



**BEHIND
THE
COOL**

**A BEGINNER'S GUIDE TO
AIR CONDITIONING
AND VENTILATION**



**COOLING
FUNDAMENTALS**



**VENTILATION
SYSTEMS**



**PRACTICAL DESIGN
& INSTALLATION**



**MAINTENANCE
& EFFICIENCY**

RAYMOND CAI



**SIMPLE
& PRACTICAL**



**REAL-WORLD
APPLICATIONS**



**COMFORT,
HEALTH &
ENERGY SAVING**

Preface

Air conditioning is more than a comfort feature — it shapes how buildings are designed, used, and experienced. In a hot and humid climate, understanding Air Conditioning and Mechanical Ventilation (ACMV), also known as HVAC, is essential for creating healthy, efficient, and comfortable indoor environments.

This book is written as a beginner-friendly guide for readers who requires a clear and structured introduction to ACMV principles without needing prior technical knowledge. It explains the fundamental ideas behind cooling, ventilation, air movement, psychometrics, system types, controls, installation, testing, and maintenance in a practical and easy-to-follow way.

The content is organized to help readers build confidence step by step, starting from basic concepts and moving toward real-world applications. Wherever possible, the explanations are supported by figures, diagrams, and tables so the ideas are easier to visualize, digest and apply.

This guide also reflects Singapore's local context, including commonly used standards and good practice such as SS553 and BCA Green Mark. Whether you are a student, technician, engineer, or simply someone interested in how buildings stay cool and comfortable, this book is designed to help you understand ACMV in a simple and structured way.

No prior knowledge is needed — just stay curiosity and a willingness to learn.

Disclaimer

This book is intended for educational and general informational purposes only. While every effort has been made to ensure accuracy, readers should always refer to the latest manufacturer manuals, applicable standards, regulations, and professional engineering advice before applying any information in practice.

Table of Contents

I. Why we demand ACMV?	3
II. How Air-conditioning Works	5
III. Key Terminology of Air-conditioning System.....	7
IV. Indoor & Outdoor Units	15
V. Types of Air-Conditioning Systems	29
VI. Mechanical Ventilation (MV) Systems	37
VII. Control System & Energy Efficiency.....	48
VIII. Indoor Air Quality & Filtration	56
IX. Design Considerations and Case Study.....	58
X. ACMV Installation Procedures	64
XI. Testing & Commissioning	68
XII. Maintenance and Brand Selection	75
Afterword	79
References	80

I. Why we demand ACMV?

If you take a look at the world map, you may be curious why Singapore is the only developed country among tropical countries. Singapore's founding father, Mr. Lee Kuan Yew, firmly believed that air conditioning was the secret to his country's success as well as key to public efficiency. The first thing he did upon becoming prime minister was to install air conditioners in buildings where the civil service worked. He even called air conditioning the 20th century's most important invention—for Singapore, at least.

An ACMV (Air Conditioning and Mechanical Ventilation), system is essential for maintaining a safe, comfortable, and healthy indoor environment. It works by actively controlling temperature and humidity while circulating fresh outdoor air and safely exhausting stale air, odors, and indoor pollutants.

- **Thermal Comfort:** It maintains precise temperature and humidity ranges, keeping building occupants comfortable regardless of extreme outdoor weather (especially crucial in tropical climates like Singapore).
- **Indoor Air Quality (IAQ):** It removes airborne pollutants, dust, allergens, and bacteria. Without fresh air circulation, environments become stuffy, potentially exacerbating allergies and respiratory issues.
- **Moisture Control:** By managing relative humidity, it prevents the growth of mold and mildew, which protects the physical structure of a building and prevents health hazards.
- **Safety & Exhaust:** Mechanical ventilation safely vents out harmful gases (like carbon monoxide from basement car parks) and toxic fumes from industrial processes or laboratories.
- **Equipment Protection:** Server rooms, data centres, and manufacturing plants rely on ACMV to prevent heat-sensitive equipment from overheating and failing.
- **Regulatory Compliance:** Proper ventilation and air conditioning are legally required in commercial and industrial spaces to meet health codes and building sustainability standards (such as Singapore's BCA Green Mark).

For a typical room, it will be designed either in **N/V (Natural Ventilation)**, **M/V (Mechanical Ventilation)** or **A/C (Air-conditioning) system**.

Natural ventilation refers to the process of exchanging indoor air with outdoor air using natural forces like wind and stack effect (temperature differences), without relying on mechanical systems like fans.

Mechanical ventilation systems are essential for continuously replacing stale indoor air with fresh, filtered outdoor air. In modern, airtight buildings—or in hot, humid climates like Singapore—they maintain safe indoor air quality, manage humidity, prevent toxic mold growth, and dilute airborne contaminants when natural airflow is inadequate.

Is NV or MV more than enough for us? No way. As we are still feeling too hot/cold!

Thanks to Willis Carrier, we have Air-Conditioner in place in 1902!

How should I choose?

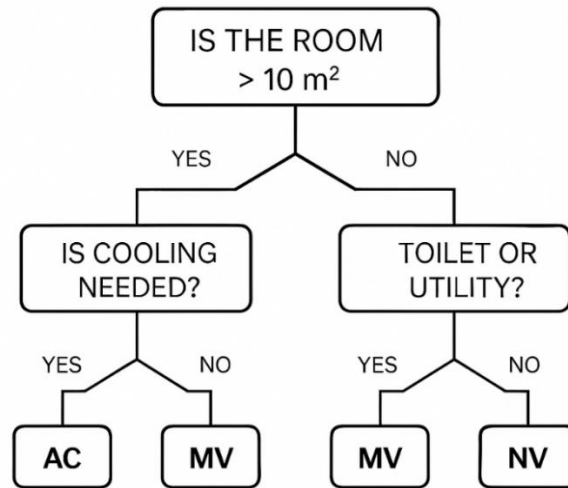


Figure 1.1 Decision Tree to Select NV, AC or MV

Air conditioning makes large and tall buildings feasible. Without air conditioning, buildings must be built narrower or with light wells so that inner spaces receive sufficient outdoor air via natural ventilation. Air conditioning also allows buildings to be taller since wind speed increases significantly with altitude making natural ventilation impractical for very tall buildings.

Besides *comfort purpose* to human, air-con aim to provide *a suitable environment for a process* being carried out as well, regardless of internal heat and humidity loads and external weather conditions. Process applications include but not limited to:

- Hospital operating or clean room: in which air is filtered to high levels to reduce infection risk and the humidity controlled to limit patient dehydration. Although temperatures are often in the comfort range, some specialist procedures such as Cardiac surgery require low temperatures (about 18 °C).
- Facilities for breeding laboratory animals: Since many animals normally only reproduce in spring, holding them in rooms at which conditions mirror spring all year can cause them to reproduce year-round.
- Data Centre: Recommended temperature range 18 °C~27 °C and relative humidity 40%~60%, for cooling down their facilities and avoid condensation. Facilities are increasingly shifting toward advanced liquid cooling to more efficiently manage dense hardware.

II. How Air-conditioning Works

Air conditioning works by transferring heat from indoor space to the outside, using refrigerant as the heat transfer medium. This process involves the refrigerant evaporating and absorbing heat indoors, and then condensing and releasing heat outdoors.

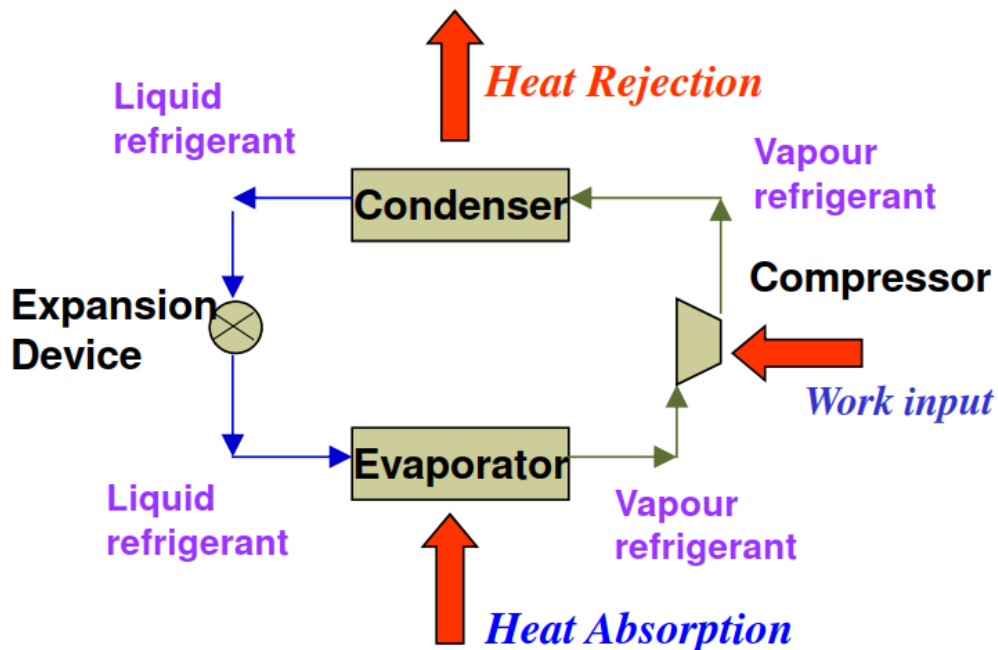


Figure 2.1 Basic Refrigerant Cycle

Where we find the main component of A/C System are:

1. **Compressor:** the **heart of the system**. compress and pump refrigerant vapor around, increasing its pressure and temperature. It comprises of:
 - Electric Motor - Drives the internal pistons, scroll, or screws
 - Compression Mechanism - Can be scroll, reciprocating piston, screw, or centrifugal
 - Oil Separator - Removes and returns lubricating oil to avoid system loss
 - Suction & Discharge Ports - Inlet for refrigerant vapor, outlet to condenser
2. **Condenser:** Perform heat rejection/release, refrigerant cools down and revert from a gaseous state to a liquid form. It comprises of:
 - Condenser Coil - Heat exchanger where refrigerant releases heat to air/water
 - Cooling Medium - Either air (air-cooled) or water (water-cooled)
 - Condenser Fan - Forces airflow across the coil to enhance heat rejection, driven by DC/AC/EC Motor.
 - aluminium fins - Improve heat transfer by increasing surface area

3. **Expansion Device:** The expansion valve controls and regulate the transition of refrigerant, allowing refrigerant temperature and pressure drop. There are 4 major types:
 - Capillary Tube (low efficiency)
 - Thermostatic (good efficiency)
 - Float Valve (high efficiency)
 - Electronic (excellent efficiency)
4. **Evaporator:** Perform **actual cooling**, where refrigerant absorb heat and convert from a liquid to a gas. It comprises of:
 - Evaporator Coil - Heat exchanger for air or fluid to lose heat to refrigerant
 - Blower Fan (in FCU or AHU) - Moves warm air across the coil for cooling, driven by DC/AC/EC Motor.
 - Drain Pan - Collects condensed moisture from air (latent heat removal)
 - Thermostatic Sensor - Monitors coil temperature to prevent icing
5. **Refrigerant:** a media used to transfer heat around. Common refrigerants are:
 - a. R-410A, a hydrofluorocarbon (HFC), does not contribute to ozone depletion but GWP (Global Warming Potential) = 2088;
 - b. R-134a, a hydrofluorocarbon (HFC), does not contribute to ozone depletion but GWP (Global Warming Potential) = 1430;
 - c. R-32, also HFC, has lower Global Warming Potential (GWP=675), meet Singapore BCA Green Mark 2021 Criteria (GWP \leq 750 and ODP = 0).

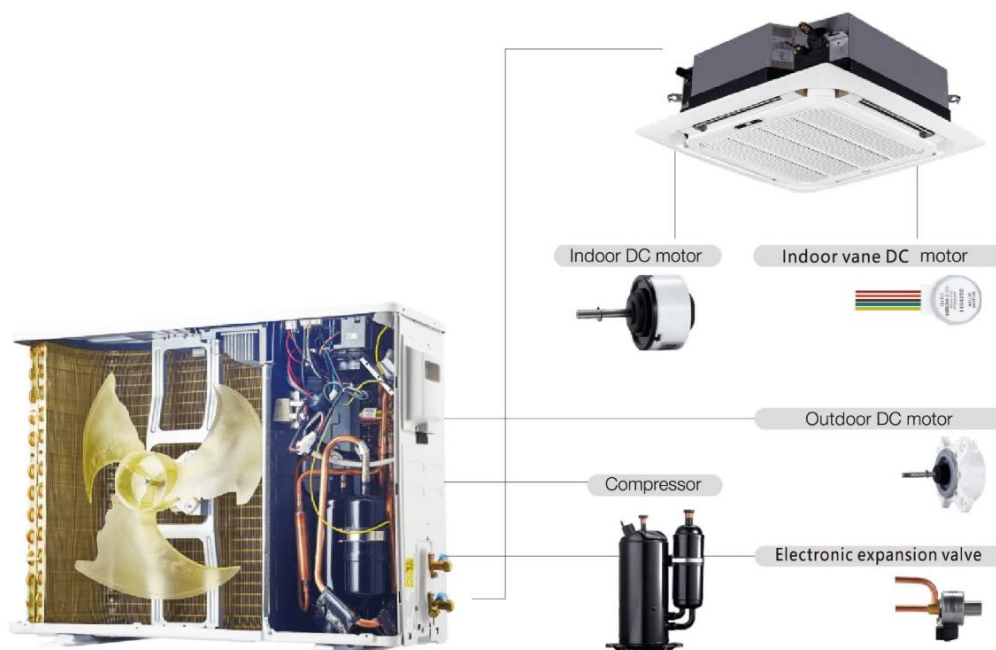


Figure 2.2 Basic A/C System Components

III. Key Terminology of A/C System:

In this chapter, we will focus on fundamental terms that will benefit your understanding of advanced part from next chapter. We will commence from cooling load and capacity, are you ready?

Cooling load

The rate at which heat energy needs to be removed from a space to maintain a specific temperature and humidity (“Need”).

Cooling capacity

The maximum amount of heat a cooling system (like an air conditioner) can remove from a space per unit of time (“Supply”). A 3.5kW air conditioner, for instance, can remove 3.5 kilowatts of heat per hour. It shall match or slightly higher than cooling load.

Standard unit for cooling capacity is Watt, RT and BTU/hr

RT (Refrigerant Ton)

1 Refrigerant Ton is the energy to melt one ton of ice in 24 hours.

BTU (British Thermal Unit)

A measure of cooling or heating capacity. To raise one pound of water by one degree Fahrenheit, requires one BTU of heat. 1 BTU = 253 Calories = 0.293 W.h

$$1 \text{ RT} = 12,000 \text{ BTU/hr} = 3.517 \text{ kW}$$

$$1 \text{ kW} = 3412 \text{ BTU/hr}$$

Note: kW here is not same meaning of electrical power

There are 3 terms for measuring A/C system efficiency: COP, EER and kW/RT

Coefficient of Performance (COP)

A measure of a heat pump's or refrigerator's efficiency. A COP of 3.5 or more is often cited as a good benchmark. A COP below 2 is generally considered less efficient for heat pumps. Sometimes it is called EER (Energy Efficiency Ratio) as well.

$$COP = \frac{\text{Cooling Capacity in kW}}{\text{Power Input in kW}}$$

Energy Efficiency Ratio (EER)

The ratio of the cooling capacity (measured in BTU/hr) of an air conditioner to its power consumption (measured in watts) at a specific operating condition. It is similar to COP

but specifically focuses on the cooling performance of an air conditioner. An EER of 12 or more is often cited as a good benchmark.

$$EER = 3.412 \times COP$$

In Singapore, NEA rates **Integrated EER** from 1 to 5 ticks, with 5 being the most efficient (*IEER more than 6.15 for 3 Phase VRF*). IEER is more accurate to reflect real energy use under part load performance (Usually higher than EER):

$$IEER = 0.02 \times EER_{100\%} + 0.617 \times EER_{75\%} + 0.238 \times EER_{50\%} + 0.125 \times EER_{25\%}$$

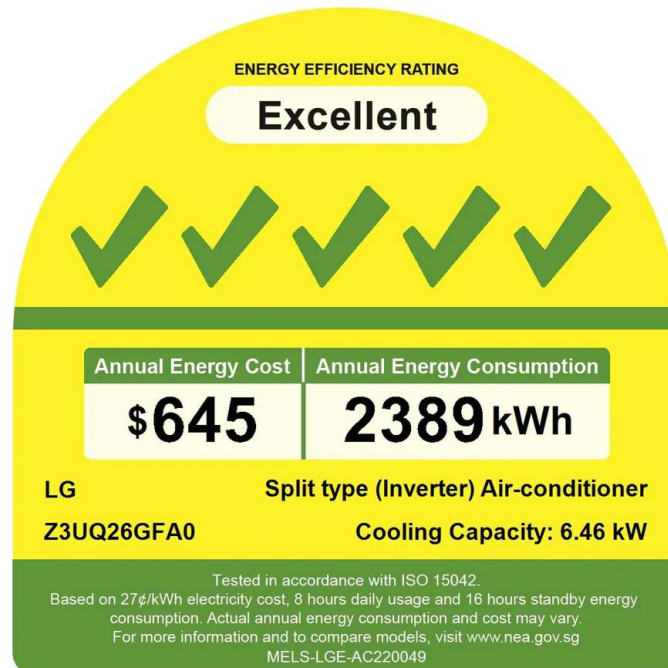


Figure 3.1 NEA Energy Rating (5 Ticks)

For more info, may visit <https://www.nea.gov.sg/our-services/climate-change-energy-efficiency/energy-efficiency/household-sector/tick-rating>

kW/RT

This system efficiency ratio essentially tells how much electrical power is needed to achieve a specific cooling capacity. A lower kW/RT value means less power is needed for the same cooling output, indicating higher efficiency.

$$1 \text{ kW/RT} = 3.5 / COP = 12 / EER$$

Next, we have some common terms for **measuring air movement:**

CMH (Cubic Meters per Hour)

A measure of the volume of air moved by a fan or air conditioning system per hour.

CFM (Cubic Feet per Minute)

Similar to CMH but in imperial unit. an air compressor rated for 30 CFM means it can move 30 cubic feet of air per minute.

$$1 \text{ CMH} = 0.588 \text{ CFM} = 0.278 \text{ L/s} = 0.000278 \text{ m}^3/\text{s}$$

FPM (Feet Per Minute)

A unit of measurement for air velocity. It indicates how fast air is moving in a specific direction, usually within a duct.

$$FPM = \frac{CMH \times 0.01639}{\text{Duct Area (m}^2\text{)}}$$

$$1 \text{ m/s} = 196.85 \text{ FPM}$$

ACH (Air Changes per Hour)

Measures how many times the entire volume of air in a room is replaced by fresh or filtered air in one hour.

$$ACH = \frac{CMH}{\text{Room Volume}}$$

ESP (External Static Pressure)

One of the key specs in FCU or AHU selection — it tells you how much resistance the unit can handle from the duct system, helping determine how long and complex your duct run can be.

Table 3.1 ESP Application Related to Duct Run

ESP (Pa)	Duct Run (m)	Remarks
30 Pa	<10 m	Very short with few fittings (e.g. hotel room)
50 Pa	10–20 m	Small room or low complexity
80–100 Pa	20–35 m	Typical for medium rooms with bends
150 Pa+	>40 m	Long runs or high-resistance systems

Psychrometric Theory