareness on energy efficient practices, technical knowledge of their staff as well as their contractors so as to enable the management and implementation of energy management programs and initiatives.

This awareness programme should not only be confined to the facility engineers or technicians but should be directed to the IT operations manager and staff as both IT and the facility support teams need to work hand in hand for the implementation of any initiative. It is critical that the IT operations manager is involved as most of the operating parameters are dictated by the IT team and any changes require their approval.

5.2. Operational Capability on Energy Management

Table 5.2 shows the capability of the sites to undertake energy demand monitoring. Only 5 out of 22 sites have the full capability to monitor energy demand and usage as well as in calculating their overall PUE. These sites are also capable of breaking down the PUE into sub levels (mechanical and electrical).

Half of the assessed sites used digital power and demand meters in their electrical system but will require additional upgrading to enable the ability to record demand and track their PUE. The remaining 30% of the sites did not have the ability to track energy demand due to the inherent design of their electrical system, which either made little use of digital power meters or did not have these meters at all. These sites will require intensive upgrading in order to have some form of rudimentary ability to track the overall PUE.

Operational Capability and Practice	No. of Sites	% of Total
<i>Use of Digital Power Monitors and Energy Demand Meters in Data Centre Facility</i>		
Complete (Main board , Sub-Distribution and Distribution)	5	23%
Partial Use (e.g. sub –distribution and distribution only, etc.)	10	45%
Minimal (only upstream for billing purposes)	7	32%
<i>Monitoring, Recording and Trending of Energy Consumption</i>		
Extensive recording and monitoring (usage and demand tracking)	3	13 %
Tracked and Recorded for Utility billing purposes only	14	64 %
No tracking at all	5	23 %

Table 5.2 Operational capability and practice

Out of these 5 sites that have the full capability to track energy demand usage, only 3 had actually implemented energy usage and site PUE tracking. 14 sites track energy demand for billing purposes only. The remaining 5 sites do not track their energy usage.

Lack of capability to monitor and track energy usage curtails any effort to implement energy management programs. The primary obstacle is that it requires the upgrading of the electrical system in existing data centres and will be disruptive to its operation. Financially, this does not require substantial capital investment to implement in small and medium sized data centres.

Recommendations

- Data centre owners should install power and energy meters throughout the data centre particularly on distribution panels that feed major equipment and loads such as chillers, CRAC/CRAH units, UPS systems, IT power distribution units.
- Incorporation of energy and power meters throughout the electrical distribution system should also be a primary requirement for the electrical system during the design stage.
- Aside from the IT load, data centre owners should undertake periodic recording of energy consumed by primary systems and equipment that are supporting the data centre.

6. Other Metrics

This section outlines metrics other than mechanical and electrical PUE, and they may be adopted to track specific energy demand trends in the data centre and so as to create a baseline. The following 3 metrics aim to establish the proportion of energy usage of lighting, cooling and fans, versus the total load of the site. These would provide points of reference for both operation and design of a data centre.

6.1. Lighting as a Percentage of Total Data Centre Power Use

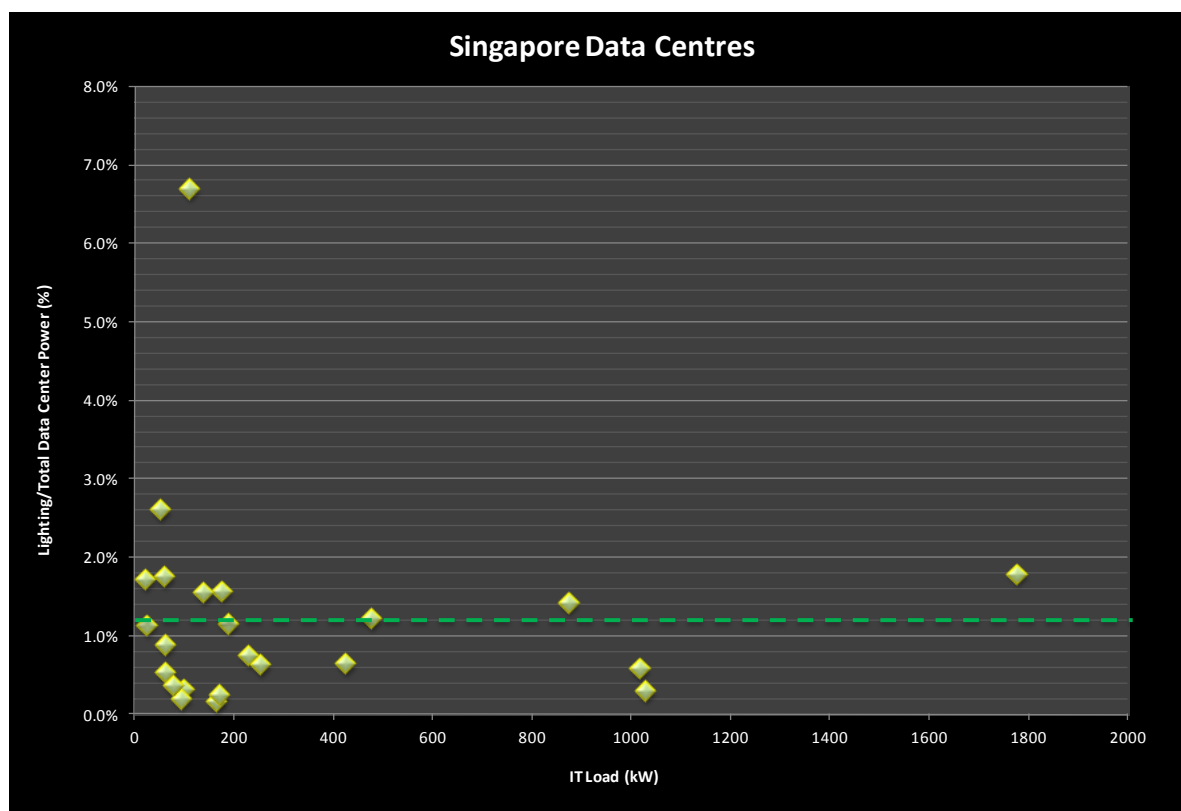


Figure 6.1 Lighting as a percentage of total data centre power use

This metric uses the ratio of lighting energy demand divided by the total data centre power demand, comparing it to the total IT power demand of the site. Although lighting generally accounts for a small percentage of a data centre's total power, it is an easy area to save energy. In addition to their nominal power consumption, an equivalent amount of heat is added to the cooling system.

From Figure 6.1 above, Singapore data centres have an average value of 1.2% with 65% of the sites falling below the average. This shows that energy demand from lighting is low for most of the sites. It was noted that most of the sites practised a "lights out" policy and are switching on the lights only when someone is working inside the room. Majority of the sites (18 out of 23) do not use automatic occupancy sensors. One site (6.8%) did not switch off the lights in the data centre. The practice of switching off lights other than those required for safety purposes is recommended. If security requirements dictate that lights is to be turned on at all times, alternative methods such as the use of low light capable monitoring cameras should be used with minimal switching on of lights.

6.2. Cooling System Power as a Percentage of Total Data Centre Power

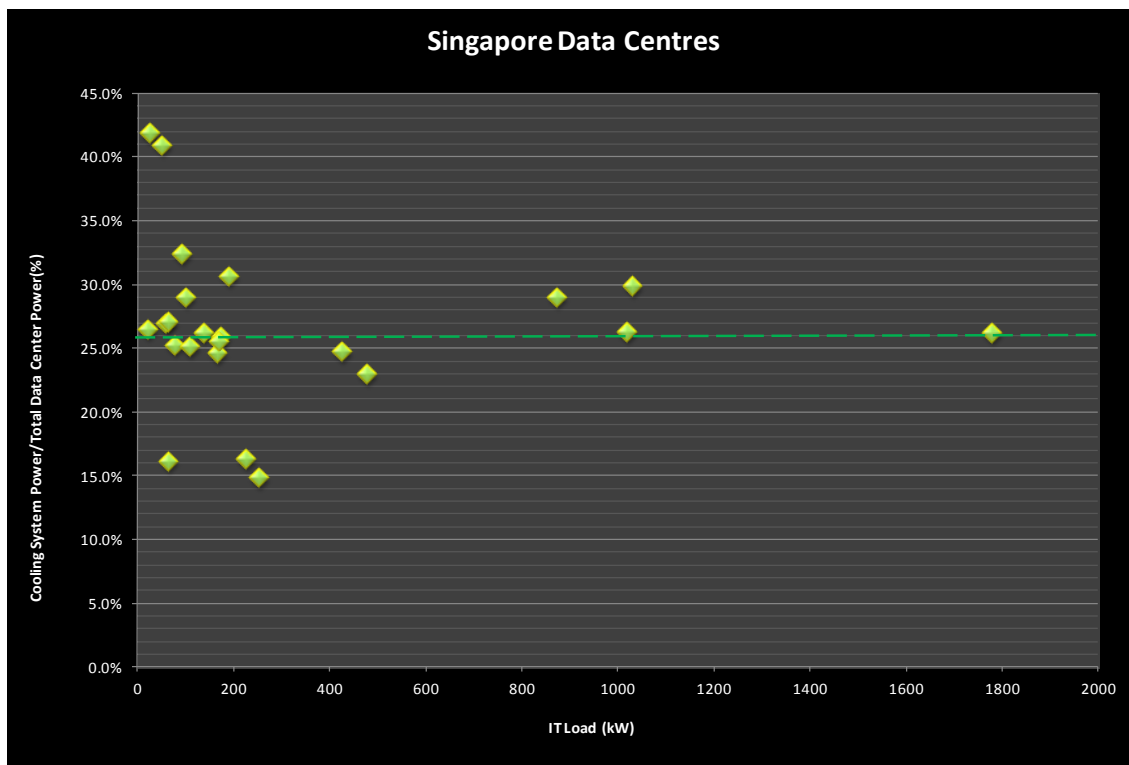


Figure 6.2 Cooling System Power as a Percentage of Total Data Centre Power

This metric uses the ratio of cooling (consumed primarily by refrigerant compressor) system energy demand divided by the total data centre power demand, comparing it to the total IT power demand of the site. Figure 6.2 shows that on average, the cooling system power demand is 26% of the total power demand of the data centre. The results above show that there is still significant room for improvement for Singapore data centres.

Out of the 3 sites that are below the 20th percentile mark, 2 are mature sites (using water cooled chilled water system) and 1 is a relatively new site using the newer generation DX CRAC (with variable capacity and variable speed fan) and UPS units (high efficiency ~94%). This observation shows that it is possible to drop the average cooling system power demand by at least 30% or more, which would be equivalent to a reduction of around 7.8 kW per 100 kW of total data centre power demand (~7.8%).

6.3. Fan Power as a Percentage of Total Data Centre Power

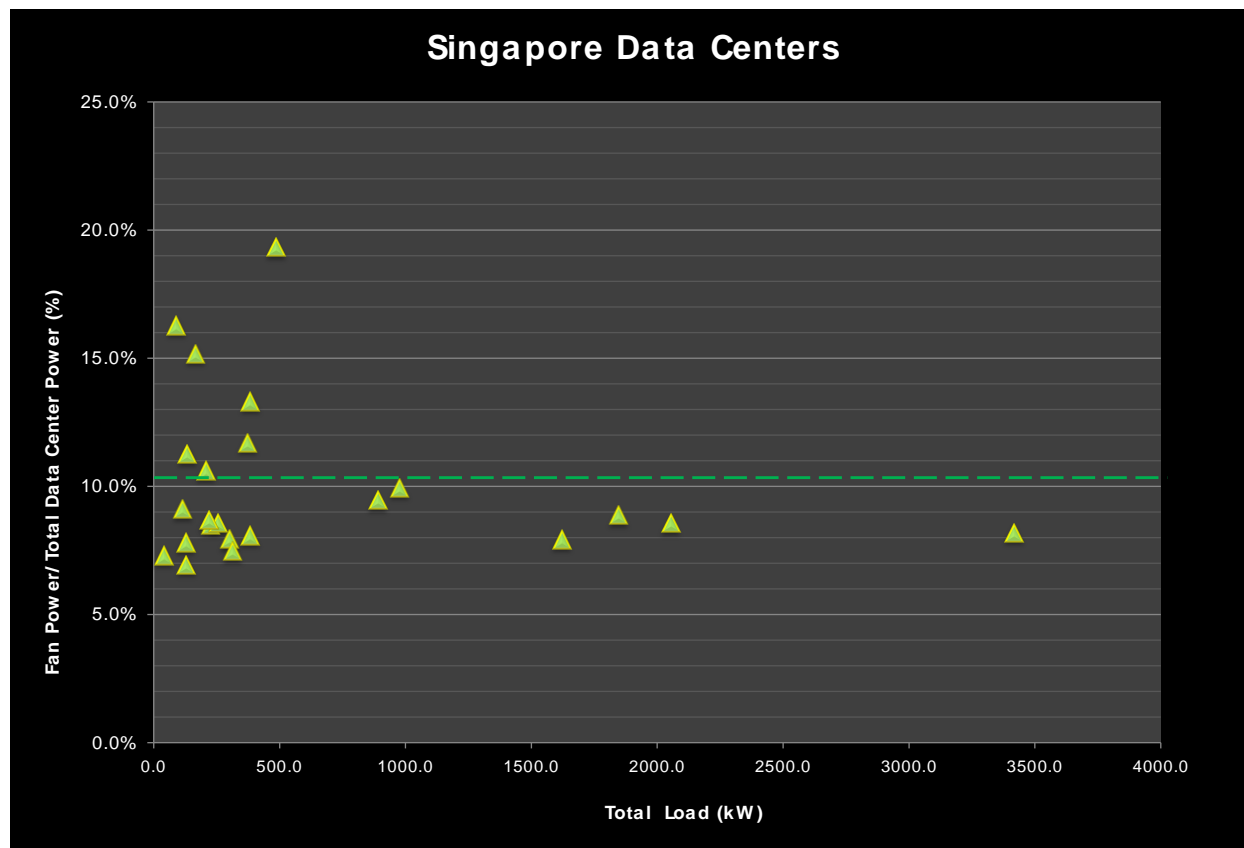


Figure 6.3 Fan Power as a Percentage of Total Data Centre Power

This metric uses the ratio of fan (consumed primarily by the data centre air delivery system) power demand divided by the total data centre power demand, comparing it to the total IT power demand of the site. Figure 6.3 shows that on average, the fan power demand is ~10.2% of the total power demand of the data centre. At least 85% of the sites surveyed used constant speed fan motors in their CRAH/CRAC units. Most of the sites are also operating more CRAC/CRAH units than needed to cool the data centre. This presents an opportunity to drop the fan power demand for the data centres to 5% or lower of the total demand. This can be achieved by the use of variable speed driven fan motors and techniques such as aisle containment and use of in-row or above row heat exchangers/passive heat exchangers. In 1 of the sites using in-row cooling units, power measurement showed that the units were only consuming around 35% of their rated fan power.

On average, 10.2 kW out of every 100 kW of power in the data centre is used by the fans to move the air around the data centre. Dropping this ratio to 5% of total would translate to an average demand reduction of 5% in total data centre power demand.

7. Overview of Common Recommendations and Cost to Implement

The 23 Singapore data centres that had energy assessments were grouped into 3 different categories based on their size. The recommendations include cost to implement, projected energy and monetary savings.

An example is shown in Table 7.1, wherein this particular set of recommendations is used to address the problem of operating an excessive number of AHU units in relation to the actual cooling load required. The recommendations include installation of blanking panels, and performing a CFD analysis to determine the best placement of return air openings in the ceiling and air supply panels. These series of actions would enable the DC owner to switch off two CRAC units in the room. The total cost of these improvement actions is \$30,000 and would result in a projected saving of \$28,140 per annum in electrical energy cost. The payback period is 1.06 years.

	Recommendation	Cost to Implement \$	Annual Savings kWh	Annual Savings \$	Payback Period
1.	Install Blanking panels in all racks	\$5,000	NA	NA	NA
2.	Review placement and area of openings of the ceiling plenum return air grilles using CFD analysis to eliminate hotspots	\$25,000	NA	NA	NA
3.	Shut off 2 CRAC units in the raised floor area	0	134,000 (16.4 kW average power demand from 2 CRACs)	\$28,140 (@ \$0.21 per kWh)\$5,585	NA
	Total	\$30,000	\$134,000	\$28,140	1.06 years

Table 7.1 Examples of typical sets of recommendations that would enable the site to turn off excess CRAH units.

It should be noted that combining these recommendations would result in an energy usage reduction package that is unique to each site. The recommendation set for each data centre has to take into consideration the design, operational requirements and constraints.

The most common recommendations to improve energy usage efficiency in data centres is the implementation of good air management practices (e.g. use of blanking panels in IT racks, sealing of cable cut-outs and reducing the number of perforated tiles). This typically precedes any action done on the cooling systems such as a temperature set point adjustment or reducing excess capacity (e.g. shutting down CRAC/CRAH units).

Although the implementation of good air management practices does not directly reduce energy consumption, it is an enabler of subsequent actions that directly reduce energy consumption of the cooling systems.

Table 7.2 provides an overview of the indicative costs of improvement recommendations provided in energy efficiency assessment reports to data centre owners during the course of this study. Specific costs for each site will depend on several factors such as size of data centre, type of cooling system, reliability configuration and site constraints.

The table below lists the estimated unitary costs or price premium percentage differential between standard and high efficiency models. This list is non-exhaustive and the costs are for equipment or material only.

Recommended Solution	Unit Cost
Ceiling Air Return Plenum	
Suspended Ceiling	\$150/sq. meter
CRAH/CRAH Extended Ducts to Ceiling with motorised damper (depends on size)	\$3,000 - \$,6000 per unit
Direct Room Return Extended Ducts for CRAH/CRAC	
CRAH/CRAH Extended Ducts to Ceiling with motorised damper (depends on size)	\$3,000 - \$,6000 per unit
Floor Cable Cut-out Sealing	
Brush grommets	\$150/unit
Rack Blanking Panels	\$5 to \$10 per U-space
Plastic sheet type blanking panels	\$5 per rack U-space
Molded Snap in plastic blanking panels	\$10 per Rack U-space
Overhead Cable Trays/Baskets for Data Cabling	
600 mm Wide	\$200 to \$300 per meter
Aisle Containment System	
Full enclosure for 12 rack long pair of rows	\$20,000 to \$30,000
Partial enclosure – plastic strips at two end of rows	\$6,000
Supplemental Spot Cooling Systems	
150 kW Cooling Capacity (10 cooling units plus heat exchanger units)	\$200,000
Computer Room Air Conditioning / Air Handling Units (CRAC/CRAH)	
DX CRAC with EC/VFD Fans and Var. Capacity Compressors (80-90 kW)	\$70,000
DX CRAC with constant speed fans and conventional compressors (80-90 kW) for comparison purposes	\$55,000
Chilled Water Cooled CRAH with VFD/EC fans (80 kW – 90 kW)	\$25,000
Chilled Water Cooled CRAH with constant speed fans (80 kW – 90 kW) for comparison purposes	\$18,000
Chiller Unit	
150 RT Air cooled screw compressor standard efficiency model	\$350,000
150 RT Air cooled screw compressor high efficiency model	\$400,000

Table 7.2 Unit cost table for various recommendations

Static UPS systems are not listed in the table as today's generation of static UPS do not have much energy efficiency performance differentiation across the various models and capacities if they are using the same technology like IGBT power circuits (Efficiency ranges from ~ 93% to 95% at full load). The SCRs and thyristors used in older generation of UPS have been almost completely replaced by IGBT technology. A typical 300 KVA UPS system with 15 minutes of battery autonomy costs around \$200,000. The cost of the system is affected greatly by the selected battery autonomy time. Some proprietary UPS technology using delta conversion can reach efficiency of up to 98% at full load.

For DRUPS systems, a 1 MVA unit costs around \$1,750,000 and is not as cost effective compared to static UPS systems for data centres that has less than 500 kW of IT load, thus limiting its use on medium to large data centres only. As a typical data centre is designed with an N+1 or 2N configuration, this makes the cost of DRUPS prohibitive for small data centres despite its advantages.

Installation of digital power meters on existing panels would be more expensive compared to specifying it to be built-in with the panels during construction. For example, the cost to install a power meter with 200 ampere rating during construction of the electrical panel is only a few hundred dollars. However, to upgrade an existing panel of the same rating could easily cost up to \$2,000 dollars due to the work involved, which includes shutting down part of the electrical branch the panel is connected to, resulting in disruption.

In most cases, high efficiency models of HVAC system still command a premium of around 20% to 30% over conventional models. The cost of HVAC systems in data centres is also highly dependent on the designed IT load density. The higher the designed load density, the higher the costs to construct the data centre. A similar relationship exists between designed availability and costs as well.

8. Business Strategy and Information Technology

8.1. Enterprise/Business Strategy

Whilst energy assessments may provide values of PUE, CUE and DCiE, these numbers are relatively useless unless there are financially prioritised recommendations on improvements. The planning and undertaking of these improvements require management of data centre owners expectations. Furthermore, these energy assessments normally turn into true strategic tools for data centre owners as many of the basic principles of legacy data centre designs are challenged providing some interesting lessons learnt.

Business strategies for data centres have to consider their operating costs (energy) and their capital expenditure (new data centres) to satisfy their business growth. PUE and DCiE provide energy usage ratios, which allow data centre owners to plan their growth and expansion plans.

Business strategies need to include business growth in terms of data centre infrastructure systems (M&E or power and cooling systems) together with IT systems efficiency. It is important that business strategy and requirements are taken into consideration when planning for a new data centre. Rightsizing of equipment not only saves capital investment but also reduces the subsequent operation costs associated with maintaining and operating the data centre. A sample DC strategy is illustrated in Figure 8.1.

Data Centre Energy Strategy

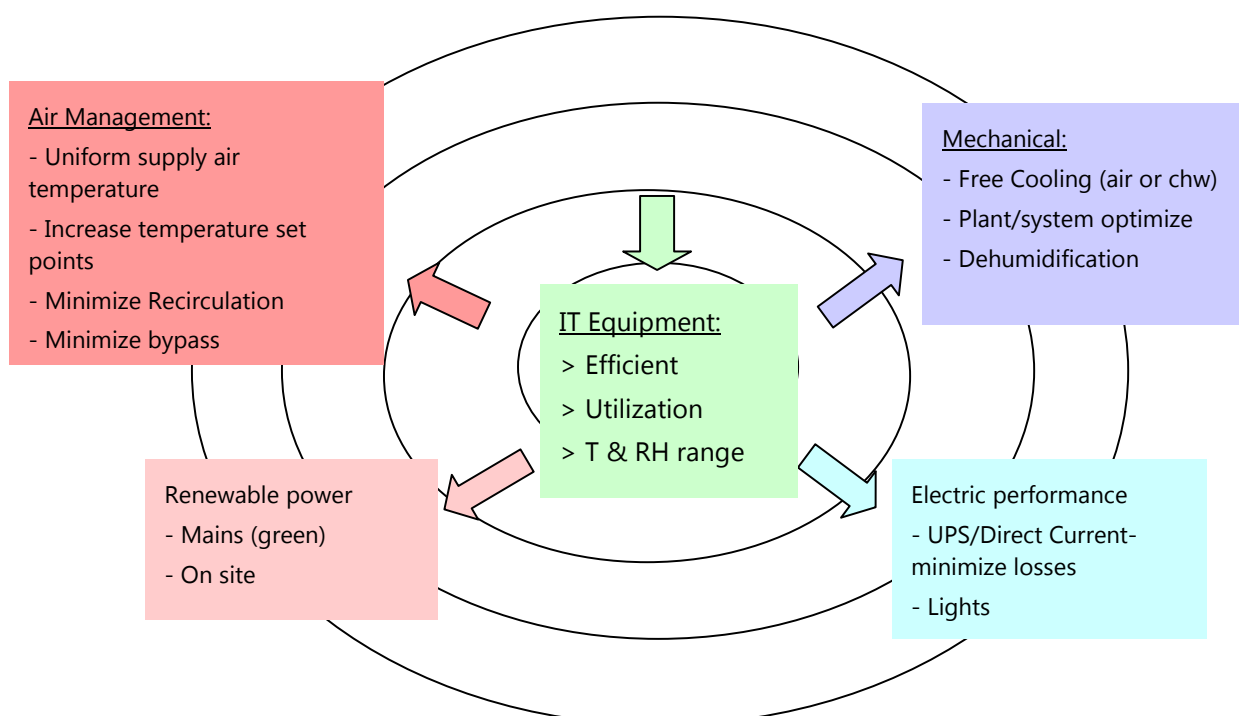


Figure 8.1 Sample Data Centre Energy Strategy

In the planning, design and operational phases of a data centre's life cycle, there are several interrelated factors that will shape how energy and other resources are used. It is necessary to look at these factors contextually and to understand how each one affects the other. This is significant simply because each data centre is unique by itself and the concepts and strategies will vary considerably based on:

- End user's business requirements (i.e., reliability level, facility size, total power requirements, construction and operating budget).
- Energy and resource use targets.
- GHG (green house gases) emissions targets.
- Renewable energy-use targets.
- Location-specific parameters (climate, jurisdictional regulations, economy, grid power reliability, water supply and discharge infrastructure).

8.2. Information Technology

One of the primary changes that are occurring in the data centre industry is hitting the energy consumption target right in the bulls-eye – the server. In the consumer PC and laptop market, the idea of different power settings to conserve battery life or to put the PC into hibernation has been around for years. Yet, this strategy is not widely used in the enterprise server market due to potential reduction of reliability and processing speed. The focus for enterprise servers has traditionally been on the power-per-instruction metric at the chip level, which if used as a benchmark of energy efficiency, shows tremendous improvements in energy efficiency over the past several years. However, this metric needs to be considered together with the fact that that power consumption of the servers themselves has been steadily increasing.

Usually the IT and facilities teams do not communicate with each other until the IT master plan is nearly complete. When this happens, the opportunity to investigate how the facility's power and cooling systems will impact the servers and other IT equipment from a reliability and energy use standpoint is lost.

In addition, many facility teams do not have the time or bandwidth to understand the dramatic changes that have occurred in the last 5 years in IT industry (power/cooling density, reliability, etc.) Looking beyond the processor power consumption and into how the servers are used within an enterprise, there are certainly opportunities in which reduction in power can be achieved:

- Multi-core processors – Through advancements in multithreading and multiprocessing using multi-core processors, reduction in power consumption can be achieved while increasing performance. This assumes that the application that is being run can be multithreaded.
- Virtualization – Through the use of virtualization (the practice of running multiple systems and/or workloads on one server) power consumption of servers is reduced by utilizing more of their capacity. Estimates put potential energy reduction at 19% to 24% via deployment of server technology capable of virtualization. Blade PCs are an example of using a pool of cabinet-mounted blade servers operating in a controlled environment with more efficient power supplies, fans, etc. The pool of servers can replace the individual desktop machines.
- Consolidation – Active mirroring, back-up, and replication of data for business continuance purposes notwithstanding, running identical applications to achieve the same end in multiple locations can not only create an IT operations, infrastructure and architecture inefficiency, but it also creates substantial increases in overall power consumption. This is an area that must be carefully coordinated and integrated to ensure compliance with the overall business, technology and facility reliability objectives. Hence, the development and implementation of robust IT planning which may include consolidation strategies can not only achieve operational efficiencies, but also reduce overall power consumption of enterprise-wide IT systems.

Leveraging Trends in ICT

Based on current market conditions, there is a confluence of events that can enable energy optimization of the IT enterprise. It takes good planning and a thorough understanding of all the elements that affect energy use. Meeting these multiple objectives – service enhancement, reliability and reduction of operational costs – once thought to be mutually exclusive, must now be thought of as key success factors that must occur simultaneously. Some of the current trends in IT operations that can be leveraged to reduce/optimize energy spending:

- Technology refresh – Planned technology refresh presents an opportunity to leverage the upgrade by looking at energy use optimization via increasing the utilisation of the new IT equipment. This can be achieved by consolidating applications into fewer servers or operating a virtualised environment rather than just going through the motion of upgrading to the latest hardware model.
- Reducing IT and operational costs – In order for companies to maintain a competitive edge in pricing products and services, reducing on-going operational costs related to IT infrastructure, architecture, applications, real estate, facility operational costs and energy use, IT and operational costs often come under scrutiny. The ideal time to incorporate thinking on energy use optimization is at the beginning of any new IT planning effort. Some of the approaches to attain these are:
 - More utilization of ICT equipment.
 - More effective (business output per energy consumed) ICT equipment.
 - Wider range of temperature and relative humidity to allow for more flexible data hall conditions.

Data Centre Facilities – Dynamic and Unpredictable

- One of the primary design goals of a data centre facility is future flexibility and scalability knowing that IT systems evolve on a life-cycle of 12 to 18 months. This however can lead to short-term over-provisioning of power and cooling systems until the IT systems are fully built-out. Even at a fully built-out stage, the computers, storage and networking equipment may experience hourly, daily, weekly and monthly variations (5-10% in internet data centres whereas enterprise data centres tend to be more stable with little variance in IT systems energy usage). This “double learning curve” of both increasing power usage over time plus on-going fluctuations of power use make the design and operation of these types of facilities difficult to optimize. Using simulation tools can help to show how these changes affect not only energy use, but also indoor environmental conditions, such as dry-bulb temperature, radiant temperature and moisture content.

9. Discussion on PUE Levels for Singapore

9.1. Existing Data Centres

For small data centres, which account for 6 out of the 23 data centres, average PUE is 2.18. Taking average values from the typical recommendations in their energy assessments, small data centres can potentially reduce their PUE from 2.18 to 1.94 through a small investment of about S\$45,750, which would be paid back in about 1.75 years and result in 69 metric tons of carbon dioxide annual avoidance. Similar analyses for medium and large data centres are shown in the tables below. The calculations are based on average values for the three categories of small, medium and large data centres benchmarked to date, and based on a fixed cost per kWh of S\$0.2728/kWh, the electricity tariff in July to September 2011. Refer to Tables 9.1, 9.2 and 9.3 on the capital requirements for energy efficiency measures.

Do note that mature enterprise data centres are much more difficult to upgrade and as such, a data centre may not be able to undertake all the recommendations that are presented to it. It would most likely choose to implement only the ones that do not pose any disruptive impact to its operations.

Data Centre Size (RFA < 300 m²)/Metrics	Value
Annual Average PUE	2.18
Target PUE	1.94
Average annual energy reduction (kWh/yr.)	137,500
Average annual energy reduction (%)	11%
Average annual energy savings (S\$)	\$33,304
Average CO ₂ avoidance (metric tons)	69
Average Cost of improvements (S\$)	\$45,750
Simple Pay Back SPB (Years)	1.75

Table 9.1 Capital requirements for energy efficiency measures of small data centres

Data Centre Size (301 m²<RFA<1000 m²)/Metrics	Value
Annual Average PUE	2.06
Target PUE	1.81
Average annual energy reduction (kWh/yr.)	263,930
Average annual energy reduction (%)	11.4%
Average annual energy savings (\$)	63,788
Average CO ₂ avoidance (metric tons)	132
Average Cost of improvements (\$)	81,000
Simple Pay Back SPB (Years)	1.68

Table 9.2 Capital requirements for energy efficiency measures of medium data centres

Data Centre Size (>1000<RFA<4500 m²)/Metrics	Value
Annual Average PUE	2.07
Target PUE	1.73
Average annual energy reduction (kWh/yr.)	1,068,825
Average annual energy reduction (%)	8.2%
Average annual energy savings (\$)	803,702
Average CO ₂ avoidance (metric tons)	758
Average Cost of improvements (\$)	1,881,000
Simple Pay Back SPB (Years)	4.2

Table 9.3 Capital requirements for energy efficiency measures of large data centres

9.2. New Data Centres

Singapore's climate is generally too warm and humid (refer to Figure B.3 in Annex B). In some parts of the year, the temperature is conducive but the humidity is too high. This rules out the use of filtered outside air directly in the data centre for cooling purposes without undergoing through a dehumidification process to reduce the moisture content to an acceptable level.

For the majority of the data centres in Singapore, it is recommended to keep the temperature of the data centres below the ASHRAE recommended range upper limit of 27°C. With this in mind, a series of energy simulations of several cooling options were conducted by HP to determine the lowest possible PUE that can be achieved based on a supply air temperature of 24°C at the server intake. The input parameters for the simulations are listed in Tables 9.4 and 9.5. The simulation is based on a 1 MW IT load and certain assumptions on the area, type and height of the building. Other than the type of cooling equipment, all other parameters used in the 3 models are common. The PUE simulation energy analysis models were developed and created using Trane Trace 700 software. Equipment parameters came from manufacturer equipment specifications.

Model 1: Air Cooled Direct Expansion CRAC System

Data hall cooling approach for air-cooled DX CRAC is conventional, which uses downthrow AHUs discharging into a raised floor plenum and ceiling plenum return. This model uses specifications for the latest generation of CRAC units with variable speed or electronically commutated (EC) AHU fans and variable capacity compressors. This model is based on a conventionally designed data centre with raised floor and CRAC units positioned in a separate gallery.

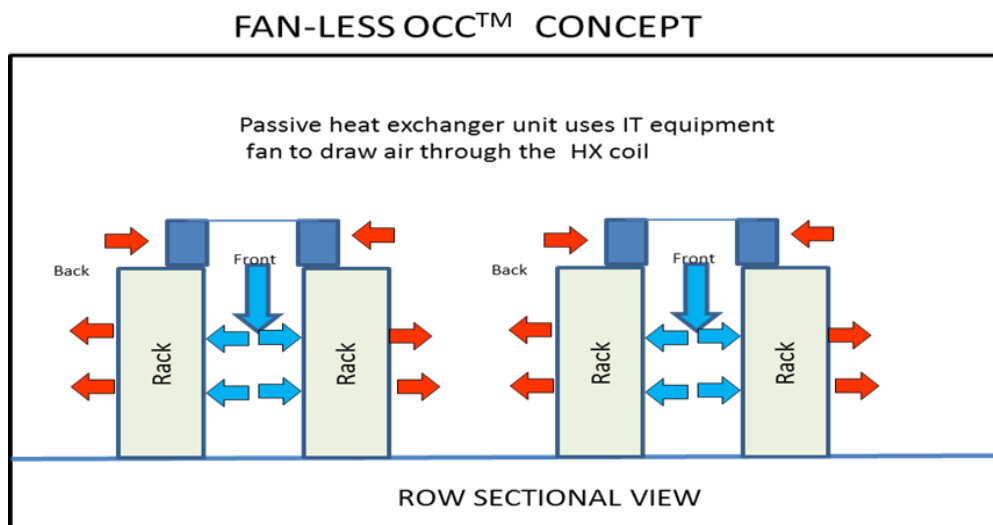


Figure 9.1 Diagram of fan-less data hall cooling approach.

Model 2: Air Cooled Chiller System

Model 2 uses a non-conventional approach in the data hall design using OCC™ (Overhead Convection Cooling) units (Refer to Figure 9.1). These are fan-less heat exchanger coils installed over a contained cold aisle. The cooling system type used is air cooled chiller. This model is used to simulate the achievable level of PUE using available technology and air cooled chillers.

Model 3: Water Cooled Chiller System

Model 3 uses a non-conventional approach in the data hall design using OCC™ (Overhead Convection Cooling) units. These are fan-less heat exchanger coils installed over a contained cold aisle. The cooling system type used is water cooled chiller. The chiller system includes open type cooling towers fitted with variable speed driven fans and operated using a variable primary pumping scheme. This model is used to simulate the achievable level of PUE using available technology and water-cooled chillers.

Parameters	Value
IT Load	1,000 kW
Building	
DC Raised Floor Area	1,000 m ²
Building Footprint Dimension & Area	30 m x 50 m (1500 m ²)
Number of Storeys/floors	2 + Rooftop for equipment
Height of Floor (slab to slab)	6 meter
Data Centre Hall Walls external exposure	None (DC is within building)
Office area	None
1st floor usage	Plant rooms
2 nd floor usage	Data centre
Type of construction	Reinforced concrete/ 150 mm brick walls/ insulated rooftop
Electrical System	
UPS efficiency at 40% Load (2N Configuration)	95%
Transformer Loss (w/ non-linear load)	0.80%
Transmission Loss/cabling (short cable runs)	0.10%
Switchgears/ Distribution Board losses	0.25%

Table 9.4 Input parameters used for data centre PUE simulation

Parameters	Value
Mechanical System	
Ambient Air Temperature	35°C
Air Cooled Chiller Performance kW/RT	1.13
Water Cooled Chiller Performance kW/RT	0.45
Air Cooled DX CRAC Performance kW/RT	0.86
Cooling Tower Type	Open Type
Cooling Tower Approach	3 °C
Cooling Tower Range	6 °C
Cooling Tower fan motors efficiency w/ VSD	90%
Condenser Water Pump Motor Efficiency	90%
Condenser water pump efficiency	80%
Chilled Water Pump motor efficiency	90%
Chilled water pumping scheme (Water cooled)	Primary variable
Chilled water pumping scheme (Air cooled)	Constant
Chilled water pump efficiency	80%
Cooling Tower Condenser Water Temperature	29 °C EWT /35 °C LWT
Chilled water supply and return Temperature	10 °C LWT /17 °C EWT
Data Centre Room Cooling Method	
Chilled water system	OCC™ fan less cooling coil
AC DX CRAC	conventional approach
Chilled water supply temperature	10 °C
Fresh air supply to Data Centre hall	0.5 air change per hour

Table 9.5 Input parameters used for data centre PUE simulation

Simulation Results

The simulation results in Table 9.6 shows that data centres using water cooled chillers (WCC) can achieve a PUE level of 1.33 while air-cooled chillers (ACC) can achieve 1.52. For data centres using conventional CRAC type of cooling system, the PUE level is 1.69. Table 9.7 shows the equipment energy usage breakdown in kWh and the percentage of the total energy usage for each of the cooling type. Do note that the compressor of the air cooled chiller systems uses more energy than that of the CRAC units.

Cooling System Type	Annual Energy Usage, kWh	Average Demand, KW	PUE
CRAC	14,774,539	1,687	1.69
ACC	13,278,328	1,516	1.52
WCC	11,682,473	1,334	1.33

Table 9.6 PUE Simulation result across 3 cooling system type

Equipment	Model 1 - CRAC		Model 2 - ACC		Model 3 - WCC	
	kWh	% of Total	kWh	% of Total	kWh	% of Total
Dehumidification/ Humidification	22,926	0.2%	22,926	0.2%	22,926	0.2%
Cooling Compressor	2,266,565	15.3%	3,045,408	22.9%	1,298,253	11.1%
Tower/Cond Fans	647,208	4.4%	212,487	1.6%	260,863	2.2%
Condenser Pump	0	0.0%	0	0.0%	154,421	1.3%
CHW Pumps	0	0.0%	154,176	1.2%	113,836	1.0%
Other Cooling Accessories	7,084	0.0%	1,752	0.0%	17,520	0.1%
AHU Fans	2,163,956	14.6%	222,073	1.7%	218,807	1.9%
Lighting	288,348	2.0%	288,348	2.2%	288,348	2.5%
IT & Other Load *	9,378,452	63.5%	9,331,158	70.3%	9,307,500	79.7%
Total	14,774,539	100%	13,278,328	100%	11,682,473	100%

Table 9.7 Breakdown of equipment energy usage across the 3 models.

**Note: IT load accounts for 8,760,000 kWh based on 1 MW load and the balance by controls, other miscellaneous equipment, electrical and UPS losses*

Impact of Cooling Air Delivery Approach on PUE

If conventional CRAHs are used for the data centre air delivery system, the energy required from the fans would push the site's PUE above 1.5 for a site that uses either air-cooled or water-cooled chillers.

The PUE for the site using air cooled chillers would go up to 1.74* while the PUE for the site using water cooled chillers would rise to 1.55*. In this case, air cooled chillers would be the least efficient as compared to sites using CRACs or water cooled chillers. This is consistent with the study findings on the impact of cooling system type to the mechanical PUE.

**Taking the average difference between Models 1 and 2, 1 and 3 of their AHU fans annual energy usage and adding them up to the total annual consumption of Models 2 & 3 respectively before using them to calculate the PUE.*

10. Conclusions

Although this study did not benchmark the IT infrastructure energy usage efficiency, it can be inferred that reduction in IT energy usage has a cascading effect on the overall energy reduction of a data centre.

First and foremost, data centre owners should look at ways to reduce the IT equipment load in their data centres. For every kilowatt of IT energy load reduction, there is potentially another kilowatt that can be saved in the mechanical cooling and electrical systems supporting the IT load (a total of ~2 kW power demand reduction as calculated based on the average PUE for Singapore data centres).

The next greatest potential for energy savings after the IT load comes from the mechanical cooling systems, followed by the electrical systems.

EE in Mechanical Systems

Mechanically, cooling system compressors and fans represent the major power consuming components of the data centre support infrastructure. In Singapore, the cooling energy demand can be reduced by implementing air management best practices, installation of ultra efficient chillers and cooling equipment, high efficiency motors, VFD on the chillers (if feasible), raising the leaving chilled water temperature (LCHWT) set points and implementing condenser water reset control as weather permits. Similarly, elimination of the dehumidification function and reheating elements in CRAC/H units through the use of wrap around coils or standalone dehumidifiers (desiccant type) will reduce the wastage associated with reheating due to the dehumidification process. Use of high efficiency motors and implementing variable speed motor controls to vary the flow of air can reduce the fan power consumption by up to 40%.

Implementation of good air management within the thermal environment is a major enabler to more efficient cooling systems that could lead to savings in both compressor and fan energy usage. Good air management practices would result in minimised mixing levels and lower air intake temperature at the IT equipment intakes. This would allow the raising of CRAH/CRAC units' temperature set-points, ramping down of units with variable speed fans or a reduction in the number of operating units.

It should be noted that there is some apathy with regards to the implementation of good air management practices in Singapore data centres. Greater effort should be made in educating and advocating the implementation of good air management practices, not just to the managers of data centres, but also to the higher management levels of both IT and facilities department. Such practices translate directly to cost savings and would be of interest to the upper management of a company.

EE in Electrical Systems

The UPS and the lighting systems are usually the only practical areas where energy savings can be made in the electrical system. Considering that electrical system losses attributed to transformers and distribution within the data centre could be equal to all of the energy consumed by the fans and pumps (25% of the mechanical system energy usage), it is prudent not to overlook the impact of the electrical system on the PUE. It is important that high efficiency transformers and UPS systems be selected to reduce transformation losses. In addition, the proper sizing of conductors and reduction of transmission distances would reduce losses during electrical power transmission.

Generally, the higher the reliability level, the greater the system losses due to the fact that UPS and PDUs run at low loads. The UPS market is responding with new UPS technology and innovative design solutions that enable very high efficiencies even at low load levels (95% efficient at 25% load level).

Additionally, energy usage by lighting systems can be further reduced through the use of energy efficient fixtures (e.g. T5, LED lights) and automatic controls.

Staff Capability on Energy Management

Data centres should appoint an energy manager for the facility; this individual would have the responsibility of understanding the energy use, establish an energy efficiency roadmap, pursue funding for projects, and direct the execution of those projects. An energy manager should also be familiar with building and energy management system, and implement such system if one does not exist. BMS systems allow monitoring of energy use within the facility and allow efficiency metrics to be calculated, viewed and trended. Energy managers should also be active in local and regional organizations that address data centre issues.

Minimum PUE Recommendation for Singapore

Based on the assessment data and observations made across the 23 sites, small, medium and large existing data centres can achieve PUE of 1.94, 1.81 and 1.73 by implementing measures with an average payback of 1.75, 1.68 and 4.2 years respectively.

New data centres should be able to achieve at least a PUE level of 1.7 or better at the full designed loading. This can be achieved by incorporating good operational and air management practices, best design practices as well as the use of highly efficient equipment.

Annex A. Energy Conservation Opportunities

Annex A.1 Best Practices Guidelines Published References

Annex A is intended for use as a reference section on the various considerations and approaches that may be taken in attaining optimum use of energy in the data centre. This section represents the mitigation methods to address the most prevalent issues found in data centres. More of the best practices for both design and operation can be found in publications from ASHRAE, TIA and ANSI-BICSI. There are other publications from other organisations that can be used as reference but the following publications are probably the most widely referenced standards and guidelines when it comes to data centre design and operating practices.

- ANSI/BICSI 002-2011 Data Center Design and Implementation Best Practices – This is by far the most comprehensive data centre design guidebook and covers almost everything in the data centre from site selection, sizing, architecture, structural, mechanical, electrical and all the way to the design process.
- TIA-942 Telecommunications Infrastructure Standard for Data Centers – this document primarily covers the standard for the telecommunications infrastructure of data centres. It covers the structured cabling design concepts and approach. The annex section contains brief guidelines for the architectural, structural, fire protection, mechanical, electrical and others requirements based on the 4 Tier classifications for data centres.
- 2011 Thermal Guidelines for Data Processing Environments – Expanded Data Center Classes and Usage Guidelines – this is a whitepaper from ASHRAE defining the expanded temperature range for the various classes of data processing environment, including an expanded class for class 1 environment.
- 2008 ASHRAE Environmental Guidelines for Datacom Equipment – This is the first revision of the 2004 Thermal Guidelines which expanded the original recommended range from the 2004 version.
- ASHRAE 2004 Thermal Guidelines for Data Processing Environments – This was the original guidelines from ASHRAE defining the environmental conditions for data processing equipment including the 4 classes of rooms.
- ASHRAE Design Considerations for Datacom Equipment Centers – This guide provides a high level overview of the design concepts that can be applied to the data centre, particularly on the cooling system. It includes concepts and approaches in air delivery to IT equipment as well as other aspects of the data centre infrastructure.
- ASHRAE Datacom Equipment Power Trends and Cooling Applications – This guideline was released in 2004 and provided the original power trend chart. This document also defined the approaches of cooling and airflow direction to the IT equipment in the cabinets and provides a good overview of the air distribution methods and approaches for the data centre.
- ASHRAE 2011 Thermal Guidelines for Liquid Cooled Data Processing Environments – This document defines the guidelines for liquid cooling in the data centre including the 5 water temperature classes (W1 to W5) as well as water quality guidelines.

Annex A.2 Air Management and Environmental Controls

With proper air management, air bypass and recirculation can be reduced and hence the CRAH and chilled water temperature set points can be increased for higher efficiency.

"Rule of thumb" Guidelines on Air Management

This list is not definitive but provides guidance on best practice approaches.

- Use Hot and Cold aisles for all IT hardware designed to use front to back cooling airflows.
- Isolate IT hardware that does not conform to front to back airflows and install them into their own areas specifically laid out for them.
- A typical 31% open ventilated panel of 600 mm x 600mm with air volume flow of 0.24 m³/ second will typically be able to provide sufficient air volume to cool up to 3.0 kW of heat load (assuming 10°C temperature rise over the IT Hardware). Note: A number of ultra high density hardware products such as blade servers will result in a 12°C to 20 °C rise over the hardware.
- Deploy no more/or less ventilated air tiles than the CRAH's capacity (airflow volume) permits excluding flow from redundant units.
- The cooling 'sweet spot' on the raised floor from the discharge of a CRAH is 10 to 15 times the raised floor depth and dependent on airflow impedance (cables, channels and other obstructions).
- Raised floor plenum fed cooling airflows beyond 10m from the CRAH discharges are rarely effective unless the system is specifically designed and modelled to cater for long distances.
- Ensure the entire return path of heated air from the IT hardware exhausts to CRAH is free from obstruction and that airflows do not short circuit back into the supply path.
- Deploy aisles with a minimum of 1200mm width for low - medium density IT hardware, expecting aisle widths to expand if the density increases beyond 6 kW/rack cabinet designs.
- If using a floor plenum for airflow supply, keep the void under the cold aisle areas free from obstructions. Place all cabling in overhead trays over the racks or in the HOT aisle areas under floor if overhead run is not feasible.
- Align computer cabinet rows at 90° angle or perpendicular to the CRAH/CRAC units.
- Make computer cabinet rows as continuous and as long as possible.
- Seal gaps between racks to prevent hot air from returning into IT equipment air intakes.
- Align IT rack fronts with the raised floor tile seams to ensures a full quota of air can be delivered from a vent tiles as close as possible to the IT equipment air intakes
- Aim to have at least an 8°C delta T (difference in temperature between air intake and discharge) on both CRAH/CRAC units as well as IT equipment.

Guidelines for high density IT hardware floor positioning

When deploying higher density IT equipment, care must be taken to place them in the computer room to maximise use of:

- Static air pressure - Assuming good placement of CRAHs/CRACs.

- Locate High Density IT racks 10 to 15 times the floor void depth from CRAH discharges as a distance guide or in the middle of rows.
- Balance loadings of CRAH/CRAC units - Place the highest density IT racks in the influence zone of the largest and more powerful CRAH/CRAC systems to avoid mal-provisioning especially if dissimilar cooling capacities are used (even when containment systems are used).
- Do not place more (IT equipment) load in a CRAH/CRAC unit's area of influence than the unit can handle.
- Allow for sufficient capacity to meet business requirements for redundancy.

Note that the use of computational fluid dynamic (CFD) analysis to determine the placement of high density racks is strongly recommended above all other methods.

Gasket/cut-outs

Most of the cable cut-outs provided in the data centre are more than what is required for the cables to pass through. Excessive airflow occurs if these are not sealed resulting in the loss of static pressure in data centres using raised floor plenum for air delivery.

Cut-outs should be fitted with gaskets or grommet seals. The grommet shown in Figure A.1 is a surface mount type for existing installations. The grommet is a two-piece assembly that splits, wraps around existing cables (without disconnecting the cables), joins together, and seals to the raised floor.

This recommendation applies only to racks with front to rear cooling and not to racks with bottom to top cooling or racks with front door that have no ventilation door grills (e.g. glass fronted racks).



Figure A.1 Raised floor gaskets

Blanking panels in Cabinets

Open spaces within IT racks presents two possible problems:

1. The IT hardware's hot exhaust short circuits back into its air intakes, thereby inducing thermal inefficiencies which increase costs, reduce equipment reliability and become a threat to reliable operations.
2. It provides an open route where valuable cooling airflows by-passes into the hot exhaust flows before any useful cooling function is served, as shown in Figure A.2.

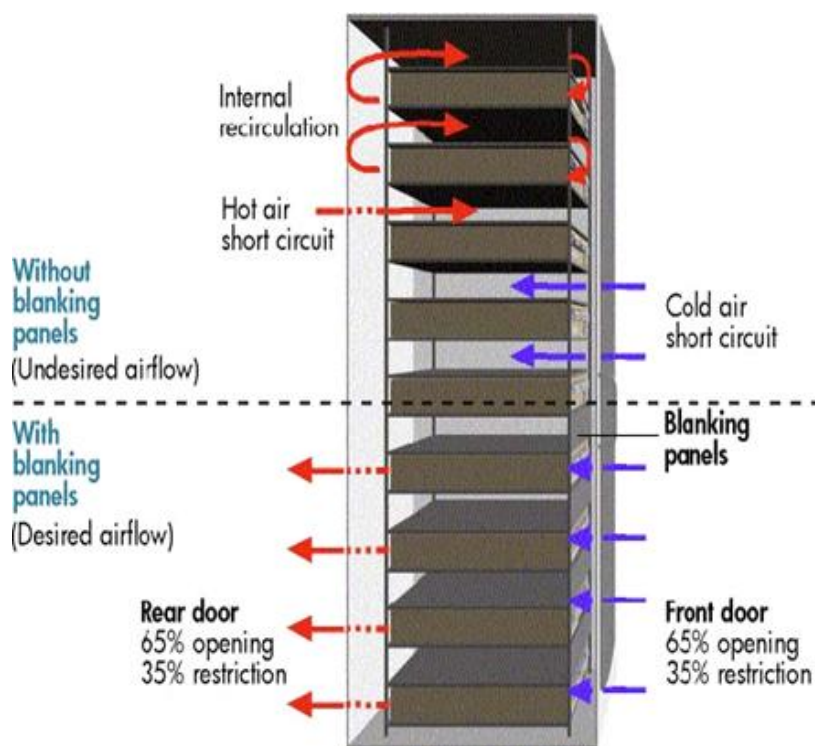


Figure A.2 Effect of installing blanking panels

Racks with glass front doors

Racks with solid front doors (Figure A.3) restrict the flow of air to the server front and will elevate the server's working temperature. These racks are incompatible with the current design of most IT equipments that draw in air from the front and exhaust at the rear. The solid rear doors keep the heated air within the rack, which can get recycled and again increase the operating temperature of installed equipment. These racks are cooled by providing openings on the raised floor panels underneath the racks. The size of the openings is much larger than required to support the cooling load resulting in only a small proportion of air actually flowing to the front and up through the narrow space between the door and equipment front face. A large proportion of air goes to the back instead where it mixed with the exhaust air. The rack doors should be replaced with perforated door panels with at least 60% free openings. Similarly, the rear door panels should be replaced. If security is not a concern, removal of the door panels would result in the optimum condition for air flow across the rack.



Figure A.3 Racks with glass front doors

Cabinets with fans

This legacy practice of fitting ventilation fans at the top of racks is not necessary and can lead to air recirculation issues in the data centre. This used to be necessary when racks are fitted with fully enclosed front and rear door panels with cooling air supplied at the bottom and exhausted at the top. All new racks supplied by manufacturers nowadays are provided with perforated metal door panels at the front and rear. Only special application racks comes fully enclosed and should not be used for normal data centre deployment.

Front-to-back cabinets

There are two general issues with front to back ventilated cabinets; first, they need to be arranged in a hot aisle/cold aisle arrangement so that the air entering the servers is not mixed with warm air from other cabinets or directly from another server. Second, the servers are drawing air from within the cabinet and recirculation can occur within a cabinet if blanking plates are not provided for every piece of equipment.

Cable Management in the Raised Floor Plenum

A large amount of cables and other equipment in the floor void (Figure A.4) will impede air flow and reduce the effectiveness of the cooling infrastructure. In some areas the depth of the cables totally obstructs the flow of air through the plenum. Proper cable management and process is required. Unused cables should be removed promptly once it is no longer used. If possible data cabling should be placed in overhead cable trays or baskets over the rack rows where it does not impede air circulation.



Figure A.4 Cable obstructions in raised floor area

Gaps in Equipment Rows

Keep equipment rows as long as safety requirements will allow. Openings in equipment rows and at the ends of rows allow air from the hot aisles to wrap around the end racks infiltrating the cold aisles. The mixing of hot and cold air raises the inlet temperature of IT equipment. If this recycling of warm air persists, the equipment will likely overheat. Note the heat migration at the end of each equipment row in Figure A.5 (yellow = hot, blue = cold). It is recommended that large gaps between racks in rows are sealed with an empty racks fully fitted with blanking panels or with sheets of fire retardant materials.

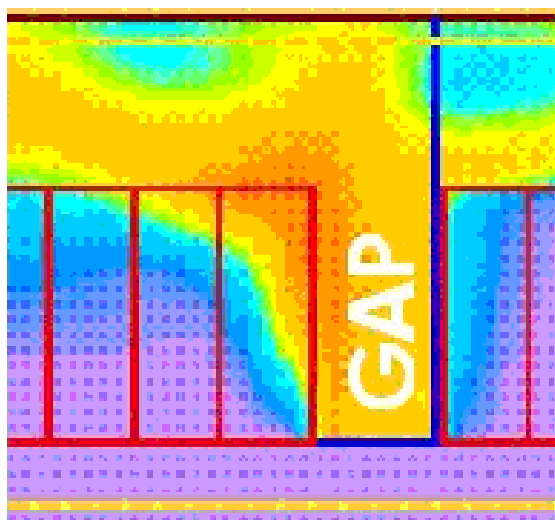


Figure A.5 Illustration of heat migration as a result of gaps in cabinet rows

Organised Data Cabling in Rear of Cabinets

Data centre operators need to ensure that all cables and wires are properly routed in the rear of server cabinets in order to minimize the impact on servers' air flow rate. Need to establish a protocol for cable management. Figure A.6 below is an example of improper cable management and example of obstruction to air flow.



Figure A.6 Air flow obstruction caused by improper cable management

Change Management includes Environmental Checks

Implement change management procedures when making any alteration to the physical computing environment particularly when it affects cooling. A proper change management process should be developed and implemented for any changes to be made inside the data centre, such as adding or removing IT equipment and any change that affects operating and environmental parameters in the data centre.

Best practices require the following to be defined, documented, checked and verified as a minimum in any environmental change process, including the introduction or removal of smaller items of hardware:

- Contingency plans.
- Quality check points.
- Back out plans.
- System power requirements.
- System heat output.
- System weight impact.
- Air flow requirements.
- Cabling requirements.
- Impact on room power and cooling capacity.
- Floor space and loading requirements, including space for maintenance access.
- Updated floor plans indicating all cabinets and power outlets and service access.
- Labelling of all data and power cables.
- Labelling of all circuit breakers.
- Spot checks made on power loadings, temperature and humidity once system is operational.
- Post implementation verification of installation quality & safety (QA).

Furthermore, as a part of the change authorization process, all interested parties should be consulted for any alteration within the productive environment e.g. engineering staff, IT staff and business sponsors, preferably as part of a change board.

Floor Plenum Static Pressure

The distribution of air within a room is dependent on the static pressure created and maintained within the floor plenum. A typical "design" static pressure is 16 Pascal to 25 Pascal. However, in practice this is never achieved and values of 0 to 10 Pascal are typical measured values.

These values are low due to the numerous openings in the floor either into the bottom of cabinets, around cables, etc. When these openings are added to the area of the floor grills, this is typically 3 or 4 times greater than required. The effect of this is that the air distribution is not controllable and cooling cannot be delivered precisely where it is required. This causes some cabinets to re-circulate warmer air and elevate the data centre temperature again, elevating the temperature of the air entering the server, possibly beyond its limits. This is typically called a "hot spot", the direct effect of re-circulated air. The effect of low floor pressure and air distribution is that 70% of the cooling air does not reach where it is needed. This air is termed "bypass" and does not contribute to any cooling of the IT equipment.

Annex A.3 HVAC

The mechanical systems typically offer more energy savings opportunities. Most of the opportunities for improvement are in the cooling systems, followed by the air movement (fan) systems. This is strongly dependant on the climate (cooling degree days).

The energy use of the HVAC system (DX, chilled-water, air-cooled, water-cooled) will vary based on the outdoor air dry-bulb and wet-bulb temperatures, the chilled-water supply temperature (for chilled-water systems only), and the wet-bulb temperature entering the cooling coil (DX systems). The annual energy consumption of a particular HVAC system is determined by the use of bi-quadratic formulas developed to estimate electrical usage of vapour compression cooling equipment. Depending on the type of HVAC systems being considered, the variables used in these equations represent temperatures for outdoor wet bulb, outdoor dry bulb, chilled-water supply, and condenser water supply.

Using this process, one can develop a profile of how PUE and other metrics vary by HVAC system type in a climate such as Singapore. Running an analysis in accordance with the requirements of Standard 90.1-2007 with specific parameters such as building size, construction materials, computer equipment load and reliability configuration, will result in a minimum energy performance profile for a particular data centre. One can then use the profile to create minimum PUE requirements for different HVAC systems in different climate zones.

The major control concept that is specific to data centres is the use of high-temperature chilled water. In other commercial building types where human comfort is the primary goal, colder water is necessary to achieve both indoor dry-bulb and wet-bulb temperatures as required by the standard on thermal comfort. In general, the most common design strategy in achieving this is the use of 7°C chilled water and 13°C supply air. Using higher chilled water temperature opens up many more options for energy savings primarily via the reduction of compressor power required.

Since the cooling system is the second highest energy consumer in a data centre (next to the servers themselves), it is valuable to take a quick look at the refrigeration cycle. The primary goal of the refrigeration cycle is to vary the pressure of the refrigerant to control the evaporation and condensing temperatures. In this cycle, lowering the total entropy will decrease the total work, or energy that is required. As the air temperature moving across the condenser coil increases, the compressor will need to create higher pressures, thereby using more energy. When water is sprayed over the coil (as in an evaporative cooler), the air temperature across the condensing coils is decreased. The lowering of the temperature results in a lowering of the pressure required to condense the refrigerant. Similarly, the higher the air or water temperature moving across the evaporator coil; (refrigerant coil in this example) the lower the pressure that will be needed to cause the refrigerant to “boil” or evaporate. So in order to decrease the overall energy consumption of the compressor, elevating the supply air temperature by increasing the chilled water supply temperature and/or reducing the temperature of the air moving across the condensing coil will cause a significant reduction in energy consumption. Figure A.7 is an example of 1000 RT centrifugal chiller power consumption at varying chilled water supply temperatures.

(Important Note: As noted in Section 3, elevated chilled water supply temperature should be properly matched with AHU heat exchanger coils designed to operate in the desired temperature range. The increase in fan power consumption should also be taken into consideration and the net power savings between the decrease in chiller compressor power consumption and the increase in fan power consumption should be significant enough to offset the increase in capital expenses of the AHU units).

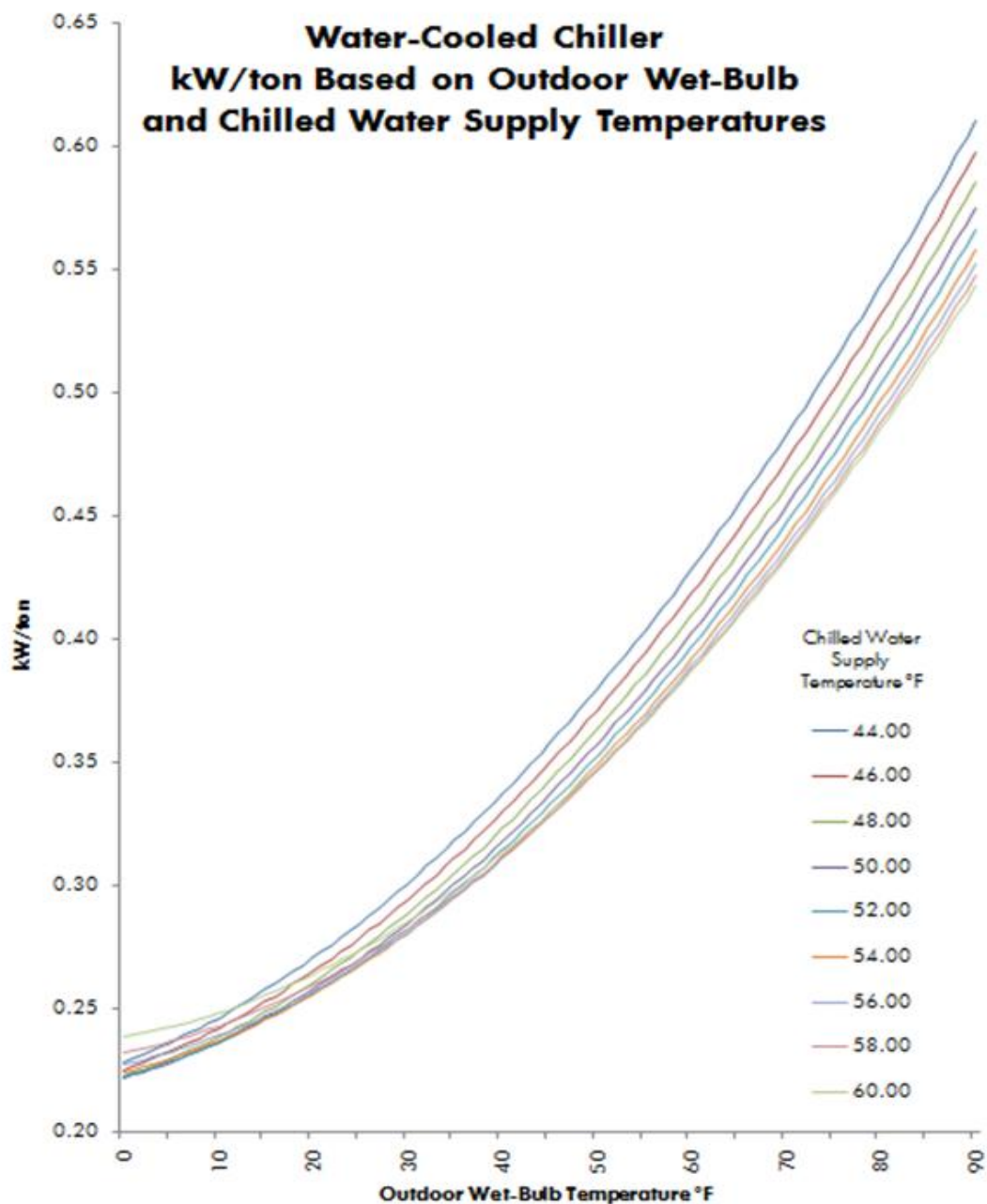


Figure A.7 Impact of chilled water set point increase on chiller power consumption

As an example, typical variable air volume (VAV) systems for commercial office buildings use 13°C air supplied to the space. This air supply temperature is used mainly because it will result in a room temperature that is within the acceptable temperature and relative humidity parameters as defined by the ASHRAE comfort standard. However in a data centre, meeting the ASHRAE comfort standard is not necessary. The optimal environmental condition at the face of the server based on ASHRAE 2008 standard is well above the 13°C to 16°C that is commonly seen in data centres.

When analysing the energy use of an air-conditioning system, it is helpful to break it down into sub-systems in order to fully understand the components. The primary building blocks are as follows:

1. Heat rejection (cooling towers, dry coolers, evaporative coolers)
2. Refrigeration (water cooled, air cooled, condensing units)
3. Air systems (CRAHs, central station air handling units)

Annex A.4 Waste Heat Reuse

The concept of re-using data centre waste heat is gaining a lot of attention as part of an overall greening effort to improve energy efficiency. The value of this energy may or may not affect PUE, depending on the location of the re-use.

If the waste energy is reused within the data center, the value of the reused energy will already be contained within the PUE calculation and needs no special consideration (For example, reusing waste heat to warm a battery space in a cool climate). The PUE would generally be lower because the HVAC system does not have to add as much energy to heat that battery space, thereby reducing the PUE when energy is measured and PUE calculated.

If the waste energy is reused outside the data centre (e.g. re-using heat to warm an office or lab that is not part of the data centre), the PUE of the data centre is not affected and waste heat reuse cannot be accounted for in the calculation of the data centre PUE due to the strict definition of PUE used in these recommendations. Currently there are on-going industry efforts to define a metric that could be used to account for this beneficial use, but it is specifically excluded from PUE.

Hence, if energy from the data centre is used in another location and reduces the energy the site would need to buy, procure, or generate, it can be accounted for in the new metric Energy Reuse Effectiveness (ERE):

$$ERE = \frac{\text{Total Data Center Energy} - \text{Reuse}}{\text{IT Energy}}$$

An Energy Reuse Factor (ERF) can be defined as

$$ERF = \frac{\text{Reuse Energy}}{\text{Total Energy}}$$

ERF is the ratio of the data center energy that is reused elsewhere in the facility and the total energy brought into the data center control volume (including IT, cooling, power, lighting, etc.) Total energy is essentially the numerator of PUE. Note that ERF will range from 0 to 1.0. The value at 0 means no energy is reused, while a value of 1.0 means all of the energy brought into the data center control volume is reused (See Figure A.8).

In Singapore's warm climatic condition, waste heat re-use is not feasible or has very little practical application for the moment.

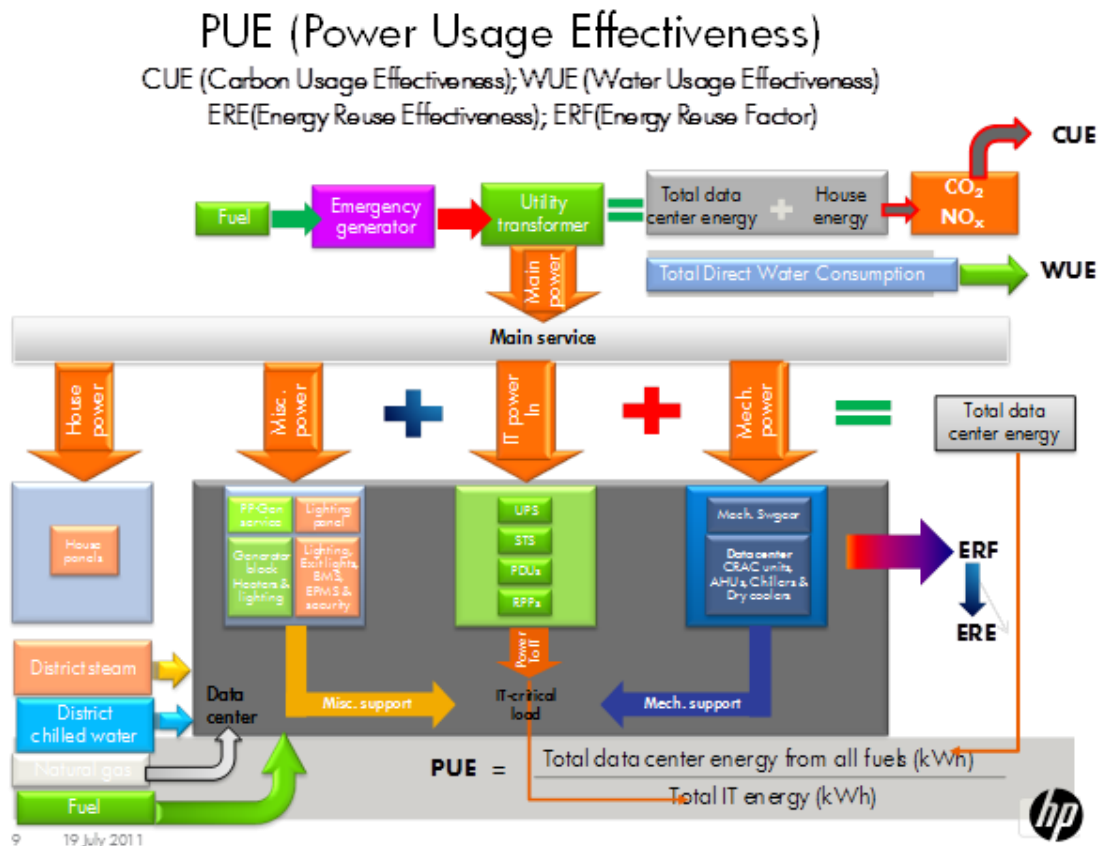


Figure A.8 Data centre energy metrics

Annex A.5 Electrical Power Distribution

Though other systems are considered, the most important one is the UPS followed by the STS/PDU/TF distribution systems. The electrical power consumption includes all the power losses starting from the utility through the UPS, PDUs, and RPPs to the IT equipment. This includes the power to the servers via the static transfer switches (STSS) and power distribution units (PDUs); UPS power (typical efficiency 0.85 to 0.96) and cable distribution losses (typical losses 1% to 1.5%). These various power distribution systems result in a typical electrical PUE range from 1.1 to more than 1.4.

The efficiency of the electrical system is determined by how much exergy is lost in the power supply chain, which spans from the utility transformers down to the individual pieces of technology and HVAC equipment. Some of these losses occur due to the following reasons:

- Transformation to different voltages.
- Thermal losses in switchboards and other electrical gear.
- Losses in wiring.
- UPS equipment efficiency.
- Percentage of total capacity that equipment is loaded to.

In order to determine the exergy losses in the electrical equipment and distribution systems, it is necessary to measure power at certain key locations. Comparing upstream and downstream power measurements will determine the efficiency level of a piece of equipment or distribution path. These power measurements can then be summed to determine an overall exergy loss for the entire electrical system. Note that it is important to include losses stemming from power distribution for HVAC systems, as this is certainly an integral part to the overall functionality of any data centre facility.

Although the electrical system does not directly consume electricity, it is still a major energy consumer. Depending upon the topology of the electrical distribution, there can be significant losses within this system.

The major contributing factors are:

- The loading on the UPS system (if one is present).
- The type of power conversion equipment.
- The type of power supply.
- The type and voltage of electrical power distributed to the computer equipment.
- Losses in transmission due to resistance in the conductors.

There is still on-going research in this area, but it is understood that overall efficiency of the power supply system chain will range from approximately 50% (traditional static UPS and power conversion) to upwards of 75% (high voltage DC power distribution). The result is that for every kilowatt meant for the computer equipment sent through the electrical distribution system, the usable power that actually gets to the computer equipment will vary from 500 watts to 750 watts (figure A.8).

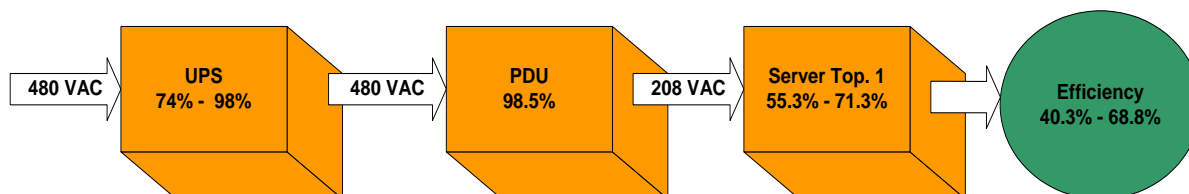


Figure A.9 Traditional AC Power Distribution

Also, having multiple concurrently energized power distribution paths, if designed correctly, can increase the availability (reliability) of the IT operations. However, running multiple systems at partial loads also decreases the efficiency of the overall system.

Annex B. Climate and Weather Analysis

Weather is the condition of the atmosphere at a specific location at a certain time. It consists of temperature (dry-bulb, wet-bulb and dew-point), barometric pressure, wind speed and direction, humidity, cloud cover and precipitation (amount of rain and snow).

Climate Data for Singapore Data centres

Weather station location: Changi Airport

Climate Zone: 1A

Location

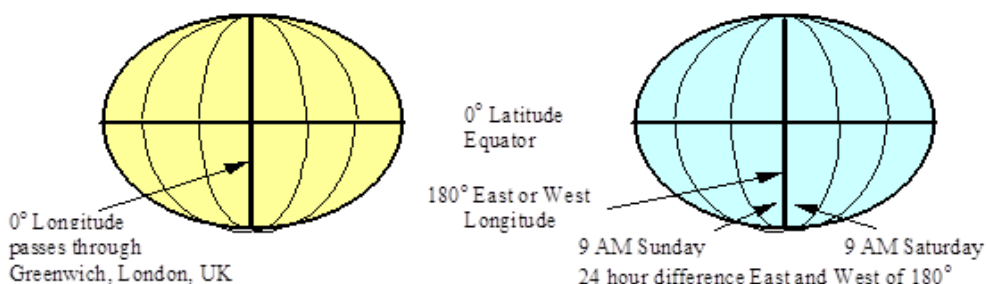
Locations are established by latitude, longitude and elevation. Locations have to be associated and identified by the nearest weather measuring station. This is usually the nearest airport to the location. Example Changi Airport, Singapore. All airports have a weather station since this information is required by arriving and departing airplanes. Most cities have just the one weather station at the airport.

Latitude

Latitudes vary from 0° (equator) to 90° N (North Pole) in the northern hemisphere and from 0° (equator) to 90° S (South Pole) in the southern hemisphere. Singapore is just 1 degree 14 minutes north of the equator which puts it in the tropics. The latitude accounts for the relatively stable and constant climate and very little variance in temperature throughout the year as compared to those locations in the upper and lower latitude. The absolute values of solar radiation intensity at a location depend on the latitude and the time (day, hour, minute, second) of the year. It has nothing to do with weather conditions. However, the actual solar radiation reaching a location depends on altitude (the air is thinner), weather (cloud cover, rain, snow, fog) and atmospheric pollution (smog).

Longitude

Longitudes vary from 0° to 180° West of Greenwich, London, UK (considered 0° longitude), and 0° to 180° East of Greenwich. In the USA, longitudes west of Greenwich are considered positive and east longitudes are considered negative. This should be considered when using energy computer programs developed in countries east of Greenwich where east longitudes might be considered positive. Since the earth is a sphere (360° circle along lines of latitude) and there are 24 hours per day, there is a change of 1 hour for every 15° change in longitude ($360/24 = 15$). The International Date Line (180° East or 180° West longitude) passes mainly over the Pacific Ocean. It is bent around the few small islands that it might split. Longitude affects the time of the day only and not the weather.



Humidity

This is the amount of water vapour in the air. Although this amount is relatively miniscule compared to the remaining mass of air, it is a critical factor in describing weather and comfort conditions. The common terms used are:

- (1) Absolute Humidity which is the mass of water vapour per unit volume of air.
- (2) Relative Humidity which can be described as the percent ratio of the moisture in the air to the maximum amount it can hold at the same DB temperature.
- (3) Specific Humidity which is the mass of water vapour per unit mass of air.

Air conditioning calculations are therefore based on absolute humidity and specific humidity of air. Humidity is measured with a hygrometer. The most widely used method for measuring humidity is a dry-wet-bulb psychrometer. Humidity is then calculated from the dry and wet bulb temperature condition. The rate of evaporation decreases as the moisture content of the air increases and approaches saturation. In addition, the saturation point (moisture-holding capacity of the air) increases rapidly as the temperature of the air rises. Thus cold air, while its moisture content is necessarily quite low (low absolute humidity), may be almost saturated with respect to the maximum amount of water vapour it is capable of holding (high relative humidity).

Cold air with high relative humidity "feels" colder than dry air of the same temperature because high humidity in cold weather increases the conduction of heat from the body. Conversely, hot air attended by high relative humidity "feels" warmer than it actually is because of an increased conduction of heat to the body combined with a lessening of the cooling effect afforded by evaporation. On the other hand, a low relative humidity "modifies" the effect of temperature extremes on the human body. Humidity decreases with altitude. Proximity to large bodies of water and the prevalence of moisture-bearing winds favour high humidity.

Climate has a very significant effect on the electricity usage of the cooling systems. Depending on the specific types of cooling equipment and the climate that the data centre is in, there can be a large variation on energy use, even if the facility and IT load are identical. For example, in a hot and dry climate where the wet bulb depression below the dry bulb temperature is significant, using a water cooled condenser will use less energy than an air-cooled condenser since the heat exchange from the refrigerant medium takes place on a higher pressure state (due to the higher condensing temperature say an ambient air dry bulb temperature at 38°C as compared to a water cooled condenser at 28°C) thus requiring more energy usage by the compressor. Conversely, using air-cooled condensers in a cool but humid location might make more sense.

When analysing the overall energy use of a data centre facility, it is important to note that the IT load is generally static, meaning the maximum and minimum power demands are fairly close. (This is not universally true, but one of the goals in optimizing server efficiency is to maintain a constant usage rate, as close to maximum as possible, as this is where the servers tend to run most efficiently). This relatively flat usage curve means that the only major change in electricity usage will come from the cooling plant, which will run at different efficiencies based on the outdoor conditions (dry bulb temperature and wet bulb temperature). All else being equal and keeping certain parameters fixed (chilled water supply temperature/flow rate and condenser water supply temperature/flow rate), as the outside air dry-bulb and wet-bulb temperatures fluctuate over the course of the year, the electricity required for the central cooling plant will also fluctuate, but not linearly. The enthalpy and not only dry bulb temperature should be used to make judgments about energy utilization.

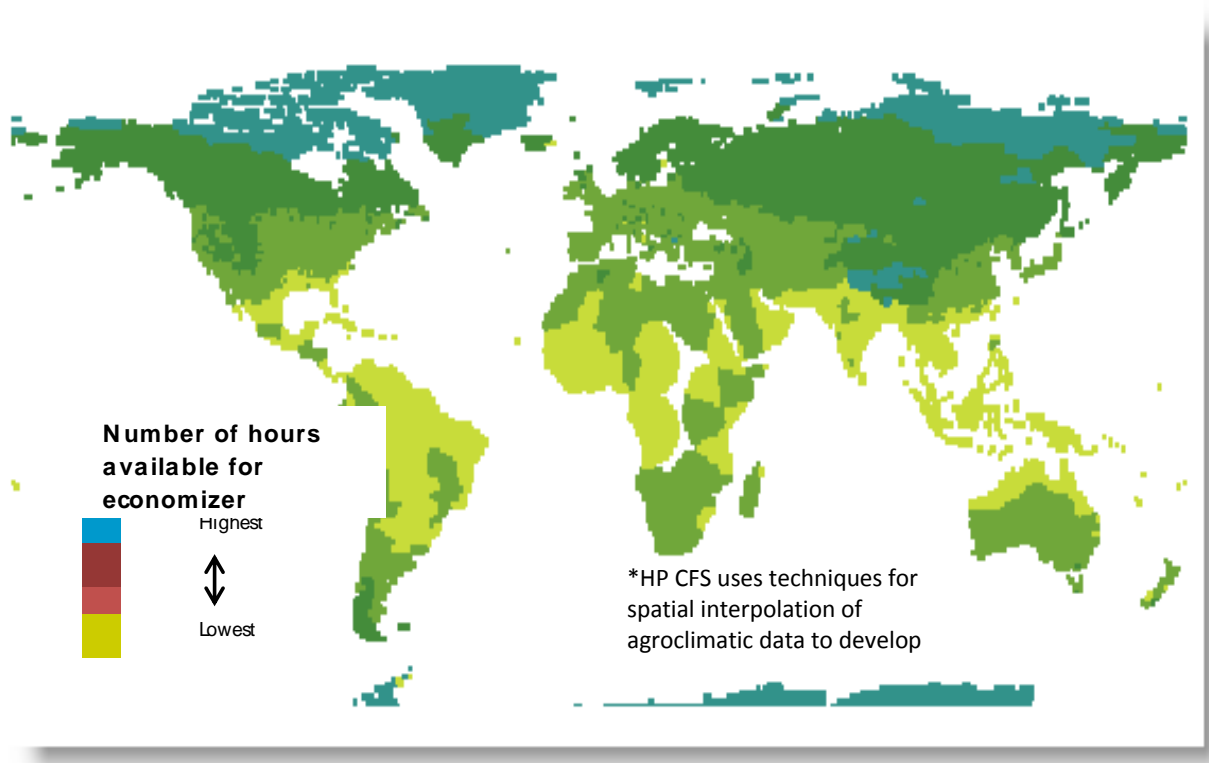


Figure B.1 International Climatic Data Visualization

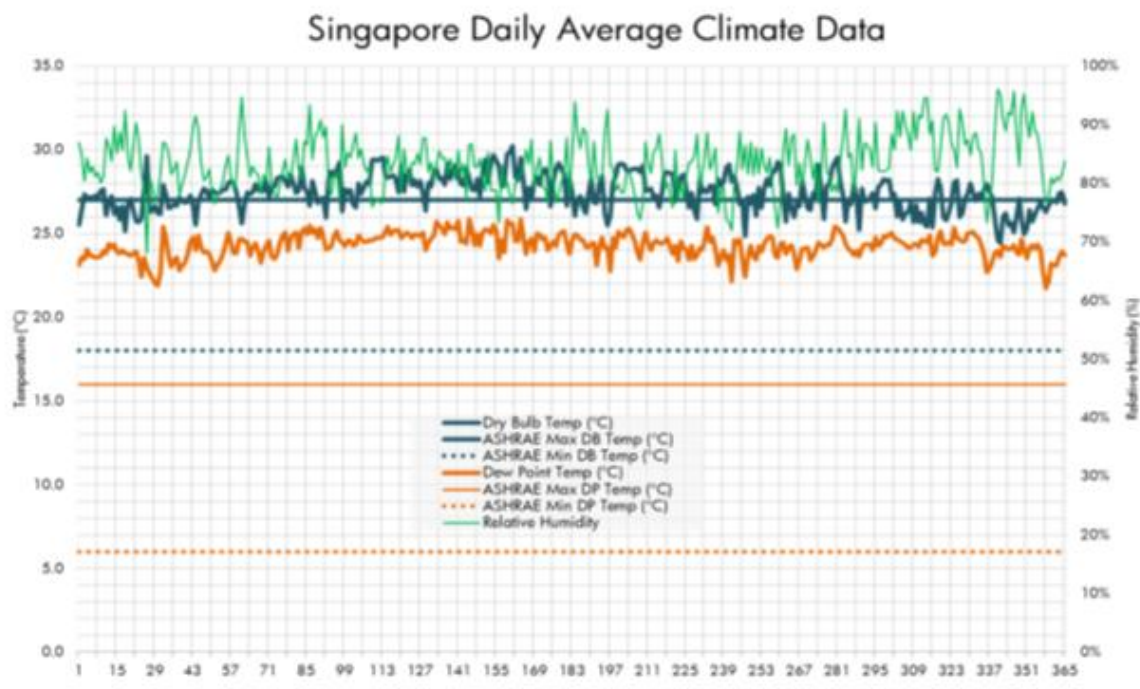


Figure B.2 Singapore weather bin data analysis over 365 days

Temperature Frequencies - Singapore

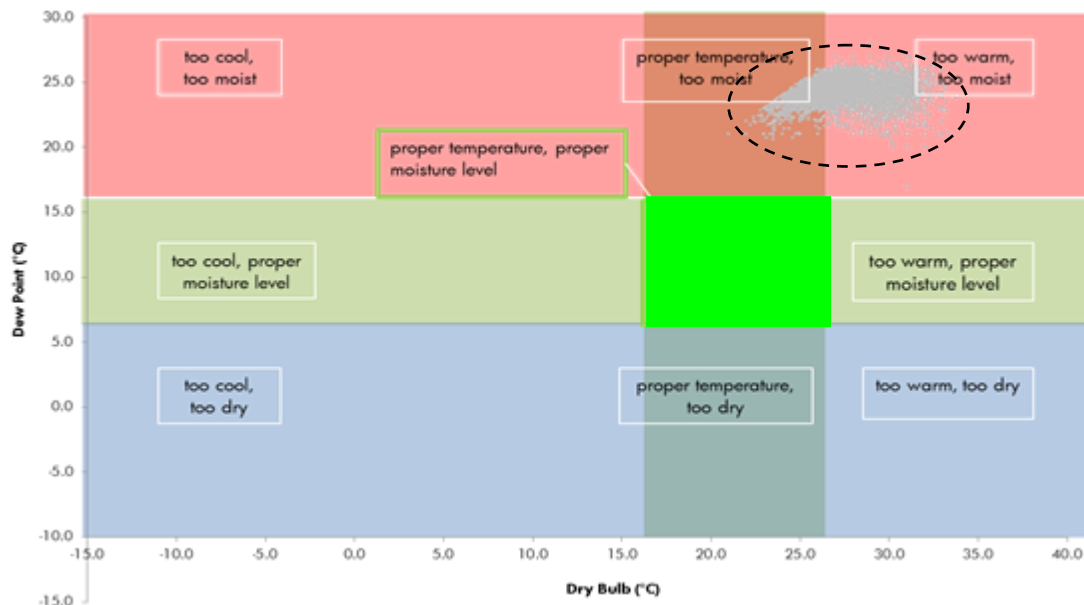


Figure B.3 Singapore dry bulb and dew point scatter plot hourly data

Ability to Use Free Cooling

Data centre energy efficiency will vary depending on the geographic location of the facility and the climate zone that the facility is located in. Singapore is located in climate 1A "hot & humid" with the lowest number of available hours for free cooling. Benchmarking comparisons have to be in terms of climate 1A and not the entire 17 climate zones defined by ASHRAE: 1A, 1B, 2A, 2B, 3A, 3B, 3C, 4A, 4B, 4C, 5A, 5B, 5C, 6A, 6B, 7, 8. (1 = hottest, 8 = coldest, A = moist, B = dry, and C = marine). The data centre annual energy utilization should be analysed with the climate zone in mind.

Figure B.3 shows ASHRAE recommended range of dry bulb, wet bulb, and dew point temperatures, (area in the bright green rectangle). The gray cloud represents (encircled with dashed oval circle) Singapore's temperature conditions. It is clear from the graph that Singapore is not able to utilise free cooling without some treatment for the humidity levels.

Annex C. Overview of Data Centre Energy Efficiency Assessment

The assessment consists of multi-step approach consisting of audit preparation, execution and reporting. This is shown in figure C.1 below with the other sub-tasks under each stage including duration.

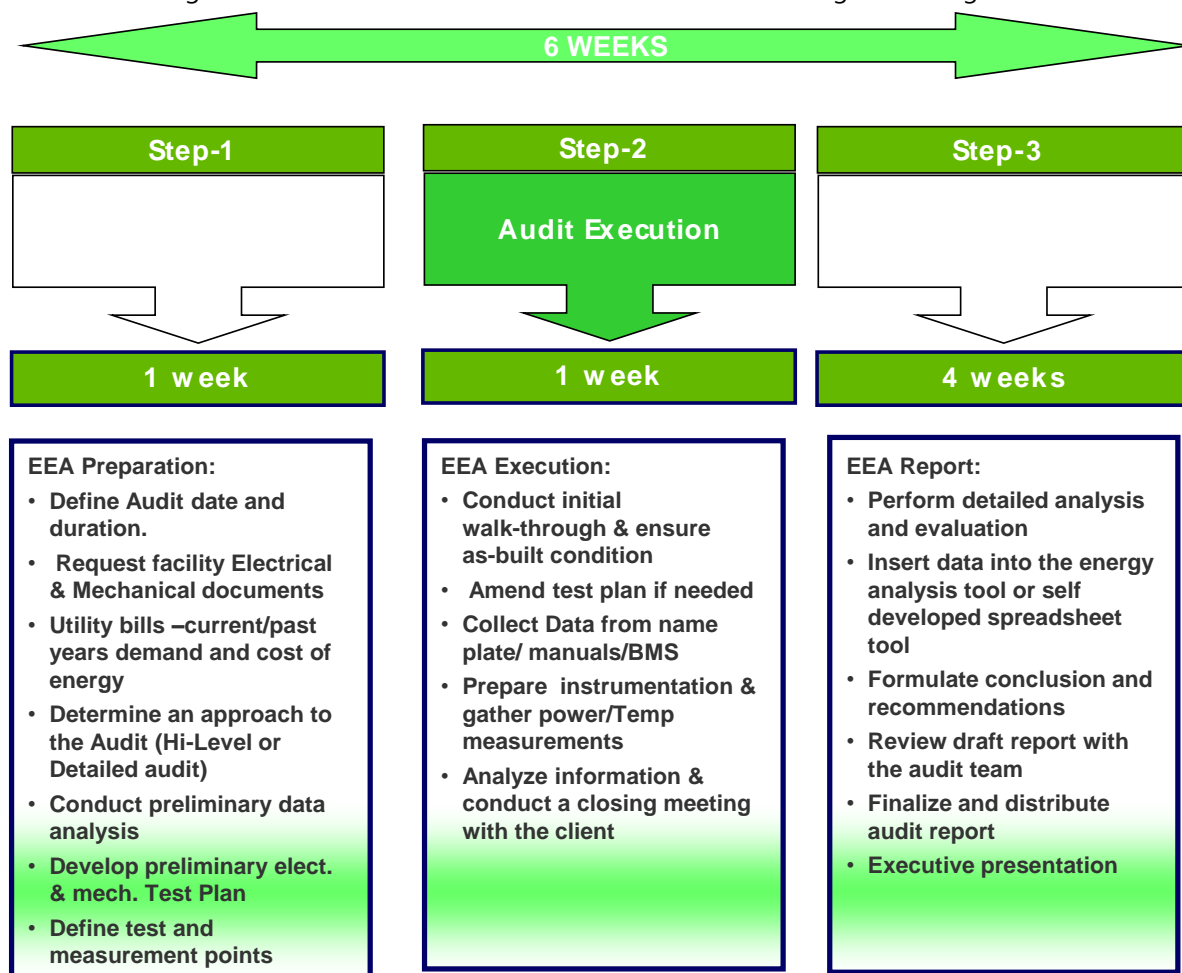


Figure C.1 Energy efficiency assessment process diagram

Preparation

Preparation works prior to data collection and measurements requires the team to analyse the data centre facility infrastructure to understand the electrical and mechanical systems that support the data centre. Measurement points are then identified on the electrical single diagrams for the site. The identified points are then surveyed to determine whether measurements can be conducted easily and safely and with the least risk to the data centre operation. Once confirmation of measurement points has been completed, a measurement plan is drawn up and submitted for approval by the site owner. This may also include a risk analysis and mitigation plan depending on the data centre site process.

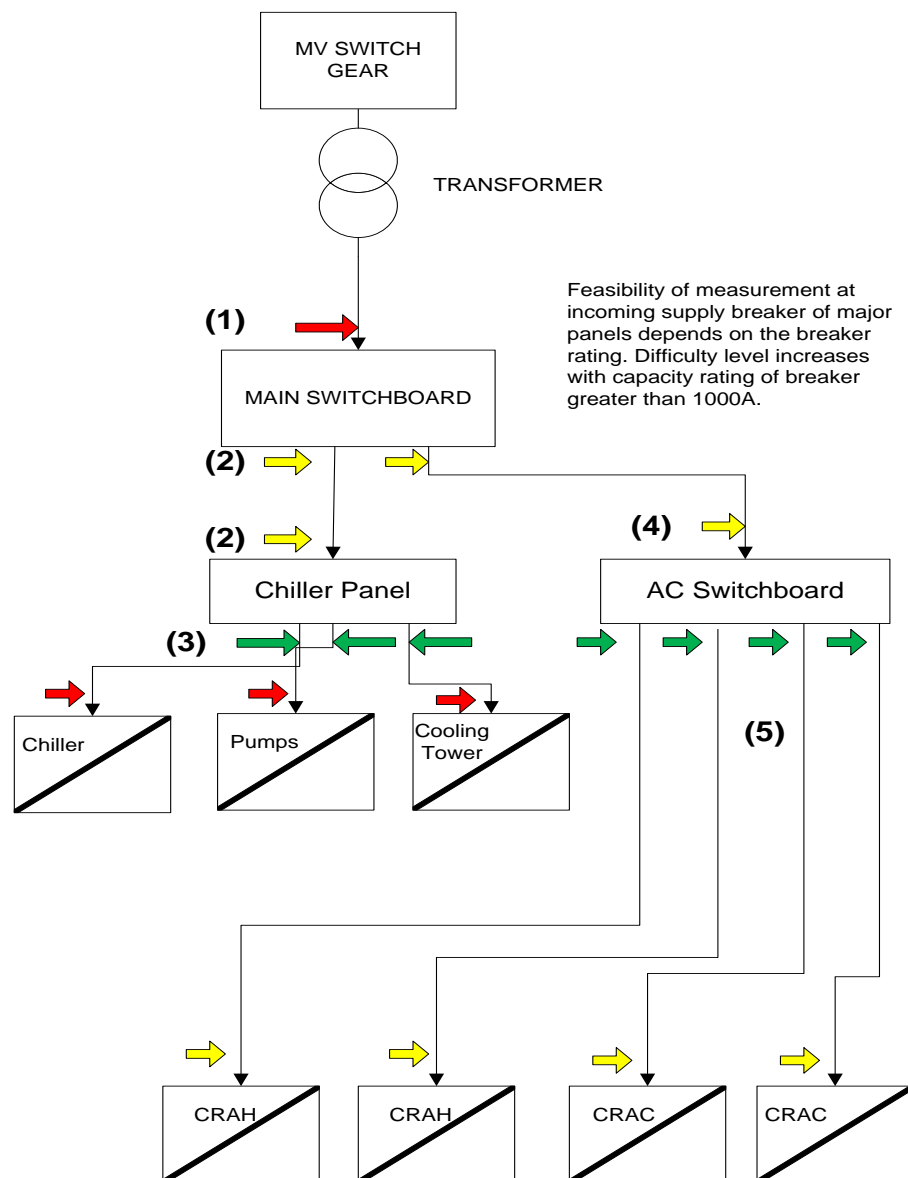


Figure C.2 Measurement of mechanical systems

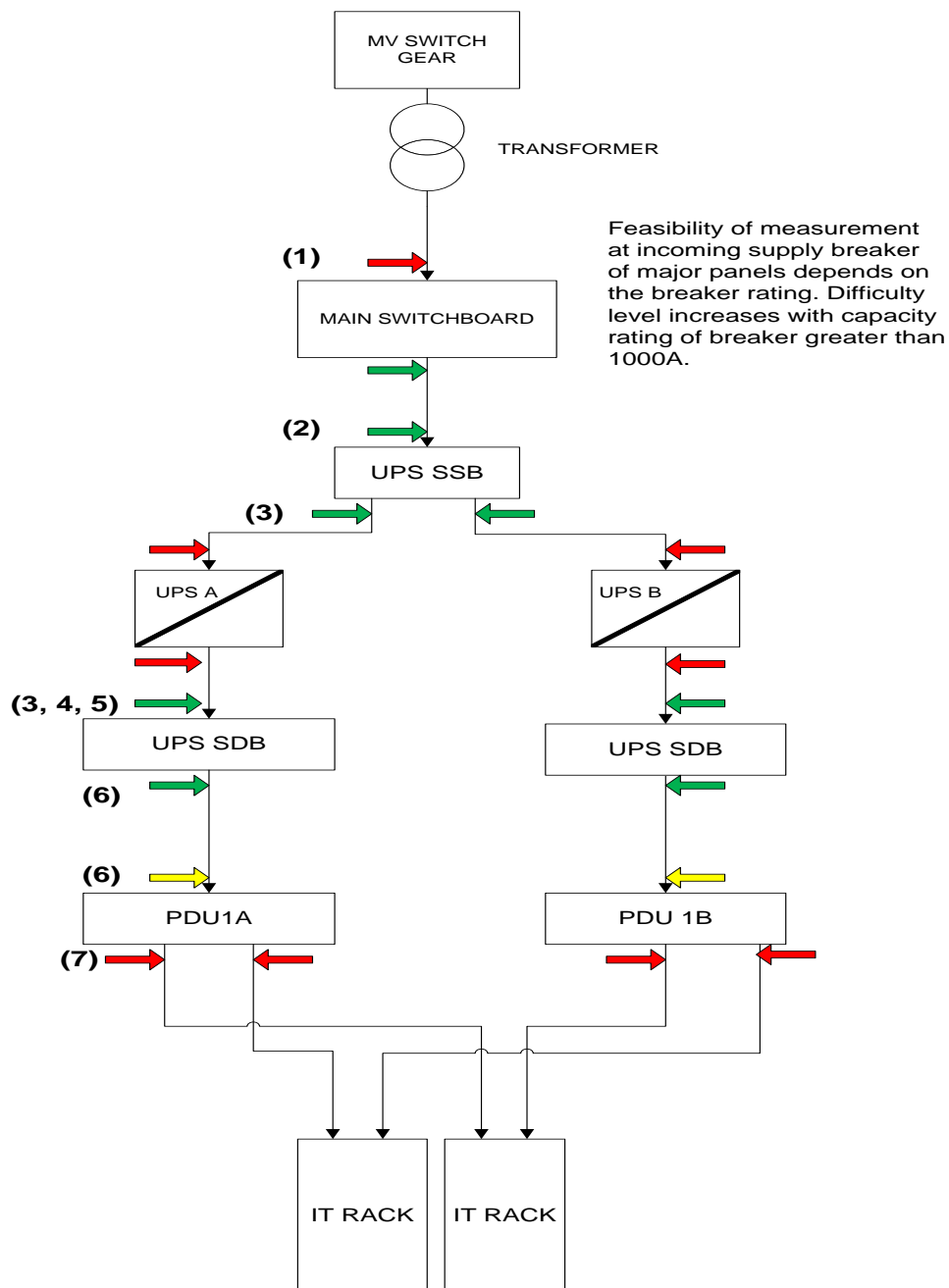


Figure C.3 Measurement of electrical systems and IT load

Data Centre Site Area Assessed

- Facilities office areas (where drawings are kept).
- Utility transformer room (if accessible).
- Main switchgear rooms.
- Generator rooms/areas.
- UPS and UPS battery rooms.
- Chiller and pumps rooms/areas.

- Cooling tower yards.
- Air handling units/CRAH units/Condensing units' areas/corridors.
- Electrical distribution rooms.
- Fire detection/suppression room(s).
- Raised floor/white space areas.
- Command/Control/Monitoring/BAS/BMS rooms.

Electrical Measurement and Data Collection Execution

The assessment team used calibrated Hioki 3197 power quality meters to capture the electrical power demand (Refer to Table C.1). The typical approach used during the study was to manually conduct site power measurements as most of the data centre sites studied did not have historical records for the electrical energy usage. There is also a lack of instrumentation on the electrical panels in most of these sites. Note that power measurement unit has to be in kW or kWh.

Electrical power demand measurements were conducted on the HVAC system electrical panel to determine the average demand over a period of 48 hours at 5 minutes interval (Refer to Figure C.2). Instantaneous power demand measurement was also conducted on individual air handling units or cooling equipment to determine actual electrical load versus manufacturer equipment specifications.

Measurement on each of the UPS system was conducted on the input and output of the system (Figure C.3) to determine the loss across the system. Most of the IT load measurement was conducted on the UPS output distribution panel rather than the last distribution panel prior to the IT load. This is done mainly to reduce the risk of disruption to the IT system.

Measurement Range	Accuracy
Meter: 500mA to 5kA Current Clamps: 100A, 1000A 5000A	Meter: • Voltage Accuracy $\pm 0.3\%$ rdg. $\pm 0.2\%$ f.s. • Current Accuracy $\pm 0.3\%$ rdg. $\pm 0.2\%$ f.s. + Clamp sensor accuracy Current Clamps: 100A: • Amplitude: $\pm 0.3\%$ rdg. $\pm 0.02\%$ f.s. , (45 to 66 Hz, f.s. = rated primary current) • Phase: $\pm 1^\circ$ or less (at 90 A or less), $\pm 1.3^\circ$ or less (at 90 A to 100 A) 1000A: • Amplitude: $\pm 1.0\%$ rdg. $\pm 0.01\%$ f.s. (45 to 66 Hz, f.s.= rated primary current) • Phase: ± 1 deg. (at 45 Hz to 5 kHz) 5000A: • Amplitude: $\pm 2.0\%$ rdg. $\pm 1.5\text{mV}$ (45 to 66 Hz, minimum input 10% of range) • Phase: ± 1 degree (45 to 66 Hz)

Table C.1 Power Measurement tool specifications

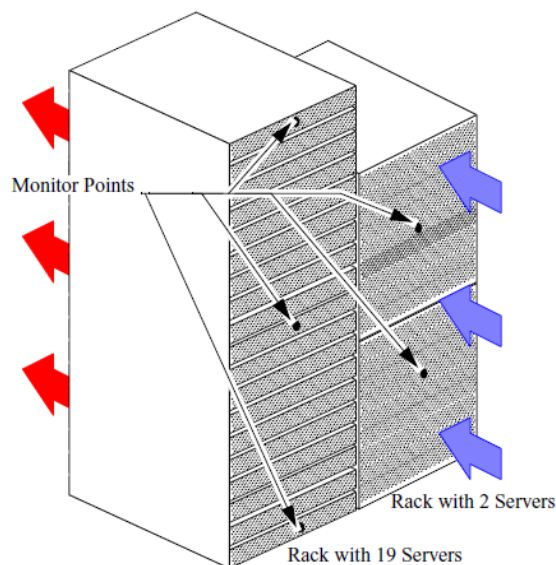


Figure C.4 Measurements of total data centre and IT power

Air Temperature Measurements

Air temperature measurements on the IT racks were conducted using handheld digital thermo-hygrometers to determine intake temperature at the server inlet and outlet. A total of 6 (3 front and 3 back) measurement points are made as illustrated in Figure C.4 at the lower, middle and high level section of the rack. Both temperature and relative humidity levels are captured. 18 capture points across 3 racks or more were made for every CRAH/CRAC unit in operation. In addition, these intake and exhaust air temperature measurements were acquired on racks at each end of the row to capture wrap-around circulation and one rack in the middle (more if the rack row has more than 9 racks in a row).

Measurements were also taken on the intake and discharge of the air handling units. The typical AHU units encountered in data centres have intake openings at least 1.8 meters x 0.9 meters in dimension. A minimum of 6 capture points were made and then averaged to represent the temperature of the return air. Measurements were made on the discharge side of the AHUs as close as possible to the discharge opening and a minimum of two captures were made and averaged.

Display panel readings from the AHU units were observed and recorded. These include air temperature, humidity, valve openings, number of fans/compressors in operation as well as the state the AHU is in such as cooling, fan only, and dehumidification or reheat modes.

Cooling Load Estimation

The cooling load calculation is based on the IT power load plus the load from the room surface, and that due to pre-cooling of fresh air into the data centre. The data centre cooling load is mostly due to heat generated by the IT equipment as well as electrical equipment and fixtures like lighting. Heat also comes from the walls, ceiling and floors of the room if the other side of the walls are non air-conditioned space or exterior walls. Solar heat gain through walls and windows can be significant depending on the direction the wall faces. Do note that all these are sensible heat gain of the room. These factors are taken into account the estimation of the cooling load for the data centre.

Latent cooling load for a data centre is minimal and not as significant as the sensible cooling load. This is mainly due to the function of the room as primarily an equipment room. Human activity is minimal and may consist of 1 or 2 people working an hour or two each day to change storage tape cassettes in the data centre room or to perform work on a data centre room that may range from a hundred to thousands of square meters in area. Moisture infiltration is mainly carried through air exchanges with other conditioned spaces in the building when doors are opened and closed.

Practically close to 100% of power drawn into IT equipment is dissipated as heat in the electronic components and circuits. Cooling load is calculated based on the IT equipment power load in kW wherein 1 kW of IT load equals 1 kW of sensible cooling load.

For walls and floors, it depends on construction and where it is located (i.e. room is bounded by conditioned space all around, above and bottom). The heat gain can range from 25 watts per square meter to 50 watts per square meter of floor area (based on a U-value of $0.4372 \text{ W/m}^2 \text{ }^\circ\text{C}$ for 150 mm brick wall). For most of the sites the factor used is 50 watts per square meter of data centre area. This is a conservative factor and is based on a conservative aggregation and averaging based on a room measuring 1000 square meter area and 4 meter high perimeter brick walls with no solar radiation exposure on the roof. Majority of the data centres have few or no windows and at most only one side of the room has externally exposed walls.

Fresh air supply pre-cooling power load (if present) is around 9 kW per cubic meter per second of fresh air cooled to 22°C (based on cooling air at 32°C 85% RH cooled to 22°C 85% RH). Cooling load from lighting is equivalent to the measured power consumed by the lighting system.

Energy demand by the cooling systems was derived from power demand and consumption measurement conducted at the sites over a period of up to 3 days or taken from existing site records. Individual cooling equipment were also measured and compared to manufacturer's specifications.

Data Analysis and Reporting

Data collected from the site surveys and subsequent measurements were entered into an HP software tool for post-processing, configuration, manipulation, analysis and modelling of the efficiency metrics (PUE, etc.) as well as creation of the final report. The entered data were segregated into either electrical or mechanical systems to enable calculation of the PUE as well as break it down into the mechanical and electrical PUE. (Refer to the common assessment framework (CAF) for details on the PUE formula used including air management metrics). Most of the sites (87%) that were assessed did not have the detailed historical energy consumption records over a 6 to 12 months period. The annual average PUE of these sites are calculated through the use of an energy modelling software tool using data captured during the onsite measurements. The simulation model uses Singapore's climate profile and past meteorological record to capture the impact of the local climate on the HVAC systems energy demand.

Engineering and financial analyses are then conducted by the engineering team to select the site specific recommendations and projected energy savings. The software also performs several other functions such as the calculation of the cooling load, carbon emissions, energy cost and more, all based on site specific physical parameters.

Fan power calculation assumes a static pressure drop of up to 3.5 inch (88.9 mm) H_2O across the air filter, cooling coils, raised floor plenum and openings, and back to the CRAH/C return. Fan efficiency is 75%. This works out to a fan power consumption of around 1.16 KW per cubic meter per second of air flow. Cooling power is calculated based on equipment's performance specifications (kW power/kW cooling) from manufacturer's technical specification sheet and multiplied by the cooling load of the data centre and ancillary rooms, if any.

Air management metrics using the air temperature measurement data from the air handling units and IT equipment racks were calculated using the relationship of the air mass flow balance and temperature in the room. This is derived from the thermodynamic equations representing the heat transfer that takes place in the room and reducing to a series of simplified equations represented by temperature of the air in the various path represented in Figure C.5. Full discussion of these metrics and formulas used are presented in the Common Assessment Framework (CAF) document.

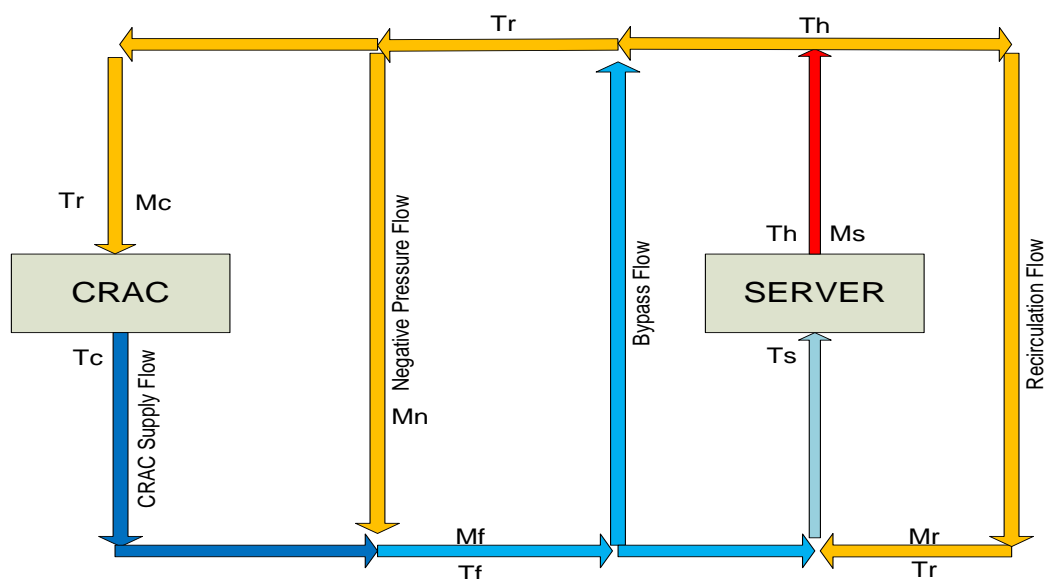


Figure C.5 Diagram showing air flow paths in the data centre

Where:

CRAC: Computer Room Air Conditioning unit

Server: IT Equipment Server

bp: Bypass

C: CRAC

f: Floor

h: Hall

m: Mass flow rate

n: Negative pressure

r: Recirculation

s: Server

T Temperature

Cp Specific heat of air

Mc CRAC flow is the total air-flow rate produced by all operating CRAC units in the data centre.

Mn Negative pressure flow - Air that is induced into the floor void due to Venturi effect

Mb Bypass air flow - This is air that leaves the floor grills and returns directly to the CRAC unit without cooling servers Bypass air flow is known also as "short circuiting".

Mr Recirculation airflow - Air that is discharged from servers, which returns and mixes with air entering the servers to cool them.

Abbreviations

Symbol	Description
AHU	Air Handling Unit
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
BMS	Building Management System
BP	Bypass
COP	Coefficient of Performance
CRAH	Computer Room Air Conditioner (with compressor)
CRAH	Computer Room Air Handling (no compressor)
DC	Data Centre
DOE	Department of Energy (of the United States)
DX	Direct Expansion
EAf	Energy Assessment Framework
ECHT	Entering Chilled Water Temperature
ECWT	Entering Condenser Water Temperature
EFLH	Equivalent Full Load Hours
EMS	Energy Management System
EPA	Environmental Protection Agency
ERE	Energy Reuse Effectiveness
ERF	Energy Reuse Factor
FA	Fresh Air
FCU	Fan Coil Unit
HX	Heat Exchanger
I	Current
IR	Infra-Red
IT	Information Technology
ITHD	Current Total Harmonic Distortion
JWH	Water Jacket Heater
kWh	Kilo Watt hour
LCHT	Leaving Chilled Water Temperature
LCWT	Leaving Condenser Water Temperature
NEA	National Environmental Agency

Symbol	Description
NP	Negative Pressure
PDU	Power Distribution Unit
PF	Power Factor
R	Recirculation
RH	Relative Humidity
RPP	Remote Power Panel
SAT	Supply Air Temperature
SLA	Service Level Agreement
SPB	Simple Pay Back
STS	Static Transfer Switch
T	Temperature
TR or kW/Ton	Ton of Refrigeration (12000 BTUH) (3.5137 kW)
UPS	Uninterruptible Power Supply
V	Voltage
VAV	Variable Area Volume
VFD	Variable Frequency Drive
W/m ²	Watts per Square Meter
WUE	Water Usage Effectiveness