BUILDING ENERGY EFFICIENCY TECHNICAL GUIDELINE FOR

ACTIVE DESIGN

COMPILED & EDITED BY:
Ir. Kevin Hor
Mira Mohd Noor

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Building Energy Efficiency Technical Guideline for Active Design
Published by the Building Sector Energy Efficiency Project (BSEEP), Malaysia.

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First published in December 2016.

ISBN 978-967-5957-30-7

PREFACE

This Energy Efficiency Technical Guideline for Active Design was written specifically for Malaysian climate zone. It is an attempt to provide a simple and yet useful guideline to practising building designers in Malaysia for design decisions to be made quickly for the promotion of energy efficiency in buildings.

An industry dialogue was carried out on 13th June 2012 to gain an understanding on the status of current energy efficiency design practices and to identify the information that is sought after by the industry, for energy efficiency to be practised on new building developments. 18 industry leaders from both private and public sectors attended the dialogue session. The valuable contributions by these attendees are recognised herewith:

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A "wish list" of information was created from the industry dialogue session. From this "wish list" a few sets of building energy simulation studies (using the weather data of Malaysia) were developed and conducted to provide the foundation for the recommendations made in this guideline.

The building energy simulation tool used for the studies made in this guide is IES <Virtual Environment> version 6.4 from the UK (http://www.iesve.com). This software meets the requirements of ASHRAE Standard 140 and Cibse AM11 for a building dynamic energy simulation tool. This software is adequately comprehensive, allowing different types of passive and active design features to be studied for the purpose of this guideline.

The weather data used for the energy simulation study is the Test Reference Year (TRY) weather data from an analysis of 21 years of weather data from the weather station of Subang Airport in Selangor and is described in detail in Chapter 2 of this guideline.

Building energy simulation studies require a significantly high amount of data to be provided to model a building accurately. The amount of data that is required is reflective of the actual situation in a building, where there are thousands of parameters that are likely to be different from building to building, such as the insulation thickness on the walls and roofs, occupancy schedules, equipment power, equipment schedules and etc. Therefore, it is not possible for this guideline to provide a guarantee on the absolute amount of energy reduction gained by the analysed feature as recommended by a fellow stakeholder during a stakeholder engagement session for this guideline.

The purpose of this guidebook is primarily to develop an understanding of the various possibilities and potential to improve energy efficiency in a building with each design feature. This guidebook is to give building designers a "feel" of the potential energy reduction from these features analysed for further and deeper investigation to be made on the actual building project whenever it is deems appropriate.

The accuracy and reliability of using energy simulation studies for this guidebook can be justified by the following items:

1. ASHRAE 90.1 recognises the accuracy and dependability of energy simulation studies. Section 11 and appendix G of ASHRAE 90.1 provides detailed guideline to conduct energy simulation studies to assess energy efficiencies in buildings.

2. For the past 10 years, many of the published ASHRAE journals on energy efficiency are based on energy simulation studies. This includes a series of 4 part articles in ASHRAE journals on optimising air-conditioning system by Steven T. Taylor from 2011 to 2012.

3. The development of Malaysian Overall Thermal Transmission Value (OTTV) in 1987 for the Malaysian Standard (MS) 1525 was based entirely on the energy simulation of one typical office building model.

Finally, due to the limited time available to produce this guideline, only one building model was used to derive all the estimated energy reductions. Different building sizes, shapes and models will yield slightly different results. However, the results and recommendations from this guideline is deemed accurate enough as a general guide to make informed building design decisions quickly in the interest of energy efficiency in buildings. Building designers are cautioned that if the designed building operational scenario is significantly different from the assumptions made in Chapter 6, it would be best to conduct another set of simulation studies based on the expected scenario of the actual building to provide a more accurate energy reduction potential for the actual designed building.

ACKNOWLEDGEMENTS

I would also like to acknowledge the following people that helped to complete this guidebook for the industry. It has been a real honour for me to receive such valuable information, comments and advice from practising industry experts. Thank you very much for your contributions:

Kevin Hor Chun Wah, whom being the National Project Manager for BSEEP, has a keen interest in lighting systems and technologies and provided many useful comments for the chapter on lighting.

Qamarrul Ariffin and **Ken Lo**, from Osram, for helping to review and provide constructive critique on the chapter on electrical lighting as well.

Darren Lai, **Zhao, Lau**, **Peter**, **Tan**, **Ah Chai**, **Yow** and **Kuan Yee**, from Trane Malaysia, for helping to review and provide many useful ideas and tips to help us revise the chapters on Air Conditioning System Design, Optimisation of Air-Side Air-Conditioning System and Optimisation of Water-Side Air-Conditioning System.

And finally, the attendees of the Active Guideline stakeholder engagement on 18th July 2013, for providing extremely valuable feedback on the draft version and pointing out many issues that needed to be carefully addressed in the active guideline. These attendees are:

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James Chua	REHDA, GreenRE
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Tian Boon Hong	MASHRAE
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To all the contributors above – thank you very much for your kind assistance in the development of this active guideline for energy efficiency in buildings.

CK Tang
Lead Consultant

Dear Readers,

Thank you for your interest in the Building Energy Efficiency Technical Guideline for Passive and Active Design. We hope that these guidelines will be useful to you.

This series was developed as part of the Building Sector Energy Efficiency Project between JKR and UNDP. We have produced this book for dissemination to the building industry for FREE and hope that the book will assist building owners, engineers and architects in building more energy efficient buildings. As intended of a guideline, we hope that the potential savings estimates will allow you to make informed decisions on architectural, material and technology choices.

To download a copy of the book, please visit **www.jkr.gov.my/bseep**. As with all good guidelines, the Passive and Active Technical Guidelines will constantly evolve and improve. To receive updates on the book please register your mailing address at **www.jkr.gov.my/cbd/**

Best Regards,

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CHAPTER

1

FUNDAMENTALS OF ENERGY EFFICIENCY IN BUILDINGS

by CK Tang & Nic Chin

1

FUNDAMENTALS OF ENERGY EFFICIENCY IN BUILDINGS

INTRODUCTION

Optimising the energy efficiency in a building is a far more cost effective measure to reduce carbon emissions than by using renewable energy. Unfortunately, there is no magic silver bullet when it comes to energy efficiency in office buildings for the Malaysian climate. In other words, there does not exist one single item which can reduce building energy consumption by 50% or more. Energy efficiency in office buildings in this climate has to be addressed holistically by addressing every available opportunity.

The typical energy breakdown in Malaysian office buildings is 50% for air-conditioning, 25% for electrical lighting and 25% for small power (equipment). In addition, air-conditioning energy consumption is not only due to heat from solar gain in the building, but also due to heat from electrical lighting, electrical equipment, conduction (through the building fabric), the provision of fresh air in the building and human occupancy. Each of these items contribute a significant part to the air-conditioning energy used. Unless air-conditioning is not used at all, it is not possible to reduce the energy consumption in a building by 50% or more by addressing only one item alone. Refer to **Chart 1.1** for a better understanding.

It is not possible to reduce the energy consumption in a building by 50% or more by addressing only one item alone

Due to the rapid technological advancements in Malaysia in electrical lighting, air-conditioning and the availability of cheap energy from the mid-20th century onwards, unhealthy energy efficiency design practices in has crept into building design and operation. Today, one can easily identify hundreds, if not thousands, of items in building design and construction that can be made better to help improve the energy efficiency in buildings. Nowadays, many building product manufacturers and suppliers are aggressively marketing building materials with claims of improving the energy efficiency in buildings.

With so many options available in the market, it has become quite confusing for building designers. Are all the claims made by suppliers 100% truthful? Is it really possible to save the amount of energy claimed? In addition, due to the complexities of energy efficiency in buildings, it is easy to mislead the market by providing and/or withholding information. One simple example that is often heard in the industry is the 'oversell' of reducing solar heat gain in buildings. While it is true that the reduction of solar gain in a building plays a very important part in the building's energy efficiency, claims of a 50% reduction in solar gain in buildings (which can be easily done, read Chapters 5 and 6), is not the same as a 50% reduction in building energy consumption.

This guideline will attempt to correct the mis-information in the building industry by providing simple and clear advice on the energy efficiency impact of typical design options already practised by many architects and engineers in Malaysia. The design options provided in this guideline are not new to architects and engineers, but an attempt is made to provide a general guide on the real and quantifiable benefits of these design options. With the provision of quantifiable benefits, it is hoped that architects and engineers will be able to make building energy efficiency decisions quickly, if not instantly, on a majority of energy efficiency design issues.

In addition, this guideline will show that the combination of many good design practices in energy efficiency will yield much greater energy savings than by addressing only one or two energy efficiency features in a building.

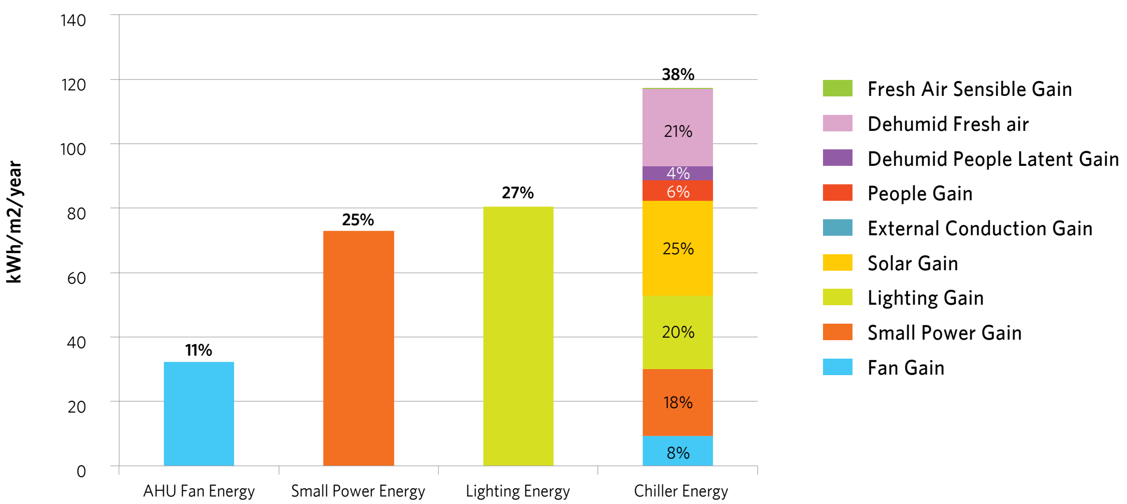
It is also very important to understand that if 50 energy efficient features are implemented in a building, even a 1% efficiency gain per feature will yield a total of 50% energy savings for the building. In addition, if more than 50 items are addressed, the inability to meet one item alone will not destroy the entire energy efficiency of a building. For example, it is not disastrous if the site does not allow for good orientation of the building because it is still possible to make improvements on many other energy efficiency features to compensate for this loss of efficiency. It is only disastrous when a majority of opportunities to improve the energy efficiency in the building are totally ignored.

This chapter also provides a quick introduction to the fundamental science related to energy efficiency in buildings. Understanding the fundamental physics is an important part of designing buildings that use building science to cool the building naturally before an active system is employed.

A HOLISTIC APPROACH

A study on the reformulation of the Malaysian Standard (MS) 1525, Overall Thermal Transfer Value (OTTV) in 2005 by Danida, produced a simple chart on the energy breakdown in typical buildings. This chart is important in this section because it provides a clear understanding of the typical energy distribution in typical office buildings in Malaysia. This chart then allows a clear strategy to be developed to address the energy efficiency priorities in buildings.

CHART 1.1 | TYPICAL ENERGY BREAKDOWN IN A BUILDING



A chiller system is used to remove heat from a building to maintain it at a certain temperature for occupant comfort. Heat in a building is generated from solar radiation, conduction, people, fresh air intake, electrical lights, electrical fans and electrical equipment. The amount of heat generated by each element may be marginally different between buildings but will not significant enough to change the conclusion of the study made in 2005.

The chiller energy breakdown in **Chart 1.1** shows the following heat elements that are removed by the air-conditioning system to provide comfortable conditions in the building:

1 Fan Gain
The 1st law of thermodynamics states that all electrical energy used by the motor to drive the fan would end up as heat within the building.

2 Small Power Gain
All electrical equipment that is plugged into a power point constitute small power energy use. The 1st law of thermodynamics states that all electrical energy used by electrical equipment will end up as heat in the air-conditioned space.

3 Lighting Gain
The 1st law of thermodynamics also states that all electrical energy used by the lighting system would end up as heat within the building.

4 Solar Radiation Gain
The heat gain due to solar radiation through the building windows is known as Solar Radiation Sensible Heat Gain.

5 Conduction Gain Due to Building Fabric
The difference in temperature between the outdoor space and the indoor space will cause conduction heat gain through the building fabric.

6 People Sensible Gain
The sensible heat gain from people is the heat emitted by people in air-conditioned spaces.

7 Dehumidification of People Latent Gain
The latent heat gain from people is the moisture emitted by people in air-conditioned spaces.

8 Dehumidification of Fresh Air Ventilation
The mechanical ventilation and infiltration (air leakage) of fresh air (outside air) into air-conditioned spaces brings along the moisture content of the fresh air.

9 Fresh Air Ventilation Sensible Gain
The infiltration of fresh air (outside air) into air-conditioned spaces brings along the heat content of the fresh air.

Depending on the cooling load, a typical chiller system may consist of a chiller, chilled water pump, condenser water pump and cooling tower or just a simple air-cooled compressor unit placed outdoors (as in a split unit air-conditioning system). The efficiency of the chiller system can vary significantly depending on the combination of equipment selected by the air-conditioning system designer based on the available budget and design concept.

Based on **Chart 1.1**, it can be summarised that energy efficiency in buildings should be prioritised according to these seven (7) fundamental steps:

1 Chiller System Efficiency

A high-efficiency chiller system will reduce the total energy use within a building significantly because less electrical energy is used to remove the same amount of heat from the building. The term 'chiller system' would typically consist of the chiller (also known as the compressor), chilled water and condenser water pumps and cooling tower fans. The entire chiller system including the chillers, pumps and fans should be optimised for energy efficiency. A technical guideline on optimising the chiller system efficiency will be produced as Part 2 of the BSEEP project.

2 Lighting Efficiency

Natural daylight harvesting is the most efficient method because it provides light with the least amount of heat. Other options for lighting efficiency include the use energy efficient lighting systems, proper zoning of lighting circuits, etc.

3 Reduce Small Power Load

Reduction of small power load in office buildings can be achieved by the selection of energy efficient computers, servers, and control systems. In addition, night time energy consumption of small power should also be closely monitored to ensure that energy is only used where needed. A very large part of the responsibility to ensure a low small power load in a building rests on the occupants of the building. Therefore, awareness of energy efficient small power equipment should be provided to existing and potential occupants of an energy efficient building.

4 Fan Efficiency

The fan described here is used by the air-conditioning system to deliver cool air to a space. The energy used by the fan is the combination of two factors – total efficiency and total pressure loss. The efficiency of the fan and motor is largely a selection choice, while the total pressure loss in a fan system is a factor of duct size, duct distance, cooling coil pressure losses and air filtration system pressure losses.

5 Control of Fresh Air Intake and Infiltration

Fresh air is required to be provided in buildings. However, too often, the amount of fresh air that is provided in Malaysian buildings far exceeds the recommended minimum fresh air requirements by the Malaysian Uniform Building By Law (UBBL) and ASHRAE 62.1 (2007). This is largely caused by uncontrolled fresh air intake by the mechanical system and the infiltration of air into the building. Since Malaysia has a hot and humid climate, the fresh air provided causes a high latent (moisture) load for the air-conditioning system. The mechanical fresh air intake system can be controlled using a CO_2 sensor, while building infiltration can be addressed using good construction practices for an air-tight building. More information can be found in Chapter 10.

6 Control of Solar Heat Gain

The control of solar heat gain is a combination of building orientation, exterior shading devices, glazing properties and interior shading devices. Chapters 3, 5 and 6 address these items.

7 Insulation of Building Fabric

The climate in Malaysia is rather moderate, therefore, insulation of the building fabric in this climate need not be excessively provided. The optimal roof and wall insulation is addressed in Chapters 7 and 8.

All seven (7) fundamental steps mentioned here need to be addressed in order to design a building that is energy efficient. The options available to address each of these fundamental steps is almost limitless. It is really up to the designers' creativity to address each fundamental step in ways that are most suited to the building aesthetics, site and budget requirements.

CREAM SKIMMING AVOIDANCE

Cream skimming is the practice of investing only in projects with relatively low initial costs and quick paybacks while avoiding those with higher investment cost. However, this may not always be the best option. Especially when it comes to energy efficiency in buildings, there are many options that will require a higher initial investment but will also offer a good return on investment in the long run. More importantly, energy costs are only going to increase in Malaysia as the subsidy on energy in this country is slowly being removed. If energy efficiency is practiced by selecting only the cheap options today, one could potentially stand to lose a lot more in the long run due to the higher future energy costs.

Finally, there is also a high probability that as the energy costs becomes higher in Malaysia, building purchasers will become more energy conscious and will be willing to pay more for an energy efficient building, providing a substantially higher profit margin for the developer.

It is recommended to avoid cream skimming on the practice of energy efficiency in buildings as the financial payoff from the implementation of energy efficiency is usually substantially higher than the interest provided by financial institutions.

1ST LAW OF THERMODYNAMICS

A basic understanding of the 1st Law of Thermodynamics is essential to understand energy flow in buildings

Energy exists in many forms, such as heat, light, chemical, kinetic (mechanical) and electrical energy. The 1st law of thermodynamics states the law of conservation of energy. **Energy can be changed from one form into another, but it cannot be created or destroyed.**

However, it is known that there exists many skeptics (trained engineers included) that would disagree with this law. Skeptics would often make claims of a perpetual machine with the ability to produce more energy than consumed. Unfortunately, according to the 1st law of thermodynamics, this type of machine cannot be made to work, although there are still many believers that it is possible to bend the 1st law of thermodynamics.

The full statement of the 1st law of thermodynamics was first made in the 1850s and until today, it has **NEVER EVER** been proven wrong. Moreover it has been proven again and again that this law is not only applicable to building science, but it is applicable for the entire universe; from a molecular level to the stars, planets and galaxies. Until today, there has been no equipment or event that has managed to disprove the 1st law of thermodynamics.

The full statement of the 1st law of thermodynamics was first made in the 1850s and until today, it has NEVER EVER been proven wrong

As building designers, you have to place your absolute confidence in this law until someone, somewhere, manages to prove otherwise. More importantly, if ever someone managed to prove this law wrong, it would be such a big event in this world that it cannot be ignored by anyone. Everyone would know about it because it would then be possible to invent a perpetual energy machine and you do not have to be concerned about energy efficiency anymore! So until this can become a reality (if ever), building designers are required to work within the limits of the 1st law of thermodynamics.

The key reason why the 1st law of thermodynamics is mentioned in this chapter is to dispel a few building industry myths that hinder the understanding energy flow in buildings. These are some of the common myths in the industry:

1

Only a fraction of the electrical lighting energy used ends up as heat in the building

MYTH – A 100 watt light bulb only produces 50 watts of heat in the building

TRUTH – A 100 watt light bulb produces 100 watts of heat in the building

Depending on the efficiency of the light bulb, a part of the electrical energy is converted into light energy, while the rest of it is immediately converted into heat energy. The light energy is then absorbed and reflected by its surroundings (depending on its colour) until it is fully absorbed by the building furniture and materials. The absorbed light energy is then converted into heat energy in these building materials. That is why a dark coloured material is always warmer than a light coloured material when it is exposed to light energy. Basically dark coloured materials absorb more light energy than light colours. This heat is then removed by the air-conditioning system.

The only situation where this myth may have some truth is when the light is directed out of the building. In this situation, part of the light energy produced by the lamp ends up outside the building and would not contribute 100% of the electricity used as heat within the building.

2

Only a fraction of the fan motor energy used ends up as heat in the building

MYTH – A 100 watt fan motor with 70% efficiency only produces 30 watts of heat in the building

TRUTH – A 100 watt fan motor of any efficiency produces 100 watts of heat in the building

It is true that with a fan motor efficiency of 70%, 30% of heat is immediately produced by the frictional losses in the motor and fan rotation while only 70% of the electrical energy used is converted into kinetic energy to move the air. The question is, what happens next to this kinetic energy? The 1st law of thermodynamics states that energy cannot be destroyed, so where would this energy end up? It will end up as heat. Frictional loses will convert all the kinetic energy in the air into heat. Frictional losses in the ducts, air filters, cooling coils and as the air flows across the office furniture and building occupants, all the kinetic energy in the air will eventually be converted into heat in the building.

Again, it is possible for this myth to have some truth. It is when the fan blows air directly out of the building. In this situation, the electrical energy used by the fan motor ends up outside the building and would not contribute to heat within the building.

3

All the electrical energy used by a pump ends up as heat in the pump room

MYTH – A 100 watt pump motor with 60% efficiency produces 100 watts of heat in the pump room

TRUTH – 40 watts will end up as heat in the pump room

The other 60 watts will heat up the water in the pipes and be stored as potential energy if the water is pumped up to height. A pump motor with a 60% efficiency means that it can convert 60% of the electrical energy into the kinetic energy to move the water. Again, the 1st law of thermodynamics states that energy cannot be destroyed, so where would the kinetic energy end up? Part of it may end up as potential energy if it lifts the water up to a higher point, and the rest will end up as heat in the water. Frictional losses in the pipes will convert all the kinetic energy in the water into heat. Therefore, the water will heat up due to the energy transferred from the pump into the water.

In summary, **energy changes form but it cannot be destroyed**. By having a clear understanding of energy flow, one can start to appreciate how energy changes within the building and how improvements made in one area has a cascading effect on the entire building. **Simply put, almost all electrical energy used within the building ends up as heat which the air-conditioning system has to remove in order to keep the building conditions comfortable for the occupants.**

FUNDAMENTALS OF AIR PROPERTIES

The properties of the air are defined with a minimum of two known parameters, such as:

- **Dry Bulb Temperature and Wet Bulb Temperature**
- **Dry Bulb Temperature and Relative Humidity**
- **Dry Bulb Temperature and Moisture Content**

Having any two known properties as defined above, it is possible to find out all other properties of the air. For example, if we know the Dry Bulb Temperature and Relative Humidity, using a psychrometric diagram or Mollier chart, we can find out the Wet Bulb Temperature, Moisture Content in the air and the Dew Point Temperature of the air.

1 Dry Bulb Temperature (°C)

The Dry Bulb Temperature is typically referred to as the air temperature. It is called "Dry Bulb" because the air temperature is as indicated by a thermometer exposed to air flow but shaded from the sun and radiation, as opposed to the "Wet Bulb" temperature where the thermometer is wrapped in permanently wet muslin.

2 Wet Bulb Temperature (°C)

The Wet Bulb Temperature is the temperature of adiabatic saturation. This is the temperature indicated by a moistened thermometer bulb exposed to the air flow. The evaporation of water from the thermometer and the cooling effect is indicated by the "Wet Bulb Temperature". The Wet Bulb Temperature is always lower than the Dry Bulb Temperature but will be identical at 100% Relative Humidity. The Wet Bulb Temperature is an indication of the lowest Dry Bulb Temperature that can be achieved when the air is 100% saturated (e.g. the use of an evaporative cooler).

3 Dew Point Temperature (°C)

The Dew Point is the temperature at which water vapour starts to condense out of the air (the temperature at which air becomes completely saturated). Above this temperature, the moisture will stay in the air and will not condensate. If condensation is found on the surface of any object, it means that the surface temperature of the object is below the Dew Point Temperature of the air.

A good example of natural condensation of water in our climate is on vehicles parked outdoors throughout the night. The colder night sky cools the vehicles' surfaces (via radiation) to below the Dew Point Temperature of the air, allowing condensate to form on the surface of the vehicles in the early morning hours.

4 Moisture Content In Air (kg/kg)

There is always water vapour in the air. A useful way to define the amount of water in the air is by using the "Moisture Content" measured as in kg (or grams) of water in 1 kg of air. In the Malaysian climate, the outdoor air moisture content is fairly consistent, day or night and throughout the year, ranging from 18 to 20 grams of water in 1 kg of air. Unfortunately, human beings are not sensitive enough to "feel" the moisture content in the air, but we are able to feel the "Relative Humidity" in the air. Moisture Content in the air also commonly known as "Humidity Ratio".

5 Relative Humidity (%)

Relative Humidity is a measure of the amount of water (moisture) in the air compared to the maximum amount of water the air can absorb, expressed as a percentage. When the air cannot absorb any more moisture (is fully saturated), its Relative Humidity is 100 percent. The higher the air temperature, the more moisture it can absorb, which is why a laundry dryer uses high temperatures to extract water out from wet laundry. This also means that the Relative Humidity is a factor of the Dry Bulb Air Temperature and Moisture Content. A Relative Humidity of 50% in an air-conditioned room at 23°C will have a Moisture Content of approximately 11g/kg, while the same 50% Relative Humidity outdoors at an air temperature of 35°C will have a Moisture Content of approximately 20g/kg.

6 Effective Sky Temperature (°C)

The Effective Sky Temperature is the temperature of the sky as seen by objects on the ground, accounting for all the gas molecules and suspended particles in the atmosphere that emit and absorb radiation. In fact, outer space is a "perfect black body" at 0° Kelvin (-273.15°C). On a cloudless night, the Effective Sky Temperature is lower than the ambient temperature, but it will not be 0°K due to the atmosphere.

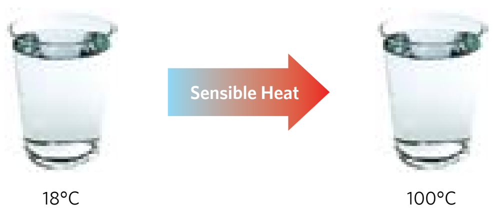
FUNDAMENTALS OF HEAT

Heat is actually a form of energy. With the right mechanism, heat can be converted into other forms of energy such as kinetic or electrical energy. Heat is also a form of energy that can easily be stored in building materials with a high thermal capacity such as water, bricks and stones.

There are two distinct types of heat: **Sensible Heat** and **Latent Heat**.

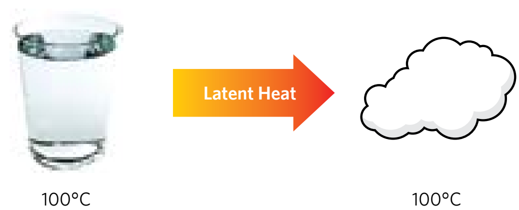
SENSIBLE HEAT

Sensible Heat is heat energy that causes a change in temperature in an object. In building science, any object that causes a temperature increase is called Sensible Heat. These objects include computers, printers, lighting, solar radiation through windows, etc.



LATENT HEAT

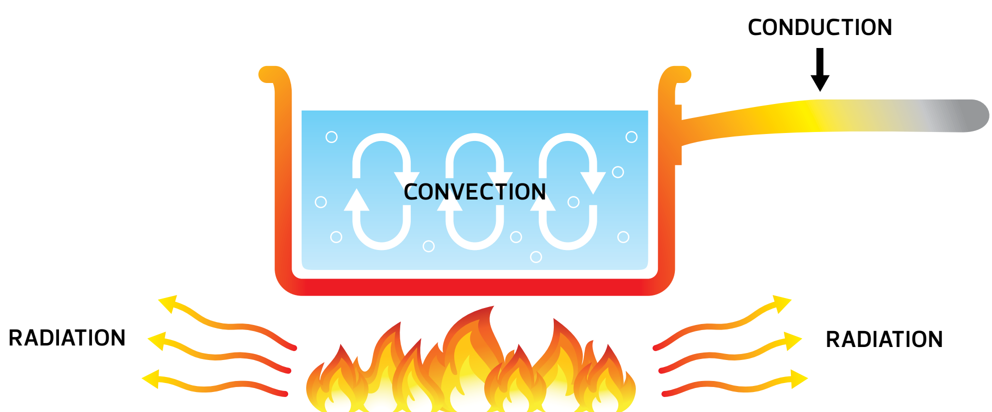
Latent Heat is heat energy that causes the change of phase of a substance from one state to another without affecting the temperature. For example, water remains at 100°C while boiling. The heat added to keep the water boiling is Latent Heat. The quantity of heat that is added to the water in order for it to evaporate cannot be displayed by an ordinary thermometer. This is because both the water and steam remain at the same temperature during this phase change.



In tropical climate building science, Latent Heat represents moisture in the air that needs to be dehumidified by an air-conditioning system. Typical air-conditioning systems remove moisture from the air by providing surfaces on a cooling coil that is below the Dew Point Temperature of the air. As water condensates on this cooling coil, heat is removed from the moisture in the air and transferred into the cooling coil.

FUNDAMENTALS OF HEAT TRANSFER

DIAGRAM 1.1



Heat transfer is classified into four mechanisms:

1. **Conduction**
2. **Convection**
3. **Radiation**
4. **Phase change (evaporation/condensation)**

> Heat transfer is always from a hotter (higher) temperature object to the colder (lower) temperature object

❶ Conduction (Sensible Heat)

Conduction is the transfer of heat when adjacent atoms vibrate against one another and those with greater molecular kinetic energy pass their thermal energy to regions with less molecular energy through direct molecular contact. The better the conductor, the more rapidly heat will transfer.

In building science, conduction heat transfer is represented by the U-value of building materials. A high U-value indicates high conduction ability. A low U-value indicates low conduction ability. The inverse of the U-value is the R-value (Resistivity Value), where a higher R-value indicates a low conduction ability (or high resistance). Both the U-value and R-value are computed from the K-value (conductivity value) and the thickness of the building material. The K-value is a measure of the heat transfer rate per meter thickness of a building material.

❷ Convection (Sensible Heat)

Convection is heat transfer from one place to another by the movement of air or water. The heated water rises and is replaced by the colder water, hence it will move away from the source of heat. In building science, the convection heat transfer is normally assumed as a constant number that is directly proportional to the air speed. A higher air speed will cause higher convection heat to be transferred.

❸ Radiation (Sensible Heat)

Radiation is often the least understood heat transfer mechanism. Radiation is heat transfer by emission of electromagnetic waves through space. As long as two objects of different temperatures can “see” each other, radiation heat transfer will occur, regardless if it is an air space or vacuum space between these two objects.

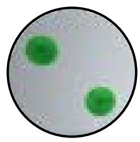
In building science, radiation is an important component of heat transfer because any object (wall, window, roof, computer screen, oven, etc.) that is hot will radiate heat to a cooler object such as a building occupant, causing thermal discomfort.

The efficiency of radiation heat transfer is determined by a material property called emissivity. Most objects have an emissivity close to 1.0 meaning that close to 100% of the heat of the object is radiated to cooler objects surrounding it. There exists low-emissivity materials such as aluminium foil that have an emissivity of 0.05 or lower. Although these low-emissivity materials may be hot, only 5% or less of the heat is radiated to cooler objects surrounding it.

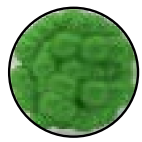
❹ Condensation/Evaporation (Latent Heat)

Condensation is the change from a vapour to a condensed state (solid or liquid), while Evaporation is the change of a liquid into a gas.

When a gas is sufficiently cooled or the pressure on the gas increases, the forces of attraction between molecules prevent them from moving apart, and the gas condenses to either a liquid or a solid. An example of condensation is when water vapour condenses and forms liquid water on the outside of a cold glass.

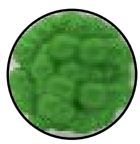


MICROSCOPIC VIEW OF A GAS

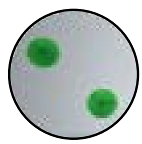


MICROSCOPIC VIEW AFTER CONDENSATION

When a liquid is sufficiently heated or the pressure on the liquid is decreased sufficiently, the forces of attraction between the molecules are weakened and the liquid would evaporate into a gas. An example is the condensate water on the outside of a cold glass evaporating when the glass warms.



MICROSCOPIC VIEW OF A LIQUID



MICROSCOPIC VIEW AFTER EVAPORATION

In building science, evaporative cooling is often used in this climate as a method of lowering the air temperature by humidifying the air. As water evaporates, it absorbs heat from the air, cooling the air.

FUNDAMENTALS OF THERMAL COMFORT

There have been many studies linking thermal comfort to productivity in offices.[1] More importantly, compared to the cost of salary for building occupants, the energy cost in a building is almost insignificant; making it almost impossible to justify energy efficiency in a building that reduces building occupant productivity.[2] Therefore, thermal comfort in a building has a higher priority than energy efficiency in building. Fortunately, when energy efficiency is implemented well in a building, the thermal comfort would be improved as well.

Within building science, thermal comfort is defined as a heat transfer balance between a person with his/her surroundings. In many literatures, thermal comfort is also defined as a condition of mind which expresses thermal satisfaction within the environment. Because there are large variations, both physiologically and psychologically, from person to person, it is not possible to satisfy everyone in a space with the same conditions. Many thermal comfort models recommend satisfying a minimum of 80% to 90% of the occupants as the minimum criteria for thermal comfort.

Although there are many thermal comfort models available in the market today; it is recommended to gain a basic understanding of the three (3) thermal comfort models that are described in this chapter as a foundation.

These three (3) basic thermal comfort models are:

1. **Operative Temperature**
2. **Fanger's PMV-PPD Thermal Comfort Model (for Conditioned spaces)**
3. **Adaptive Thermal Comfort Model (for Natural and Hybrid Ventilation spaces)**

The above 3 thermal comfort models are internationally recognised by both ASHRAE and ISO standards.

[1] D.P. Wyon, Indoor environmental effects on productivity. IAQ 96 Paths to better building environments/Keynote address, Y. Kevin. Atlanta, ASHRAE, 1996, pp. 5-15.
[2] R.Kosonen, F.Tan, Assessment of productivity loss in air-conditioned buildings using PMV index. Halton OY, CapitaLand Commercial Limited, 2004.

Within building science, thermal comfort is defined as a heat transfer balance between a person with his/her surroundings

1 OPERATIVE TEMPERATURE

The Operative Temperature is perhaps the simplest and most useful indicator of thermal comfort in buildings.

Operative Temperature describes the average of Air Temperature and Mean Radiant Temperature. While Air Temperature is simply the temperature of the air, the Mean Radiant Temperature is more complicated; it is the average surface temperature of the surrounding walls, windows, roof and floor. Hot equipment like ovens and halogen lights also add to the Mean Radiant Temperature of a space. In addition, the view factor (percentage of exposure) of each surface also contribute to the final Mean Radiant Temperature of a space.

In a typical conditioned space in Malaysia where the relative humidity ranges from 50% to 65%, the Operative Temperature is recommended to be maintained below 25°C to provide comfortable thermal conditions. This means that if the Air Temperature is set to 23°C, the maximum allowable Mean Radiant Temperature is 27°C in order to obtain an Operative Temperature of 25°C.

This also means that if a room's Mean Radiant Temperature is more than 28°C, the Air Temperature of the room needs to be lower than 22°C to provide comfort to the building occupants. **Table 1.1** on the next page shows the various Air Temperatures in combination with the Mean Radiant Temperatures to provide the same comfort condition.

In the Malaysian climate, it is possible to provide adequate insulation to external walls, windows or roofs to reduce the Mean Radiant Temperature in the building to match the Air Temperature of the space. However, it is not possible to reduce it below the Air Temperature using insulation alone. Active cooling technologies are required to reduce the Mean Radiant Temperature below the Air Temperature. Active surface cooling technologies are also known as Radiant Cooling Systems, including technologies such as chilled floor slabs, chilled beams, chilled ceilings, etc.

The Operative Temperature is a better indicator of thermal comfort than Air Temperature alone because both the Air Temperature and the Mean Radiant Temperature have an equal influence on the thermal comfort of a person.

TABLE 1.1 | AIR TEMPERATURE, MEAN RADIANT TEMPERATURE AND OPERATIVE TEMPERATURE

Air Temperature (°C)	Mean Radiant Temperature (°C)	Operative Temperature (°C)
22	28	25
23	27	25
24	26	25
25	25	25
26	24	25
27	23	25
28	22	25

2 FANGER'S PMV-PPD THERMAL COMFORT MODEL

The Fanger's PMV-PPD thermal comfort model states that thermal comfort is a balance of heat transfer between a person with his/her surroundings. This model has identified six (6) primary factors that must be addressed when defining conditions for thermal comfort.

The six primary factors are:

1. **Metabolic Rate**
2. **Clothing Insulation**
3. **Air Temperature**
4. **Mean Radiant Temperature**
5. **Air Speed**
6. **Relative Humidity**

All six of these factors may vary with time. However, this standard only addresses thermal comfort in a steady state. As a result, people entering a space that meet the requirements of this standard may not immediately find the conditions comfortable if they have experienced different environmental conditions just prior to entering the space. The effect of prior exposure or activity may affect comfort perceptions for approximately one hour.

Fanger's PMV-PPD comfort model provides a set of equations to compute two (2) factors:

1. **Predicted Mean Vote (PMV)**
2. **Predicted Percentage Dissatisfied (PPD)**

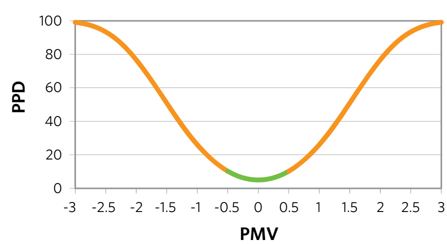
1 Predicted Mean Vote (PMV)

The PMV index predicts the mean response of a larger group of people according to the ASHRAE thermal sensation scale of -3 to +3 where 0 is neutral.

-3	-2	-1	0	+1	+2	+3
cold	cool	slightly cool	neutral	slightly warm	warm	hot

2 Predicted Percentage Dissatisfied (PPD)

The PPD predicts the percentage of people that will be thermally dissatisfied. The PPD curve is based on the PMV as provided below.



The ISO 7730 on thermal comfort recommends that the PPD should not be higher than 10%, while ASHRAE 55 recommends that the PPD should not be higher than 20%. There are many free softwares available on the internet to calculate the PMV and PPD.

❸ ADAPTIVE THERMAL COMFORT MODEL

While the Fanger's PMV-PPD is well accepted for conditioned spaces, many published papers suggest other thermal comfort models should be used for naturally ventilated spaces.[3,4] The adaptive thermal comfort model in ASHRAE 55 was provided to address this.

The adaptive model states that people in general are naturally adaptable. They will make various adjustments to themselves and their surroundings to reduce discomfort and physiological stress. Typical actions taken in a warm climate like Malaysia includes alteration of clothing (no jacket), diet (consuming cold drinks), ventilation (opening/closing windows) and air movement (switching on the fan). It was presented that due to these adaptive actions taken, people would be able adapt to a comfort condition that is close to the average air temperature.

The thermal adaptive model suggests the following equation to predict the thermal comfort requirement:

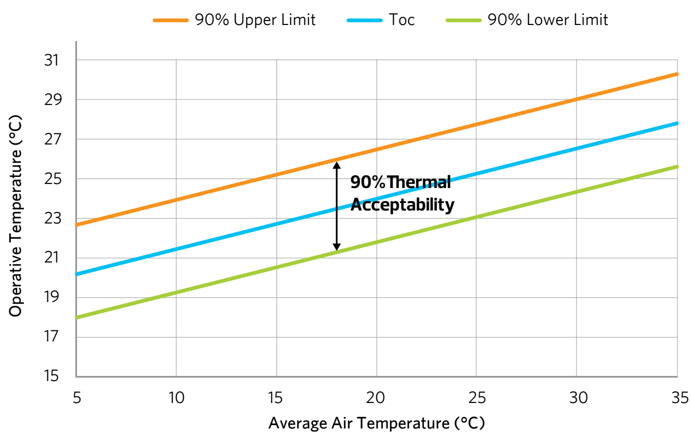
$$T_{oc} = 18.9 + 0.255\, T_{out}$$

Where:
T_{oc} is the operative comfort temperature (°C)
T_{out} is the outdoor average day and night temperature (°C)

The boundary temperatures for a 90% thermal acceptability are approximately T_{oc} +2.5°C and T_{out} -2.2°C.

For the Malaysian climate where the annual average temperature is 26.9°C (refer to Chapter 2), T_{oc} = 25.75°C.
At 90% thermal acceptability, the upper limit of T_{oc} = 25.75°C + 2.5°C = 28.25°C.

CHART 1.2 | ADAPTIVE THERMAL COMFORT



This comfort model is recommended for natural and hybrid ventilated spaces and states that for the Malaysian climate, it is recommended to maintain the Operative Temperature below 28.25°C for a 90% acceptance.

[3] Deuble, M.P. and de Dear, R.J. (2012) Mixed-mode buildings: A double standard in occupants' comfort expectations', Building and Environment, Volume 54, Issue 8, Pages 53-60
[4] Denis J. Bourgeois, 2005, Detailed occupancy prediction, occupancy-sensing control and advanced behavioural modelling within whole-building energy simulation, Chapter 6, Thermal adaptation: applying the theory to hybrid environments

SUMMARY

In a conditioned space, it is recommended to use Fanger's PMV-PPD thermal comfort model to predict the comfort condition. Alternatively, the design operative temperature of not more than 25°C is suggested as the simplest design indicator of thermal comfort in conditioned spaces in this climate zone. However, for a naturally ventilated space, the Adaptive Thermal Comfort model is recommended to be used instead of Fanger's PMV-PPD model. In this climate zone the Adaptive Thermal Comfort model states that we should maintain operative temperature below 28°C for a 90% acceptance of the comfort level provided.

END OF CHAPTER 1

CHAPTER

2

MALAYSIA'S WEATHER DATA

by CK Tang & Nic Chin

2 MALAYSIA'S WEATHER DATA

INTRODUCTION

A clear understanding of Malaysia's weather data enables designers to design buildings that benefit from the climate conditions

The daily climate in Malaysia is fairly consistent throughout the entire year; therefore it is useful to have an overview of an average day's patterns and the maximum and minimum hourly weather values for a full year. This chapter provides information on dry bulb temperature, wet bulb temperature, relative humidity, humidity ratio (moisture content), dew point temperature, global radiation, direct radiation, diffuse radiation, cloud cover, wind speed & direction, effective sky temperature and ground temperature. Charts are provided to make it easier to understand the data and a table of raw cross tabulation data made using the pivot table function in Excel is also provided for users who wish to make use of this data for more in-depth analysis on their own.

SOURCE OF WEATHER DATA

The hourly weather data of Kuala Lumpur used in this chapter was based on a Test Reference Year (TRY)[1] weather data developed in University Teknologi Malaysia (UiTM) under the DANCED (Danish International Assistant) project for Energy Simulations for Buildings in Malaysia. The TRY is based on 21 years (1975 to 1995) of weather data from the Malaysian Meteorological Station in Subang, Klang Valley, Selangor. The hourly weather data that was obtained from this station is as shown in **Table 2.1** below.

TABLE 2.1 | WEATHER DATA COLLECTED IN SUBANG

Subang Meteorological Station
(Klang Valley, Selangor, Malaysia)
Longitude: 101deg 33'
Latitude: 3deg 7'

Parameters (hourly[2])	Units
Cloud Cover	[oktas]
Dry Bulb Temperature	[°C]
Wet Bulb Temperature	[°C]
Relative Humidity	[%]
Global Solar Radiation	[100*MJ/m^2]
Sunshine Hours	[hours]
Wind Direction	[deg.]
Wind Speed	[m/s]

A Test Reference Year (TRY) consists of weather data for a given location. In order for the TRY to be representative of the climate, it was constructed on the basis of at least 10 years of weather data. The TRY is made up from actual monthly data (not average values) that are picked after having been subjected to different types of analysis.

It should be noted that a typical energy simulation program requires two extra data values that were not collected by the Malaysian Meteorological Service, namely the direct and diffuse radiation. The missing radiation data was calculated for the TRY via Erbs' Estimation Model from the horizontal global solar radiation.

Although not perfect, the TRY is currently the only known set of weather data for energy simulation that was compiled based on statistical analysis and it has been used in many energy simulations of various buildings in Malaysia with satisfactory results. This weather data was also used for the development of the constants in the Overall Thermal Transmission Value (OTTV) equation found in the Malaysia Standard (MS) 1525 (2007), Energy Efficiency in Non-Residential Buildings.

[1] Reimann, G. (2000) Energy Simulations for Buildings in Malaysia, Test Reference Year, 18-25.
[2] The values are integrated over a period of one hour, but the exact time interval has not been specified.

LOCATION AND SUN-PATH

The global position and solar noon of six (6) cities in Malaysia is provided in **Table 2.2** below.

TABLE 2.2 | GLOBAL POSITIONING AND SOLAR NOON OF 6 CITIES IN MALAYSIA

Locations	Latitude (°N)	Longitude (°E)	Solar Noon
1. Kuala Lumpur (Subang)	3.12	101.55	13:11
2. Penang	5.30	100.27	13:16
3. Johor Bharu	1.48	103.73	13:02
4. Kota Bharu	6.17	102.28	13:08
5. Kuching	1.48	110.33	12:36
6. Kota Kinabalu	5.93	116.05	12:13

The sun-path diagram for the 6 locations above is presented in this section and shows that the sun position is almost the same for all six (6) locations, except for the time of the Solar Noon. The Solar Noon (when the sun is at its highest point) is 13:11 in Kuala Lumpur, while in Kota Kinabalu it is about an hour earlier at 12:13.

The sun-path is generally from east-west with the sun approximately 25° to the north during summer solstice and 25° to the south during winter solstice for all locations in Malaysia.

The sun-path diagram is a useful tool to help in the design of external shading devices. The sun-path diagram is used to estimate the sun's angle at various times of the day and year, allowing architects and engineers to design shading devices to block or allow direct sunlight into the building at any time of the day.

CHART 2.1.1 | LARGE SUN-PATH OF KUALA LUMPUR

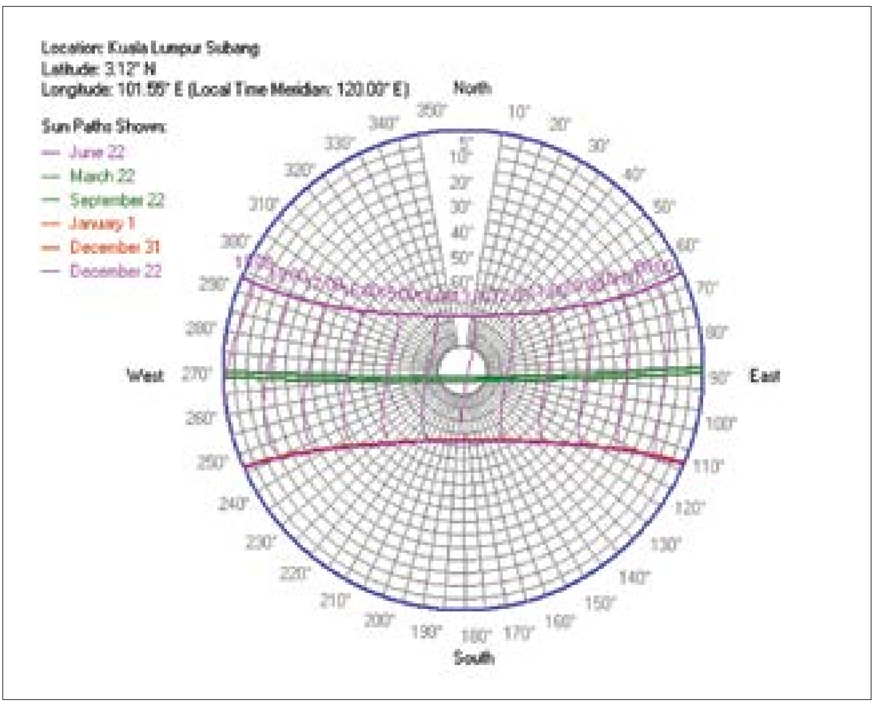


CHART 2.1.2 | SUN-PATH OF KUALA LUMPUR

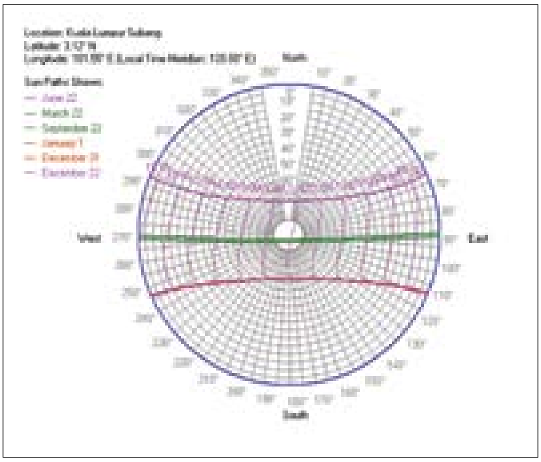


CHART 2.1.3 | SUN-PATH OF PENANG

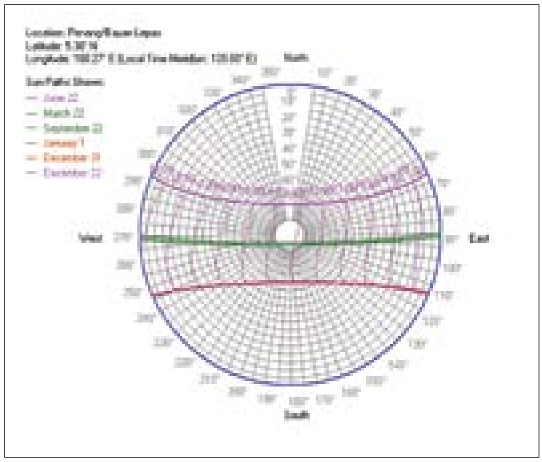


CHART 2.1.4 | SUN-PATH OF JOHOR BHARU

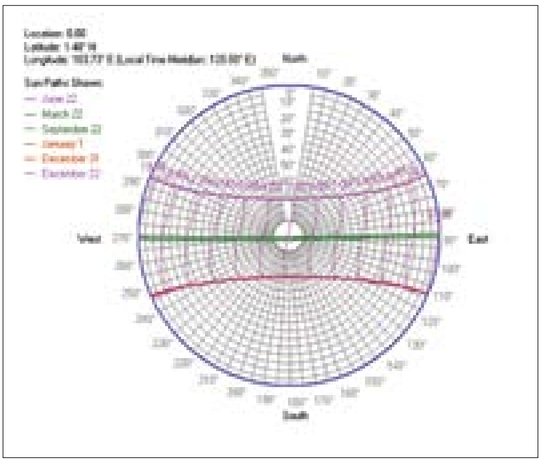


CHART 2.1.5 | SUN-PATH OF KOTA BHARU

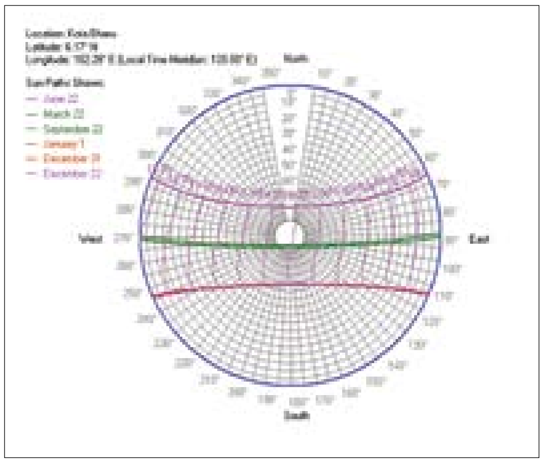


CHART 2.1.6 | SUN-PATH OF KUCHING

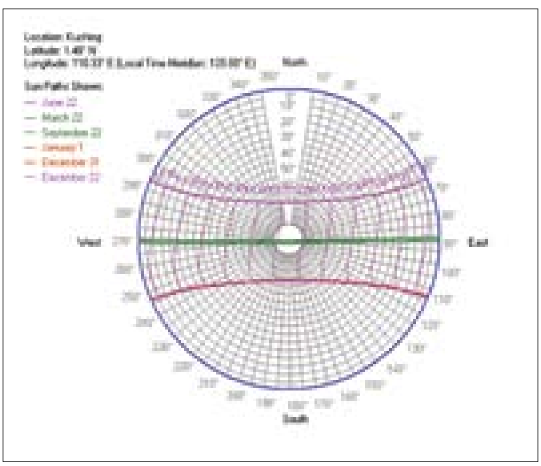
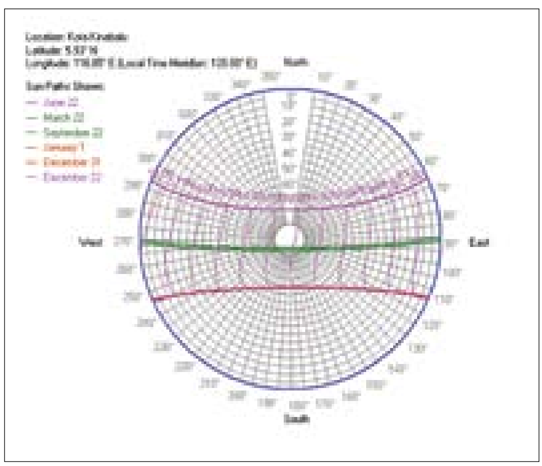


CHART 2.1.7 | SUN-PATH OF KOTA KINABALU



DRY BULB TEMPERATURE

The daily average, maximum and minimum dry bulb temperature is shown in the chart in this section. The standard deviation is more than 2°C from 2pm to 6pm indicating that the afternoon hours have a higher change of temperature from day to day; while in the hours of midnight to 7am, the standard deviation of the dry bulb temperature is less than 1°C, indicating a fairly consistent and predictable dry bulb temperature from midnight to the early morning hours.

The average dry bulb temperature of the whole year (including day and night) is 26.9°C.

The average peak dry bulb temperature is just below 32°C between 1pm to 2pm, while the maximum dry bulb temperature of the TRY is 35.6°C at 3pm.

The average low dry bulb temperature is 23.7°C at 6am in the morning; while the lowest dry bulb temperature of the TRY is 20.6°C at 7am in the morning.

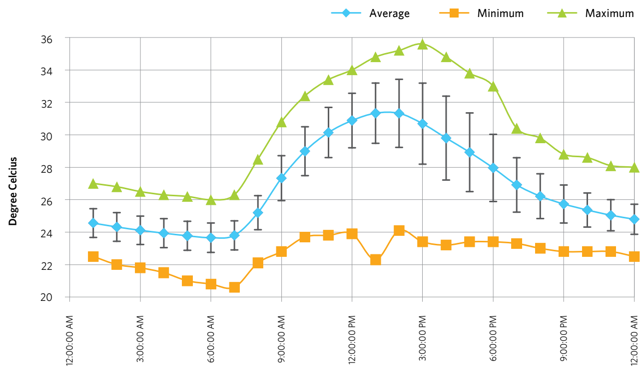
DESIGN POTENTIAL

The understanding of the dry bulb temperature allows a clear appreciation of when natural ventilation will work and when it is not likely to work. In addition, data centre designers can also make use of this knowledge to provide natural ventilation to the computer servers whenever possible to save a significant amount of air-conditioning energy.

DESIGN RISK

The TRY is 21 years of weather data in Subang Airport from year 1975 to 1995. During these years, the Subang Airport location was fairly well surrounded by greenery. The peak dry bulb temperature in cities is expected to be higher due to the urban heat island effect.

CHART 2.2 | DRY BULB TEMPERATURE



RAW DATA | DRY BULB TEMPERATURE

Hours	Average	Minimum	Maximum	Std Dev.
1:00:00 AM	24.6	22.5	27.0	0.9
2:00:00 AM	24.3	22.0	26.8	0.9
3:00:00 AM	24.1	21.8	26.5	0.9
4:00:00 AM	23.9	21.5	26.3	0.9
5:00:00 AM	23.8	21.0	26.2	0.9
6:00:00 AM	23.7	20.8	26.0	0.9
7:00:00 AM	23.8	20.6	26.3	0.9
8:00:00 AM	25.2	22.1	28.5	1.1
9:00:00 AM	27.3	22.8	30.8	1.4
10:00:00 AM	29.0	23.7	32.4	1.5
11:00:00 AM	30.1	23.8	33.4	1.5
12:00:00 PM	30.9	23.9	34.0	1.7
1:00:00 PM	31.3	22.3	34.8	1.9
2:00:00 PM	31.3	24.1	35.2	2.1
3:00:00 PM	30.7	23.4	35.6	2.5
4:00:00 PM	29.8	23.2	34.8	2.6
5:00:00 PM	28.9	23.4	33.8	2.4
6:00:00 PM	28.0	23.4	33.0	2.1
7:00:00 PM	26.9	23.3	30.4	1.7
8:00:00 PM	26.2	23.0	29.8	1.4
9:00:00 PM	25.7	22.8	28.8	1.2
10:00:00 PM	25.4	22.8	28.6	1.1
11:00:00 PM	25.0	22.8	28.1	1.0
12:00:00 AM	24.8	22.5	28.0	0.9

WET BULB TEMPERATURE

The wet bulb temperature is fairly consistent between day and night and throughout the year. The average peak of the wet bulb temperature is 25.4°C at 2pm, while the maximum wet bulb temperature in the TRY is 28.4°C at 2pm.

The average low of the wet bulb temperature is 23.1°C at 6am, and the lowest wet bulb temperature in the TRY is 19.9°C at 7am in the morning.

DESIGN POTENTIAL

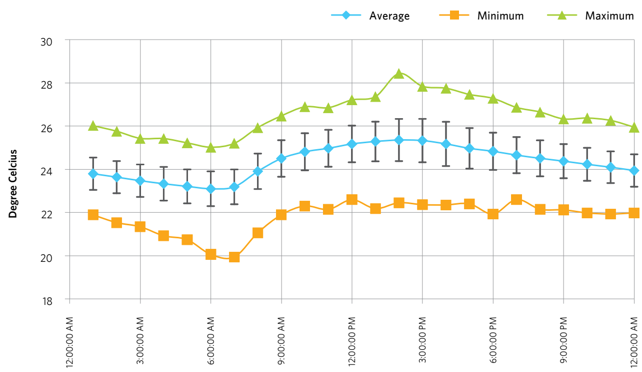
The wet bulb temperature is a good indicator of the potential of a direct evaporative cooling strategy. If the direct evaporative cooling system is 100% efficient, the lowest air temperature that can be achieved by the evaporative cooling system is the wet bulb temperature. The efficiency of direct evaporative cooling devices depends on the system water droplet size, wetted surface area and air speed, and an efficiency of up to 90%[3]. During the daytime, the dry bulb temperature is significantly higher than the wet bulb temperature; therefore, evaporative cooling will work well. However, during the night time, the dry bulb temperature is very close to the wet bulb temperature, therefore the effectiveness of evaporative cooling is reduced significantly, i.e. the reduction of air temperature is very small with the use of evaporative cooling, even at 90% efficiency.

The wet bulb temperature is also a very important factor for sizing and predicting the performance of a cooling tower. The lower the wet bulb temperature, the better the performance of the cooling tower. ASHRAE recommends designing an approach temperature of the cooling tower to be 5.5°C higher than the wet bulb temperature. The lower the condenser water temperature as it exits from the cooling tower, the more efficient it is for the performance of the chiller. Based on the TRY data, it will be best to run the chiller early in the morning, when the wet bulb temperature is the lowest, to gain the maximum efficiency from the chiller. Unfortunately, most buildings are only occupied from 8am onwards and the use of thermal storage solutions will normally introduce further inefficiencies that may negate any efficiency gained by running the chiller system in the early morning hours.

DESIGN RISK

The wet bulb temperature is not much affected by the urban heat island effect. Therefore, the wet bulb temperature provided by the TRY is reliable to be used.

CHART 2.3 | WET BULB TEMPERATURE



RAW DATA | WET BULB TEMPERATURE

Hours	Average	Minimum	Maximum	Std Dev.
1:00:00 AM	23.8	21.9	26.0	0.7
2:00:00 AM	23.6	21.5	25.8	0.7
3:00:00 AM	23.5	21.3	25.4	0.8
4:00:00 AM	23.3	20.9	25.4	0.8
5:00:00 AM	23.2	20.7	25.2	0.8
6:00:00 AM	23.1	20.1	25.0	0.8
7:00:00 AM	23.2	19.9	25.2	0.8
8:00:00 AM	23.9	21.1	25.9	0.8
9:00:00 AM	24.5	21.9	26.5	0.8
10:00:00 AM	24.8	22.3	26.9	0.9
11:00:00 AM	25.0	22.1	26.9	0.9
12:00:00 PM	25.2	22.6	27.2	0.8
1:00:00 PM	25.3	22.2	27.4	0.9
2:00:00 PM	25.4	22.5	28.4	1.0
3:00:00 PM	25.3	22.4	27.8	1.0
4:00:00 PM	25.2	22.4	27.8	1.0
5:00:00 PM	25.0	22.4	27.5	0.9
6:00:00 PM	24.8	21.9	27.3	0.9
7:00:00 PM	24.7	22.6	26.9	0.8
8:00:00 PM	24.5	22.2	26.7	0.8
9:00:00 PM	24.4	22.1	26.3	0.8
10:00:00 PM	24.2	22.0	26.4	0.8
11:00:00 PM	24.1	21.9	26.3	0.7
12:00:00 AM	23.9	22.0	26.0	0.8

[3] http://www.wescorhvac.com/Evaporative%20cooling%20white%20paper.htm

HUMIDITY RATIO (MOISTURE CONTENT)

The humidity ratio or moisture content of the TRY weather data is fairly consistent throughout the year. The average moisture content in the TRY is 18.3g/kg and is consistent day or night. Day to day fluctuation is highest at 2pm in the afternoon with a peak standard deviation of 1.6g/kg.

DESIGN POTENTIAL

The humidity ratio gives us information about how much water is in one kilogram of air; therefore, it gives a potential water quantity that can be "squeezed" out from the air. The following known methodologies for "squeezing" water out from the air are:

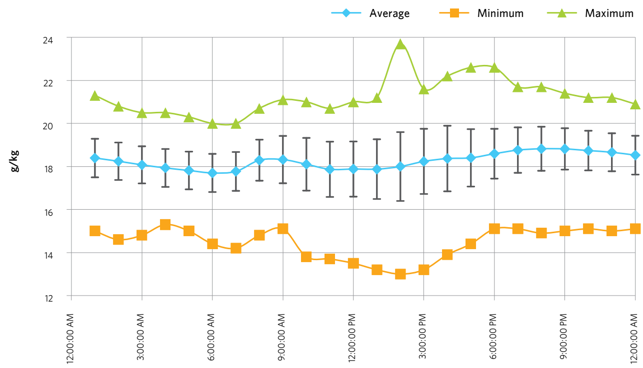
- Cold surfaces that are below the dew point temperature
- Desiccant material that absorbs moisture from the air

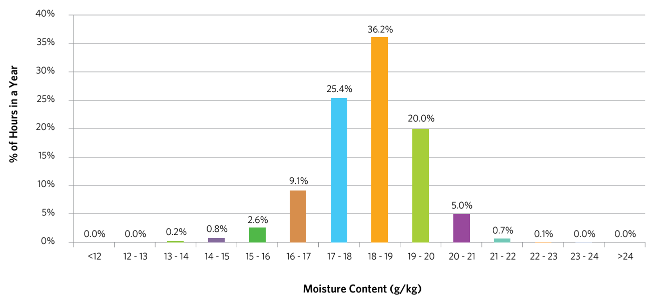
A clear understanding of the humidity ratio (moisture content) provides a very useful method for engineers to estimate the amount of latent load and condensation rate that the system needs to be designed for. For example, the humidity ratio provides an indication of the amount of water that needs to be extracted from the outdoor air to supply air-conditioned air at 11°C and 100% relative humidity (approximately 8.2g/kg) at the cooling coil (off-coil condition). As the average moisture content of outdoor air in Malaysia is 18.3g/kg, an average extraction of 10.1 grams of water from each kilogram of outdoor air is required to provide a supply of air-conditioned air at 11°C and 100% relative humidity. This value provides an approximation of the condensation rate of a typical cooling coil in Malaysian air handling units due to the intake of fresh air.

DESIGN RISK

Water features and greenery would increase the moisture content in the air. During the photosynthesis process, greenery expels moisture from the leaves to provide evaporative cooling to the environment. Therefore, it is not necessarily true that placing a fresh air intake duct near to greenery (to take in cooler air) will yield lower energy use because it may have a higher moisture content in it.

CHART 2.4 | MOISTURE CONTENT





RAW DATA | MOISTURE CONTENT

Hours	Average	Minimum	Maximum	Std Dev.
1:00:00 AM	18.4	15.0	21.3	0.9
2:00:00 AM	18.2	14.6	20.8	0.9
3:00:00 AM	18.1	14.8	20.5	0.9
4:00:00 AM	17.9	15.3	20.5	0.9
5:00:00 AM	17.8	15.0	20.3	0.9
6:00:00 AM	17.7	14.4	20.0	0.9
7:00:00 AM	17.8	14.2	20.0	0.9
8:00:00 AM	18.3	14.8	20.7	1.0
9:00:00 AM	18.3	15.1	21.1	1.1
10:00:00 AM	18.1	13.8	21.0	1.2
11:00:00 AM	17.9	13.7	20.7	1.3
12:00:00 PM	17.9	13.5	21.0	1.3
1:00:00 PM	17.9	13.2	21.2	1.4
2:00:00 PM	18.0	13.0	23.7	1.6
3:00:00 PM	18.2	13.2	21.6	1.5
4:00:00 PM	18.4	13.9	22.2	1.5
5:00:00 PM	18.4	14.4	22.6	1.3
6:00:00 PM	18.6	15.1	22.6	1.2
7:00:00 PM	18.8	15.1	21.7	1.1
8:00:00 PM	18.8	14.9	21.7	1.0
9:00:00 PM	18.8	15.0	21.4	1.0
10:00:00 PM	18.7	15.1	21.2	0.9
11:00:00 PM	18.7	15.0	21.2	0.9
12:00:00 AM	18.5	15.1	20.9	0.9

DEW POINT TEMPERATURE

The dew point temperature is directly linked to the moisture content in the air. However, the dew point temperature has the advantage of providing us information on the condensation risk due to exposure to outdoor air. Any surface temperature that is below the dew point temperature will have condensation on it. The average dew point temperature in the TRY is 23.4°C and is fairly consistent day or night and throughout the year. The peak standard deviation of the dew point temperature is 1.5°C at 2pm in the afternoon.

For more than 70% of the hours, the dew point temperature is below 24°C and for more than 95% of the hours, the dew point temperature is below 25°C.

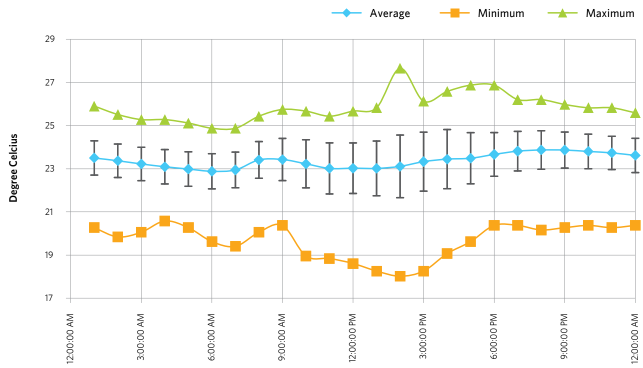
DESIGN POTENTIAL

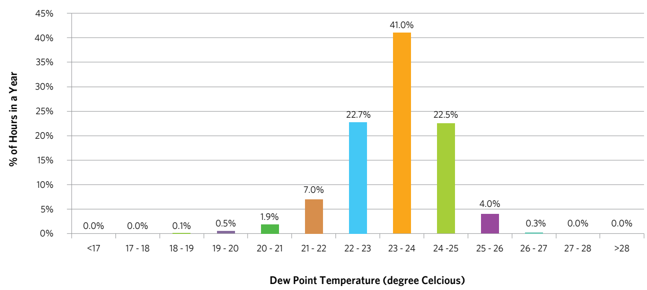
The dew point temperature provides an indication when condensation will occur. As long as the surface temperature is kept above the dew point temperature, there will be no condensation. For example, if a surface temperature exposed to outdoor air is kept above 25°C, the risk of condensation is less than 5% and above 26°C, the risk of condensation is less than 0.5%. This provides a possibility to provide radiant cooling to an outdoor area (e.g. al-fresco dinning, etc.) where the surface temperature can be kept above the dew point temperature to avoid condensation while minimising energy consumption to cool occupants in an outdoor space.

DESIGN RISK

If there are water features, greenery and cooking done (evaporation of water) within the space, the moisture content in the air may increase and cause the dew point temperature to increase as well. Therefore, condensation may occur at a higher surface temperature due to these micro-climatic conditions.

CHART 2.5 | DEW POINT TEMPERATURE





RAW DATA | DEW POINT TEMPERATURE

Hours	Average	Minimum	Maximum	Std Dev.
1:00:00 AM	23.5	20.3	25.9	0.8
2:00:00 AM	23.4	19.8	25.5	0.8
3:00:00 AM	23.2	20.1	25.3	0.8
4:00:00 AM	23.1	20.6	25.3	0.8
5:00:00 AM	23.0	20.3	25.1	0.8
6:00:00 AM	22.9	19.6	24.9	0.8
7:00:00 AM	22.9	19.4	24.9	0.8
8:00:00 AM	23.4	20.1	25.4	0.8
9:00:00 AM	23.4	20.4	25.7	1.0
10:00:00 AM	23.2	19.0	25.7	1.1
11:00:00 AM	23.0	18.8	25.4	1.2
12:00:00 PM	23.0	18.6	25.7	1.2
1:00:00 PM	23.0	18.3	25.8	1.3
2:00:00 PM	23.1	18.0	27.7	1.5
3:00:00 PM	23.3	18.3	26.1	1.4
4:00:00 PM	23.4	19.1	26.6	1.4
5:00:00 PM	23.5	19.6	26.9	1.2
6:00:00 PM	23.7	20.4	26.9	1.0
7:00:00 PM	23.8	20.4	26.2	0.9
8:00:00 PM	23.9	20.2	26.2	0.9
9:00:00 PM	23.9	20.3	26.0	0.8
10:00:00 PM	23.8	20.4	25.8	0.8
11:00:00 PM	23.7	20.3	25.8	0.8
12:00:00 AM	23.6	20.4	25.6	0.8

RELATIVE HUMIDITY

Relative humidity is a measure of the amount of water (moisture) in the air as compared to the maximum amount of water the air can absorb, expressed in percentage. It is not a direct indicator of how much water is in the air, as provided by the humidity ratio (moisture content) or dew point temperature. The dry bulb temperature determines the maximum moisture the air can absorb; therefore, relative humidity is directly linked to both the humidity ratio (moisture content) as well as the dry bulb temperature, expressed in percentage of moisture in the air.

As the moisture content in the air is fairly constant day or night, the change of relative humidity is strongly related to the dry bulb temperature of the air. During the night time and early morning hours when the dry bulb temperature is low, the relative humidity is very high (between 90% to 100% relative humidity). However during the daytime hours when the dry bulb temperature is high, the relative humidity has an average low of 62%.

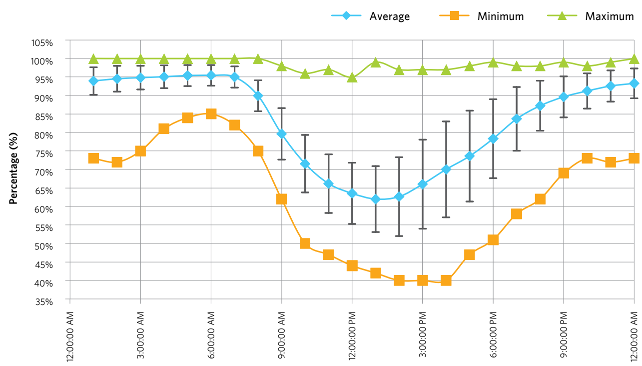
DESIGN POTENTIAL

A low relative humidity is an indication of how well evaporative cooling will work. The lower the relative humidity, the easier it is for water to evaporate to reduce the dry bulb air temperature. At a very high relative humidity level of 90% or more, only a very small amount of water will be able to evaporate.

DESIGN RISK

Relative humidity is a factor of both the dry bulb temperature and moisture content. It is not possible to compute energy changes when provided with the relative humidity alone. For example, how much energy will it take to reduce the relative humidity of 90% to 50%? It would not be possible to give an answer to such a question. However, it will be possible to compute the energy change if the question is rephrased into how much energy will it take to reduce the relative humidity of 90% at 25°C to a relative humidity of 50% at 23°C. Relative humidity is useful as an indicator of moisture in the air only when provided with the dry bulb temperature.

CHART 2.6 | RELATIVE HUMIDITY



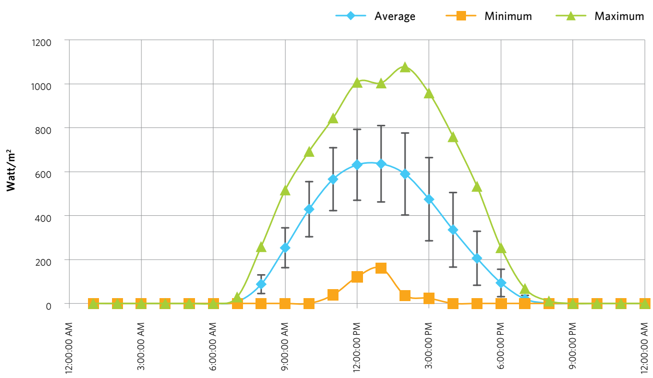
RAW DATA | RELATIVE HUMIDITY

Hours	Average	Minimum	Maximum	Std Dev.
1:00:00 AM	93.9	73	100	3.7
2:00:00 AM	94.5	72	100	3.5
3:00:00 AM	94.8	75	100	3.2
4:00:00 AM	95.1	81	100	3.1
5:00:00 AM	95.4	84	100	2.8
6:00:00 AM	95.4	85	100	2.8
7:00:00 AM	95.0	82	100	2.9
8:00:00 AM	89.9	75	100	4.2
9:00:00 AM	79.6	62	98	7.0
10:00:00 AM	71.6	50	96	7.8
11:00:00 AM	66.2	47	97	7.9
12:00:00 PM	63.6	44	95	8.3
1:00:00 PM	62.0	42	99	8.9
2:00:00 PM	62.7	40	97	10.7
3:00:00 PM	66.0	40	97	12.0
4:00:00 PM	70.0	40	97	13.0
5:00:00 PM	73.6	47	98	12.3
6:00:00 PM	78.3	51	99	10.7
7:00:00 PM	83.7	58	98	8.6
8:00:00 PM	87.2	62	98	6.8
9:00:00 PM	89.6	69	99	5.5
10:00:00 PM	91.2	73	98	4.8
11:00:00 PM	92.6	72	99	4.2
12:00:00 AM	93.3	73	100	4.0

HORIZONTAL GLOBAL RADIATION

The average global radiation is almost a perfect symmetry between the morning hours and afternoon hours with its peak close to the solar noon. The average peak is 636 W/m^2 at 1pm while the absolute peak in the TRY is 1,077 W/m^2 at 2pm, western sun. The absolute peak of solar radiation is almost double the average peak. This indicates that there are days where the cloud cover is low, allowing direct solar radiation to cause high solar gain in buildings. However on average, the cloud cover in a tropical climate provides good protection to reduce the impact of direct solar radiation. The TRY data also showed that it is possible at any time of day for the solar radiation to be reduced to close to zero, most likely caused by heavy rain cloud cover.

CHART 2.7 | HORIZONTAL GLOBAL RADIATION



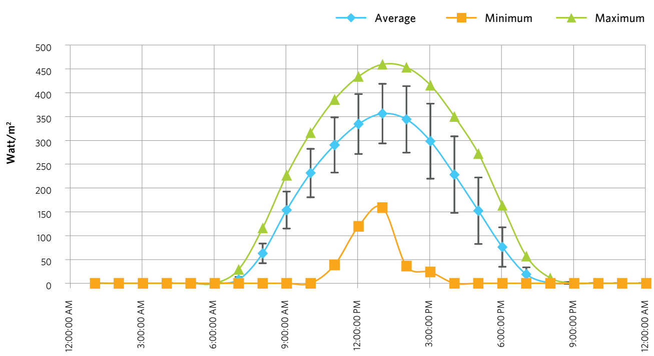
RAW DATA | GLOBAL RADIATION

Hours	Average	Minimum	Maximum	Std Dev.
1:00:00 AM	0.0	0.0	0.0	0.0
2:00:00 AM	0.0	0.0	0.0	0.0
3:00:00 AM	0.0	0.0	0.0	0.0
4:00:00 AM	0.0	0.0	0.0	0.0
5:00:00 AM	0.0	0.0	0.0	0.0
6:00:00 AM	0.0	0.0	0.0	0.0
7:00:00 AM	7.7	0.0	29.2	5.7
8:00:00 AM	87.5	0.0	259.1	42.4
9:00:00 AM	253.6	0.0	516.2	90.7
10:00:00 AM	429.0	0.0	692.8	125.4
11:00:00 AM	565.7	38.9	844.3	143.2
12:00:00 PM	631.0	120.8	1006.4	161.3
1:00:00 PM	635.9	161.1	1003.7	173.8
2:00:00 PM	589.2	36.1	1076.5	186.7
3:00:00 PM	474.6	23.7	958.0	189.3
4:00:00 PM	335.2	0.0	759.7	169.7
5:00:00 PM	205.7	0.0	532.7	122.8
6:00:00 PM	93.2	0.0	254.1	62.4
7:00:00 PM	20.0	0.0	67.7	16.7
8:00:00 PM	0.7	0.0	11.1	1.7
9:00:00 PM	0.0	0.0	0.0	0.0
10:00:00 PM	0.0	0.0	0.0	0.0
11:00:00 PM	0.0	0.0	0.0	0.0
12:00:00 AM	0.0	0.0	0.0	0.0

DIFFUSE SOLAR RADIATION

The average peak diffuse radiation is 356 W/m^2 at 1pm, while the absolute peak diffuse radiation is 460 W/m^2 also at 1pm. The standard deviation is generally low, with the highest at 80 W/m^2 at 4pm in the afternoon.

CHART 2.8 | DIFFUSE SOLAR RADIATION



RAW DATA | DIFFUSE RADIATION

Hours	Average	Minimum	Maximum	Std Dev.
1:00:00 AM	0.0	0.0	0.0	0.0
2:00:00 AM	0.0	0.0	0.0	0.0
3:00:00 AM	0.0	0.0	0.0	0.0
4:00:00 AM	0.0	0.0	0.0	0.0
5:00:00 AM	0.0	0.0	0.0	0.0
6:00:00 AM	0.0	0.0	0.0	0.0
7:00:00 AM	7.7	0.0	29.2	5.7
8:00:00 AM	62.8	0.0	116.1	20.7
9:00:00 AM	153.8	0.0	227.1	38.8
10:00:00 AM	231.4	0.0	316.2	50.8
11:00:00 AM	290.4	38.7	386.1	58.0
12:00:00 PM	334.4	119.7	434.0	62.9
1:00:00 PM	356.2	158.9	459.7	62.5
2:00:00 PM	344.1	36.0	453.3	69.8
3:00:00 PM	298.4	23.6	415.9	78.8
4:00:00 PM	228.1	0.0	350.1	80.4
5:00:00 PM	152.3	0.0	272.5	69.8
6:00:00 PM	76.1	0.0	163.3	41.4
7:00:00 PM	18.8	0.0	57.1	14.6
8:00:00 PM	0.7	0.0	11.1	1.7
9:00:00 PM	0.0	0.0	0.0	0.0
10:00:00 PM	0.0	0.0	0.0	0.0
11:00:00 PM	0.0	0.0	0.0	0.0
12:00:00 AM	0.0	0.0	0.0	0.0

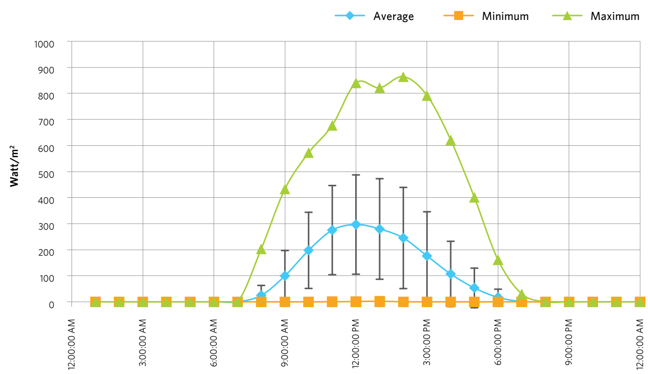
DIRECT SOLAR RADIATION

The average peak direct radiation is 297 W/m^2 at 12noon, while the absolute peak direct radiation is 865 W/m^2 at 2pm in the afternoon.

The absolute peak direct solar radiation is almost 3 times higher than the average peak direct solar radiation. The standard deviation is rather high, with the highest at 194 W/m^2 at 2pm in the afternoon.

All this data indicates that there is a significant difference between the average and the absolute peak direct radiation in the TRY. It is also quite clear from the direct radiation chart that the average direct radiation is higher in the morning hours than the afternoon hours. However, the absolute peak direct solar radiation occurs in the afternoon hours.

CHART 2.9 | DIRECT SOLAR RADIATION



RAW DATA | DIRECT SOLAR RADIATION

Hours	Average	Minimum	Maximum	Std Dev.
1:00:00 AM	0.0	0.0	0.0	0.0
2:00:00 AM	0.0	0.0	0.0	0.0
3:00:00 AM	0.0	0.0	0.0	0.0
4:00:00 AM	0.0	0.0	0.0	0.0
5:00:00 AM	0.0	0.0	0.0	0.0
6:00:00 AM	0.0	0.0	0.0	0.0
7:00:00 AM	0.0	0.0	0.0	0.0
8:00:00 AM	24.7	0.0	203.2	38.2
9:00:00 AM	99.8	0.0	433.1	97.1
10:00:00 AM	197.6	0.0	572.2	146.1
11:00:00 AM	275.2	0.2	677.7	171.1
12:00:00 PM	296.7	1.2	840.6	190.6
1:00:00 PM	279.7	2.3	821.7	193.0
2:00:00 PM	245.1	0.1	864.5	194.2
3:00:00 PM	176.2	0.0	792.2	169.6
4:00:00 PM	107.0	0.0	621.7	125.4
5:00:00 PM	53.4	0.0	401.0	76.0
6:00:00 PM	17.2	0.0	160.8	31.4
7:00:00 PM	1.2	0.0	30.6	4.0
8:00:00 PM	0.0	0.0	0.0	0.0
9:00:00 PM	0.0	0.0	0.0	0.0
10:00:00 PM	0.0	0.0	0.0	0.0
11:00:00 PM	0.0	0.0	0.0	0.0
12:00:00 AM	0.0	0.0	0.0	0.0

COMPARISON OF GLOBAL, DIRECT & DIFFUSE RADIATION

Placing the average global, direct and diffuse radiation in the same chart provides a distinct understanding that the average direct solar radiation is more intense in the morning while the average diffuse radiation is more intense in the afternoon hours.

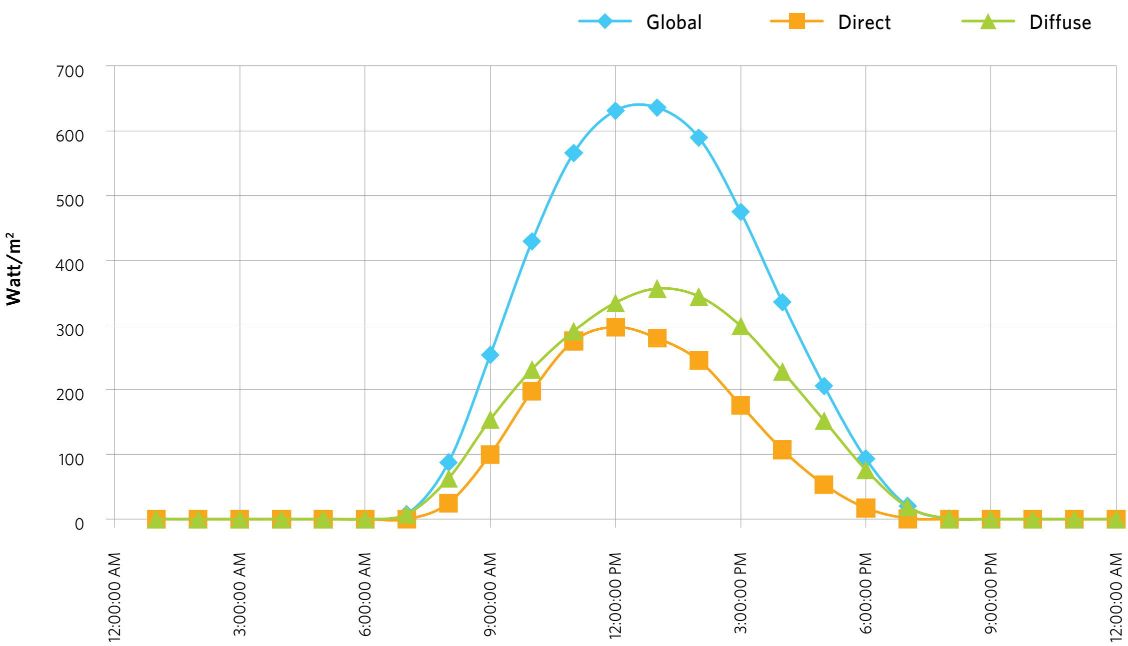
DESIGN POTENTIAL

It is important to shade the western façade from direct solar radiation to reduce the peak cooling load in buildings. The peak cooling load in a building determines the size of air-conditioning equipment to be provided. However for energy efficiency, the plotting of average solar radiations showed that it is more important to shade the eastern façade from direct solar radiation to reduce the annual energy consumption in building.

DESIGN RISK

The direct and diffuse radiation in the TRY is not a measured value but computed from the measured horizontal global radiation using the Erbs' Estimation Model. However, the result generally agrees with the daily observation of solar radiation in this climate. In the tropical climate where it rains more often in the afternoon than in the morning creates skies with a heavier average cloud cover in the afternoon than in the morning.

CHART 2.10 | AVERAGE DAILY RADIATION



CLOUD COVER (OKTAS)

The cloud cover in the TRY is measured in Oktas units. Oktas is defined by the World Meteorological Organization as provided by the table below[4].

Oktas	Definition	Category
0	Sky clear	Fine
1	1/8 of sky covered or less, but not zero	Fine
2	2/8 of sky covered	Fine
3	3/8 of sky covered	Partly Cloudy
4	4/8 of sky covered	Partly Cloudy
5	5/8 of sky covered	Partly Cloudy
6	6/8 of sky covered	Cloudy
7	7/8 of sky covered or more, but not 8/8	Cloudy
8	8/8 of sky completely covered, no breaks	Overcast

The cloud cover is generally high in the TRY and is reflective of a tropical climate. The average cloud cover has an Oktas of 6.8 in Malaysia and is fairly consistent day and night and throughout the year. The maximum cloud cover has the maximum Oktas of 8 and can occur at any time of day. However the minimum 0 Oktas is recorded by the TRY happening at 6am and 7am in the early morning and the minimum cloud cover in the afternoon is at least 1 Oktas higher than in the morning, indicating that minimum cloud cover is heavier in the afternoon than in the morning.

The standard deviation is higher in the morning as compared to the afternoon, indicating that there is a larger day to day variation of cloud cover in the morning as compared to the afternoon. In other words, in the afternoon, the sky is consistently heavy with clouds, whereas in the morning, the cloud cover may sometimes be low.

DESIGN POTENTIAL

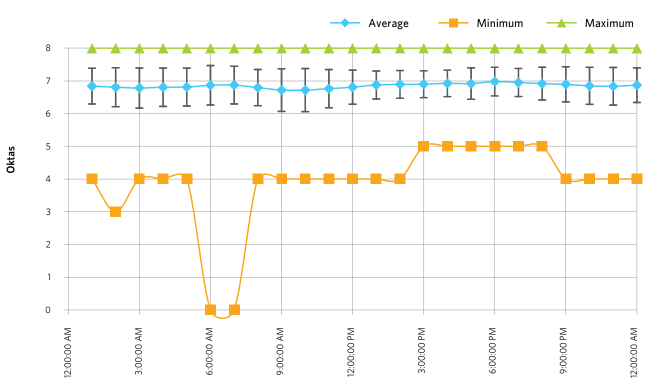
High Oktas numbers indicate heavy cloud cover in Malaysia's climate. It also means that during the daytime, the Malaysian sky is normally bright because the sky will be illuminated by the clouds as opposed to clear blue skies.

Heavy cloud cover also hinders radiation heat transfer between objects on the ground with the sky. In general the lower the Oktas number, the better it is for the sky to cool objects on the ground surface.

DESIGN RISK

Oktas measurements are done manually by meteorologists. They would take a look at the sky and decide how many eighths of the sky is covered by clouds.

CHART 2.11 | CLOUD COVER



RAW DATA | CLOUD COVER

Hours	Average	Minimum	Maximum	Std Dev.
1:00:00 AM	6.8	4.0	8.0	0.5
2:00:00 AM	6.8	3.0	8.0	0.6
3:00:00 AM	6.8	4.0	8.0	0.6
4:00:00 AM	6.8	4.0	8.0	0.6
5:00:00 AM	6.8	4.0	8.0	0.6
6:00:00 AM	6.9	0.0	8.0	0.6
7:00:00 AM	6.9	0.0	8.0	0.6
8:00:00 AM	6.8	4.0	8.0	0.6
9:00:00 AM	6.7	4.0	8.0	0.7
10:00:00 AM	6.7	4.0	8.0	0.7
11:00:00 AM	6.8	4.0	8.0	0.6
12:00:00 PM	6.8	4.0	8.0	0.5
1:00:00 PM	6.9	4.0	8.0	0.4
2:00:00 PM	6.9	4.0	8.0	0.4
3:00:00 PM	6.9	5.0	8.0	0.4
4:00:00 PM	6.9	5.0	8.0	0.4
5:00:00 PM	6.9	5.0	8.0	0.5
6:00:00 PM	7.0	5.0	8.0	0.4
7:00:00 PM	7.0	5.0	8.0	0.4
8:00:00 PM	6.9	5.0	8.0	0.5
9:00:00 PM	6.9	4.0	8.0	0.5
10:00:00 PM	6.8	4.0	8.0	0.6
11:00:00 PM	6.8	4.0	8.0	0.6
12:00:00 AM	6.9	4.0	8.0	0.5

[4] http://worldweather.wmo.int/oktas.htm

EFFECTIVE SKY TEMPERATURE

It is useful to provide the effective sky temperature in this chapter because it provides an indication of the possibility of using the sky to cool buildings passively. The effectiveness of radiation heat exchange between objects on the ground surface with the sky is defined by the effective sky temperature. The effective sky temperature is not provided by the TRY but is estimated from the dry bulb temperature, the dew point temperature and the cloud cover using equations provided by Clark and Blanplied[5].

The estimated average effective sky temperature in the TRY is 18°C. It is higher during the daytime and lower during the night time. The average lowest effective sky temperature is 14.6°C at 7am in the morning. While the absolute lowest effective sky temperature was estimated to be 9.5°C at 8am in the morning. Although the daytime average effective sky temperature is in the low 20s°C, the direct and diffuse solar radiation during the daytime provides much more heat than the sky removes.

On average, the effective sky temperature is below 20°C from the hours of 6pm to 11am. The lowest average effective sky temperature is approximately 15°C at 6am in the morning.

DESIGN POTENTIAL

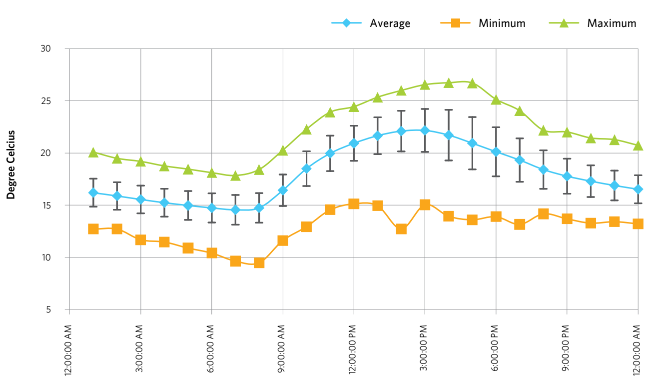
The lower the effective sky temperature is, the better it is for the sky to absorb heat from (cooling) objects on the ground. Therefore, as long as a surface is shielded from direct radiation or does not absorb solar radiation (as in products with very high solar reflectivity), during the night time (no solar radiation) the sky can be used as a means of heat rejection or cooling source.

A roof system that can block heat gain during the daytime and release heat during the night time will potentially be an effective means of cooling a building. Buildings that are mainly used during the night time such as residential homes will benefit significantly from such a roof design. Movable roof insulation, cool roof paints that reject solar radiation during the daytime while having high emissivity to release heat, etc. may be interesting solutions for residential homes.

DESIGN RISK

An average effective sky temperature above 20°C during the daytime is not considered to be sufficient to cool objects on the ground. Therefore, using the sky to cool objects on the ground will only be useful during the night time when the effective sky temperature reduces below 20°C. In countries where the cloud cover is low and the ambient air temperature is moderate, it is possible for the sky to provide a consistent effective sky temperature below 10°C (in some places, even below 0°C, making it possible to make ice in the night sky[6]). The high effective sky temperature found in this climate is largely due to the high moisture content in the air and the heavy cloud cover.

CHART 2.12 | EFFECTIVE SKY TEMPERATURE



RAW DATA | EFFECTIVE SKY TEMPERATURE

Hours	Average	Minimum	Maximum	Std Dev.
1:00:00 AM	16.20	12.7	20.1	1.3
2:00:00 AM	15.89	12.7	19.5	1.3
3:00:00 AM	15.55	11.7	19.2	1.3
4:00:00 AM	15.24	11.5	18.8	1.3
5:00:00 AM	14.98	10.9	18.5	1.4
6:00:00 AM	14.74	10.4	18.1	1.4
7:00:00 AM	14.56	9.6	17.9	1.4
8:00:00 AM	14.75	9.5	18.4	1.4
9:00:00 AM	16.43	11.6	20.3	1.5
10:00:00 AM	18.51	12.9	22.3	1.7
11:00:00 AM	19.97	14.6	23.9	1.7
12:00:00 PM	20.93	15.1	24.4	1.7
1:00:00 PM	21.66	15.0	25.4	1.8
2:00:00 PM	22.10	12.7	26.0	1.9
3:00:00 PM	22.17	15.0	26.6	2.1
4:00:00 PM	21.72	13.9	26.7	2.4
5:00:00 PM	20.94	13.6	26.7	2.5
6:00:00 PM	20.12	13.9	25.1	2.4
7:00:00 PM	19.33	13.2	24.1	2.1
8:00:00 PM	18.42	14.2	22.2	1.8
9:00:00 PM	17.78	13.7	22.0	1.7
10:00:00 PM	17.31	13.3	21.4	1.5
11:00:00 PM	16.89	13.4	21.3	1.4
12:00:00 AM	16.53	13.2	20.7	1.3

[5] Gene Clark and M. Blanpied, 1979. "The Effect of IR Transparent Windscreens on Net Nocturnal Cooling from Horizontal Surfaces," Proceedings of the 4th National Passive Solar Conference, Kansas City, MO.
[6] "Lesson 1: History of Refrigeration, Version 1 ME". Indian Institute of Technology Kharagpur. Archived from the original on 2011-11-06.

GROUND TEMPERATURE

The ground temperature was computed from the TRY using Kasuda's equation[7] at a 1 meter depth. It was computed that the soil temperature is constant at 26.9°C for the entire year. Further investigation using Kasuda's equation showed that at any depth greater than 0.5 meters, the ground temperature will be constant at 26.9°C.

It is also important to note that the groundwater temperature will also be the same temperature as the ground (soil) temperature.

DESIGN POTENTIAL

There exists designs that channel air intake into a building through an underground chamber to pre-cool the air before entering the building. However, this strategy will only work well in this climate during the daytime when the outdoor air temperature is higher than the soil temperature. During the night time, the outdoor air temperature is lower than the soil temperature, so channelling night air into the underground chamber will heat up the air instead of cooling it down. In short, this strategy will work well with office buildings where the building is occupied during daytime; it will not work well for residential homes because the homes are normally occupied during the night time.

The TRY has an average wet bulb temperature of 24.3°C and a typical cooling tower design calls for an approach temperature of 5.5°C higher than the wet bulb temperature, providing an average of 29.8°C return water temperature to the chiller. The groundwater temperature is estimated to be 26.9°C; therefore it is approximately 3°C cooler than the water from the cooling tower. Colder water for the condensing side of the chiller will improve the efficiency of the chiller significantly. Water from deep lakes would also have good potential for such an opportunity to improve the efficiency of the chiller because the temperature of the water in deep lakes will also follow the ground temperature.

DESIGN RISK

Kasuda's equation does not account for rainfall on the soil. As water from the soil will evaporate at the wet bulb temperature, the surface of the soil may be cooler on average for a climate such as Malaysia's where it rains fairly often and consistently throughout the year. The effect of rainfall on the ground temperature is expected to be minimal. However, actual measurement of the on-site ground temperature is highly recommended.

In addition, further studies are recommended to ensure that the cooler daytime air achieved via an underground chamber can be achieved without increasing the moisture content of the air. An increase in moisture content will increase the energy consumption of the air-conditioning system.

Excessive groundwater harvesting without adequate recharge will cause soil properties to deteriorate and may cause the ground to sink. Moreover, pumping water over long distances will also increase the water temperature due to friction and conduction gain through the pipes, which may cause the predicted 3°C cooler water temperature to be unachievable.

[7] Kasuda, T., and Archenbach, P.R. 1965. Earth Temperature and Thermal Diffusivity at Selected Stations in the United States, ASHRAE Transactions, Vol. 71, Part 1.

WIND SPEED

The average wind speed in the TRY showed that the wind speed is low (less than 0.5 m/s) from the hours of 8pm to 8am. The wind speed starts to increase at 8am and has an average peak of 3.5 m/s at 3pm in the afternoon. The hourly maximum wind speed showed that it is possible to have a high wind speed at any time of the day, with the lowest chance of a high wind speed at 8am in the morning. The data also showed that it is also possible to have zero wind speed at any time of the day.

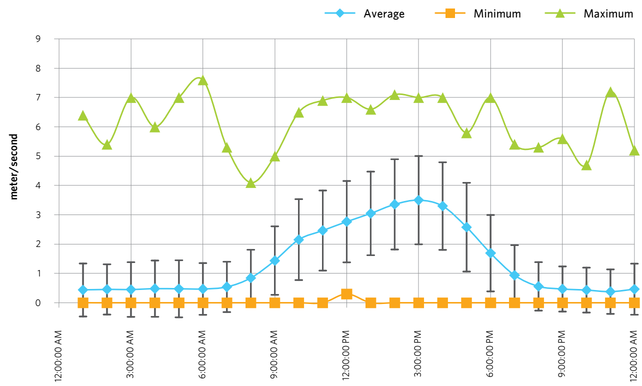
DESIGN POTENTIAL

It is important to note that the peak average wind speed occurs at the same time of high dry bulb temperature. Similarly, when the dry bulb temperature is low, the average wind speed is also low. This indicates that buildings designed with cross-ventilation at all hours will on average bring more hot air than cool air into the building. As the wind speed data showed that high wind speeds can occur at any time, it is also possible for cross ventilation to bring in cool air to benefit the building occupants. Therefore, cross-ventilation designs need to consider the hours occupants make use of the space and also the possibility of diverting hot wind away from occupants during certain hours/conditions of the day and to divert cool air towards the occupants during certain hours/conditions of the day. Operable windows, where the building occupant has control over when cross ventilation is used is highly recommended.

DESIGN RISK

The wind speed and wind direction data should be checked further against other year's data to ensure that the data in the TRY is reflective of the actual situation. The selected months of the TRY data was predominantly selected based on the dry bulb temperature, global horizontal solar radiation and humidity ratio. Therefore, it is recommended for academicians and researchers to investigate the wind data further to confirm the behaviour of wind speed and wind direction according to the hour of the day and day of the year.

CHART 2.13 | WIND SPEED



RAW DATA | WIND SPEED

Hours	Average	Minimum	Maximum	Std Dev.
1:00:00 AM	0.44	0.0	6.4	0.9
2:00:00 AM	0.46	0.0	5.4	0.9
3:00:00 AM	0.45	0.0	7.0	0.9
4:00:00 AM	0.48	0.0	6.0	1.0
5:00:00 AM	0.48	0.0	7.0	1.0
6:00:00 AM	0.47	0.0	7.6	0.9
7:00:00 AM	0.54	0.0	5.3	0.9
8:00:00 AM	0.85	0.0	4.1	1.0
9:00:00 AM	1.44	0.0	5.0	1.2
10:00:00 AM	2.15	0.0	6.5	1.4
11:00:00 AM	2.46	0.0	6.9	1.4
12:00:00 PM	2.77	0.3	7.0	1.4
1:00:00 PM	3.05	0.0	6.6	1.4
2:00:00 PM	3.36	0.0	7.1	1.5
3:00:00 PM	3.50	0.0	7.0	1.5
4:00:00 PM	3.30	0.0	7.0	1.5
5:00:00 PM	2.58	0.0	5.8	1.5
6:00:00 PM	1.69	0.0	7.0	1.3
7:00:00 PM	0.94	0.0	5.4	1.0
8:00:00 PM	0.56	0.0	5.3	0.8
9:00:00 PM	0.47	0.0	5.6	0.8
10:00:00 PM	0.43	0.0	4.7	0.8
11:00:00 PM	0.38	0.0	7.2	0.8
12:00:00 AM	0.46	0.0	5.2	0.9

WIND DIRECTION & HOURS OF AIR TEMPERATURE BELOW 29°C

Based on ASHRAE 55's thermal adaptive comfort model for natural ventilation, an operative temperature of 29°C in Malaysia's climate will provide an 80% population satisfaction rate[8]. Harvesting natural ventilation with air temperatures above 29°C will only heat up the environment, providing uncomfortable conditions for the building occupants. Therefore, natural ventilation should only aim to harvest the cool wind that is below 29°C. This section provides information on which direction wind below 29°C normally comes from and what is the right hour in the day to harvest cool wind in Malaysia.

Detailed analysis of the TRY's wind direction and dry bulb air temperature shows that for a significant 37.5% of the hours in the whole year, the dry bulb (wind) temperature is below 29°C. The occurrence of cool wind is largely during the hours of late evening to mid-morning. Charts provided in this section show that cooler wind comes from the North (946 hours, 29%), North-West (593 hours, 18%), East (430 hours, 13%), South (326 hours, 10%), South-East (297 hours, 9%), South-West (249 hours, 8%), North-East (248 hours, 8%) and lastly West (196 hours, 6%). In short, cooler wind is primary from the North and North-West (combined to provide 47% of the total cool wind available), then followed by the East and South.

Cool wind from the North and North-West normally occurs during the late afternoon (~5pm) until the late morning (~9am). While cool wind from the East mainly occurs in the morning hours of 8am to 9am. Cool wind from the South is low but is consistent throughout the day.

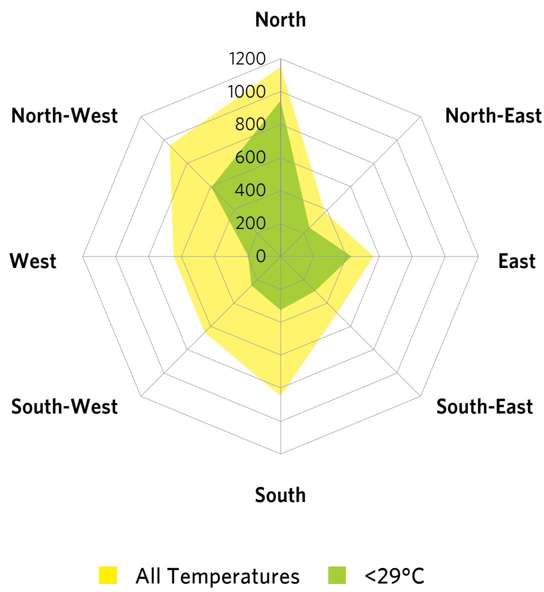
DESIGN POTENTIAL

Capturing wind from the North and North-West should be the primary objective to use natural ventilation to cool the environment. Cool wind is primary available from the hours of 5pm to 9am. When the air temperature is high during noon, it will not be comfortable to harvest natural ventilation. Ideally the building occupants should have control over the natural ventilation by giving the building occupants the ability to close windows or doors, to divert the wind away from the occupied space when the wind is hot and to allow wind towards the occupied space when the wind is cool. Motorised louvres with temperature sensors may also be used to provide this diversion of natural ventilation without requiring manual intervention.

DESIGN RISK

The wind speed and wind direction data should be checked further against other year's data to ensure that the data in the TRY is reflective of the actual situation. The selected months of the TRY data was predominantly selected based on the dry bulb temperature, global horizontal solar radiation and humidity ratio. Therefore, it is recommended for academicians and researchers to investigate the wind data further to confirm the behaviour of wind speed and wind direction according to the hour of the day and day of the year.

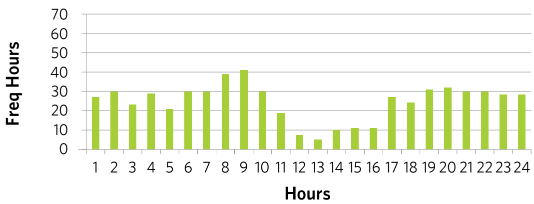
CHART 2.14 | HOURS OF WIND DIRECTION IN THE TRY



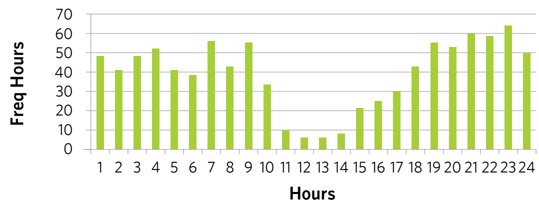
[8] ASHRAE 55

CHARTS 2.15 | WIND CHARTS OF AIR TEMPERATURE BELOW 29°C

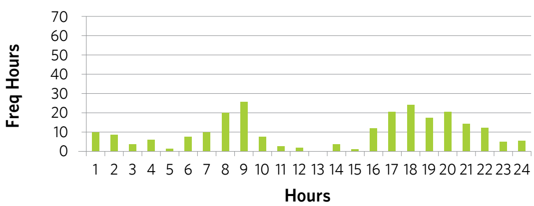
NORTH-WEST WIND



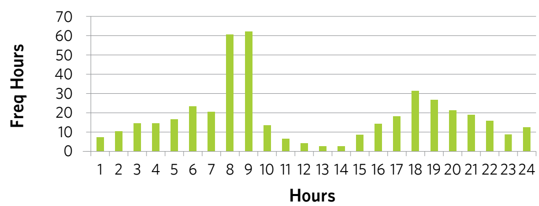
NORTH WIND



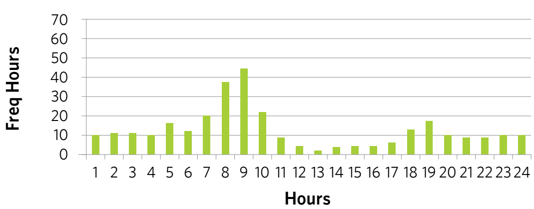
NORTH-EAST WIND



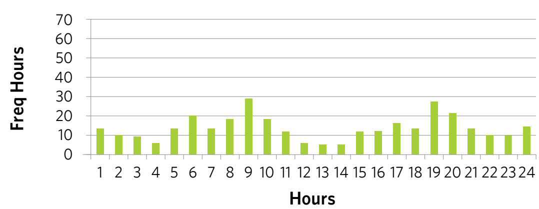
EAST WIND



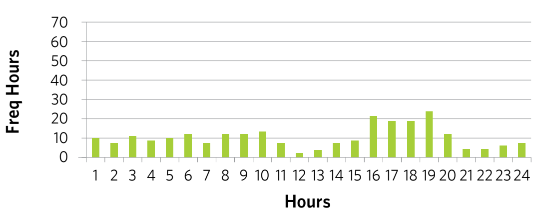
SOUTH-EAST WIND



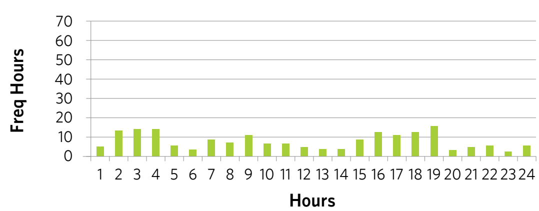
SOUTH WIND



SOUTH-WEST WIND



WEST WIND



SUMMARY

A clear understanding of our local weather data will enable architects and engineers to become better building designers. Fortunately, the Malaysian climate zone is easy to comprehend because the seasonal variation is rather small, i.e. every day is more or less the same for the whole year.

An attempt is made in this chapter to clarify the Malaysian climate on its dry bulb temperature, wet bulb temperature, dew point temperature, moisture content, relative humidity, effective sky temperature, ground temperature, solar radiation and the relationship of wind speed and direction to the air temperature based on the Test Reference Year weather data. An attempt is also made to provide the Design Potential based on each of these climatic properties presented, providing the possibility of design options to harness the climate to benefit the building design for low energy consumption.

There may also be situations where the localised micro-climatic conditions may alter the design possibilities presented by the Test Reference Year weather data. The Design Risk is therefore provided for each climatic property presented, allowing building designers to understand the risk of implementing the design options presented in this chapter.

Building designers are encouraged to make use of the data provided in this chapter to innovate building designs to benefit from the climate. Ideally, buildings in Malaysia should benefit from night cooling from the sky, taking advantage of the cooler night time air temperatures while preventing heat gain during the daytime from solar radiation, warm air temperatures and high moisture content. The challenge to the building designer is to strike the right balance between all these various climatic conditions to provide a comfortable environment for the building occupants while minimising carbon-based energy use.

It is also proposed that the data provided in this chapter be used as a fundamental check against any new design ideas proposed by designers, suppliers and manufacturers that may not understand the Malaysian climate well enough. For example, an evaporative cooling system that seems to work very well in an air-conditioned exhibition hall/showroom where the air is both cool and dry, will not be effective if used outdoors during the night time because the relative humidity is very high during the night time in this climate zone, but it is still possible to use it during the daytime because the relative humidity is lower during the daytime in this climate zone.

END OF CHAPTER 2

CHAPTER

3

ENERGY RATING OF ELECTRICAL APPLIANCES

by CK Tang & Nic Chin

3

ENERGY RATING OF ELECTRICAL APPLIANCES

INTRODUCTION

The use of electrical appliances (such as computers, printers, refrigerators, hot/cold water dispensers, etc.) in buildings in the Malaysian zone has a negative impact on energy efficiency. The electrical energy used by these appliances ends up as heat within the space where the appliance is, heating up the environment. The 1st law of thermodynamics states the law of conservation of energy, that the total amount of electrical energy used will eventually end up as heat "energy" in the building. Since heat is hardly ever desirable in the Malaysian climate, it is necessary to minimise the use of energy by electrical appliances by selecting those that can perform the same task using a minimum amount of electricity.

There are many products in the market that claim to be "energy efficient". Purchasers are easily confused by these claims and many have reservations on the validity of these efficiency claims. Therefore, as an aid to the consumers, it is necessary to have an authoritative, independent and publicly accepted green (eco) label or energy efficiency scheme that identifies products with the same functions in the market (Green Label Scheme, Green Council, 2013).

The use of electrical appliances in office buildings is normally known as "plug load" or "small power". Plug load has become one of the fastest growing sources of energy demand in commercial buildings due to the heavy reliance on computers as opposed to the typewriter many years ago. In Malaysian offices, plug load easily accounts for 20-35% of total building energy consumption. It has even been reported in recent studies in California that plug loads from office equipment can reach as high as 40-60% of all electricity consumed in office buildings. This largely due to the fact that many plug loads are kept running 24-hours daily.

It is still common today among many building design practitioners to think that air-conditioning is the highest energy consumer in any office building (typically accounting for 50-70% of the building's total energy consumption) and therefore, only the air-conditioning system needs to be optimised. Plug loads (and electrical lighting loads) are usually ignored as part of the energy efficiency design practice in buildings. This is a misconception that has to be addressed because it is easier and more effective to increase the energy efficiency in a building by a simple selection of plug loads. More importantly, by optimising the plug load, the air-conditioning energy required also reduces significantly.

Due to the reasons mentioned, it is important to address plug load reduction in buildings by implementing Green or Energy Efficient procurement policies by the building occupants. This chapter provides an overview and understanding of available energy efficient electrical appliances in this region.

TWOFOLD BENEFIT OF USING ENERGY EFFICIENT EQUIPMENT IN THE MALAYSIAN CLIMATE

Equipment that consumes high amounts of energy will produce more heat in a space. In the Malaysian climate, heat is not desirable in buildings because it increases the air-conditioning load, which in turn increases the installed capacity of the air-conditioning equipment, increasing capital cost and running cost of a building. In short, if energy efficient equipment can be specified for use in a building, it is possible to reduce the cooling load which in turn reduces the cost of the air-conditioning system and the running cost of the building.

In summary, the benefit of using energy efficient equipment in the Malaysian climate is twofold; one, it saves energy during equipment use, and two, it reduces the heat produced in the space, reducing the cooling load in the building.

If energy efficient equipment is used, it is possible to reduce the cooling load which in turn reduces the cost of the air-conditioning system and the running cost of the building

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ENERGY EFFICIENCY PROGRAMMES

1 ENERGY STAR PROGRAMME

The Energy Star Programme was introduced as a voluntary programme in 1992 in United States. Energy Star is a government-backed programme. It gives technical information and tools that consumers can select from, for their energy efficiency solutions and best management practices, making it feasible to save money while protecting the environment for future generations.[1]

Energy Star is one of the international symbols of premium energy efficiency which comprise a vast range of energy efficient rated products. The products such as home appliances, computers, heating & cooling systems, water heaters, lightings, fans and electronics.

The Energy Star rating covers a very broad range of products. These products stem from 2 main categories, products for the home and products for the office and government. For homes, Energy Star ratings are provided for white goods, building products, computers, electronics, battery chargers, heating & cooling systems, lighting and fans. For businesses and government, Energy Star rates commercial appliances, commercial food service equipment and building products.

In addition to consumer products, the Environmental Protection Agency's strategic management approach also certifies industrial plants and facilities with Energy Star ratings that meet a set of defined criteria. Industrial sector plants must score in the top 25% within their industry nationwide to be rated as an Energy Star plant.

[1] Energy Efficiency Guide For Industry In Asia, About Energy Efficiency, United Nations Environment Programme 2006

The Energy Star certification is awarded when a product surpasses the specifications listed by the EPA. This specification is based on federal government standards. For example, a full-sized refrigerator has to be at least 20% more energy efficient than the minimum federal government standard determined by standard testing procedures.

A product that has been awarded the Energy Star rating can display the Energy Star logo on its packaging.

By purchasing Energy Star rated equipment, it promises the consumer that the particular product consumes 20-30% less energy compared to the minimum U.S. Federal standards. This results in savings on the electricity bill for normal usage. On the flip side, Energy Star rated equipment have been touted to be more expensive compared to conventional alternatives. This is most probably due to newer technology being used. However, the EPA has argued that savings in the long run on the electricity bill will eventually offset the premium that was paid for a greener product. In addition to that, CO_2 emissions will have been significantly reduced as well.

More information on various products can be found on the official Energy Star website:
http://www.energystar.gov/

In July 2009, the EPA strengthened requirements for computers to be awarded the Energy Star rating. The first important requirement is that desktop computers and notebooks have to adhere to stringent Total Energy Consumption (TEC) goals. An Energy Star rated computer will deliver substantial savings compared to a non-rated computer because it has a lower TEC and incorporates low power modes during periods of inactivity. These power management features are required to obtain an Energy Star rating.

TABLE 3.1 | ESTIMATED SAVINGS BY THE EPA[2]

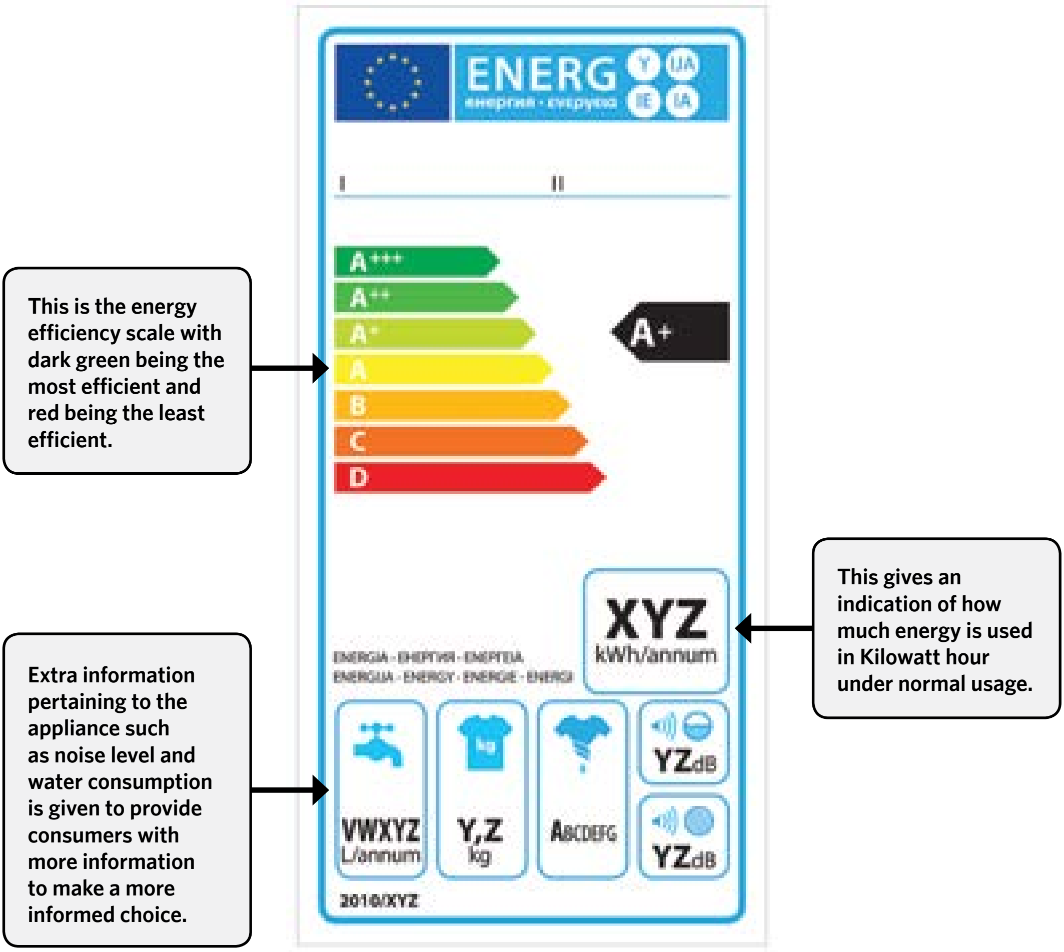
How Your Computers are Used	Estimated Lifetime (4 yrs) Savings per Desktop Computer	
	If you pay \$0.11 per kWh	If you pay \$0.18 per kWh
We typically leave our computers on nights & weekends	\$88	\$144
We typically turn our computers off every night	\$24	\$40
We will activate power management settings on the new computers, but did not do so on the old computers	\$216	\$352

[2] http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=CO

❷ EU ENERGY EFFICIENCY LABEL

EU energy labels have become a common sight in many home appliance showrooms. They are found on a selection of white goods and other products and are designed to help consumers see how energy efficient a model is before they purchase it. Therefore, what exactly does an energy label show and tell you about a particular item? We will have a closer look at how appliances are awarded an energy-efficiency rating, how to compare the models and what should one look for when shopping *(Energy labels explained, Which works for you?, 2013).*

Under the EU Directive 92/75/EEC, labelling of product information on the consumption of energy and other essential resources and additional information are needed for certain types of household appliances. This directive applies for items such as refrigerators, freezers and their combinations, washing machines, driers and their combinations, dishwashers, ovens, water heaters and hot-water storage appliances, lighting sources, air-conditioning appliances.[3] This list is constantly expanding and products are added periodically.



[3] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31992L0075:EN:NOT

In accordance with the EU Directive 2010/30/EU, this label must be attached clearly onto the front of the appliance while on sale. The scale ranges from A+++ (Dark green) to G (Red) where the former is most efficient and the latter is least. These rankings are based on the Energy Efficiency Index (EEI) and the limits for each class differs based on categories.

The importance of this scale is twofold. Firstly, by ranging the scale from A+++, the EU commission hopes to spur manufacturers to produce goods that are much more energy efficient than currently available and provide better differentiation for consumers. Secondly, this complements Ecodesign regulations that prohibits products below a certain ranking from entering the EU market. For instance, in 2013, only washing machines with a rank A and above were allowed to enter.[4]

There are significant differences between the EU Energy Efficiency Label and Energy Star although both are a means of demonstrating energy efficiency.

TABLE 3.2 | COMPARISON BETWEEN THE EU ENERGY EFFICIENCY LABEL AND ENERGY STAR

	EU ENERGY EFFICIENCY LABEL	ENERGY STAR
Governing Body	European Commission	Environmental Protection Agency, United States
Energy Efficiency Scale	Yes	No
Voluntary?	No	Yes
Adopting Countries	EU nations	Australia, Canada, Japan, New Zealand, Taiwan, EU nations
Appliances	As listed	Similar to the EU Energy Efficiency Labels but also rates computers, servers, heating and cooling systems. This also applies to buildings which use 15% less energy than standard homes.

It is obvious that a product with a higher rating has greater energy efficiency as measured by the Energy Efficiency Index. This translates to savings on the electricity bill as less energy is required to do the same amount of work.

Further information on EU rated equipment can be found at the following websites:

http://ec.europa.eu/energy/efficiency/labelling/labelling_en.htm
http://en.wikipedia.org/wiki/European_Union_energy_label
http://europa.eu/legislation_summaries/other/l32004_en.htm
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69295/pb13466-eu-energy-label.pdf

[4] http://www.energyagency.at/fileadmin/dam/pdf/publikationen/berichteBroschueren/comeonlabels_vergleich.pdf

❸ SINGAPORE ENERGY LABELLING SCHEME

NATIONAL CLIMATE CONTROL COMMITTEE

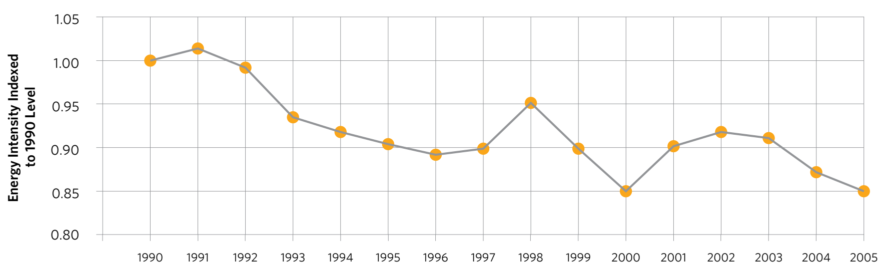
When there was an announcement about the Singapore plan to consent to the Kyoto Protocol in 2006, the National Energy Efficiency Committee (NEEC) expanded its scope to cover climate change issues and has also been renamed the National Climate Change Committee (NCCC) to better show its expanded function *(Singapore Air Con: Energy Labelling Scheme, 2007)*.

THE ENERGY EFFICIENCY REVOLUTION

In order to take action on climate change in the world, the National Environment Agency (NEA) is devoted to improving the energy efficiency in Singapore. They are leading a whole-of-government approach and have formed the Energy Efficiency Programme Office (E^2PO) to coordinate the drive towards an energy efficient Singapore (E^2 Singapore).

ENERGY EFFICIENCY IN SINGAPORE

Singapore's energy intensity improved by 15% between 1990 and 2005 due to the adoption of better technology in power generation and the more productive use of energy in other sectors (E^2 Singapore).



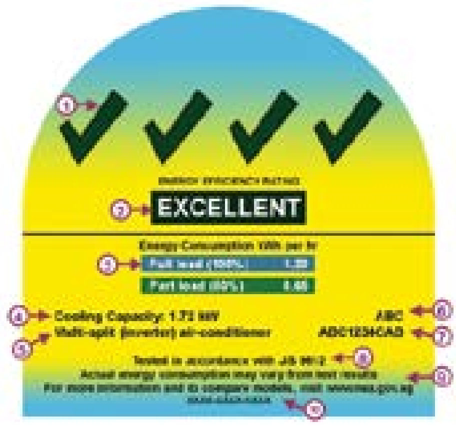
A whole-of-government approach has been adopted to implement the various mitigating measures to improve energy efficiency and achieve energy reductions across the various sectors. The Energy Efficiency Programme Office (E^2PO), a multi-agency committee led by NEA and the Energy Market Authority (EMA) has been established.

NEA has been actively promoting energy efficiency through legislation, incentives, providing information and public education in the industry, households and public sectors.

Reference:
http://app2.nea.gov.sg/energy-waste/energy-efficiency/household-sector/

ENERGY LABELLING OF APPLIANCES

The more energy efficient an appliance is, the less electricity it will consume. The benefit is a smaller energy bill every month. The Singapore Green Labelling Scheme was launched in April 2002 to give such information to consumers. Refrigerators, air-conditioners and appliances are now labelled and consumers can find out which models are more efficient than the others. The more Green Ticks provided, the more energy efficient it is *(National Climate Control Committee, 2013).*



<table>
<tr><th>FEATURE</th><th>AIR CONDITIONER</th><th>REFRIGERATOR</th><th>CLOTHES DRYER</th></tr>
<tr><td>1 Ticks</td><td colspan="3">The number of Ticks shall conform to the Tick Rating System</td></tr>
<tr><td>2 Energy Efficiency Rating</td><td colspan="3">The model's relative energy efficiency rating is also expressed in words:
<table>
<tr><th>Green Ticks</th><th>Energy Efficiency Rating</th></tr>
<tr><td>0</td><td>Low</td></tr>
<tr><td>1</td><td>Fair</td></tr>
<tr><td>2</td><td>Good</td></tr>
<tr><td>3</td><td>Very Good</td></tr>
<tr><td>4</td><td>Excellent</td></tr>
</table></td></tr>
<tr><td>3 Energy Consumption</td><td>Effective power input x 1h expressed in kWh per hour and rounded to two decimal places. For inverter type air-conditioners, the energy consumed at part-load cooling capacity shall also be displayed on the label.</td><td>Energy consumption over 24 hours x 365 days expressed in kWh.</td><td>Energy consumption per wash expressed in kWh and rounded to two decimal places.</td></tr>
<tr><td>4 Capacity</td><td>Full load cooling capacity expressed in kW and rounded to two decimal places.</td><td>Measured total storage volume expressed in litres (l) in whole digits.</td><td>Rated capacity expressed in kilograms (Kg) and rounded to one decimal place.</td></tr>
<tr><td>5 Type</td><td>Type of air-conditioners:
• Casement
• Window
• Single Split (non-inverter/ inverter)
• Multi split system (non-inverter/inverter)</td><td>Type of refrigerators:
• Refrigerator
• Refrigerator Freezer</td><td>Type of clothes dryer:
• Air-vented
• Condenser</td></tr>
<tr><td>6 Brand Name</td><td>Brand of air-conditioner</td><td>Brand of refrigerator</td><td>Brand of clothes dryer</td></tr>
<tr><td>7 Model Number</td><td>The model number found on the air conditioner's nameplate. For multi-split type air-conditioners, only the model number of the outdoor unit shall be displayed.</td><td>The model number found on the refrigerator's nameplate.</td><td>The model number found on the clothes dryer's nameplate.</td></tr>
<tr><td>8 Test Standard</td><td colspan="3">The test standard used as specified here</td></tr>
<tr><td>9 Disclaimer</td><td colspan="3">The following disclaimer applies to all appliances:
"Actual energy consumption may vary from test results"</td></tr>
<tr><td>!0 Registration Number</td><td colspan="3">A unique number found on the registered model's COR, which is issued by NEA upon successful registration of the model.</td></tr>
</table>

4 MALAYSIA ENERGY EFFICIENCY

SIRIM ECO LABEL

SIRIM
ECO-LABEL

The SIRIM Eco-label scheme is conducted under the authority of SIRIM QAS International Sdn Bhd, which is a wholly owned subsidiary of the SIRIM group. SIRIM QAS International is a member of the Green Eco-labelling Network (GEN) which is an international association of eco-labelling schemes. This scheme was launched on the 17th of September 2004.

According to SIRIM, this label was introduced to facilitate green procurement by the government and private sectors as well as to enable industries to make credible claims on the environmental attributes of their products.

The label is awarded by testing the product against a set criterion determined by SIRIM QAS International. This phase of testing and inspection includes an audit of the factory and testing samples of products. Over the years, 6 criteria set by SIRIM have been converted to Malaysian Standards. There are 43 categories that have an Eco-label Criteria and can be awarded with this label. This ranges from Environmentally Degradable & Non-Toxic Plastic Packaging Material, Printing Ink, Solid Body Soap Products, Energy Saving Electronic Ballasts, Tableware from Biomass and many others.

As a result, this label is not a measure of energy efficiency but rather an indication that the production of the product was done in an environmentally-conscious way. This label is not able to certify that a product is more energy efficient and able to help a consumer save on energy costs in the long run.

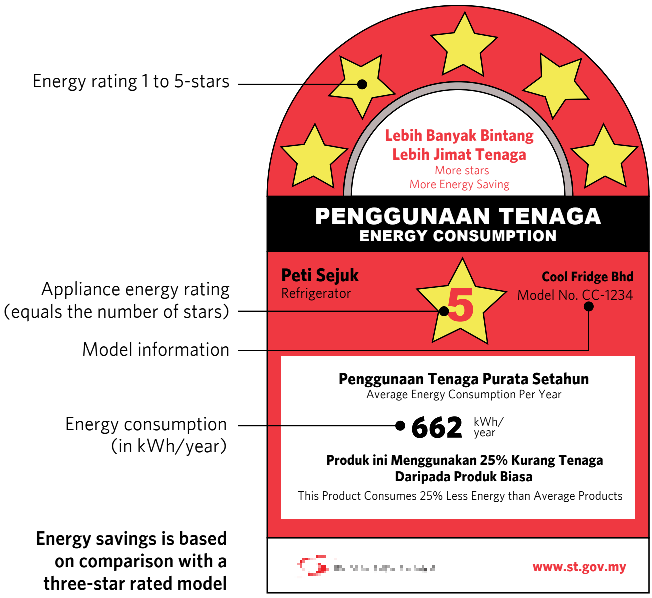
MALAYSIAN GREEN LABEL SCHEME

Malaysia's Prime Minister Datuk Seri Najib Razak, launched the Ministry of Energy, Green Technology and Water's (KeTTHA) Greentag label, which will aid the consumers in identifying and selecting products, as well as services based on environmental factors. The Greentag label encourages and promotes environmentally friendly goods and services. The label will permit consumers to identify and select products and services based on environmental factors and aid them in making more responsible purchasing decisions that will eventually reduce carbon emissions.

The products that are included in Greentag are: electrical appliances, food and beverage, construction materials, household products, stationery and office supplies, furniture and packaging, clothing, agricultural and sustainable timber products. The businesses with products and services that are certified with the Greentag label are in a position to benefit from improved eligibility for green procurement projects in the future, as well as be able to market their products under the Greentag label *(Malaysia launches green labelling scheme, Green Prospects, 2012).*

ENERGY EFFICIENCY LABELS

KeTTHA has developed an EE label as a way of informing consumers on what constitutes an energy-efficient appliance. The EE label is based on a star rating, with the most efficient appliances having five-stars.



The Energy Commission's six year-old energy efficiency label is still not compulsory for electrical appliances, manufacturers and importers *(Conserve Energy and Reduce Costs, Save Energy Save Money, Ministry of Energy, Green Technology and Water, 2013)*

SAVE REBATE PROGRAMME

SAVE or Sustainability Achieved Via Energy Efficiency, is a programme that is led by the Ministry of Energy, Green Technology and Water (KeTTHA) to improve energy efficiency in Malaysia. 100,000 rebate vouchers for 5-Star rated refrigerators, and 65,000 vouchers for 5-Star rated air-conditioners were allocated to states across Malaysia. The programme commenced on the 7th of July 2011 and ended at the end of 2012. There were more than 4,000 retail outlets nationwide that were registered with KeTTHA under the SAVE Rebate Programme, with 12 different brands for the consumers to choose from *(SAVE Rebate Programme, Tenaga Nasional Berhad, 2013)*.

TABLE 3.3 | SAVE REBATE PROGRAMME REBATES AND ELIGIBILITY

REBATE	ELIGIBILITY
Refrigerator (RM200/unit) Quantity: 100,000 units	• Only Malaysian households that consume an average of 200-400kWh of electricity per month in Peninsular Malaysia • All Malaysian domestic users registered with SESB or SESCO in Sabah, Labuan and Sarawak • Models with capacity up to 400 litres only
Air-conditioner (RM100/unit) Quantity: 65,000 units	• Models capacity up to 2.5 horsepower only • All Malaysian households in Peninsular Malaysia, Sabah and Sarawak
Chiller (RM200/RT) Quantity: 72,000 RT	• Registered private entities in Malaysia • Chiller for air conditioning systems in commercial buildings for comfort cooling only

ENERGY EFFICIENCY OF OFFICE EQUIPMENT

Office equipment such as computers, printers and copiers can generate high heat gains in a building. Unfortunately, the actual power consumption is rarely reflected on the nameplate of office equipment.[5] In general, office equipment with a nameplate power rating up to 480W has been found to consume less than 100W during use. The actual proportion of the total heat gain to the stated nameplate ranges from 25% to 50%. This could lead to an oversizing of the cooling load if the nameplate power is used at the design stage. The actual power consumption of each office's equipment should be evaluated based on the type and model of equipment as it can vary, as well as the operating hours, taking into account the sleep/standby mode.

For instance, desktop computers' power consumption in operation could vary from about 50W to 100W. **Table 3.4** below, reproduced from the 2009 ASHRAE Handbook, presents typical computer power consumption values versus the nameplate values. It shows that the actual power consumption of office equipment only is about 10% to 15% of the nameplate value.

TABLE 3.4 | NAMEPLATE VERSUS MEASURED ENERGY USE FROM TYPICAL COMPUTER EQUIPMENT (2009 ASHRAE HANDBOOK - FUNDAMENTALS, TABLE 8)

Equipment	Description	Nameplate Power Consumption (W)	Average Power Consumption (W)
Desktop Computer	Manufacturer A (Model A); 2.8 GHz processor, 1 GB RAM	480	73
	Manufacturer A (Model B); 2.6 GHz processor, 2 GB RAM	480	49
	Manufacturer B (Model A); 3.0 GHz processor, 2 GB RAM	690	77
	Manufacturer B (Model B); 3.0 GHz processor, 2 GB RAM	690	48
	Manufacturer A (Model C); 2.3 GHz processor, 3 GB RAM	1200	97
Laptop Computer	Manufacturer 1; 2.0 GHz processor, 2 GB RAM, 430mm screen	130	36
	Manufacturer 1; 1.8 GHz processor, 1 GB RAM, 430mm screen	90	23
	Manufacturer 1; 2.0 GHz processor, 2 GB RAM, 355mm screen	90	31
	Manufacturer 2; 2.13 GHz processor, 1 GB RAM, 355mm screen, Tablet PC	90	29
	Manufacturer 2; 366 MHz processor, 130 MB RAM, 355mm screen	70	22
	Manufacturer 3; 900 MHz processor, 256 MB RAM, 265mm screen	50	12
Flat-Panel Monitor	Manufacturer X (Model A); 760mm screen	383	90
	Manufacturer X (Model B); 560mm screen	360	36
	Manufacturer Y (Model A); 480mm screen	288	28
	Manufacturer Y (Model B); 430mm screen	240	27
	Manufacturer Z (Model A); 430mm screen	240	29
	Manufacturer Z (Model C); 380mm screen	240	19

[5] ASHRAE's research project RP-1055.

TABLE 3.5 | NAMEPLATE VERSUS MEASURED ENERGY USE FROM TYPICAL LASER PRINTERS & COPIERS (2009 ASHRAE HANDBOOK - FUNDAMENTALS, TABLE 9)

Equipment	Description	Nameplate Power Consumption (W)	Average Power Consumption (W)
Laser Printer, typical desktop, small-office type	Printing speed up to 10 pages per minute	430	137
	Printing speed up to 35 pages per minute	890	74
	Printing speed up to 19 pages per minute	508	88
	Printing speed up to 17 pages per minute	508	98
	Printing speed up to 19 pages per minute	635	110
	Printing speed up to 24 pages per minute	1,344	130
Multifunction (copy, print, scan)	Small, desktop type	600	30
	Small, desktop type	40	15
	Medium, desktop type	700	135
Scanner	Small, desktop type	19	16
Copy Machine	Large, multiuser, office type	1,750	800 (idle 260)
	Large, multiuser, office type	1,440	550 (idle 135)
	Large, multiuser, office type	1,850	1,060 (idle 305)
Fax Machine	Medium	936	90
	Small	40	20
Plotter	Manufacturer A	400	250
	Manufacturer B	456	140

The energy consumption of personal laser printers in offices varies between 75W to 140W, and the average power consumption of 110W is recommended to be used. Power consumption for the large photocopy/printer machines ranges from about 550W to 1,100W in copy mode while the idle mode varies from 130W to 300W. Nameplate values do not represent actual power consumption and hence it should not be used to estimate energy consumption in buildings.

The actual power consumption is rarely reflected on the nameplate of office equipment. It is shown that the actual power consumption of office equipment is only about 10% to 15% of the nameplate value.

Table 3.6 below compares energy star rated printers to those that are not energy star rated.

TABLE 3.6 | COMPILED DATA FROM VARIOUS MANUFACTURING WEBSITES ABOUT ENERGY CONSUMPTION OF PRINTERS

Printer	Energy Star	PPM (Pages Per Minute)	"Ready" Power Consumption (Avg.)	Printing Power Consumption (Avg.)
HP LaserJet Pro CP1025 Colour Printer	Yes	16	8W	295W
HP LaserJet Pro 400 Printer M401dw	Yes	33	7.3W	570W
Canon LBP6000	No	19	1.6W	850W
Samsung ML-2165W	No	21	<30W	<310W

Based on **Table 3.6** above, it can be concluded that for printers in the same category, printers with the Energy Star rating consume less power in "Ready" and print mode.

TABLE 3.7 | COMPARISONS OF DESKTOP AND NOTEBOOK POWER USAGE[6]

Make & Model	Type	Basic Specifications	Average Power Usage (Watts)
Dell OptiPlex 9010 w/Dell LCD (purchased mid 2012)	Desktop	Core i7, 8.0 GB RAM, Windows 7 Ultimate (clean)	66
Apple iMac/Intel 27-inch (purchased late 2009)	Desktop	Core i5, 4.0 GB RAM, 500 GB hard drive, OS X 10.7.4 (clean)	92 - 96
Dell OptiPlex GX270 w/17-inch Dell LCD (purchased mid 2003)	Desktop	Pentium 4, 1.0 GB RAM, 100 GB/7200 RPM hard drive, UltraSharp 1703FP display, Windows XP Professional SP1 (clean)	104 - 162
Dell XPS 12	Notebook	2.6 GHz Core i5, 8.0 GB RAM, 256 GB solid state drive, Windows 8 Pro 64-bit (dirty)	38 - 40
Apple MacBook Pro 13-inch "Retina" (purchased mid 2012)	Notebook	2.5 GHz Core i5, 8.0 GB RAM, 256 GB solid state drive, OS X 10.8.3 (dirty)	49 - 53
Apple MacBook Pro 15-inch (purchased early 2008)	Notebook	2.5 GHz Core 2 Duo, 4.0 GB RAM, 250 GB/5400 RPM hard drive, OS X 10.5.6 (dirty)	55 - 58

From **Table 3.7**, it is interesting to note that desktop systems have a higher power consumption than notebooks. This is because most manufacturers have focused on designing mobile devices such as notebooks with low power consumption to increase battery life. By using notebooks in the office rather than desktop systems, employees are able to get basic word processing, spread sheets and other rudimentary functions achieved with lower power consumption. The drawback is that notebooks generally lack processing power compared to desktops which would be unsuitable for offices which require such processing power such as visual designers and video editors.

It is also important to note that newer computer systems are getting more energy efficient. The newer motherboards and CPUs are more energy efficient due to newer manufacturing processes. Intel Core i7 and Haswell chips are known to be very energy efficient. In addition, todays computer operating systems have very good energy management software built-in. Energy management software, when activated, will put the computer to sleep, hibernation or shut down automatically when the computer is not in use for a set amount of time. By investing into newer technologies, companies will benefit from energy savings in the long run.

[6] http://www.upenn.edu/computing/provider/docs/hardware/powerusage.html

SUMMARY

Energy labelled equipment has an advantage by giving consumers greater awareness about the energy requirements of the product and give a clear indication of its energy efficiency, allowing consumers to make an informed choice. Both the European Union Commission and the Environmental Protection Agency have set stringent standards for appliances to be given their respective ratings which far surpass conventional standards. By favouring energy labelled equipment, a consumer is assured that the product has been tested and proven to be energy efficient. This also leads to energy savings in the long term which offsets short term losses in terms of higher initial price points, and at the same time also reduces CO_2 emissions that cause global temperatures to rise.

Aside from taking the green procurement route, many buildings can benefit from the easiest fix, which is to "**Switch Things Off**" and "**Turn Things Down**".

By favouring energy labelled equipment, a consumer is assured that the product has been tested and proven to be energy efficient

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END OF CHAPTER 3

CHAPTER

4

EFFICIENT LIGHTING DESIGN STRATEGIES

by CK Tang & Nic Chin

4

EFFICIENT LIGHTING DESIGN STRATEGIES

INTRODUCTION

There is a very common misconception in the Malaysian building industry (even amongst engineers) that only a portion of electricity consumed by the lights ends up as heat in a room. It is also common for Malaysian air-conditioning engineers to use a higher lighting power density to size the air-conditioning load than as actually installed in the building. Such an assumption seems to say that electrical lighting would produce more heat energy than the electrical energy consumed by it. Unfortunately both of these assumptions are fundamentally incorrect.

The 1st law of thermodynamics says that energy cannot be created or destroyed; therefore 100% of electricity used by the lighting appliance will become heat in the room where the electrical energy is consumed. Since the first explicit statement of the 1st law of thermodynamics in the 1850s by Rudolf Clausius, it has never been proven wrong until today. Even the findings of Higgs Bosons (nicknamed the "god particle", smallest particle ever discovered) and the entire universe of galaxies and planetary systems does not violate the 1st law of thermodynamics. Therefore, please have faith in the 1st law of thermodynamics and do not invent new theories or make assumptions that go against the 1st law of thermodynamics until some scientist can prove otherwise. If it ever does happen, it will be gigantic news because it would then be possible to create more energy than the energy used.

In short, the same amount of electricity used by the lights will end up as heat in the building. Therefore, reducing the power consumption of lights in a building will also reduce the cooling load of the building, providing double benefits. It is highly desirable, especially in this climate, to ensure that the electrical lighting power consumption is as low as possible in a building. In addition, an efficient lighting design will provide savings in air-conditioning peak load capacity and will reduce the capital cost of air-conditioning equipment.

This chapter provides the fundamental steps to create an efficient and effective lighting system. It provides a summary on:

- Lighting terminologies
- Lighting technologies
- Lighting controls, and
- Current energy efficiency status of LED lighting systems

KEY RECOMMENDATIONS

There are just two (2) rules in the design of an energy efficient lighting system that will lead to efficient lighting in a building:

1. **Ensure installed lighting power density (W/m^2) is as low as possible while providing the required amount of light and quality.**

2. **Ensure that electrical lights are switched off when they are not required.**

The first rule is to ensure that the installed lighting power densities are as low as possible for a building within the budget available.

As a recommendation, **Table 4.1** below shows the lighting power densities in an office space that can be achieved today to light up an office space with an average of 350 lux level.

TABLE 4.1 | RECOMMENDED TYPICAL EFFICIENT LIGHTING POWER DENSITY FOR AN OFFICE SPACE

For Office Spaces with an Average of 350 lux	Typical Efficient Lighting Power Density (W/m^2)
Lighting Fittings that follows Ceiling Grid	7 to 9 W/m^2
Lighting Fittings that does not need to follow Ceiling Grid	4 to 6 W/m^2

Reduction of lighting power density also directly reduces cooling load and energy use in a building. The reduction of 1 kW of installed lighting power in building would contribute to the following:

1. Peak load reduction of 1 kW of sensible heat.
2. Energy reduction in an air-conditioned area can be estimated using **Equation 4.1** below.

EQUATION 4.1

$$ER = LPR \times H + \frac{LPR \times H}{SCOP}$$

Where:
ER = Energy Reduction in a year (kWh)
LPR = Lighting Power Reduction (kW)
H = Hours of use in a year
SCOP = Average Operating Air-Conditioning System Coefficient of Performance*

**For a typical Split Unit System, use a value of 3.0 for SCOP, if a full chilled water system is used, the SCOP may be as high as 6.0 in this climate zone. Please consult with your air-conditioning system designer for the most accurate value to use.*

Lifecycle costing, financial payback or internal rate of return should be computed using **Equation 4.1** to estimate the feasibility of implementing low lighting power densities in a building.

The second rule of energy efficiency in lighting systems is to ensure that lightings are switched off when they are not required, especially when a space is not in use or when daylight provides adequate lighting levels for the space. This can be achieved by ensuring that lightings are zoned according to the opportunities of having them switched off using manual switches, motion sensors or photocell sensors.

USEFUL LIGHTING TERMINOLOGIES

It is useful to understand the following lighting terminologies that are commonly used in the building industry for lighting design:

1 CANDELA

The candela (cd) is the standard unit of luminous intensity in the International System of Units (SI). It is scientifically defined as the magnitude of an electromagnetic field, in a specified direction, that has a power level of 1/683 watt (1.46 x 10 -3 W) per steradian at a frequency of 540 terahertz (540 THz or 5.40 x 10 14 Hz). Luminous intensity is a measure of the power emitted by a light source in a particular direction based on a standardised model of the human eye to the visible wavelength.

For the rest of us, one unit of candela is roughly equivalent to the luminous intensity of a typical candle light.

2 LUMEN

The lumen is a measure of the total “amount” of visible light emitted from a source. It is defined by **Equation 4.2** shown below.

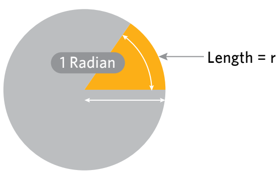
EQUATION 4.2

$$\text{Lumen} = \text{cd.sr}$$

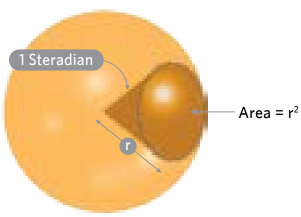
Where:
cd = candela
sr = steradian (measurement of an unit angle in 3D spherical coordinate system)

A steradian is related to the surface area of a sphere in the same way a radian is related to the circumference of a circle.

A **Radian** “cuts out” a length of a circle’s circumference equal to the radius.



A **Steradian** “cuts out” an area of a sphere equal to the radius $(radius)^2$.



For a perfect sphere, the Area of a sphere’s surface is always 4π.

In short, a lumen describes how much light is provided per unit angle in a 3D spherical coordinate system.

Most lighting devices sold in Malaysia provide the lumens output on its packaging. This indicates how much light is being emitted by the lighting device. The higher the lumens, the more light is provided. Different manufacturers have slightly different lumen outputs for the same technology used.

A typical 1,200mm T8 fluorescent light tube produces approximately 2,550 lumens. If this light is distributed in perfectly spherical distribution, its equivalent in candela is:

$$\text{Candela} = \frac{2{,}550 \text{ lumens}}{4\pi} = 199 \text{ candle light equivalent}$$

3 LUX LEVEL (ILLUMINANCE)

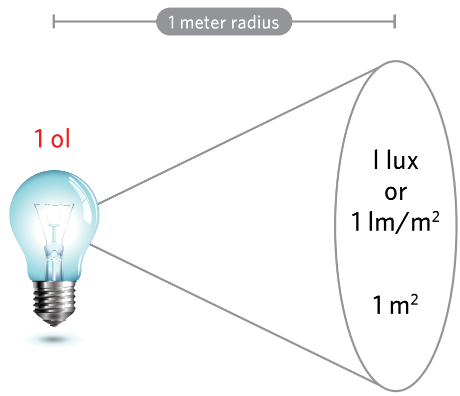
The lux is a measurement of luminous flux per unit area at a distance from the light source. It is defined as:

EQUATION 4.3

$$\text{Lux} = \frac{\text{Lumen}}{\text{m}^2}$$

The lux level defines the brightness level of a point in space. The lux level requirement is normally provided on the working plane of a space. For an office space, the lux level provided defines the brightness on the horizontal surface of a table top.

FIGURE 4.1 | 1 LUX IS MEASURED AT A DISTANCE OF 1 METER RADIUS FROM A 1 CANDELA LIGHT SOURCE



Illuminance (or lux level) is the typical indicator of brightness level and is normally measured at table top height or at working level (or position). A sample of typical lux level requirement from the Malaysian MS 1525[1] is provided in **Table 4.2** below:

TABLE 4.2 | RECOMMENDED LUX VALUES IN MS 1525

Task	Illuminance (Lux)	Example of Applications
Lighting for infrequently used area	100	Interior walkway and carpark
	100	Entrance hall, lobbies, waiting room
Lighting for working interiors	200	Infrequent reading and writing
	300 - 400	General offices, shops and stores, reading and writing
	200	Restaurant, Canteen, Cafeteria
	100	Toilet
	100	Bedroom
	300 - 500	Classroom, Library
	200 - 750	Shop, Supermarket, Department Store
	300	Museum and Gallery

[1] Malaysian Standard (MS) 1525, Energy Efficiency for Non-Residential Buildings, available from Sirim Berhad.

4 LAMP

A lamp is a light emitting device. Fluorescent tubes, incandescent bulbs and solid state lighting (LED) diodes are considered as lamps. Most suppliers of lamps provide the lumens output and the power consumption on their packaging and brochures as a quick indicator of their efficiency.

5 LUMINOUS EFFICACY

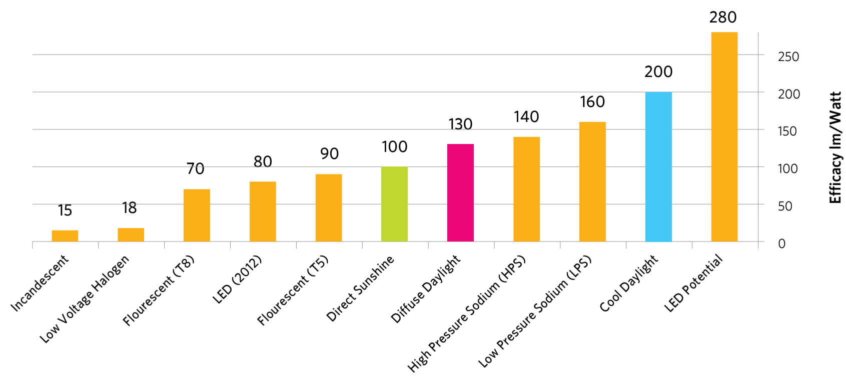
Luminous Efficacy is an indicator of the efficiency of the lamps. It is defined as:

EQUATION 4.4

$$\text{Efficacy} = \frac{\text{Lumen}}{\text{Watt}}$$

The higher efficacy values indicate higher efficiency, producing more light for the same energy used. Typical luminous efficacy values are as shown in **Figure 4.2** below.

FIGURE 4.2 | TYPICAL LUMINOUS EFFICACY OF VARIOUS LIGHT SOURCES



6 COLOUR RENDERING INDEX (CRI)

The Colour Rendering Index (CRI) is a measure of a light source's ability to show object colours "realistically" or "naturally" compared to a familiar reference source, either incandescent light or daylight. It is based on a scale of 0 to 100, where 100 is the natural colour under natural daylight.

TABLE 4.3 | COLOUR RENDERING INDEX PERFORMANCE AND USE

CRI	Importance	Typical Usage
90 to 100	Accurate colour matching	Galleries, medical examinations, colour mixing, retail
80 to 90	Accurate colour judgement	Home, hotels, offices, schools
60 to 80	Moderate colour rendering	Industry, offices, schools
40 to 60	Accurate colour rendering is of little importance	Industry, sports halls
20 to 40	Accurate colour rendering is of no importance	Street lighting

In most instances, a minimum CRI of 80 is recommended for office spaces.

7 LUMINAIRE LIGHT OUTPUT RATIO

A luminaire (light fitting/fixture) is a casing that houses the lamp(s). Most luminaires have reflectors to direct the light in the desired direction and some may also contain aperture and ballast housing as well. Depending on the type of luminaire used, up to 50% of the light emitted by the lamp may be lost in the luminaire itself. Lighting suppliers will be able to provide the output efficiencies of their luminaires. The Light-Output-Ratio (LOR) is normally provided by the light fitting suppliers as an indicator of the output efficiency.

EQUATION 4.5

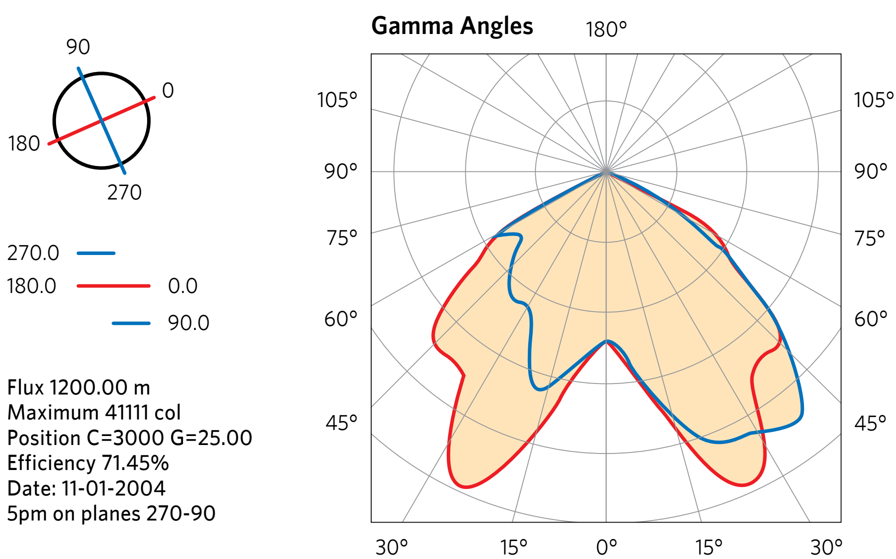
$$\text{LOR} = \frac{\text{Output of Luminaire}}{\text{Output of Lamp}}$$

A higher or lower LOR can have a dramatic effect on how many luminaires are required to achieve the same light level for the same area. However, depending on the room's shape and size, it may not always be necessary to use the best LOR luminaire. Luminaires with a LOR above 90% are available in the Malaysian market.

8 PHOTOMETRIC DISTRIBUTION (POLAR CURVE)

It is most useful to display photometric distribution of luminaire in polar curve diagram as indicated below. This diagram illustrates the distribution of luminous intensity, in candelas, for the transverse (red line) and axial (blue line) planes of the luminaire. These curves provide a visual guide to the type of distribution expected from the luminaire (e.g. wide, narrow, direct, indirect etc.) in addition to the intensity.

FIGURE 4.3 | TYPICAL POLAR CURVE OF LIGHT FITTINGS



9 GLARE INDEX

Glare evaluation can be quite subjective and varies from person to person. For example, older folks are more sensitive to glare than younger persons because their irises are no longer as flexible. The International Commission on Illumination (CIE) defines glare as:

> **"Visual conditions in which there is excessive contrast or an inappropriate distribution of light sources that disturbs the observer or limits the ability to distinguish details and objects."**

There are many types of glare indices used by the lighting industry, such as the CIE Glare Index, CIBSE Glare Index, Visual Comfort Probability (VCP), etc. that are used as a measurement guide for glare. In recent years, the Unified Glare Rating (UGR) as recommended by the CIE has become most widely accepted as a general formula for assessing glare. The formula is given below:

EQUATION 4.6

$$UGR = 8log\frac{0.25}{L_b}\Sigma_n(\frac{L_n^2\omega_n}{p_n^2})$$

Where:
L_b = background luminance
L_n = luminance of each light source numbered n
ω_n = the solid angle of the light source seen from the observer
p_n = Guth position index

This formula requires the prior knowledge of the position and brightness of each potential glare source. It is quite accurate but relatively difficult to work with. It is best used from within some computer software. Such software packages exist from most major producers of light fittings. These softwares require the modelling of the scene under investigation and produces a glare index for a defined position within a room.

The recommended maximum allowable Unified Glare Index (UGR) is provided in **Table 4.4** below.

TABLE 4.4 | MAXIMUM ALLOWABLE UNIFIED GLARE INDEX (UGR) FOR DIFFERENT TYPE OF SPACES

Working Area	Maximum allowed UGR
Drawing rooms	16
Offices	19
Industrial work, fine	22
Industrial work, medium	25
Industrial work, coarse	28

Most luminaire suppliers can provide the maximum UGR computation of their luminaires for any designed space.

10 LIGHTING POWER DENSITY

Lighting power density (LPD) is defined as the installed lighting power per square meter of a space.

EQUATION 4.7

$$\text{LPD} = \frac{\text{Lighting Power (watt)}}{\text{Area (m}^2\text{)}}$$

This is a useful indicator of the efficiency of the installed lighting system. The MS 1525[2] have specified the maximum allowable LPD for different types of spaces. A sample is reproduced herewith:

TABLE 4.5 | A SELECTION OF LIGHTING POWER DENSITY FROM MS 1525

Type / Space Type of Usage	Maximum lighting power density W/m^2
Offices	15
Supermarkets/ Department Stores/ Shops	25
Stores/ Warehouses/ Stairs/ Corridors/ Lavatories	10
Car Parks	5

Documents such as MS 1525 and ASHRAE 90.1 provide recommendations on the maximum allowable installed lighting power density. Unfortunately, they do not provide an indication of how low the lighting power density can be. As a reference guide, the Malaysian Green Technology Centre (MGTC) in Bangi, has an installed lighting power density of 4.8 W/m^2, while providing an average of 350 lux level on the tables.

[2] Malaysian Standard (MS) 1525, Energy Efficiency for Non-Residential Buildings, available from Sirim Berhad.

TYPES OF LIGHTING TECHNOLOGY

1 INCANDESCENT BULB

Incandescent bulbs are manufactured in a wide range of sizes, light outputs, and voltage ratings, from 1.5 volts to about 300 volts. They require no external regulating equipment, have low manufacturing costs, and work equally well on either alternating current or direct current. As a result, the incandescent bulb is widely used in household and commercial lighting, for portable lighting such as table lamps and flashlights, car headlamps, and for decorative and advertising lighting. However, incandescent bulbs have very low luminous efficacy and it will be banned from use in many nations around the world within the next 5 years.

2 HALOGEN LAMP

A halogen lamp, also known as a tungsten halogen lamp or quartz iodine lamp, is an incandescent lamp that has a small amount of a halogen added chemically through iodine or bromine. The combination of the halogen gas and the tungsten filament produces a halogen cycle chemical reaction which redeposits evaporated tungsten back onto the filament, increasing its life and maintaining the clarity of the envelope. Because of this, a halogen lamps can be operated at a higher temperature than a standard gas-filled lamp of similar power and operating life, producing light of a higher luminous efficacy (than incandescent bulbs) and higher Colour Rendering Index (close to 100). Due to its small size and very good CRI values, its use is very popular among retail shop owners and interior designers to bring out the quality of products or spaces being displayed.

3 FLUORESCENT LAMP

A fluorescent lamp or fluorescent tube is a low pressure gas-discharge lamp that uses electricity to excite mercury vapour. The excited mercury atoms produce short-wave ultraviolet light that then causes a phosphor to fluoresce, producing visible light. A fluorescent lamp converts electrical power into useful light much more efficiently than incandescent bulbs. The luminous efficacy of a typical fluorescent light tube is about 60-100 lumens per watt, 4-7 times the efficacy of a typical incandescent bulb.

The conventional fluorescent lamps used in Malaysia is known as the T8 type. The T8 lamps are 1 inch (26 mm) in diameter and come in several lengths. The most common T8 length used in Malaysia is 48 inches (1,200 mm) and consume 36 watts (46 watts including the use of a conventional magnetic ballast).

A cost effective and energy efficient replacement of T8 is a T5 fluorescent lamp. The T5 lamps are 5/8 of an inch (16 mm) in diameter and also come in several lengths. The T5 lamp replacement of 48 inch (1,200 mm) T8 is slightly shorter at 1,149mm in length and only consumes 28 watts (31 watts including the use of typical electronic ballast), while producing a similar lumens output of a typical T8 lamp. Retrofits of existing T8 light fixtures into T5 will require an adapter to extend the length of T5 into T8 light fixtures and the use of electronic ballasts instead of magnetic ballasts. Adopters of this technology are cautioned to test out the solution to ensure that it provides similar or better performance (on energy efficiency, lux level, life-span and power quality) before implementing it for the whole building.

Ballast

Both T8 and T5 fluorescent lamps require a ballast (electronic gear) to start and maintain the light source from the lamp. While it is possible to use either magnetic or electronic ballasts for T8, the T5 will only work with electronic ballasts. Magnetic ballasts have traditionally been consuming up to 12 watts in operation, however, newer low-loss magnetic ballasts have reduced the amount to below 6 watts.

Electronic high-frequency ballasts typically increases the combined lamp-ballast efficacy, leading to increased energy efficiency and lower operating costs. Electronic ballasts operate lamps using electronic switching power supply circuits. Electronic ballasts are typically more efficient than magnetic ballasts in converting input power to the proper lamp power, and it operates the fluorescent lamps at higher frequencies reducing end losses, resulting in an overall lamp-ballast system efficacy increase of 15% to 20% compared to conventional magnetic ballasts.

Electronic ballasts have a number of other advantages over magnetic ballasts. Electronic ballasts are readily available that can operate three or four lamps, allowing the use of a single ballast in 3-lamp and 4-lamp luminaires. It also allows fluorescent lamps to be dimmed. Other advantages of the electronic ballast include reduced weight, quieter operation, and reduced lamp flicker. Electronic ballasts are directly interchangeable with magnetic ballasts, and they are able to operate full-size and also compact fluorescent lamps.

Recently, manufacturers of magnetic ballasts have introduced low-loss magnetic ballasts with a similar efficiency as electronic ballasts; unfortunately, they cannot be coupled with T5 lamps and will only operate on T8 lamps. It is also relevant to state that certain high performance T8 lamps in combination with low-loss magnetic ballasts have been known to challenge and even surpass the efficiency of conventional T5 lamps with electronic ballasts. Therefore, designers are recommended to base their energy efficiency decision on **the lighting power density and cost rather than just on the technology used.**

4 COMPACT FLUORESCENT LAMP

A compact fluorescent lamp (CFL) is also called a compact fluorescent light, energy-saving light, and compact fluorescent tube. It is basically a fluorescent lamp designed to replace an incandescent bulb; many types fit into light fixtures formerly used for incandescent bulbs. The lamps use a tube that is curved or folded to fit into the space of an incandescent bulb, and a compact electronic ballast is built into the base of the lamp. It has a luminous efficacy 3-4 times higher than an incandescent light bulb. CFL are mainly divided into two major types, integrated ballast CFL and non-integrated ballast CFL. Most plug-in pin based CFL with non-integrated ballasts are dimmable.

5 METAL-HALIDE LAMP (HID)

A metal-halide lamp is a type of High Intensity Discharge (HID) lamp that has a typical luminous efficacy of 70-110 lumens per watt, offers moderately long bulb life (6,000 to 20,000 hours) and produces an intense white light. Two types of burners are typically available for metal-halide lamps, ceramic or quartz. Ceramic lights are a newer generation of metal halide lights and are claimed to be designed to be more efficient than quartz.

As one of the most efficient sources of high CRI white light, metal-halides are popular lamps in the lighting industry. They are often used for wide area overhead lighting of commercial, industrial, and public spaces such as parking lots, sports arenas, factories and retail stores, as well as for residential security lighting and automotive lighting. Metal-halide lamps take up to several minutes to "warm-up" to produce a full lumens output and therefore are not suitable for office spaces or residential homes, where "near full brightness" are expected immediately upon switching on the lights. Finally, some manufacturers of metal-halide do not recommend dimming for this type of lamp, while others says that it is possible to dim it down to 33% of the full output.[3]

6 SODIUM-VAPOUR LAMP

A sodium-vapour lamp is also another type of High Intensity Discharge (HID) lamp that uses sodium in an excited state to produce light. There are two varieties of such lamps: low pressure and high pressure. Low-pressure sodium lamps are very efficient electrical light sources, offering efficacies up to 160 lumens per watt, but their yellow light restricts applications to outdoor lighting such as street lamps. High-pressure sodium lamps have a broader spectrum of light but also offer poor colour rendering index. The CRI of sodium-vapour lamps is in the low range of 20 to 50. Dimming capability is easily available for high-pressure sodium lamps.

[3] 2002, David Houghton, PE, Architectural Lighting Magazine, Metal Halide - Advances & Improvements.

7 SOLID-STATE LIGHT (SSL)/ LIGHT EMITTING DIODE (LED)

A light-emitting diode (LED) is a semiconductor light source. It is also known as a solid-state light. LEDs appeared as a practical electronic component in the early 1960s and was only available in low-intensity red light, but modern versions are available across the visible, ultraviolet, and infrared wavelengths, with very high brightness.

Efficient LEDs in year 2012 has a typical luminous efficacy of 80 and is comparable to the efficacy of a T5 fluorescent tube. Unfortunately, LEDs cost approximately 8 to 10 times more than a T5 fluorescent tube at this point in time. Since it has similar efficacy to a T5 fluorescent tube, it does not offer a good payback to replace T5 fluorescent tubes with LEDs. Until LEDs performance improves further and the cost is significantly reduced, it will not be justifiable to use LEDs as a replacement for fluorescent tube in offices. In addition, a report published by the U.S. Department of Energy in December 2011 recommends that it is not financially feasible in December 2011 to use LEDs as street lights in replacement of high pressure sodium lights (typical street lighting).[4]

In the current scenario, it is recommended to ask for the LED's CRI, lamp efficacy and the installed lighting power density, for the spaces that LED is proposed to be used. Different manufacturers will provide different CRI at different lamp efficacies. As this is a fast changing technology, the numbers may differ significantly between manufacturers.

LED technology is improving very fast and is expected have improved CRI performance and higher lamp efficacy very soon. Lighting designers should keep abreast of LED technological advancement because it is likely that it will become financially feasible to use it as a primary lighting source for office spaces in the coming years and has the potential to change the whole building lighting scenario drastically with its small size, potentially higher efficiency and higher CRI performance.

Heat Dissipation for LED lamps

The life-span of LED lamps is highly dependent on its luminaire's ability to dissipate heat. Failure to provide adequate heat dissipation will reduce the lifespan of the LEDs significantly. Therefore, it is important to choose LEDs with good heat sink designs that will help to dissipate the heat from the diode to maximise the lifespan of a LED lamp.

Driver for SSL/LED

A LED driver is a self-contained power supply (typically at low voltages) that has outputs matched to the electrical characteristics of the LED or array of LEDs. Choosing the right driver (power supply) is the key to ensuring the best performance from the LED lamp. It is important to note that the long lifespan of LED lamps push manufacturers of power supply units to match it with similar lifespans.

LED drivers come in either Constant Current (CC) or Constant Voltage (CV) configurations. If strings of LEDs are used in series, the most efficient way to drive them is to use a constant current power supply. However, if strings of LEDs are connected in parallel, a constant voltage driver is recommended. The goal is to ensure identical current flows though the many LED strings in parallel to ensure similar light outputs. Constant current drivers are easily dimmable, while a constant voltage driver requires an additional switch for dimming function.

Finally, based on the specific use of the LEDs, the power supply unit may require additional features:

- Dust and water resistance
- Temperature dependent current regulation
- Voltage surge protection
- Power factor close to one
- High efficiency
- High reliability
- Long lifetime to match LED lifespan

8 INDUCTION LAMP

An induction lamp is basically an electrode-less fluorescent lamp. It is being marketed as a green solution by manufacturers namely because of it long lifespan. It is recommended to be used in spaces where re-lamping is expensive.

Advantages of induction lamps:

- Longer life: no electrodes. Electrodes fail in normal fluorescent lamps shortening life, the tungsten thins and brakes.
- Longer life: sealed tube, by not having electrodes the tube can be perfectly sealed. When seals fail in regular fluorescent lamps, gas escapes and the lamp fails.
- No flickering
- Dimmable
- Can light both small and large areas depending on which type of induction lamp

Disadvantages:

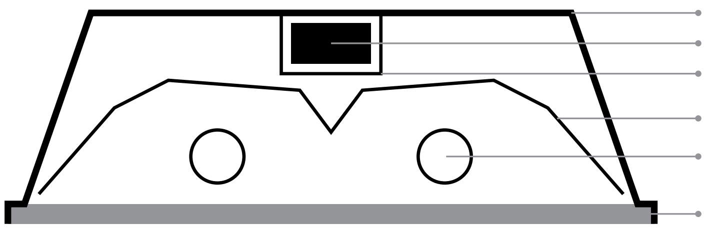
- Bulky design for large area lighting, the discharge tube is large compared to HID lamps.

[4] Assessment of LED Technology in Ornamental Post-Top Luminaires, Host Site: Sacramento, California, Prepared for the U.S. Department of Energy by Pacific Northwest National Laboratory, December 2011.

9 LIGHT FITTING/FIXTURE/LUMINAIRE

The luminaire, or light fitting as it is often referred to, is the equipment that physically supports the lamp and provides it with a safe connection to the electricity supply. It also provides protection for the lamp, particularly in hazardous areas and areas where broken glass would be a particular problem. Light fittings also provide the optical control that ensures the light is directed to where it is required as well as obstructing it from those areas where it is not needed. This involves the use of reflectors, refractors and/or diffusers. Most luminaires also have an appearance or style that can be an important consideration for the designer. A typical ceiling recessed luminaire is shown below.

FIGURE 4.4 | TYPICAL LUMINAIRE CROSS SECTION



The following luminaire technology and terminology is presented:

1 Specularity and Reflectivity of Reflectors

The material of the reflector will determine the specularity and reflectivity of the luminaire. Typical materials used are shown in **Table 4.6** below:

TABLE 4.6 | SPECULARITY AND REFLECTANCE OF DIFFERENT TYPES OF REFLECTORS

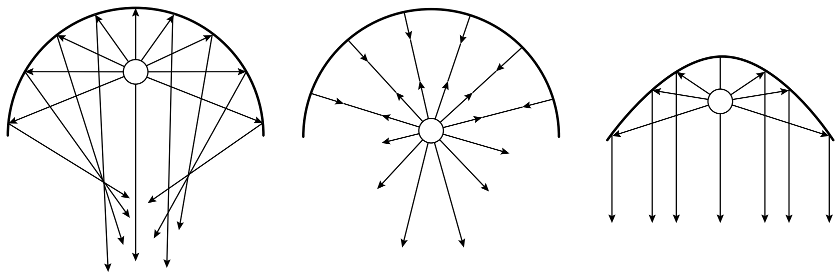
Material	Reflection Type	Typical Reflectance
Glossy white Enamelled Steel	Mixed Specular	0.85
Anodised Al	Specular	0.75
Stainless Steel	Mixed Specular	0.60
Silver (polished and anodised)	Specular	0.90
Aluminised Plastic	Specular	0.85
Super-purity Aluminium	Specular	0.95
White plastic Glossy white	Diffuse	0.90

Low reflectance values such as stainless steel (0.60) indicates that only 60% of the light is reflected, 40% is absorbed by the stainless steel and would end up as heat.

2 Reflector Design

The curvature and placement of the reflector will determine how the light is distributed and influence the polar curve of the luminaire.

FIGURE 4.5 | LIGHT REFLECTION OF VARIOUS TYPES OF REFLECTOR DESIGN

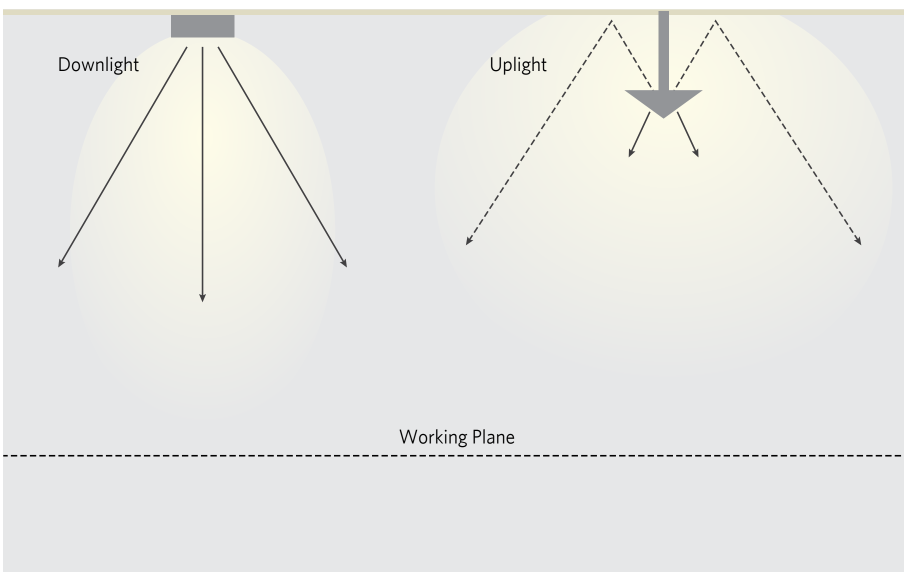


Certain reflectors are designed to deflect the light wide, while some are designed to concentrate the light at one point. For an office space, light deflectors should be matched with the lamp output and installation height of the luminaires, to ensure that the light level is evenly distributed and meets the minimum desired lux level while minimising the number of required luminaires.

3 Pendant Lighting for Offices

There is a trend towards pendant lights for offices in European countries and the USA. These pendant lights provide both up-light and down-light. The down-light is used to provide task illumination while the up-light provides light on the ceiling which will usually have a beneficial effect on the appearance of the room – it helps to make the place appear brighter, which is important to the satisfaction of the occupants.

FIGURE 4.6 | SCHEMATIC PERFORMANCE OF DOWNLIGHT AND UPLIGHT LUMINAIRES



SUMMARY OF LIGHTING TECHNOLOGY

Table 4.7 below displays the typical luminous efficacy, colour rendering index and working hours of different types of common lamps.

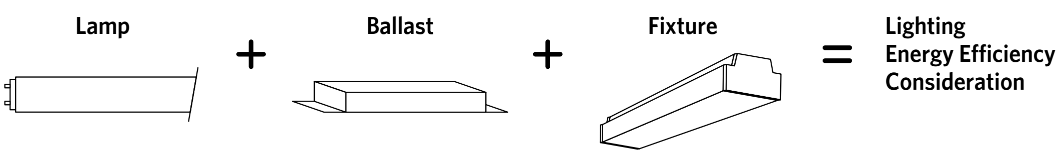
TABLE 4.7 | SUMMARY OF LUMINOUS EFFICACY AND CRI OF VARIOUS LIGHTING SOURCES

Type of Lamp	Luminous Efficacy*	CRI*	Working Hours*
Incandescent	8~15	100	750 ~ 2,000
Halogen	11~27	100	1,500 ~ 5,000
Compact Fluorescent	40~75	82	8,000 ~ 20,000
Fluorescent (T8)	60~90	50~98	10,000 ~ 75,000
LED (2012)	80	70~90	15,000 ~ 50,000
Induction Lamps	85	85	30,000 ~ 100,000
Fluorescent (T5)	73~114	70~90	10,000 ~ 45,000
Ceramic Metal-Halide	80~114	80~96	10,000 ~ 20,000
Direct Sunshine	100**	100	4.6 billion years
Diffuse Daylight	130**	100	
High Pressure Sodium (HPS)	70~150	24	14,000 ~ 32,000
Low Pressure Sodium (LPS)	100~177	10	12,000
Cool Daylight (diffuse daylight filtered by spectrally selective glazing)	200	100	4.6 billion years
LED Potential[5]	287 239	70 90	At this stage of development of SSL technology, we do not know exactly how long the products will last

* Number varies slightly between different manufacturers.
**For sunshine and daylight, it is the heat element for the lumens provided, since no electrical energy is required for sunshine and daylight. It is shown here to highlight that daylight is "cooler" than many electrical lights; unfortunately it is difficult to control the lumen level from direct sunshine, where too many lumens also means too much heat, while diffuse daylight is plentiful in Malaysia and it is also easier to control the amount of lumens provided by diffuse daylight.

In addition, the efficiency of a lighting system in an office space is a combination of these 3 major factors: lamp, ballast and luminaires (fixtures). Please keep in mind that specifying T5 lamps alone will not guarantee low energy usage. It is still best to specify the maximum allowable lighting power density to achieve the minimum lux level requirement for the desired office space and then allow the lighting designer, supplier and manufacturer to make the best offer.

FIGURE 4.7 | EFFICIENCY OF A TYPICAL OFFICE LIGHTING FIXTURE IS DEPENDENT ON THESE 3 ITEMS



[5] Solid-State Lighting Research and Development, Multi-Year Program Plan, Lighting Research and Development, Building Technologies Office, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy, April 2013.

LIGHTING CONTROLS

The function of lighting controls is to ensure that electrical lights are switched off when they are not required to be on. When rooms are not occupied or when daylight provides adequate lighting, the electrical lights should be switched off to save energy.

Depending on the situation, lighting control is as simple as providing adequate manual lighting switches, up to a complex system such as a combined system of motion and photosensors. In addition, the wiring circuitry of lighting should be carefully designed to allow lighting to be switched off without affecting occupied areas. It is often found that lights for certain areas cannot be switched off although they are not required (because the space is empty or adequate daylight is available) because they are connected to lighting circuits in occupied and/or non-daylight areas.

1 DIMMING CONTROLS

The advantage of using dimming technology is not significant in the Malaysian climate zone. Referring to Chapters 2 and 4 of the Passive Design Technical Guideline, the Malaysian sky is shown to be consistently bright most of the time from the hours of 8am to 5pm. In very rare instances, dimming is required to be used. In these instances, it is just as visually comfortable to just switch the lights on fully during these short intervals. The energy lost due to such short hours between dimming the lights and having them fully on is not significant in most cases.

However, in certain cases, dimming technologies have its advantages. For example, in China, they have recently implemented dimming controls for street lighting during the midnight hours and have documented that it does not increase discomfort or crime rates, whilst providing energy reduction.[6]

[6] Case Study of a Highly-Reliable Dimmable Road Lighting System with Intelligent Remote Control, Chung H.S.H., Ho N.M, Hui S.Y.R., Mai W.Z, e.Energy Technology Ltd, City University of Hong Kong, Municipal Management Bureau, Heshan City, 2005.

2 MANUAL SWITCHES

Providing manual switches requires the building occupants to have awareness on energy efficiency for it to work. In Malaysia, the best example use of manual switches is in our primary and secondary public schools, where the teachers are constantly ensuring that electrical lights are switched off whenever the daylight is adequate (most of the time, the class monitor is put in charge of it).

In a large company (i.e. with more than 20 employees), it may require significant effort to build up adequate awareness of energy efficiency to allow manual switches to work effectively.

Manual switches will only work when it is made convenient to switch lighting off. This means that manual switches should be placed strategically to allow building occupants walking out of their room to conveniently flick the switch off as they are walking out of the room, without requiring them to take any extra steps. In short, the lighting switch should be placed on the wall side close to the door handle. This means that if a door swings to the left, the manual lighting switch should be conveniently placed for the right hand to flick it off, and if a door swings to the right, the switch should be conveniently placed for the left hand to flick it off. The switch should be placed as conveniently as possible without requiring the building occupant to take even a single extra step to flick the switch off as they walk out of the room.

Where manual switches are used in daylight spaces, building occupants are required to be aware of energy efficiency and switch the lights off when daylight is adequate. Awareness or training programmes are encouraged to be conducted when this strategy is implemented for the first time. It is also useful to have a monitoring programme to show how much energy is saved due to the actions of the building occupants themselves.

If the building occupants cannot be depended on to switch lights off responsibly, then more advanced control systems such as occupancy and daylight sensors are required.

3 OCCUPANCY/MOTION SENSOR

Occupancy sensors are switching devices that respond to the presence and absence of people in the sensor's field of view. The system consists of a motion detector, an electronic control unit, and a controllable switch (relay). The motion detector senses motion and sends the appropriate signal to the control unit. The control unit then processes the input signal to either close or open the relay that controls power to the lights. The basic technology behind the occupancy sensor is derived from security systems developed for residential and commercial applications to detect intruders. However, the motion sensor has been refined so that it responds not only to the presence of occupants, but also to the absence of occupants in the space. Other enhancements of the technology have centered on reducing costs, increasing control intelligence, improving the ability to detect minor movements, and increasing adjustment capabilities.

Similar to photosensor, a "manual-on and auto-off" strategy is recommended for better energy efficiency. This strategy is also known as absence detection, requires the lights to be switched on manually by the building occupant via the manual switch. However, when the system detects that there is no movement in the room, it will automatically switch the lights off. This prevents the lights from being automatically switched on when a person only needs to retrieve a small item (pen, car key, hand phone, etc.) quickly from the room.

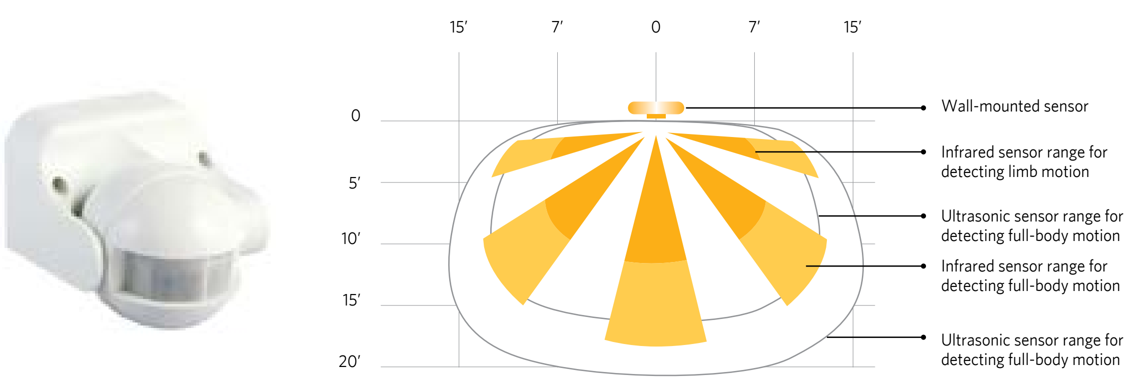
1 PASSIVE INFRARED (PIR)

Passive infrared (PIR) sensors react to the infrared heat energy emitted by people. PIR sensors are passive devices in that they only detect radiation; they do not emit it. They are designed to be maximally sensitive to objects that emit heat energy at a wavelength of around 10 microns (the peak wavelength of heat energy emitted by humans). PIR sensors are strictly line-of-sight devices. They cannot "see" around corners and a person will not be detected if there is an obstruction, such as a partition, between the person and the detector.

PIR sensors employ a pyroelectric transducer to detect infrared radiation. The device converts the IR energy into a voltage signal. A multi-faceted lens surrounds the transducer and focuses heat energy onto the detector. The lens views the area with a multitude of narrow and discrete beams or cones. As such, it does not view the area in a continuous fashion. As an occupant moves a hand, arm, or torso from one cone of vision to another, a positive signal is generated and sent to the controller. The detection pattern of PIR sensors is fan shaped – formed by the cones of vision seen by each segment of the faceted lens.

As shown in **Figure 4.8**, coverage gaps occur between the cones of vision of alternate segments of the lens. These gaps widen with distance. At 10m from the sensor, for instance, coverage gaps of up to 2m wide may be present. Since the sensor is most sensitive to motion that moves from one sensing cone to another, its sensitivity decreases with distance as the gaps between sensing cones widen. Most PIR sensors are sensitive to hand movement up to a distance of about 3.5m, arm and upper torso movement up to 6m, and full body movement up to about 13m. However, the sensitivity range of PIR sensors can vary substantially, depending on the product quality and electronic circuitry design.

FIGURE 4.8 | DETECTION AREA OF INFRARED AND ULTRASONIC SENSORS



2 ULTRASONIC SENSORS

Ultrasonic occupancy sensors activate a quartz crystal that emits ultrasonic waves throughout the space. The unit then senses the frequency of the reflected waves. If there is motion, the reflected wave's frequency will shift slightly (Doppler effect). Ultrasonic sensors operate at frequencies that are above human sensitivity (20 kHz). Typical operating frequencies are 25, 30, and 40 kHz.

Figure 4.8 shows the detection pattern of an ultrasonic sensor. The ultrasonic sound waves cover the entire area in a continuous fashion – there are no blind spots or gaps in the coverage pattern. For this reason, ultrasonic sensors are somewhat more sensitive to movement. For example, hand motion can be detected at a distance of about 8m, arm and torso motion detected at 10m and full body motion can be detected at over 13m. However, the sensitivity range of different products will vary significantly.

Comparisons between passive infrared (PIR) and ultrasonic occupancy sensors offer very similar characteristics in terms of overall performance. Ultrasonic sensors are more expensive, as a rule, but provide greater coverage than PIR detectors. However, increased sensitivity means that ultrasonic sensors are more susceptible to false triggering due to any movement in the space. For example, unless carefully calibrated, ultrasonic sensors will react to non-occupant movement such as breezes from open windows or HVAC systems. In most cases the sensitivity of the ultrasonic system, like the PIR system, is based on line-of-sight. In some circumstances, however, the movement of occupants behind partitions may be detectable by ultrasonic sensors, due to the reflectance of the emitted sound waves around the partitions.

3 OTHER SENSOR TECHNOLOGIES

In the lighting controls industry, passive infrared and ultrasonic sensors currently dominate the occupant sensor market. Sensors that use microwave and tomographic technologies are also available; however, at the present time, these are primarily limited to the security and alarm industries.

Hybrid occupant sensors, now available from many manufacturers, employ both infrared and ultrasonic capabilities in the same unit, offering improved operation with a minimal false triggering.

4 LIFE SPAN

It is difficult to adequately assess the life span of occupancy sensor systems. Life cycle testing procedures seem to suggest that a reasonable life span estimate for most occupancy sensors would range between 10 to 15 years.[7]

5 SUGGESTIONS

The price of motion sensors varies depending on the sensitivity requirements. For example, motion sensors for an office space requires detection of fine movement, whereas for a corridor space, the motion sensor is only required to detect large movements.

Motion sensors are particularly effective in spaces where the lights are typically left on when the space is unoccupied, such as infrequently used corridors or toilets.

It may be necessary in certain situations not to link all lights to the motion sensor, allowing a couple of lights to remain switched on at all times, so that the space will not be pitch black when the lights are switched off accidentally. In addition, it may also be unpleasant to walk into a pitch black room and have to wait a couple of seconds for the motion sensor to respond.

[7] Advanced Lighting Guidelines: 1993 (Second Edition), California Energy Commission.

4 DAYLIGHT SENSOR

Daylight sensors can detect a specific user-defined daylight level in a space and automatically switch lighting on, off or dim them. It uses photocell technology to measure the amount of available light.

When using a daylight sensor, it is very important to position the daylight sensor such that it is not confused by electrical lights. Designers should also be careful with motion sensors incorporated with both motion and daylight sensors as the 'viewing direction' for motion and daylight may be different.

For the Malaysian climatic zone with plenty of daylight from the hours of 8am to 6pm, the energy savings provided by dimming is rather small and is not required to be used. A simple on/off daylight sensor will provide very similar energy savings to a dimmable one.

When daylight is harvested in an office space, it is recommended to practice the strategy of "auto-off and manual-on". This means that the electrical lights are automatically switched off whenever the measured daylight is adequate, but to switch on the light when the daylight drops below the desired lux levels, the building occupants will have to go to the switch to flick it on manually. However, in public or common area spaces, it may be more convenient to program it to automatically switch the lights on as well when it drops below the desired lux value.

5 TIME DELAY SWITCH

Time delay switches can be quite useful for energy management of lighting. A time delay switch is a switch which incorporates a timer, allowing the user to delay off cycles of the switch. There are a number of different styles of delay switches available for a variety of applications, and many are very easy to configure so that users can get the switch to do exactly what they need it to.

Hotel backroom operations and common areas in buildings can use these time delay switches to turn corridor lights off when not in use, for example, giving people a set period of time after they turn the switch on to reach their destination before the lights are turned off automatically. Time delay switches can also be used in bathroom vanity mirrors and supply closets to ensure that lights aren't left on continuously while no one is present.

6 CENTRALISED LIGHTING MANAGEMENT

In medium to large buildings, it is useful to have a centralised lighting management system (LMS) incorporated into the building energy management system (EMS). This system can be pre-programmed with a fixed pattern to switch lights on/off for the entire building's common areas, accounting for weekdays, weekends and public holidays. Systems such as this will ensure that lights are switched off during non-occupancy hours. It is also common to link occupancy and daylight sensors to such a system to have a centralised control to optimise the efficiency of the lighting system for the building.

However, in office buildings, some occupants may be working late on certain nights and will require common areas such as corridor lights to be switched on until late as well. In such situations, a line of communication between the occupants and the building operator has to be established to allow adequate common area lighting for building occupants to exit the building safely. If this happens infrequently, it will not be expensive to allow common area lights to be switched on for a few nights a year.

However, if this kind of situation happens frequently, it will be very efficient to combine a centralised lighting control system with a motion sensor system. An agreement may be made such that a minimum amount of night lights are provided for the common areas, while the rest of the common area lights are fully controlled via motion sensors after typical working hours.

7 LOW AMBIENT LIGHT LEVEL & TASK LIGHTING

In 2009, Pacific Gas and Electric Company in the United States published a research paper on a Low Ambient/ Task Lighting Pilot Project that showed a significant increase in user satisfaction and reduction in energy consumption.[8] A summary of their study is provided in **Table 4.8** on the next page.

[8] Heschong Mahone Group, Large Office ("Ziggurat" Building) Site Report, High Efficiency Office: Low Ambient/Task Lighting Pilot Project, Pacific Gas and Electric Company, 2009.

TABLE 4.8 | SUMMARY OF RESEARCH ON LOW AMBIENT/ TASK LIGHTING

Description	Existing lighting	Low ambient/task lighting	Reduction %
Installed ambient lighting power density (W/m^2)	13.2	6.0	54%
Installed task lighting power density (W/m^2)	1.0	1.1	-11%
Total installed lighting power density (W/m^2)	14.2	7.1	50%
Lighting energy use intensity (kWh/m^2/yr)	42.0	18.3	56%
Peak lighting load (W/m^2)	13.6	7.0	48%

Their report showed that the low ambient/task lighting configuration reduces lighting energy consumption by 56%, while the peak lighting load reduced by 48% for the building studied. This was achieved while providing better satisfaction to the building occupants.

In the Malaysian scenario, the Malaysian Standard (MS) 1525 (2007) recommended lux level brightness for "Infrequent reading and writing" is 200 lux, while the recommended lux level for an office space is a maximum of 400 lux. In addition, the MS 1525 (2007) allowable lighting power density for 400 lux is 15 W/m^2. Meanwhile, a typical task light power consumption ranges from 5 to 19 watts depending on the technology used (LED vs. fluorescent) and will easily be able to provide up to 800 lux on the table top.

Providing an ambient space with 200 lux will only require a maximum 7.5 W/m^2 when 400 lux is achievable using 15 W/m^2. Assuming an occupant density of 10 m^2/person and one task light of 11 watts is provided for each person, the task light power density for the space will be:

$$\textbf{Task Light Power Density} = \frac{\textbf{11 Watt / person}}{\textbf{10m}^2\textbf{ / person}} = \textbf{1.1 Watt/m}^2$$

The total installed lighting power density in a low ambient/task light scenario will then be 7.5 W/m^2 + 1.1 W/m^2 = 8.6 W/m^2. Or a reduction of 43% from 15 W/m^2 of installed lighting power density. It should also be highlighted that part of the task lights will not be switched on due to building occupants attending meetings away from their desks, and some may not be doing any paper reading work because they are just working on the computer (where 200 lux level is adequate). In addition, for each Watt of power saved on the lighting, there is approximately 0.2 to 0.35 watts of electricity saved on the air-conditioning because no heat is produced by the lights that are off.

More interestingly, there will be a cost reduction on the installation of the ambient lighting system because less luminaires are required to provide a 200 lux level. This saving is approximately the same cost of providing one task light every 10m^2 of space. In short, it is possible to save approximately 50% lighting energy without any additional cost using this strategy.

8 LIGHT ZONING

One of the quickest and easiest ways to reduce energy consumption in a building is to ensure that electrical lights are switched off when the space is not being used or daylight is available. However, it is often found that lights in empty or daylit spaces cannot be switched off because the lighting circuitry is linked to other spaces that require the lights to be switched on. Therefore, it is important to plan the light zoning carefully.

In addition, it is often found that the same lighting fixture locations may be ideal for emergency, night lighting and security lighting purposes. However, these three functions, and their operating schedules, should be considered independently, so that the best system of luminaires and controls can be designed to ensure safety and energy efficiency. Emergency lighting must meet stringent codes and standards for emergency egress when the building is occupied. Night lighting provides minimal lighting during generally unoccupied periods, to allow safe passage through unoccupied spaces or to provide access to light switches or areas controlled by automatic occupancy sensors. Security lighting provides illumination for security personnel or cameras, and may operate intermittently or continuously, depending on the continuity of surveillance.

More importantly, careful planning of lighting zones is a very effective, low-cost solution that can potentially provide very high efficiency yields.

1 INDIVIDUAL ROOMS

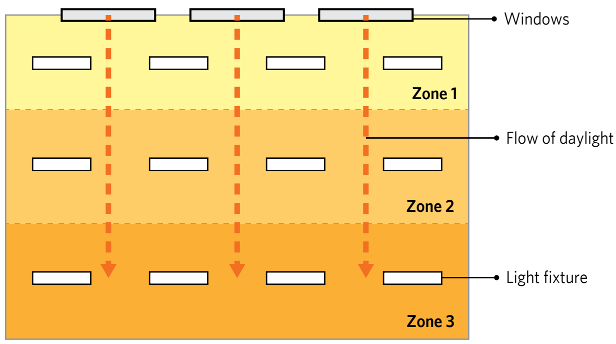
No matter how small the individual office room is, it is always a good practice to provide a separate lighting zone for the lights in the room. Typical individual office rooms are occupied by high ranking office staff that are important to the company. It is very common that individual office rooms are empty for a significant part of the office hours because important staff are often required to attend meetings outside their own office room, perhaps more than they are required to be working in their own room.

2 DAYLIT AREAS

It is useful to map out the areas of daylight harvested in a building. This is easily done in an existing building by having a walkthrough in the building. However, in new buildings, the potential daylit spaces are not as obvious. In the case of new building design, it is recommended that the lighting designer should always have a discussion with the architect to understand the design intent of the windows and skylight provided in the design to map out the potential spaces that will be daylit due to the architectural design.

Figure 4.9 shows the recommended lighting zone plan, taking into consideration how natural light flows into a space. As the outdoor daylight intensity varies over the day, the zoning should allow lights to be switched off/on according to the depth from the façade of the building.

FIGURE 4.9 | ARTIFICIAL LIGHTING SYSTEM ZONED TO TAKE ADVANTAGE OF DAYLIGHT



3 OPEN PLAN OFFICES

It is often difficult to predict how open-plan offices will be used. One study indicates that the daily average peak occupancy in an open-plan office is 63% for a federal office building in the US.[9] And more interestingly, the tested solution of using workstation-specific luminaires coupled with motion sensors for the open-plan office provided a very significant 40% lighting energy reduction.[10] The proposed solution is a very comprehensive method of lighting zone control, where each workstation is provided with a motion sensor and luminaire.

However, in the interest of low installed lighting power density and initial cost, most luminaire designs in Malaysia will cover more than one workstation. Therefore, it is more complicated and subjective, to decide how the open-plan office lighting system should be zoned. In this case, it is recommended for the lighting designer to have a discussion with the potential tenant of the building to discuss the optimum light zoning strategy to be employed. One possible solution may be to zone the open-plan lighting system according to the company's departments, organisation or job functions.

In the worst case scenario, where there is no information available to the lighting designer, the consensus seems to be that an open-plan office should not have more than 100m^2 per lighting zone.[11]

[9,10] Achieving Energy Savings with Highly-Controlled Lighting in on Open-Plan Office, Francis Rubinstein, Abby Enscoe, Lawrence Berkeley National Laboratory, 2010.
[11] Australia Lighting Council and Malaysian Green Building Index.

4 EMERGENCY LIGHTING

Emergency luminaires are those designed to operate when there is an interruption in normal building power. They are often selected from the luminaires providing general building illumination. In addition to meeting all the relevant codes and standards, emergency lights should be located and aimed to orient the occupants to the most direct paths of egress, with the least amount of confusion and glare. In addition, emergency luminaires receive emergency power directly from a circuit breaker panel that is connected to an emergency generator, or are powered by individual emergency ballasts.

If emergency lights are used for normal space lighting, any controls that dim them or turn them off (for daylight harvesting, pre-set scenarios, dimming, etc.) must be wired in such a way that the luminaires will revert to full operation in case of a loss of power. Manufacturers of lighting or dimming controls can assist the design team in achieving this configuration.

5 NIGHT LIGHTING

A night lighting system serves several functions in buildings. It allows the first few occupants in the morning or the last few occupants after hours to safely navigate circulation paths in a familiar building until ambient lights can be manually turned on or off. It is also provided for security personnel to move from area to area without leaving all the lights on in between. Finally, it allows firemen, police, or other emergency personnel to find light switches in an unfamiliar building. This can generally be accomplished by activating only a few luminaires for a short amount of time. Night lighting should be designed to prevent energy wastage by a careful examination of the actual needs for after hours lighting. Some combination of dawn-to-dusk operation only of lights at entry doors, combined with low-level lighting activated by occupancy sensors, should be considered.

Design of night lighting requirements in office buildings in Malaysia is commonly practiced by providing 50% of the corridors light for night use without any other considerations. However, a significant amount of lighting energy can be saved while providing a better environment to the building occupants if more effort is made during the design stage to plan the night lighting requirements.

Night lighting in offices is also required to be provided to create a safe environment for building occupants that work late beyond the normal office hours. In situations such as this, it useful to plan all possible travelling routes (from desk to pantry, toilet or exit) and provide the necessary night lighting strategy for it. While it may not be necessary to provide the full light level on these routes when not in use, it is practical to allow the building occupants to fully light up these routes when they are using it via manual, time-delay, or motion sensor switches.

In addition, it is often a good idea to enable lights to be switched on at strategic places, adequate enough for late night workers to feel safe in the building. If this is not done, it is common for office workers to light up the entire floor even though only a small area is used by them.

Strategies should be in place that a late night office worker leaving the building should be able to take actions to turn off the lighting in the office space. This may be done manually from strategically placed manual switches, motion sensors or by informing the guards on duty.

6 SECURITY LIGHTING

Security personnel can often use the night lighting system to move around a facility, and activate higher levels of lighting only when it is necessary. Security lighting should operate continuously only if the space or camera images of the space are directly and continuously viewed, and immediate action can be taken. Otherwise, lights associated with security cameras can be controlled by occupancy sensors, so that both lights and cameras are activated by an intruder. In security cases, advanced motion sensor technologies such as microwave or tomographic sensors may be considered for a higher level of safety provision.

7 COMMISSION THE LIGHTING SYSTEM

Calibration and Commissioning of lighting controls is essential, for proper operation and to capture the potential energy savings. Even if no other part of the project is commissioned, lighting controls must be properly calibrated and documented.

Commission the lighting system before occupancy. All lighting controls must be calibrated and commissioned after the furniture is in place but prior to occupancy. This is a very small window of time. Even a few days of occupancy with poorly calibrated controls can lead to permanent overriding of the system, and a loss of all savings.

Calibrate and recheck. Most photosensors require both daytime and night time calibration sessions.

Calibrate daylight dimming and switching systems for the specific conditions, to minimise distractions and ensure user acceptance. For example, many occupants may expect a daylighted space to be brighter. Consequently, the calibrated lux level settings for a daylighting system are set higher than the lux levels intended for the electric lighting alone.

8 FINE-TUNING AND CONTINUOUS MONITORING

All new buildings need a period of fine-tuning to adapt to the actual building occupant usage patterns. During the fine-tuning period, all common area lighting operational hours are adjusted and re-circuited where necessary. Sometimes additional sensors are added during this stage to the installed lighting system to meet the comfort requirements of the building occupants while minimising energy consumption.

Continuous monitoring of the energy consumption of the lighting system via a set of sub-meters should also be implemented. This is to ensure that any deviation from the normal operational mode of the lighting system can be quickly identified for it to be investigated and fixed when necessary.

SUMMARY

Electrical lights in an office building contributes up to 25% of the energy used in the building. It also contributes up to 20% of the heat gain for the air-conditioning system. Therefore, it is highly desirable to design lighting systems in buildings with **low lighting power density**. Low lighting power density can be achieved using efficient lamps in combination with efficient ballasts and efficient light fittings that distribute light wide and evenly. For fluorescent lights, the efficiency of the ballasts (gears) will also contribute to the final efficiency of the lighting system.

In addition to having an installed low lighting power density, lighting controls are important to ensure that **lights are switched off when they are not required**. Adequate manual switches, building occupant awareness training, occupancy sensors, daylight sensors, light schedules, delay timers, lighting management systems, etc. are used to improve the energy efficiency of the lighting system in building by ensuring that lights are switched off when not required.

It is also important to plan for night lighting requirements, security lighting requirements, fire safety lighting requirements and façade lighting requirements. Making plans for such lighting systems early will ensure that the energy efficiency considerations during the operation stage will be taken into account.

Finally, the lighting system should be properly commissioned, fine-tuned and be continuously monitored. This will ensure that the installed lighting system is optimised for the comfort of the building occupants and yet energy efficient for the life-time of the building.

The combination of all these measures mentioned will help to reduce lighting energy consumption in a building significantly and is recommended to be practiced in all building designs.

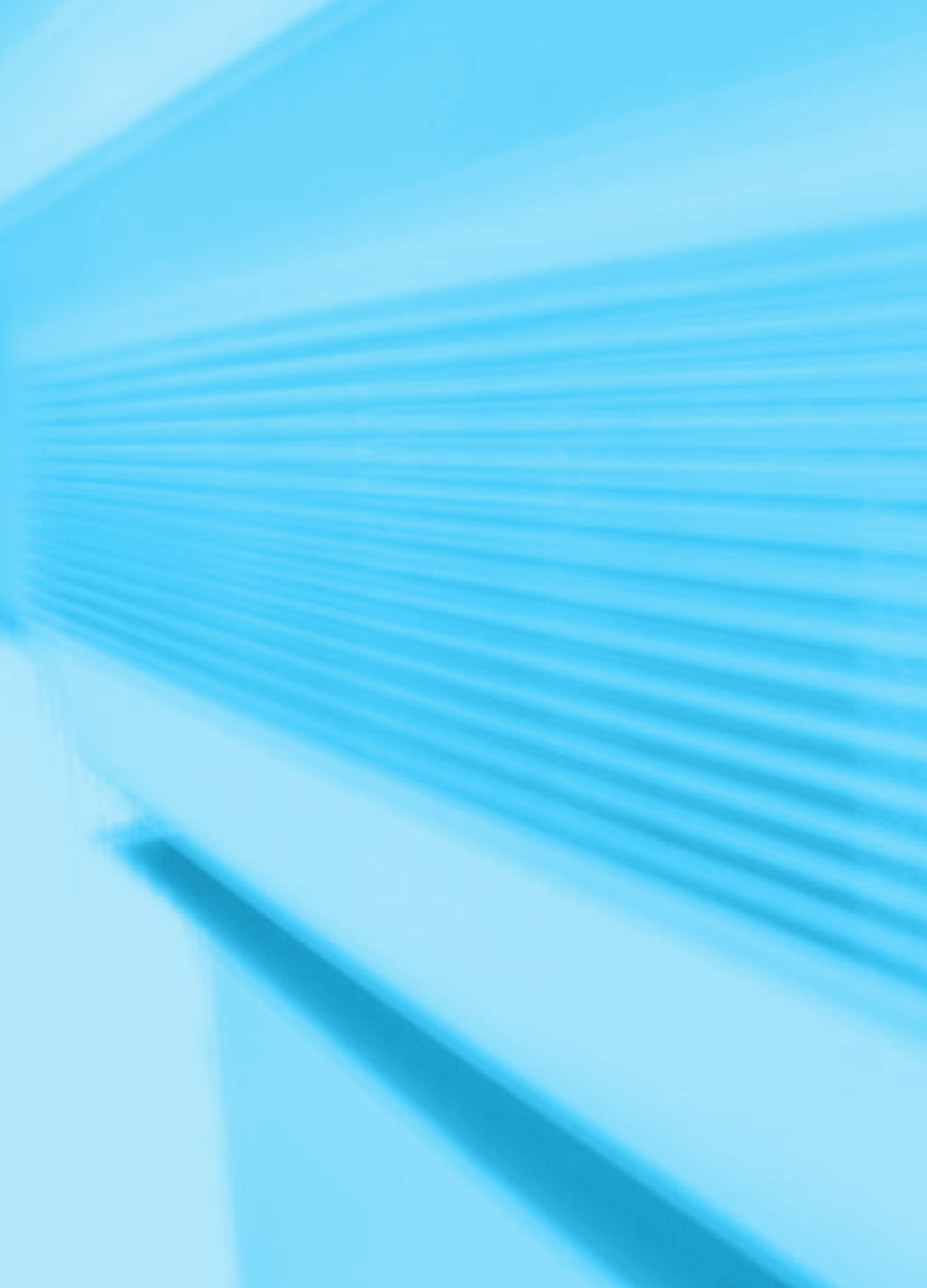
END OF CHAPTER 4

CHAPTER

5

AIR-CONDITIONING SYSTEM DESIGN

by CK Tang & Nic Chin



5

AIR-CONDITIONING SYSTEM DESIGN

INTRODUCTION

The cooling load calculation of a building determines the air-conditioning capacity that is required to be installed in the building. This design calculation has a large impact on the initial cost of the air-conditioning system for the building. The right-sizing of the air-conditioning system will lead to a lower air-conditioning system cost and lower running cost because the system is running close to its optimal design point. If the computation is done too conservatively (which is usually the case), the initial installation cost of the air-conditioning system will be more expensive (and wasteful) for the building owner, who will also have to pay for higher running costs during operation because the equipment was oversized and would not be running at its optimal design point.

On the other end, if the air-conditioning system is undersized, the building will not be provided with adequate cooling and will cause significant distress to both the building owner and design engineers due to complaints from the building occupants. Due to this reason alone, most air-conditioning system designers tend to be conservative in their design and oversize the air-conditioning system. The level of conservativeness of each designer depends on the person's understanding of the various components of a building's cooling load. A designer with a clear understanding of the various contributors to the cooling load in a building will be able to make the necessary design assumptions to optimise the capacity of the air-conditioning system without excessively oversizing the cooling system.

Over the years, over-reliance on computers to size air-conditioning systems has also caused some engineers to lose touch with the basic fundamentals of air-conditioning system sizing. In addition, it is also known that there are engineers in Malaysia that only rely on rules-of-thumb to size air-conditioning systems for buildings in Malaysia, sizing using a value of ~230 watts per square meter (or ~80 Btu-hr per square feet), regardless of other design parameters of the building such as the building envelope or the actual internal gain of the building design specification.

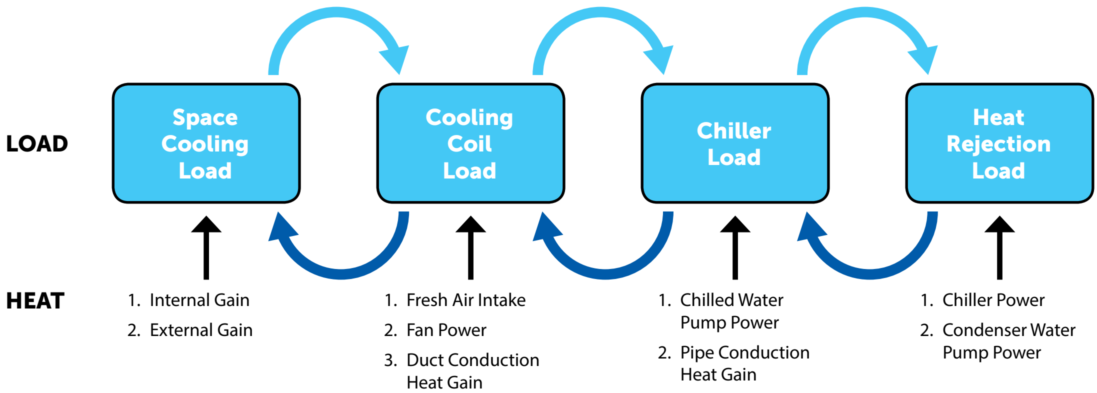
This chapter is provided as a guide for air-conditioning system design engineers to understand the fundamentals of the air-conditioning sizing methodology. The assumption is made that cooling load computations are done by design engineers using computer programs. It is therefore the intention of this chapter to provide adequate technical knowledge to provide reasonable inputs into the computer to crunch the building's cooling load and size the air-conditioning system correctly, accounting for all components of heat load in the building. It is hoped that the information provided in this chapter will improve the quality of cooling load computations by air-conditioning designers in Malaysia.

Finally, this chapter is not intended to teach the details of the heat-balance method or radiant-time series method of cooling load calculation for buildings. These methodologies can be found in ASHRAE handbooks (air-conditioning system designers are encouraged to look it up to gain a deeper understanding of cooling load calculation methodologies).

KEY RECOMMENDATIONS

It is important to understand all the contributing components of heat gain in each part of the air-conditioning system to ensure that the entire system is sized correctly for each part of the system. A complete understanding of heat gain components reduces the need to put in "extra" safety factors during the design stage to cater for "unknown" factors that might arise during the operational stage. **Figure 5.1** is provided as a summary of the various components of heat gain at each stage of the cooling load as heat is transferred from a space in the building to the outdoors.

FIGURE 5.1 | HEAT GAIN COMPONENTS FOR EACH COOLING LOAD IN A TYPICAL AIR-CONDITIONING SYSTEM



The following heat gains have to be addressed to compute the **space cooling load**:

1) Internal Gain
- a) People
- b) Electrical lights
- c) Equipment and appliances

2) External Gain
- a) Heat gain entering from the exterior walls and roofs
- b) Solar heat gain transmitted through the fenestrations
- c) Conductive heat gain coming through the fenestrations
- d) Heat gain entering from the partition walls and interior doors
- e) Infiltration of outdoor air into the air-conditioned space

In a **cooling coil load**, the following heat gains are in addition to the space cooling load:

1) Mechanical Fresh Air Intake
2) Fan Power
3) Fresh Air (or Return) Duct Conduction Heat Gain (if it is located outside the air-conditioned space)

In a **chiller load**, the following heat gains are added to the cooling coil load:

1) Chilled Water Pump Power
2) Chilled Water Pipe Conduction Heat Gain (if it is located outside the air-conditioned space)

In a **heat rejection load**, the following heat gains are added to the chiller load:

1) Chiller Power (Electrical load used by chiller)
2) Condenser Water Pump Power

These are all the heat gain components that need to be accounted for to size air-conditioning systems properly. The rest of the chapter will describe the boundaries of input values for these heat gain components.

SPACE COOLING LOAD

The cooling load of a space is a simple summation of all the heat generated internally and received from external sources for a space. The heat generated internally is commonly known as the internal cooling load, while the heat received from external sources are known simply as the external cooling load.

Internal heat gains or cooling loads are caused by the following items:

1) People (Q_{ppl})
2) Electrical Lights (Q_{lgt})
3) Equipment and Appliances (Q_{eqp})

External heat gains or cooling loads are caused by the following items:

1) Heat gain entering from the exterior walls and roofs (Q_{cd})
2) Solar heat gain transmitted through the fenestrations (Q_{solar})
3) Conductive heat gain coming through the fenestrations(Q_{cdf})
4) Heat gain entering from the partition walls and interior doors (Q_{intw})
5) Infiltration of outdoor air into the air-conditioned space (Q_{infl})

The total cooling load of a space is just a simple summation of all the simultaneous internal and external cooling loads as shown in the equation below.

EQUATION 5.1

$$Q_{total} = Q_{ppl} + Q_{lgt} + Q_{eqp} + Q_{cd} + Q_{solar} + Q_{cdf} + Q_{intw} + Q_{infl}$$

Q_{total} is the total cooling load that is required to be delivered into the space to maintain the room's air temperature. In hot and humid climates such as in Malaysia, the Q_{total} is made up of both sensible heat and latent heat as shown below and can be rewritten as below.

EQUATION 5.2

$$Q_{total} = Q_{total\ sensible} + Q_{total\ latent}$$

Where:
$Q_{total\ sensible}$ = Sensible Heat of ($Q_{ppl} + Q_{lgt} + Q_{eqp} + Q_{cd} + Q_{solar} + Q_{cdf} + Q_{intw} + Q_{infl}$)
$Q_{total\ latent}$ = Latent Heat of ($Q_{ppl} + Q_{infl}$)

The cooling load of a space is a simple summation of all the heat generated internally and received from external sources for a space

In a typical office building scenario, latent heat is only produced by people and infiltration. However, designers are cautioned that latent heat can also be produced by any other moisture source such as boiling water, leaking roofs, etc.

The supply air flow rate due to sensible heat is provided by **Equation 5.3** below.

EQUATION 5.3

$$AF_{sensible} = \frac{Q_{total\ sensible}}{C_p\ \rho\ \Delta T}$$

Where:
$AF_{sensible}$ = Air Flow Rate due to sensible cooling load
$Q_{total\ sensible}$ = Total Sensible Cooling Load
C_p = Specific Heat of Air
ρ = Density of Air
ΔT = Room Design Temperature - Supply Air Temperature
(Typical Room Design Temperature = 23°C, Typical Supply Air Temperature = 11°C, Typical ΔT = 23°C – 11°C = 12°C)

The supply air flow rate due to latent heat is provided by **Equation 5.4** below.

EQUATION 5.4

$$AF_{latent} = \frac{Q_{total\ latent}}{H_v\ \rho\ \Delta X}$$

Where:
AF_{latent} = Air Flow Rate due to latent cooling load
$Q_{total\ latent}$ = Total Latent Cooling Load
H_v = Latent Heat of Vaporisation
ρ = Density of Air
ΔX = Room Design Moisture Content - Supply Air Moisture Content
(Typical Room Design Condition = 23°C, 55% relative humidity, from psychrometrics Moisture Content = 9.7g/kg,
Typical Supply Air Condition = 11°C, 99% relative humidity, from psychrometrics Moisture Content = 8.1g/kg,
Typical ΔX = 9.7g/kg – 8.1g/kg = 1.6g/kg)

In theory, air flow rates for both the sensible and latent cooling load should be computed and the higher flow rate is used to ensure adequate sensible and latent cooling is delivered to the space. In actual practice, for an office building scenario, the sensible cooling load dominates the latent cooling load significantly; therefore the air flow rate is normally computed from the sensible cooling load only. Designers are advised to be especially careful if the higher air flow rate is caused by the requirements of the latent load, because at this flow rate, it will over-cool the space beyond the design air temperature.

1 PEOPLE HEAT GAIN

Table 5.1 below provides a sample of sensible and latent heat produced by people from the ASHRAE Handbook.[1]

TABLE 5.1 | SENSIBLE AND LATENT HEAT FROM PEOPLE

Degree of Activity	Sensible Heat (W/person)	Latent Heat (W/person)
Seated at theatre, night	70	35
Seated, very light work	70	45
Moderately active office work	75	55
Standing, light work; walking (Department store; retail store)	75	55
Bowling	170	255

From the building occupancy density in m^2 per person, the total sensible and latent heat from people can be calculated.

The building occupant density is normally well defined by the building owner or developer. Typically, it ranges from a dense value of $8m^2$ per person to a sparse occupant density of $16m^2$ per person.

It is also often useful to understand the diversity of occupant density as it will help to reduce the peak cooling load in a building. Designers are encouraged seek out this information from the potential building owner or intended tenant. It the building owner is currently occupying an existing building, a site visit is highly encouraged, just to observe the existing work culture in their organisation.

It is often useful to understand the diversity of occupant density as it will help to reduce the peak cooling load in a building. Designers are encouraged seek out this information from the potential building owner or intended tenant.

[1] 2009 ASHRAE Fundamentals, F18, Non-Residential Cooling and Heating Load Calculations, Table 1.

2 ELECTRICAL LIGHTING HEAT GAIN

From the 1st law of thermodynamics (Chapter 1), 100% of electrical lighting energy used will end up as heat in the building. Therefore, the actual installed lighting power density should be used as the input for sizing the cooling load in a building.

In the absence of the actual design lighting power density, the MS 1525[2] provides the maximum allowable lighting power density to be installed for different types of spaces. A sample is reproduced in **Table 5.2** below.

TABLE 5.2 | MAXIMUM ALLOWABLE LIGHTING POWER DENSITY IN MS 1525

Type/space Type of Usage	Max. lighting power density W/m^2
Offices	15
Supermarkets/ Department Stores/ Shops	25
Stores/ Warehouses/ Stairs/ Corridors/ Lavatories	10
Car Parks	5

Table 5.2 above can be used as a "first-cut" study for sizing air-conditioning system. Actual design of lighting power density is recommended to be used for actual sizing of the air-conditioning system.

In addition, if the lighting system is installed with occupancy sensors, daylight sensors or adequate manual lighting switches are provided, the designer may make a guess-timate on the diversity use of the lighting power density. A lighting diversity factor of 0.5 was measured in the demonstration Low Energy Office (LEO) building of the Ministry of Energy, located in Parcel E4/5, Putrajaya, Malaysia. In this office building, light and occupancy sensors were placed in every individual room. The installed lighting power density in the LEO building was 12 W/m^2 and during operation less than 6 W/m^2 was measured to be operating at any one time.

However, please do take note that the diversity factor varies between organisations depending on their work culture. Designers are highly encouraged to learn about the organisation's work culture to make better design assumptions. Moreover, there is no guarantee that an existing work culture in an existing building (with low diversity factor) will be the same in the new building. Again the designer should make reasonable self-assessments to make the right assumptions on the diversity factor to be applied.

The diversity factor varies between organisations depending on their work culture. Designers are highly encouraged to learn about the organisation's work culture to make better design assumptions.

[2] Malaysian Standard (MS) 1525, Energy Efficiency for Non-Residential Buildings, available from Sirim Berhad.

❸ EQUIPMENT AND APPLIANCES HEAT LOAD

The 1st law of thermodynamics dictates that 100% of electrical energy used by equipment and appliances will end up as heat in the building. Unlike electrical lighting, it is usually not possible to predict the exact energy used by equipment and appliances because these are brought in by the building occupants at a later stage. Therefore assumptions have to be made.

The ASHRAE Fundamental handbook has provided guidelines on the typical energy consumption (therefore, also the heat produced) of many types of computers, printers, medical equipment, kitchen appliances and more.[3]

For an office building, the following recommendations were made by ASHRAE and are shown in **Table 5.3** below:

TABLE 5.3 | RECOMMENDED LOAD FACTORS FOR VARIOUS TYPE OF OFFICES [4]

Load Density of Office	Load Factor W/m^2	Description
Light	5.4	Assumes 15.5 m^2/workstation (6.5 workstations per 100m^2) with computer and monitor at each plus printer and fax. Computer monitor and fax diversity 0.67, printer diversity 0.33.
Medium	10.8	Assumes 11.6 m^2/workstation (8.5 workstations per 100m^2) with computer and monitor at each plus printer and fax. Computer monitor and fax diversity 0.75, printer diversity 0.50.
Medium/Heavy	16.1	Assumes 9.3 m^2/workstation (11 workstations per 100m^2) with computer and monitor at each plus printer and fax. Computer monitor and fax diversity 0.75, printer diversity 0.50.
Heavy	21.5	Assumes 7.8 m^2/workstation (13 workstations per 100m^2) with computer and monitor at each plus printer and fax. Computer monitor and fax diversity 1, printer diversity 0.50.

Again, whenever possible, designers are highly encouraged to ask the intended building occupants about the type of equipment that will be brought into the building. In addition, it is also important to learn about the intended building occupant's work culture, which may lead to a potential use of diversity factor for equipment and appliances, especially if some of the computers are switched off when the building occupants are not in their office space.

Finally, in the evolution of the "green" and/or "sustainable" global movement, many manufacturers of computers, monitors and other electrical appliances are rapidly reducing their equipments' energy consumption. Therefore, office space heat gain from equipment and appliances may reduce in the near future. In addition, advancements in technology is also rapidly changing the way people usually work, leading to building occupants using tablets instead of computers to do their work. This may further reduce the heat load caused by equipment in an office building. Designers are encouraged to keep themselves abreast with the changes that are happening in the office environment and account for the effects they may have on air-conditioning system load calculations.

[3] 2009 ASHRAE Fundamentals, F18, Non-Residential Cooling and Heating Load Calculations, p 6-14.
[4] 2009 ASHRAE Fundamentals, F18, Non-Residential Cooling and Heating Load Calculations, Table 11.

4 CONDUCTION AND SOLAR RADIATION HEAT GAIN

Conduction heat gain through the building envelope, solar radiation heat gain and the effect of thermal storage is best left to the computer programs to compute based on the selected design weather data. The input data that influences the impact of the conduction (thermal mass) and solar radiation is provided in this section.

ASHRAE VS. MS 1525 DESIGN WEATHER DATA

The ASHRAE design weather database v4.0 and the Malaysian Standard (MS) 1525 recommend slightly different maximum design temperatures for Kuala Lumpur. A selection of the weather data is reproduced in **Table 5.4** below for comparison basis.

TABLE 5.4 | MAXIMUM OUTDOOR DESIGN TEMPERATURE

Descriptions	ASHRAE design weather database v4.0	MS 1525	Test Reference Year @ peak dry bulb temperature	Test Reference Year @ peak enthalpy
Dry Bulb Temperature (°C)	35.1	33.3	35.6	30.9
Wet Bulb Temperature (°C)	26.3	27.2	25.9	28.4

The computed psychrometric from the above conditions are shown in **Table 5.5** below:

TABLE 5.5 | AIR PSYCHROMETRIC PROPERTIES AT VARIOUS DESIGN CONDITIONS

Descriptions	ASHRAE design weather database v4.0	MS 1525	Test Reference Year @ peak dry bulb temperature	Test Reference Year @ peak enthalpy
Enthalpy (J/kg)	79,300	84,200	77,300	91,100
Relative Humidity (%)	47.9	60.9	44.0	82.1
Moisture Content (g/kg)	17.2	19.8	16.2	23.4
Dew Point Temperature (°C)	22.4	24.7	21.4	27.5

The MS 1525 recommends a design condition with higher enthalpy than the ASHRAE design weather database. Comparisons with the hourly weather data of Kuala Lumpur in the Test Reference Year (TRY) as described in Chapter 2 shows that the ASHRAE recommended design weather data is similar to the conditions of the peak dry bulb temperature in the TRY. However, at this design condition (peak dry bulb temperature), the enthalpy of the air properties is 15% lower than the peak enthalpy found in the TRY and may cause an undersize of the latent load in the building.

From this simple comparison, the MS 1525 recommended design condition seems to be a good compromise, accounting for both sensible and latent heat gain and references well to the peak conditions of the TRY weather data.

CONDUCTION

Conduction heat gain in a building is a combination of the following:

1 Colour of Wall

The colour of the wall/roof influences the conduction of heat into buildings. Dark colours absorb heat and light colours reflect heat away from the building. The impact of this is computed by most computer programs as an input for the wall/ roof solar absorption value (α). Light colours have solar absorption values close to zero, while dark colours have solar absorption values close to 1.

2 Conductivity of Building Materials

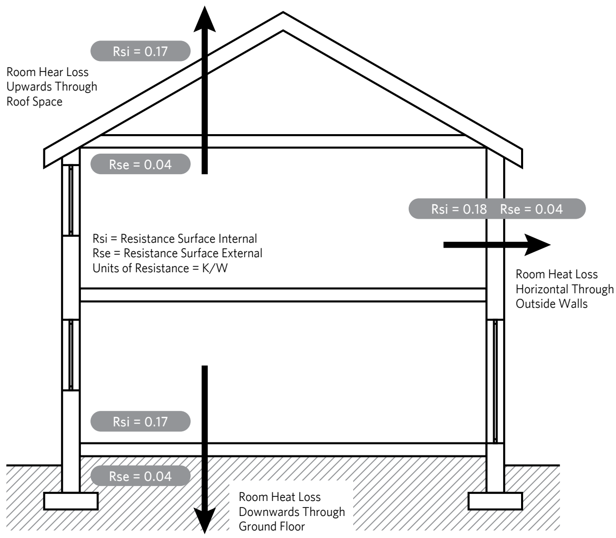
Conductivity (commonly known as K-value) and thickness of the building material influences the rate of heat transfer through wall/roof. Together with the surface film resistance on both sides, the U-value of wall/roof is computed. The U-value is a simplified indicator of steady state heat conduction through the wall/roof. In reality, heat transfer through the wall/roof of a building is never in a steady state.

3 Surface Film Resistance

Surface film resistance is an equivalent conductance of both radiation and convection heat transfer on a surface of a material. It is important to recognise that a surface film does not exist in reality. This term "film" is simply used to compute an equivalent conductive heat flow due to radiation and convection on the surfaces for U-value computation. Due to the reason that radiation heat transfer emissivity (e) from surfaces is typically a constant value (0.9 for most materials) and convection heat transfer coefficient (hc) is infinitely changing (depending on the wind speed, surface roughness, temperature differences, etc.), a fixed surface resistance is provided instead by ASHRAE to ease the computation of U-values. Some software enables the user to select different forms of surface heat transfer method to be used during computation.

Also important to note that surface resistance for different emissivity values and heat flow direction in a confined air-space is provided in ASHRAE Fundamentals (2009), chapter F26. These values were provided to ease the computation of U-values of building materials with air-spaces, such as the use of a low emissivity material under a roof.

Resistance Layers



4 Thermal Storage by Building Envelope

Finally, the building envelope density (kg/m^3) and specific heat (kJ/kg.K) influences the thermal storage "ability" of a building. Typical buildings in Malaysia are constructed with high thermal mass (with concrete/brick walls). This type of building envelope increases the typical office building cooling load on Monday mornings (in tropical climates) because of the "heat storage effect" during the weekends.

SOLAR RADIATION

All air-conditioning sizing computer programs will compute the solar radiation and effect of local shade based on the ASHRAE methodology (or similar) for a clear sky condition for direct and diffuse solar radiation. The important things to take note of for solar radiation properties for the Malaysian climate are the following:

1 Direct Solar Radiation Heat Gain

This is direct sunlight (from the sun position) that proper external shading devices can reduce significantly. It is possible for certain louvre designs on windows to reduce direct solar radiation gain to zero.

2 Diffuse Solar Radiation Heat Gain

This is diffuse daylight (from the entire hemispherical sky dome and also ground reflectance). Typical external shading devices (while still providing a view out) would not be able to reduce diffuse solar radiation to zero.

3 Ground Reflection

Typically taken as 0.2 for the Malaysian climate zone to be representative of a mixture of ground conditions. This value can be as high as 0.9 for snow covered ground (which is not possible in Malaysia).

4 Solar Heat Gain Coefficient (SHGC)

These are properties of glazing, external and internal shades (refer to Chapter 6 of the Passive Design Guideline) that describe the amount of solar radiation (both direct and diffuse) that passes through the device into the building. The lower the SHGC value, the less heat is gained in the building. Most air-conditioning computer programs will compute the effect of local external shades accurately based on the physical shape and size but requires SHGC values for glazing properties and internal shade properties. Short of asking the SHGC from the material suppliers, Chapters 5 and 6 of the Passive Design Guideline provide details on various SHGC values for different types of glazing properties and internal shades.

5 Radiation does not Heat the Air Space Immediately

Radiation is always absorbed by building materials, heating them up (depending on their thermal mass) and then transferred to the air space by convection from the surface of building material into the air, causing a delay of heat transfer from solar radiation heat gain. If a building has low internal thermal mass, the delay will be short, while a high thermal mass building will have a longer delay. Depending on the cause of the peak cooling load in a building, this knowledge may be put to use to reduce the size of the air-conditioning system.

5 INFILTRATION HEAT GAIN

Infiltration of outdoor air into air-conditioned spaces has a significant impact on the sizing of the air-conditioning system, energy efficiency and indoor environmental quality in a building. In the Malaysian climate, infiltration introduces both sensible and latent (moisture) heat into a building.

Traditionally, most large Malaysian buildings are designed to be positively pressured by the air-conditioning systems due to the fresh air intake by the system. The intake of fresh air is a requirement by ASHRAE 62.1 to maintain the air quality in a building. The fresh air requirement by ASHRAE 62.1 (2007) is approximately 0.50 air-changes per hour (ACH) (for most office buildings with a floor to floor height of 4.0m) for a building occupant density of 10 m^2/person. Therefore, typical buildings in Malaysia with mechanical fresh air intakes are positively pressured by ex-filtrating approximately 0.5 ACH out of the building, especially so when toilets are naturally ventilated. The positive pressure in buildings reduces the risk of mold growth in buildings by reducing the possibility of infiltration.

In mechanically ventilated toilets, air is typically extracted at a rate of 10 ACH for the toilet space to remove odour out of it. If the toilet is located in the middle of the building, this extraction of air from the toilet will cause negative pressure in the toilet space, sucking air-conditioned air into it. In this case, it is important for the designer to ensure that the toilet air extraction does not exceed the fresh air intake on a per-floor-basis. If it does, then the building will be negatively pressured causing infiltration into building, resulting in a higher cooling load requirement and a host of other problems.

Infiltration in Malaysian buildings can be caused by any (or all) of the following:

1. **Open doors between air-conditioned spaces and non-conditioned spaces**
2. **Open windows between air-conditioned spaces and non-conditioned spaces**
3. **Cracks between doors/windows on the building façade**
4. **Smoke extraction ducts without dampers**
5. **Utility shafts/ducts without sealing when they punch through partitions (especially above the false ceiling level)**
6. **Missing partitions between air-conditioned spaces and non-conditioned spaces above the false ceiling level**
7. **Many other possibilities**

A study of 10 buildings back in 2008 by the Public Works Department of Malaysia, found that the measured total fresh air intake rates in buildings were as high as 2.0 ACH, with an average of 1.0 ACH per building.[5] Since the fresh air ventilation rate requirement by ASHRAE 62.1 typically provides approximately 0.5 ACH in buildings, this indicates that on average, Malaysian buildings are infiltrating an additional 0.5 ACH of fresh air.

It is strongly suggested here that building designers should pay attention to fixing air leakages in the building rather than designing an air-conditioning system that is oversized to cater for these types of outdoor air leakages into the building.

It is also important to note that an air-tight building would provide further opportunities to improve the energy efficiency and reduce the cooling load in building with the use of heat recovery systems to pre-cool and pre-dry the fresh air provided for the building.

[5] Ezzuddin Ab Razad, CK Tang, Public Works Department (PWD), Kuala Lumpur, Malaysia. Control Of Moisture & Infiltration For Advanced Energy Efficient Buildings In The Tropics, Conference on Sustainable Building South East Asia, 4-6th May 2010, Malaysia

COOLING COIL LOAD

In addition to the heat from space cooling, the cooling coil load has additional heat gain from the mechanical fresh air intake system, fan power and conduction heat gain from fresh air (or return air) ducts that are located outside the air-conditioned space.

1 MECHANICAL FRESH AIR INTAKE

Mechanical fresh air is a requirement in air-conditioned buildings to maintain an acceptable air quality for an indoor space. The primary objective of fresh air intake is to replace the oxygen and dilute contaminants produced by indoor building materials, furniture, body odour, chemical fumes from printers and cleaners, etc. It has been shown that insufficient provision of fresh air results in building occupants feeling tired, nauseous and more prone to falling ill. Therefore, it is very important that fresh air intake is designed and provided for in all air-conditioned buildings in Malaysia to ensure building occupants' health and productivity is maintained.

While it is extremely important to provide fresh air into air-conditioned buildings, the over-provision of fresh air intake in a building increases energy use significantly and also increases the cooling system capacity, increasing the cost of building construction. Therefore, it is important for designers to ensure that the fresh air is provided at the minimum required amount at all times to reduce energy consumption and the cooling system capacity while ensuring good air quality in the building.

The minimum amount of fresh air intake in Malaysia is currently determined by ASHRAE 62.1 (2010), Ventilation for Acceptable Air Quality. There are 2 paths to complying with ASHRAE 62.1. The most commonly used method is "Ventilation Rate Procedure" and is discussed here. The second method is called "Indoor Air Quality Procedure" that uses mass balance analysis to maintain specific contaminant levels indoors. The second method is rarely used in Malaysia and is not discussed in this chapter.

The "Ventilation Rate Procedure" requirement in ASHRAE 62.1 is split into two (2) parts, one, fresh air intake requirement for the number of people and, two, fresh air intake requirement for the floor area covered. The requirement for an office building is provided herewith:

1. **People Requirement: 2.5 l/s per person (5 cfm per person)**
2. **Floor Area Requirement: 0.3 l/s per m^2 (0.06 cfm per ft^2)**

Once the occupant density is known, the total fresh air requirement per person is easily computed using **Equation 5.5** shown below:

EQUATION 5.5

$$\textbf{Total Fresh Air (l/s per person)} = O_d \times FA_r + P_r$$

Where:

O_d = Occupant Density: $\dfrac{m^2}{\text{person}}$

FA_r = Floor Area Fresh Air Requirement: $\dfrac{0.3\ l/s}{m^2}$

P_r = People Fresh Air Requirement: $\dfrac{2.5\ l/s}{\text{person}}$

TABLE 5.6 | TOTAL FRESH AIR REQUIREMENTS PER PERSON FOR DIFFERENT OCCUPANT DENSITIES

Occupant Density (m^2/person)	Floor Area Requirement l/s per person	People requirement l/s per person	Total l/s per person*	Total cfm per person*	Total l/s per m^2	Total cfm per ft^2
8	2.4	2.5	4.9	10.4	0.61	0.121
10	3.0	2.5	5.5	11.7	0.55	0.108
12	3.6	2.5	6.1	12.9	0.51	0.100
14	4.2	2.5	6.7	14.2	0.48	0.094
16	4.8	2.5	7.3	15.5	0.46	0.090
18	5.4	2.5	7.9	16.7	0.44	0.086
20	6.0	2.5	8.5	18.0	0.43	0.084

* Valid for most cooling delivery systems with the exception of low velocity displacement achieving unidirectional flow and thermal stratification (in which case, divide the numbers in the table by 1.2) and where the total fresh air is less than 15% of the minimum primary supply air flow rate.

Table 5.6 above is valid in most cases except for these two (2) situations mentioned below, where further computation is required:

1. **Where, cooling is provided via low velocity displacement achieving unidirectional flow and thermal stratification**. This method of air quality delivery is deemed to have a higher distribution effectiveness compared to the other methods of delivery, allowing a reduction of 20% of the fresh air requirement. It is also important to note that in Table 6-2 in ASHRAE 62.1, "*floor supply of cool air and ceiling return provided that the 150 fpm (0.8 m/s) supply jet reaches 4.5 ft (1.4 m) or more above the floor. Note: Most underfloor air distribution systems comply with this provision*", does not qualify for a reduction of 20% of the fresh air requirement.

2. **Where, the percentage of total fresh air supply flow rate is higher than 15% of the minimum primary supply air flow rate**. When this situation occurs, an increased fresh air supply is required to maintain adequate air quality in a building. In the Malaysian climatic zone, this situation will likely arise from the use of variable-air-volume (VAV) systems (where the minimum flow rate may be as low as 30% of the design air flow rate) or from the use of any type of radiant cooling system, where the recirculated air flow rate is minimal, therefore the percentage of fresh air in such systems may be higher than 15%. Refer to ASHRAE 62.1, System Ventilation Efficiency, for details to compute the minimum fresh air requirement for these conditions.

2 FAN POWER

The 1st law of thermodynamics states that energy cannot be destroyed, therefore, the use of fans to deliver cold air into spaces also causes heat gain for the cooling system. In most cases, 100% of the power used by the fan is converted into heat gain seen by the cooling coil (the only case where this is not so is when the motor for the fan is located outside the air-conditioned space). The heat gain produced by the fan has to be captured in the air-conditioning system sizing computation. Most computer programs that conduct cooling load calculations provide inputs for the basic fan power design parameters. Usually the typical input parameters are:

1. **Total Flow Rate**
2. **Total Fan Pressure**
3. **Total Fan Efficiency**

1 TOTAL FLOW RATE

The total flow rate is computed from the space cooling load requirement as described earlier in this chapter.

The total fan power is described by **Equation 5.6** below.

EQUATION 5.6

$$W_f = \frac{Q\,\Delta P_t}{\mu_f}$$

Where:
W_f = Fan Power (Watt)
Q = Volume of Air Flow Rate (m^3/s)
ΔP_t = Total Fan Pressure (Pa)
μ_f = Total Fan Efficiency (%)

2 TOTAL FAN PRESSURE

The fan total pressure can be summarised by **Equation 5.7** as shown below:

EQUATION 5.7

$$\Delta P_t = SP_d + PD_{af} + PD_c + \Delta D_p$$

Where:
ΔP_t = Fan Total Pressure (Pa)
SP_d = Duct Total Static Pressure (Pa)
PD_{af} = Pressure Drop in Air Filter (Pa)
PD_c = Pressure Drop in Cooling Coil (Pa)
ΔD_p = Differential Dynamic Air Pressure $= \frac{1}{2}\rho\,(V_o^2 - V_i^2)$
Where:
ρ = air density (1.2 kg/m^3)
V_o = velocity of air at fan exit (m/s)
V_i = velocity of air at fan inlet (m/s)

1. **Total Static Pressure Drop Due to Duct Size and Length**

   - Designers are recommended to keep duct length as short as possible to reduce static pressure in ducts. The location of the AHU will have a significant influence on this design factor.
   - Upsizing ducts will also help to reduce the static pressure drop in ducts.

2. **Air Dynamic Pressure**

   - Air dynamic pressure is a factor of air speed and is determined by the fan inlet and outlet area.

3. **Pressure Drop Due to Air Filters**

   - Selection of low pressure loss air filters will also help to reduce the coil cooling load. In addition to the Minimum Efficiency Reporting Value (MERV, filtration efficiency rating) rating of air-filter, it is also important to specify the maximum allowable pressure loss in air filters. For typical office buildings, a MERV rating of 5 to 8 is typically used with an allowable peak pressure drop of 150Pa.
   - Energy efficient air filters will be able to provide a MERV rating of 5 to 8 while reducing pressure loss to below 100Pa.
   - The key criterion that reduces pressure loss in a mechanical air filter is the reduction of the air-speed that flows across the air-filter. The reduction of air speed is achieved by having a large surface area for the air to flow through the air-filter. Air-filters that have a W or V-shaped design and other types of folded designs are made to increase the surface area, to reduce the pressure drop across the air-filters.

4. **Pressure Drop Due to Cooling Coils**

   - Cooling coil selection would also contribute to the pressure drop. High fin density and increased number of coil rows will increase the air pressure drop in cooling coils. Air pressure drops ranging from a low of 30Pa to a high of 300Pa is possible depending on the design flow rate parameters and coil height.
   - The key criterion that reduces the pressure drop in cooling coils is the exposed surface area of the cooling coil. The larger the surface area provided for the return air intake, the less pressure losses there will be. Unfortunately, a larger surface area also increases the costs of the AHU due to the use of more materials to construct it.

3 TOTAL FAN EFFICIENCY

The total fan efficiency is the combined efficiency of fan, motor and fan-belt as shown in **Equation 5.8** below.

EQUATION 5.8

$$FE_t = F_e \times M_e \times B_e \times V_e$$

Where:
FE_t = Fan Total Efficiency (%)
F_e = Fan Efficiency (%)
M_e = Motor Efficiency (%)
B_e = Fan Belt Efficiency (%)
Where:
B_e = 100%, if fan is direct driven by the motor
V_e = Variable Speed Drive Efficiency (%)
Where,
V_e = 100%, if no Variable Speed Drive is used

A. FAN EFFICIENCY

The Energy Efficiency and Conservation Guidelines for Malaysian Industries published by Pusat Tenaga Malaysia in 2008 provides the following recommendations for minimum fan efficiency for different air flow rates and fan types.

TABLE 5.7 | MINIMUM FAN EFFICIENCY FOR DIFFERENT AIR FLOW RATES AND FAN TYPES

Type of Fan	Category of Fan Type	Air Flow Rate (m^3/hr)	Minimum Fan Total Efficiency (%)
Centrifugal	Forward Curved	1,800	52
		3,400	60
		6,800	62
		10,200	67
		13,600	67
		17,000	67
	Backward Curved	1,800	72
		3,400	76
		6,800	77
		10,200	78
		13,600	78
		17,000	80
	Air Foil	1,800	75
		3,400	79
		6,800	81
		10,200	82
		13,600	83
		17,000	83
	Radial Blade	1,800	60
		3,400	60
		6,800	61
		10,200	63
		13,600	65
		17,000	65
Axial	Propeller	1,800	52
		3,400	55
		6,800	56
		10,200	56
		13,600	56
		17,000	62
	Tube Axial	1,800	60
		3,400	63
		6,800	63
		10,200	62[6]
		13,600	64
		17,000	66
	Vane Axial	1,800	63
		3,400	63
		6,800	63
		10,200	67
		13,600	67
		17,000	70
	Mixed Flow	1,800	63
		3,400	63
		6,800	65
		10,200	70
		13,600	73
		17,000	74

[6] This number may be incorrectly published in the document.

B. MOTOR EFFICIENCY

Most motors operate at a constant speed. A typical constant speed of motor ranges from 500 to 1,800 revolutions per minute (RPM). The power consumption of a motor is basically the rotational Torque multiplied by the RPM. Since the RPM is fixed, the power consumption of a motor is directly linked to the Torque.

The MS 1525 (2007) provides the following recommended minimum efficiencies for motors:

TABLE 5.8 | 4 POLES MOTOR MINIMUM EFFICIENCY

Motor Capacity (kW)	Motor Efficiency (%)	
	Motor Class Eff2	Motor Class Eff1
1.1	≥ 76.2	≥ 83.8
1.5	≥ 78.5	≥ 85.0
2.2	≥ 81.0	≥ 86.4
3	≥ 82.6	≥ 87.4
4	≥ 84.2	≥ 88.3
5.5	≥ 85.7	≥ 89.2
7.5	≥ 87.0	≥ 90.1
11	≥ 88.4	≥ 91.0
15	≥ 89.4	≥ 91.8
18.5	≥ 90.0	≥ 92.2
22	≥ 90.5	≥ 92.6
30	≥ 91.4	≥ 93.2
37	≥ 92.0	≥ 93.6
45	≥ 92.5	≥ 93.9
55	≥ 93.0	≥ 94.2
75	≥ 93.6	≥ 94.7
90	≥ 93.9	≥ 95.0

TABLE 5.9 | 2 POLES MOTOR MINIMUM EFFICIENCY

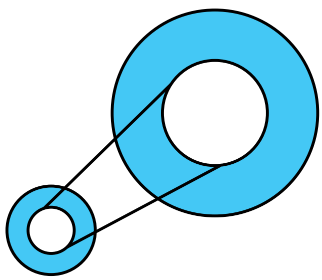
Motor Capacity (kW)	Motor Efficiency (%)	
	Motor Class Eff2	Motor Class Eff1
1.1	≥ 76.2	≥ 82.8
1.5	≥ 78.5	≥ 84.1
2.2	≥ 81.0	≥ 85.6
3	≥ 82.6	≥ 86.7
4	≥ 84.2	≥ 87.6
5.5	≥ 85.7	≥ 88.6
7.5	≥ 87.0	≥ 89.5
11	≥ 88.4	≥ 90.5
15	≥ 89.4	≥ 91.3
18.5	≥ 90.0	≥ 91.8

C. BELT EFFICIENCY

AHU belt efficiency typically ranges from 95% to 98% depending on the size and belt type. Most fan manufacturers (such as Kruger or Nicotra) will be able to provide the total fan efficiency inclusive of fan, motor and belt during the fan selection process.

Direct driven fans are more efficient because there are no belt losses.

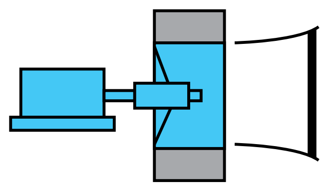
BELT DRIVE



DISADVANTAGES
4 bearings required
Belt dust
Load on bearings exceeds wheel weight

ADVANTAGE
Change pulleys to adjust capacity

DIRECT DRIVE



ADVANTAGES
No drive losses (typ. 3.5%)
No belt wear
No belt tensioner required
Less bearing load - Longer bearing life
No belt noise

DISADVANTAGES
Adjust width to adjust capacity

Depending on the actual design, fan power can range from less than 2 W/m^2 to a high of 10 W/m^2 of the conditioned space. In other words, the heat gain caused by fan power may be has high as electrical lighting or equipment (appliances plug load) if it is not designed well. The authors have personally encountered many air-conditioning systems sized with the fan energy assumed to have zero static pressure. This may explain the reason behind why some air-conditioning system designers insist on using 20 W/m^2 for lighting power density to size the air-conditioning system regardless of the lower installed lighting power density used.

3 CONDUCTION HEAT GAIN FROM DUCTS

It is important to address this especially if the return air ducts or fresh air ducts are located outside the conditioned space. It is common for fresh air ducts to be routed outside the air-conditioned spaces. In addition, there are times that supply and return air ducts are routed in roof attic spaces that are not conditioned. If the roof is not insulated, these ducts in the roof attic spaces would gain heat due to conduction. Designers should always be wary of potential heat gains due to duct routes.

CHILLER LOAD

In addition to the heat from the cooling coil, the chiller load has additional heat gains from the chilled water pump and conduction heat gains in pipes. These heat gains are described below.

1 CHILLED WATER PUMP

The chilled water pump power would contribute heat to the cooling load of a chiller. Part of the energy used by the pump is transferred into the chilled water as heat. Since the motor for pumps is typically located outside the chilled water loop, the heat lost from the motor (due to motor inefficiencies) will not contribute to the chiller load. The rest of the motor power (and energy) is then transferred to the pump shaft to rotate the pump. Some of the heat loss from the pump is located outside the chilled water loop from bearing losses in the motors. The rest of the power (and energy) is then transferred into the fluid (chilled water), converting it to kinetic energy to move the chilled water, which will eventually become heat due to frictional losses. Usually, 90% of the pump power is assumed to be converted into heat in the chilled water loop.

Input data in computer programs for cooling load sizing will normally ask for the following input parameters to account for this heat gain:

1 ΔT (Temperature Differences) of Supply and Return Chilled Water Temperature

- Default design chilled water supply temperature is 44°F (6.7°C) and 56°F (13.3°C) for return, providing a ΔT of 12°F (6.7°C).

- Higher ΔT reduces flow rate and pump power requirements. However, at the same time, the efficiency of the chiller is reduced if the supply temperature is lowered below 44°F (6.7°C). Moreover, cooling coil pressure (both air and water-side) may increase due to the longer distance travelled in the cooling coil for the heat transfer to be made, increasing energy consumption. Designers are recommended to conduct adequate computations to ensure that the advantages gained from such implementation reduces the net energy consumption of the system.

2 Pump Head

- The pump head is a factor of the flow rate, pipe size, number of bends/elbows and fittings used.

- Typical pump heads in office buildings in Malaysia range from 15m to 45m of water height. Keeping the pump head low reduces energy consumption.

3 Pump Efficiency

- The Energy Efficiency and Conservation Guidelines for Malaysian Industries published by Pusat Tenaga Malaysia in 2008 provides the following recommendations for minimum pump efficiency for different flow rates and pump types.

TABLE 5.10 | RECOMMENDED MINIMUM PUMP EFFICIENCY

Flow (gpm)	Efficiency (%)				
	End Suction (incl. vertical & closed impeller types) (%)	Horizontal / Vertical Split Casing (centrifugal and closed impeller types) (%)	Vertical Multistage & Horizontal Multistage / Closed Coupled (closed impeller types) (%)	Submersible (semi open and open impeller types) (%)	Process Pump (open impeller types) (%)
100	50 – 60	-	55 – 75	48 – 55	48 – 52
110 – 250	65 – 75	73 – 76	68 – 75	48 – 55	48 – 52
300 – 450	75 – 80	75 – 79	70 – 75	55 – 65	48 – 52
460 – 600	78 – 82	75 – 79	-	55 – 65	48 – 52
700 – 1000	80 – 85	78 – 82	-	65 – 72	48 – 52
1100 – 1500	83 – 87	78 – 82	-	60 – 68	-
1600 – 2500	83 – 87	78 – 83	-	60 – 70	-
2600 – 3600	-	80 – 86	-	70 – 75	-
3700 – 4000	-	82 – 86	-	75 – 80	-
> 5000	-	80 – 88	-	75 – 80	-

4 Pump Motor Efficiency

- The recommendations are the same as Fan Motor Efficiency in on page 107.

2 CONDUCTION HEAT GAIN IN PIPES

If the chilled water pipe is located outside the air-conditioned space, the conducted heat gain through the pipe will contribute to the chiller load. It is especially important to carry out this calculation when the chilled water pipe is routed outside conditioned spaces, exposing the chilled water pipes to outdoor conditions. ASHRAE Fundamentals (2009), Chapter 4, Example 1, page 3-4, offers a methodology to estimate the heat gain in pipes based on a one-dimensional, steady-state heat transfer equation for round pipes with insulation. This method would provide a good approximation of heat gained by the pipes. This heat will add on to the final chiller load.

Instead of providing the complex equations of conduction heat gain in pipes in this document, it would be more practical to provide a link to a computer program that does such computations. One such tool is 3EPlus®. 3EPlus® was developed by the North American Insulation Manufacturers Association (NAIMA) to simplify the task of determining how much insulation is necessary to use less energy, reduce plant emissions and improve process efficiency. It is available for download free of charge from **http://www.pipeinsulation.org**. This type of computation requires an assumption of the pipe surface temperature, which normally is the ambient air temperature. However, if the pipe surface is exposed to direct sunlight and is black in colour, the surface temperature of the pipe may be significantly higher than the ambient air temperature.

HEAT REJECTION LOAD

Since the cost of the heat rejection system, i.e. cooling tower or air-cooled coil, is only a fraction of the air-conditioning system cost, it is less important to get this system sized exactly right. For consistency purposes, the following items add heat to the heat rejection system.

1 CHILLER POWER

The electrical power used by the chiller to drive the compressor will end up as heat in the condenser (heat rejection) part of the chiller. From the coefficient of performance (COP) curve of a chiller, the electrical power can be estimated from the chiller cooling load. In a hermetically sealed chiller, where the motor is cooled by the refrigerant, 100% of the power used by the chiller will end up as heat on the condenser side.

2 CONDENSER PUMP

The condenser water pump's heat contribution to the heat rejection system is exactly the same as the chilled water pump. The recommendations for the chilled water pump is applicable here as well.

SUMMARY

This chapter provides an overview of all possible components of heat load for an office building. It is intended to provide a clear comprehension of the various heat load components. Hopefully, by understanding the heat flow process in an air-conditioning system, designers will be able to make better design decisions and assumptions, reducing the oversizing of systems. This will lead to lower installation costs by building developers and yet improving the energy efficiency in the building, providing a win-win situation for all.

It has been shown in this chapter that typical air-conditioning system cooling load computations in buildings can be broken-down into the following loads:

1. **Space Cooling Load**
2. **Cooling Coil Load**
3. **Chiller Load**
4. **Heat Rejection Load**

For each of the cooling loads, the various heat gain components and their corresponding typical design values are provided in this chapter.

It is strongly recommended that designers should always keep in mind the 1st law of thermodynamics, that energy (as in heat for the air-conditioning system) cannot appear out of nowhere and energy also cannot disappear into the thin air. As long as a designer has accounted for all the various potential heat gains in a building, it is unnecessary to use design values that are not based on actual design conditions, for example, using a lighting power density of 20 W/m^2 for air-conditioning sizing computations, when the actual designed lighting power density is only 10 W/m^2.

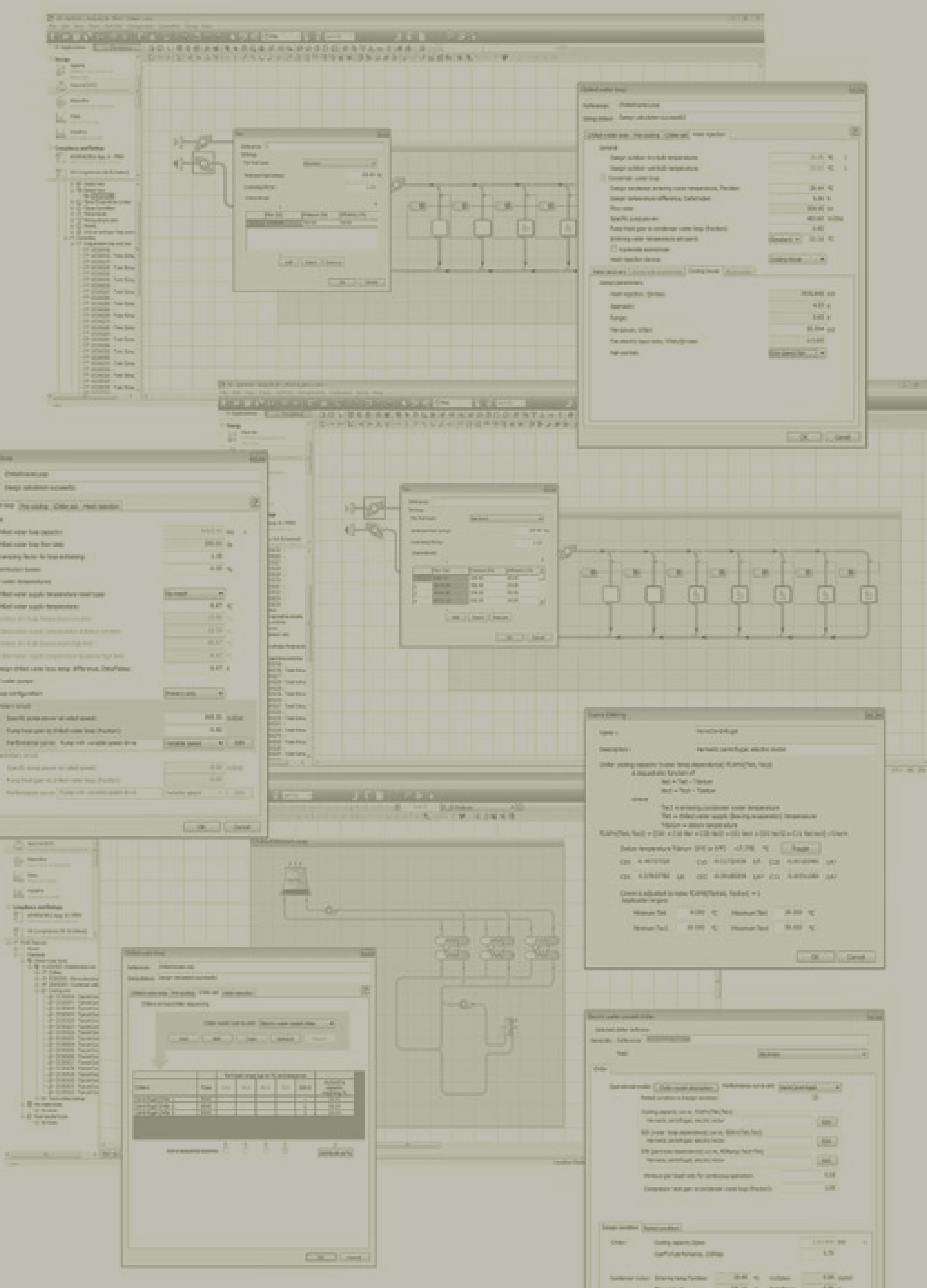
END OF CHAPTER 5

CHAPTER

6

SIMULATION INPUT DETAILS FOR CHAPTER 7 & 8

by CK Tang & Nic Chin



6

SIMULATION INPUT DETAILS FOR CHAPTER 7 & 8

INTRODUCTION

The outputs and recommendations in Chapter 7 & 8 rely heavily on the simulation case studies of test case reference scenarios of a Malaysian reference building. Therefore Chapter 6 is dedicated to describing the reference building scenarios.

This chapter describes the simulation engine, weather data, internal gain, building fabric and the air-conditioning system in detail.

SIMULATION ENGINE

The software used for the building energy simulation for Chapter 7 & 8 is the **VE-Pro software IES, UK, version 2012**.

The VE-Pro software consists of a suite of modules and tools for detailed energy simulations that comply to all the requirements of ASHRAE 90.1 (2007).

WEATHER DATA

The hourly weather data of Kuala Lumpur used in this chapter was based on a Test Reference Year (TRY)[1] weather data developed in University Teknologi Malaysia (UiTM) under the DANCED (Danish International Assistant) project for Energy Simulations for Buildings in Malaysia. The TRY is based on 21 years (1975 to 1995) of weather data from the Malaysian Meteorological Station in Subang, Klang Valley, Selangor. The hourly weather data that was obtained from this station is as shown in **Table 6.1** below.

TABLE 6.1 | WEATHER DATA COLLECTED IN SUBANG

Subang Meteorological Station
(Klang Valley, Selangor, Malaysia)
Longitude: 101deg 33′
Latitude: 3deg 7′

Parameters (hourly[2])	Units
Cloud Cover	[oktas]
Dry Bulb Temperature	[°C]
Wet Bulb Temperature	[°C]
Relative Humidity	[%]
Global Solar Radiation	[100*MJ/m^2]
Sunshine Hours	[hours]
Wind Direction	[deg.]
Wind Speed	[m/s]

A Test Reference Year (TRY) consists of weather data for a given location. In order for the TRY to be representative of the climate, it was constructed on the basis of at least 10 years of weather data. The TRY is made up from actual monthly data (not average values) that are picked after having been subjected to different types of analysis.

It should be noted that a typical energy simulation program requires two extra data values that were not collected by the Malaysian Meteorological Service, namely the direct and diffuse radiation. The missing radiation data was calculated for the TRY via Erbs' Estimation Model from the horizontal global solar radiation.

Although not perfect, the TRY is currently the only known set of weather data for energy simulation that was compiled based on statistical analysis and it has been used in many energy simulations of various buildings in Malaysia with satisfactory results. This weather data was also used for the development of the constants in the Overall Thermal Transmission Value (OTTV) equation found in the Malaysia Standard (MS) 1525 (2007), Energy Efficiency in Non-Residential Buildings.

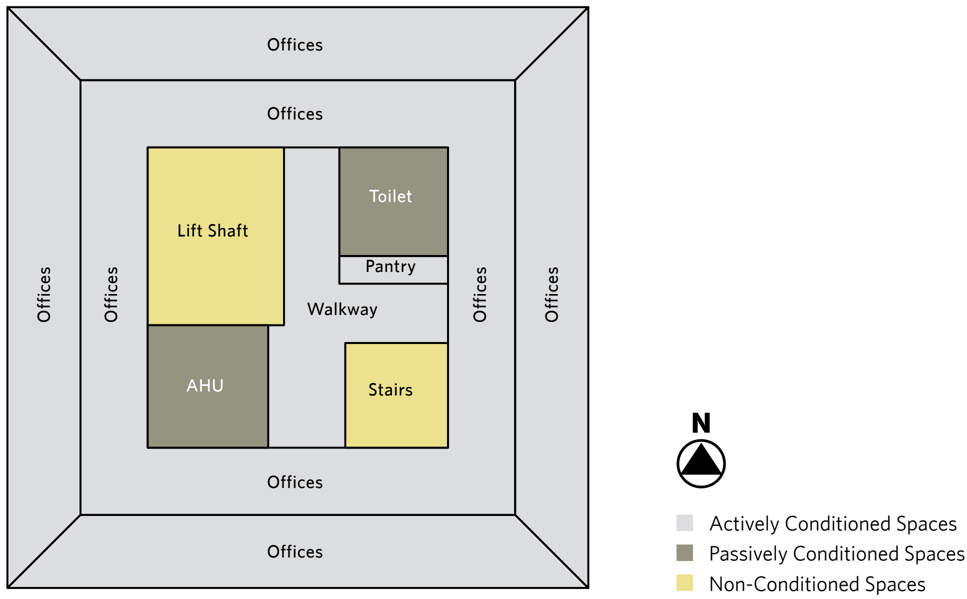
[1] Reimann, G. (2000) Energy Simulations for Buildings in Malaysia, Test Reference Year, 18-25.
[2] The values are integrated over a period of one hour, but the exact time interval has not been specified.

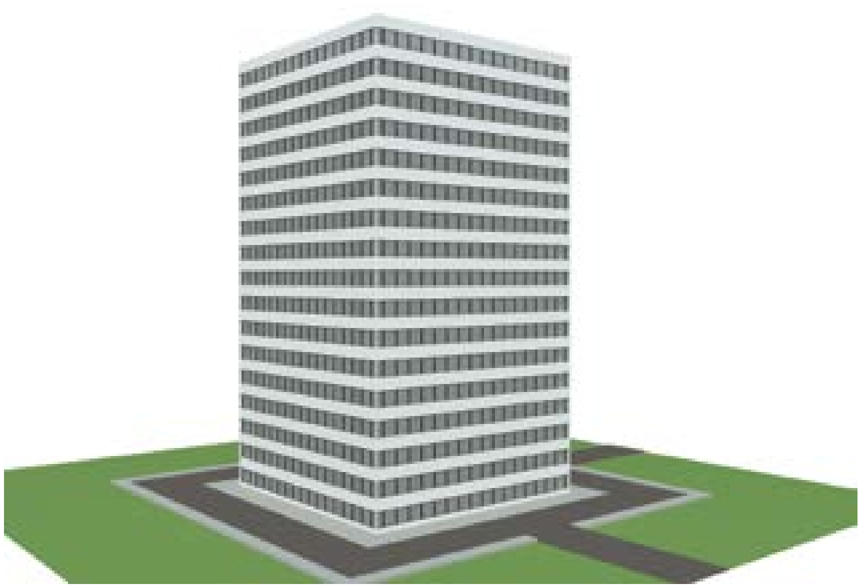
BUILDING MODEL

A medium-rise building of 17 floors is assumed for this study. The floor to ceiling height is assumed to be 4 meters. The floor areas are as described in the table below.

No	Description	Floor Area	Units	Ventilation Concept
1	Office Floor Area	1,650	m^2/floor	AC
2	Lift Lobby/Walkway	170	m^2/floor	AC
3	AHU Rooms	100	m^2/floor	AC
4	Lift Shafts	165	m^2/floor	NV
5	Pantry	22	m^2/floor	NV if located with external façade. AC otherwise.
6	Fire Staircases	72	m^2/floor	NV
7	Toilets	80	m^2/floor	NV if located with external façade. 10 ACH otherwise.
	Total Area per Floor	**2,259**	m^2/floor	
	No. of Floors	**17**	floors	
	Total Building GFA	**38,403**	m^2	

CASE 1 - SQUARE BUILDING CENTER CORE





BASE MODEL INPUTS

These assumptions were made in this study:

No	Description	Location: Not Connected to any External Wall
1	**Toilet Ventilation Strategy**	Mechanically ventilated for 10 ACH as exhaust air. Fan Static Pressure of 2" w.g. (500 Pa) assumed. Combined fan, motor and belt (total) efficiency of 50% assumed. Fan operates during occupancy hours of 9am to 6pm.
2	**Toilet Lighting Strategy**	100% electrical lights at 10W/m^2, switched on during occupancy hours. Occupancy sensor is assumed to be installed. It is assumed that the toilet lights is only switched on 50% of the time during occupancy hours and switched off during non-occupancy hours.
3	**Pantry Lighting Strategy**	100% electrical lights at 10W/m^2, switched on during occupancy hours. Occupancy sensor assumed as well, that will keep the lights switched off 50% of the time.
4	**Pantry Ventilation Strategy**	Air-conditioned as part of Office space with same operating hours of Office space.
5	**Pantry Small Power**	A small 330 watt fridge is on continuously.
6	**Fire Escape Staircases Lighting Strategy**	2 W/m^2 Lights are switched on 24 hours daily.
7	**Lift Lobby/Walkway**	100% lights at 10 W/m^2 switched on during occupancy hours from 9am to 6pm weekdays. 50% lights on during other hours and weekends. Because this space is air-conditioned, it will always be assumed to be located away from an external wall. i.e. since it is an air-conditioned space, locating it with an external wall would give it the same conditions as an office space, which would defeat the purpose of this study.
8	**AHU Rooms**	Always assumed to be located away from the external wall because it does not benefit in terms of daylight harvesting or view out and because it is also an air-conditioned space.
9	**Office Lighting Strategy**	15 W/m^2 switched on from the hours of 9am to 6pm on weekdays. Office spaces with external walls are assumed to harness daylight up to 3.5 meters depth from the façade whenever the outdoor horizontal illumination is higher than 15,000 lux. In addition, 5% lights are assumed switched on during non-occupancy hours in the office space.
10	**Office Small Power**	15 W/m^2 peak load is assumed during office hours of 9am to 6pm with 30% dip in power consumption from 12:30 noon to 1:30pm on weekdays. 35% of the peak load is assumed for all other hours.

Other key assumptions:

No	Description	Assumptions
11	**Window to Wall Ratio**	70% for façade connected to Office space. Window area assumed to be 10% of floor area for external façade connected to Pantry, Toilet, and Fire Escape Staircase. Note: Locating a non-air-conditioned core space on an external wall will cause the office space to lose one façade to the exterior, reducing the heat gain (70% WWR on one façade is gone), but also losing the view out and reducing the potential for daylight harvesting in an office space.
12	**Glazing Properties**	Single glazing tinted. SHGC = 0.65 VLT = 45% U-value 5.7 W/m^{2}K
13	**External Wall Properties**	Typical 100mm thick Concrete Wall with 15mm Cement Screed, U-value 3.2 W/m^{2}K

14	**Internal Wall Properties**	Typical Internal Brick Wall with Cement Screed, U-value 2.0 W/m^{2}K
15	**Roof Properties**	Insulated Flat Roof, Heavy Weight with 50mm polystyrene foam used for a U-value of 0.52 W/m^{2}K
16	**Base Ventilation System**	VAV Fan Total Pressure: 3" w.g. (750 Pa) Fan Total Efficiency: 65% Turn Down Ratio: 30% Design Off-coil Temperature: 12°C
17	**Base Chill Water System**	Variable Primary Flow Pump Total Head: 35m Pump Total Efficiency: 65% Specific Pump Power: 535 W per l/s Minimum Flow Rate: 70% of peak Chill Water Supply Temperature: 6.7°C Chill Water Return Temperature: 13.4°C
18	**Base Chiller**	3 Centrifugal Chillers in Parallel. Chiller capacity is identical with an allowable maximum per chiller of 800 ton. COP = 5.7 (0.62 kW/ton)
19	**Base Condenser System**	Constant flow at rated condition (2.4 gpm/ton) Pump Total Head: 30m Pump Total Efficiency: 65% Specific Pump Power: 456 W per l/s Design Condenser Water Temperature Return to Chiller: 29.4°C Design Condenser Delta Temperature: 5.6°K
20	**Cooling Tower**	Fan power at 0.038 kW/HRT
21	**Fresh Air Supply**	ASHRAE 62.1 (2007)
22	**Infiltration**	The infiltration rate of the building is based on the assumption of a crack along the window perimeter. Windows are assumed to be 2.8m height (for 70% WWR with ribbon window layout) and each piece of window is 1.2 meters width. It is also assumed that 2 pieces of window is required to make the total height of 2.8 meters. The assumption of crack coefficient is based on 0.13 (l s^{-1} m^{-1} Pa$^{-0.6}$) for a weather-stripped hinged window.[1] The simulation study uses the wind pressure coefficients taken from the Air Infiltration and Ventilation Centre's publication *Air Infiltration Calculation Techniques – An Applications Guide*[2]. These coefficients are derived from wind tunnel experiments.
23	**Office Occupancy**	Weekdays: 10 m^2/person, 9am to 6pm, with 50% reduction at lunch time of 12.30 noon to 1.30pm. Weekends: Empty
24	**Lift Core**	Lift Core is assumed to have an infiltration rate of 1 ACH during occupancy hours and 0.5 during non-occupancy hours. Lift power is ignored in this study.
25	**Façade and External Lights**	Façade and external lights are ignored in this study.
26	**Other Misc Power**	All other miscellaneous power use is ignored. These items include potable water pumps, escalators, security access systems, etc.

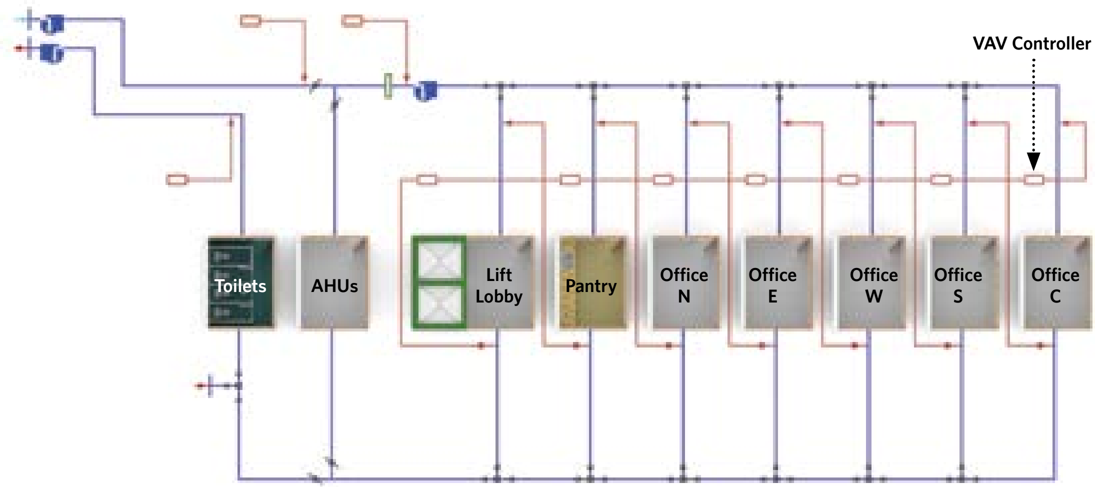
[1] An Analysis and Data Summary of the AIVC's Numerical Database. Technical Note AIVC 44, March 1994. Air Infiltration and Ventilation Centre.
[2] Air Infiltration Calculation Techniques – An Applications Guide, Air Infiltration and Ventilation Centre. University of Warwick Science Park. Sovereign Court, Sir William Lyons Road, Coventry CV4 7EZ.

AIR CONDITIONING SYSTEM

AIR-SIDE DETAILS

One AHU is modelled per floor, with 7 air-conditioned zones.

FIGURE 6.1 | AIR-SIDE SCHEMATIC MODEL IN IES, REPRESENTING 7 AIR-CONDITIONED ZONES



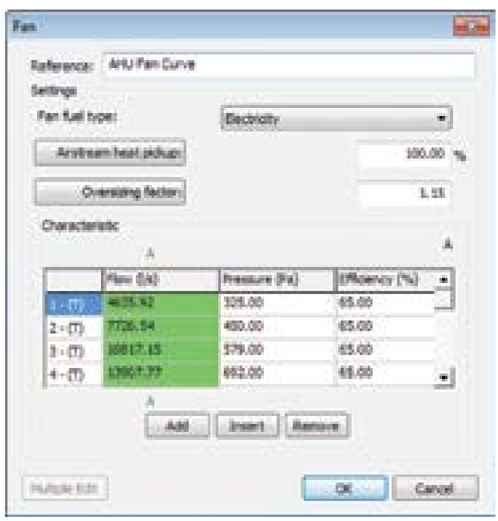
1 FAN PERFORMANCE CURVE

The fan performance curve follows ASHRAE 90.1 (2004), Table G3.1.3.15, Part-Load Performance for VAV Fan Systems.

Fan Part-Load Ratio	Fraction of Full-Load Power
0.30	0.13
0.50	0.30
0.70	0.54
0.90	0.83
1.00	1.00

The total fan efficiency is assumed constant while the total fan pressure is varied to match ASHRAE 90.1 (2004), Table G3.1.3.15.

Fan max flow rate is sized based on the supply air flow temperature, room air temperature and the zone peak sensible heat gain.

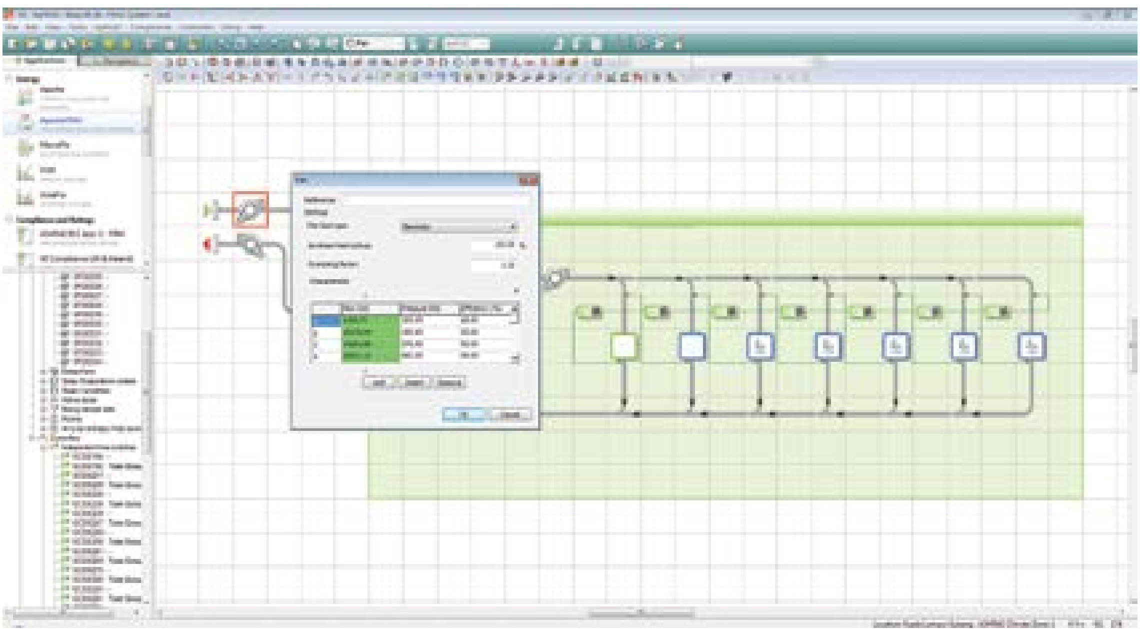


2 FRESH AIR CONTROLLER

Fresh air provided at 1,040.7 l/s during air-conditioning hours based on the ASHRAE 62.1 (2007) requirement of fresh air for the space and people density.

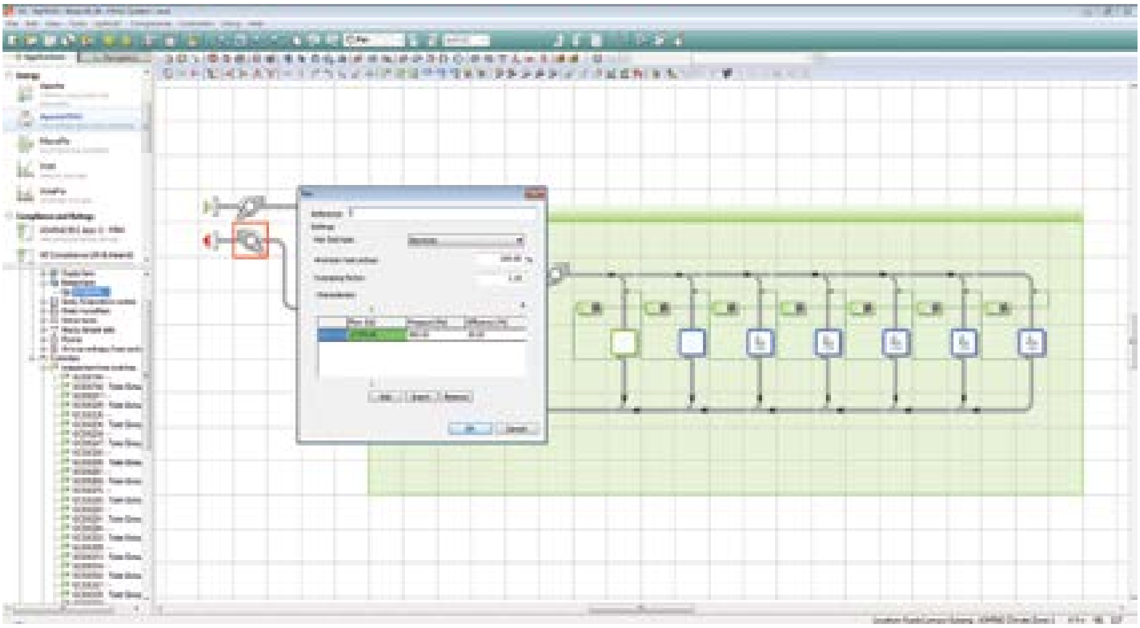
3 FRESH AIR FAN ON THE ROOF

Fan max flow rate is auto-sized based on the flow rate assigned for each floor.



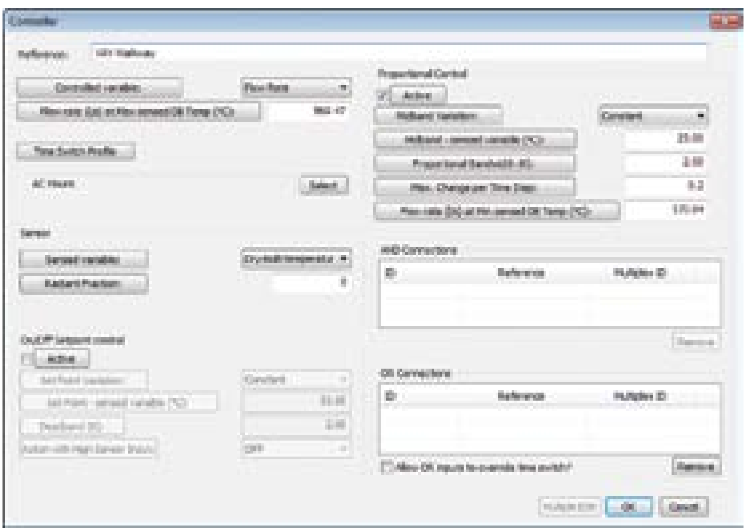
4 EXHAUST AIR FAN ON THE ROOF

Exhaust fan flow rate is auto-sized based on the toilet exhaust from each floor. A fan total pressure of 500 Pa and 50% fan total efficiency is assumed.



5 VAV BOX CONTROLLER

An active proportional controller is assigned to the VAV box that controls the supply air flow rate based on the sensed dry bulb temperature from the zone.



The minimum allowable flow rate is set at 30% of the maximum flow rate. The temperature set point is 23°C with a proportional bandwidth of 2°K or 23°C +/- 1°C.

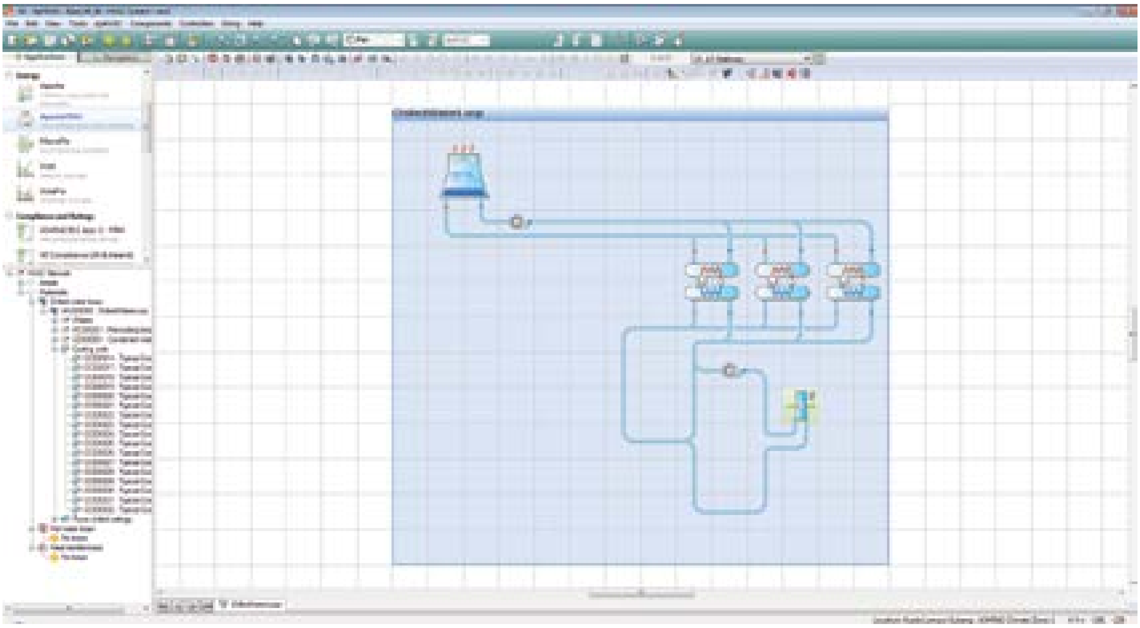
6 COOLING COIL

Cooling coil is auto-sized during system sizing run. A cooling coil contact factor of 0.91 is assumed. Cooling coil is oversized by 15% as per ASHRAE 90.1 requirements.

4 EXHAUST AIR FAN ON THE ROOF

WATER-SIDE – CHILLED WATER LOOP

The base system has a primary variable chilled water pump with a 3-chiller configuration.



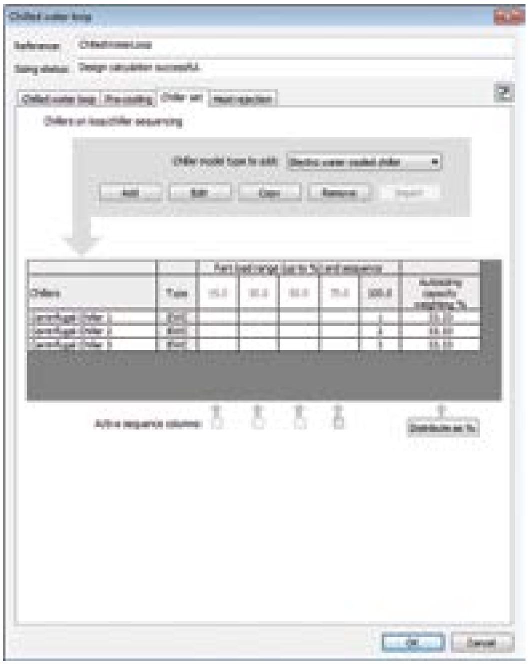
1 CHILLED WATER DISTRIBUTION

The chilled water pump is oversized by 15% and 0% distribution losses are assumed as per ASHRAE 90.1 requirements. Chilled water supply temperature is set at 6.67°C (44°F) and a ΔT of 6.67°C (12°F) is assumed. The cooling coil in the AHU is automatically sized to these requirements based on the design off-coil temperature.

A primary only variable pump is assumed with a specific pump power of 545 W per l/s.

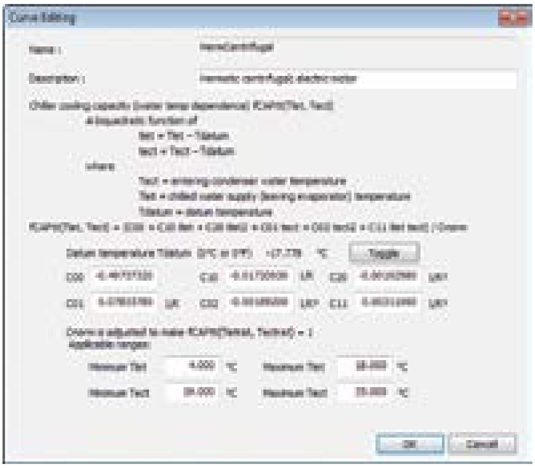
2 CHILLERS

Three (3) chillers are required for this building model. These chillers are sized equally and are sequenced to operate in a stack mode, i.e. when one of the chillers has reached maximum capacity, an additional chiller is turned on to provide cooling.

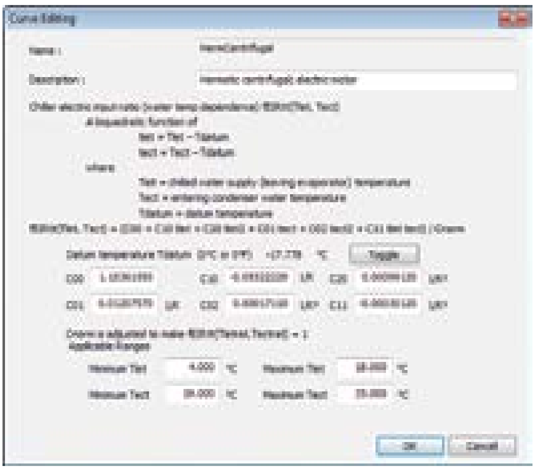


The base chiller is a centrifugal chiller with a COP of 5.7 and has a peak cooling capacity of 2,138 kW (608 ton) per chiller.

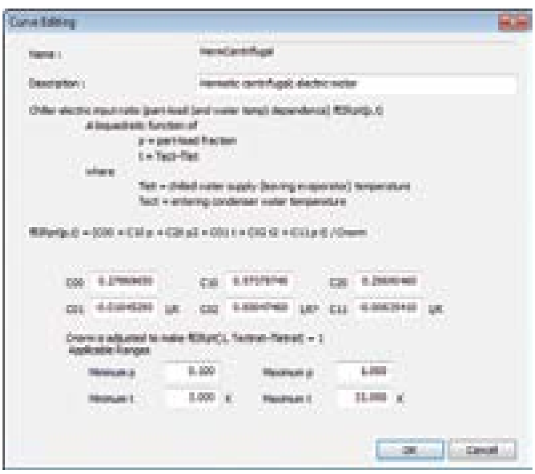
COOLING CAPACITY CURVE



EIR (WATER TEMPERATURE DEPENDENCE) CURVE



EIR (PART LOAD DEPENDENCE) CURVE



HEAT REJECTION & COOLING TOWER

IES REPORT GENERATION

1 LOCATION & SITE DATA

Location	Kuala Lumpur Subang
Region	Malaysia
Latitude	3.12 N
Longitude	101.55 E
Altitude	22.0m
Time zone (Hours ahead of GMT)	8.0 hours
• Daylight Saving Time	
Time adjustment	0.0 hours
From	
Through	
Adjustment for other months	0.0 hours
• Site Data	
Ground reflectance	0.2
Terrain type	Suburbs
Wind exposure (CIBSE Heating Loads)	Normal
Weather Simulation Data	
ApacheSim File	SubangTRY.fwt

DESIGN WEATHER DATA	
• Design Weather Data Source & Statistics	
Source of Design Weather	ASHRAE design weather database
ASHRAE weather location	Kuala Lumpur Subang , Malaysia
Monthly percentile for Heating Loads design weather	99.6 %
Monthly percentile for Cooling Loads design weather	0.4 %
• Heating Loads Weather Data	
Outdoor Winter Design Temperature	22.0°C
• Cooling Loads Weather Data	
Max. Outside Dry-Bulb	35.1°C
Max. Outside Wet-Bulb	26.3°C

WEATHER MODEL DATA

	Temperature		Humidity	Solar Radiation
	Dry bulb T Min (°C)	Dry bulb T Max (°C)	Wet bulb T at Max Dry bulb (°C)	Linke Turbidity Factor
Jan	25.50	34.00	24.50	2.74
Feb	25.80	34.80	24.90	2.70
Mar	26.40	35.10	25.20	2.68
Apr	26.50	34.90	26.20	2.76
May	26.90	34.80	26.30	2.79
Jun	26.00	34.20	25.40	2.85
Jul	26.00	34.00	25.40	2.86
Aug	26.10	34.10	25.30	2.80
Sep	26.00	34.00	25.20	2.72
Oct	26.10	34.00	25.50	2.74
Nov	25.60	33.20	25.60	2.71
Dec	25.60	33.20	25.00	2.75

2 THERMAL TEMPLATE: AHU ROOM

BUILDING REGULATIONS	
Room Type	Heated or occupied room
External Ventilation	0 air changes per hour
NCM Building Type	
NCM Activity	
ROOM CONDITIONS	
• Heating	
Profile	off continuously
Setpoint: Constant	19 °C
Hot Water consumption	0.00 l/(h·pers)
• Cooling	
Profile	off continuously
Setpoint: Constant	23 °C
• Model Settings	
Solar Reflected Fraction	0.05
Furniture Mass Factor	1.00
SYSTEMS	
HVAC System	Main system
Auxilliary vent. system	Main system
DHW system	Main system
• Heating	
Radiant Fraction	0.20
Capacity	0.00 kW
• Cooling	
Radiant Fraction	0.00
Capacity	unlimited
• Humidity Control	
Min. % Saturation	0 %
Max. % Saturation	100 %
• System outside air supply	
Min. Flow Rate	0.30 l/(s·m²)
Add. Free Cooling Capacity	0.00 AC/h
Variation Profile	off continuously
INTERNAL GAINS	
	None
AIR EXCHANGES	
• Infiltration Non-AC Hours	
Type	Infiltration
Variation Profile	NonAC Hours
Adjacent Condition	External Air
Max A/C Rate	0.50 AC/h

ROOMS USING THIS TEMPLATE	
Room ID	Name
[AHU_0000]	01 AHU
[AHU_0001]	02 AHU
[AHU_0002]	03 AHU
[AHU_0003]	04 AHU
[AHU_0004]	05 AHU
[AHU_0005]	06 AHU
[AHU_0006]	07 AHU
[AHU_0007]	08 AHU
[AHU_0008]	09 AHU
[AHU_0009]	10 AHU
[AHU_0010]	11 AHU
[AHU_0011]	12 AHU
[AHU_0012]	13 AHU
[AHU_0013]	14 AHU
[AHU_0014]	15 AHU
[AHU_0015]	16 AHU
[AHU_0016]	17 AHU

3 THERMAL TEMPLATE: LIFT SHAFT

BUILDING REGULATIONS	
Room Type	Heated or occupied room
External Ventilation	0 air changes per hour
NCM Building Type	
NCM Activity	
ROOM CONDITIONS	
• Heating	
Profile	off continuously
Setpoint: Constant	19 °C
Hot Water consumption	0.00 l/(h·pers)
• Cooling	
Profile	off continuously
Setpoint: Constant	23 °C
• Model Settings	
Solar Reflected Fraction	0.05
Furniture Mass Factor	1.00
SYSTEMS	
HVAC System	Main system
Auxilliary vent. system	Main system
DHW system	Main system
• Heating	
Radiant Fraction	0.20
Capacity	0.00 kW
• Cooling	
Radiant Fraction	0.00
Capacity	unlimited
• Humidity Control	
Min. % Saturation	0 %
Max. % Saturation	100 %
• System outside air supply	
Min. Flow Rate	0.30 l/(s·m^2)
Add. Free Cooling Capacity	0.00 AC/h
Variation Profile	off continuously
INTERNAL GAINS	
	None
AIR EXCHANGES	
• Lift shaft infiltration	
Type	Infiltration
Variation Profile	Infiltration
Adjacent Condition	External Air
Max A/C Rate	1.00 AC/h

ROOMS USING THIS TEMPLATE	
Room ID	Name
[LFTS0000]	01 LiftShaft
[LFTS0001]	02 LiftShaft
[LFTS0002]	03 LiftShaft
[LFTS0003]	04 LiftShaft
[LFTS0004]	05 LiftShaft
[LFTS0005]	06 LiftShaft
[LFTS0006]	07 LiftShaft
[LFTS0007]	08 LiftShaft
[LFTS0008]	09 LiftShaft
[LFTS0009]	10 LiftShaft
[LFTS0010]	11 LiftShaft
[LFTS0011]	12 LiftShaft
[LFTS0012]	13 LiftShaft
[LFTS0013]	14 LiftShaft
[LFTS0014]	15 LiftShaft
[LFTS0015]	16 LiftShaft
[LFTS0016]	17 LiftShaft

④ THERMAL TEMPLATE: OFFICE SIDE

BUILDING REGULATIONS	
Room Type	Heated or occupied room
External Ventilation	0 air changes per hour
NCM Building Type	
NCM Activity	
ROOM CONDITIONS	
• Heating	
Profile	off continuously
Setpoint: Constant	19 °C
Hot Water consumption	0.00 l/(h·pers)
• Cooling	
Profile	AC Hours
Setpoint: Constant	23 °C
• Model Settings	
Solar Reflected Fraction	0.05
Furniture Mass Factor	1.00
SYSTEMS	
HVAC System	Main system
Auxilliary vent. system	Main system
DHW system	Main system
• Heating	
Radiant Fraction	0.20
Capacity	0.00 kW
• Cooling	
Radiant Fraction	0.00
Capacity	unlimited
• Humidity Control	
Min. % Saturation	0 %
Max. % Saturation	50 %
• System outside air supply	
Min. Flow Rate	0.55 l/(s·m^2)
Add. Free Cooling Capacity	0.00 AC/h
Variation Profile	AC Hours
INTERNAL GAINS	
• Fluorescent Lighting : Office Lighting Side	
Max Sensible Gain	3744.00 W
Max Power Consumption	3744.00 W
Radiant Fraction	0.45
Fuel	Electricity
Variation Profile	Off Lgt Side DL
Dimming Profile	on continuously
• People : Office People Side	
Max Sensible Gain	90.00 W/P
Max Latent Gain	60.00 W/P
Occupant Density	25.00 people
Variation Profile	Off Ppl

INTERNAL GAINS	
• Computers : Office Computer Side	
Max Sensible Gain	3744.00 W
Max Power Consumption	3744.00 W
Radiant Fraction	0.22
Fuel	Electricity
Variation Profile	Off SmPwr
AIR EXCHANGES	
	None

ROOMS USING THIS TEMPLATE			
Room ID	Name	Room ID	Name
[FFC10000]	01 Office1N	[FFC30008]	09 Office3S
[FFC20000]	01 Office2E	[FFC40008]	09 Office4W
[FFC30000]	01 Office3S	[FFC10009]	10 Office1N
[FFC40000]	01 Office4W	[FFC20009]	10 Office2E
[FFC10001]	02 Office1N	[FFC30009]	10 Office3S
[FFC20001]	02 Office2E	[FFC40009]	10 Office4W
[FFC30001]	02 Office3S	[FFC10010]	11 Office1N
[FFC40001]	02 Office4W	[FFC20010]	11 Office2E
[FFC10002]	03 Office1N	[FFC30010]	11 Office3S
[FFC20002]	03 Office2E	[FFC40010]	11 Office4W
[FFC30002]	03 Office3S	[FFC10011]	12 Office1N
[FFC40002]	03 Office4W	[FFC20011]	12 Office2E
[FFC10003]	04 Office1N	[FFC30011]	12 Office3S
[FFC20003]	04 Office2E	[FFC40011]	12 Office4W
[FFC30003]	04 Office3S	[FFC10012]	13 Office1N
[FFC40003]	04 Office4W	[FFC20012]	13 Office2E
[FFC10004]	05 Office1N	[FFC30012]	13 Office3S
[FFC20004]	05 Office2E	[FFC40012]	13 Office4W
[FFC30004]	05 Office3S	[FFC10013]	14 Office1N
[FFC40004]	05 Office4W	[FFC20013]	14 Office2E
[FFC10005]	06 Office1N	[FFC30013]	14 Office3S
[FFC20005]	06 Office2E	[FFC40013]	14 Office4W
[FFC30005]	06 Office3S	[FFC10014]	15 Office1N
[FFC40005]	06 Office4W	[FFC20014]	15 Office2E
[FFC10006]	07 Office1N	[FFC30014]	15 Office3S
[FFC20006]	07 Office2E	[FFC40014]	15 Office4W
[FFC30006]	07 Office3S	[FFC10015]	16 Office1N
[FFC40006]	07 Office4W	[FFC20015]	16 Office2E
[FFC10007]	08 Office1N	[FFC30015]	16 Office3S
[FFC20007]	08 Office2E	[FFC40015]	16 Office4W
[FFC30007]	08 Office3S	[FFC10016]	17 Office1N
[FFC40007]	08 Office4W	[FFC20016]	17 Office2E
[FFC10008]	09 Office1N	[FFC30016]	17 Office3S
[FFC20008]	09 Office2E	[FFC40016]	17 Office4W

5 THERMAL TEMPLATE: OFFICE CORE

BUILDING REGULATIONS	
Room Type	Heated or occupied room
External Ventilation	0 air changes per hour
NCM Building Type	
NCM Activity	
ROOM CONDITIONS	
• Heating	
Profile	off continuously
Setpoint: Constant	19 °C
Hot Water consumption	0.00 l/(h·pers)
• Cooling	
Profile	AC Hours
Setpoint: Constant	23 °C
• Model Settings	
Solar Reflected Fraction	0.05
Furniture Mass Factor	1.00
SYSTEMS	
HVAC System	Main system
Auxilliary vent. system	Main system
DHW system	Main system
• Heating	
Radiant Fraction	0.20
Capacity	0.00 kW
• Cooling	
Radiant Fraction	0.00
Capacity	unlimited
• Humidity Control	
Min. % Saturation	0 %
Max. % Saturation	50 %
• System outside air supply	
Min. Flow Rate	0.55 l/(s·m^2)
Add. Free Cooling Capacity	0.00 AC/h
Variation Profile	AC Hours

INTERNAL GAINS	
• Fluorescent Lighting : Office Lighting Core	
Max Sensible Gain	9774.00 W
Max Power Consumption	9774.00 W
Radiant Fraction	0.45
Fuel	Electricity
Variation Profile	Off Lgt Core
Dimming Profile	on continuously
• People : Office People Core	
Max Sensible Gain	90.00 W/P
Max Latent Gain	60.00 W/P
Occupant Density	65.00 people
Variation Profile	Off Ppl
• Computers : Office Computer Core	
Max Sensible Gain	9774.00 W
Max Power Consumption	9774.00 W
Radiant Fraction	0.22
Fuel	Electricity
Variation Profile	Off SmPwr
AIR EXCHANGES	
• Infiltration NonAC Hours	
Type	Infiltration
Variation Profile	NonAC Hours
Adjacent Condition	External Air
Max A/C Rate	0.50 AC/h

ROOMS USING THIS TEMPLATE	
Room ID	Name
[FFC50000]	01 Office5C
[FFC50001]	02 Office5C
[FFC50002]	03 Office5C
[FFC50003]	04 Office5C
[FFC50004]	05 Office5C
[FFC50005]	06 Office5C
[FFC50006]	07 Office5C
[FFC50007]	08 Office5C
[FFC50008]	09 Office5C
[FFC50009]	10 Office5C
[FFC50010]	11 Office5C
[FFC50011]	12 Office5C
[FFC50012]	13 Office5C
[FFC50013]	14 Office5C
[FFC50014]	15 Office5C
[FFC50015]	16 Office5C
[FFC50016]	17 Office5C

6 THERMAL TEMPLATE: PANTRY CORE

BUILDING REGULATIONS	
Room Type	Heated or occupied room
External Ventilation	0 air changes per hour
NCM Building Type	
NCM Activity	
ROOM CONDITIONS	
• Heating	
Profile	off continuously
Setpoint: Constant	19 °C
Hot Water consumption	0.00 l/(h·pers)
• Cooling	
Profile	AC Hours
Setpoint: Constant	23 °C
• Model Settings	
Solar Reflected Fraction	0.05
Furniture Mass Factor	1.00
SYSTEMS	
HVAC System	Main system
Auxilliary vent. system	Main system
DHW system	Main system
• Heating	
Radiant Fraction	0.20
Capacity	0.00 kW
• Cooling	
Radiant Fraction	0.00
Capacity	unlimited
• Humidity Control	
Min. % Saturation	0 %
Max. % Saturation	50 %
• System outside air supply	
Min. Flow Rate	0.30 l/(s·m^2)
Add. Free Cooling Capacity	0.00 AC/h
Variation Profile	AC Hours
INTERNAL GAINS	
• Fluorescent Lighting : Pantry Lighting Core	
Max Sensible Gain	220.00 W
Max Power Consumption	220.00 W
Radiant Fraction	0.45
Fuel	Electricity
Variation Profile	Off Lgt Core
Dimming Profile	on continuously
• Machinery : Small Fridge	
Max Sensible Gain	330.00 W
Max Latent Gain	0.00 W
Max Power Consumption	330.00 W
Radiant Fraction	0.22
Fuel	Electricity
Variation Profile	on continuously
AIR EXCHANGES	
• Infiltration Non-AC Hours	
Type	Infiltration
Variation Profile	Non-AC Hours
Adjacent Condition	External Air
Max A/C Rate	0.50 AC/h

ROOMS USING THIS TEMPLATE

Room ID	Name
[PNTR0000]	01 Pantry
[PNTR0001]	02 Pantry
[PNTR0002]	03 Pantry
[PNTR0003]	04 Pantry
[PNTR0004]	05 Pantry
[PNTR0005]	06 Pantry
[PNTR0006]	07 Pantry
[PNTR0007]	08 Pantry
[PNTR0008]	09 Pantry
[PNTR0009]	10 Pantry
[PNTR0010]	11 Pantry
[PNTR0011]	12 Pantry
[PNTR0012]	13 Pantry
[PNTR0013]	14 Pantry
[PNTR0014]	15 Pantry
[PNTR0015]	16 Pantry
[PNTR0016]	17 Pantry

7 THERMAL TEMPLATE: STAIRCASE CORE

BUILDING REGULATIONS	
Room Type	Heated or occupied room
External Ventilation	0 air changes per hour
NCM Building Type	
NCM Activity	
ROOM CONDITIONS	
• Heating	
Profile	off continuously
Setpoint: Constant	19 °C
Hot Water consumption	0.00 l/(h·pers)
• Cooling	
Profile	off continuously
Setpoint: Constant	23 °C
• Model Settings	
Solar Reflected Fraction	0.05
Furniture Mass Factor	1.00
SYSTEMS	
HVAC System	Main system
Auxilliary vent. system	Main system
DHW system	Main system
• Heating	
Radiant Fraction	0.20
Capacity	0.00 kW
• Cooling	
Radiant Fraction	0.00
Capacity	unlimited
• Humidity Control	
Min. % Saturation	0 %
Max. % Saturation	100 %
• System outside air supply	
Min. Flow Rate	0.30 l/(s·m²)
Add. Free Cooling Capacity	0.00 AC/h
Variation Profile	AC Hours
INTERNAL GAINS	
• Fluorescent Lighting : Stairs Lighting	
Max Sensible Gain	144.00 W
Max Power Consumption	144.00 W
Radiant Fraction	0.45
Fuel	Electricity
Variation Profile	on continuously
Dimming Profile	on continuously
AIR EXCHANGES	
	None

ROOMS USING THIS TEMPLATE	
Room ID	Name
[STR_0000]	01 Stair
[STR_0001]	02 Stair
[STR_0002]	03 Stair
[STR_0003]	04 Stair
[STR_0004]	05 Stair
[STR_0005]	06 Stair
[STR_0006]	07 Stair
[STR_0007]	08 Stair
[STR_0008]	09 Stair
[STR_0009]	10 Stair
[STR_0010]	11 Stair
[STR_0011]	12 Stair
[STR_0012]	13 Stair
[STR_0013]	14 Stair
[STR_0014]	15 Stair
[STR_0015]	16 Stair
[STR_0016]	17 Stair

8 THERMAL TEMPLATE: TOILET CORE

BUILDING REGULATIONS	
Room Type	Heated or occupied room
External Ventilation	0 air changes per hour
NCM Building Type	
NCM Activity	
ROOM CONDITIONS	
• Heating	
Profile	off continuously
Setpoint: Constant	19 °C
Hot Water consumption	0.00 l/(h·pers)
• Cooling	
Profile	off continuously
Setpoint: Constant	23 °C
• Model Settings	
Solar Reflected Fraction	0.05
Furniture Mass Factor	1.00
SYSTEMS	
HVAC System	Main system
Auxilliary vent. system	Main system
DHW system	Main system
• Heating	
Radiant Fraction	0.20
Capacity	0.00 kW
• Cooling	
Radiant Fraction	0.00
Capacity	unlimited
• Humidity Control	
Min. % Saturation	0 %
Max. % Saturation	100 %
• System outside air supply	
Min. Flow Rate	0.00 l/(s·m²)
Add. Free Cooling Capacity	0.00 AC/h
Variation Profile	AC Hours
INTERNAL GAINS	
• Fluorescent Lighting : Toilet Lights Core	
Max Sensible Gain	800.00 W
Max Power Consumption	800.00 W
Radiant Fraction	0.45
Fuel	Electricity
Variation Profile	AC Hours
Dimming Profile	on continuously
AIR EXCHANGES	
• Infiltration Non-AC Hours	
Type	Infiltration
Variation Profile	NonAC Hours
Adjacent Condition	External Air
Max A/C Rate	0.50 AC/h

ROOMS USING THIS TEMPLATE	
Room ID	Name
[TLT_0000]	01 Toilet
[TLT_0001]	02 Toilet
[TLT_0002]	03 Toilet
[TLT_0003]	04 Toilet
[TLT_0004]	05 Toilet
[TLT_0005]	06 Toilet
[TLT_0006]	07 Toilet
[TLT_0007]	08 Toilet
[TLT_0008]	09 Toilet
[TLT_0009]	10 Toilet
[TLT_0010]	11 Toilet
[TLT_0011]	12 Toilet
[TLT_0012]	13 Toilet
[TLT_0013]	14 Toilet
[TLT_0014]	15 Toilet
[TLT_0015]	16 Toilet
[TLT_0016]	17 Toilet

9 THERMAL TEMPLATE: LOBBY / WALKWAY

BUILDING REGULATIONS	
Room Type	Heated or occupied room
External Ventilation	0 air changes per hour
NCM Building Type	
NCM Activity	
ROOM CONDITIONS	
• Heating	
Profile	off continuously
Setpoint: Constant	19 °C
Hot Water consumption	0.00 l/(h·pers)
• Cooling	
Profile	AC Hours
Setpoint: Constant	23 °C
• Model Settings	
Solar Reflected Fraction	0.05
Furniture Mass Factor	1.00
SYSTEMS	
HVAC System	Main system
Auxilliary vent. system	Main system
DHW system	Main system
• Heating	
Radiant Fraction	0.20
Capacity	0.00 kW
• Cooling	
Radiant Fraction	0.00
Capacity	unlimited
• Humidity Control	
Min. % Saturation	0 %
Max. % Saturation	50 %
• System outside air supply	
Min. Flow Rate	0.30 l/(s·m²)
Add. Free Cooling Capacity	0.00 AC/h
Variation Profile	AC Hours
INTERNAL GAINS	
• Fluorescent Lighting : Lobby Lighting	
Max Sensible Gain	1700.00 W
Max Power Consumption	1700.00 W
Radiant Fraction	0.45
Fuel	Electricity
Variation Profile	Lobby Lights
Dimming Profile	on continuously
AIR EXCHANGES	
• Infiltration Non-AC Hours	
Type	Infiltration
Variation Profile	NonAC Hours
Adjacent Condition	External Air
Max A/C Rate	0.50 AC/h

ROOMS USING THIS TEMPLATE	
Room ID	Name
[WLKW0000]	01 Walkway
[WLKW0001]	02 Walkway
[WLKW0002]	03 Walkway
[WLKW0003]	04 Walkway
[WLKW0004]	05 Walkway
[WLKW0005]	06 Walkway
[WLKW0006]	07 Walkway
[WLKW0007]	08 Walkway
[WLKW0008]	09 Walkway
[WLKW0009]	10 Walkway
[WLKW0010]	11 Walkway
[WLKW0011]	12 Walkway
[WLKW0012]	13 Walkway
[WLKW0013]	14 Walkway
[WLKW0014]	15 Walkway
[WLKW0015]	16 Walkway
[WLKW0016]	17 Walkway

10 CONSTRUCTIONS ASSOCIATED WITH THIS MODEL

	ID	Description	U-value ISO ($W/m^2 \cdot K$)	Total shading coefficient (glazed only)	No. of rooms
Roof	FROOF2	Typical Flat Roof wt Insulation	0.522		187
Ceiling	CCR101	Carpeted 100mm reinforced-concrete ceiling	2.283		187
External Wall	STD_WAL2	standard concrete construction	3.179		187
Internal Partition	IWP1B	13mm pll 105mm bri 13mm pll	1.965		187
Ground Floor	STD_FLO2	standard floor construction (2002 regs)	0.821		187
Door	DOOR	wooden door	2.194		0
External Glazing	GDPK6	base single glz tinted	5.322	0.779	68
Internal Glazing	GSP4I	4mm Pilkington single glazing	3.689	1.006	0
Rooflight	RGDPK6	low-e double glazing (6mm+6mm) (2002 regs)	2.103	0.736	0

END OF CHAPTER 6

CHAPTER

7

OPTIMISING THE AIR-SIDE AIR-CONDITIONING SYSTEM

by CK Tang & Nic Chin

7

OPTIMISING THE AIR-SIDE AIR-CONDITIONING SYSTEM

INTRODUCTION

The air-side air-conditioning system consists of the supply air, return air, ducts, diffusers, fresh air intake systems, air filters, cooling coils, motors and fans. The combination of air filter, cooling coil, fan and motor is commonly known as an Air Handling Unit (AHU) or Fan Coil Unit (FCU). An AHU is a larger system that is typically installed on each floor inside an AHU room, while a FCU is a description used for smaller units of AHU that are installed within the ceiling plenum, ceiling or are wall mounted.

The intent of the information provided in this chapter is to promote energy efficiency on the air-side air-conditioning equipment by providing an estimate of the energy efficiency potential in air-side optimisation based on case studies of a typical office building scenario. It is hoped that by providing the energy reduction potential, readers of this chapter will be able to design and implement systems of higher efficiency by being able to gauge the potential efficiency gains on the air-side system.

The Active Design guideline is focused on providing the fundamentals of energy efficiency in buildings. Therefore, this chapter only addresses Constant Air Volume (CAV) and Variable Air Volume (VAV) systems and will not address advanced options of displacement ventilation systems or combinations of radiant cooling and ventilation systems.

A CAV system maintains a constant supply air flow rate. It controls the room temperature by varying the off-coil (or supply air) temperature, as opposed to a VAV system that keeps the off-coil temperature constant and controls the room temperature by varying the supply air flow rate. On this basis alone, it is easy to understand why a VAV system has lower fan energy consumption than a CAV system and is seen as a common energy efficient feature for buildings. However, the exact quantum of energy savings of a VAV system over a CAV system has never really been quantified for this climate zone and is now addressed in this chapter.

This chapter provides the results from a series of simulation case studies of a typical office building scenario to test various options of improving the efficiency of the air-side air-conditioning system. The test building scenario was based on a model as described in Chapter 6 of this Active Design Technical Guideline. As a quick guide, the simulation test building is a 17 floor office building with 34,400m^2 gross floor area and a floor efficiency of 78%.

This chapter also provides estimates of building energy index (BEI) reduction for each energy efficiency feature assessed based on the test model described. These estimates of energy reduction in this chapter should be used as a first round guesstimate to evaluate the financial feasibility of any proposed energy efficiency feature as described in this chapter. These results are provided for designers and building owners to make quick decisions and to evaluate if such features are worth the effort to be investigated further by the design team.

The actual BEI reduction on a specific building will likely vary from the numbers provided here as the actual building operational scenario will not be exactly the same as the simulation case scenario. Variations on passive design features such as window-to-wall ratios, windows, wall and roof properties, occupant density, operational hours and active design features such as the number of chillers, pump efficiencies, fan efficiencies, static pressure, etc. will cause the predicted BEI in this chapter to be different from the actual building scenario. In addition, the predicted BEI reduction is also highly dependent on the sequence implementation of energy efficient features in a building. For example, if the building already has a very efficient chiller, the reduction of lighting power density will not provide as significant a reduction on chiller energy used, compared to a case with inefficient chillers.

Conducting energy simulations on buildings can be very time consuming, therefore a guideline such as this is required to fill the “gap” to allow building designers to make quick decisions on the building design and to proceed with further investigations when deemed necessary.

Finally, it is recommended to test the actual building design performance on the actual building being designed, using building energy simulation tools such as IES <VE>, DesignBuilder, Equest, Trnsys, TAS, EnergyPlus, HAP-2, etc. whenever feasible for a project. Such software will help to establish the exact potential efficiency gains on the building based on the actual design proposal. Experienced energy modelers will be able to provide realistic assumptions and input data into the simulation engine to provide fairly accurate results for the building. Conversely, inexperienced energy modelers may use assumptions that are incorrect and provide results that may be unrealistically high or low.

It has also been advised that the provision of BEI reduction in this chapter for each energy efficiency feature may be misleading to the industry and it has been advised not to provide these estimates to the industry. However, it is the author’s opinion that the absence of such “rule-of-thumb” information for the building industry in Malaysia is one of the key obstacles for the industry to practice energy efficiency in buildings. In addition, the absence of such “rule-of-thumb” BEI reduction in the industry has also led to the propagation of design myths about the practice of energy efficiency in buildings. Many of these industry “myths” are not supported by actual facts and data, but mostly by the “gut feelings” of “experienced” design engineers, incomplete data and rumours among practitioners.

It is hoped that the provision of these case study results will challenge both inexperienced and experienced design engineers to re-examine some of the industry “myths”, to pay attention to the actual fundamentals engineering and to make proper engineering evaluations by conducting their own investigations before accepting industry rumours as the holy truth.

It is hoped that the provision of these case study results will challenge both inexperienced and experienced design engineers to re-examine some of the industry “myths”, to pay attention to the actual fundamentals engineering and to make proper engineering evaluations

KEY RECOMMENDATIONS

1. The design off-coil (supply air) temperature of a CAV system should be as low as allowed by the chilled water supply temperature, cooling coil and the room dew point temperature. From the simulation results, the lowest possible design off-coil temperature of a CAV system is 11°C using a draw-through AHU configuration that warms up the supply air to avoid condensation on the outlet diffusers. Although the simulation results showed that more efficiency can be gained from a lower design off-coil temperature, there is a significantly high risk of condensation at the AHU casing and outlet diffusers at lower design off-coil temperatures. This risk can be reduced by careful selection of insulated AHU casings with good thermal breaks.

2. The optimum design off-coil temperature of a VAV system is 11°C. Reducing it below 11°C increases the building's energy consumption because the chiller energy increment (due to the additional latent heat removed) is more than the reduction of fan energy. Moreover, the risk of condensation on the outlet diffusers increases significantly at design off-coil temperatures below 11°C. Increasing the design off-coil temperature beyond 11°C increases the fan energy higher than the savings achieved from a reduced latent load removal and is not recommended to be implemented.

3. It is also recommended to design a CAV system with a variable speed drive to allow optimisation on the CAV to be conducted during the operational stage of the building to match the building's actual sensible load. In the simulation study conducted, it was found that a significant amount of energy reduction can be obtained when the air flow rate was recalibrated based on the actual sensible heat measured at the site. This also indicates that it would be a good practice to provide continuous monitoring of the sensible heat exchange of all major AHUs by measuring its flow rate, on-coil temperature and off-coil temperature. This energy efficiency option is also applicable for a VAV system, where the measured on-site peak sensible heat can be used to limit the peak VAV flow rate.

4. The advantage of using a VAV system instead of a CAV system was simulated to provide a saving of 7 kWh/m^2.year based on the same design off-coil condition of 11°C (where both systems are using the same cooling coil size).

5. It is also recommended to implement a static pressure reset in a VAV system to gain further energy efficiency at part load conditions. A static pressure reset in a VAV system reduces the static pressure set point in the supply air duct during part load conditions. A proper commissioning and functioning test should be conducted to ensure that the static pressure reset on a VAV system is operating as intended because the controls for this system to work is delicate.

6. The BEI was simulated to reduce by 2 kWh/m^2.year per 100Pa reduction of fan total pressure in the simulation case scenario of a typical office building.

7. The BEI was simulated to reduce by 2 kWh/m^2.year per 10% improvement of fan total efficiency in the simulation case scenario of a typical office building.

8. The use of CO_2 demand controlled fresh air ventilation provided only marginal energy reductions when the building occupant density during operation is the same as the design assumption (typically the worst case scenario at full occupant density). However, the BEI reduces significantly when the building occupant density is operating below the design assumption. The simulation study provided a reduction of 0.5 kWh/m^2.year for each 10% reduction of occupant density from the design assumption of 14 m^2/person.

9. The over provision of fresh air by the system was simulated to be very expensive for the building. Unfortunately, commissioning of the actual flow rate of the fresh air intake system is rarely conducted by the industry. It is highly recommended to include measurement of the fresh air flow rates during the commissioning of a building.

10. The use of a heat recovery system to pre-cool and pre-dry the fresh air intake using the exhaust air from a building was simulated to reduce the BEI in a building between 2 and 4 kWh/m^2.year, depending on the infiltration rate of the building. A higher infiltration rate in a building reduces the need for fresh air intake by the system when it is controlled by a CO_2 demand ventilation system.

CONSTANT AIR VOLUME (CAV) SYSTEM

A Constant Air Volume (CAV) system is where the design of the air flow rate is fixed at the maximum design flow rate. If the temperature in the space supplied by the CAV system is higher than the set point temperature (i.e. room is hot), the supply air temperature is reduced by increasing the flow rate of chilled water into the cooling coil. If the temperature of the space supplied is lower than the set point temperature by the sensor (i.e. room is cold), the supply air temperature is increased by reducing the flow rate of chilled water into the cooling coil.

A CAV system is used by many existing buildings in Malaysia because it is a system with very few moving parts and is very simple to maintain.

The design of the maximum supply air flow rate is provided by **Equation 7.1** below for a typical office building (where sensible heat normally dominates):

EQUATION 7.1

$$q_a = \frac{H_{\text{total sensible}}}{C_p \, \rho \, \Delta T}$$

Where:
q_a = Air Flow Rate due to sensible cooling load
$H_{\text{total sensible}}$ = Peak Total Sensible Cooling Load
C_p = Specific Heat of Air
ρ = Density of Air
ΔT = Space Design Temperature - Supply Air Temperature (off-coil temperature)
(Typical Room Design Temperature = 23°C, Typical Supply Air Temperature = 11°C
Typical ΔT = 23°C - 11°C = 12°C)

In this chapter, it was assumed that the space peak sensible cooling load is already optimised and is a fixed value. The space design temperature is normally fixed around 23°C or 24°C depending on the comfort condition that it is designed for, leaving the design supply air temperature as the only design parameter that can be varied by the designer. Higher design supply temperature reduces and increases the supply air flow rate. Lower design off-coil temperature increases and reduces the supply air flow rate.

The fan power equation is provided below as **Equation 7.2** below.

EQUATION 7.2

$$\text{Fan Power (W)} = \frac{q_a \times \Delta P}{\eta}$$

Where:
q_a = Supply Air Flow Rate (m^3/s)
ΔP = Total Fan Pressure (Pa)
η = Total Fan Efficiency (%)

From **Equation 7.2** above, it can be seen that a higher supply air flow rate increases fan power, while a lower air flow rate reduces fan power. However, a lower supply air flow rate also increases moisture (latent heat) removal by the cooling coil that will increase the energy consumption of the chiller due to the additional latent heat removed by the cooling coil.

Finally, the supply air temperature is required to be compared against the room dew point temperature. If the supply air temperature is lower than the room dew point temperature, condensation will occur at the supply air outlet diffusers. Interestingly, the room dew point temperature is also a function of the supply air off-coil temperature. The lower the off-coil temperature, the more moisture would be removed from the supply air, thereby reducing the moisture content in the air-conditioned room, reducing its dew point temperature.

SIMULATION STUDIES

Two sets of simulation studies were conducted to study the effect of off-coil temperature on a CAV system.

The first set of simulation studies assumed that the chilled water system has a fixed supply chilled water temperature of 6.67°C (44°F), while the design supply air off-coil temperature varies from 8°C to 15°C. The design air flow rate is then computed for each off-coil temperature selected.

The second set of simulation studies assumed that the supply chilled water temperature increases with the increase of design supply air (off-coil) temperature. This is possible because higher design off-coil temperatures will allow higher temperature supply chilled water to be used. The only requirement is for the cooling coil to be sized for these design possibilities. The interest in doing this is to test the benefit of improving chiller efficiency at the expense of fan power.

1 FIXED SUPPLY CHILLED WATER AT 6.67°C (44°F)

This set of simulation studies is an attempt to understand the optimum design off-coil (supply air) temperature for a CAV system. The advantages and disadvantages of increasing the design off-coil temperature in a CAV system are as listed below:

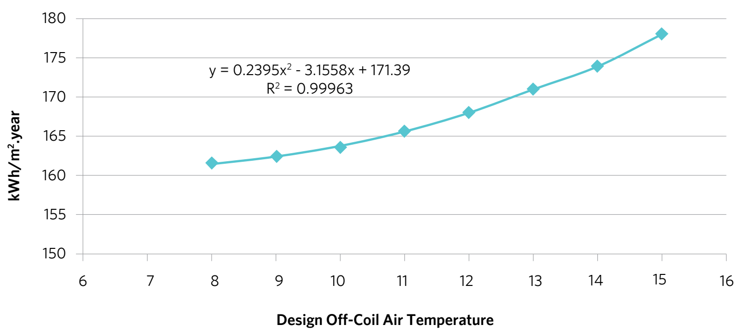
Advantages of increasing the design off-coil temperature in a CAV system:

- Reduces rate of moisture removal, leading to lower chiller energy consumption.
- Reduces cost of cooling coil (smaller cooling coils are required for a higher supply air temperature) when supply chilled water is fixed.

Disadvantages of increasing the design off-coil temperature in a CAV system:

- Increases fan energy and leads to a higher sensible heat load from the fan due to higher flow rate.
- Increases cost for fan and motor due to higher flow rate required.

FIGURE 7.1 | TOTAL BUILDING ENERGY INDEX (BEI) OF A CAV SYSTEM AT DIFFERENT DESIGN SUPPLY AIR TEMPERATURES



*Note that y-axis (BEI) does not start at zero.

The simulation results showed that in a CAV system, reducing the design off-coil temperature improves the overall efficiency of the building. This indicates that it is more important to keep the fan power as low as possible rather than trying to reduce the latent heat removal in a building via a high off-coil temperature setup.

From **Figure 7.1** above, the optimum design off-coil air temperature of a CAV system is shown to be 8°C. However, the supply air temperature at design off-coil of 8°C is below the room dew point temperature and will therefore cause condensation at the outlet diffusers. The limiting factor of reducing the design off-coil temperature to optimise energy efficiency on a CAV system is found to be the risk of condensation at outlet diffusers. Further analysis showed that the lowest possible design off-coil temperature for a CAV system is 11°C (in a draw-through AHU configuration) without condensation happening at the outlet diffusers.

It is important to take note that the cooling coil required to provide lower off-coil temperatures will be larger. The increase of cooling coil costs should be factored in to compute the financial payback study for the implementation of this design feature. It is also important to consider the need for cleaning access to large cooling coils. Cleaning of cooling coils is addressed in ASHRAE 62.1 (2007), Section 5.12.2, where it states the following:

"Individual finned-tube coils or multiple finned-tube coils in series without adequate intervening access space(s) of at least 18 in. (457 mm) shall be selected to result in no more than 0.75 in. w.c. (187 Pa) combined pressure drop when dry coil face velocity is 500 fpm (2.54 m/s). Exception: When clear and complete instructions for access and cleaning of both upstream and downstream coil surfaces are provided."

Please note that the heat gained from the energy used to move the fluid through the pipes will cause the chilled water temperature to be higher than 6.67°C when it finally reaches the cooling coils in a building. In addition, any conduction heat gain along the pipe distance will further increase the chilled water supply temperature. The simulation study made for this chapter ignored conduction heat gained by pipes as per the modelling recommendation of ASHRAE 90.1 (2007). Therefore, it is important that the sizing of the cooling coil should account for these potential increases in chilled water supply temperature.

Figure 7.1 can also be used as a quick approximation of the potential savings of CAV system between two design off-coil temperatures as shown in the calculation example below.

CALCULATION EXAMPLE

How much energy can be saved in a CAV system with fixed chilled water supply temperature if the design off-coil temperature is reduced from 13.5°C to 11°C? The building GFA is 55,000 m^2.

The BEI at design off-coil temperature of 13.5°C is computed using the curve fit equation shown the trend line in **Figure 7.1** on the previous page.

The BEI at design off-coil temperature of 13,5°C is:

BEI = $0.2395(13.5)^2 - 3.1558(13.5) + 171.39 = 172.4$ kWh/m^2.year

The BEI at design off-coil temperature of 11°C is:

BEI = $0.2395(11)^2 - 3.1558(11) + 171.39 = 165.7$ kWh/m^2.year

Approximate BEI reduction = 172.4 – 165.7 = 6.7 kWh/m^2.year

Approximate energy saving = 6.7 kWh/m^2.year x 55,000 m^2 = 368.5 MWh/year

Assuming a fixed electricity tariff of RM 0.43 per kWh (TNB, 2013, Tariff B for commercial building)

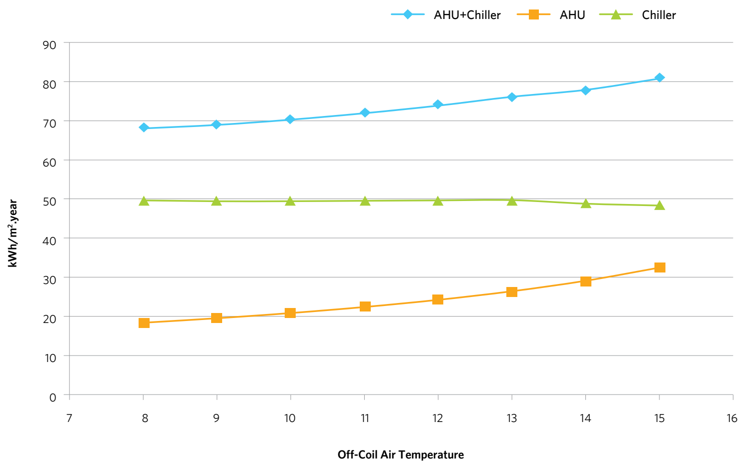
Approximated running cost saving per year is: 368,500 kWh/year * RM 0.43/kWh = RM 158,500 per year

This saving should then be compared to the additional cost of the cooling coil needed to reduce the design off-coil temperature from 13.5°C to 11°C for computation of payback and rate of return.

**This estimate is based on the simulated model. The actual savings provided by the actual building may differ from this output. This financial estimate calculation is provided to give an approximate rule-of-thumb for quick estimates during the conceptual stage to make a quick decision if such a design feature should be considered.*

Further investigation of the results in the **Figure 7.2** on the right shows that the reduction of chiller energy consumption (due to less moisture being extracted by the cooling coil) from a higher off-coil temperature is relatively small compared to the savings from lower fan energy due to a lower off-coil design temperature. In fact, there was an increase of chiller energy used when the off-coil temperature was increased from 9°C to 13°C due to the higher sensible heat load produced by the fan. The reduction of latent heat on the chiller only overcomes the increase in fan sensible heat load when the design off-coil temperature is increased beyond 13°C. However, this reduction cannot compensate for the increased fan energy at higher design off-coil temperatures.

FIGURE 7.2 | CHILLER AND AHU COMPONENTS OF BEI IN A CAV SYSTEM AT DIFFERENT DESIGN SUPPLY AIR TEMPERATURES

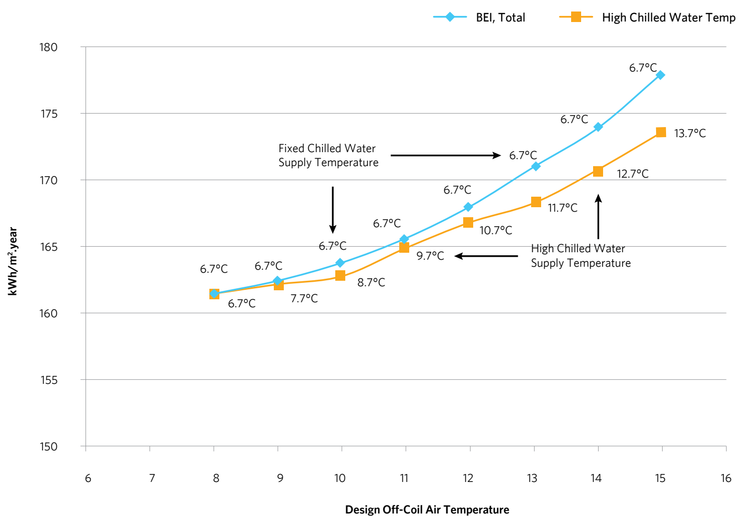


❷ VARIED CHILLED WATER SUPPLY TEMPERATURE FROM 6.67°C (44°F) TO 13.67°C (56.6°F)

This set of simulation studies is an attempt to understand the optimum design off-coil temperature for a CAV system. The chilled water supply temperature in this set of simulation studies was increased to the highest possible temperature while maintaining its ability to provide the design off-coil condition for each option studied. A fixed design ΔT is assumed for the chilled water return temperature in this case. The purpose of this study was to identify if increasing the supply chilled water temperature helps to increase the overall efficiency of the building by improving the chiller efficiency.

The results of these studies as displayed in **Figure 7.3** indicates that the energy saved due to higher chilled water supply temperatures is not enough to compensate for the extra fan energy used due to higher design off-coil temperatures. This result strongly indicates that in a CAV system, it is most important to design the off-coil temperature as low as possible for the lowest air flow rate. This result also indicates that for an existing building scenario where the air-conditioning system has oversized capacity, it is better to reduce the CAV fan flow rate, rather than increase the chilled water supply temperature to gain energy efficiency for a building.

FIGURE 7.3 | TOTAL BUILDING ENERGY INDEX (BEI) OF A CAV SYSTEM AT DIFFERENT DESIGN SUPPLY AIR TEMPERATURES AND DIFFERENT CHILLED WATER SUPPLY TEMPERATURES



*Note that y-axis (BEI) does not start at zero.

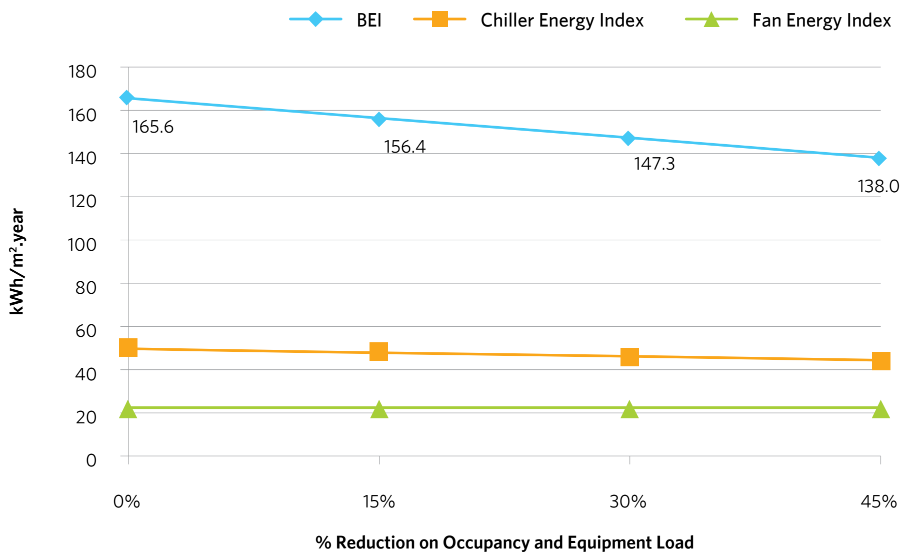
PERFORMANCE OF CAV SYSTEM OPERATING AT PARTIAL LOAD

As engineers are rightly trained to be conservative, a CAV system is designed (sized) for the worst case scenario of peak cooling load of a building, with assumptions made for the peak building occupant density, peak equipment load, peak lighting power density, peak fresh air intake and etc. However, during actual building operation, the occupant density, lighting load and equipment load would more likely be operating below the assumed peak design conditions. A set of simulation studies were conducted to provide an understanding of a CAV system operating at partial load conditions.

The following scenarios were tested:

Case	Description
Base Case	Building operates at design condition of 10 m^2 per person and 15 W/m^2 of equipment load
Case 1	Actual operating occupant and equipment load is reduced by 15% from Base Case. Air flow rate of CAV system based on peak load design condition.
Case 2	Actual operating occupant and equipment load is reduced by 30% from Base Case. Air flow rate of CAV system based on peak load design condition.
Case 3	Actual operating Occupant and equipment load reduced by 45% from Base Case. Air flow rate of CAV system based on peak load design condition.
Case 4	Actual operating Occupant and equipment load reduced by 45% from Base Case. Air flow rate reduced to match reduced actual operating occupant and equipment load.

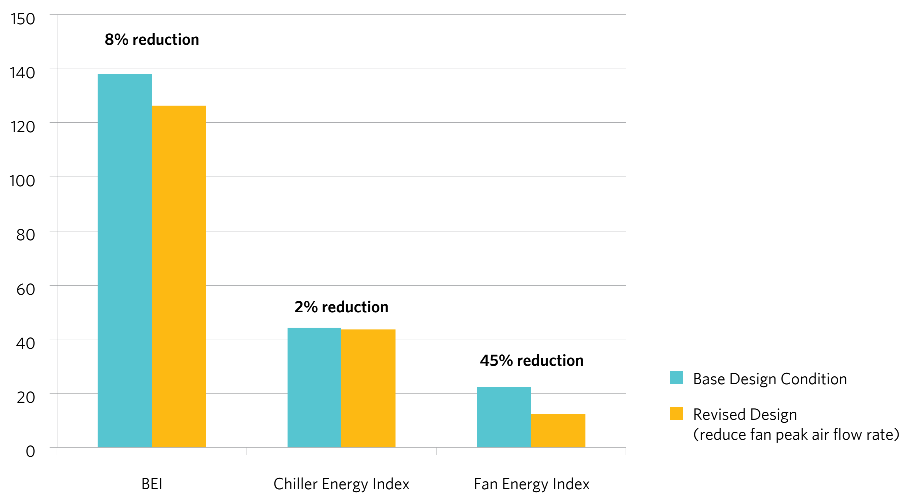
FIGURE 7.4 | PERFORMANCE OF A CAV SYSTEM AT PARTIAL LOAD



This study showed that the energy reduction in the chiller is small, while there are no savings in fan energy at all in a CAV system that is running at design conditions, even though the cooling load was reduced significantly (due to the reduction of occupancy and equipment load). The reduction of the BEI shown in **Figure 7.4** above is primarily due to the reduction of equipment (small power) energy consumption in the building because there is hardly any reduction on the fan and chiller energy index.

Figure 7.5 below displays the effect of reducing the supply air flow rate of a CAV system according to the actual cooling load in the building. A very significant building energy reduction of 8% is achieved, reducing the building energy index (BEI) from 138 to 126 kWh/m^2.year, saving approximately RM155,000 per year on this simulation building model of 17 floors and a GFA of 38,400m^2.

FIGURE 7.5 | PERFORMANCE OF A CAV SYSTEM AT REDUCED SUPPLY AIR FLOW RATE TO MATCH ACTUAL BUILDING SENSIBLE LOAD AT PART LOAD



It was interesting to note that in the simulated model, a reduction of building occupants and equipment by 45% allowed a reduction of 20% of the supply air flow rate. Modelling the reduction of 20% of the air flow rate reduces the fan energy by 45%. The fan energy reduction is from a combined effect of a reduction in total pressure loss and a lower air flow rate (this double reduction effect is known as the "Fan Affinity Law"). The fan energy reduction also leads to a further reduction of 2% in chiller energy consumption due to the lower heat energy produced by the fan. The compounding effects of reducing the supply air flow rate by 20% in this model lead to a very significant total building energy reduction of 8%.

Based on this result, it is recommended to provide CAV system with a variable speed drive (VSD) for all major AHUs in a building, especially for buildings where there is a possibility that the actual building occupancy may be significantly lower than the design assumptions. This would make it possible for an energy manager (or facility manager or a commissioning agent) of the building to fine-tune the AHU system based on the actual operating heat load on site.

A reduction of the supply air flow rate in a CAV system may require rebalancing work to be conducted again on the duct network to ensure that the supply air is evenly distributed. The need to rebalance the air flow from diffusers may be minimised by providing a duct network design that would cater for minor changes in air flow rate in a CAV system.

VARIABLE AIR VOLUME (VAV) SYSTEM

A Variable Air Volume (VAV) system is a system where the design supply air temperature is fixed. If the temperature in the space supplied by the VAV system is higher than the set point temperature by the sensor (room is hot), the supply air volume is increased via a control system consisting of a VAV box and variable speed drive (VSD) on the motor for the fan. A VAV box is basically a motorised damper with a temperature sensor. If it senses the space temperature is higher than the set point temperature, it will signal the motorised damper to open to allow more supply air into the cooled space. The opening of the damper will reduce the pressure in the supply duct. A pressure sensor located in the duct system will detect the pressure drop and will signal the VSD to ramp up the motor to increase the fan speed to maintain the pressure in the ducting system. The reduction of fan speed during part load scenarios reduces fan power consumption in the building, increasing the building's energy efficiency.

Static Pressure Reset

In addition, during actual operation, the implementation of a static pressure reset of a VAV system will increase efficiency by reducing the static pressure set point when the building is running at part load. A static pressure reset reduces the fan static pressure at part load by allowing the VAV boxes to be fully open for low restriction of air flow. The successful implementation of a static pressure reset is highly dependent on the controller logic and the location of the pressure sensor in the duct network. In some cases it may require more than one pressure sensor to be installed. Designers are recommended to seek further design and installation tips to implement this successfully from ASHRAE journals and publications such as "Increasing Efficiency with VAV System Static Pressure Setpoint Reset" by Steven T. Taylor, 2007.

It is becoming common these days to have VAV systems specified for new buildings in Malaysia because of the keen interest in energy efficiency. A VAV system may be designed with a couple of VAV boxes in the ducting system to provide comfort control of East and West zones or may have many VAV boxes to provide comfort control of individual (or group of) rooms. These VAV boxes improve the control and comfort condition of the air-conditioning system by ensuring that each zone is maintained at the right air-temperature even at different times of the day. A VAV system will have lower energy consumption than a CAV system because it allows the fan to run at lower speed (and with a static pressure reset, lower pressure too) depending on the cooling load of the building.

However, the use of multiple VAV boxes, temperature sensors, pressure sensors and motorised dampers in a VAV system also increases the possibility of equipment failure in comparison to a simple CAV system. Finally, a VAV system will have a higher cost of implementation than a CAV system.

OFF-COIL TEMPERATURE SIMULATION STUDIES

A set of simulation studies were conducted to test the effect of various design off-coil (supply air) temperatures in a VAV system. These studies were conducted based on the following possibilities of improving energy efficiency, where a lower off-coil temperature will reduce the flow rate into the cooled space, reducing energy consumption, but at the same time, at lower off-coil temperatures, more moisture is removed from the air, thus increasing the energy consumption of the chiller to remove the latent heat.

FIGURE 7.6 | EFFECT ON BUILDING BEI BASED ON VARIOUS DESIGN OFF-COIL TEMPERATURE ON A VAV SYSTEM

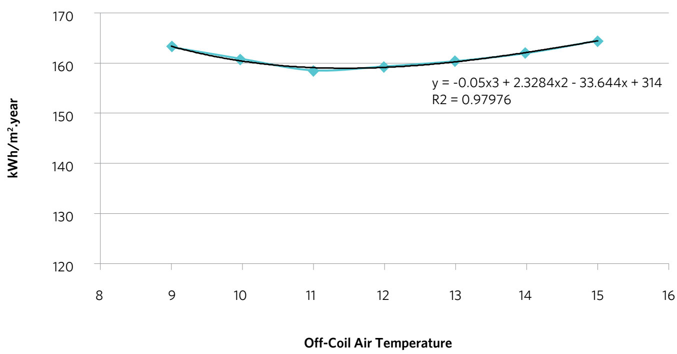
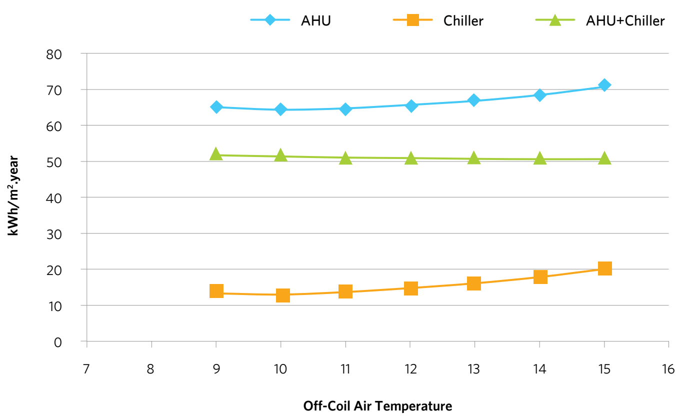


FIGURE 7.7 | PERFORMANCE COMPARISON OF AHU AND CHILLER ENERGY CONSUMPTION ON VARIOUS DESIGN OFF-COIL TEMPERATURE ON A VAV SYSTEM



The result of this set of simulations for a VAV system indicates that the optimum design off-coil temperature for a VAV system is 11°C. The fan power of a VAV system does not reduce much with further reduction of the design off-coil temperature, while it quickly increases above 11°C, namely due to the lower temperature differences between the room set point temperature and the supply air temperature.

However, reducing the design off-coil temperature of a VAV system below 11°C increases the chiller load due to the higher amount of moisture removed. The moisture content at 100% relative humidity at various off-coil temperatures are shown in **Table 7.1** below to illustrate the potential amount of moisture content at various off-coil temperatures (The off-coil conditions in the Malaysian climate for a cooling scenario will typically have a relative humidity close to 100%, depending on the coil contact factor). The on-coil moisture content is relatively constant. This moisture comes from a mix of the return air and fresh air and typically ranges from 12 to 14 g/kg. The amount of latent heat removed is a direct factor of the differences of the on-coil and off-coil moisture content. The larger the difference, the more moisture is removed.

TABLE 7.1 | MOISTURE CONTENT AT 100% RELATIVE HUMIDITY FOR VARIOUS OFF-COIL TEMPERATURES

Dry Bulb (°C)	Relative Humidity (%)	Moisture Content (g/kg)
8	100	6.7
9	100	7.2
10	100	7.7
11	100	8.2
12	100	8.8
13	100	9.4
14	100	10.0
15	100	10.7

CAV VS. VAV

1 ENERGY EFFICIENCY

A VAV system reduces the energy consumption in a building by minimising the fan energy used compared to a CAV system. In addition, the reduction of fan energy also reduces the fan sensible heat produced in the cooling load of the building. Therefore, reducing fan energy use is similar to a lighting system where the benefits are gained in two ways:

1. Directly, through the savings in electrical energy used to drive the fan, and
2. Indirectly, through the reduction of sensible heat, in which the cooling coil and eventually chiller energy is needed to remove.

Three (3) scenarios provided below illustrate the efficiency of a CAV and VAV system based on the simulation studies conducted.

The 1st scenario, presented in **Table 7.2** below, is an office building operating at design occupancy. It shows that a VAV system will reduce the building's BEI by 4.3%, providing a reduction of 7.1 kWh/m^2.year. In this case, the design off-coil temperature is the same between the CAV and VAV system. This means that the cooling coil size is the same between the two systems.

TABLE 7.2 | BUILDING BEI OF CAV VS. VAV SYSTEM OPERATING AT 100% OCCUPANCY AT SAME DESIGN OFF-COIL TEMPERATURE

Descriptions	BEI	Units
CAV (at 11°C off-coil)	165.6	kWh/m^2.year
VAV (at 11°C off-coil)	158.6	kWh/m^2.year
BEI VAV improvement	7.1	kWh/m^2.year
% VAV improvement	4.3%	Percentage

The 2nd scenario, presented in **Table 7.3** below, is where both the CAV and VAV systems were designed for full load conditions, however during operation, the actual occupancy in the building is 45% lower than the design condition (45% reduction is made for both occupancy and small power during operation). The advantage of a VAV system over the CAV system increased marginally in this case by 0.4 to 7.5 kWh/m^2.year from the 1st case scenario. As expected, this indicates that a VAV system reduces more energy than a CAV system when a building is operating at part load.

TABLE 7.3 | BUILDING BEI OF CAV VS. VAV SYSTEM OPERATING AT 45% OCCUPANCY, WHILE FLOW RATE IS MAINTAINED AT DESIGN CONDITIONS OF FULL OCCUPANCY

45% Reduction in Occupancy	BEI	Units
CAV (at 11°C off-coil)	138.0	kWh/m^2.year
VAV (at 11°C off-coil)	130.4	kWh/m^2.year
BEI VAV improvement	7.5	kWh/m^2.year
% VAV improvement	5.5%	Percentage

The 3rd scenario, presented in **Table 7.4** below, is where the air flow rate of a CAV system is reduced to match the actual operating conditions of peak sensible load of the building with a 45% reduction in occupancy, while the VAV system is not changed from its design condition. The VAV system is not changed from its design condition because it is likely that a VAV system, once installed, is assumed to be "self-regulating" and the facility manager may think that it is not necessary to recalibrate a VAV system based on actual operating conditions. The result of this scenario showed that it is possible for a CAV system to have lower energy consumption than a VAV system, by 4.0 kWh/m^2.year, when it is recalibrated to the actual building load that is lower than the design assumption.

TABLE 7.4 | BUILDING BEI OF CAV VS. VAV SYSTEM OPERATING AT 45% OCCUPANCY, WHERE FLOW RATE IS MAINTAINED AT DESIGN CONDITIONS OF FULL OCCUPANCY FOR VAV SYSTEM BUT FLOW RATE IS REDUCED FOR CAV SYSTEM TO MATCH THE LOWER PEAK COOLING LOAD OF THE BUILDING AT REDUCED OCCUPANCY

45% Reduction in Occupancy	BEI	Units
VAV at design conditions	130.4	kWh/m^2.year
CAV at reduced flow rate	126.4	kWh/m^2.year
BEI CAV improvement	4.0	kWh/m^2.year
% CAV improvement	3.1%	Percentage

In summary, these 3 scenarios provided the following conclusions:

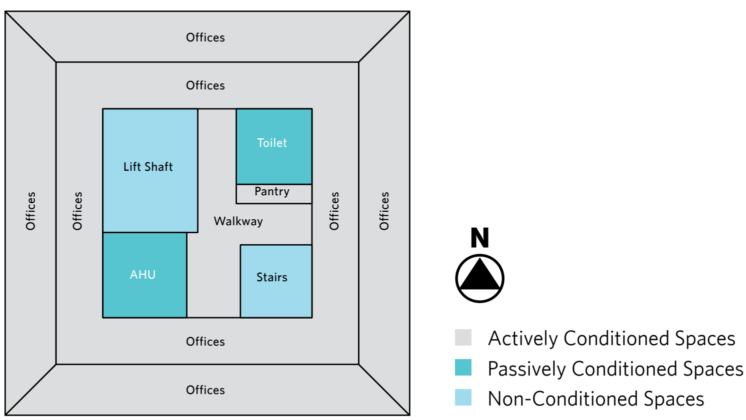
1. A VAV system will provide approximately 7 kWh/m^2.year savings in a building compared to a CAV system in this climate zone based on the same design conditions.
2. A significant energy reduction is obtained when a CAV (or VAV) system is recalibrated to match the actual operating conditions. Therefore, it is recommended to provide permanent sensible heat measurement in AHUs, which will then provide a computation of the actual air flow rate requirement based on the design supply air temperature, for the energy manager (or facility manager) to make the necessary optimisation.

2 COMFORT (AIR TEMPERATURE AND RELATIVE HUMIDITY)

This simulation study has split each of the floors into 7 zones for the VAV box to respond to, these zones are:

- 4 perimeter zones for the office space of 6 meters depth, for north, south, east, west
- 1 center core office zone
- 1 zone for pantry
- 1 zone for the lift lobby walkway

FIGURE 7.8 | AIR-CONDITIONING ZONING LAYOUT PER FLOOR OF THE SIMULATED TEST CASE SCENARIO

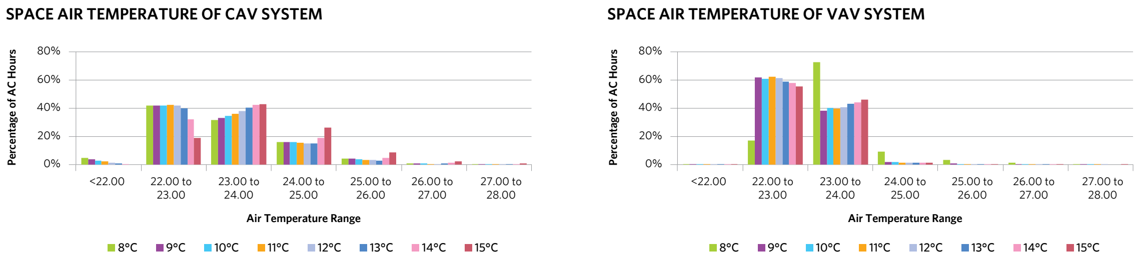


One AHU system (i.e. fan) was modelled to be delivering the supply air into these 7 zones. Refer to Chapter 6 for details.

The air flow rate for both the CAV and VAV system was sized according to the peak flow rate for these 7 zones. On the CAV system, the flow rate is fixed for these 7 different zones, and the supply air temperature is regulated based on the average return air temperature, while on the VAV system, the supply air temperature is fixed and each VAV zone air temperature is regulated by the amount of supply air flow rate. The temperature set point of both systems was fixed at 23°C (or a minimum of 22°C and a maximum of 24°C).

A comparison of CAV and VAV air temperatures of the offices showed that a CAV system has a much wider variation of air temperatures compared to a VAV system. This result is more or less expected due to the fact that a VAV system can control the air temperature in each zone independently, while a CAV system controls the return air temperature, which is the average of all 7 zones' air temperatures.

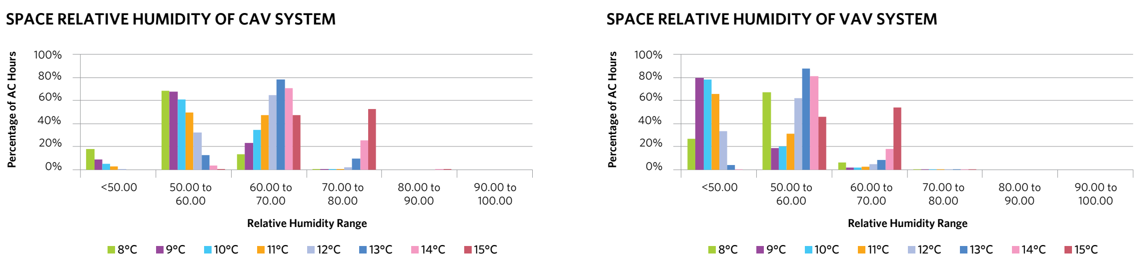
FIGURE 7.9 | SIMULATED AIR TEMPERATURE DISTRIBUTION IN THE OFFICE SPACE OF A CAV AND VAV SYSTEM DURING OCCUPANCY HOURS AT DIFFERENT DESIGN OFF-COIL TEMPERATURES



The results also showed that the air temperature in the office space is not influenced much by the design off-coil temperature. The controls provided are generally adequate to maintain the desired air temperature in the office space for the various tested design off-coil temperatures. However, it is shown in **Figure 7.10** below that the design off-coil temperature has a significant influence on the office space's relative humidity, especially on a CAV system. From the results of these studies, it is recommended not to design off-coil temperatures of 13°C or higher for a CAV system, because it will lead to a relative humidity that exceeds 70% (the recommended limit by MS 1525) for a significant percentage of the occupancy hours. Fortunately, it was shown earlier that a CAV system is more efficient when operating at lower design off-coil temperatures, which would also help in keeping the relative humidity within the recommended limits.

The office space relative humidity for a VAV system is shown to remain below 70% even with design off-coil temperatures as high as 15°C. This is because in a VAV system, the off-coil temperature will always be fixed at the design condition of 15°C, while in a CAV system, the off-coil temperature is higher than the design temperature of 15°C during part-load conditions.

FIGURE 7.10 | SIMULATED AIR RELATIVE HUMIDITY DISTRIBUTION IN THE OFFICE SPACE OF A CAV AND VAV SYSTEM DURING OCCUPANCY HOURS AT DIFFERENT DESIGN OFF-COIL TEMPERATURES



3 COST, MAINTENANCE AND LIFECYCLE

A VAV system is a more expensive system than a CAV system. For each zone, a VAV system requires one VAV box that consists of a motorised damper and temperature sensor. In addition to that, a VAV system also requires a pressure sensor and a VSD to control the motor that drives the fan.

All these extra mechanisms required by a VAV system will also increase the complexity of maintenance. Typical service intervals recommended for air-conditioning equipment is once every 3 to 6 months.[1] In this building model with a GFA of 38,400m^2 with 7 zones per floor and 17 floors, there will be 119 VAV boxes that require servicing every 3 to 6 months. In reference to this, designers should also ensure that access holes are made to service VAV boxes in the building.

All these additional requirements of a VAV system compared to a CAV system is the reason that a CAV system is the default installation in most buildings today, because a CAV system is simpler to install and maintain. However, the energy saved by using a VAV system can be significant, but more importantly, a VAV system will provide better comfort conditions and also lower the risk of mold growth due to its ability to control the relative humidity in a building better.

Unfortunately, it will require substantially more studies to be conducted to work out the financial lifecycle analysis of using a VAV system instead of a CAV system, that this guideline does not have the time for. This is because the additional cost of a VAV system is subject to the number of zones that are being provided for and the percentage of actual occupancy during operation.

It is possible to provide a VAV system with hundreds of zones, where one VAV box is allocated per individual room or individual diffuser for an optimised flow rate reduction during partial load. It is also possible to provide a VAV system with only 2 zones per floor (one VAV box to control east zone and one VAV box to control west zone). The energy reduction potential will also be significantly influenced by the percentage of time each VAV zone is unoccupied (unoccupied rooms have a lower heat load due to less heat gain from people, computers and lighting). Therefore, a significantly large number of studies need to be conducted on a range of potential variables before it is possible to draw some kind of conclusions for recommendations to be made on the optimum zoning of a VAV system for an optimum lifecycle cost for this climatic zone. It is suggested that academicians should pick up on this issue, to provide a comprehensive lifecycle study analysing the optimum number of VAV zones to be provided for each potential occupancy scenario in the building.

[1] Mandatory Preventative Maintenance Standard, August 1999, Integrated Workplace Solutions (IWS), Vancouver, British Columbia.

FAN TOTAL PRESSURE

The Fan Total Pressure is the sum of the duct total static pressure, pressure drop in air filter, pressure drop in cooling coil and air dynamic pressure.

EQUATION 7.3

$$FP_t = SP_d + PD_f + PD_c + \Delta DP$$

Where:
FP_t = Fan Total Pressure (Pa)
SP_d = Duct Total Static Pressure (Pa)
PD_f = Pressure Drop in Air Filter (Pa)
PD_c = Pressure Drop in Cooling Coil (Pa)
ΔDP = Differential Dynamic Air Pressure = $\frac{1}{2}\rho (V_o^2 - V_i^2)$

Where:
ρ = Air Density (1.2 kg/m³)
V_o = Velocity of Air at Fan Exit (m/s)
V_i = Velocity of Air at Fan Inlet (m/s)

The simulation results of reducing the Fan Total Pressure yielded a straight line curve fit for both cooling coil load and energy reduction, as shown in the **Figures 7.11** and **7.12**.

These curve fit lines can be used as an estimate for the cooling coil load reduction due to the reduction of Fan Total Pressure using **Equation 7.4** below:

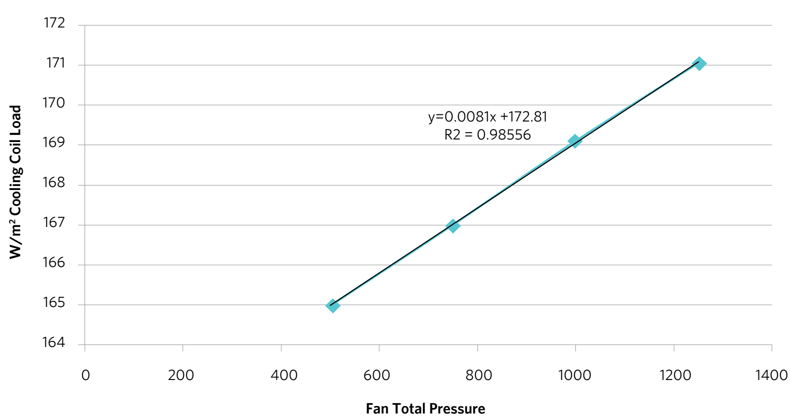
EQUATION 7.4

$$\Delta CC_l = 0.0081 \times \Delta FP_t$$

Where:
ΔCC_l = Change of Cooling Load (W/m²)
ΔFP_t = Change in Fan Total Pressure (Pa)

In short, the cooling coil load can be approximated as an increase of 0.8 W/m² for an increase of 100 Pa Fan Total Pressure. Therefore, an increase of 1,000 Pa (4" w.g.) will provide an increase of cooling load by 8 W/m² of air-conditioned space.

FIGURE 7.11 | COOLING LOAD RELATIONSHIP TO FAN TOTAL PRESSURE



From the simulation case studied, it was estimated that the impact on BEI due to the change in Fan Total Pressure is:

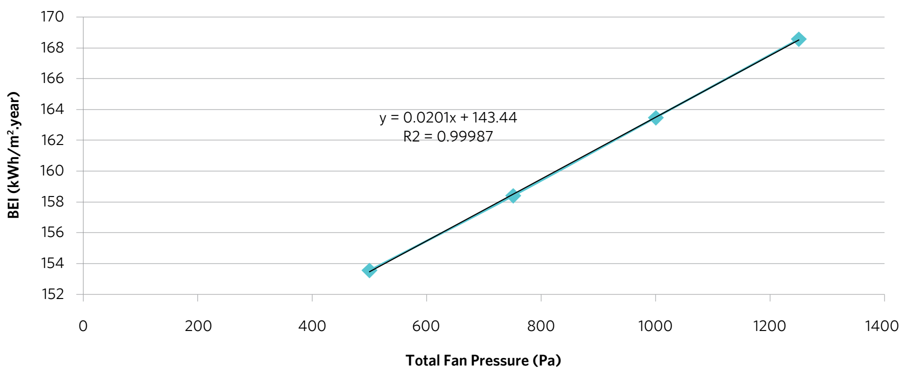
EQUATION 7.5

$$\Delta BEI = 0.0201 \times \Delta FP_t$$

Where:
ΔBEI = Change of Building Energy Index (kWh/m^2.year)
ΔFP_t = Change in Fan Total Pressure (Pa)

In short, this case study showed that the building energy index increases by 2 kWh/m^2.year for an increase of 100 Pa Fan Total Pressure. An increase of 1,000 Pa (4″ w.g.) will increase BEI of this case study by 20 kWh/m^2.year.

FIGURE 7.12 | BEI RELATIONSHIP TO FAN TOTAL PRESSURE



It should be highlighted that these cooling loads and BEI reduction estimates are provided for the simulated case scenario of a typical office building, operating from 9am to 5pm weekdays. These estimates are provided for air-conditioning designers and building owners to make a quick estimate of potential savings from the implementation of fan total pressure reduction. Buildings that operate longer hours will provide higher BEI reductions than the estimates shown here, however these buildings would have a higher BEI in the first place. In summary, it becomes more important to have efficient equipment in buildings that operate for longer hours.

FAN TOTAL EFFICIENCY

The Fan Total Efficiency is the combined efficiency of fan, fan-belt, motor and variable speed drive as shown in **Equation 7.6** below.

EQUATION 7.6

$$FE_t = F_e \times M_e \times B_e \times V_e$$

Where:
FE_t = Fan Total Efficiency (%)
F_e = Fan Efficiency (%)
M_e = Motor Efficiency (%)
B_e = Fan Belt Efficiency (%) Where, B_e = 100%, if fan is direct driven by the motor
V_e = Variable Speed Drive Efficiency (%) Where, V_e = 100%, if not used

The simulation study on the impact of Fan Total Efficiency on cooling loads and energy consumption yielded a polynomial curve fit. However, to keep it simple, a straight-line estimate is provided instead, while providing a decent coefficient of determination (R^2) of 0.986. The impact of Fan Total Efficiency on the cooling coil load can be estimated using **Equation 7.7** as shown below:

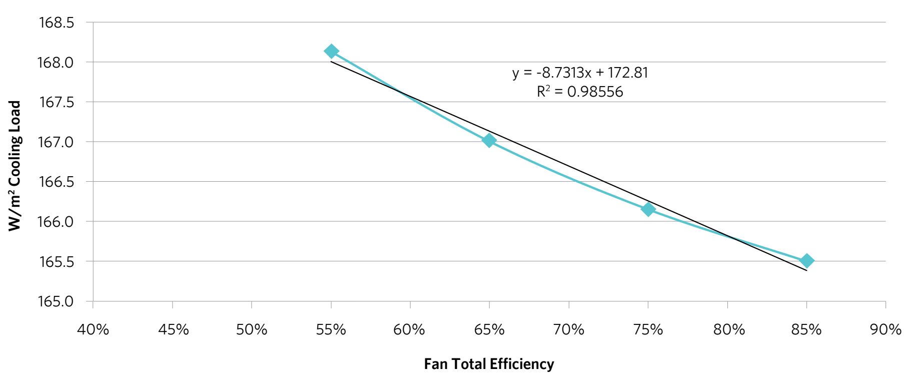
EQUATION 7.7

$$\Delta CC_l = -8.73 \times \Delta FE_t$$

Where:
ΔCC_l = Change of Cooling Load (W/m²)
ΔEP_t = Change in Fan Total Efficiency (%)

This case study showed a reduction of 0.87 W/m² on the cooling coil load for an increase of 10% Fan Total Efficiency. Improving the Fan Total Efficiency by 30% reduces 2.6 W/m² of cooling load on the cooling coil.

FIGURE 7.13 | COOLING LOAD RELATIONSHIP TO FAN TOTAL EFFICIENCY



The impact of Fan Total Efficiency on the BEI can be estimated using **Equation 7.8** as shown below:

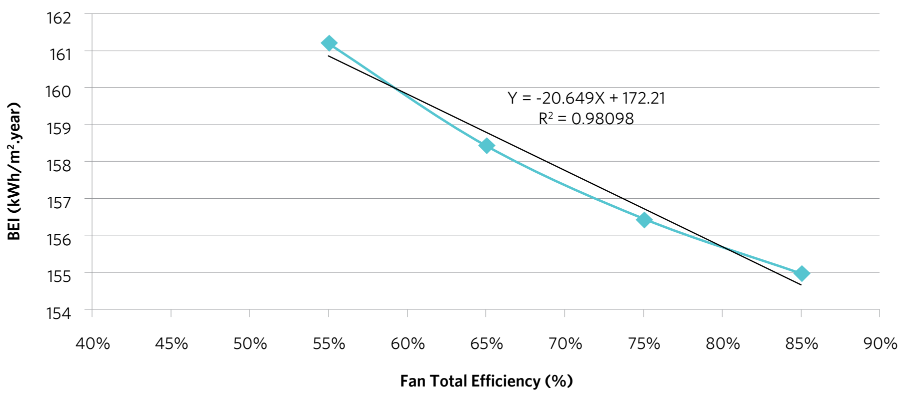
EQUATION 7.8

$$\Delta BEI = -20.65 \times \Delta FE_t$$

Where:
ΔBEI = Change of Building Energy Index (kWh/m².year)
ΔFE_t = Change in Fan Total Efficiency (%)

From this case study, the BEI reduces by approximately 2.1 kWh/m².year for an increase of 10% Fan Total Efficiency. A 30% increase in Fan Total Efficiency will reduce the BEI by 6.3 kWh/m².year on the case study building.

FIGURE 7.14 | BEI RELATIONSHIP TO FAN TOTAL EFFICIENCY



FRESH AIR DEMAND CONTROL USING CO_2 SENSORS

ASHRAE 62.1 (2007), Appendix C, allows the use of CO_2 sensors to regulate the fresh air intake in buildings. More specifically, it says that keeping the CO_2 level in the room no higher than 700ppm above the outdoor condition will yield satisfaction for a majority of visitors entering the building. The outdoor CO_2 level varies depending on the site location. In locations surrounded by lush greenery, the CO_2 level may be as low as 350ppm during the daytime, while in a city space, the CO_2 level may be has high as 450ppm due to exhausts from vehicles.

The IES simulation software used for this study has a default outdoor CO_2 level at the at world average of 380ppm (latest measurements have shown the world average CO_2 level to exceed 400ppm[2]). The simulation study with a CO_2 level set point of 900, 700, 600 and 500ppm was conducted, providing the following set points above the outdoor level:

1. 900 – 380 = 520 ppm above outdoor condition
2. 700 – 380 = 320 ppm above outdoor condition
3. 600 – 380 = 220 ppm above outdoor condition
4. 500 – 380 = 120 ppm above outdoor condition

In the worst case scenario, the simulated CO_2 set point is 520ppm above the outdoor condition, to account for a likely preference for a higher amount of fresh air by Malaysian occupants due to the many years of living in leaky buildings, instead of the 700ppm limit as specified by ASHRAE.

In this simulation study, the fresh air intake by the AHU was modelled to be controlled by a CO_2 sensor measuring the CO_2 level of the return air. It was basically modelled the way it is commonly practiced in Malaysian buildings *(It should be highlighted that after this simulation study was completed, the author found a paper that described this method as unreliable and is recommended not to be used anymore.[3] Instead, it is proposed that the location of CO_2 sensor should be placed in the breathing zone, typically adjacent to the temperature sensor, because it was mentioned in the paper that return air sensing of the CO_2 level does not work in an actual building scenario).*

In addition, the demand control mechanism was simulated to always provide a minimum amount of fresh air equivalent to the ventilation rate requirements for the floor area during air-conditioning hours as per the requirements in ASHRAE 62.1 (2007), even when the measured CO_2 level is below the set point.

The results of the simulation case study showed that the use of demand controlled fresh air intake (via a CO_2 sensor) reduces the peak cooling load in the simulated building by 2.3 W/m^2. Upon investigation, it was found that the peak cooling load on the test building occurs during the morning hours when the air-conditioning system is switched on. During this time, the CO_2 level in the building is low due to the infiltration of fresh air from the night before, therefore, the demand controlled fresh air intake only needs to provide the minimum fresh air requirement, reducing the peak cooling load significantly.

TABLE 7.5 | BUILDING PEAK COOLING LOAD REDUCTION DUE TO THE USE OF CO_2 DEMAND CONTROLLED FRESH AIR VENTILATION STRATEGY

Description	Peak cooling load (W/m^2)
No CO_2 sensor	167.0
With CO_2 sensor, Set point 900 ppm	164.7
Difference	2.3

[2] Tom Bawden, Environment Editor, Friday 10 May 2013
[3] Dave Kahn, Ventilation for Acceptable Indoor Air Quality 62.1-2010, Rocky Mountain Institute, 2010

In terms of energy efficiency, the benefit of using a demand controlled fresh air intake becomes more significant when the actual building occupant density is below the design occupant density. The estimated BEI savings due to the use of a CO_2 sensor at different percentages of occupancy is shown in **Figure 7.15** below and **Equation 7.9** is provided for a quick estimation of the BEI reduction due to the use of a CO_2 sensor for the tested case building scenario.

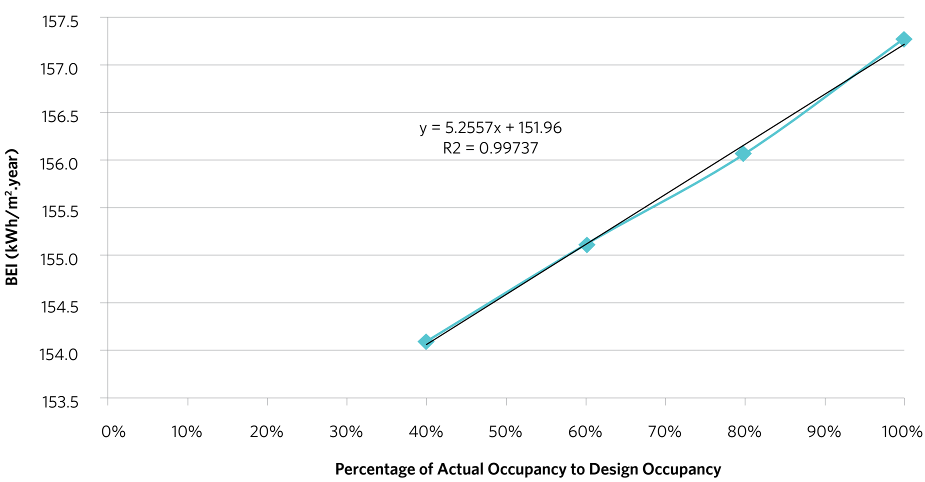
EQUATION 7.9

$$\Delta BEI = 5.26 \times \Delta O_c$$

Where:
ΔBEI = Change of Building Energy Index (kWh/m^2.year)
ΔO_c = Change in Occupant Density from Design Scenario (10 m^2/person) (%)

The following rule-of-thumb is derived from this study on the use of a CO_2 sensor; for every 10% reduction of occupant density from the design scenario of 14 m^2/person, the BEI reduces by 0.5 kWh/m^2.year.

FIGURE 7.15 | RELATIONSHIP BETWEEN BEI AND PERCENTAGE OF ACTUAL OCCUPANCY WITH THE USE OF CO_2 CONTROLLED FRESH AIR VENTILATION STRATEGY



Finally, the energy saved due to the use demand controlled fresh air intake system is also closely linked to the CO_2 set point level. **Figure 7.16** on the next page shows the results of different CO_2 set points in the case where the actual building occupancy is only at 40% of the design occupancy (i.e. 25 m^2/person instead of 10 m^2/person). The sparsely occupied building does not increase the energy consumption at all by reducing the CO_2 level from 900ppm to 700ppm because the low number of people in the building has kept the CO_2 level below 700ppm from the minimum fresh air supplied (based on ASHRAE area requirements). However, reducing the CO_2 set point below 700ppm increases the BEI significantly. It can be seen from **Figure 7.16** on the next page that in a sparsely occupied building, that below the 700ppm set point, every additional 100ppm reduction of the CO_2 set point increases the BEI by 3.9 kWh/m^2.year.

FIGURE 7.16 | IMPACT ON BEI BASED ON CO_2 SET POINT IN A SPARSELY OCCUPIED BUILDING (40% DESIGN OCCUPANCY)

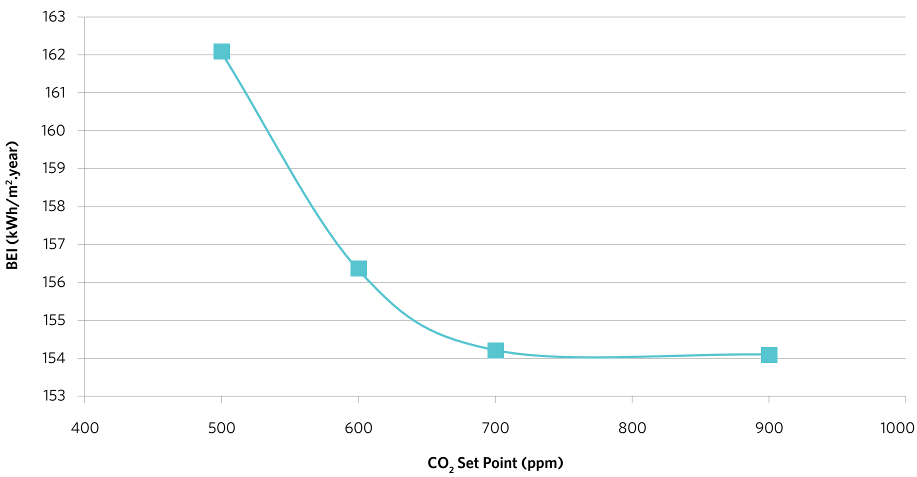


TABLE 7.6 | BEI (KWH/M².YEAR) WITH AND WITHOUT CO_2 SENSOR AT VARIOUS BUILDING OCCUPANCY LEVELS

Description	With CO_2 Sensor	No CO_2 Sensor		
	Design Condition	Design Condition	Add 50% FA	Add 100% FA
Full Occupancy	157.3	158.6	164.1	169.8
80% Occupancy	156.1	157.6	162.8	168.5
60% Occupancy	155.1	156.6	161.7	167.4
40% Occupancy	154.1	155.6	160.7	166.1

Table 7.6 shows that if the fixed fresh air supply system is supplying 50% more fresh air than is specified by the ASHRAE 62.1 (2007) requirement, the savings from the use of a demand controlled fresh air intake increases to 6.7 kWh/m².year. If the fixed fresh air supply system is supplying 100% more fresh air than specified by the ASHRAE 62.1 (2007) requirement, the savings from the use of a demand controlled fresh air intake increases to 12.3 kWh/m².year. This result indicates that it is very important to commission a building to ensure that the fixed fresh air intake system is operating according to the design assumptions. Over-provision of the fresh air intake is shown to be very expensive. Unfortunately, it is not a common practice to measure the fresh air intake during the commissioning of buildings in Malaysia. Based on this result, it is strongly recommended that all buildings in Malaysia should at the very least, measure and tune the fresh air intake into the building during the commissioning stage or implement CO_2 sensors to regulate the fresh air intake.

SENSIBLE AND LATENT HEAT RECOVERY

It is not a common building design practice in Malaysia to use a heat recovery system. However, if it is designed right, significant savings can be derived from the use of a heat recovery system.

It is very important that such systems be designed to take into account the quantity of fresh air intake, exhaust air from toilets and the potential infiltration (or exfiltration) of the building envelope to derive the actual quantity of exhaust air available for the heat recovery system. The exhaust air ducts should then be sized according to the anticipated peak available exhaust air from the building.

The current industry practice in Malaysia is to use the mechanical fresh air intake in a building to provide positive pressure in the building to exfiltrate through the building leakages. This has the advantage that it keeps the infiltration amount low in Malaysian buildings, reducing the risk of condensation and potential mold growth that is caused by infiltration of hot and humid air coming in contact with the cold supply air diffuser or any surface that is below the dew point of the infiltrated air.

Exhaust air from buildings is typically provided by the toilet exhaust air requirements. This exhaust requirement may be lower or higher than the mechanical fresh air intake in the building (in buildings with a small floor plate, the toilet exhaust may exceed the fresh air intake in the building, so designers are cautioned to be careful not to create negative pressure in the building, which could lead to mold growth problems). In most situations, it is common not to have enough exhaust air for a heat recovery system to be feasible.

If it is designed right, significant savings can be derived from the use of a heat recovery system

In all cases, it is recommended to keep the building as air-tight as possible. This would make it possible to reduce exfiltration from the building, thereby increasing the amount of available exhaust air for heat recovery to be implemented.

Due to Malaysia's hot and humid climate, it is most appropriate to implement a heat recovery system that recovers both sensible and latent heat. In the simulation study conducted, the heat recovery system was modelled to take all the exhaust air from the toilets, and expelled at the building roof top to pre-cool and pre-dry the entire fresh air intake into the building.

It is important to point out that the efficiency declared by suppliers of air to air heat exchangers, such as heat recovery wheels, often quote the efficiency based on the same volume of air intake and exhaust. However, in an actual building situation, the intake volume is normally higher than the exhaust volume because the building needs to be positively pressured to prevent infiltration of outside air into the building. Therefore, the actual performance of the heat recovery system will be operating below the efficiency as claimed by the suppliers, because the fresh air intake is more than the available exhaust air from the building.

FIGURE 7.17 | BEI REDUCTION BASED ON THE BOTH SENSIBLE AND LATENT EFFICIENCY OF HEAT RECOVERY

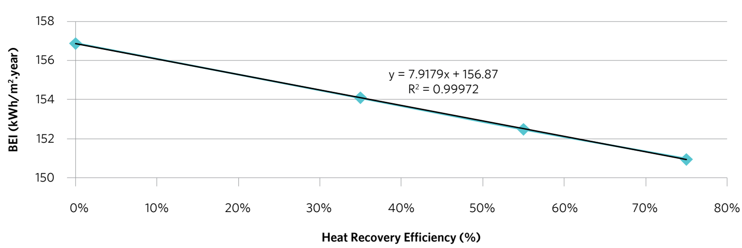


Figure 7.17 shows that the BEI of the simulated building case study would reduce at a rate of 0.8 kWh/m^2.year for each 10% efficiency gain of both sensible and latent heat recovery between the exhaust air and fresh air intake.

FIGURE 7.18 | RELATIONSHIP BETWEEN BEI AND INFILTRATION RATE FROM THE USE OF HEAT RECOVERY AT 55% EFFICIENCY OF BOTH SENSIBLE AND LATENT HEAT

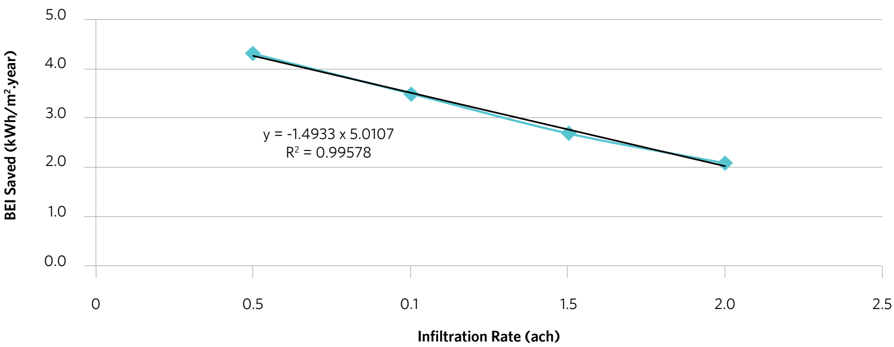


Figure 7.18 displays the results of a heat recovery system with 55% efficiency on both sensible latent heat exchanges at various infiltration rates in the building. The higher infiltration rate in the building reduces the need for fresh air supply from the system, i.e. less fresh air is treated by the heat recovery system. While a higher exfiltration rate from the building reduces the available exhaust air for the heat exchanger to pre-cool and pre-dry the fresh air intake, reducing its effectiveness. In short, these results show that it is important to keep the building air-tight to increase benefits from a heat recovery system.

SUMMARY

This chapter is a set of simulation case studies to provide the approximate impact of optimising the air-side air-conditioning system on the peak cooling load and energy consumption in a typical office building scenario. However, it should be noted that the rules-of-thumb provided in this chapter is based on the simulation studies of a "standard" base case office building scenario as described in Chapter 6.

There may be instances that certain buildings may not behave like this "standard" base case building. In such cases the energy savings predicted in this chapter may under or over achieve. In such instances, it is recommended that designers engage a building simulation professional to model the building as it is. This would test the feasibility of the ideas presented in this chapter based on the actual building designed.

On this note, it is recommended that building design engineers should pick up building energy modelling skills to enhance their design capabilities for the building industry. Building energy simulation tools are much easier to use today than it was 10 years ago. Software such as IES <Virtual Environment>, DesignBuilder, TAS, Trnsys, Visual-DOE, Equest and HAP are fairly well known dynamic energy simulation softwares in the market place today.

It is also important to note that there are hundreds, if not thousands of input parameters in a complex simulation model. Therefore, it is important to engage experienced energy modelers to obtain accurate results. The term "GIGO" for garbage in, garbage out is applicable here.

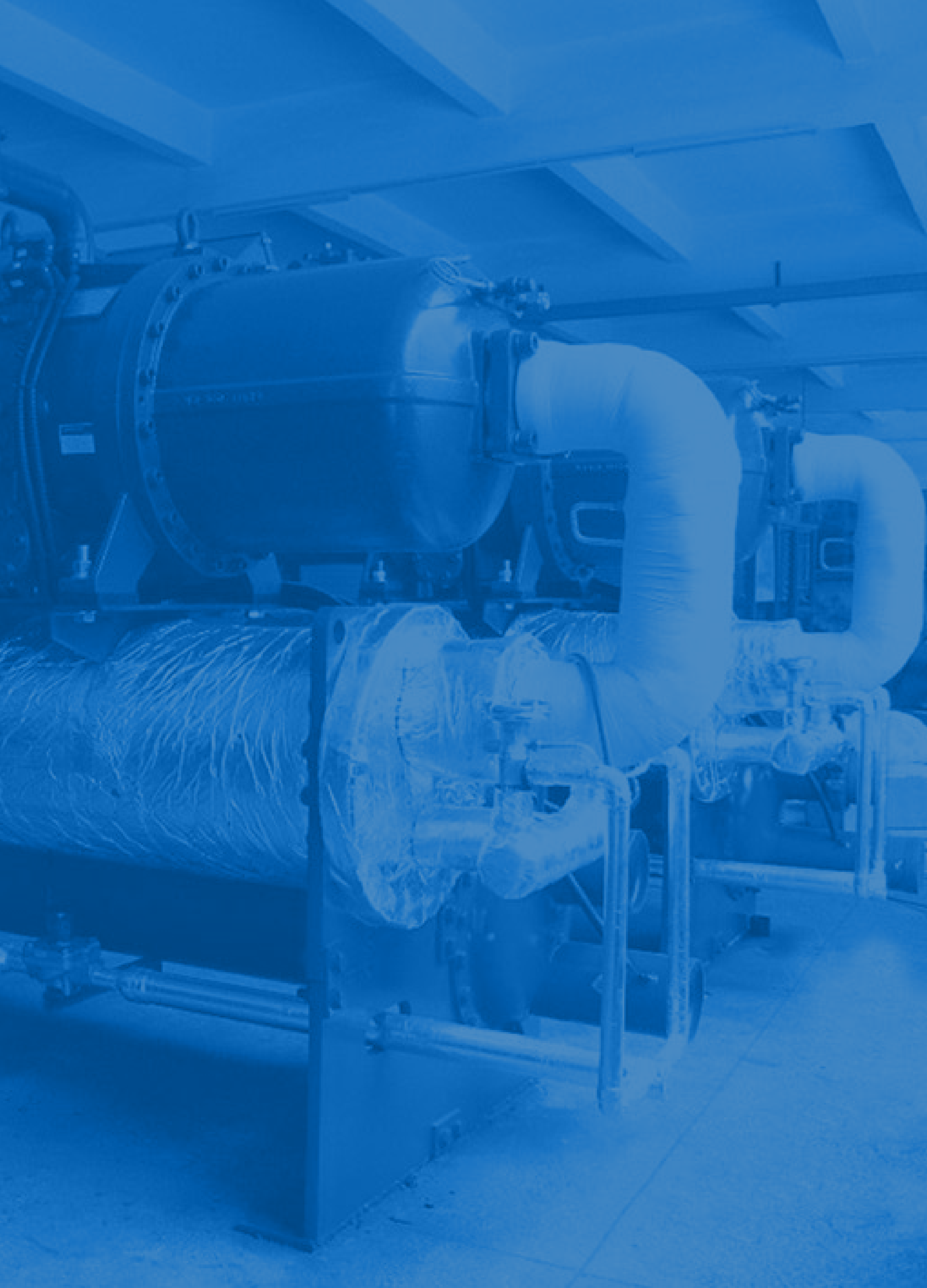
END OF CHAPTER 7

CHAPTER

8

OPTIMISING THE WATER-SIDE AIR-CONDITIONING SYSTEM

by CK Tang & Nic Chin



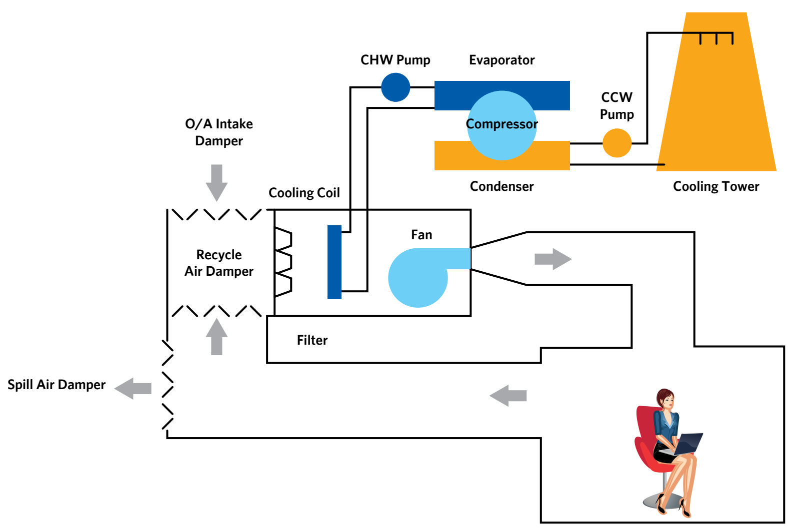
8

OPTIMISING THE WATER-SIDE AIR-CONDITIONING SYSTEM

INTRODUCTION

The water-side air-conditioning system consists of the chilled water distribution system, chiller, condenser water distribution system and cooling tower. The current version of the Malaysian Standard, MS 1525 (2007), for non-residential buildings, provides a minimum performance requirement for chillers but it does not provide any minimum performance or recommendations for the chilled water distribution system, condenser water distribution system and cooling tower performance. The current MS 1525 (2007) only contains minimum performance requirements on the chiller Coefficient of Performance (COP) for the water-side air-conditioning system.

FIGURE 8.1 | SCHEMATIC OF TYPICAL AIR-CONDITIONING SYSTEM IN MALAYSIA



This chapter is an energy simulation study of the energy saving potential by optimising the efficiency of the water-side air-conditioning equipment. Readers should be aware that the study conducted for this guideline is based on a "typical" office building scenario. The energy savings predicted in this document should only to be used as a general guide for quick decision making and in most cases should be reasonably accurate. Readers should be cautioned against using this document as a performance guarantee because building simulation studies require hundreds (and in a detailed model – thousands) of input parameters. Therefore, it would be impossible to provide all possible variations of a building performance in a guideline such as this.

The emphasis of this guideline is to provide rules-of-thumb that are applicable for the Malaysian climatic zone to optimise the water-side air-conditioning system in large buildings. The key topics addressed in this chapter are the following:

1. Energy impact of different types of chilled water distribution systems
2. Energy impact of various chilled water supply and return temperatures
3. Energy impact of chilled water pump efficiency
4. Energy impact of chiller types and efficiency
5. Energy impact of condenser flow rate and system efficiency
6. Energy impact of cooling tower temperature set point and system efficiency
7. Pipes and pump installation recommendations

The intent of the information provided in this guideline is to promote an efficient, practical design that advances standard design practices to achieve cost-effective energy reduction in buildings.

The input assumptions made for this Chapter is based on the building model as described in Chapter 6 of this guidebook.

KEY RECOMMENDATIONS

From the simulation studies conducted for this chapter, it was found that the following items are important for an optimised chilled water distribution system:

❶ Specific Pump Power

The term specific pump power is explained on the next page. It is basically a simple way to understand the most fundamental efficiency rating of a water pumping system. Try to keep this number as low as possible for energy efficiency.

❷ Chilled Water Distribution System

Variable primary flow was found to be the most efficient system of distributing chilled water, however the advantage gained is small when specific pump power is low to start with.

❸ High ΔT Chilled Water Distribution

All tested high ΔT chilled water supply scenarios were found to be more efficient than standard ΔT scenarios, however, the high ΔT supply temperature of 5.56°C (42°F) and return of 14.44°C (58°F) was found to increase efficiency without a significant increase in cooling coil size. It is recommended to conduct a lifecycle analysis, taking into account of the additional cooling coil cost and space used versus the energy reduction potential for higher ΔT options.

❹ Chiller Efficiency

It was found from the case studies conducted for this chapter that an improvement of COP by 1.0 reduces the building energy consumption by approximately 10 kWh/m^2.year. In addition, it is recommended to ensure that VSD chillers are operating at part load conditions to gain the optimum benefit from it. The advantage of operating VSD chillers at full load condition is only marginally better than non-VSD chillers.

❺ Efficiency of Condenser Water Distribution

It was found that reducing the condenser flow rate to 2 gpm/ton (a supply temperature of 36.11°C (97°F) and return at 29.44°C (85°F)) has a higher efficiency than the standard 2.4 gpm/ton (a supply temperature of 35°C (95°F) and return at 29.44°C (85°F)). The energy reduction of the condenser pump due to the lower flow rate exceeds the energy gained by the chiller due to the loss of chiller efficiency on all tested specific pump power on the simulated building scenario.

❻ Cooling Tower Efficiency

The selection of an efficient cooling tower by its fan energy (kW) use per heat rejection ton (HRT) is the most fundamental method to improve cooling tower fan efficiency. In addition, a VSD cooling tower fan was found to provide a significant energy reduction as well. Finally, upsizing (or downsizing) cooling tower has a minimal impact on net energy efficiency of the simulated building.

❼ Pipe and Pump Installation Optimisation

It was observed that most pipe and pump installations in Malaysia do not follow the recommended straight pipe of 5 to 10 pipe diameter lengths before pump suction. Having a pipe bend right before the pump suction reduces the pump efficiency significantly. It is recommended for engineering consultants to be meticulous in the installation details of pipes and pumps by contractors to ensure long term efficiency and problem-free operation by observing the simple installation guide as provided at the end of this chapter.

Specific Pump Power (W per l/s)

The specific pump power is a term used in ASHRAE 90.1 (2007) to describe the power used per flow rate of chilled water or condenser water in an air-conditioning system. It is useful for it to be introduced here because it was found through the simulated studies that the energy consumption in a building has a linear relationship with specific pump power, however, it has a polynomial relationship with pump efficiency. Since it is easier to visualise linear relationships, effort is made to introduce this term here and to promote the use of this term, specific pump power. The specific pump power is defined as follows:

EQUATION 8.1

$$P = \frac{\rho\, g\, h}{\mu\, x\, 1000}$$

Where:

P = Specific Pump Power (W per l/s)
ρ = Fluid Density (Water = 1,000 kg/m^3)
g = Gravity (9.81 m^2/s)
h = Pump Total Pressure (m of water)
μ = Pump Total Efficiency (%)

Since the fluid density and gravity are constants, the pump specific power is only related to pump total pressure and pump total efficiency.

CHILLED WATER DISTRIBUTION SYSTEM

Pump power equation is provided as **Equation 8.2** below, and is shown to be a factor of chilled water flow rate, pump total pressure and pump total efficiency, while the fluid density and gravity is a constant.

EQUATION 8.2

$$P_h = \frac{q \rho g h}{3.6x10^6 \ x \ \mu}$$

Where:
P_h = Pump Power (kW)
q = Flow Capacity (m^3/h)
ρ = Fluid Density (kg/m^3), Water = 1,000 kg/m^3
g = Gravity (9.81 m^2/s)
h = Pump Total Pressure (m of water)
μ = Pump Total Efficiency (%)

A decrease in flow rate and pump total pressure (head) reduces pump power, while a reduction in pump total efficiency increases pump power. Therefore, in the interest of energy efficiency, it is desirable to reduce flow rate and pump total pressure (head), while increasing the pump total efficiency.

Three (3) types of chilled water distribution systems were tested in this chapter, these are:

1 Primary Constant

The chilled water is circulated from the chiller to AHU/FCU in the building at a constant flow rate. A three-way valve is located at the AHU/FCU to divert excess flow back to the return pipe. This is the conventional way of circulating chilled water in a building because it is the simplest method to deliver chilled water around the building.

2 Primary/Secondary Variable

This is a system where the chilled water is circulated at a constant flow rate through a primary loop to the chiller, while a secondary loop is provided with a VSD pump to provide a variable flow rate as required by the AHU/FCU. In this case, a two-way valve is installed at the AHU/FCU that closes the valve to increase the pressure in the pipe at part load conditions. The secondary loop has a pressure sensor that will detect the increase or decrease in pressure in the pipe and send a signal to the VSD pump to reduce or increase the pump speed to maintain the pressure in the chilled water pipe. The secondary loop pump power reduces significantly at a reduced flow rate, following the pump affinity's law.

3 Primary Variable

Improvements in the latest technology allows variable flow through a number of chillers (unfortunately, not all chillers today allow this technology to be implemented). With the use of such chillers, it is possible to implement a primary variable flow chilled water distribution system. Energy reduction in pump power is achieved by allowing a reduction of the chilled water flow rate during part load. In addition, this system is also cheaper to implement than a primary/secondary system.

FIGURE 8.2 | CONVENTIONAL PRIMARY ONLY SYSTEM

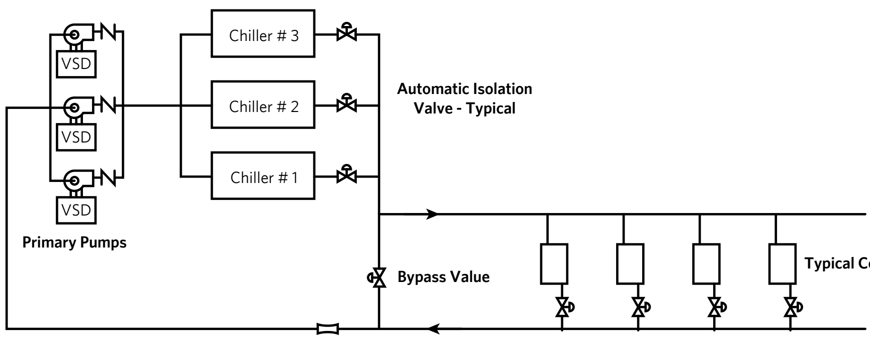
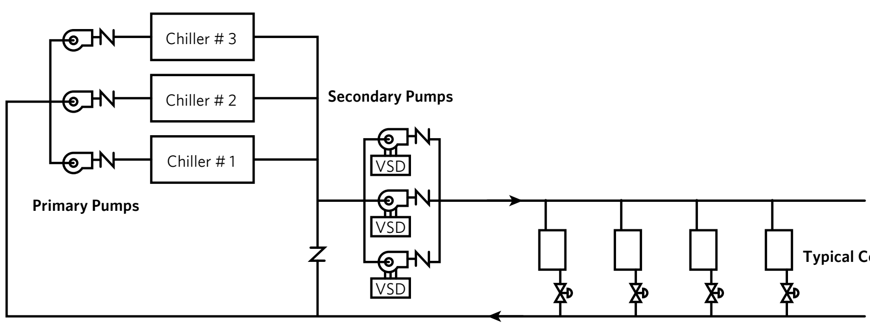


FIGURE 8.3 | CONVENTIONAL PRIMARY/SECONDARY SYSTEM



SIMULATION STUDIES

In order to study the energy efficiency impact of these various chilled water distribution technologies, the following set of simulation runs were conducted:

TABLE 8.1 | SIMULATION CASE SCENARIOS CONDUCTED

Case	Description
1	Specific pump power of 545 W per l/s. Primary Constant Flow
2	Specific pump power of 545 W per l/s. Primary Variable Flow
3	Specific pump power of 545 W per l/s. Primary/Secondary Variable Flow Primary Constant Pump: assumed 20% of 545 = 109 W per l/s Secondary Variable Pump: assumed 80% of 545 = 436 W per l/s
4	Specific pump power of 545 W per l/s + 10% = 599.5 W per l/s Primary/Secondary Variable Flow Primary Constant Pump: assumed 20% of 599.5 = 119.9 W per l/s Secondary Variable Pump: assumed 80% of 599.5 = 479.6 W per l/s
5	Specific pump power of 545 W per l/s + 20% = 654 W per l/s Primary/Secondary Variable Flow Primary Constant Pump: assumed 20% of 654 = 130.8 W per l/s Secondary Variable Pump: assumed 80% of 654 = 523.2 W per l/s
6	Specific pump power of 545 W per l/s + 30% = 708.5 W per l/s Primary/Secondary Variable Flow Primary Constant Pump: assumed 20% of 708.5 = 141.7 W per l/s Secondary Variable Pump: assumed 80% of 708.5 = 566.8 W per l/s
7	Specific pump power of 280 W per l/s. Primary Constant Flow
8	Specific pump power of 280 W per l/s. Primary Variable Flow
9	Specific pump power of 280 W per l/s. Primary/Secondary Variable Flow Primary Constant Pump: assumed 20% of 280 = 56 W per l/s Secondary Variable Pump: assumed 80% of 280 = 224 W per l/s
10	Specific pump power of 280 W per l/s + 30% = 364 W per l/s Primary/Secondary Variable Flow Primary Constant Pump: assumed 20% of 364 = 72.8 W per l/s Secondary Variable Pump: assumed 80% of 364 = 291.2 W per l/s

Case 4, 5, 6 and **10** were created due to the reason that a primary/ secondary system requires more pipes, valves and fittings than a primary only system and this will require a higher pump power to be installed.

The specific pump power for a primary/secondary system was increased incrementally from 10% to 30% from the base specific pump power used for a primary only system. At 30% increment, the secondary pump power is higher than the primary only system and no further increment was made because it is not possible for a secondary pump power to exceed a primary only pump power because a secondary system has lower pressure losses. A primary only system will have higher pressure losses because the chilled water has to flow across the heat exchanger in the chiller.

RESULTS

The results of this simulation study showed that at a high specific pump power of 545 W per l/s, a primary variable system reduces the building energy index (BEI) by 5 kWh/m^2.year compared to a primary constant flow system. Meanwhile a primary/secondary system is shown to reduce between 2.3 to 3.7 kWh/m^2.year compared to a primary constant flow system depending the increase of pumping power required by a primary/secondary system.

FIGURE 8.4 | BEI REDUCTION DUE TO VARIOUS CHILLED WATER PUMPING SYSTEMS AT SPECIFIC PUMP POWER OF 545 W PER L/S

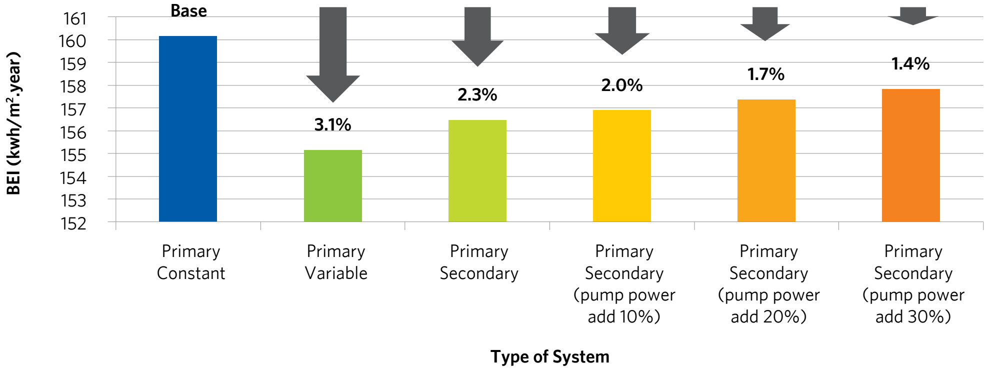


TABLE 8.2 | BEI REDUCTION DUE TO VARIOUS CHILLED WATER PUMPING SYSTEMS AT SPECIFIC PUMP POWER OF 545 W PER L/S

Case	Description @ Specific Pump Power of 545 W per l/s	BEI (kWh/m^2.year)	BEI reduction (kWh/m^2.year)	% Improvement
1	Primary Constant	160.2	Base	Base
2	Primary Variable	155.1	5.0	3.1%
3	Primary Secondary	156.5	3.7	2.3%
4	Primary Secondary (pump power add 10%)	156.9	3.3	2.0%
5	Primary Secondary (pump power add 20%)	157.4	2.8	1.7%
6	Primary Secondary (pump power add 30%)	157.8	2.3	1.4%

At a low specific pump power of 280 W per l/s, the primary variable system provided an energy reduction of 2.6 kWh/m^2.year, while a primary/secondary system provided an energy reduction range between 1.2 to 1.9 kWh/m^2.year.

TABLE 8.3 | BEI REDUCTION DUE TO VARIOUS CHILLED WATER PUMPING SYSTEMS AT SPECIFIC PUMP POWER OF 280 W PER L/S

Case	Description @ Specific Pump Power of 545 W per l/s	BEI (kWh/m^2.year)	BEI reduction (kWh/m^2.year)	% Improvement
7	Primary Constant	156.2	Base	Base
8	Primary Variable	153.6	2.6	1.6%
9	Primary Secondary	154.3	1.9	1.2%
10	Primary Secondary (pump power add 30%)	155.0	1.2	0.8%

In summary, a primary variable system is the most efficient option among the 3 options studied. It is also important to note that a primary/secondary system is shown to be more efficient than a primary constant system in this tested office scenario. Since an office cooling load is fairly consistent daily, it is expected that a variable flow system will provide an even higher energy reduction in buildings where the cooling load varies significantly; for example, retail malls usually have low cooling loads during weekdays and high cooling loads during weekends.

In addition, it was also shown that it is possible for a primary constant system at a low specific pump power to have a lower BEI than using a primary variable system with a high specific pump power. This shows that it is possible to design a constant flow pump system with a low specific pump power to be as efficient as a variable chilled water pump system with a moderate specific pump power.

HIGH ΔT CHILLED WATER SYSTEM

The conventional design of chilled water supply temperature is 6.67°C (44°F) and a return temperature of 13.33°C (56°F) for a ΔT of 6.67°C (12°F). In a high ΔT scenario, the ΔT is increased beyond 6.67°C (12°F). The advantage of increasing the ΔT is to reduce the chilled water flow rate. According to the pump affinity's law, the pump power reduces by a cubic factor from the flow rate reduction. However, at the same time, reducing the chilled water supply temperature below 6.67°C (44°F) reduces the chiller efficiency. Therefore, this study was made to test the impact of reducing flow rate through a high ΔT design on various conditions of supply chilled water temperature.

Equation 8.3 and **8.4** below displays the relationship between the chilled water flow rate with the heat load and ΔT. The cooling load is assumed constant at this stage of design (i.e. the cooling load should have been optimised by this stage), therefore, the chilled water flow rate is only related to ΔT. As ΔT is the denominator in **Equation 8.4**, a high ΔT will ensure the chilled water flow rate is low and vice-versa.

EQUATION 8.3

$$H = 1.16\, Q\, \Delta T$$

Where:
H = Cooling Load (kW)
Q = Chilled Water Volume Flow Rate (m^3/h)
ΔT = Temperature Difference (°C)

Rewriting it,

EQUATION 8.4

$$Q = \frac{H}{1.16\, \Delta T}$$

Where:
H = Cooling Load (kW) (~constant at this stage of design)
Q = Water Volume Flow Rate (m^3/h), reduces with higher ΔT

The advantage of increasing the ΔT is to reduce the chilled water flow rate. This study was made to test the impact of reducing flow rate through a high ΔT design on various conditions of supply chilled water temperature

SIMULATION STUDIES

The following set of simulation cases were conducted to study the energy efficiency impact of these various ΔT chilled water flow options:

TABLE 8.4 | SIMULATION CASE STUDIES OF VARIOUS ΔT SCENARIOS

Case	Description
Cases below are for a Primary Constant System. Specific pump power remains at 545 W per l/s, assuming that pipe size will be reduced to maintain same pressure at lower flow rates.	
1	ΔT = 6.67°C (12°F) Supply Temperature: 6.67°C (44°F) Return Temperature: 13.33°C (56°F) Primary Constant System @ 545 W per l/s
2	ΔT = 7.78°C (14°F) Supply Temperature: 6.67°C (44°F) Return Temperature: 14.44°C (58°F) Primary Constant System @ 545 W per l/s
3	ΔT = 8.89°C (16°F) Supply Temperature: 6.67°C (44°F) Return Temperature: 15.56°C (60°F) Primary Constant System @ 545 W per l/s
4	ΔT = 10.00°C (18°F) Supply Temperature: 6.67°C (44°F) Return Temperature: 16.67°C (62°F) Primary Constant System @ 545 W per l/s
5	ΔT = 8.89°C (16°F) Supply Temperature: 5.56°C (42°F) Return Temperature: 14.44°C (58°F) Primary Constant System @ 545 W per l/s
Cases below changes from a Primary Constant System to a Primary Variable System. Specific pump power remains at 545 W per l/s, assuming that pipe size will be reduced to maintain same pressure at lower flow rates.	
6	ΔT = 6.67°C (12°F) Supply Temperature: 6.67°C (44°F) Return Temperature: 13.33°C (56°F) Primary Variable System @ 545 W per l/s
7	ΔT = 7.78°C (14°F) Supply Temperature: 6.67°C (44°F) Return Temperature: 14.44°C (58°F) Primary Variable System @ 545 W per l/s
8	ΔT = 8.89°C (16°F) Supply Temperature: 6.67°C (44°F) Return Temperature: 15.56°C (60°F) Primary Variable System @ 545 W per l/s
9	ΔT = 10.00°C (18°F) Supply Temperature: 6.67°C (44°F) Return Temperature: 16.67°C (62°F) Primary Variable System @ 545 W per l/s
10	ΔT = 8.89°C (16°F) Supply Temperature: 5.56°C (42°F) Return Temperature: 14.44°C (58°F) Primary Variable System @ 545 W per l/s

Cases below reduces Specific Pump Power. This is assuming pipe sizes remain the same as base design. i.e. no reduction in pipe size, pressure will be lower at lower flow rates.	
11	ΔT = 7.78°C (14°F) Supply Temperature: 6.67°C (44°F) Return Temperature: 14.44°C (58°F) Primary Variable System @ 409 W per l/s, pipe sizes same as case 1
12	ΔT = 8.89°C (16°F) Supply Temperature: 6.67°C (44°F) Return Temperature: 15.56°C (60°F) Primary Variable System @ 327 W per l/s, pipe sizes same as case 1
13	ΔT = 10.00°C (18°F) Supply Temperature: 6.67°C (44°F) Return Temperature: 16.67°C (62°F) Primary Variable System @ 259 W per l/s, pipe sizes same as case 1
14	ΔT = 8.89°C (16°F) Supply Temperature: 5.56°C (42°F) Return Temperature: 14.44°C (58°F) Primary Variable System @ 327 W per l/s, pipe sizes same as case 1
Cases below test conditions with a low specific pump power of 280 W per l/s.	
15	ΔT = 6.67°C (12°F) Supply Temperature: 6.67°C (44°F) Return Temperature: 13.33°C (56°F) Primary Constant System @ 280 W per l/s
16	ΔT = 8.89°C (16°F) Supply Temperature: 5.56°C (42°F) Return Temperature: 14.44°C (58°F) Primary Constant System @ 280 W per l/s
17	ΔT = 6.67°C (12°F) Supply Temperature: 6.67°C (44°F) Return Temperature: 13.33°C (56°F) Primary Variable System @ 280 W per l/s
18	ΔT = 8.89°C (16°F) Supply Temperature: 5.56°C (42°F) Return Temperature: 14.44°C (58°F) Primary Variable System @ 280 W per l/s, pipe sizes reduced to maintain pressure
19	ΔT = 8.89°C (16°F) Supply Temperature: 5.56°C (42°F) Return Temperature: 14.44°C (58°F) Primary Variable System @ 140 W per l/s, pipe sizes same as case 17

RESULTS

Regardless of the chilled water distribution system in use, increasing the ΔT increases energy efficiency. This indicates that it is possible to reduce energy consumption while reducing pipe size, providing a reduction in capital costs as well as running costs. However, designers are cautioned that there will be an increase in the size of the cooling coil to provide a high ΔT return temperature. A lifecycle analysis between the reduction of costs in pipes and an increase in costs of cooling coil should be studied alongside the reduction of energy consumption to derive the optimum solution for a building.

The energy saved on a primary constant system from the use of a high ΔT chilled water system is higher than a primary variable system. This is because a primary variable system is already a more efficient system than a primary constant system.

FIGURE 8.5 | BEI RELATIONSHIP WITH DIFFERENT ΔT OF CHILLED WATER FOR A PRIMARY CONSTANT SYSTEM

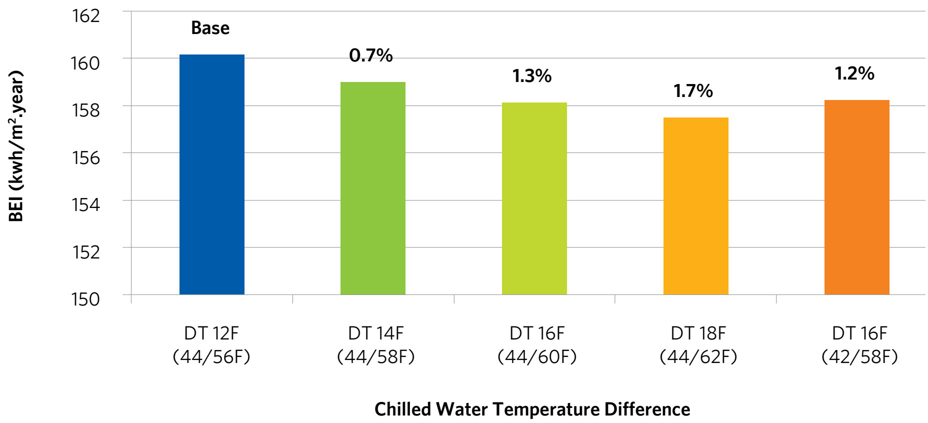


Figure 8.5 shows that with a higher ΔT of chilled water, the BEI reduction is higher. It was also interesting note that reducing the supply chilled water temperature while maintaining the same ΔT reduces the BEI marginally due to the lower chiller efficiency.

It should also be highlighted that the cooling coil size becomes larger when the temperature of chilled water supplied is higher, even for the same rate of heat transfer (same ΔT).

Therefore the design selection of supply chilled water temperature and ΔT is a choice between the cooling coil size (and cost increment) and the savings that are provided by it due to a reduced flow rate, reduced pump size, pipe size and a reduced BEI.

FIGURE 8.6 | BEI RELATIONSHIP WITH DIFFERENT ΔT OF CHILLED WATER FOR A PRIMARY VARIABLE SYSTEM

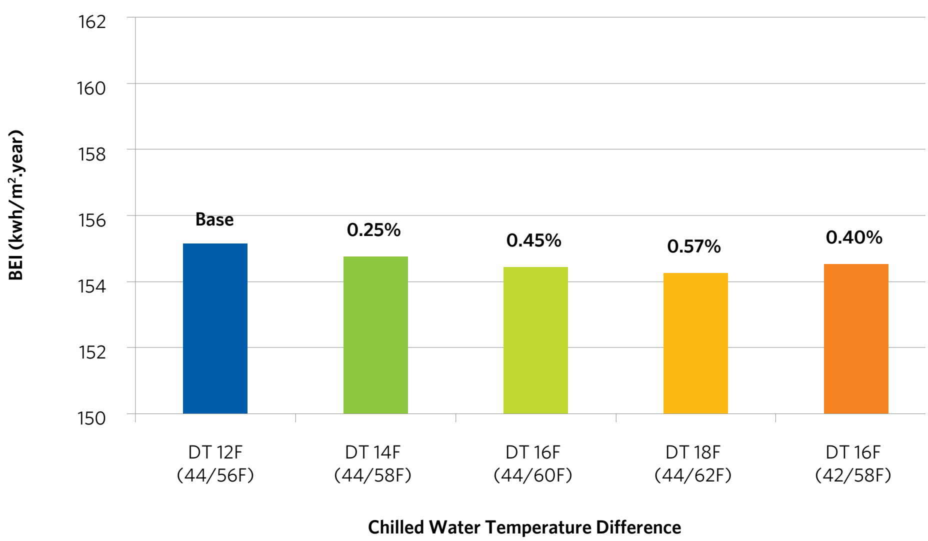


FIGURE 8.7 | BEI RELATIONSHIP WITH DIFFERENT ΔT OF CHILLED WATER FOR A PRIMARY VARIABLE SYSTEM WITH PIPE SIZE DESIGNED FOR A STANDARD ΔT

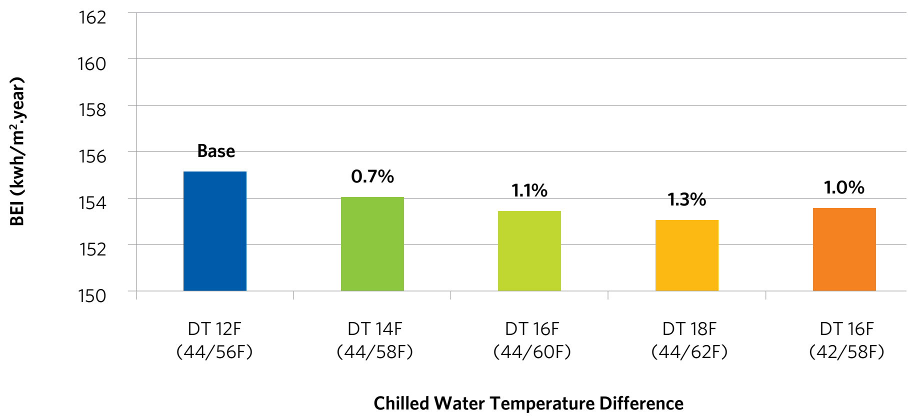


TABLE 8.5 | SIMULATION RESULTS OF VARIOUS ΔT SCENARIOS

Case	BEI (kWh/m².year)	BEI Reduction (kWh/m².year)	% Reduction	Remarks
C1	160.2	Base	Base	Base Case: Primary Constant System. Specific pump power @ 545 W per l/s ΔT = 6.67°C (12°F)
C2	159.0	1.2	0.7%	ΔT = 14°F, Supply T = 44°F
C3	158.1	2.0	1.3%	ΔT = 16°F, Supply T = 44°F
C4	157.5	2.7	1.7%	ΔT = 18°F, Supply T = 44°F
C5	158.2	1.9	1.2%	ΔT = 16°F, Supply T = 42°F
C6	155.1	5.0	3.1%	Base Case Changed to Primary Variable System. Specific pump power @ 545 W per l/s ΔT = 6.67°C (12°F)
C7	154.8	5.4	3.4%	ΔT = 14°F, Supply T = 44°F
C8	154.4	5.7	3.6%	ΔT = 16°F, Supply T = 44°F
C9	154.3	5.9	3.7%	ΔT = 18°F, Supply T = 44°F
C10	154.5	5.6	3.5%	ΔT = 16°F, Supply T = 42°F
C11	154.0	6.1	3.8%	C11 = C7 with pipe size = C1
C12	153.4	6.7	4.2%	C12 = C8 with pipe size = C1
C13	153.1	7.1	4.4%	C13 = C9 with pipe size = C1
C14	153.6	6.6	4.1%	C14 = C10 with pipe size = C1
C15	156.2	4.0	2.5%	C15 = C1 with Specific Pump Power of 280 W per l/s
C16	155.2	4.9	3.1%	C16 = C5 with Specific Pump Power of 280 W per l/s
C17	153.6	6.6	4.1%	C17 = C6 with Specific Pump Power of 280 W per l/s
C18	153.4	6.8	4.2%	C18 = C10 with Specific Pump Power of 280 W per l/s
C19	152.7	7.4	4.6%	C19 = C18 with Specific Pump Power of 140 W per l/s (pipe size is not reduced when flow rate is reduced)

CHILLED WATER PUMP EFFICIENCY

The chilled water pump efficiency is a factor of flow rate, pressure and efficiency. Reduction of flow rate can be achieved by ensuring the low cooling load and implementation of a high ΔT chilled water flow. The reduction of pump total pressure and increment of pump total efficiency will also reduce chilled water pump energy used.

The pump total pressure (head) is a factor of pipe size (which is also flow rate dependent), valves/fittings k-factor and the number of bends and elbows. While the pump total efficiency is a factor of pump and motor selection. The recommended efficiency of pumps is provided by the Energy Efficiency and Conservation Guidelines for Malaysian Industry (Part 1) by Pusat Tenaga Malaysia for different types of pumps and flow rates. A selection of typical pump efficiencies applicable for air-conditioning systems are extracted into **Table 8.6** as shown on the right.

TABLE 8.6 | A SELECTION OF RECOMMENDED MINIMUM PUMP EFFICIENCIES BY ENERGY EFFICIENCY AND CONSERVATION GUIDELINES FOR MALAYSIAN INDUSTRY (PART 1)

Flow (gpm)	Efficiency [%]	
	End Suction (incl. vertical & close impeller types) [%]	Horizontal / Vertical split casing (centrifugal and close impeller types) [%]
100	50 – 60	-
110 – 250	65 – 75	73 – 76
300 – 450	75 – 80	75 – 79
460 – 600	78 – 82	75 – 79
700 – 1000	80 – 85	78 – 82
1100 – 1500	83 – 87	78 – 82
1600 – 2500	83 – 87	78 – 83
2600 – 3600	-	80 – 86
3700 – 4000	-	82 – 86
> 5000	-	80 – 88

SIMULATION STUDIES

The following set of simulation studies were made to study the impact of chilled water pump efficiency on the BEI:

TABLE 8.7 | SIMULATION CASES TO STUDY THE IMPACT OF PUMP EFFICIENCY AND PUMP HEAD

Case	Total Pump Efficiency	Total Pump Head	Specific Pump Power	
			W per l/s	W/gpm
C1	72%	45	613.1	38.7
C2	72%	35	476.9	30.1
C3	72%	25	340.6	21.5
C4	72%	15	204.4	12.9
C5	50%	35	686.7	43.3
C6	60%	35	572.3	36.1
C7	70%	35	490.5	30.9
C8	80%	35	429.2	27.1

RESULTS

Based on the results provided in **Figure 8.8** to **8.10** below, it is recommended to use the term specific pump power to represent the chilled water pump efficiency because it was found that the BEI has a linear relationship with the specific pump power, while it has a polynomial relationship with pump efficiency. The specific pump power was already defined on page 167 and a simplification of the specific pump power formula is made below for a typical chilled water system:

EQUATION 8.5

$$P = \frac{9.81 \ x \ h}{\mu}$$

Where:

P = Specific Pump Power (W per l/s)
h = Pump Total Pressure (m of water)
μ = Pump Total Efficiency (%)

FIGURE 8.8 | BEI RELATIONSHIP AT DIFFERENT PUMP HEAD

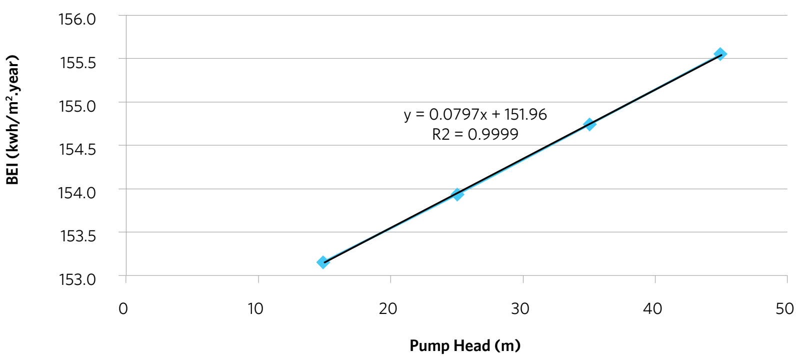


FIGURE 8.9 | BEI RELATIONSHIP AT DIFFERENT PUMP EFFICIENCY

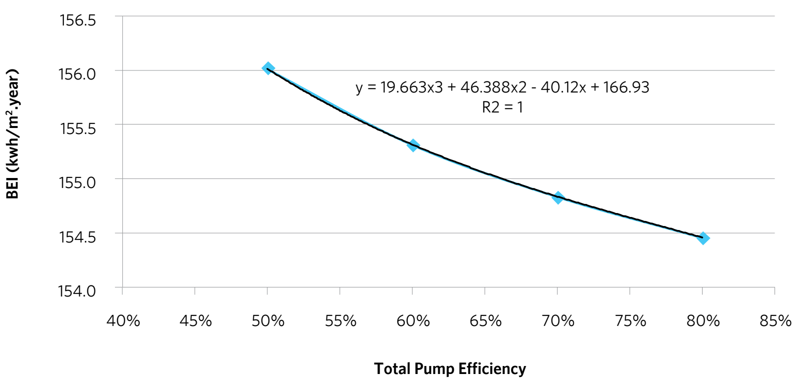
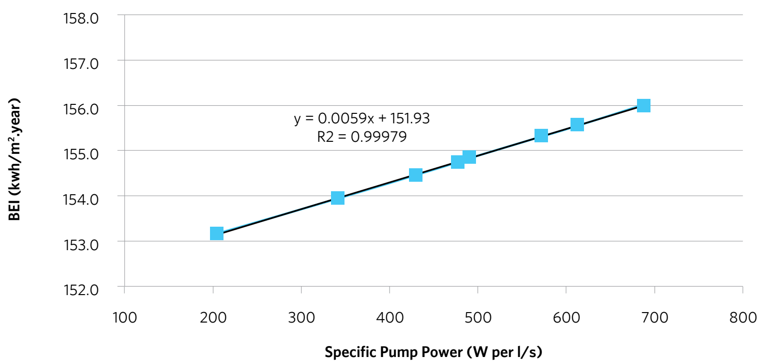


FIGURE 8.10 | BEI RELATIONSHIP AT DIFFERENT SPECIFIC PUMP POWER



The specific pump power is useful because it combines the two important factors describing the pump total efficiency, namely the pump total pressure and pump total efficiency.

A reduction of 100 W per l/s of specific pump power reduces the building BEI by approximately 0.6 kWh/m^2.year on a primary variable system.

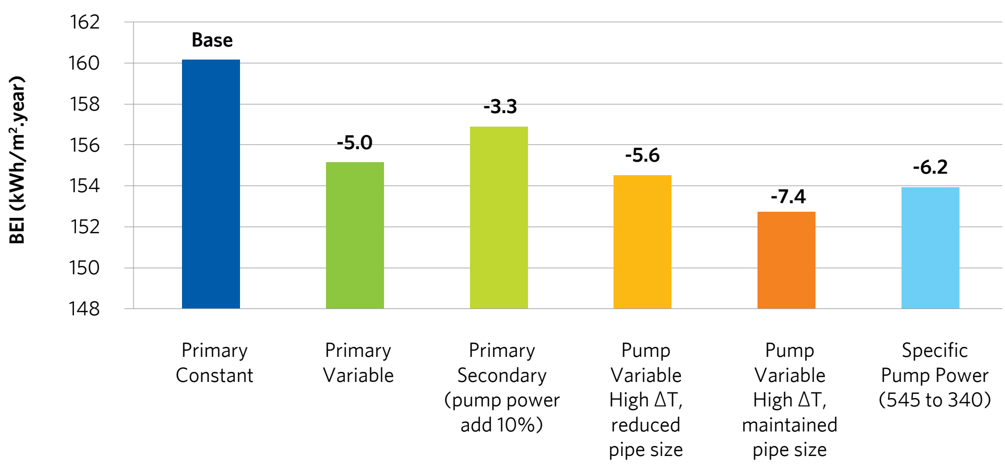
SUMMARY OF OPTIMISING THE CHILLED WATER DISTRIBUTION SYSTEM

Figure 8.11 below provides a summary of the various chilled water distribution optimisation options. Based on this set of results, the following conclusions can be made for the case studies conducted:

1. **Highest efficiency is gained (a reduction of ~7 kWh/m^2.year compared to a base constant flow scenario) when a primary variable system is operated with a high ΔT, while maintaining the pipe size as per a standard design**

2. **Reduction of the specific pump power by 100 W per l/s provides a reduction of ~0.6 kWh/m^2.year on a typical primary variable chilled water distribution system**

FIGURE 8.11 | A SUMMARY OF BEI RELATIONSHIP OF DIFFERENT CHILLED WATER DISTRIBUTION OPTIONS



CHILLER EFFICIENCY

Chiller efficiency is represented by the Coefficient of Performance (COP). The COP is defined as:

EQUATION 8.6

$$\text{COP} = \frac{\text{Cooling Provided } (\text{kW}_{\text{cooling}})}{\text{Electricity Consumed by Chiller } (\text{kW}_{\text{e}})}$$

Since the nominator and denominator is both kW, the term COP is a unit-less number. In Malaysia, it is also common to use the term "kW per ton" (where ton is refrigeration tonnage, equivalent to average heat transfer rate of 1 *short* ton of ice that melts at 0°C in 24 hours) to represent the chiller efficiency. The relationship between COP and "kW per ton" is shown below:

EQUATION 8.7

$$\text{kW per ton} = \frac{12}{\text{COP x 3.412}}$$

OR

EQUATION 8.8

$$\text{COP} = \frac{12}{\text{"kW per ton" x 3.412}}$$

Table 8.8 below is provided for easy reference:

TABLE 8.8 | CONVERSION TABLE BETWEEN COP AND KW PER TON FOR CHILLER EFFICIENCIES

COP	kW/ton
2.50	1.41
3.00	1.17
3.50	1.00
4.00	0.88
4.50	0.78
5.00	0.70
5.50	0.64
6.00	0.59
6.50	0.54
7.00	0.50

Typically, the chiller efficiency is requested from the chiller manufacturer. More efficient chillers are usually more expensive. The MS 1525 (2007) provides a range of minimum efficiency requirements for various types of chillers and capacities. A highlight of the MS 1525 is provided below together with known very good COP that is available today:

TABLE 8.9 | RECOMMENDED MINIMUM CHILLER EFFICIENCIES IN MS 1525

Equipment	Size	Sub-category	Minimum COP (MS 1525, 2007)	Known Very Good COP*
Air conditioners: Air cooled with condenser	< 19 kWr	Split system	2.7	2.9
		Single package	2.7	2.9
	≥ 19 kWr and < 35 kWr	Split system and single package	2.6	2.9
	≥ 35 kWr	Split system and single package	2.5	2.9
Air conditioners: Water and evaporatively cooled	< 19 kWr	Split system and single package	3.0	3.3
	≥ 19 kWr and < 35 kWr	Split system and single package	3.5	3.8
	≥ 35 kWr	Split system and single package	3.6	3.9

Equipment	Size	Minimum COP (MS 1525)	Known Good COP*
Air cooled, with condenser	< 105 kWr (30RT)	2.6	3.0
	≥ 105 kWr and < 530 kWr (150RT)	2.7	3.1
	≥ 530 kWr and < 1,060 kWr (300RT)	2.8	3.2
	≥ 1,060 kWr (300RT)	2.9	3.4
Water cooled, positive displacement (Reciprocating and Scroll)	All capacities	4.0	5.0
Water cooled, positive displacement (Rotary Screw)	< 530 kWr (150RT)	4.0	5.0
	≥ 530 kWr and < 1,060 kWr (300RT)	4.4	5.4
	≥ 1,060 kWr (300RT)	5.4	6.1
Water cooled, centrifugal	< 1,060 kWr (300RT)	5.2	6.3
	≥ 1060 kWr (300RT)	5.7	7.0

*Designers are recommended to request for the latest COP ratings from chiller manufacturers.

Due to the recent interest in energy efficiency worldwide, chiller manufacturers are improving their chiller efficiencies rapidly. It is recommended that ACMV designers keep up to date with the latest chiller efficiencies available from the respective manufacturers instead of relying on the table provided.

SIMULATION STUDIES

A set of simulation studies were conducted to test the impact of the use of different types of chillers and efficiency ratings. The simulation case model required the use of 3 chillers to meet the building cooling load, to keep each chiller below the 1,000 ton refrigerant capacity. The case studies made are shown below:

TABLE 8.10 | CHILLER SIMULATION CASE STUDIES

Case	Type of Chiller	Chiller Rated COP	3 Chillers, Operating Sequence*
1	Screw	4.0	Stacked
2	Screw	4.5	Stacked
3	Screw	5.0	Stacked
4	Screw	5.5	Stacked
5	Centrifugal	5.0	Stacked
6	Centrifugal	5.5	Stacked
7	Centrifugal	6.0	Stacked
8	Centrifugal	6.5	Stacked
9	VSD	5.0	Stacked
10	VSD	5.5	Stacked
11	VSD	6.0	Stacked
12	VSD	6.5	Stacked
13	Screw	5.5	Parallel
14	Centrifugal	5.5	Parallel
15	VSD	5.0	Parallel
16	VSD	5.5	Parallel
17	VSD	6.0	Parallel
18	VSD	6.5	Parallel

***Stacked** = additional chiller is only switched on when operating chiller has reached maximum capacity and is unable to meet the cooling load anymore.

Parallel = all 3 chillers are operating at the same time regardless of cooling load (note that this is normally not practiced because chiller lifespan is dependent on its operating hours, where longer operating hours will reduce chiller lifespan, as in parallel mode).

The default performance curves for screw, centrifugal and VSD chillers from DOE-2[1] were used for these simulations. The chiller performance curves by DOE-2 account for the following variations:

1. Cooling capacity curve based on entering condenser water temperature, chilled water leaving temperature and datum temperature. This curve adjusts the available capacity of the chiller as a function of evaporator and condenser temperature (or lift).

2. Water temperature dependence curve based on chilled water supply temperature, entering condenser water temperature and datum temperature. This curve adjusts the efficiency of the chiller as a function of evaporator and condenser temperature (or lift).

3. Part-load dependence curve based on part load fraction, chilled water supply and entering condenser water temperature. This curve adjusts the efficiency of chiller as a function of part-load operation.

In addition, DOE-2 has recently included a new model for variable-speed-chillers that includes temperature terms in the curve fit equations. The variable speed chiller model was based on an ASHRAE Symposium paper, "Development and Testing of a Reformulated Regression Based Electric Chiller Model.[2]

[1] DOE-2 is a computer program for the design of energy-efficient buildings. Developed for the U.S. Department of Energy by Lawrence Berkeley National Laboratory's Simulation Research Group, DOE-2 calculates the hourly energy use and energy cost of a commercial or residential building given information about the building's climate, construction, operation, utility rate schedule, and HVAC equipment.
[2] Hydeman, M.; N. Webb; P. Sreedharan; S. Blanc. "Development and Testing of a Reformulated Regression Based Electric Chiller Model." ASHRAE, Atlanta GA. HI-02-18-02.2002.

RESULTS

Figure 8.12 displays the BEI of various types of chiller. These chillers were all assigned with the same COP of 5.5. Based on the chiller performance curve provided by DOE-2, the centrifugal chillers were shown to have a higher BEI than the screw chillers. The VSD chillers are shown to have the lowest BEI among the tested chillers. Moreover if VSD chillers were run in parallel to ensure that it is kept on part load most of the time, the BEI is the lowest even though all the chillers have the same COP of 5.5. However, it should also be pointed out that chiller lifespan is highly dependent on its operating hours. Running VSD chillers in parallel mode to "force" it to operate at a more efficient part load condition will increase chiller operating hours significantly, thereby, reducing its lifespan. Additionally, VSD chillers are known to be more expensive than non-VSD chillers, therefore, it is a more likely scenario that VSD chillers are coupled with non-VSD chillers to be used in practice. An additional simulation case study was added in this chapter where one VSD chiller is used in combination with two non-VSD chillers. The results indicate that this chiller configuration is as efficient as running all VSD chillers in a stacked mode. Since non-VSD chillers are less expensive, the capital cost is lower than purchasing all VSD chillers.

FIGURE 8.12 | BEI PERFORMANCE OF DIFFERENT TYPES OF CHILLER AT COP OF 5.5

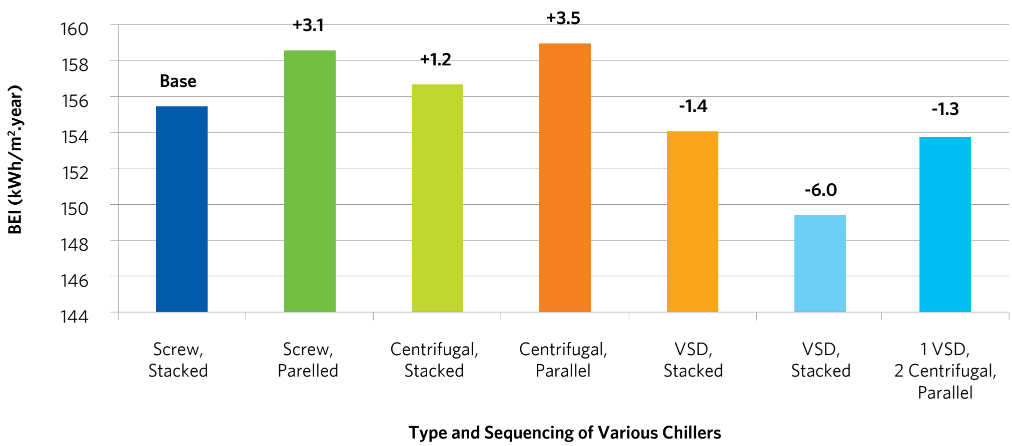
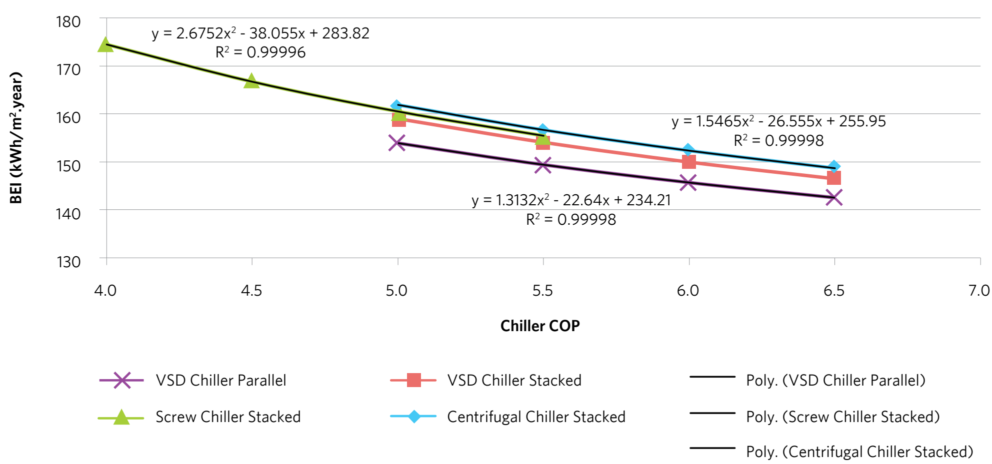


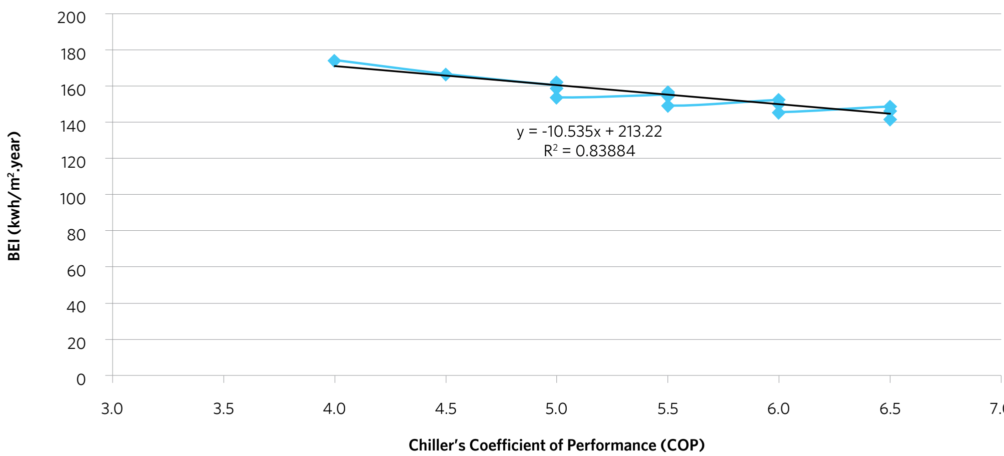
Figure 8.13 below provides the curve fit equation for quick estimates of BEI reduction due to the type of chiller used and COP selection.

FIGURE 8.13 | BEI PERFORMANCE OF DIFFERENT TYPES OF CHILLER AT VARIOUS COP



In general, a quick rule-of-thumb to estimate the BEI reduction due to the selection of chiller efficiency, COP is provided in **Figure 8.14** below. The BEI is reduced approximately by 10.5 kWh/m².year for a COP increase of 1.0.

FIGURE 8.14 | CURVE FIT OF BEI AND COP OF CHILLERS



Figures 8.15 to **8.20**, display the simulated operating chiller COP due to the building load. The COP value is not a fixed value at the peak building load because it is also related to the weather at the point of time of the building peak load. The outdoor wet bulb temperature changes the return condenser water temperature from the cooling tower, which will influence the operating COP of the chiller (where a lower condenser water temperature increases chiller efficiency).

A screw chiller with rated COP of 5.5 operates mostly between a COP of 5.5 and 6.0 when it is operated in stacked sequencing mode. However, when the same screw chiller is operated in parallel sequencing, its COP is mostly operating between 5.0 to 5.5 for a building load up to 80% and only become more efficient with a COP of 5.5 to 6.0 when the building load exceeds 80%. This shows that a screw chiller is most efficient when it is run close to the full load.

FIGURE 8.15 | OPERATING COP OF SCREW CHILLER WHEN CHILLERS ARE OPERATED IN STACKING SEQUENCE

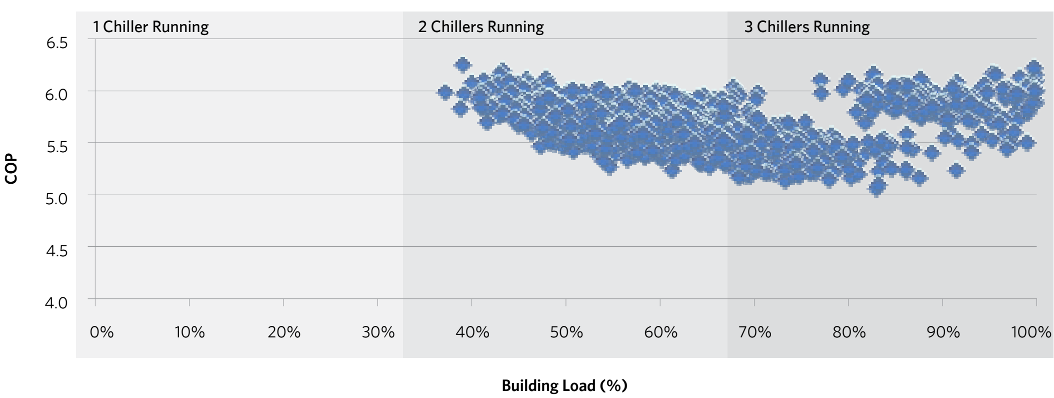
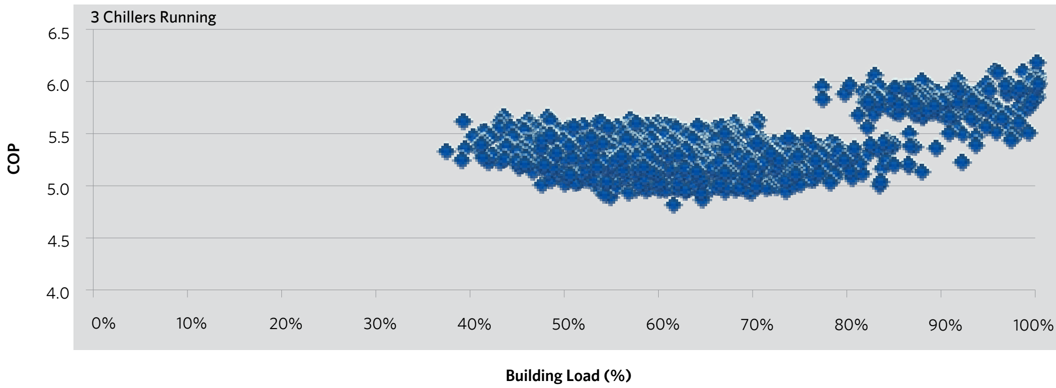


FIGURE 8.16 | OPERATING COP OF SCREW CHILLER WHEN CHILLERS ARE OPERATED IN PARALLEL SEQUENCE



A centrifugal chiller with a rated COP of 5.5 operates mostly between a COP of 5.0 and 6.0 when it is operated in stacked sequencing mode. However, when the same centrifugal chiller is operated in parallel sequencing, its COP dropped to as low as 4.5 when the building load is at 40%, and increases incrementally up to a COP of 6.0 at building load of 100%. This shows that a centrifugal chiller is also most efficient when it is running close to the full load.

FIGURE 8.17 | OPERATING COP OF CENTRIFUGAL CHILLER WHEN CHILLERS ARE OPERATED IN STACKING SEQUENCE

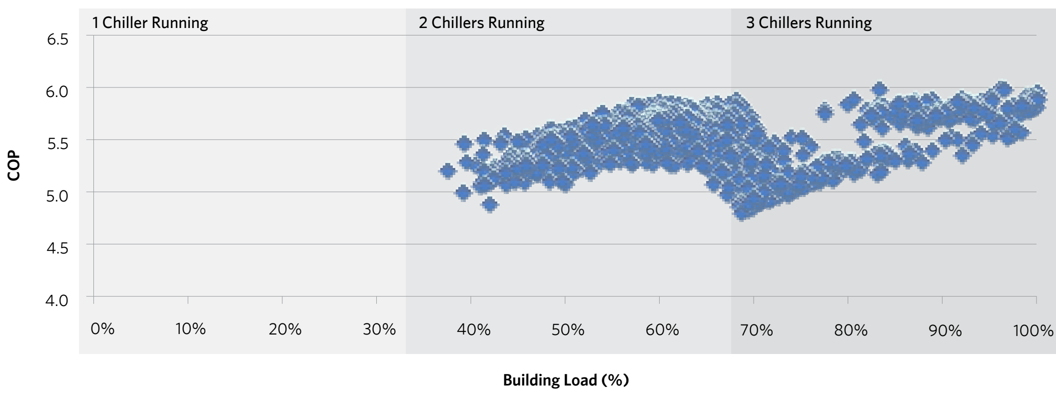
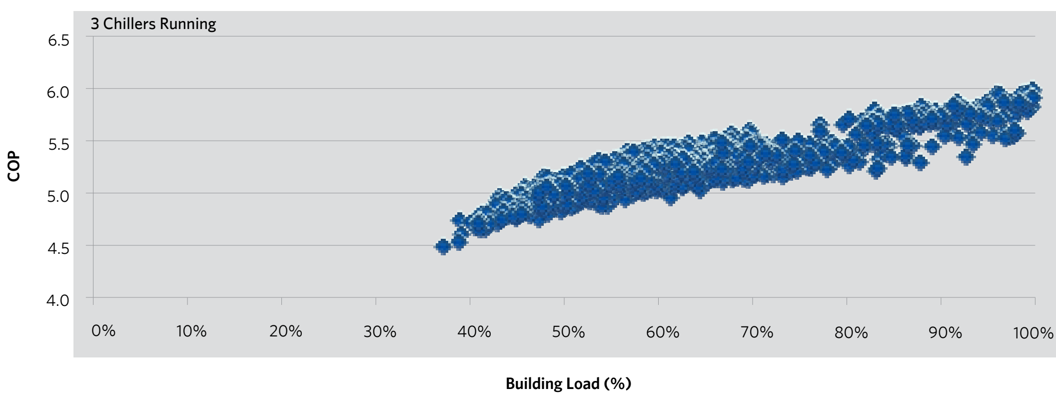


FIGURE 8.18 | OPERATING COP OF CENTRIFUGAL CHILLER WHEN CHILLERS ARE OPERATED IN PARALLEL SEQUENCE



Figures 8.19 and **8.20** display the results of VSD chillers with a rated COP of 5.5, operating in stacked sequencing mode and parallel mode respectively. The default VSD chiller performance curve from DOE-2 was used in this study. When these VSD chillers were operating in a parallel mode, each VSD chiller is "forced" to operate at part load condition for an extended length of time. It was interesting to note from the simulation results that VSD chillers operating in parallel sequencing mode, have a significant number of hours where the COP of the VSD chiller was higher than 7.0 (during part load conditions). However, when the same VSD chillers are operated in stacked sequencing mode, there are hardly any hours where its COP exceeds 7.0.

Operating VSD chillers in parallel mode is shown in this case study to provide much better efficiency than running them in stacked mode. A proper lifecycle analysis should be conducted to assess the benefit of running VSD chillers in parallel mode to 'force' it to operate at part load for better energy efficiency, taking into account of the potential reduction of chiller lifespan.

It is likely the most financially feasible solution is to use one VSD chiller in combination with the rest being non-VSD chillers (results shown in **Figure 8.21**). In this design configuration, the non-VSD chillers are operated at peak load conditions while the VSD chiller is used to fill in the part load conditions. Non-VSD chillers should be coupled with constant flow pumps, while the VSD chillers should be coupled with variable flow pumps to cater for part-load conditions. Since the supply and return chilled water temperature is the same for all the chillers (installed in parallel), the constant flow pump will ensure that non-VSD chillers are operating at peak load all the time, while the VSD chiller is used at part load condition with the variable speed pump for optimum system efficiency.

FIGURE 8.19 | OPERATING COP OF CENTRIFUGAL CHILLER WHEN CHILLERS ARE OPERATED IN STACKING SEQUENCE

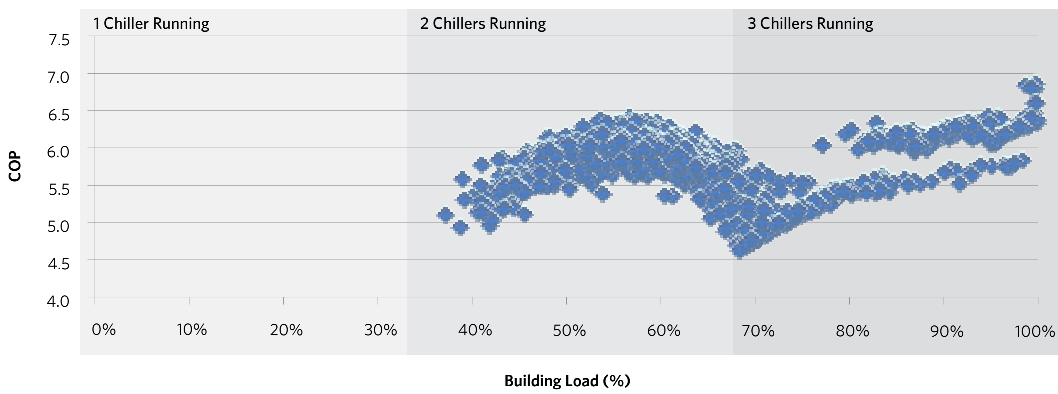


FIGURE 8.20 | OPERATING COP OF CENTRIFUGAL CHILLER WHEN CHILLERS ARE OPERATED IN PARALLEL SEQUENCE

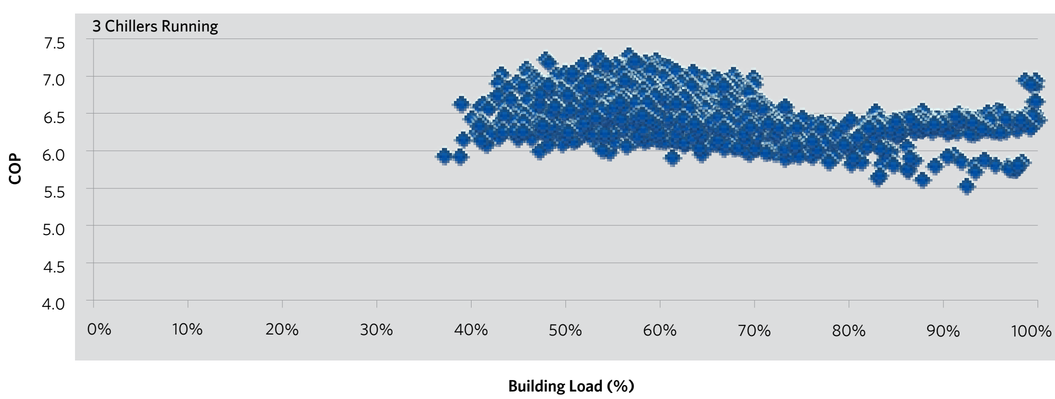
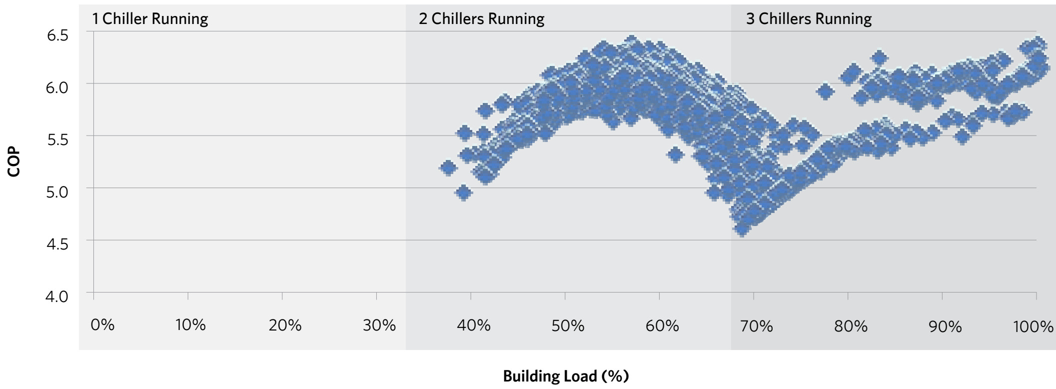


FIGURE 8.21 | OPERATING COP OF 1 VSD CHILLER AND 2 CENTRIFUGAL CHILLERS WHEN CHILLERS ARE OPERATED IN STACKING SEQUENCE WITH THE VSD CHILLER OPERATING AT PART-LOAD WHENEVER POSSIBLE AND CENTRIFUGAL CHILLERS ARE ONLY OPERATED AT FULL-LOAD



SUMMARY OF CHILLER EFFICIENCY

The following rules-of-thumb are derived from the studies made:

1. **An increase of COP of 1.0, reduces BEI approximately by 10 kWh/m^2.year**
2. **It is most efficient to run a screw and centrifugal chiller close to its maximum load**
3. **It is most efficient to run a VSD chiller at part-load condition**
4. **To minimise capital cost and increase efficiency, it is recommended to consider a chiller design where one (1) VSD chiller is used in combination with non-VSD chillers**

CONDENSER PUMP EFFICIENCY

Similar to chilled water pump efficiency, the condenser pump efficiency is a factor of the flow rate and specific pump power.

The flow rate on the condenser pump system is a factor of the amount of rejected heat and temperature differences between the supply and return temperature (ΔT) on the condenser side. The amount of rejected heat is a factor of the building cooling load and ACMV system efficiencies. The more efficient the building is, the less heat is required to be rejected, reducing the condenser flow rate requirement. However, if the entire upstream cooling load is optimised, the only possibility to reduce the condenser flow rate is to provide a high ΔT design on the condenser side. Unfortunately, providing a high ΔT design on the condenser side reduces the efficiency of the chiller. It is often argued by many in the building industry that it is more important to increase the efficiency of the chiller by providing a higher flow rate on the condenser side to improve chiller efficiency. However, a higher condenser flow rate increases pump energy. This section explores the benefit of increasing or reducing condenser flow rate via a set of simulation studies.

In addition to the possibility of providing a high ΔT on the condenser side to reduce flow rate and energy, typical energy efficiency implementation on reducing the specific pump power can be implemented. The specific pump power as shown earlier is a factor of total pump head and total pump efficiency.

SIMULATION STUDIES

The following set of simulation studies were conducted to study the impact of 3 sets of condenser flow rates against a range of specific pump power. The rationale behind this set of simulation cases was to test the crossover point where increasing the condenser flow rate would increase the energy consumption of the system due to a high specific pump power requirement.

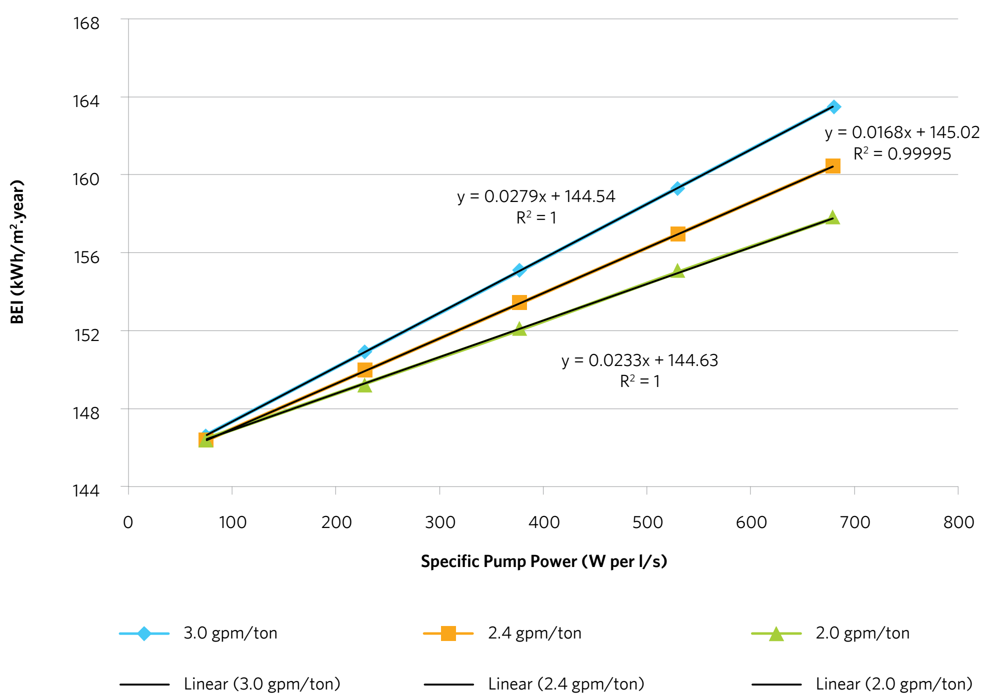
TABLE 8.11 | CONDENSER PUMP EFFICIENCY TEST CASES

Case	ΔT (°C)	ΔT (°F)	Flow Rate (gpm/HRT)	Specific Pump Power (W per l/s)
1	4.45°C (33.89/29.44)	8 °F (93/85)	3.0	679.15
2	4.45°C (33.89/29.44)	8 °F (93/85)	3.0	528.23
3	4.45°C (33.89/29.44)	8 °F (93/85)	3.0	377.31
4	4.45°C (33.89/29.44)	8 °F (93/85)	3.0	226.38
5	5.56°C (35.00/29.44)	10 °F (95/85)	2.4	679.15
6	5.56°C (35.00/29.44)	10 °F (95/85)	2.4	528.23
7	5.56°C (35.00/29.44)	10 °F (95/85)	2.4	377.31
8	5.56°C (35.00/29.44)	10 °F (95/85)	2.4	226.38
9	6.67°C (36.11/29.44)	12 °F (97/85)	2.0	679.15
10	6.67°C (36.11/29.44)	12 °F (97/85)	2.0	528.23
11	6.67°C (36.11/29.44)	12 °F (97/85)	2.0	377.31
12	6.67°C (36.11/29.44)	12 °F (97/85)	2.0	226.38

RESULTS

The simulation results in **Figure 8.22** below indicates that in the Malaysian climatic zone, it is beneficial to design a reduced condenser flow rate from the current standard ΔT option of 35.00/29.44°C (95/85°F) to a high ΔT option of 36.11/29.44°C (97/85°F) (from 2.4 gpm/ton to 2 gpm/ton of condenser flow rate). The energy reduction from the condenser pump power exceeds the chiller energy increment for all conditions tested on the base case building with centrifugal chillers.

FIGURE 8.22 | BEI RELATIONSHIP TO CONDENSER FLOW RATE AND CONDENSER SPECIFIC PUMP POWER



SUMMARY OF CONDENSER PUMP EFFICIENCY

It is recommended to increase the condenser pump efficiency via the following:

1. **Reduce specific pump power by reducing pump head and increasing pump efficiency**
2. **Reduce condenser flow rate by designing for a high ΔT on the condenser side**

COOLING TOWER EFFICIENCY

The efficiency of cooling towers is provided by the Energy Efficiency and Conservation Guidelines for Malaysian Industry (Part 1) by Pusat Tenaga Malaysia in the rating terms of Fan Power per Heat Rejected Ton or kWe/HRT. From the table provided in the guideline, the cooling towers were shown to have a range of kWe/HRT between 0.0220 to 0.0463. This range is quite large, 110% to be exact, and it indicates that it is possible for a cooling tower to consume twice the energy between the best and the worst cooling tower selections, even within the recommendations of the Energy Efficiency and Conservation Guidelines.

It is also known that it is a fairly common practice in the industry to "oversize" a cooling tower, in the anticipation that providing a colder condenser return temperature to the chiller will provide a net increase in energy efficiency of the building. However, an "oversized" cooling tower will also have a higher fan energy consumption.

Finally, it is also possible to implement a variable speed drive (VSD) to reduce the fan speed to save energy in a cooling tower. However, implementation of a VSD to reduce the fan speed may increase the condenser return temperature to the chiller, as compared to a fixed fan speed, increasing the energy consumption of the chiller.

Therefore, a set of simulation studies were conducted to test all these possible variations to gain an understanding on the larger influence on the net building energy efficiency by these various possibilities of designing and operating a cooling tower.

It is a fairly common practice in the industry to "oversize" cooling tower, in the anticipation that providing a colder condenser return temperature to the chiller will provide a net increase in energy efficiency of the building. However, an "oversized" cooling tower will also have a higher fan energy consumption

SIMULATION STUDIES

A set of simulation studies were developed to study the impact of cooling tower optimisation based on all the issues raised on the previous page.

TABLE 8.12 | COOLING TOWER EFFICIENCY TEST CASES

Case	Descriptions	kWe/HRT	Design Cooling Tower Leaving Water Temperature (°C/°F)	Cooling Tower Leaving Water Temperature Set Point (°C/°F)
C1	Constant Speed Fan, Base Case	0.045	29.4/85	21.1/70
C2	Constant Speed Fan	0.035	29.4/85	21.1/70
C3	Constant Speed Fan	0.025	29.4/85	21.1/70
C4	Constant Speed Fan	0.015	29.4/85	21.1/70
C5	C2 with 2 Speed Fan	0.035	29.4/85	21.1/70
C6	C2 with Variable Speed Fan	0.035	29.4/85	21.1/70
C7	C2 with lower design condenser return temperature (oversized)	0.035	28.9/84	21.1/70
C8	C2 with lower design condenser return temperature (oversized)	0.035	28.3/83	21.1/70
C9	C2 with lower design condenser return temperature (oversized)	0.035	27.8/82	21.1/70
C10	C2 with lower design condenser return temperature (undersized)	0.035	30.0/86	21.1/70
C11	C2 with lower design condenser return temperature (undersized)	0.035	30.6/87	21.1/70
C12	C2 with lower design condenser return temperature (undersized)	0.035	31.1/88	21.1/70
C13	C6 (VSD Fan) Condenser return temperature set point varied	0.035	29.4/85	23.9/75
C14	C6 (VSD Fan) Condenser return temperature set point varied	0.035	29.4/85	26.7/80
C15	C6 (VSD Fan) Condenser return temperature set point varied	0.035	29.4/85	27.2/81
C16	C6 (VSD Fan) Condenser return temperature set point varied	0.035	29.4/85	27.8/82
C17	C6 (VSD Fan) Condenser return temperature set point varied	0.035	29.4/85	28.3/83
C18	C6 (VSD Fan) Condenser return temperature set point varied	0.035	29.4/85	28.9/84
C19	C6 (VSD Fan) Condenser return temperature set point varied	0.035	29.4/85	29.4/85
C20	C6 (VSD Fan) Condenser return temperature set point varied	0.035	29.4/85	30.0/86
C21	C6 (VSD Fan) Condenser return temperature set point varied	0.035	29.4/85	30.6/87
C22	C6 (VSD Fan) Condenser return temperature set point varied	0.035	29.4/85	31.1/88
C23	C6 (VSD Fan) Condenser return temperature set point varied	0.035	29.4/85	32.2/90

RESULTS

Figure 8.23 shows that for an improvement of cooling tower fan efficiency by 0.01 kWe/HRT, the BEI will reduce by approximately 1.5 kWh/m².year on a constant fan speed cooling tower.

FIGURE 8.23 | BEI RELATIONSHIP TO COOLING TOWER EFFICIENCY AT CONSTANT FAN SPEED

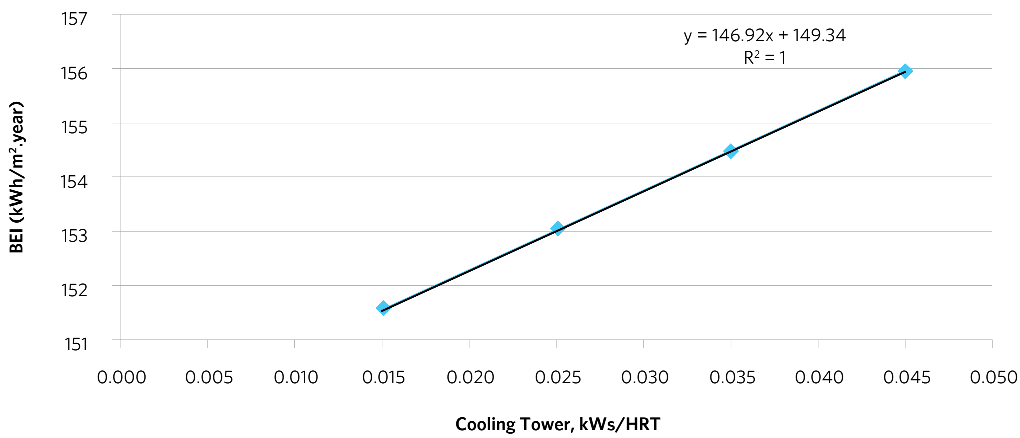


Figure 8.24 shows that there is almost no efficiency gain with the use of a 2-speed fan or variable speed fan when the cooling tower leaving water temperature set point was fixed at a low value of 21.11°C (70°F). This is because our climate does not have such a low wet-bulb temperature in the first place for this temperature set-point to be achieved; therefore, the cooling tower fan will be running at full speed for all conditions.

FIGURE 8.24 | BEI RELATIONSHIP TO COOLING TOWER FAN OPTIONS WITH LEAVING WATER TEMPERATURE SET POINT OF 21.11°C

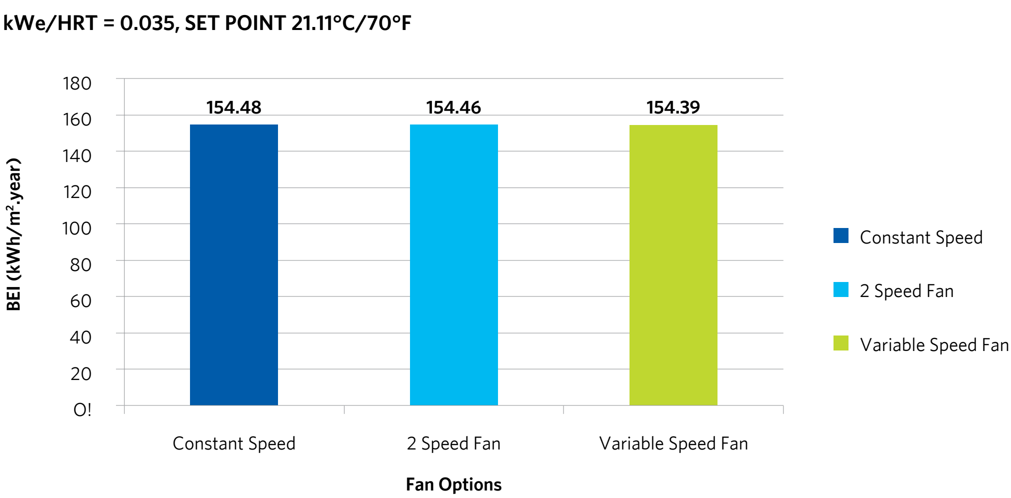
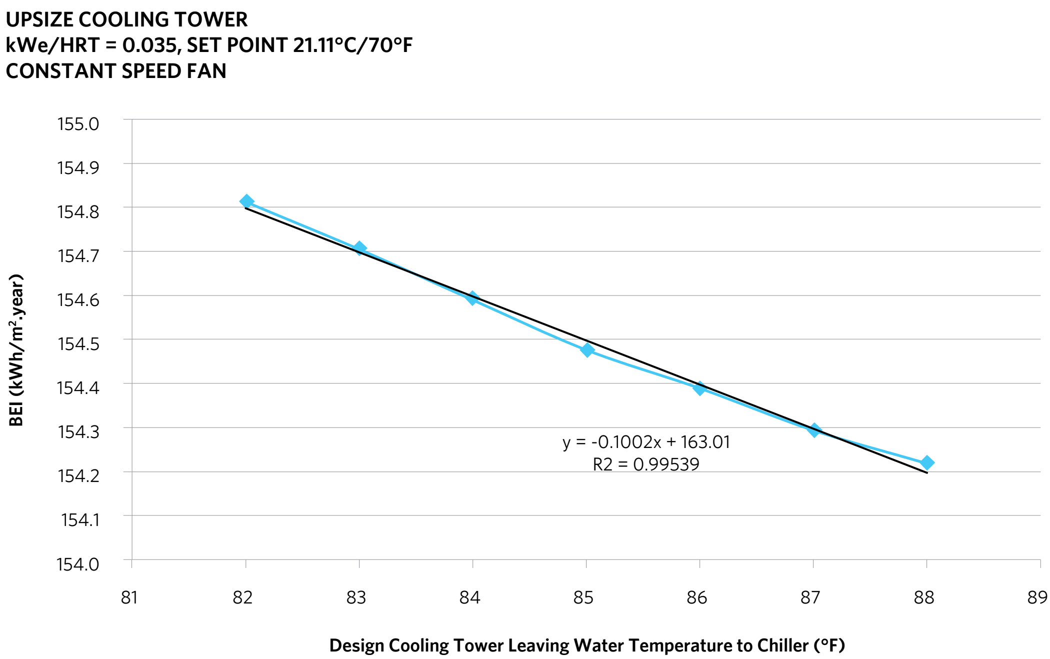


Figure 8.25 is the simulated result of the testing an upsized or downsized cooling tower. The upsizing of a cooling tower is conducted via the design of a lower leaving water temperature from the cooling tower. The current standard of practice in the industry is to size the cooling tower for a water leaving temperature of 29.44°C (85°F). Sizing it for a lower leaving water temperature will a require larger cooling tower, while a sizing for a higher leaving water temperature will indicate a smaller cooling tower is used. The simulated results in **Figure 8.25** indicate that reducing the cooling tower size reduces building energy consumption due to the smaller fan power used. The results show that the loss of chiller efficiency is minimal due to the use of a smaller cooling tower and fan. Finally, it is very important to note that the impact on energy efficiency due to the upsizing or downsizing of the cooling tower is very minimal. Therefore, designers should not be too concerned over upsizing or downsizing cooling tower to achieve better efficiency in a building.

FIGURE 8.25 | BEI RELATIONSHIP TO DESIGN COOLING TOWER WATER LEAVING TEMPERATURE



*Take note of the scale of BEI presented on the Y-axis, which is very small.

Figures 8.26 to **8.28** indicates the energy efficiency of using variable speed drive (VSD) fan on a cooling tower with different set points of water leaving temperature. The VSD will reduce the fan speed when the leaving water temperature meets the set point temperature to reduce the cooling tower fan energy consumption. The results of the simulation show that it is most efficient to run a VSD on a cooling tower with a water leaving temperature set point of 28.33 – 30.00°C (83 - 86°F). Somehow the results show that having the water leaving temperature set point at 27.78°C (82°F) and 30.56°C (87°F) increases chiller energy consumption significantly via a reduction of chiller efficiency. Further investigation showed that this result is largely due to the centrifugal chiller performance curve-fit used in this study, where the efficiency of the chiller is particularly low then the water leaving temperature set point is fixed at 27.78°C (82°F) and 30.56°C (87°F) .

Figure 8.27 shows that as the leaving water temperature from a cooling tower increases, the cooling tower fan energy reduces with the use of a VSD. **Figure 8.28** shows that as the leaving water temperature from a cooling tower increases, the chiller energy increases with a particular spike at the water temperature set point of 27.78°C (82°F) and 30.56°C (87°F). The most ideal water leaving temperature set point for a cooling tower with a VSD is found between 29.44°C (85°F) and 30°C (86°F).

FIGURE 8.26 | BEI RELATIONSHIP TO SET POINT TEMPERATURE OF A VARIABLE FAN SPEED COOLING TOWER

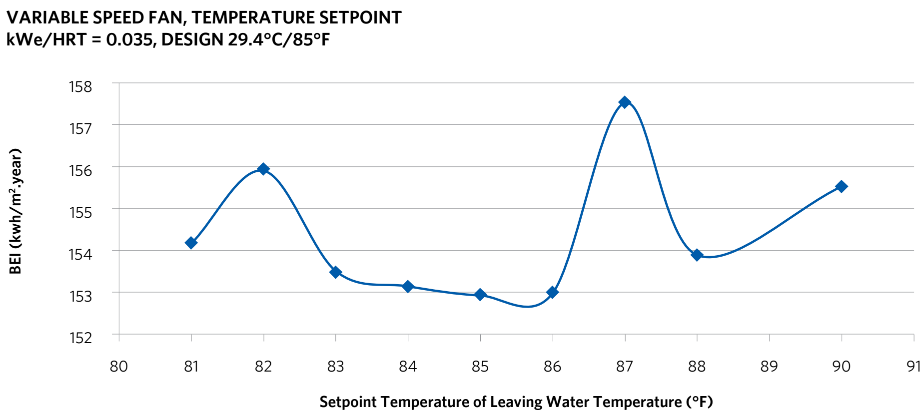
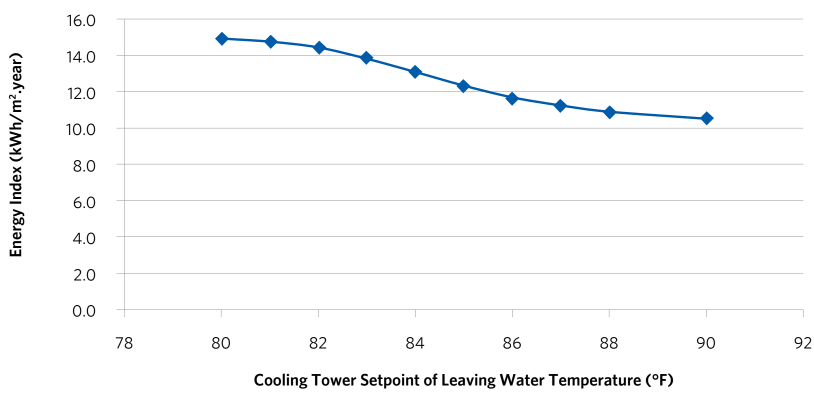
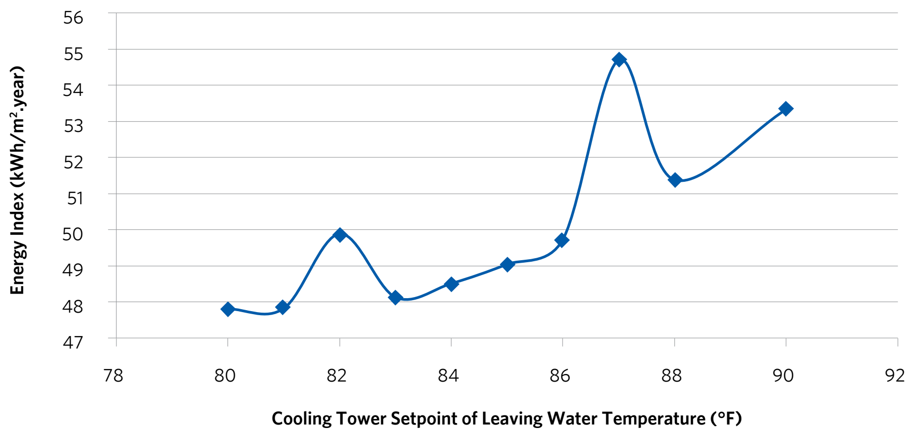


FIGURE 8.27 | HEAT REJECTION ENERGY INDEX* RELATIONSHIP TO SET POINT TEMPERATURE OF A VARIABLE FAN SPEED COOLING TOWER



*Heat Rejection Energy = Condenser Pump Energy + Cooling Tower Fan Energy, since condenser pump is kept constant in this study, the change of heat rejection energy index is only attributed to the cooling tower leaving water temperature set point.

FIGURE 8.28 | CHILLER ENERGY INDEX RELATIONSHIP TO SET POINT TEMPERATURE OF A VARIABLE FAN SPEED COOLING TOWER



SUMMARY OF COOLING TOWER EFFICIENCY

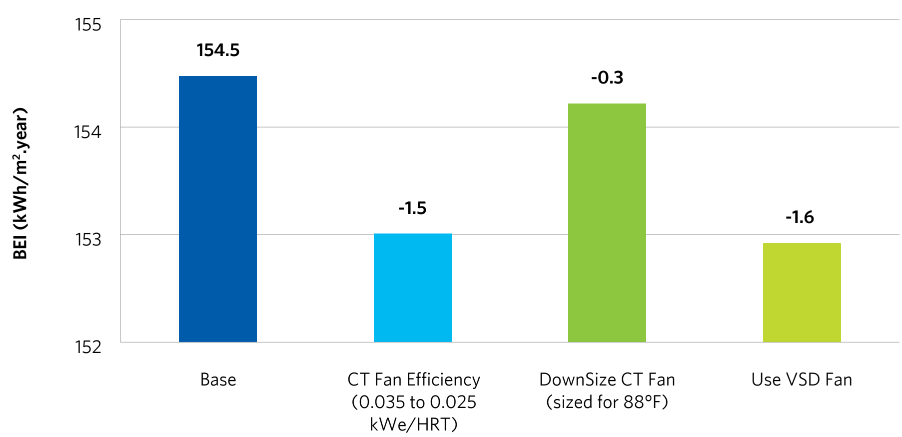
Based on the studies conducted on the cooling tower, it can be summarised as follows:

1. **It is important to select an efficient cooling tower. A reduction of 0.01 kWe/HRT of a constant flow fan cooling tower would reduce approximately 1.5 kWh/m^2.year for the building**

2. **The use of a VSD fan on a cooling tower will provide an approximate reduction of 1.6 kWh/m^2.year. This was based on a cooling tower efficiency of 0.035 kWe/HRT. A more efficient cooling tower will yield lower energy reduction with the use of a VSD fan on the cooling tower**

3. **It is not necessary to be concerned over upsizing or downsizing the cooling tower from the current design practice because the impact on the overall energy efficiency of the building is found to be very small**

FIGURE 8.29 | A SUMMARY OF BEI FOR VARIOUS COOLING TOWER EFFICIENCY OPTIONS



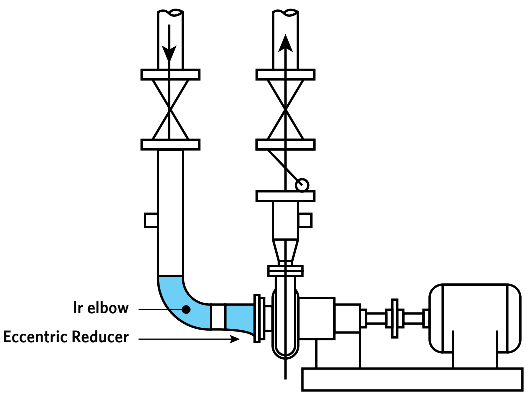
INSTALLATION RECOMMENDATIONS FOR PUMPS AND PIPES

The following list of recommendations are provided to ensure that air-conditioning pumps and piping systems are installed efficiently:

1

One of the common oversights observed in pump/pipe installations in Malaysian buildings is the requirement of a 5 to 10 diameter straight pipe length before entering the pump suction flange is not adhered to by the building industry practitioner. This typical mistake made is as shown in **Figure 8.30** below where the elbow is placed right before the pump section in the interest of saving space in the plant rooms.

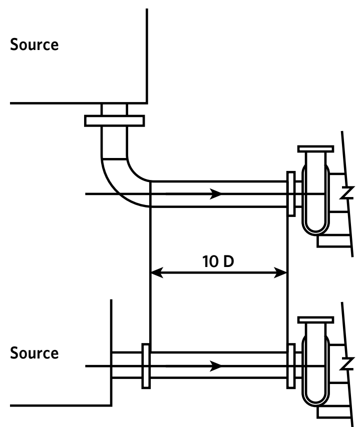
FIGURE 8.30 | TYPICAL SINGLE END-SUCTION PIPING ARRANGEMENT



2

The ideal pump suction pipe should have a minimum straight length of 5 to 10 pipe diameters (depending on the pump manufacturer's installation manual) before the pump suction. Provision of a straight pipe length shorter than 5 pipe diameters will reduce the pump efficiency and increase the risk of bearing failures due to an imbalanced load on the bearings.

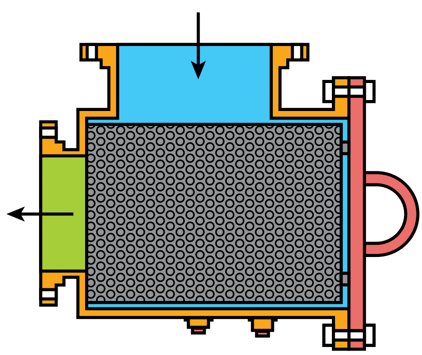
FIGURE 8.31 | THE RULE OF 10D



3

ASHRAE Fundamentals (2008) mentioned that suction diffusers may be installed in lieu of the straight pipe requirement where spacing is a constraint. However, suction diffusers increases the pump head and will increase the long term energy consumption.

FIGURE 8.32 | TYPICAL SUCTION DIFFUSER



4 The installation of flow meters is becoming more common in buildings that are going for energy efficiency. It is recommended that flow meters should always be installed as per the installation manual. Usually, a minimum straight pipe length is required before and after the flow meter to ensure the flow rate is measured correctly in a pipe.

5 In addition, if a reducer is required to be used from the pipe to the pump suction flange, eccentric reducers with a flat top should be used to reduce the potential of air pockets being formed in the suction line.

6 It is recommended to use a fine mesh screen during initial start-up to remove residual debris from the piping system. However, it should be replaced with a normal sized screen after commissioning to protect the pump and minimise the suction pressure drop.

7 It is recommended to install a check valve in the pump discharge to prevent reverse flow in a non-running pump whenever multiple pumps are installed in parallel.

8 Adequate pressure gauges should also be provided in the pumping system to verify system pressure and pressure drops.

9 **Figure 8.34** (the elevation view) indicates the wrong and correct way to accommodate a size reduction from the header to the suction take-off line, to reduce pressure losses in pipes.

10 **Figure 8.35** shows a plan view of the wrong and correct ways to make header connections. Note that the minimum distance between connections should be 3 pipe diameter lengths and that "Y-branches" oriented in the direction of the flow should be used in lieu of a right angle or "T" configuration to minimise pressure losses.

Following these recommendations will help ensure that air-conditioning pumps and piping systems are installed efficiently

FIGURE 8.33 | ECCENTRIC REDUCERS

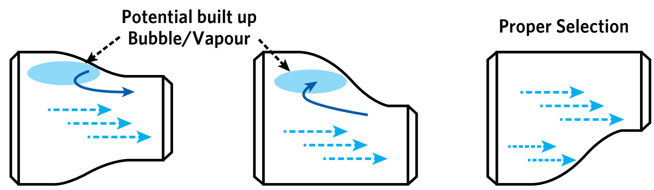


FIGURE 8.34 | SIZE REDUCTION PIPE INTERSECTION

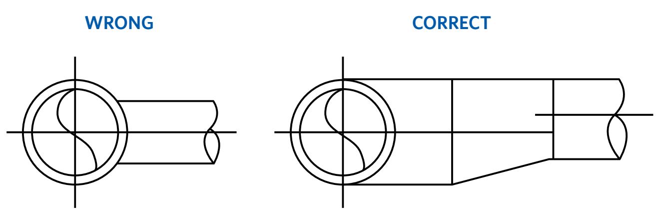
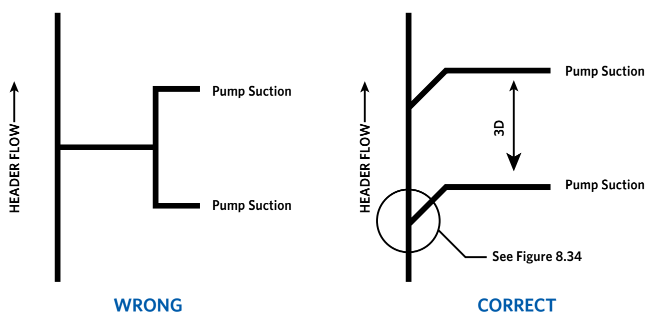


FIGURE 8.35 | PLAN VIEW OF PIPE MANIFOLD ARRANGEMENT



SUMMARY

This chapter is a set of simulation case studies to offer a simple form of guidance for building designers to optimise the water-side air-conditioning system. The simulation studies were based on a typical office building scenario in the Malaysian climatic zone. Many simulations were conducted to test various theories of energy efficiency on a water-side air-conditioning system to understand the impact on the building's net efficiency within a Malaysian climatic zone.

Users of this guideline are recommended to be careful with the data provided in this guideline when it is extrapolated to other building types. As a general rule-of-thumb, any energy efficiency feature that is financially feasible for an office building, is likely to provide a faster payback if applied on buildings with longer air-conditioning hours, as the benefit gained is over a longer operating period.

Finally, as recommended in previous chapters, building design engineers are encouraged to pick up building energy modelling skills to enhance their design capabilities for the building industry. Building energy simulation tools are much easier to use today than they were 10 years ago. Software such as IES <Virtual Environment>, DesignBuilder, TAS, Trnsys, Visual-DOE, Equest and HAP are fairly well known dynamic energy simulation softwares in the market place today and can be used to optimise the actual building design instead of relying solely on this guidebook.

END OF CHAPTER 8

CHAPTER

9

COMMISSIONING, FINE-TUNING & CONTINUOUS MONITORING

by CK Tang & Nic Chin


Range
Range
File Edit View History Bookmarks Window Help
Where I've used electricity in the past 16 days: Top 12 Circuits
Electricity Cost This Month
Top 3 Users, Last 16 days
Past Year
Past Month
Past Day
Past Week
Past Month
View History Details
View Circuit Details
powermeter
Activate
Export Data

9 COMMISSIONING, FINE-TUNING & CONTINUOUS MONITORING

INTRODUCTION

The experience in the Low Energy Office (LEO) Demonstration Project in Parcel E4/5 in Putrajaya, Malaysia, showed that proper commissioning and fine-tuning of a building reduced the building's energy index (BEI) of the LEO building from a high of 170 kWh/m^2.year down to 120 kWh/m^2.year (a reduction of 30%) within the first 3 months of occupancy in 2003.

One of the key lessons learned from the LEO demonstration building is that building designed to be energy efficient will not operate efficiently until proper commissioning and fine-tuning is conducted on it. It is therefore very important that buildings are commissioned and fine-tuned to operate optimally based on the actual building operational needs to ensure that efficiency is obtained in reality.

This fact is supported by many other case studies around the world with some estimates that it is possible for a properly commissioned and fine-tuned building to reduce energy consumption by (as high as) 40%.[1] Another report states that the commissioning of projects in over 10,000 buildings in the US resulted in a median **whole-building energy reduction of 16%** with a payback time of 1.1 years in existing buildings.[2] A typical office building with an area of 50,000m^2 would have an approximate energy cost of RM3.6 million per year (based on current electricity tariff) in Malaysia. A reduction of 16% energy consumption will yield a significant saving of approximately RM600,000 per year for the building owner.

It is not a simple task to translate the building's projected energy performance during the design stage into real, actual energy performance during operation. Furthermore, Malaysian energy costs, along with the rest of the world, is likely to maintain an upward trend in the short and long term scenario, hence the need to ensure that buildings are operating energy efficiently has become more important than ever before. The basic elements that are needed to bridge the gap between design and operational efficiency in building are:

- **Appointment of Building Energy Manager**
- **Commissioning**
- **Fine-tuning, and**
- **Continuous Monitoring**

[1] National Renewable Energy Laboratory, 2013 http://www.nrel.gov/tech_deployment/climate_neutral/energy_efficient_building_management.html
[2] Evan Mills, Lawrence Berkeley National Laboratory, Building Commissioning - A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions, California, USA, p 1, 2009.

KEY RECOMMENDATIONS

1 APPOINT A BUILDING ENERGY MANAGER

A building energy manager should be appointed to ensure successful implementation of energy efficiency in a building. It is also important to ensure that the building energy manager receives adequate training to ensure that this person will be able to perform his/her duties adequately.

The building energy manager may be the same person as the building facility manager or any other person that is close to the building's top management. This person is then put in charge to ensure that the building is energy efficient during operation.

2 COMMISSIONING

Commissioning is more than just a functional test of equipment. Commissioning should measure all performance parameters to ensure that all major equipment is operating as per the design intent. For example, variable speed drive fans and pumps should be tested to be operating as per the design intention at full-load and part-load conditions.

Commissioning should also provide adequate data to enable the efficiency of major equipment to be measured on-site. Any equipment that is measured to be performing at efficiencies significantly lower than the supplier data may indicate an installation fault that needs to be corrected before the handing over of the building by the contractor.

It is also recommended to start commissioning early in the design process to ensure that essential installation guides, testing and commissioning requirements are captured early in the contractual documentation for the appointed contractor to avoid any disputes at the end of the project stage.

3 FINE-TUNING

All new buildings are required to be fine-tuned during the actual operation of the building to optimise the building's performance based on actual occupant behaviour. This may refer to reprogramming operational hours of common area lighting, reprogramming the air-conditioning pre-cooling hours, etc. It may even involve complicated manoeuvres such as optimising the air-conditioning supply air flow rate based on the actual measured sensible load to reduce the building's energy consumption if the building is not fully occupied as per the design assumptions.

4 CONTINUOUS MONITORING

Finally, it is important to establish a system of continuous monitoring of the building's energy performance via a set of sub-meters in the building. A weekly summary of energy consumption of major sub-meters in the past 6 months should be provided to the building's top management to ensure that any drastic changes are captured, analysed and acted upon when necessary to maintain the building's energy efficiency performance.

These keys recommendations made are also applicable for existing buildings.

It is fairly common in existing buildings that failure of non-critical equipment such as the temperature sensors, motorised damper/valves, etc. are not repaired to its original design intent state. The priority of most building facility technicians is to "fix" the system to get "some sort" of air-conditioning to the building occupants. Energy efficiency is the last thing on their mind when the system is not working. Unfortunately, the failure of these non-critical equipment will lead to significantly higher energy consumption in a building due to inadequate feedback and control to optimise building's energy during use. The implementation of these four (4) basic recommendations in an existing building will allow these issues to be identified and fixed for the long term benefit of the building.

Finally, the Malaysian Standard (MS) 1525 provides detailed guidance on Energy Management Systems (EMS) and is highly recommended to be practiced by the building industry for buildings where the air-conditioned area exceeds 4,000m^2.

APPOINTMENT OF BUILDING ENERGY MANAGER

It is highly recommended to appoint one person that answers directly to the building owner to be the building energy manager that is responsible for the efficient energy performance of the building. Although it is easiest to appoint the building facility manager as the building energy manager as well, this may not necessarily be the best option. If the building energy manager is appointed early during the design stage of the building, he/she will be able to learn from the whole design process and the decisions made on energy efficiency for the building along the way. In addition, the building energy manager can also help to contribute to the design process by ensuring the energy efficiency needs are addressed during the entire design, construction and commissioning process.

The appointed building energy manager will also need to have the authority and support of the management to take necessary action, such as setting aside a yearly budget for maintaining (and improving) energy efficiency in the building. This budget can be used on promotional programmes to instill energy efficiency awareness for the building occupants, to repair equipment that has failed or any other work that will bring added benefit to reduce the energy consumption in the building without compromising on the occupants' comfort.

It is also very important for the building energy manager to be properly trained for this role. There are many regular training programmes available in Malaysia. A few of these regular training programmes are listed below:

- **AEMAS Energy Management Training Course by GreenTech Malaysia (www.greentechmalaysia.my)**
- **Energy Manager Training Course by Malaysia Association of Energy Service Companies (MAESCO) (www.measco.org.my)**
- **Electrical Energy Manager Qualification Course by Malaysia Productivity Corporation (MPC) (www.mpc.gov.my)**
- **Certificate in Energy Management by Federation of Manufacturer, Malaysia (FMM) (www.fmm.org.my)**

COMMISSIONING

The commissioning process is a quality-oriented process for verifying and documenting the performance of facilities, systems and assemblies installed in the building. A commissioner uses various methods and tools to carry out the verifications throughout the delivery of the project. Commissioning activities happen in each phase of the project, beginning from the pre-design to completion stage. To provide the optimal performance of the building, the commissioner needs to coordinate work with the different team members in each phase with the aim of ensuring every energy efficiency feature is implemented properly.

It is also recommended to nominate a person in the design team to be the leader in energy efficiency at the start of a building project, whose specific task is to look into all aspects of energy efficiency for the building. The energy efficiency leader should be someone that has a reasonable knowledge of energy efficiency in buildings and should have the ability to evaluate different options of energy efficiency design features by providing estimated payback and return on investment studies. The following is a list of potential candidates that could qualify as an energy efficiency leader for a project:

- **Building Services Engineers (Mechanical and Electrical Consultants)**
- **Commissioning Specialists**
- **Green Building Index Facilitators**
- **Energy Efficiency Specialists**

Upon appointment of a leader in energy efficiency, a Commissioning Team should be formed for the project. The members of this Commissioning Team may include the owner/project manager, energy efficiency leader, designers and subsequently contractors and building operators, to be added as they are hired.

A description of the commissioning activities at each project phase is outlined below.

1 CONCEPTUAL OR PRE-DESIGN PHASE

Pre-design is a preparatory phase to lay the groundwork for the team members and to plan for commissioning activities at the later phases. The Commissioning Team output at this stage is to ensure that the installation and operation of all energy related systems are considered from the beginning of the pre-design phase.

The tasks to be accomplished during the pre-design phase are:

- **Develop Owner's Project Requirements and Targets**
- **Develop Design Intent Commissioning Plan**

1 Develop Owner's Project Requirements (OPR)

The OPR is a very crucial piece of design intent documentation. This document is an explanation of the ideas, concepts and criteria that the owner deems important. As the design progresses, the owner, designers and commissioner may enhance the OPR by adding the basic acceptance criteria.

2 Develop Design Intent Commissioning Plan

The design intent commissioning plan provides an update on the design-phase plan and develops a preliminary construction-phase plan to guide development of the commissioning specifications. The plan generally consists of a list of the systems and specific equipment to be commissioned, general modes to be tested and the testing methods. In addition, various team member responsibilities are defined and scheduling is made.

2 DESIGN PHASE

In the design phase, the Commissioning Team should perform a commissioning design review. This ensures that the documented OPR are being implemented. Additional design reviews are made in areas of special concern to the owner. The main energy efficiency leader duties during this phase are the following:

1 Update the Commissioning Plan

Additional details may need to be added as the commissioning process evolves from one phase to another phase. It is a living document that requires commitment to update as the project progresses. Specific roles and responsibilities of the team members will be refined in this phase.

2 Update Basis of Design

The energy efficiency leader is also responsible for reviewing the basis of design against the OPR to optimise the design where possible. The basis of design document describes the systems, components, conditions and methods of selection in complying with the requirements. For example, it contains which standards/codes, parameters, temperatures and occupancy levels were used in sizing the systems.

3 Commissioning Specifications

There should be specific commissioning process requirements to be included in the contractor's documents. It specifies equipment details and component performance requirement checklists with appropriate cross-references. Such specifications should include any special equipment or instrumentation that must be available in order to obtain measurements during functional testing. Additional monitoring points, test ports and gauges can make the building more commissioning-friendly.

The specifications should ensure that all major equipment should be tested at its peak design condition as well as at partial load conditions to ensure that all the controls are functioning as per the design intent.

A proposed list of measurement points during commissioning is provided below to establish the performance of a typical chilled water plant air-conditioning system. It may also be advantageous to provide continuous monitoring of some of these proposed points in a building management system (BMS) or energy management system (EMS). Continuous monitoring of this data will ensure that the building is monitored to be operating at optimum conditions at all times. Any deviation or loss of efficiency can also be easily detected when adequate monitoring points are provided.

PROPOSED MEASUREMENT POINTS DURING COMMISSIONING

1) AHU System

a. ΔP Total Pressure between the inlet and outlet of the fan (Pa)

- This data verifies the computed pressure loss in ducts, air filters, cooling coil and dynamic air pressure.
- This data is also required to compute the Fan Total Efficiency.

b. ΔP Static Pressure between the air filter (Pa)

- This data verifies the pressure drop across the air filter.
- In addition, a permanent monitoring of this data is recommended as an indicator of service requirement on the air filter. Unless, this is monitored, it is not possible to know the optimum time to service or change the air filter.

c. Supply Air Flow Rate

- The measured supply air flow rate provides many opportunities for ACMV optimisation. These opportunities are:
    1. Computation of Sensible, Latent and Total Heat Load
    2. Computation of Fan Total Efficiency
    3. Potential to reduce peak air flow rate during fine-tuning period to reduce building energy consumption especially if building is not fully occupied

d. On-coil Air Temperature

- This data is required to compute the sensible cooling load.

e. On-coil Moisture Content
- This data is required to compute the latent cooling load.

f. Off-coil Air Temperature
- This data is required to compute the sensible cooling load.

g. Supply Air Moisture content
- This data is required to compute the latent cooling load.

h. Chilled Water Supply Temperature (°C)
- This data is required to compute the chilled water flow rate across the AHU.
- In addition, this is a useful check on the chilled water supply temperature to ensure that the system meets design specifications.

i. Chilled Water Return Temperature (°C)
- This data is required to compute the chilled water flow rate across the AHU.
- In addition, this is a useful check on the chilled water return temperature to ensure that the system meets design specifications.

j. Fan Power
- This data is required to compute the Fan Total Efficiency.
- Permanent monitoring of this data is recommended as this is one of the primary indicators that something may be wrong with the system.

k. Fresh Air Supply Air Flow Rate
- This data is required ensure that the fresh air supply is meets the requirements of ASHRAE 62.1
- Permanent monitoring of this data is recommended because the provision of fresh air is vital for the building occupants' health and productivity. In addition, an over-supply of fresh air is very energy inefficient in this climate zone.

l. CO_2 of Return Air (if it is used as a fresh air demand controlled ventilation strategy)
- This data is to ensure that the fresh air supply is reduced to the minimum rate when the measured CO_2 level is low. Reduction of the fresh air supply reduces energy consumption in buildings significantly.

m. Total Fan Efficiency (%)
- This data is required to be compared to the supplier datasheet of the installed total fan efficiency. Unusually low measured Fan Total Efficiency may be an indication that there is a problem with the installation. This data is computed from the measured air flow rate, total pressure loss and the power consumption of the motor.

n. Total Sensible Cooling Load Transferred per AHU (kW at peak condition)
- This data is required to verify the performance of the cooling coil meets the design specification.
- In addition, when this data is continuously monitored during operation, the measured peak sensible cooling load during occupancy hours can be used to fine-tune the supply air flow rate to optimise energy efficiency in the building.

o. Total Latent Cooling Load Transferred per AHU (kW at peak condition)
- The occupant latent load can be easily estimated from the number of people in the building, which is usually a very small number in this climate zone when compared to the latent load from fresh air.
- The rest of the latent load is an indicator of fresh air intake in tropical climate buildings. Significantly high latent loads in a building may be an indicator of excessive air infiltration or water leaking into the building.

p. Total Cooling Load Transferred per AHU (kW)
- This data, along with the chilled water supply, return temperature and room temperature allows checks on the performance of the cooling coil and serves as an indicator of the servicing requirements of the cooling coil in the AHU.

q. Chilled Water Supply Flow Rate to each AHU (l/s)
- The measurement or computation of the chilled water supply flow rate into each AHU is used as an indicator of the cooling coil performance.

2) Chilled Water Distribution System

a. ΔP Total Pump Head between the Suction and Supply Side of the Pump (m of H_2O)
- This data is required to compute Total Pump Efficiency.
- Care should be taken that the total pump head is measured correctly as it also involves the height between the measuring points of static pressure. Dynamic pressure should also be accounted for, if the pipe size between suction and supply is different.

b. Chilled Water Supply Flow Rate (l/s)
- This data is required to compute the total cooling load supplied.

- This data is also required as a verification of the installation meeting the design intention.

c. Chilled Water Supply Temperature from Chiller (°C)
- This data is required to compute the total cooling load supplied.

d. Chilled Water Return Temperature to Chiller (°C)
- This data is required to compute the total cooling load supplied.

e. Pump Power (kW)
- This data is required to compute the Total Pump Efficiency.

f. Total Cooling Load Provided (kW)
- This data is required to compute the Chiller COP.

g. Total Pump Efficiency (%)
- If the efficiency is far below the pump performance curve, the building energy manager should investigate the cause of it. This may be due to improper pump/pipe installation.

3) Chiller

a. Chiller Power
- This data is required to compute the Chiller COP.
- It is also required to compute the System COP.

b. Chiller Coefficient of Performance
- Continuous monitoring the Chiller performance ensures that any performance lost by the Chiller is observed and action can be taken.

c. System Coefficient of Performance
- This is the simplest indicator of system performance. Continuous monitoring of this data is recommended.

d. Total Heat Rejection Power
- This data is computed from the total cooling load delivered, Chiller power and Condenser pump power.
- This data is then used to estimate the condenser flow rate based on the condenser supply and return temperature.

4) Condenser Water Distribution System

a. Condenser Water Supply Temperature (°C)
- This data is required to compute the condenser flow rate.

b. Condenser Water Return Temperature (°C)
- This data is required to compute the condenser flow rate.

c. Pump Power (kW)
- This data is required to compute the Total Pump Efficiency.

d. ΔP Total Pump Head between the Suction and Supply Side of the Pump (m of H_2O)
- This data is required to compute the Total Pump Efficiency.

e. Condenser Flow Rate (l/s)
- This data is required to compute the Total Pump Efficiency.

f. Total Pump Efficiency
- Computed Pump Efficiency that is significantly lower than the design/supplier efficiency indicates installation issues.

5) Cooling Tower

a. Fan Power (kW)
- This data is required to compute the cooling tower efficiency.

b. Ambient Air Wet Bulb Temperature (°C)
- This data is required to compute the approach temperature of the cooling tower.

c. Ambient Air Dry Bulb Temperature (°C)
- This data is useful to estimate the fresh air sensible load.

d. Water Leaving Temperature (°C)
- This data is required to compute the approach temperature of the cooling tower to ensure that the cooling tower is meeting design specifications.

e. Approach Temperature
- This data indicates the performance of the cooling tower and should be compared to the design specifications.

f. Cooling Tower Efficiency (kWe/HRT)
- This value is provided as an indicator of the cooling tower efficiency.

4 Contract Document Requirements

To ensure that the OPR and Basis of Design are in place, the Commissioning Team has to review the bid documents, up-to-date design narratives to ensure consistency with the owner's project requirements, testing and commissioning requirements, and acceptance criteria.

In addition, the Commissioning Team's process activities have to be integrated into the contractor's specifications. As such, attending a pre-bid meeting to educate and equip the contractors on the benefits of commissioning and the procedures for implementation is essential as part of the Commissioning Team's process.

3 CONSTRUCTION PHASE

It is an effective measure to have the Commissioning Team monitor the construction phase on all items related to energy efficiency in the building. The main tasks to be accomplished during this stage are as listed below:

1 Kick-off Meeting

The Commissioning Team should carry out a construction phase commissioning kick-off meeting with the appointed contractors. The role of the Commissioning Team during the meeting will be to review and discuss the OPR and the communication protocols that the project team has developed. In this meeting, an outline of the roles and responsibilities of each of the team members are specified. Procedures for documenting commissioning activities, resolving issues and reviews of preliminary construction phase commissioning plans and schedules are made at this stage.

A list of submittal requirements by the contractor should be provided by the Commissioning Team early in the construction phase. The submittal requirements should provide the contractor a list of equipment and installation procedures that require approval before installation is allowed to be conducted on-site. All critical installation layouts that are crucial to the efficient operation of the installed equipment should be part of the list of submittal requirements. The proposed functional tests and commissioning procedures before handing over by the contractor should also be a part of the submittal requirements.

Finally, the Commissioning Team should maintain a record of issues and findings in a log that requires further attention. The log should be updated regularly and discussed with the project manager and team and resolved during construction meetings.

2 Submittal Review

The Commissioning Team should review, comment and approve the contractor's submittal to ensure that contractors are providing equipment and installations that meet the design intent of the project. This is an essential scope of work by the Commissioning Team to ensure that the procurement of major equipment and installation methods comply with the necessary specifications to meet the efficiency targets of the OPR.

4 COMMISSIONING BEFORE HANDING OVER

All major equipment should be commissioned as per the contract documentation and is recommended to be witnessed by the following key persons: the Commissioning Team representative, building services designer, client representative, main-contractor and relevant sub-contractors.

Ensure that a detailed testing plan is made for all major components and is submitted to the Commissioning Team for approval prior to work done on-site. The plan should include all expected sequences of operation conditions and states. It is also highly recommended to perform testing and commissioning with the support of all relevant contractors – it is most efficient if small errors in the system can be corrected on-the-spot.

It is also recommended to measure on-site efficiencies of major equipment to ensure that they meet the specified efficiency requirements. Chillers, pumps and fans in particular can have significantly lower efficiencies due to minor installation errors with no visible symptoms, such as vibration or unusual noise. Only by measuring the on-site efficiency of these items, installation errors can be detected and corrected before handing over to client.

5 POST-ACCEPTANCE PHASE/ HAND-OVER PHASE

In this phase, the building is already in the hands of the owner and operators. Although the project is considered complete, some commissioning activities from the initial commissioning contract may continue throughout the warranty period.

1 Periodic Testing

Periodic testing should be conducted as per equipment maintenance schedules to ensure the system is running efficiently. Any testing that is delayed due to site conditions, equipment status or rainy weather needs to be completed as early as possible and certainly before the end of the defect liability period.

2 On-going Training

The Commissioning Team will verify the completion of the commissioning process by ensuring that all related training is provided by the contractor to the building facility management team as part of the handing-over process. This includes the updating of the system manual and documentation in a version that can be understood and implemented by the building facility management team. It is also important to ensure the hand-over of a manual on the building management system (or energy management system) that is relevant to the building. The operation manual should provide the typical (and design) operating set points of all equipment for the installed air-conditioning system.

FINE-TUNING

Fine-tuning in a building is the process of matching the building comfort conditions to the actual requirements of the building occupants, while optimising building energy performance. Every new building needs a period of fine-tuning to match the operational needs of the building occupants while improving the energy efficiency in the building. Examples of typical fine-tuning work to be conducted in new buildings are described below:

❶ Lighting Schedules

There is a need to match the common area lighting schedules such as the lift lobbies, toilets and main entrances to the building occupant needs. Where spaces are provided with daylight, it may be possible keep the lights off during the daytime. Sometimes, re-circuiting of lighting points may be necessary at this stage because the building occupants may be using the building differently from the assumptions made during the design stage.

❷ Motion Sensor Calibration

It is very common for motion sensors to be repositioned during the fine-tuning period to enable them to better capture the building occupants' movements because they may not be using the space as assumed in the design stage.

❸ Air-Temperature Set-Point

Fine-tuning a building also involves setting air temperatures for optimum comfort of the building occupants. Building occupants sitting close to the building external wall may require a slightly lower air temperatures due to the higher mean radiant temperature in that area. Chief Executive Officers (CEOs) in large companies may be dressed in formal business suits during normal working hours and may require lower air temperatures to provide comfortable conditions.

❹ Supply Air Redistribution

In buildings installed with Constant Air Volume (CAV) systems, it may be necessary to provide a slightly higher supply air flow rate to occupants sitting closer to building external walls due to the higher mean radiant temperature in that area. During the fine-tuning period, the air flow rate may be diverted to areas where more is required.

❺ Lift Operation Mode

After typical office hours, a percentage of the lifts may be taken off-duty to reduce the standby energy consumption from the lifts. However, different business industries or departments may have different "overtime" scenarios, therefore it is necessary to fine-tune the operational hours of the lifts during the actual operational period of the building.

❻ Air-Conditioning Hours

It is common in many office buildings to turn on the air-conditioning system an hour before official working hours to pre-cool the building to comfortable conditions. During the fine-tuning stage, the pre-conditioning hour can be slowly reduced until it is optimal for the actual building operation. Typically, an office building will require longer pre-conditioning hours on a Monday morning due to the reason that the building structure (typically of high thermal mass) is warmer from the unconditioned hours of Saturday and Sunday.

❼ Computers & Other Electrical Appliances

Power saving modes can be implemented on computers, such that these equipment will shut themself down when unattended for a certain amount of time. It is also possible to install timer controls to turn off non-essential electrical appliances such as water dispensers, printers, microwave ovens and etc. during non-occupancy hours.

❽ Occupant Awareness Campaign

A public awareness campaign on switching off lights, switching off at the power point for any equipment not in use and keeping doors and windows closed to reduce infiltration, may be implemented to encourage building occupants to reduce energy wastage in the building.

The above are just a few examples of simple fine-tuning potential that can be made to the building during the occupancy period. There are many more options for the air-conditioning system such as the off-coil temperature set-point in a Variable Air Volume (VAV) air-handling unit, chilled water temperature reset, VAV system static pressure reset, cooling tower fan reset and much more, that can be implemented to fine-tune a building to perform energy efficiently during operation.

The appointed (and trained) building energy manager should propose a list of fine-tuning possibilities for the building and have them implemented to provide a safe and comfortable environment for the building occupants while minimising energy consumption in the building.

Finally, fine-tuning of a building is best complimented by continuous monitoring through a set of sub-meters together with good implementation of an Energy Management System (EMS).

CONTINUOUS MONITORING

Continuous Monitoring helps the building owner to manage energy consumption and maintain optimal equipment performance by ensuring that critical building systems, such as the HVAC, lighting and building controls function properly all the time. Continuous monitoring is a process of collecting and analysing the data from a set of sub-meters and various controlling parameters of a building to ensure that the building continues to operate at optimum performance for the lifetime of the building.

Without continuous monitoring, degradation of energy performance in a building is often not noticed by the building owner. This is because the degradation of energy performance in buildings occur in small increments that are not noticeable from the monthly energy bill. For example, most building owners will not notice a 1% increase in the energy bill per month. However, three years later, the bill may be 36% higher and they will still have no clue why it has increased so much over the years. Sub-metering in combination with continuous monitoring will be able to address this issue by ensuring that any degradation of energy performance in a building is detected early and more importantly, to identify the source of the performance reduction in the building.

Continuous monitoring in buildings require the following items to be implemented during the design and construction stage of the building:

1. **Energy Sub-Meters**, and
2. **Energy Management System**

❶ ENERGY SUB-METERS

Adequate energy sub-meters are recommended to be provided in a building to allow a breakdown of energy consumption in a manner where it is feasible for a building energy manager to identify the areas of inefficiency or equipment failure. Without sub-metering, it is nearly impossible to track inefficiencies (especially in a medium to large sized building) from the bulk energy meter provided by the power utility company for these following reasons:

1. **In a 20 storey building, an increase of 1% per month on the bulk energy meter is not noticeable. However, an increase of 1% on the bulk energy meter is a noticeable 20% increase on one of the floors.**

2. **The building energy manager will have no idea where to start to track down inefficiency in the building. This person has to make wild guesses as to where the energy increase is happening in the building and may have to spend a significant amount of time, effort and money (to re-commission the building) to track it down if sub-metering is not provided in building.**

Therefore, it is very important to ensure that energy sub-meters are planned for and provided from the beginning of the building design stage.

Unfortunately, the rule of implementing energy sub-metering in a building is not clearly defined. As a general rule, adequate energy sub-meters should be provided to enable any building energy manager to identify equipment that is operating inefficiently within a day of detecting a significant increase on the sub-meter, so that action can be taken quickly to correct any glitches found in the building system.

In an ideal set-up, energy sub-meters should be provided on every floor of a building to provide a breakdown of energy consumption for lighting, equipment (small power/plug load) and air-conditioning on each floor. However, it is also possible to provide it based on location or on a departmental basis as long as it allows the building energy manager to narrow down the search for inefficient equipment in the building. In addition, sub-meters should also be provided to separately monitor the energy consumption of major equipment such as chillers, pumps and cooling towers.

2 ENERGY MANAGEMENT SYSTEM (EMS)

The Malaysian Standard (MS) 1525 provides detailed guidance on an Energy Management System (EMS) and is highly recommended to be practiced in buildings where the air-conditioned area exceeds 4,000m^2.

A building Energy Management System (EMS) is an extension of a typical Building Management System (BMS) that is commonly employed in buildings with more than 4,000m^2 of air-conditioned space. A BMS is typically provided as a simple and easy method for a building manager to manage the operating hours of lighting and the air-conditioning system in a large building because it would be impractical to have it done manually. The BMS would normally provide the functions of a calendar and time system for the building manager to program for normal operation of a building. In addition to the calendar and time system, it also allows simple fine-tuning operation of the air-conditioning system, such as setting the supply air temperature in a VAV system, chilled water supply temperature and etc. In addition, a BMS system is also provided to monitor the 'health' of the air-conditioning system by monitoring the chilled water return temperature, room air temperature, relative humidity and much more.

In terms of energy efficiency, it is recommended that the typical BMS system be enhanced into an Energy Management System (EMS) by ensuring that the data collected is monitored, data-logged and charted when necessary. The proposed data to be collected in this section enables a very detailed tracking of the energy transfer between systems. The provision of the proposed data collected in its various forms (line charts, bar charts, etc.) will provide opportunities for the building energy manager to fine-tune and reduce energy consumption in buildings easily.

The MS 1525 recommends that the EMS should be supplied with a full complement of energy management features including but not limited to:

- **a) Direct digital control algorithms**
- **b) Starting and stopping of equipment based on a time schedule**
- **c) Temporary override of the time schedules to accommodate changes in usage**
- **d) Chilled water leaving and/or entering temperature reset algorithm**
- **e) Control loop set point reset algorithm**
- **f) Chiller sequencing and optimisation algorithm**
- **g) Demand limiting algorithm**
- **h) Duty cycling algorithm**

The EMS should come with an energy tracking and reporting system so that a historical record of energy usage is maintained for analysis and energy audit purposes.

It is recommended that the typical Building Management System (BMS) system be enhanced into an Energy Management System (EMS) by ensuring that the data collected is monitored, data-logged and charted when necessary.

It is further recommended in this guideline that the historical records kept by the EMS should be provided with simple to use analysis tools to provide line charts and bar charts for quick analysis of the historical records.

The following features are recommended to be provided for analysis of historical records from the EMS:

A For each energy meter and variable speed drive, a minimum logging interval of 10 minutes shall be kept and the following displays shall be provided by the EMS:

1) LINE CHARTS

The line charts must have the ability to add an unlimited number of meters to the chart for comparison purposes.

- Daily, kW and W/m^2 (y-axis) vs. time (x-axis)
- Last 7 days, kW and W/m^2 (y-axis) vs. time (x-axis)
- Last 1 month line chart, kW and W/m^2 (y-axis) vs. time (x-axis)
- At the end of each month, a PDF version of the 1 month line chart shall be created for each meter and equipment monitored and filed with date of creation on it.

2) BAR CHARTS (kWh ONLY)

The bar charts must have the ability to add an unlimited number of meters to the chart for comparison purposes.

- Weekly Bar charts. Each bar provides (kWh/m^2/day) for last 7 days. *i.e. 7 bars*
- Monthly Bar charts. Each bar provides (kWh/m^2/day) for 1 month. i.e. 30/31 bars
- Yearly Bar charts. Each bar provides (kWh/m^2/week) for 1 year. i.e. 52 bars for 1 year
- Unlimited yearly bar charts. Each bar provides (kWh/m^2/year) for the number of years the building has been running.

3) GROUPING CHARTS

The following groups (as applicable) are recommended to be provided:

- Total Common Area Lighting Power
- Total Tenant(s) Small Power
- Total Façade/Outdoor Lighting Power
- Total Air Handling Unit Power
- Total Chiller Power
- Total Chilled Water Pump Power
- Total Condenser Water Pump Power
- Total Cooling Tower Fan Power
- Total Car Park Lighting Power
- Total Plumbing Power
- Total Miscellaneous Power
- Total Building Power (Sum of all the power consumption above)

All Grouping Charts shall provide the following displays:

- Daily, kW and W/m^2 (y-axis) vs. time (x-axis)
- Last 7 days, kW and W/m^2 (y-axis) vs. time (x-axis)
- Last 1 month line chart, kW and W/m^2 (y-axis) vs. time (x-axis)
- Daily Bar charts per week. Each bar provides (kWh/m^2/day) for 7 days
  i.e. 7 bars (To be printed out weekly as a report)
- Daily Bar charts per month. Each bar provides (kWh/m^2/day) for 1 month
  i.e. 30/31 bars (To be printed out monthly as a report)
- Weekly Bar charts per year. Each bar provides (kWh/m^2/week) for 1 year
  i.e. 52 bars for 1 year (To be printed out yearly as a report)
- Yearly bar charts. Each bar provides (kWh/m^2/year) for the number of years the building has been running *(To be printed out yearly as a report)*

B For each CO_2 meter, the following line charts should be provided with a minimum logging interval of 10 minutes:

- Daily, CO_2 ppm (y-axis) vs. time (x-axis)
- Last 7 days, CO_2 ppm (y-axis) vs. time (x-axis)
- Last 1 month, CO_2 ppm (y-axis) vs. time (x-axis)
- At the end of each month, a PDF version of the 1 month chart shall be created and filed with the date of creation on it.

C For each Temperature Meter (air-side and water-side), the following line charts should be provided with a minimum logging interval of 10 minutes:

- Daily, degree Celsius (y-axis) vs. time (x-axis)
- Last 7 days, , degree Celsius (y-axis) vs. time (x-axis)
- Last 1 month, degree Celsius (y-axis) vs. time (x-axis)
- At the end of each month, a PDF version of the 1 month chart shall be created and filed with the date of creation on it.

D For each Energy Meter (commonly known as BTU meter in Malaysia) for chilled water, the following line charts should be provided with a minimum logging interval of 10 minutes for kWcooling provided, Chiller Coefficient of Performance (COP) and System Coefficient of Performance (SCOP):

- Daily, kWcooling/COP/SCOP (y-axis) vs. time (x-axis)
- Last 7 days, kWcooling/COP/SCOP (y-axis) vs. time (x-axis)
- Last 1 month, kWcooling/COP/SCOP (y-axis) vs. time (x-axis)
- At the end of each month, a PDF version of the 1 month chart shall be created and filed with the date of creation on it.

E For each Flow Meter provided in the building, the following line charts should be provided with a minimum logging interval of 10 minutes:

- Daily, m^3/h (y-axis) vs. time (x-axis)
- Last 7 days, m^3/h (y-axis) vs. time (x-axis)
- Last 1 month, m^3/h (y-axis) vs. time (x-axis)
- At the end of each month, a PDF version of the 1 month chart shall be created and filed with the date of creation on it.

F For each Digital Pressure Sensor provided, the following line charts should be provided with a minimum logging interval of 10 minutes:

- Daily, Pa (y-axis) vs. time (x-axis)
- Last 7 days, Pa (y-axis) vs. time (x-axis)
- Last 1 month, Pa (y-axis) vs. time (x-axis)
- At the end of each month, a PDF version of the 1 month chart shall be created and filed with the date of creation on it.

All raw logging data should be kept for a minimum of 28 days (or 1 month) on the server. At the end the month, a PDF version of the 1 month line chart should be created and filed with the date of creation on it to ensure that a history of performance is kept for each meter and equipment. The raw logging data is allowed to be deleted after the PDF file has been created. This is to streamline the amount of raw data that is collected and stored on the server.

SUMMARY

Even when buildings are designed to be energy efficient, the predicted efficiency during the design stage will not materialise without the appointment of a building energy manager, and the implementation of a proper commissioning, fine-tuning and continuous monitoring work.

The appointment of a building energy manager is essential to the long term energy efficiency of a building. The additional running cost of an inefficient mid to large sized building far outweighs the cost of hiring a good and responsible building energy manager to keep the building efficient at all times by ensuring that equipment is well maintained for optimum efficiency. Moreover, it is absolutely necessary to appoint someone to be responsible for the overall efficiency of a building. If no one is appointed, then no one is responsible for the building's energy efficiency and no one will care if the energy bill has increased significantly over the years because it is "assumed" that the building owner is "still happy" paying for it.

It is also essential that building owners, consultants and contractors implement a set of proper commissioning works before handing over the building to ensure that the equipment installed in the building is performing to design specifications. Proper commissioning work is more than just starting the air-conditioning system to supply cool air into the room. Each part of the system should be tested to perform to the design intent at full load and part load conditions. In addition, on-site measurement of equipment efficiency is high recommended. Any installation errors are easily detected from proper commissioning work and can be rectified by the contractors before they remove themselves from the building site.

Fine-tuning work is required to optimise the building's energy performance to the actual building occupant comfort requirements. Its function is to increase the building occupants' comfort level while improving energy efficiency. There are hundreds of fine-tuning strategies that can be implemented in buildings. The appointed building energy manager should try to implement as many of the available fine-tuning strategies as possible to ensure that the building is performing optimally at all times.

Finally, continuous monitoring of the building's energy efficiency should be made a standard operational practice to ensure that the optimum efficiency is maintained for the life-time of the building. Failure of small and non-critical components in buildings are often ignored because they only lead to small increments in running costs of the building. However, when many of these defects (or failure of non-critical components) start to pile up in the building, the energy wastage can be significant and yet go unnoticed by the building owner because these failures occur over a length of time and the small incremental cost increases in the energy bill every month is hardly noticeable. However, by having continuous monitoring of the building's energy efficiency via a set of sub-meters, such defects will be quickly noticed and be rectified to maintain the optimum energy performance of the building.

END OF CHAPTER 9

CHAPTER

10

ENERGY EFFICIENT TECHNOLOGY IN LIFT AND ESCALATOR

by Yeow Tow Guan


Lift to platforms 1 & 2

10 ENERGY EFFICIENT TECHNOLOGY IN LIFT AND ESCALATOR SYSTEMS

INTRODUCTION

Means of vertical transportation have been employed by mankind since ancient times. The use of vertical transport leap frogged during the industrial revolution through the use of electric motors in 1880 to what we have today where lifts can be found installed in a large majority of high rise and low rise commercial buildings and multi-storey residential dwellings. Despite its common use, consultants have insufficient documents to guide them to design and specify these systems. With the myriad of codes available such as MS1525 and ASHRAE 90.1 to guide designers on building envelope aspects, energy use in lifts remains largely unregulated due to it being an incidental load and its unpredictability.

It was only since the development of ISO 25745 that a well-documented methodology existed to provide guidance to consultants and designers a metric to evaluate the energy characteristics of lift systems. This allows for a more prescriptive approach in specifying lift systems but adopting an industry wide prescriptive approach is likely to be challenging since a thorough understanding of energy use behaviour is required. A proper design of the vertical transport system starts with an understanding of estimated and expected movement of people within the building. The usage of the lift in an office setting will be different from a factory or a condominium. Each of the lift will have a different purpose and specifications. It gets complex when the building has multiple combined functions, especially in Malaysia, where it is a vastly popular design to have shopping malls below offices and residences. While simulation software packages exist, the Malaysian industry has yet to define an efficiency metric that is both useful and simple.

If the building was initially designed as a warehouse, a cargo lift used to carry heavy loads at low speed, is installed. Thereafter, the building is used as a showroom, where passenger traffic is higher; the lift system might not be able to cope with traffic volume. Change of use situations like this clearly illustrates the point that lifts and elevators are engineered systems where once installed, the core elements such as the cabs and hoist are often left unchanged. Therefore it is difficult for consultants to define the best design strategy at time of design. It is therefore a challenge and critical that the right decisions are made at the very beginning as to how permanent the installations will be.

Conventionally, design options like space, reliability and safety, riding comfort, etc. have been the main focus of all manufacturers, however in recent years, we have witnessed a change of course with these manufacturers where they have been at the forefront at introducing energy efficient technologies as a competitive advantage thus helping customers save energy and money.

The guide is not intended to teach finer details of the technology nor modify industry standards or legal requirements enforced by the relevant authorities, Department of Occupational Safety and Health, ensuring safety of the users.

THE ELEVATOR MARKET

While it may appear that elevators are sold as mass market products, each installation is often individually engineered for a specific application as characterized by the owner and design team. The author is aware of the existence of a Hong Kong technical guideline for lifts and escalators, however, its wide spread applicability in Malaysia should be subject to further debate among industry as the variance in building stock type in Malaysia and Hong Kong is large. It is therefore not simple or cost effective to regulate lift and elevator efficiency in a broad based manner unless regulators begin defining sample building types and benchmarking performances, there is no simple way to predict energy efficiency of specific features.

Instead of offering a prescriptive guideline in this chapter, we will focus on the technology available that can help improve energy efficiencies in the lifts and escalators so that you, the reader, can appreciate the potential energy savings of each. A list of areas for optimisation will also be presented albeit not as an exhaustive guide.

STANDARDIZATION AND CERTIFICATION

An ISO standard is now available in the form of ISO 25745 entitled “Energy performance of lifts, escalators and moving walks” which should be a good guide for the building owners and designers in determining the efficiency of the products proposed in projects. The standard comprises of 2 parts where the first deals with energy measurement and verification while the second deals with the energy calculation and classification of elevators.

Alternative standards in the form of the German VDI 4707 is also available. The use of these standards and guidelines allow for a comprehensible and transparent comparison of lift systems from various manufacturers without complex calculations.

It is recommended that elevator efficiency labels or ratings be displayed on the lifts to increase the awareness of the users of the lift towards its quality.

FACTORS THAT AFFECT ENERGY CONSUMPTION

Annual power consumption of a lift and elevator can be determined by three factors:

- **the amount of power drawn at standstill,**
- **the amount of power drawn during travel and**
- **frequency of use.**

The power consumption of the first two factors above is typically determined by engineers based on the technical characteristics of the system's components and its efficiency ratings. Without a change in the system components, the power consumption will not change significantly over the course of the system's service life. It is to be noted here that while a lift or elevator could be consuming small amounts of power during operation, it does not imply low consumption when idling – and vice versa.

The third factor which is often the most difficult to ascertain and model, is the actual trip frequency along with the location, purpose for which the lift is used (barrier-free access, moving loads, etc.) and the nature of the user groups. Differences in the frequency of use can mean widely diverse annual energy consumption levels even in units of identical design. It is for this factor that the most practical efficiency practices for lifts and elevators is through the utilization of the best available technologies

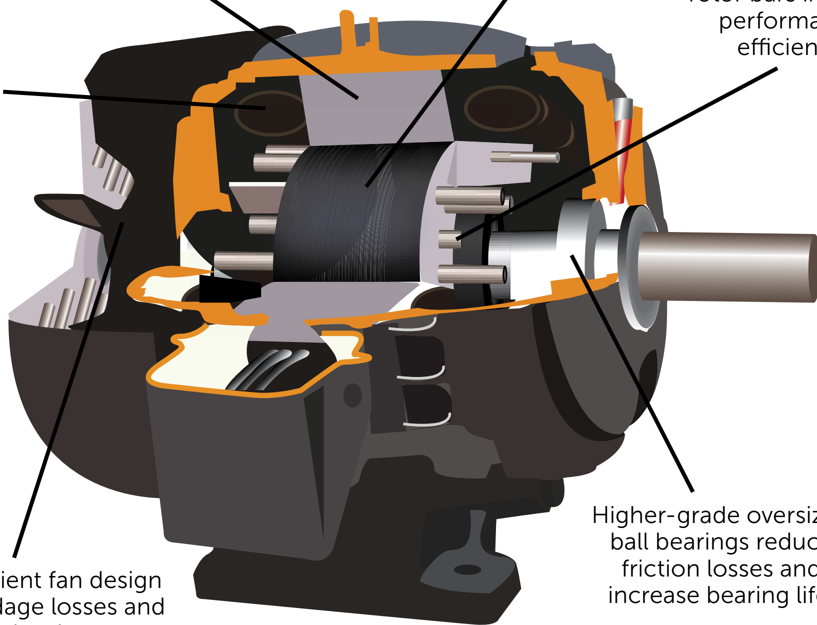
PREMIUM EFFICIENCY INDUCTION MOTORS

High efficiency motors are constructed with superior magnetic material, larger magnetic circuits with thinner laminations, larger copper or aluminium cross section in stator and rotor windings, tighter tolerances, better quality control and optimised design. These motors therefore have lower losses and improved efficiency. Due to lower losses, the operating temperature is lower thus improving reliability.

Stator losses are reduced by increasing cross-section of stator windings which lowers electrical resistance, reducing power losses. However, high efficiency motors contain 20% more copper than standard equivalent size motor.

The increased cross section of rotor conductors, increases conductivity thus increasing total flux across rotor and stator which reduces rotor losses. Lengthening of lamination stack and using magnetic steel with better magnetic properties in the lamination, reduces flux density within the flux stack, therefore reduces core losses. Reducing Eddy current by reducing lamination thickness, increasing adequate insulation between lamination minimizes power losses through the stack.

FIGURE 10.1 | HIGH EFFICIENCY MOTOR CONSTRUCTION



LINEAR MOTORS

Linear motors operate with low duty cycle, making it possible to get a higher thrust by scaling force capabilities of rotary motors, thus making it possible to overload a linear synchronous motor without affecting its reliability. This makes the motor cost effective solution for high speed (>10 m/s) lifts.

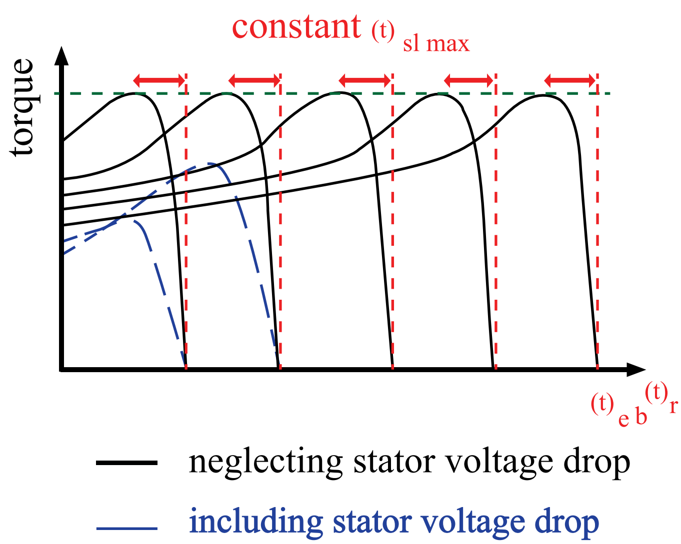
If linear motors are mounted on cars, then counterweight can be eliminated and make the system rope-less, thus creating possibility of multiple cars travelling within the same shaft. The current biggest concern is the production costs of such motor, which is expected to decrease as technology matures. Coupled with recent developments in intelligent controls and safety system, the system could improve handling capacity by 40%.

The technology can be also used for lift doors, reducing moving parts on the door, thus reducing maintenance issues significantly. Current door problems account for most of the breakdown service calls.

ADVANCED DRIVE AND REGENERATION

The development of power semiconductors and evolution of AC motor control technique has led to lower maintenance, faster response, energy savings, lower peak demand and better power factor drive systems. The most widely used drive system today is the Variable Voltage Variable Frequency (VVVF) drive. VVVF relies on the principle that speed of the induction motor coupled is directly linked with the supply frequency applied to the stator windings. By varying the frequency and keeping the voltage/frequency ratio constant, the speed-torque curve is moved while maintaining a constant pull-out torque and the same slope of the linear operation region.

FIGURE 10.2 | SPEED - TORQUE CURVE OF A VVVF DRIVE



The most common used VVVF drive is the PWM (Pulse Width Modulation) type. The lower voltage harmonics can be attenuated thus making the motor rotate smoothly at low speed, maintaining a good ride comfort quality at high levels. Other advantages such as higher order harmonic motor current are limited by the motor inductance, near unity power factor at nearly the whole speed range, low distortion of the motor current. Therefore it is the most ideal choice.

Some VVVF drive uses vector control method. The objective is to give independent control of torque and flux in the AC motor. While keeping voltage/frequency ratio constant, the flux is held approximately constant. Combining with encoder for feedback measurement of slip, we are able to derive full motor torque even at very low speed such as zero rpm.

REGENERATIVE POWER

Potential energy is being transferred while car is moving. The generated braking power in the motor is dissipated in a resistance, and then returned to the main supply naturally. Or acting as a generator which is connected directly to the grid allows this braking energy to be injected back to the power network.

In theory, if there were no losses, the regenerated energy would be equal to the motoring energy. However, there are still losses due to friction, motor losses and gearbox losses. When the lift moves downward, the load larger than the counterweight, then motor torque is opposite direction of speed, thus motor is breaking. In this case, energy savings can be reached with systems installed with regenerative VVVF drive.

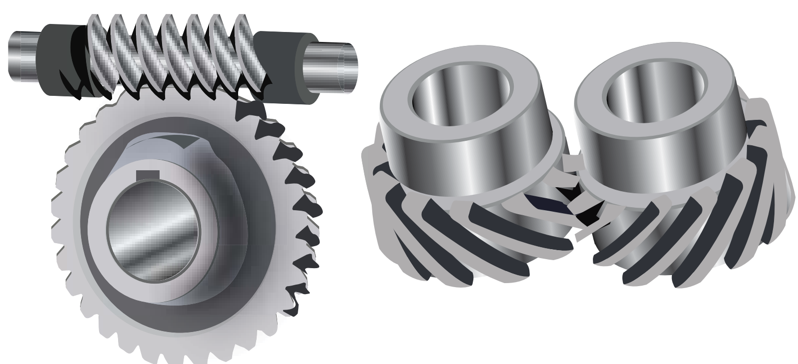
The possible energy savings in lifts using this technology can reduce energy consumption by at least 20% compared to conventional systems. However, regenerative technology isn't always a cost effective solution especially in low traffic, medium rise buildings.

GEARED LIFTS

Geared lifts are mainly used for mid-rise buildings where high speed is not a concern. Typical speed range from 0.1 m/s to 2.5 m/s. The reduction fear allows use of smaller less expensive motors size. The most common type is the work gear type, comprising a worm and worm wheel. However these gears are relatively inefficient.

Worm gear is the most common type but the efficiency is relatively low as compared to helical gears. In recent times, helical gears typically have 98% higher efficiency than work gears per stage. Since there is less sliding between gear teeth, it presents improved efficiency.

FIGURE 10.3 | WORM GEAR & HELICAL GEAR



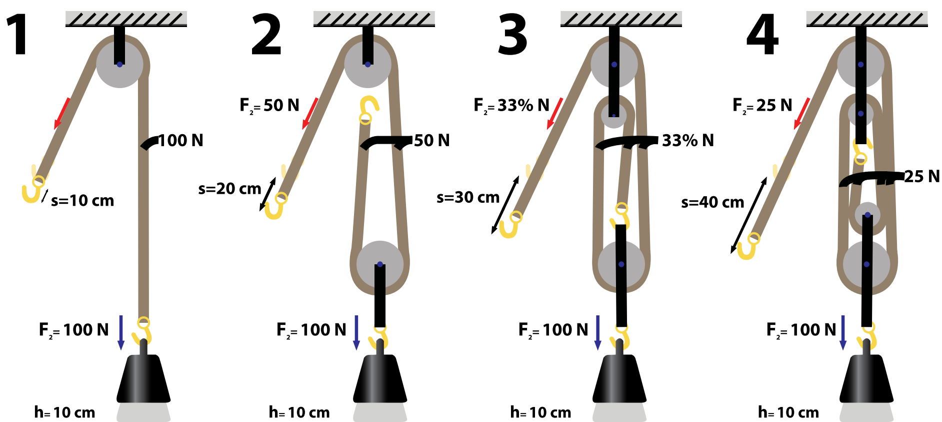
GEARLESS LIFTS

Gearless lifts have sheave driven directly by the motor thus eliminating losses in the gearbox. It is mainly used for high rise buildings with speeds above 2.5m/s up to 10m/s. Since motor is coupled directly to traction sheave, both rotate at the same speed reducing transmission losses. Rope speed is equal to the circumference of sheave multiplied by rotational speed of motor.

ROPE SYSTEM

Motor size can be reduced by roping system. The ends of the cable are fixed to the structure; suspension sheaves are located below car and counterweight thus creating a force multiplying compound pulley system. With 2:1 roping system, car speed can reduced by half, load on rope is reduced by half thus diameter and number of ropes are reduced which finally results in a smaller motor.

FIGURE 10.4 | ROPE SYSTEM BASICS



Under normal conditions, the smaller the number of pulleys, the lower the losses, therefore the traction sheave is located directly above than to divert the rope with additional pulleys. Roller bearings pulley gives a 10% reduced losses as compared to friction bearings. The internal frictional losses increase with the thickness of the rope, decreases with the diameters of the sheave and as rope pulley increases.

The weight of the rope becomes an issue as the building height increases. It could create a significant additional load for high rise buildings. A new technology, Aramid rope could replace the normal ropes. These belts consist of ultra thin steel cable wrapped in a polyurethane sheath. It is proven to be 20% stronger than normal rope but do not require maintenance lubrication and able to prolong the lifespan of the rope by 2 times.

Some manufacturers have gone with solutions with 10:1 roping systems, thus avoiding the need for counterweights and thus freeing up space for larger car. This system is able to substitute older lifts with confined space issues.

FIGURE 10.5 | SPACE SAVED WITH 10:1 ROPE SYSTEM

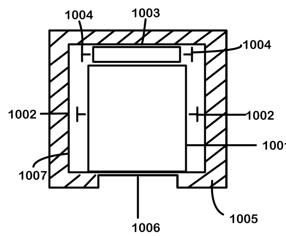


Fig. 10.5a

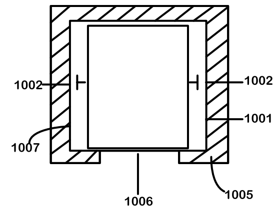


Fig. 10.5b

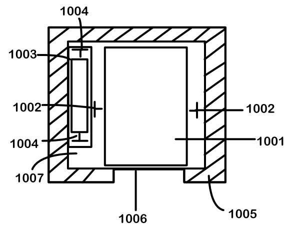


Fig. 10.5c

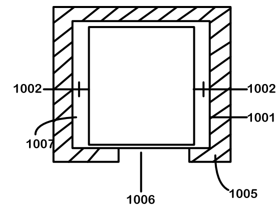


Fig. 10.5d

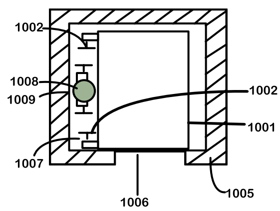


Fig. 10.5e

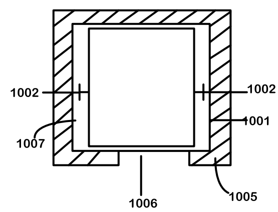


Fig. 10.5f

PERMANENT MAGNET MOTORS

Permanent Magnet Synchronous Motors are becoming very common today. Its advantages includes improved comfort, reduce noise and vibration, simplified mechanical system and energy savings. These motors do not have windings in the rotor; the magnetic field is provided by magnets which have less Joule losses and magnetic losses in the rotor. The use of permanent magnets allow for a multiple pole arrangement hence a more compact, higher efficiency, high torque, low speed machine can be ideally created for gearless lift.

Since it no longer requires an existing current, these motors have higher efficiency and present faster response speed. It is able to maintain high efficiency regardless of the number of poles. Coupled with a Pulse Width Modulation Variable Voltage drive, the power factor is maintained near one.

The compactness of the motor allow the motor room to be smaller, even allowed the elimination of motor room thus creating motor room less systems. This is reduce construction costs and frees up valuable space.

TRAFFIC MANAGEMENT

Lift controllers have 2 main objectives:

1. Control the lift car movement, up or down and stopping at the appropriate landing.
2. Efficiently serve passengers in a group, coordinate operation of individual lift cars to make efficient use of the lift group.

An efficient operation is achieved by optimizing acceleration, speed and deceleration while maintaining a good ride quality and reasonable waiting and travelling time. Lift can be installed as a single unit or as part of a group. When more than one lift is installed together, some interconnecting method is required to optimize operation. Main function of the group control system is to efficiently assign landing calls to each individual lift car, yet at the same time, distribute the passengers among the floors to which they wish to go.

The controller receives multiple inputs, the more information available for the controller, the better it can perform. In most office buildings, passenger demand is highest during the morning, lunch hour and evening. At the other times, the demand is low. The traffic control system relies on more than a single algorithm to allocate lifts to landing calls thus enhancing effectiveness.

The controller will perform better if the destination of the passenger is known, therefore a new more intelligent system known as hallcall control systems were developed. The passenger keys in their destination, the controller computes and informs the passenger which lift to enter. This system is able to group the passengers of similar destination together, thus significantly reduces start/stops and travel time. This system not only reduces the waiting and travelling time, but also helps reduces energy consumption.

By efficiently delivery passengers, might be able to reduce wastage caused by passengers with improper use of the lift (eg. Pushing both up and down buttons).

During low traffic periods, it makes sense to disable some of the lifts, without significantly affecting the traffic performance. By putting lifts on standby or temporarily shutdown mode, the electrical consumption will then be lower.

Appropriate zoning arrangement is practical for high rise building, allowing the lift to serve certain floors, thus reducing number of start/stop cycles and avoid energy losses.

MONITORING DEVICES

The modern controllers can have logging capabilities which is very useful for maintenance purposes. It is able to record breakdowns and failures. It can provide additional data that can be used to further improve the system. Such monitoring system provides information that helps improving awareness of building owners or managers on electrical consumption of the systems.

DOUBLE DECK LIFTS

Double deck lifts is one of the possible solutions in improving traffic handling capabilities of a lift system in very high-rise building. It consists of two-individual lift cars that travel together, one servicing the upper odd number floors and the lower one serving even number floors. Since both lift cars are within the same shaft, using the same drive system, thus it saves space and resources.

FIGURE 10.6 | DOUBLE DECK LIFT

CONTROLS: STANDBY MODE

Energy can be saved by switching off equipment. As mentioned previously, it is possible to place a lift into standby mode. There should be 2 different stages of standby mode. The first stage is the switching off of lighting, ventilation, car display, and dimmable landing display.

The second stage of standby should include the shutdown of drive unit, door operators and car electronics. The first stage would not affect customers waiting time. However equipment shutdown from the second stage would require longer time to reboot the system.

LIGHTING

Lighting is one of the main contributors of electrical load during standby mode. LED lighting is a technology that has seen tremendous improvements over the last few years. LED lights have a longer life span as compared to the normal ones. And their lifespan is not reduced by frequent switching on and off.

HYDRAULIC LIFTS

Conventional hydraulic lifts are inefficient and typically consumes 3 times more electricity as compared to counterweight lifts. However, there are some benefits of hydraulic lifts.

1. Simple installation.
2. Minimal space required for controllers, motor to be installed.
3. Narrower shaft size.
4. Extremely low speed.

Hydraulic lifts typically have low usage, ideal for home lift where there is no large traffic volume to manage. Thus having low standby power consumption is an important part of reducing the total energy consumption of the lift.

All hydraulic lifts only consume energy while going up. It depends on gravity and controlled oil flow to bring the lift down. One simple strategy to reduce the energy consumption is to reduce the up speed and decrease the down speed while maintaining the total round trip time. A lower up speed will result in a smaller motor being used thus reducing the total energy consumed.

Reduce car weight by using stronger and lighter material. A lighter car will result in a smaller motor being used.

Mechanical hydraulic valves allow the control of oil through internal hydraulic feedback have issues compensating for variations in oil viscosity and pressure. By using electronic sensing of flow using proportional solenoids helps compensate for these variances thus providing better efficiency.

By introducing VVVF drives to power the oil pumps, only the necessary amount of oil to move the lift is supplied as opposed to conventional method of constant flow. It also reduces starting current. However the additional of VVVF drives will increase the standby power consumption especially in lifts with very low usage, like home lifts.

ESCALATORS AND TRAVELATORS

As in lifts, the efficiency of individual components is important. High efficiency motors, drives, transmissions, bearing can yield significant savings. Proper maintenance and lubrication of components also helps keep the equipments at its maximum efficiency.

Traditionally, escalators moves constantly regardless of load condition thus causing huge amount of energy being wasted. Therefore the biggest savings potentially could come from adjusting the speed according to the passenger demand with the use for VVVF drives.

Introduction of VVVF drives provide very smooth speed transition. Therefore it is very useful with new control methodology. From a normal operation of 0.5m/s, after a period of inactivity, the escalator slows down into a "reduced speed" mode usually about 0.2m/s. After another period of inactivity in "reduced speed" mode, then the escalator get into stop mode. Using VVVF drives, it is possible to have smooth transition between these 3 different modes while being able to significantly reduce power consumption especially during low peak period.

Normal running speed of escalators is 0.5m/s. By reducing the running speed to 0.4m/s could help save up to 16% in energy saving. Depending on traffic volume, this might not be noticeable towards the average users. However, in areas where there are high traffic volumes, this might not be the ideal solution.

Step chain is an important moving part in the escalator system. It requires constant lubrication which leads to over-lubrication that will cause pollution of environment, or insufficient lubrication causing additional friction to the system, making passengers uncomfortable and high energy consumption. A possible solution is to have lubrication-free step chain installed. These chains are permanently greased and sealed do not require additional lubricant. Truss maintains clean thus reducing servicing downtime.

QUALITY OF INSTALLATION

Lifts are individually engineered installation. The exact same model and design could produce different energy consumption depending on the quality of the installation. If a lift or escalator is not properly installed, there will be vast amount of energy wasted to overcome unnecessary friction caused by poor installation quality.

Traditionally, plumb line strings are used to ensure that lifts are installed vertically. However such lines are hard to maintain in a high rise building with strong winds. Today's technology allows installers to use laser beam to help ensure the verticality of the installation works.

There are thousands of screws, nuts and bolts as part of the assembly works at site. A loose bolt on the car frame might cause unnecessary vibration, increasing the friction losses that the motor will use additional power to overcome.

SERVICING AND MAINTENANCE

Even with the best energy efficient product or technology installed, improper servicing and maintenance of the equipment could cause damages and making the system less efficient. The lifespan of the equipment is also very much dependent on the maintenance of the equipment. Certain moving parts will require sufficient lubrication in order for optimum efficiency, wear and tear of moving parts within the lift like guide rails shoe have shorter life span thus need replacing to ensure the system is consistently at its optimum level.

HOW TO OPTIMIZE ENERGY EFFICIENCY FOR BEST COST-VALUE RATIO

While it is not generally applicable for all projects, the guidelines below may serve as important points for consideration when designing and specifying an energy efficient lift system.

- Purchase energy efficient installations
- Maximize energy efficiency by correctly sizing
- Ensure installation and maintenance are carried out by qualified personnel
- Reduce lighting load during standby
- Use intelligent controllers that can make adjustments during low demand periods and even switch off equipment during low demand periods
- Car door operator only active on door movement
- Use energy efficient systems and components such as high efficiency electric motors, advanced drives, high efficiency lamps, etc.
- Consider geared or gearless traction elevators capable of high or variable speed operation for mid and high rise buildings
- Install data collection systems - new elevator control software can data log and provide information that elevator consultants use to perform elevator bank traffic studies which can be used to refine control strategies in the long term of building operations.
- Query the manufacturer on the details of standby consumption since current standards and guidelines allow manufacturers the discretion to decide on this. However stand by energy efficiency measures are not too critical for installations with a medium/high number of trips since the lifts rarely have an opportunity to go into standby mode.
- An important consideration is that lifts consume higher power consumption during the acceleration and deceleration phases, this results in a higher power consumption for lift systems having less travel height than it is the case for installations having a more travel height.

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END OF CHAPTER 10

CHAPTER

11

THE BUILDING AUTOMATION ENERGY EFFICIENCY TECHNICAL GUIDELINE

by Siwanand Misara

11 THE BUILDING AUTOMATION ENERGY EFFICIENCY TECHNICAL GUIDELINE

INTRODUCTION

The Building Sector Energy Efficiency Project (BSEEP) has for its goal the reduction in the annual growth rate of greenhouse gases (GHG) emissions and management of assets in a more strategic manner. There are numerous policies worldwide aimed at promoting energy efficiency through incentives, prescriptive measures, building codes, and other means (BSEEP, 2013).

The building automation energy efficiency system seems to be one of the most favorable policies driving governments and organizations to adopt new technologies to monitor and control energy use in buildings.

When speaking about Building Automation Systems (BAS), it is usually referred to Building Automation and Control Systems (BACS), Building Control System (BCS), and/or Building Management System (BMS). Building Energy Management Systems (BEMS) or Energy Management System (EMS) are also known to be the same as BAS but with special emphasis on energy metering/monitoring. Also, BEMS is related to Smart (Intelligent) Building since Smart buildings need to be equipped with a data-rich BEMS.

BEMS in Malaysian buildings is targeted to homes, offices, retail premises, sport centers, cinemas, schools, universities, and other commercial premises. It is dealing with minimizing the energy consumption and energy waste (e.g. heating, ventilating and air-conditioning (HVAC) and lighting) as well as maximizing the use of local produced renewable energy resources, while providing the desired environmental conditions and services inside the building at the least cost.

The Malaysian Standard (MS) 1525 provides detailed guidance for a BEMS, and is highly recommended to be practiced in large scale buildings, particularly where the air conditioned area exceeds 4,000 m2 (BSEEP, 2013). At the same time, building automation and control software is leveraging the increase in data availability and analytical capabilities. This leads to identify a range of low and no-cost-performance improvements for building operation as well as failures corrections for building maintenance. In addition, it is necessary to achieve a proper understanding of the interfaces and requirements of related Malaysian stakeholders in building applications (e.g. building owner, utility, system operator, etc.).

The objective of this building automation energy efficiency technical guideline is the improvement of the BEMS utilization in Malaysian buildings sector, particularly for those new buildings in the commercial and government sectors. This can be achieved by providing all related information and recommendations as well as common understanding and minimum requirements of BEMS to all related stakeholders, especially decision makers and/or building owners. The guide shall not be used to circumvent any safety, health or environmental requirements.

This guideline comprises 5 sections. The first section illustrates the general background of Building Energy Management System (BEMS) as well as why it is important today for a facility to acquire a BEMS. In the second section, the baseline of BEMS deployment in Malaysia will be described together with their barriers and problems. At the same time, all related stakeholders will be assessed based on different phases of BEMS deployment: design and installation phase, operations phase and indirect supporting stakeholders.

Section three describes a common understanding between Building Automation System (BAS) and Building Energy Management System (BEMS) as well as characteristics (e.g. building controller, custom application controller, application specific controller and other controller device) and control levels of BEMS. At the same time, the role of interoperability will be described. It is an ability to integrate information between systems from different manufacturers. Finally, the benefits and necessity of BEMS deployment will be described under smart grid and smart cities environments.

In section four, the significant role of ICT is described together with its corresponding data analytic capabilities. The system architecture has to be defined in correspond to Smart Grid Architecture Model (SGAM) framework in order to provide a thorough view of the flexibility of system integration viewed by the different participating stakeholders. It comprises five abstract interoperability layers (Business, Function, Information, Communication and Component). At the same time, the BEMS gateway will be introduced with regards to SGAM framework. Finally, the steps involved in providing a building energy management system (BEMS) from design through the end of warranty will be described in section five.

MALAYSIAN BUILDING AUTOMATION ENERGY EFFICIENCY

Driven by continued adoption by commercial and governmental customers, the global BEMS market is expected to grow from $1.8 billion in 2012 to $5.6 billion in 2020. Additionally, as utilities continue to work with increasingly stringent energy efficiency requirements, they are looking more and more toward the deployment of BEMS to reduce energy demand.

With respect to energy consumption in Malaysia by different sectors in 2013, the energy consumption in domestic and commercial sectors are 24,853 TWh and 39,064 TWh, which correspond to 21.41% and 33.65% of total energy consumption of 116,087 TWh. This energy consumption is produced only with less than 1% from renewable energy sources (RES) excluding hydro power. Figure 11.1 & 11.2 represents the energy generation mix by fuel types (1) and energy consumption by sectors (2) in Malaysia. In Malaysia, the average electricity selling prices are 33.88 sen/kWh at Peninsular Malaysia, 29.12 sen/kWh at Sabah and 29.87 sen/kWh at Sarawak. For commercial buildings, the electricity selling prices are 40.86 sen/kWh at Peninsular Malaysia, 32.98 sen/kWh at Sabah and 31.95 sen/kWh at Sarawak (Energy Commission

FIGURE 11.1 | ENERGY GENERATION MIX BY FUEL TYPE

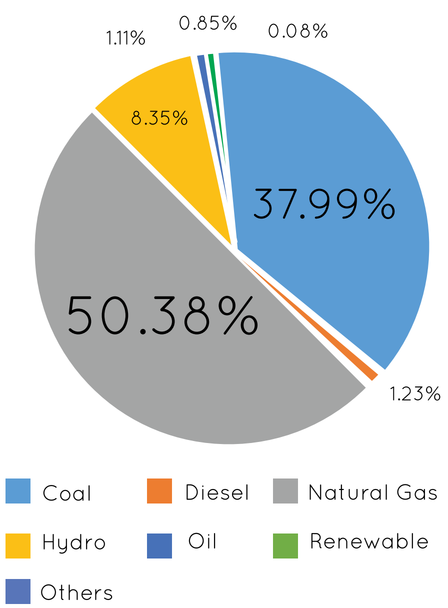
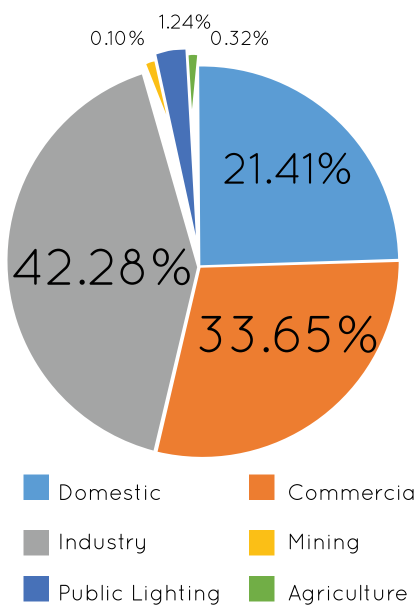


FIGURE 11.2 | ENERGY CONSUMPTION BY SECTORS IN MALAYSIA



Since Q3/2014, the value of construction works done in Malaysia is around 28 billion Ringgit Malaysian (RM) per quarter, in which nearly 35% of total construction costs come from commercial buildings sector (Department of Statistics Malaysia, 2014).

With buildings in commercial sector accounting for more than 40% of energy consumption, BEMS can lead to significant savings for property owners up to 30% of the energy consumption through inefficiencies usages (Robinson & Stanberry, 2014). With the increasing of low cost and local renewable energy generation in buildings, property owners can further save their energy bills through the deployment for BEMS system.

BASELINE OF BUILDING AUTOMATION ENERGY EFFICIENCY SYSTEM IN MALAYSIA

With respect to the assessment of the strengths, weaknesses and suitability for publication of the existing building automation energy efficiency produced by Building Sector Energy Efficiency Project (BSEEP), it can be evaluated that Information and Communication Technologies (ICT) is one of the most crucial elements for a future BEMS together with its corresponding data analytics, considering different stakeholders' requirements and business models analysis (BSEEP, 2013).

- Information and communication technologies (ICT) and data analytics are making possible analysis and levels of performance that could not be achieved as recently as ten years ago. Equipment and systems used in buildings, transportation, and manufacturing are becoming adaptive to environmental inputs, anticipatory in their performance, and networked to one another within a facility as well as throughout a supply chain. These intelligent or smart technologies exist along a continuum of complexity and potential for energy savings (Ethan A., 2013).

Moreover, the smart grids and smart cities environments and related information have to be taken into account (e.g. variable prices, grid constrains, renewable energy sources with its corresponding fluctuating behaviors) (CEN-CENELEC-ETSI, 2012).

- Smart grid data management and analytics technologies provide deeper insight into grid operations, which utilities can more precisely manage the grid. They enable utilities to better run their energy efficiency programs, integrate more variable renewable resources, and decrease the need for electricity generated by high-emitting peaking power plants (Robinson, 2015).

At the same time, the cost-benefit analysis is another element that could affect the decision makers. Basically there are different levels (e.g. different I/O ports, zone and/or floor controls) to deploy BEMS system. With respect to their corresponding investment costs and system utilization at different BEMS levels, the cost-benefits-analysis would assist the building owners to understand and make a decision at which levels to deploy the BEMS system.

Barriers

Barriers to rapid market acceptance arise with every leap in technology, and intelligent energy efficiency technology is of no difference. These can be examined as a number of social, financial, technical and structural barriers to broader acceptance of intelligent efficiency as illustrated in the Figure 11.3 (Ethan A., 2013).

FIGURE 11.3 | BARRIERS FOR ADOPTING BEMS

Social Barriers	• They reflect a lack of awareness among consumers and policymakers in Malaysia about intelligent efficiency technologies and their associated benefits. • They are largely being addressed through efforts to educate consumers and through the continual improvement of data security.
Technical Barriers	• The technical challenges are mainly on the incompatible communication strategies and platforms for smart devices, different methods of reporting energy savings information and legal and regulatory structures in the utility sector.
Financial Barriers	• They are such as the upfront costs of implementing the new smart building and networked system technologies. • They are not significantly different from those related to the adoption of other energy measures, namely, the challenges of financing capital investments in tight economic times.
Structural Barriers	• Traditionally, the energy efficiency programs have focused on providing incentives for energy consumers to purchase more efficient equipment and devices. • The EMS deployment has not been considered yet in those Malaysian's energy efficiency programs.

Problems of BEMS Deployment in Malaysia

With respect to current BEMS deployment in Malaysia, the following problems rise while the BEMS is put in use.

- Input/Output Implementation: It arises from the configuration of input and output points that occur prior to turning over the BEMS to the building operator (e.g. incorrect high and low span values).

- Input/output drawback during operation: The I/O ports defects around 10%/year after building has been commissioned.

- Programming problems: There is problems related to programming arising from incorrect or inappropriate control logic and parameters that produce output to control HVAC equipment (e.g. improper reset control strategies and set points) (House, Corsi, & Klaassen, 2004).

- Data management failures: It is associated with producing information from data including data monitoring, display, alarming, and logging. For example, inability of application of specific controllers to trend data necessary for control monitoring and diagnostics, and false alarms. These problems are associated with the operation of the BEMS software and its interface to the computer operating system such as loss of control set points and/or parameters due to a power outage or a file download (Bernardo, Martins, & Gaspar, 2013).

In order to measure the future performance on energy management, a baseline and key performance indicators (KPI) are needed to be set. It is important to identify the types of energy to be used (e.g. electricity, natural gas, LPG, oil, diesel or other). Then, use the information on past energy consumption over a suitable time period (up to 3 years) for a similar existing building to establish an energy baseline. Normalize the baseline data in order to adjust for variables which affect energy use and/or consumption, e.g. production levels, outdoor temperatures, building occupancy, etc (SEAI, 2015).

Stakeholder Analysis

In order to support decision makers for BEMS system, it is necessary to establish a vision for stakeholders' role for the building automation energy efficiency system in buildings sector. This vision is needed to address the different stakeholders (e.g. building owner, designers, facility manager, utility, etc.) and their corresponding interfaces and requirements, whether there is any coordination between partners or not.

In general, an actor can be an external role, human or device that interacts with the system. Hereunder, the role of every stakeholder involved is going to be discussed (ASHRAE, 2015) (BDigital-1, 2012).

The stakeholders can be divided into two configurations depending on the phase of employment: design and installation phase as well as operation phase. At the same time, there are still numerous stakeholders, who have indirect impact on the development of BEMS system.

Stakeholders During Design and Installation

BEMS designer is the creator of the work or the author of the specification. The BEMS designer may be a consulting engineer, a licensed professional engineer, a facility master system integrator, or other.

Contractor is the performer of the work defined in the specification; the person or company who enters into contractual agreement to execute the work and the entity responsible for its completion in accordance with the contract documents. While a Subcontractor is the performer of the work defined in the specification; this person or company is contracted by the contractor, not by owner, to perform some or all of the work defined by the specification in accordance with the contract documents.

Manufacturers, designers, architects, developers, etc. Their role is to ensure with the government that all national targets can be met through identifying and implementing adequate policies. They should take part in monitoring, verification and enforcement programs at international level to share information, and develop national or international programs for product and installation certification and quality assurance.

Stakeholders in The Operation

User could be considered as an actor that can directly interact with the BEMS system, for example, by providing his/her own personal requirements regarding his/her room temperature and lighting intensity.

Building owner who has no direct interest in controlling all the systems through the BEMS system. He/she is the person or company that executes the contract for the work; this entity will assume ownership of the completed work in accordance with the contract documents.

The facility management (could be a facility owner, third-party company or a single person) is responsible for the operation of all the different systems within a facility (e.g. Heating, Ventilation and Air Condition (HVAC), lighting, etc.).

Utility - energy trading company (market operator) represents the electricity, gas or in general the energy supplier of a facility. Normally, this actor is responsible for energy trading in wholesale markets and its retail trading (energy sell) to end customers.

Utility - energy DSO (Distribution System Operator) represents the electricity, gas or in general energy company normally in charge of managing energy generation and transmission systems. In some countries, DSO and energy trading company could be the same person.

Weather information/forecast providers represent another external system interacting with the future BEMS system in order to provide updated weather information and/or weather forecast to perform energy optimizations.

State, provincial and local governments implement the required policies through local code authorities and energy agencies, provide equal compensation and incentives to utilities to invest in distributed and efficiency technologies, promote public awareness, and apply energy efficient technologies in public buildings.

Indirect Supporting Stakeholders

Non-governmental organizations promote public awareness on energy efficiency technologies, and work with standards organizations like ASHRAE and builders' groups to develop more performance-based standards and guides.

Environment/energy/resource ministries and regulators improve the collection of statistics on end-use energy consumption and energy indicators, develop ambitious roadmaps with targets for energy efficient technologies with specific dates, ensure the regulatory framework for rewards investment in energy efficiency and remove any fiscal barriers for these investors.

Economics/finance ministries provide financial and taxation incentives either for manufacturers or importers of energy efficient technologies.

Supranational organizations (e.g. the UNDP) monitor and evaluate the launch of energy efficient heating and cooling technologies among national governments, convene workshops and co-ordinate sharing of expertise, R&D, lessons learned from policy programs, etc., and publish periodical progress reports including best practices.

Energy generating and consuming systems as well as energy storage system can be seen as actors that can be monitored and controlled by the EMS system. There are many different systems that are already in place in an infrastructure (or would be in place in the short term) such as HVAC, lighting, PV panels, Electric Vehicles (EVs), etc.

BUILDING MANAGEMENT SYSTEM (BMS) & BUILDING ENERGY MANAGEMENT SYSTEM (BEMS)

In most instances, Building Automation System (BAS) correspond to Building Automation and Control System (BACS), Building Control System (BCS), and/or Building Management System (BMS) (KMC Control, 2015). In contrast, Smart Building Energy Management System (BEMS) are generally understood to be the same as a BAS, but may have special emphasis on energy metering/monitoring, interface to smart grid and smart city related external information and its corresponding data analysis.

At the beginning, pneumatic or air-based control systems were used to control various equipment in building automation applications. Since Direct Digital Control (DDC) has been introduced in the 1990s, a true BMS became possible. It was an isolated system accessible only by facilities department. Various manufacturers created their own communication schemes/languages (proprietary). There were no common standards for this communication between different equipment as well as manufacturers. It was not interoperable, which means the communication of different equipment from different vendors is not possible. The building automation system is locked to specific manufacturers.

In 2000s, BMS/BEMS were moving towards to standardization on "open" communication systems, so called "Open Protocols", which allows different equipment from different manufacturers to be able to cooperate with each other. It is so called interoperable. BEMS can be designed and specified to co-exist with existing enterprise Local Area Network (LAN) along with computers, tablets, smartphones, and other IP-based devices. BEMS have energy monitoring, alarms, runtime and data on equipment health that owners share with other departments in the enterprise.

At the beginning of 2010s, the system architectures have been introduced by Smart Grid platform. It aims for providing a thorough view of many aspects of a system viewed by the different participating stakeholders throughout the overall system lifecycle. It enhances the flexibility of system integration and avoids misunderstanding between stakeholders from different domains involved in the system development as well as increases the global reliability and acceptance in the smart grid environment.

Interoperability is seen as the key enabler of the intelligent BEMS system. It describes the ability of two or more devices from different vendors to reliably and timely exchange information and use that information for correct co-operation. This functionality is required at all the levels of the network where different manufacturers' devices must interoperate (CEN-CENELEC-ETSI, 2012).

- While the current project may be only an HVAC project, it does not make sense to design a BEMS with any proprietary protocols, because the owner may install lighting, security, or fire alarm systems and will expect to interoperate with the original HVAC system in the future.

- Other functions, such as the exchange and manipulation of alarms, schedules, and trends, also may need to occur in the multivendor environment. However, this communication happens at the operator workstation and building controller levels.

Building Management System (BMS)

BMS is the automatic centralized control of a building and/or facility including a group of interlinked networks and devices (hardware and software), which monitors, manages, and controls one or multiple aspects of a facility's core operations, services, and utilities. The facility could be commercial, industrial, or residential. It is typically provided as a simple and easy method for a building administrator to manage the heating, ventilation and air conditioning, lighting, and others. For instance, it automatically controls the operating hours of the lighting and the air conditioning systems in a large building because it would be impractical to have it done manually.

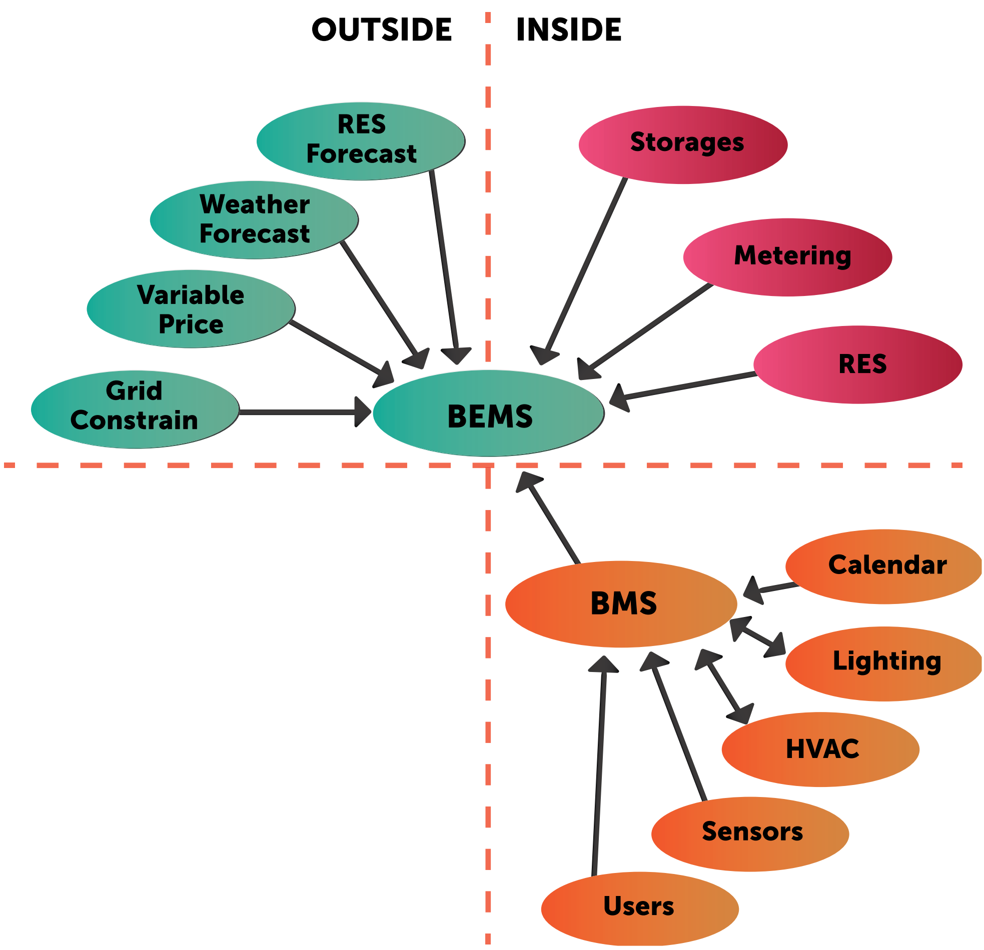
The BMS would normally provide the function of a calendar and time system for the building administrator to program for normal operations. Moreover, it allows simple fine-tuning operation of the air-conditioning (AC) system, such as setting the supply air temperature in a Variable Air Volume (VAV) system, chilled water supply temperature and etc. Besides, a modern BMS system is configured to monitor the 'health' and detect the failures of the air conditioning system by monitoring the chilled water return temperature, room air temperature and relative humidity.

Building Energy Management Systems (BEMS)

The provision of the collected energy metering/monitoring data and its corresponding analysis in various forms (line charts, bar charts, etc.) will facilitate for the building administrator the ability to determine how a building is currently consuming energy. It also easily helps the administrator to fine-tune and reduce energy consumption, and, thus, reduce the energy bill. Energy analysis can help stakeholders to identify the areas for improvement that could not be detected by human inspection, and determine where to make future efficiency investments.

Apart from gathering the energy metering/monitoring data inside the building, BEMS also provides the access to all smart grid related information (e.g. variable prices, grid constrains, renewable energy sources (RES) with its corresponding fluctuating behaviors), which can help the systems to be operated more efficiently (Figure 11.4). These smart grid related information can be classified into information inside the building (e.g. RES, metering and thermal and electrical energy storage) and information outside the building (e.g. variable prices, weather and power output forecast and grid constrains from utility). In addition, leveraging large energy analytics data via the cloud system could save substantial time and costs compared with the traditional manual methods of performing building assessments and audits.

FIGURE 11.4 | SCOPE OF BUILDING AUTOMATION SYSTEM (BAS) AND BUILDING ENERGY MANAGEMENT SYSTEM (BEMS)

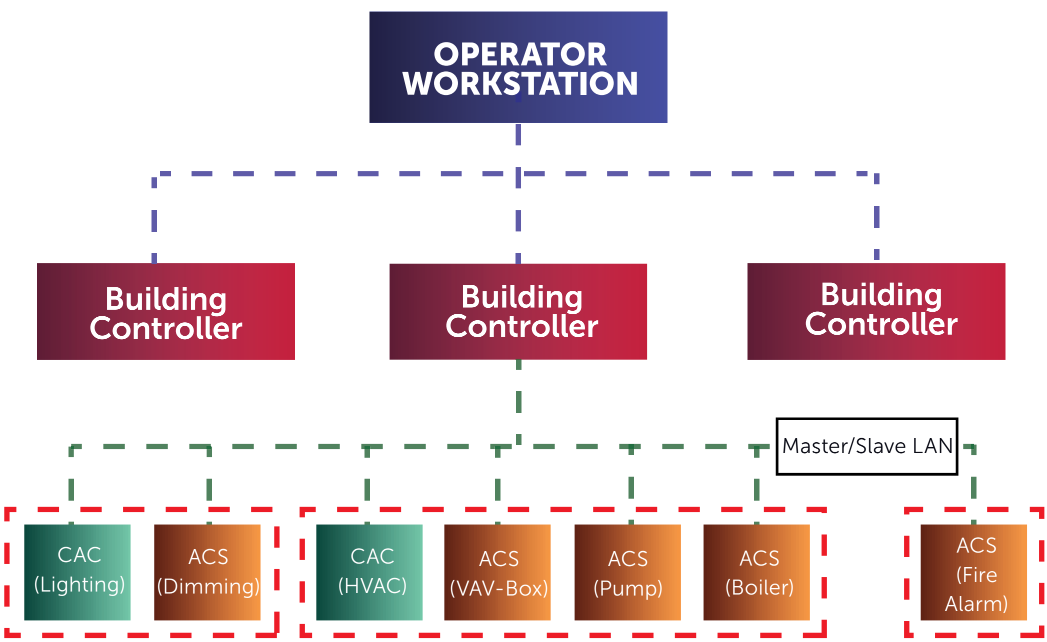


Characteristics of BEMS

The BEMS is a combination of hardware devices mounted to equipment and software to manage the sequence of operation and maintenance in a building. The range of mechanical, electrical and plumbing systems in a building is vast and, generally, only lighting, ventilation and air-conditioning systems are controlled.

The controls for the HVAC and lighting system typically includes: chillers, boilers, air handling units (AHUs), roof-top units (RTUs), fan coil units (FCUs), variable air volume boxes (VAVs) and motion sensors and lux sensors. More complex systems allow the control of: power monitoring, security, close circuit video (CCTV), card and keypad access, fire alarm system, elevators/escalators, and plumbing and water monitoring. It is a distributed system controller performing the processing of information close to the source of the inputs and their controlled devices. There are three main types of controllers: building controllers (BC), custom application controllers (CAC), and application-specific controllers (ASCs), which all represent the combination between hardware and software together with different sensor and actor units. Figure 11.5 represents the configuration of distributed system controller in building (ASHRAE, 2015).

FIGURE 11.5 | CONFIGURATION FOR DISTRIBUTED SYSTEM CONTROLLER IN BUILDINGS



With respect to the cost-benefit analysis of each BEMS sub-systems, it is important to note that the distributed system controllers are not always necessary to connect to prior building controller system. It could also be employed in a stand-alone mode.

Building Controller (BC)

A building controller is a general term to describe a variety of controller types, depending on the environment, protocol, vendor, or integrator terms. The main objective of the building controller is to coordinate and provide building management functions for all of the devices on the sub-network. These functions typically include communication, time-of-day scheduling, alarm processing, trending, sequencing, and other custom programmed functions (ASHRAE, 2015).

It acts as a peer on the network and can store and forward information to the graphical user interface (GUI). It typically resides on the same network as the personal computers that serve as the operator interface, but they can also reside directly on the control network, depending on the technology platform and system requirements (ASHRAE, 2015).

In general, it is programmable and may have a high concentration of input and output (I/O) points or have no I/O at all. Typically, it may connect to a sub-network of custom application programmable controllers (CAC), application-specific controllers (ACS), and/or network interfaces. In building complex, it may have several one building controllers connected to operator workstation, which represents different buildings with various sub-systems (ASHRAE, 2015).

Custom Application Controller (CAC)

A custom application controller is a programmable device with sufficient memory and device specific I/O points from manufacturer, which normally controls specific pieces of complex, custom equipment (such as an air-handling unit or a cooling tower).

It normally resides on the sub-network, but it also may exist on the system network. It is connected to the building controller, which may be in a "master/slave" relationship to a building controller. Master/slave means that the controller can control the equipment in a stand-alone mode, but still relies on the users' requirements/information from building controller to provide it with updated data or variables such as outdoor air temperature (ASHRAE, 2015).

Application Specific Controller (ASC)

An ASC is normally used to control VAV boxes, chillers, rooftop units, water-source heat pumps, and other equipment. The controller comes complete with preprogrammed ("canned") routines prepared by the manufacturer. The user selects the appropriate sequence from a menu (e.g., does the VAV box have reheating or does the unit ventilator have cooling?). ASCs are typically more economical, but they offer less flexibility than custom application controllers (ASHRAE, 2015).

Other Controller Devices

Table 11.1 describes the differences of other controller devices (PLC, DDC, DCS and SCADA) and their corresponding controller types.

Differences Between DCS, DDC, PLC & SCADA	Controllers Types
PLC (Programmable Logic Controller) is a controller, which can be re-programmed. It is mainly designed for small applications. Its programming language is ladder logic and functional block diagram which work on relay logic (discrete/sequence functions). If the PLC is only a stand-alone and not combined with other PLCs, it is called DDC.	CAC
DDC (Direct Digital Control) is a universal controller where both analog and digital input/outputs are combined in one controller. It is specially designed for the HVAC (Heat ventilation air conditioning) systems.	ACS
DCS (Distributed Control System) is a control system with several controllers. It coordinates the work of all these controllers referred to the PLC. It means PLC is a sub system of a large system called DCS. DCS is mainly used in a continuous and very highly efficiency plant.	BC
DCS (Distributed Control System) is a control system with several controllers. It coordinates the work of all these controllers referred to the PLC. It means PLC is a sub system of a large system called DCS. DCS is mainly used in a continuous and very highly efficiency plant.	BC

TABLE 11.1 | DIFFERENCES BETWEEN DCS, DDC, PLC AND SCADA AND CORRESPONDING CONTROLLER TYPES IN BUILDING

Other Communication Devices

In addition to the functions described for the BC, CAC and ASC, some vendors offer devices whose only function is to provide communication. This fourth type of device is often referred to as a communication gateway.

Gateways are typically used to convert between two communication protocols and may be used to convert between proprietary and standard protocols, between two proprietary protocols, or between two different standard protocols. Gateways may be used to interface equipment such as packaged chillers and boilers. They also may be used to connect existing (or legacy) systems to standard open protocols. Depending on the manufacturer, this translation may be performed by a building controller, a custom application controller, or by a separate hardware device.

- **Gateway vs Router:** Gateway is sometimes confused with router because gateway also performs translation works from one protocol to another in addition to routing tasks. The distinction between a gateway and a router is that a router connects networks using the same application protocol messages without translation.

Operator Interface

The operator interface should be specified based on the building operator's needs. This operator interface is a software package that provides the setup and operation of the system, and usually includes schematic representation of air-handling systems, boilers, and other systems. The operator can use these graphics to view temperatures and status, change set-points, and override equipment as well as perform basic functions, such as changing set-points or schedules, without the need for a computer.

The operator interfaces can be resided on the same LAN or on cloud platform, which facility manager or service technician can remotely operate the system over internet connection. At the same time, the operator interface also could be a LCD that is mounted on the BEMS panel.

- **Web-Server Appliance.** Web-server appliances that provide data storage and user interface capabilities are becoming more common. This could be part of building controllers, custom application controllers (CAC), and application-specific controllers (ASCs). It provides the user with a browser-based interface that can be accessed from a PC, smartphone, tablet, or imbedded device and simply display Web pages. They can also include some control logic, scheduling, data store-and-forward, protocol translation, media translation, and more functionalities.

The PC-based operator interface will typically use a multitasking operating system apart from monitoring, control, and display. This includes editing documents, processing work orders, or using other PC-based software programs.

BEMS Control Levels

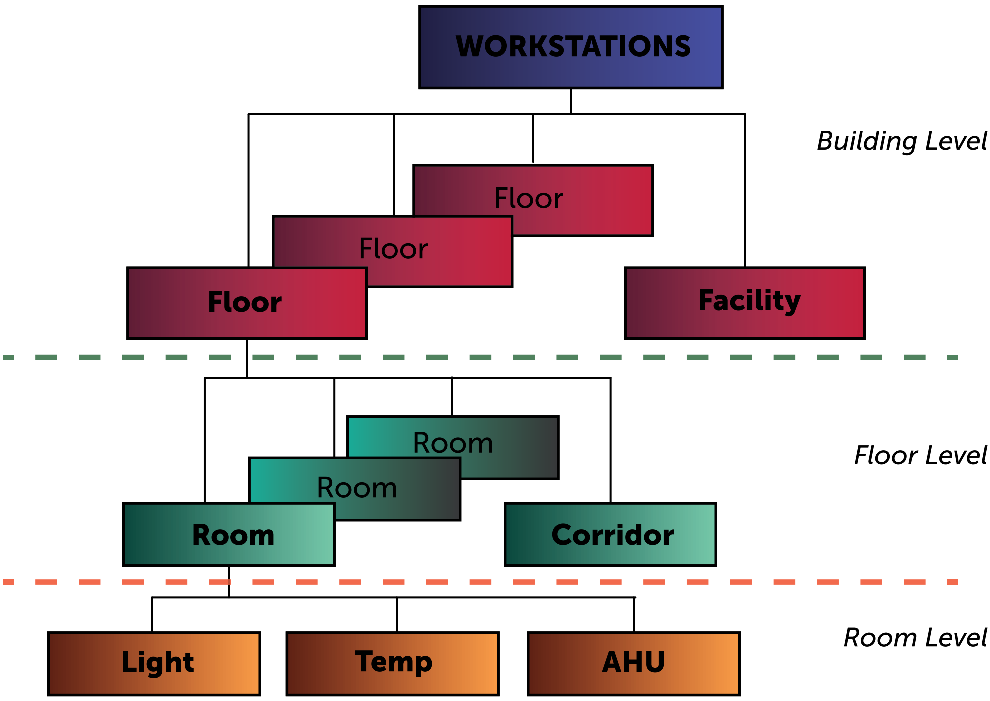
With respect to the configuration of distributed system controller in buildings in Figure 11.5, a logical hierarchy of systems and sub-systems is needed. Figure 11.6 exhibits the different control levels (room, floor and building levels). It is important to note that each sub-system should also be classified in different control levels. For instance in HVAC sub-system, the fan coil units are controlled at room level, while VAV and AHU will be operated at floor level and chiller will be at building level. A logical hierarchy of systems and sub-systems becomes crucial for (ASHRAE, 2015):

- Efficient system operation: zone VAV determines the need for heating and cooling, which is transferred to the air handler. The air handler, in turn, conveys the need for chilled and hot water to the central cooling and heating plants. In this way, systems operate efficiently and only when needed.

- Cost-benefit analysis for the deployment of each sub-system at different levels: with respect to implementation costs and system utilization at different levels, the cost-benefit-analysis would assist the building owners to understand and make a decision at which levels to deploy the BEMS. For instance, lighting in the corridor is normally operated more than 16 hours a day. To deploy an automatic ON/OFF switch in correspond to occupancy sensors, it could lead to payback time longer than leaving the system to operate 24 hours a day.

- Share measured parameters: some input parameters of each sub-system may be shared by other systems in order to reduce the deployment cost. For example, vacancy/occupancy sensors may be installed by the lighting system contractor. The state of these sensors may be used by the HVAC system contractor to control the VAV-box damper position. When the vacancy/occupancy sensor considers the room to be unoccupied during the day, the VAV-box controller can set the airflow to a minimum position, thus creating part-load occupancy savings for the owner.

FIGURE 11.6 | A LOGICAL HIERARCHY OF SYSTEMS AND SUB-SYSTEMS



Many sub-system manufacturers often offer only primary controls, where the secondary control will be done by itself. The arrangement of the controllers and how they are linked together in a network is called system architecture or network topology. Selection of the physical media (wires) and data link layers (called communication buses) is an individual choice at each installation. There are generally three types of communication buses related to BEMS (ASHRAE, 2015):

- Communication between workstations: This type of communication is high speed and data rich. While communication between workstations may not be frequent, it usually involves large blocks of data, particularly file exchanges, which must occur at high speed. The communication between controllers at building and floor levels and workstation can also occur on this bus (e.g. alarm reporting and acknowledgement, graphic display updates, and so on). It is very useful for the facility management to operate different objects simultaneously.

- Communication between primary controllers (and the workstation to primary controllers): Some sub-system manufacturers often provide only the primary controllers interface to the workstations. There is no direct interface from workstations to secondary controllers. For instance, Cogeneration or combined heat and power (CHP) manufacturer provides only an interface to its main primary controller, without any direct access to information of thermal storage or heat exchanger. This bus can have the greatest effect on overall system throughout. All global objects will communicate over this bus, as well as alarms. Additionally, operator-entered commands and requests for information are transmitted over this bus. This bus must be responsive enough to guarantee timely alarm reporting while still processing regular activities, such as reports and global objects. Response time in seconds is still the best measure.

- Communication between secondary level controllers (such as fan coil unit controllers). It provides communication to the workstation, routed through a primary controller (or other interface). The most common use for this bus is terminal unit controllers. As space temperature has a large capacity and does not change rapidly, bus response can be relatively slow in many cases. It typically does not create large errors if the reported information is 30 or even 60 seconds old.

Interoperability

The demands of the BEMS owners are requiring manufacturers to design and build products that have the ability to integrate information between systems of different manufacturers.

What are the driving factors for interoperability?

- Vendor independence - this gives the customer the freedom to select from a variety of price and performance options and not be limited to the offerings of one manufacturer.

- Integration with other applications - Integrating subsystems selectively and intelligently should allow for device interactions and provide additional comfort. An example of this is the possible interaction between access control, lighting, elevators, security cameras, and HVAC control systems. For example, a person entering a building using an access badge will cause the security camera to pan toward the door to record his/her entry; it will cause an elevator to go to the first floor to pick up that person; and the lights and HVAC system will turn on before the person enters the office.

- Single-seat user interface - this refers to the ability to operate, from a single seat or workstation, a variety of dissimilar subsystems through an interface that displays information in a common format. It allows data from different systems to be grouped into a single display and uses a common methodology to execute commands. This increases productivity and greatly reduces the learning burden for facility management personnel.

- Media sharing - many sites have an existing LAN or WAN for business or other applications and have sufficient bandwidth to allow for more use. Allowing the BEMS to use the existing network can decrease installation expense. Consideration must be given to the risk of network failure or downtime and its impact on building-wide monitoring and control.

- Investment protection - the useful life of an existing system can be extended through interoperable systems by adding new technology incrementally, rather than performing a complete system replacement or upgrade. Factors that determine the economic feasibility of the expansion or replacement decision are based on the size of the existing system, cost of maintenance, cost of failure, accessibility to assistance (and parts), and annual capital budgets.

- Maintaining multiple vendors' equipment - for each new manufacturer added, the operating personnel must be trained in that system and stay current with it, and a certain amount of repair inventory must be added.

- Complexity of system integration issues with multiple vendors - when an interoperable system falls short of performance expectations, someone must spend time troubleshooting. Unless specifically designated before installation, the purchaser bears the burden of total system performance. The following should be taken into account when considering interoperability:

  (a) how will this data be used and stored? For example, the majority of the trend logs are only retained for a month, whereas energy trend logs may be retained for years,
  (b) who within the organization and team will need access?
  (c) what systems and equipment will be connected?
  (d) which data points are shared?
  (e) how much control is required? (ASHRAE, 2015)

For example, there may be full control over the HVAC system, but the fire alarm system is only monitored because the front end is not a UL-hardened workstation. Other systems, such as lighting, may have a hybrid of control in that the lighting system is monitored for alarms and the user has the ability to turn lights on and off to satisfy energy requirements. Otherwise, the lighting system runs on its own programmed sequences.

What Needs to Happen to Achieve Interoperability?

Once it has been determined that an interoperable system has an economic benefit for the user from a life-cycle standpoint, the next step is to define the degree of interoperability within the system (ASHRAE, 2015).

- Define what information needs to be exchanged - while the sequence of operations describes the outcomes desired from the control system, it is essential to specify the object information desired to be available on the network. The object list is an ideal mechanism for addressing this issue.

- Define how far down into the network openness must occur - The point in the network architecture at which an open protocol is employed affects system performance and cost.

Benefits of Building Energy Management System (BEMS)

- A BEMS comprises both hardware with microprocessor controls and software with a flexible platform, which one or all of the following can be applied: control algorithms, scheduling events, event notification, trend data collection, and network communications.

- A BEMS can incorporate the algorithms for energy conservation and system optimization (such as night setback, optimum start/stop and demand limiting and set-point reset for variable-air-volume (VAV) systems).

- With the advent of networked occupancy and/or vacancy systems, the BEMS can also read the state of the occupancy or vacancy, and can have the terminal equipment controllers reduce the airflow and/or set-point temperature when the space is unoccupied for a specified period.

- A BEMS provides advanced scheduling features for building equipment and systems to be scheduled to operate under different time-of-day schedules (i.e., Sunday through Saturday), as well as scheduling for nonbusiness days (i.e., holidays) for years in advance.

- A BEMS provides event notification for alarms, system, and operator events with time/date stamp and/or built-in audit trail functions to allow the building operator to track and monitor events.
- A BEMS provides the ability to collect trend data from any controllers, which is a valuable tool for commissioning and performance monitoring of building systems.

- A BEMS can now co-exist on the existing enterprise Local Area Network (LAN) along with desktop computers, servers, and other devices. The maintenance of a separate network infrastructure, secure BEMS assets and the information as well as grant access rights can be performed by the Information Technology (IT) department, not necessarily by the facilities department.

- A networked BEMS can utilize both hardwired and wireless network protocols. Wireless does have the advantage of not requiring more cabling infrastructure, which is particularly advantageous in existing buildings. However, some owners prohibit the use of wireless for security reasons.

- Integration of other building systems (such as weather station, lighting, security, fire, submeters, emergency generators, etc.) into the BEMS provides the opportunity for global optimization of building systems for energy conservation, occupant comfort, and safety. Integration of other building systems is accomplished by the use of different industry standard communication protocols.

- A BEMS reduces labor, maintenance and energy costs through remote monitoring and troubleshooting, by which the response time for correcting building system problems can be minimized.

- A BEMS is often necessary to meet specifications of sustainability guidelines such as LEED™, Green Globes™, and Go Green™. The BEMS will also monitor the various systems, which allows the user to commission the systems and ensure compliance to these standards. It can also be used as a measurement and verification tool.

- A BEMS offers a viable platform, which can provide facility managers and operators to easily assess the current and historical performance of the building/facility as a whole, as well as its significant energy consuming systems and components.

- Many BEMS device manufacturers offer product that conforms to worldwide interoperability standards at no extra cost over a proprietary communications protocol (ASHRAE, 2015).

When is a BEMS not required?

In the past, it was common not to install a BEMS for small buildings with one or more rooftop units. This is often not the case today as rooftop units, heat pumps, or other packaged equipment come with their own built-in on-board automation controls that allow this equipment to be connected to a BEMS to permit remote monitoring and control. In making a decision on controls, property owners and managers need to understand that BEMS technology is not a solution to all building problems (ASHRAE, 2015).

a. A BEMS should not be installed before proper needs including cost-benefit assessment have been made.

b. A BEMS cannot correct problems with mechanical systems that are under capacity, poorly designed, or do not meet current codes.

c. There will be cases such as high-hazard buildings where electronic controls that could generate a spark are not allowed. In this case, pneumatic controls or intrinsically safe electric controls may be the only solution.

d. Other building codes may necessitate the use of hardwired interlocks between the fire alarm and the corridor pressurization fans in the facility. It is commonly practiced to wire a flow switch through the chiller starter circuit rather than making a software interlock between these two devices with the BEMS. The BEMS designer should consider providing BEMS controls to monitor these non-electronic control interlocks.

e. Unit heaters in shops or mechanical rooms often use simple line voltage controls, which may not require any controls from BEMS. In this case, the BEMS designer should not rule out the option for controlling this equipment to permit remote monitoring and control.

INFORMATION AND COMMUNICATION TECHNOLOGIES (ICT) IN BEMS

Information and communication technologies (ICT) are the main key component to achieve new levels of energy efficiency. More than being programmable or having variable responses, it is dealing with the deployment of affordable next-generation sensors. As well as, it deals with communication between isolated information of equipment and systems used in buildings and external smart grid related information. It is also working with large volume data analysis and intelligent control algorithms to improve device, process, facility, or organization performances and achieve new levels of energy efficiency.

All the components equipped with sensors and communication capabilities can communicate current data and their current situation to other parts of the system. This enables the system to react or adapt their behaviors based on incoming information. The full integration of smart energy efficiency technology will connect facility operations to corporate enterprise management, which will help to coordinate a facility's operational objectives with the corporate financial objectives, as well as corporation's energy and sustainability objectives.

Energy Management System (EMS) Architecture

In order to employ the EMS with regards to all requirements, the system architecture has to be defined, which has to be matched with Smart Grid Architecture Model (SGAM) framework (Figure 11.7). In general, system architectures aim for providing a thorough view of the flexibility of system integration by the different participating stakeholders throughout the overall system lifecycle. It enhances the flexibility of system integration and avoids misunderstanding between stakeholders from different domains involved in the system development as well as increases the global reliability and acceptance in the smart grid environment.

There are five interoperability layers (Business, Function, Information, Communication and Component) with the two dimensions of the Smart Grid Plane, i.e. zones (hierarchical levels of power system management) and domains (electrical energy conversion chain) (CEN-CENELEC-ETSI, 2012) (OGEMA Alliance, 2011).

For a clear interaction between stakeholders and equipment, the interoperability categories are aggregated into five abstract interoperability layers:

- Business layer: In order to ensure that whatever market or business models are selected, the correct business services and underlying architectures are developed in a consistent and coherent way.

- Function layer: In order to effectively employ the EMS system, the intelligent controls will be provided to describe functional architectures and give an architectural overview of typical functional groups intended to support the high-level business services.

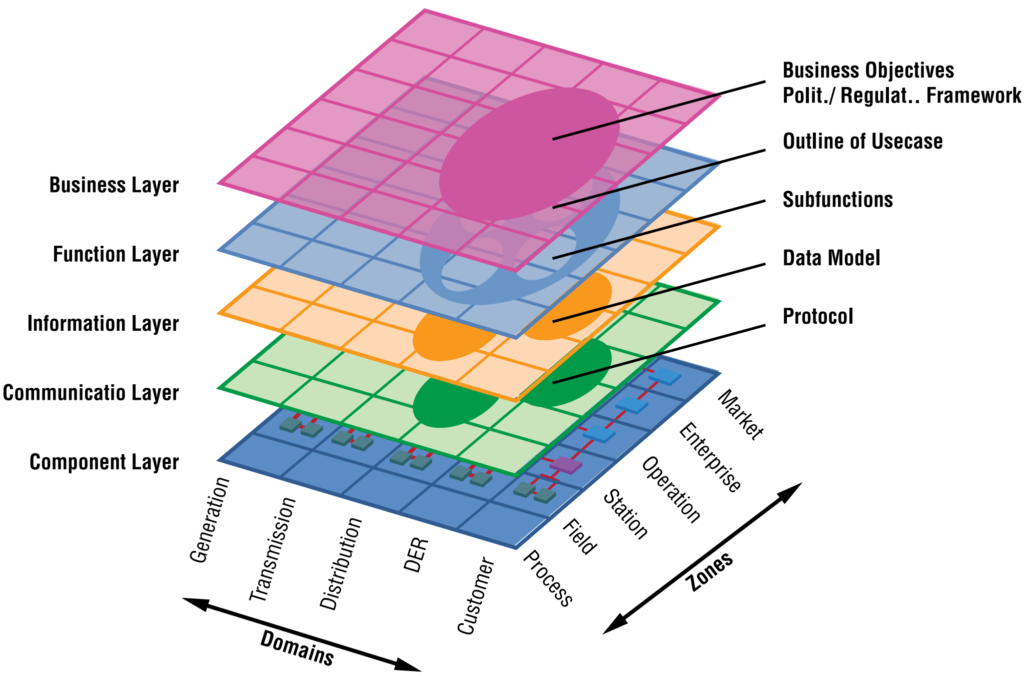
- Information layer: In order to provide the interchangeability feature, the information layer will address the notions of data modeling and interfaces. It introduces the concept of logical interfaces, which is aimed at simplifying the development of interface specifications especially in case of multiple actors/ vendors with relationships across domains.

- Communication layer: In order to allow the interaction between components and the interoperability feature, the corresponding standard communications protocols will be evaluated on both wired and wireless medium.

- Component layer: All related building's equipment, renewable energy sources and external information needs to be identified based on stakeholders and requirements. It also includes the deployment of sensors, actors and smart meters.

With respect to different level of distributed system controller, it is not mandatory to include all interoperability layers in the controller.

FIGURE 11.7 | SMART GRID ARCHITECTURE MODEL (SGAM)



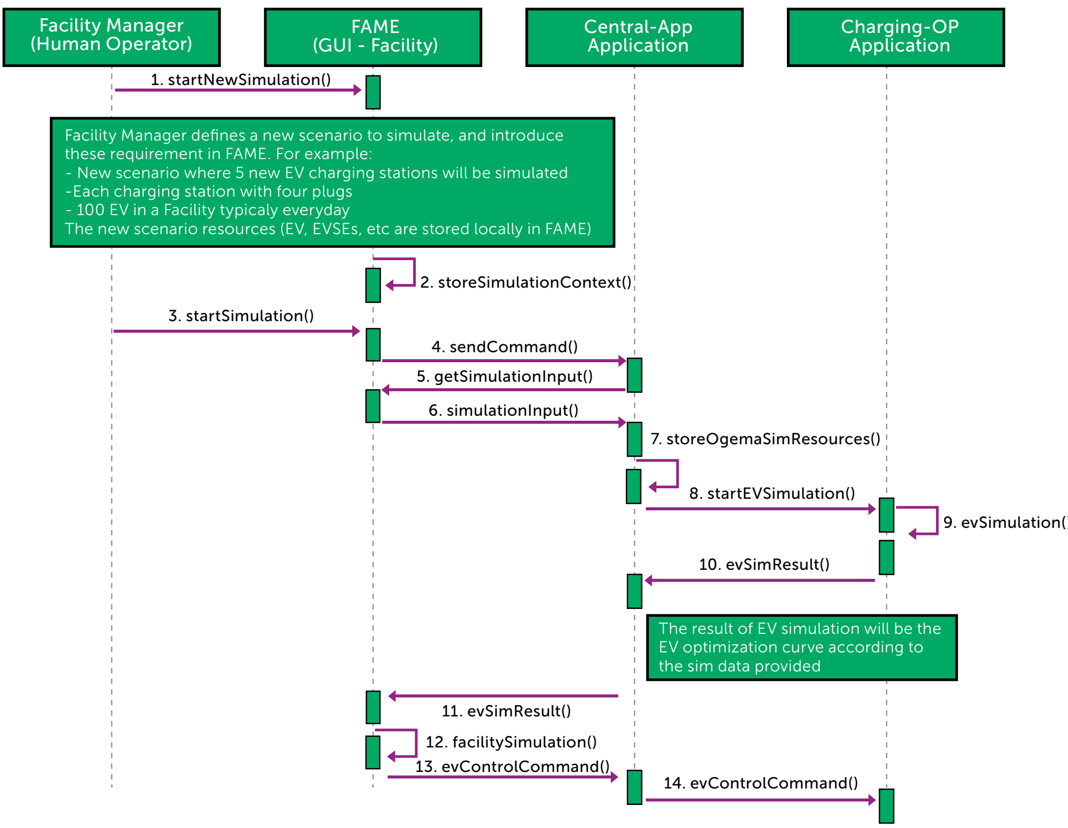
Business Layer

It is commonly understood that ICT solutions are meant to support business processes, and that business processes of an organization produce products or services (in the service industry). This business layer can also be understood as products and/or services (so called applications) offered by that organization to its customers in a market. Therefore, it is essential that while creating ICT standards for interoperability, the relation to markets, products and processes is well understood and aligned to a specific use case.

With respect to the MS 1525 recommendation, a full complement of energy management features has to be taken into account in the business layers of SGAM framework. It includes the measurement and prediction of the energy consumption based on current building used, renewable energy production of a building, provision of intelligent controls for the different systems inside the building and recommendations for improvement (e.g. demand limiting, PID load control), warning system for system maintenance (e.g. anti-short cycling) as well as the development of a strategy for maintaining continuous improvements in the energy performance. Moreover, the EMS should come with an energy tracking and reporting system so that a historical record of energy usage is maintained for analysis and energy audit purposes.

These business layer applications should be edited and stored on the PC workstation, where facility manager or building owner can access all information. This shall allow for future system changes or additions by users under proper password protection. An online guidance should be provided to help the operator without referring to the reference manuals. It is recommended that a copy should be also stored off site, since the EMS system will be operating offline. In case of controller failure, it can be reloaded using the backed up data.

FIGURE 11.8 | SEQUENCE DIAGRAM OF SIMULATION SUPPORT TOOLS FOR FACILITY MANAGER



In order for facility managers and building owners to understand the sequential operation of each application, the EMS designer should firstly prepare the sequence diagram. It is essential to begin with this step because it describes how the entire system will operate under a given set of conditions. It defines the used cases and/or operation modes. Afterwards, the corresponding stakeholders including equipment will be defined. Finally, the control events including trigger conditions will be sequentially described. It includes the interaction among stakeholders and equipment one after another.

Figure 11.8 represents a sequence diagram of simulation support tools. The facility manager triggers the simulation and other stakeholders will react to this trigger consequently (BDigital-2, 2012). In this example, FAME represent a main GUI for facility manager with some simulation functions, while Central-App represent the main real-time controls of EMS system. At the same time, the Charging-OP is an electric charging station, which the facility manager would like to simulate. For application developer, the system could also trigger automatically.

For instance, if the ambient temperature is changed or new solar irradiation resource is connected, the EMS system will trigger the photovoltaic power output calculation and store it in database. At the same time, the plausibility check function will be evaluated in parallel with a maintenance application. If the readings exceed a specific range, warning systems will be generated and sent to a corresponding person (ASHRAE, 2015).

Function Layer

A function layer is intended to describe the functional elements of a system and their relationship independent from physical implementation, applied technology, or assigned actor. It may contain a basic function or function groups used to enable individual system or system groups to support the high-level/business level services as mentioned above. These functions can be classified into (ASHRAE, 2015) (OGEMA Alliance, 2011):

- Administration of resources will allow different applications to be executed/operated simultaneously (e.g. share parameters for different applications). Java™ and OSGi are one of the widely accepted software standards that provide a cross-platform execution environment. OSGi provides the functionality to execute different functions in parallel.

- System run-time environment (Time Control) is dealing with clock synchronization. Since most systems will have multiple devices with real-time clocks, a method of coordinating the clocks should be provided.

- Program execution frequency represent how often to operate the sub-systems, such as time-of-day scheduling and demand limiting for HVAC applications. It is varied depending on the type of controllers (e.g. DDC-controller needs to run once every 30 seconds).

- Persistent Storage of preferences data of applications and data structures in database. When the EMS system is re-started after a shutdown, a black-out or a crash, the last state of the resources is recovered. Resource demands, resource access modes and virtual resources are not necessary to store persistently. It should be re-issued by the applications.

- User interface can be achieved via website. The access to these registered resources is based on the access rights of users. Specific implementations may define additional GUI-related services. It is very important for facility managers and/or building owners to communicate offsite with controllers. It is important to note that how often the system operator display data on the screen.

- Data security is required for authorized personnel to perform system functions and track operator actions. Since the system's PC workstations are frequently located in unsecured areas, it is required to set up a username and password for authorized personnel in order to avoid unauthorized access.

- Data logging services is used for logging messages as well as of measurement data series. It can be configured for periodic logging or for logging whenever the resource's value changes. The historic values are stored persistently as a time series. Access to them can be done via the direct access to the time series' entries or, alternatively, with a filtering function (e.g. the mean value over given time intervals).

- Schedule is a resource version with time series. It is attached to simple resources and typically provides future information about them (forecasts, calendar and programs). Time series are functions over time, which are defined by a set of support points (each with timestamp, value and quality) and an interpolation mode that defines what the functions' values are between the support points.

- Grouping is extremely useful to be able to group together equipment with similar functions and/or locations.

- Alarm notifies the operator when something has gone wrong, which could be directly occurred on user interface. The user may only want critical alarms sent to a cell phone as an e-mail. It is necessary to consider the time taken for the operator to notice an alarm.

- Object command and scan represent the time taken for a commanded output to react to an operator-entered change, and any building controller to register and react to a change of state or value of any point, variable, or alarm on the system, respectively.

- Control stability and accuracy is a plausibility check of controller variable (temperature, pressure, humidity) and device accuracy including loss of data transmission. It is necessary to obtain desired accuracy and repeatability of measured and calculated performance metric indices for the performance monitoring system.

Information Layer

While systems and applications in the past were often operated separately, today business requires interactions between multiple systems and applications from different vendors/manufacturers to operate effectively. To do so, a coupling of former separated and heterogeneous systems is necessary. This requires solutions to integrate those systems in a way their functionality is still available and can be adapted to the changing need.

The establishment of a common information model that is to be used throughout many applications and systems requires solutions to cope with different data sources from the various actors. It is the principal term to achieve interoperability. It is indispensable that all applications agree on where exactly in the resource graph information is being placed and how it is encoded. An information model is an abstraction of hardware, so called data model.

It represents their entities including their properties, relationships and operations. It allows both applications and drivers to be developed against this common interface definition. It is the main element to ensure the interchangeability features for the EMS system. It represents an ability that a system can be directly replaced by another system from different vendors without any restricted access or implementation.

This information model can be described through Class-diagram. Its goal is to describe a modeling language in the field of software engineering that is intended to provide a standard way to visualize the design of a system. Figure 11.9 represents the information model based on Class diagram for variable electricity price (BDigital-2, 2012). It exhibits how a software system is split into components and shows the dependencies among these components (ASHRAE, 2015).

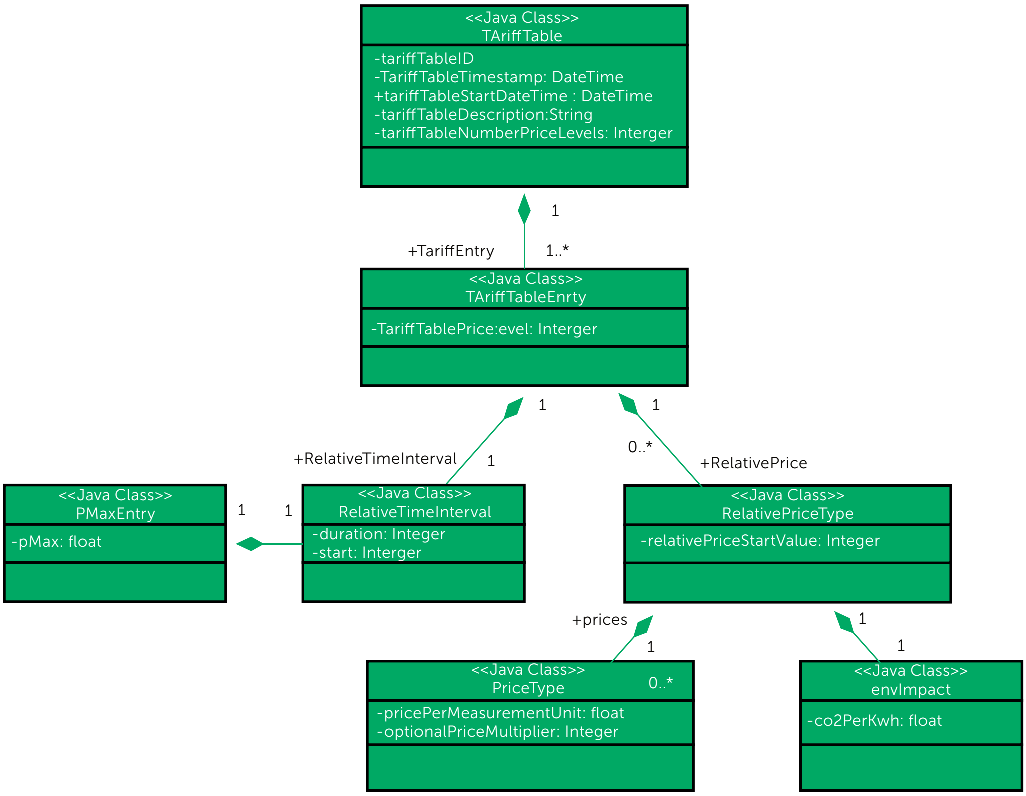


FIGURE 11.9 | CLASS DIAGRAM OF VARIABLE ELECTRICITY PRICE

Communication Layer

A communication layer allows different devices/components to communicate and transfer the information to each other via any kinds of physical mediums, which are classified between wired and wireless.

It contains the rules or standards, so called communication protocols, which defines the syntax, semantics and synchronization of communication and possible error recovery methods. In this way, the information of the physical connection of each resource is made transparent to the rest of the EMS framework. Protocols may be implemented by hardware, software, or a combination of both. They have to be agreed upon by the parties/devices involved, which may be developed into a technical standard.

Communication Types	Physical Mediums	Communication Protocols
Wired	Power line, LAN, RS232, RS485	BACnet, LONWork, KNX, ModBus, DLMS, MBus
Wireless	Radio frequency (433MHz, 868 MHz, 2,4 GHz)	ZigBee, Zwave, WLAN, WMBus, EnOcean

TABLE 11.2 | COMMUNICATION TYPES AND THEIR CORRESPONDING PHYSICAL MEDIUMS AND COMMUNICATION PROTOCOLS

The word standard is often used in discussions of protocols. There are degrees of propriety to the standards continuum, and they can be explained as follows:

a. Industry recognized standard: A protocol that is formally recognized and/or listed by an independent, industry standards organization (e.g. BACnet, KNX, LONWork).

b. Defacto standards: Very popular proprietary protocols in the marketplace that have been embraced by users and manufacturers, and are offered as communications options on a variety of equipment (e.g. Modbus, Allen Bradley DH+, and Opto 22).

c. Proprietary standards: A manufacturer makes proprietary protocols available on a limited basis for use in integrating other products into that manufacturer's network (ASHRAE, 2015).

In practice, if the existing system uses a protocol that is not open (proprietary), it may not be possible to be fully interoperable without physically changing the electronics that perform the communication in the existing devices. It is also possible that the actual physical media that connect the existing devices would not be one of the standard physical links allowed in the chosen open protocol. The most likely solution would be to use a device that acts as an adapter between the existing proprietary network and the new open network.

This adapter would possess enough memory and intelligence to translate the vocabulary and grammar rules of the open protocol to the existing proprietary protocol and back again. The adapter also would contain a map of the existing points that were to be readable and/or writable on the open internetwork. This adapter could also be a complex gateway contains multi-protocols, data models and control algorithms.

In order to make the gateway as affordable and usable as possible, the system EMS designer should limit the number of different points that the gateway must make available from the existing network to the new open network. The system EMS designer also should thoroughly describe any graphics or reporting features he/she desires that use objects (points) from the existing network. If using a system integrator to perform the work of integrating systems that use one communication protocol with systems using another protocol, the BEMS designer will need to define the duties and functions of this service. Figure 11.10 exhibits the process for EMS designer to integrate different sub-systems with different communication protocols (ASHRAE, 2015).

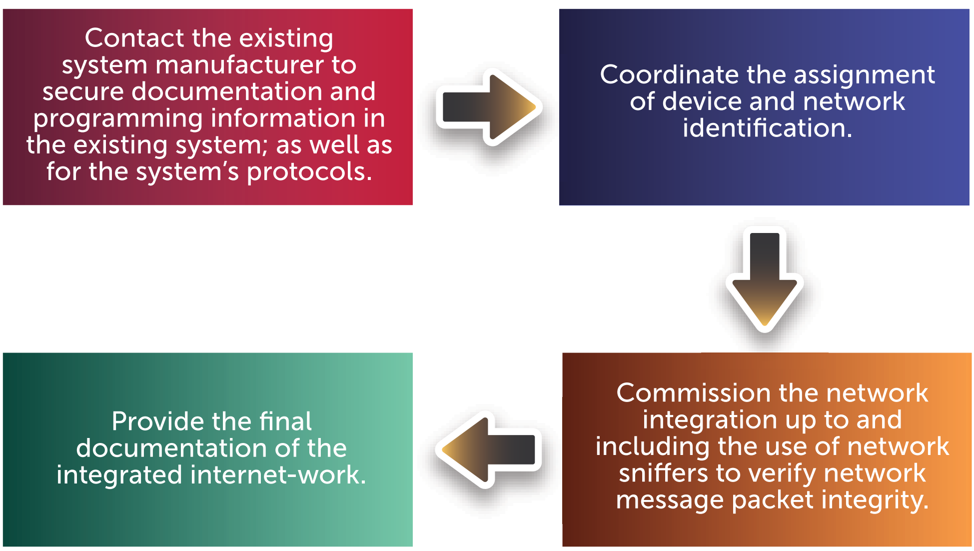


FIGURE 11.10 | SYSTEM INTEGRATION PROCESS BETWEEN DIFFERENT COMMUNICATION PROTOCOLS

With respect to the Internet-of-Thing and industrial internet issues, the Internet-Protocol (IP)-based technologies are still open including transport layers (e.g. TCP, UDP), applications layers (e.g. HTTP, SMTP) and messaging technologies (e.g. AMQP, MQTT, JMS REST).

Component

It is dealing with all building related equipment (e.g. HVAC, lighting, fire alarm), renewable energy generation (e.g. PV, CHP), I/O points (sensors, actors) and power measurement employed in building and/or facility as well as external information (e.g. weather forecast, variable prices), persons (e.g. facility manager) and organizations (e.g. utilities). Some equipment are directly equipped with distributed system controller (BC, CAC or ACS). Therefore, it will also be considered as components under SGAM model.

In order to allow the systems to communicate to each other, all components should be equipped with communication interfaces with corresponding communication mediums (e.g. wired and wireless) and communication protocols as mentioned previously.

- Building related equipment (e.g. HVAC, lighting, fire alarm) and is mostly equipped with distributed system controller. They are mostly comprised with specific communication interfaces (e.g. BACnet, KNX).

- Renewable energy generation (e.g. PV, CHP) is also mostly equipped with distributed system controller with manufacturers' proprietary protocols. However, manufacturers start to deploy with standard protocols (e.g. ModBus).

- I/O ports: Input sensors collect all measured data (e.g. temperature, pressure, humidity, air and water flow, equipment status, metering data and alarms) and then transmit information to the controller by a change in voltage (0-10VDC), current (4-20mA), or resistance (RTD or thermistor). This information could also be analog or digital. Outputs include the start/stop of equipment and modulation of dampers, valves, pumps, and fans.

- Power measurement: It can be classified into power meter with one-way communication and smart meter with two-way communication. They both measure the power consumption and transmit the information via different protocols. The ModBus, S0 and D0 are mostly the used protocols for power meter to communicate with EMS, while the DLMS/COSEM is the most well-known protocols to communicate to utilities in a two-way communication.

- External information: They are all related external information to be used to control the facilities. These include information from utilities (e.g. variable price, grid constrain), facility managers (e.g. calendar, comfort constrain), third parties (e.g. weather forecast, energy contractor requirements) and facility owner (e.g. report). Most of the information will be available in schedule/array format (each with timestamp, value and quality).

The object list is a tabulation of all system hardware and software points for each sub-system. These points can be physical points that are wired to the system or virtual software points that are calculated from other parameters. It is obvious, that EMS designer cannot list all of the software objects since they will tend to be specific to the manufacturer and system installer.

If a specific object is required for interoperable operations, sequences of operation, or other system functions, then it must be included in the object list. Table 11.3 represents an object list of AHU sub-system (ASHRAE, 2015), (OGEMA Alliance, 2012), (BaaS, 2013)

Entity	**AHU**	**ID[1]**	**XXX.XXX.XXX**		
Name	Short description	HW/SW Input/ Output Data Type[2]	Unit Default value Value Ranges	GUI Trend[3]	Remarks
Info:	Information to AHU	SW Input String	- - -	Y -	
Zone Temperature	10000 ohm thermistor or 1000 ohm RTD	HW Input Float	°C 23°C –1°C to 38°C	Y 15min	
Return Air Temperature	Locate upstream of air handler's return air damper	HW Input Float	°C 23°C 16°C to 32°C	Y 15min	
Cooling Valve	Control of cooling circuit, ensure the quantity of	HW Output Float	M^3/h - -	Y 15min	
Supply Fan Start/Stop	Start/stop switch for supply air	HW Output True/False	- On On/Off	Y COV	
Cooling Setpoint	Cooling temperature in the space	SW - Float	ºC 25 ºC 15ºC - 28 ºC	Y +/- 0.6 ºC	
Schedule	Operation schedule	SW - Array(Float)	hh.mm - -	Y -	
Supply Fan Failure	Warning system in case of fan failure	SW - True/False	- Off On/Off	N -	

Remarks
1. System ID should be classified with regards to the control levels defined in Figure 11.6
2. Data types include String, Integer, Float and True/False as well as arrays string, integer and float
3. Trends include trending time interval (for analog points), change of value (COV for binary points), or a differential value change (for analog points).

TABLE 11.3 | OBJECT LIST OF AIR HANDLING UNIT

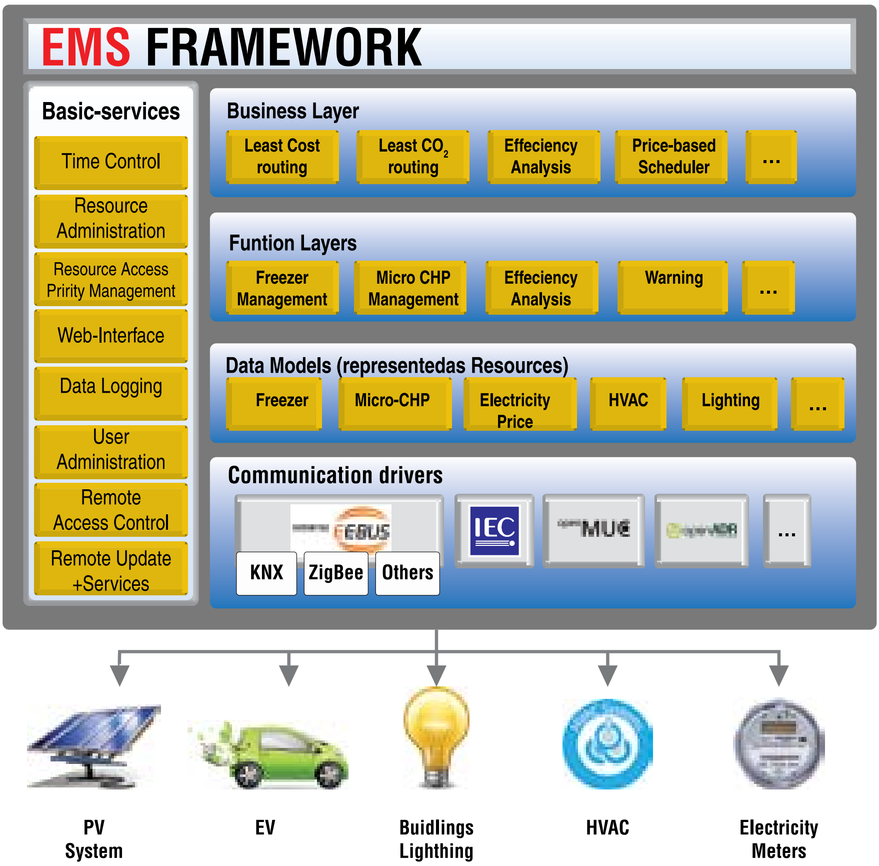
EMS Gateway

In order to allow the system to communicate with more communication networks and/or external information with different application protocol messages while maintaining the data security of the system, Gateway must be used.

It is the most important component for EMS system, which is assumed to be the main interface between internal and external systems. The gateway acts as a firewall between the public and the private communication systems allowing only the interaction between the systems as defined by the gateway configuration.

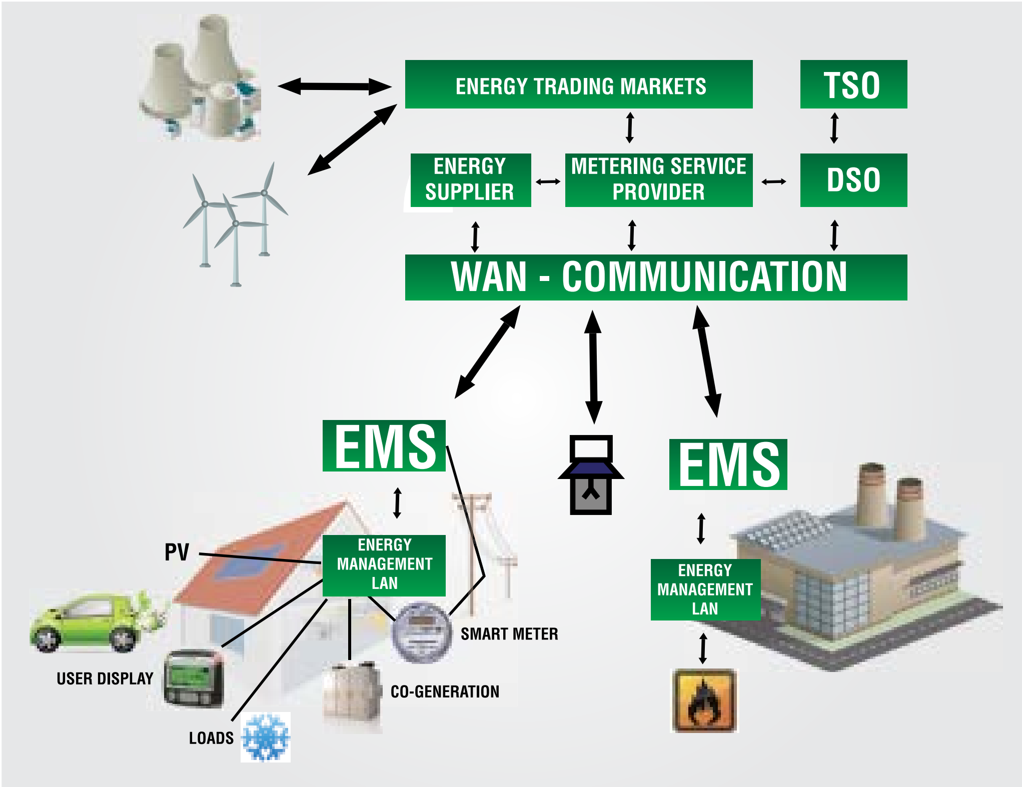
A gateway is a platform allowing the communication among different sub-systems including energy generators and consumers as well as storage subsystems (e.g., lighting, HVAC, PV, etc.), the high level facility monitoring and control platform through facility manager, and external stakeholders (e.g. utilities, weather forecast, etc.). Figure 11.11 exhibits the five dimensions of interoperability layers of EMS Gateway as well as the interfaces to components/equipment employed in buildings.

FIGURE 11.11 | EMS GATEWAY ARCHITECTURE



It could be also employed by smart meter for the billing issue, so called "Smart Meter Gateway" and/or EMS system for the flexibility of building intelligent control, so called EMS-Gateway. Figure 11.12 represents the interaction between EMS Gateway inside the building and external stakeholders including energy suppliers, distributed system operator (DSO), metering services and energy trading market (OGEMA Alliance, 2011).

FIGURE 11.12 | INTERACTION BETWEEN EMS GATEWAY TO EXTERNAL STAKEHOLDERS



In some situations, a gateway can provide connectivity between devices in times that it would not be possible in any other way. In addition, a gateway can create a competitive bidding situation. The financial savings resulting from competition may make the limitations and cost of the gateway worthwhile. Thus, gateways provide a way to retain installed proprietary equipment that is still functioning satisfactorily, while migrating toward open, interoperable systems in a step-by-step manner as the proprietary systems and components reach the end of their useful life. Moreover, a gateway can provide the opportunity to allow connectivity between different BEMS, such as life safety and HVAC control, yet maintain the integrity of the critical life safety systems.

Unfortunately, all gateways have finite information storage and processing resources. Specifications for gateways must clearly state what information must be available through the gateway, and how much future expansion is required. Also, they have a limited ability to translate dissimilar concepts such as schedules, alarms, prioritized commands, and trending data. In addition, it is usually not possible to program or configure controllers over the network by passing messages through a gateway. Instead, a separate connection that bypasses the gateway is usually required.

Noticeably, failure of the gateway results in a loss of communication between all devices on opposite sides of the gateway. Moreover, gateways can introduce time delays when attempting to retrieve information. Gateways make troubleshooting network problems more difficult. The speed of the gateway may make accessing data a slower process. Furthermore, if the equipment or system that the gateway is using to integrate is replaced or upgraded, the gateway often needs to be replaced or reprogrammed in order to enable continued data exchange.

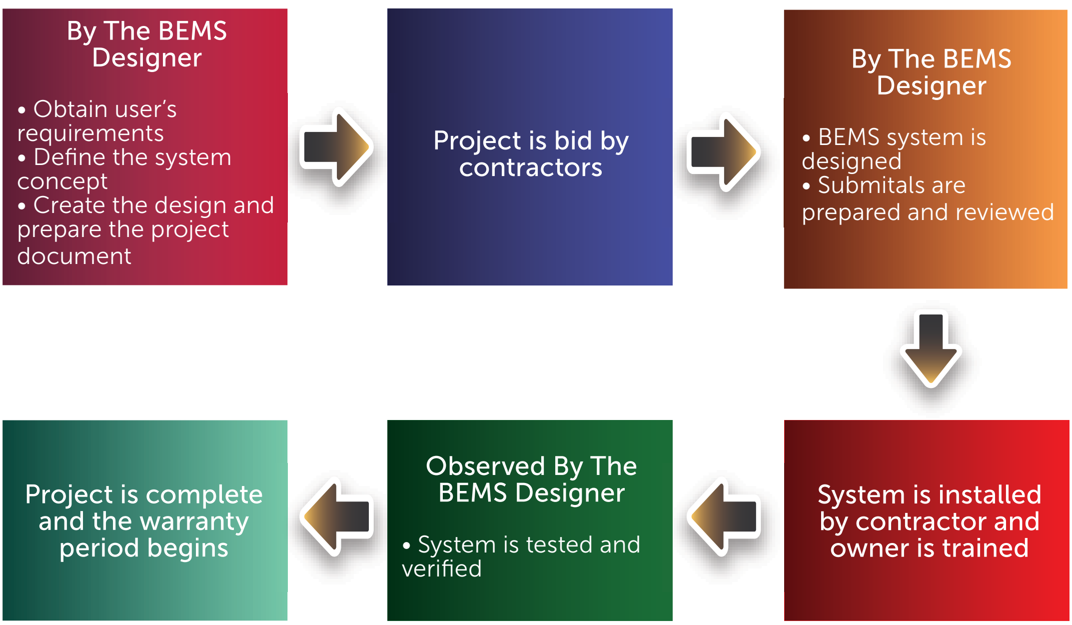
DESIGN OF A BEMS

The following section describes the steps involved in providing a BEMS from design through the end of the warranty. The BEMS designer is the focal point for these steps and the contractors will be responsible for implementation. It is necessary to perform these steps properly in order to run the BEMS in the most efficient manner and satisfy the clients, respectively.

Steps in providing a BEMS

The steps involved in providing a BEMS are shown in Figure 11.13 (ASHRAE, 2015).

FIGURE 11.13 | EMS DEPLOYMENT PROCESS



Designing the BEMS

After the project scope has been defined, the BEMS designer can complete the detailed BEMS specification. Following are methods recommended by this guideline (ASHRAE, 2015):

a. Designer should isolate each sub-system. If multiple systems are used, a single typical system can be created, and minor modifications can be shown.

b. For each system, the BEMS designer should produce a system schematic drawing. The drawing will need to show the critical control components and its physical relationships of various components. It includes layout of piping, equipment, sensors and valves for steam, hot-water, and chilled-water systems,

c. Using the drawings, create the sequences of operation, which could be followed by sequence diagram. The sequences of operation could appear either in the sequence diagram or in the written specification.

d. With the sequence and the system drawing, the BEMS designer can now prepare a system object list including component lists defined and its corresponding communication protocols. This is an important system document that shows which hardware and software points the contractor will need to provide, along with the key functions of these points.

e. The mechanical and electrical drawings will need to show BEMS elements in correspond to BEMS control levels. These will typically include equipment locations, space and outdoor sensor locations on the floor plans, damper locations and schedules on the mechanical plans, and locations of control panels requiring 120 VAC on the electrical plans.

f. The BEMS designer can start to create the project specifications. This could be created using a built up series of "master specifications", which will provide a good starting point for producing an unbiased document, but it must be edited to suit the considerations of each individual project.

g. Determine who is responsible for the IP and non-IP network connectivity, how the system will be secured, how the system will be designed and who will perform the design work. For example, the mechanical and electrical designers design the equipment and systems. The integration of these systems may be performed by facility master system integrator (FMSI).

Project Drawings

Control drawings are a critical element in documenting the system design. It is necessary to guarantee a graphical depiction for the contractor, provide a clearer definition of the control hardware requirements and facilitate system checkout during both the shop drawing and installation phases of the project.

A drawing shows the contractor the physical relationships of various components, such as fans and coils. The control devices can be accurately located relative to the system components (e.g., the freeze stat should be shown upstream of the heating coil). Flow diagrams showing a schematic layout of piping and equipment should be provided for steam, hot-water, and chilled-water systems. Control devices (sensors and valves) should be shown in the appropriate locations in the piping (ASHRAE, 2015).

Sequences of Operation

The sequences of operation describe how the system shall function and are the designer's primary method of communication to the control system programmer. It is important to achieve a clear sequence of controls of all operation modes and the limitations of the specific controls hardware. The followings are suggestions to assist in developing successful control sequences (ASHRAE, 2015):

a. Provide a description of the system at the beginning of each section to assist the reader in understanding the system.

b. Organize sequences into the logical hierarchy of systems and the subsystems they serve. The most energy-efficient sequences usually start at the lowest level and feed operational requests upward.

c. Use tables and diagrams where possible to assist in conveying sequencing logic.

d. Show formulas in the sequences if they are to be used in calculations.

e. Write the sequences in such a way that it will make it easy to use the document to verify system functionality during construction and testing.

f. Control loop initial or default set points should be provided.

g. Keep the sequences as simple as reasonably possible, but without compromising energy conservation and other performance goals.

h. Use sequences that have been used successfully on similar projects as a template.

i. Show what objects (points) may be shared by other systems. For example, the vacancy/occupancy sensors in the lighting system could be shared with HVAC system.

j. Global sequences may also exist that affect all systems that need to be included in the contract documents.

Object list

The object list describes all system hardware and its corresponding communication protocols as well as software points.

Project Specification

When editing a master specification, it is important to refer to the project criteria that were collected at the beginning of the process. A large project with critical needs may require a more complex sequence, submittal, and checkout. A small project may not require an on-site user interface or extensive sequences. Any specification section must answer three questions:

a. What interrelationships exist between the work of this section and the remainder of the project?

b. What materials and products are involved?

c. How are they incorporated into the work?

Network Connectivity Requirements

The following connectivity requirements should be identified in the project specification (ASHRAE, 2015):

a. Control network infrastructure, including wiring, routers, gateways, panels.

b. Data network (LAN/Ethernet) infrastructure, switches, routers, hubs, and BEMS connectivity points.

c. Coordination of responsibilities between IT, FMSI, controls contractor, and equipment supplier.

d. Requirements for the BEMS front-end software server, software, graphics, and integration with BEMS devices.

e. Security, access, firewalls, and related infrastructure issues, i.e. passwords, user levels, administration rights, etc.

Warranty

The warranty is a written guarantee, issued to the purchaser of a product by its manufacturer/installer, promising to repair or replace it if necessary within a specified period of time; providing sometimes periodic servicing. This specific period varies according to the type of project and the owner's requirements. It is usually 1 year, but sometimes it exceeds that depending on the owner's desires.

The owner of the BEMS should contact the manufacturer/installer in case of notification of failure and/or defects. The response time to correct the failures and/or defects should not exceed 24 hours unless there are exceptions, and this should be clear and acceptable from both sides (owner and manufacturer/installer) in the warranty terms.

Also, this warranty should guarantee for the software updates and periodic maintenance services. Maintenance shall include, but not be limited to, control components/instruments, accessories, hardware, and software (ASHRAE, 2015).

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END OF CHAPTER 11

GLOSSARY OF TERMS

ACH	Air Changes per Hour
ACMV	Air Conditioning and Mechanical Ventilation
AHU	Air Handling Unit
BEI	Building Energy Index
BMS	Building Management System
BSEEP	Building Sector Energy Efficiency Project
CAV	Constant Air Volume
CFL	Compact Fluorescent Lamp
CRI	Colour Rendering Index
EMS	Energy Management System
FCU	Fan Coil Unit
HID	High Intensity Discharge
HRT	Heat Rejection Ton
HVAC	Heating, Ventilation and Air-Conditioning
LED	Light Emitting Diode
LMS	Lighting Management System
LOR	Light Output Ratio
LPD	Lighting Power Density
LSG	Light-to-Solar Gain
MERV	Minimum Efficiency Reporting Value
OTTV	Overall Thermal Transmission Value
PIR	Passive Infrared
PMV	Predicted Mean Vote
PPD	Predicted Percentage Dissatisfied
RPM	Revolutions Per Minute
SHGC	Solar Heat Gain Coefficient
TRY	Test Reference Year
UGR	Unified Glare Index
VAV	Variable Air Volume
VLT	Visible Light Transmission
VSD	Variable Speed Drive
WWR	Window-to-Wall Ratio

APPENDIX

Additional information and data for each of the chapters in this book is available on the BSEEP website:

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