Air Conditioning System

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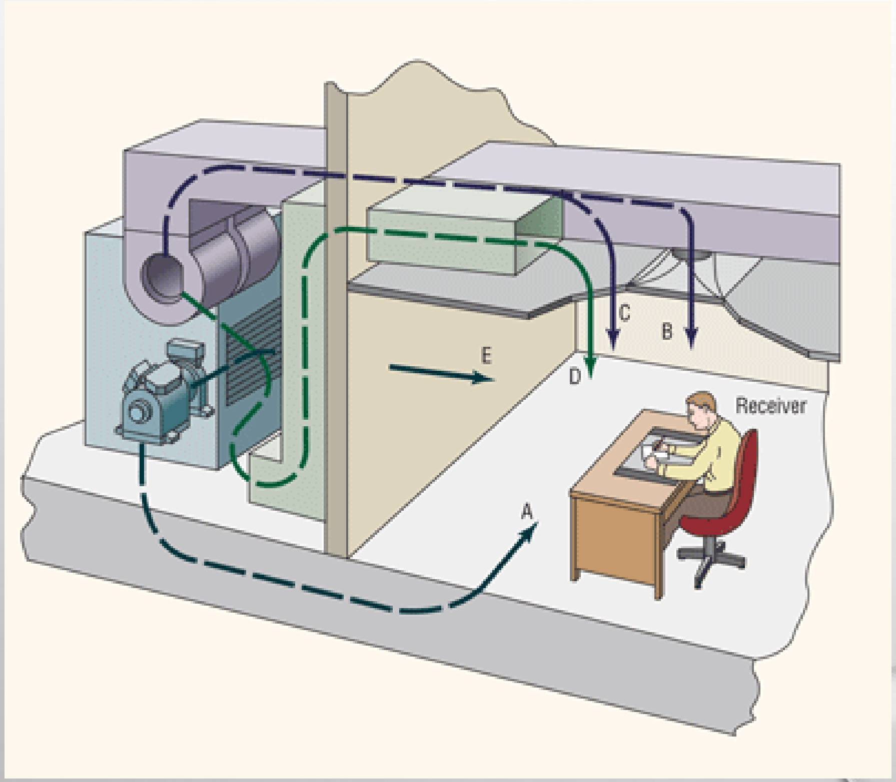
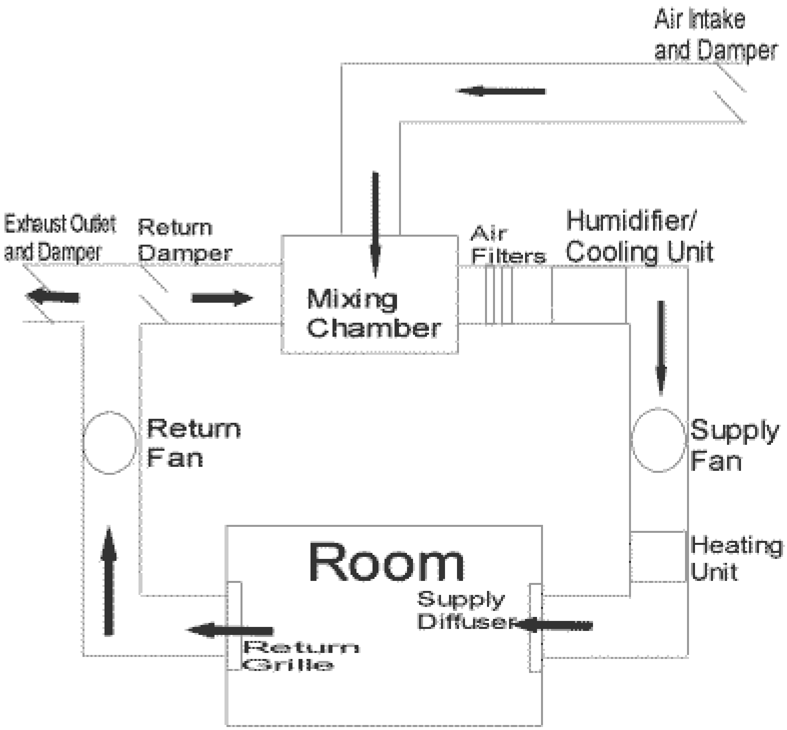
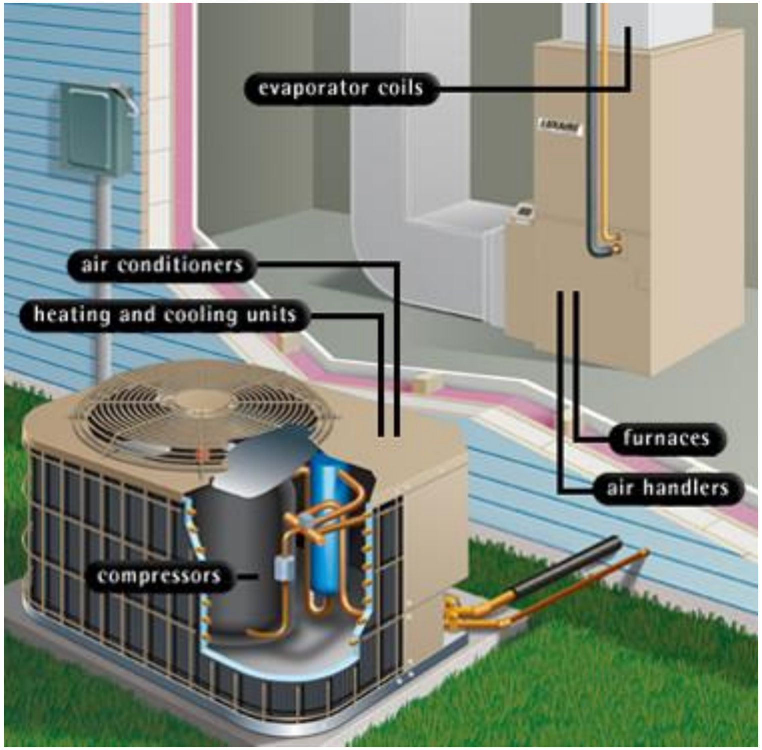
Departemen Teknik Mesin Universitas Diponegoro

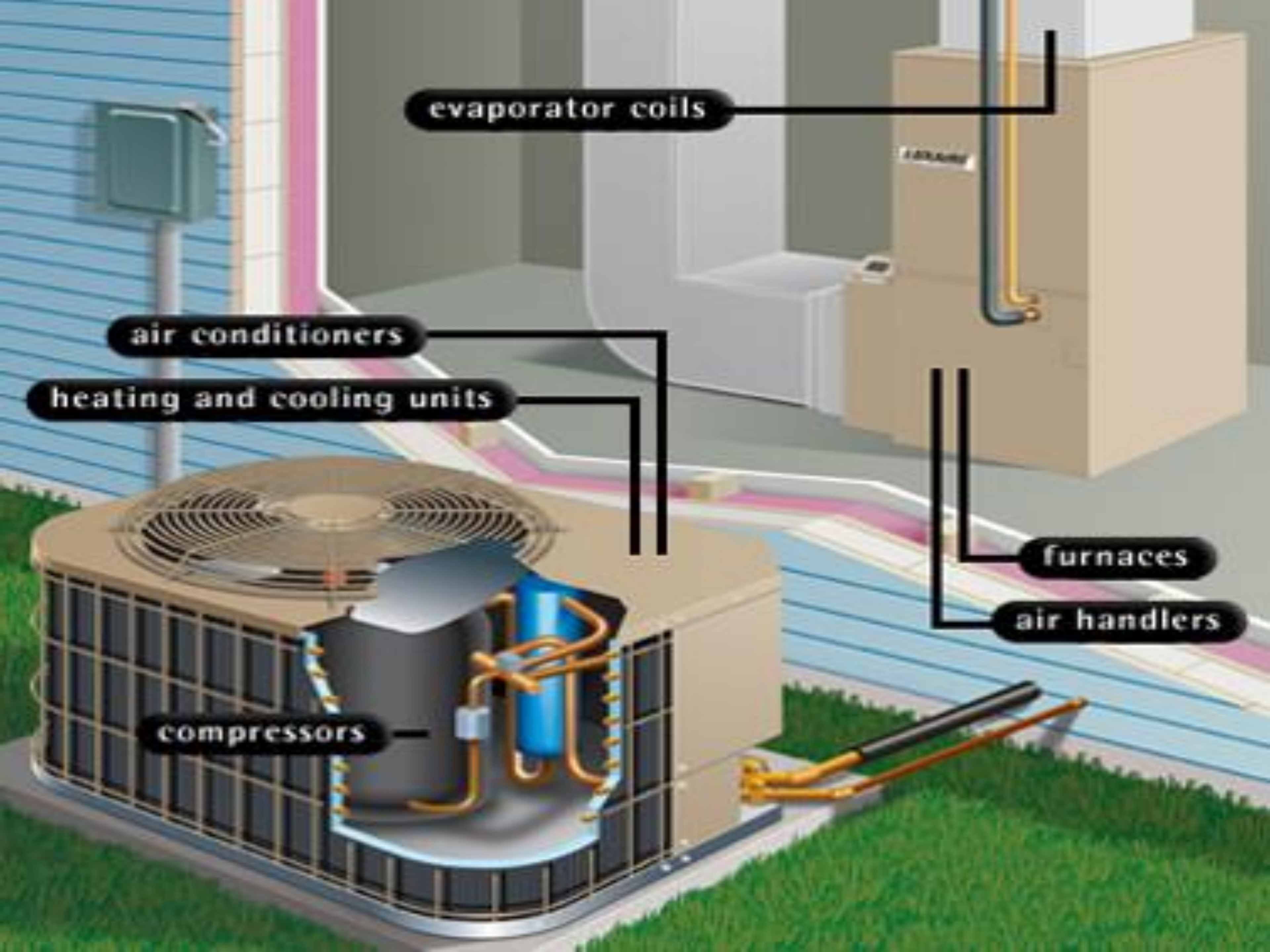
AIR CONDITIONING EQUIPMENT AUDIT

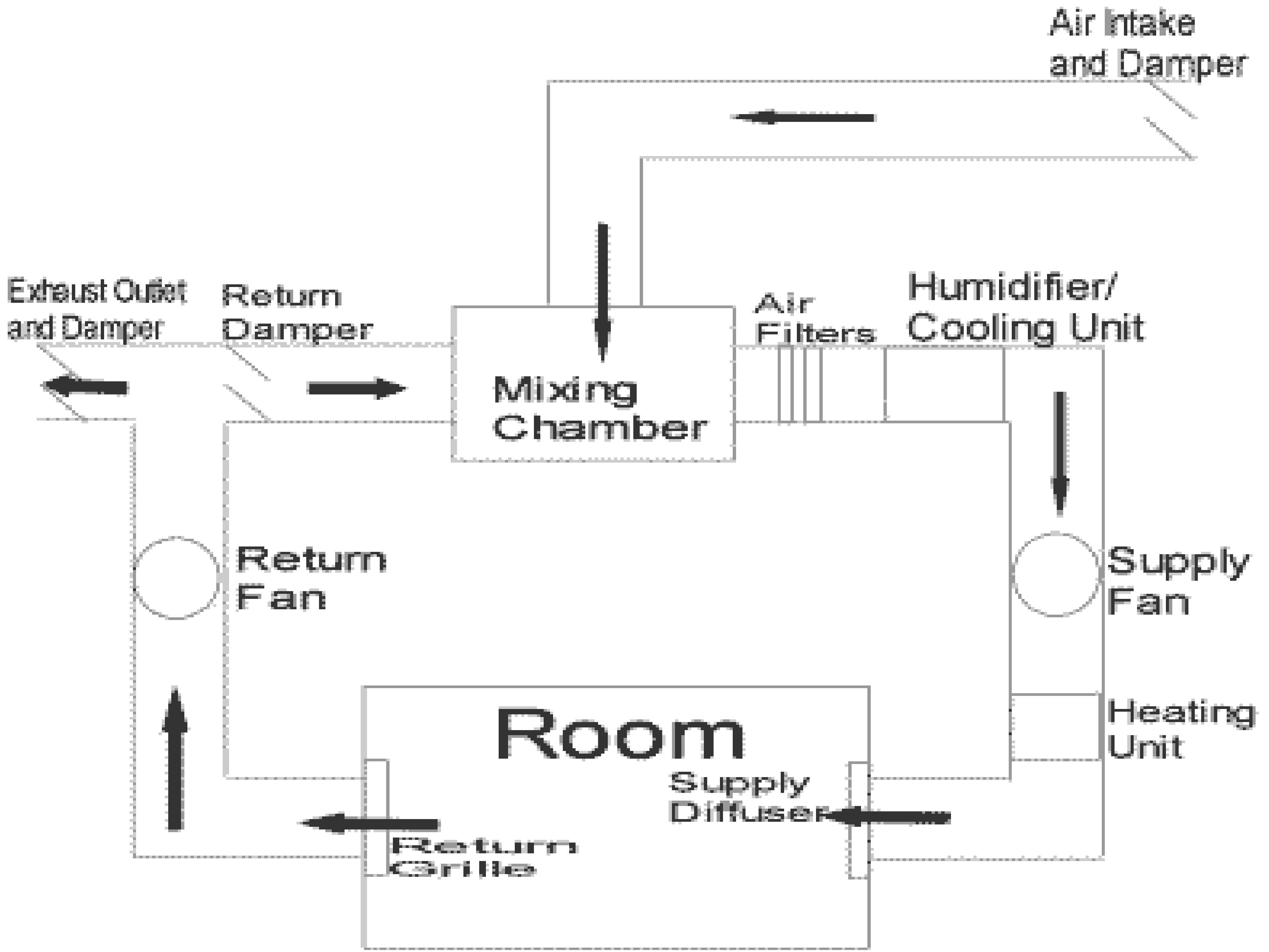


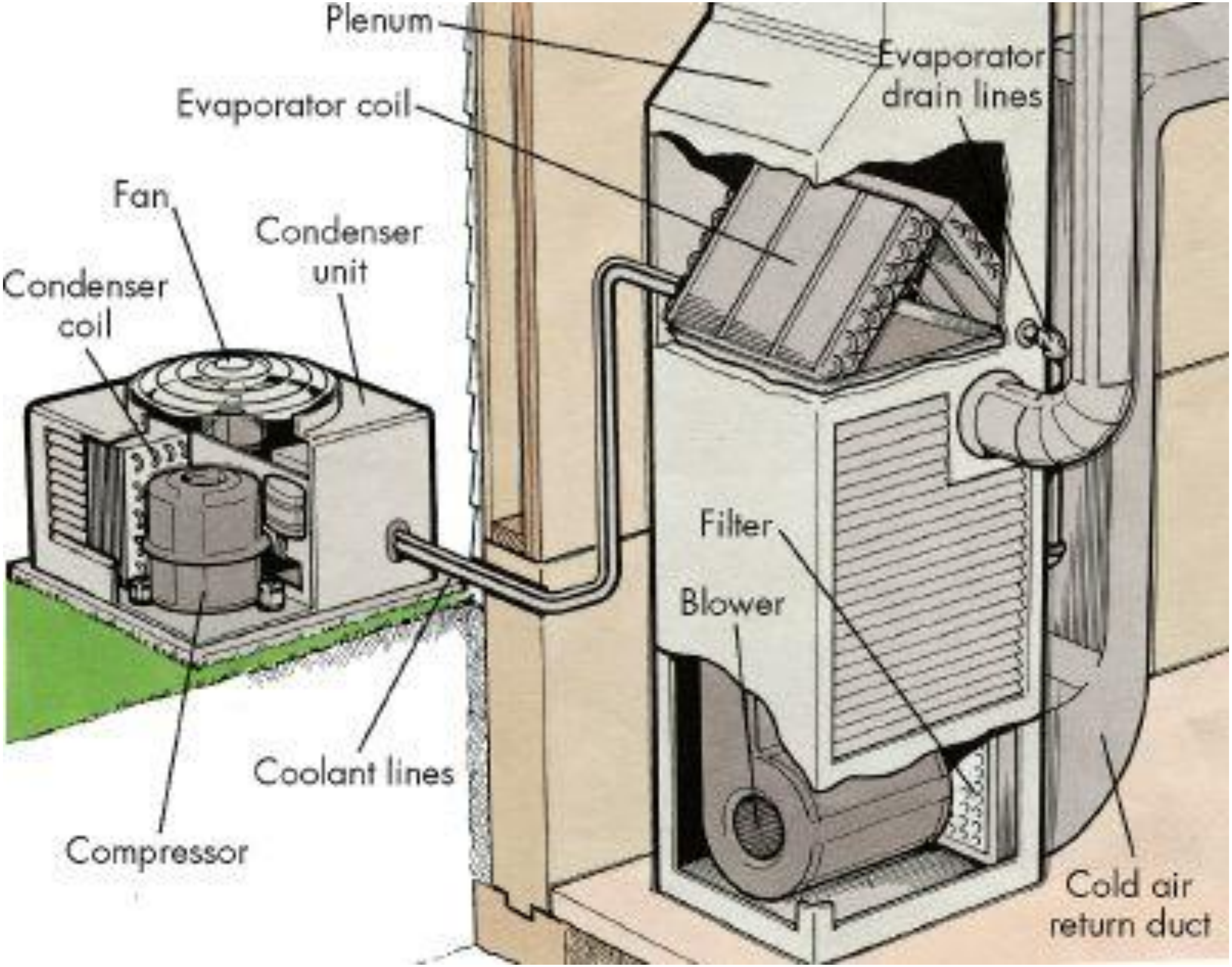
Air Conditioning System

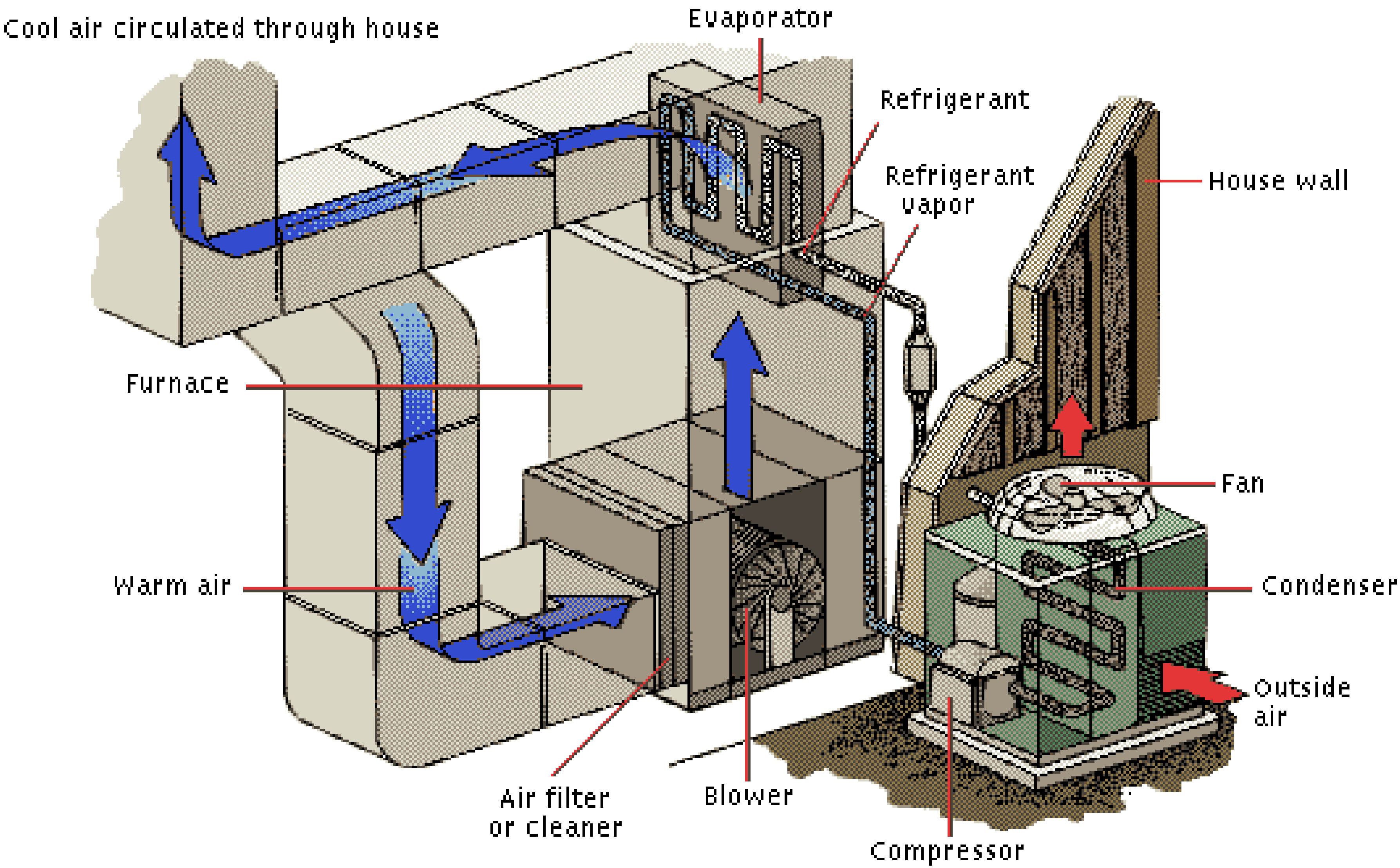




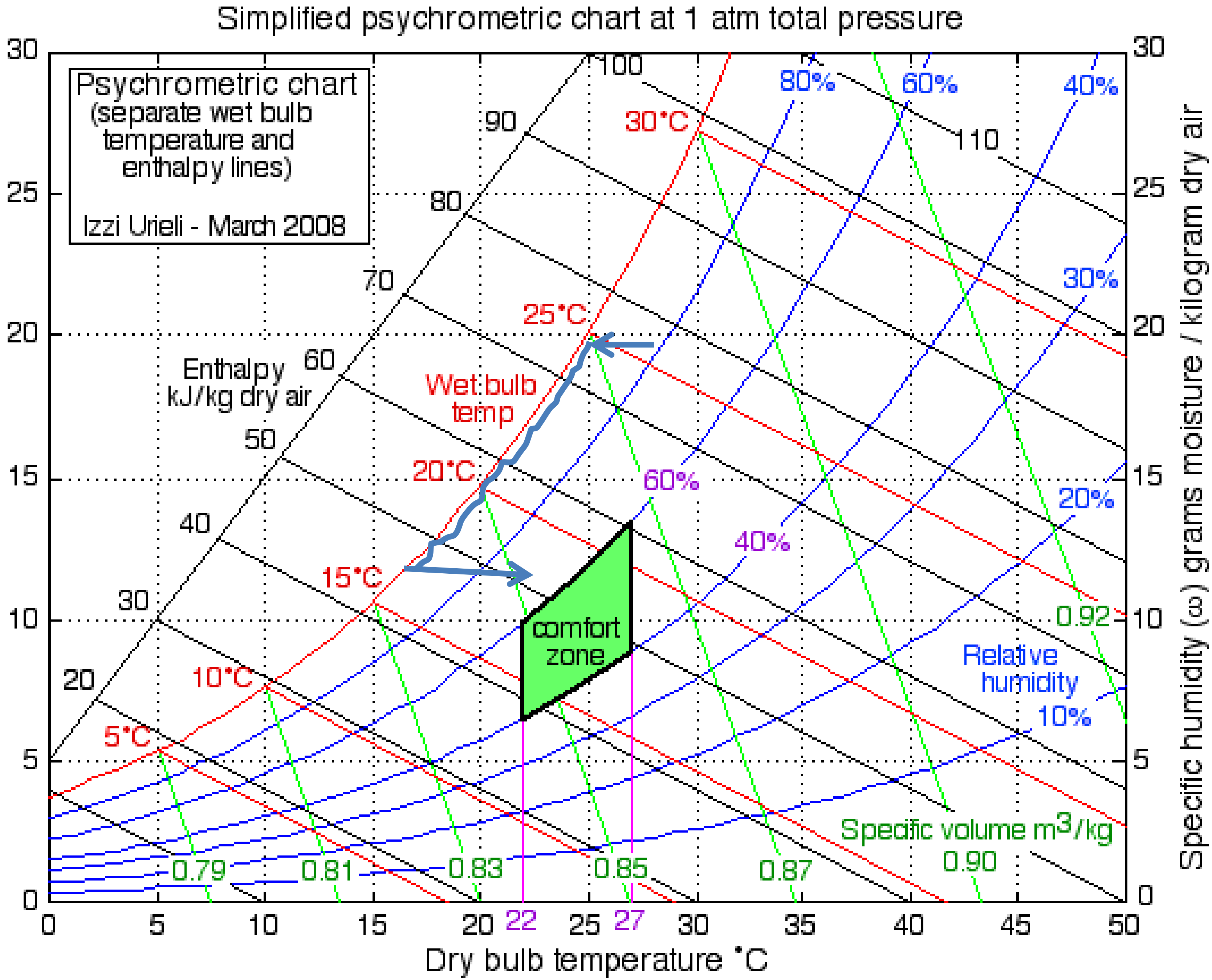

evaporator coils
air conditioners
heating and cooling units
furnaces
air handlers
compressors


Air Intake
and Damper
Exhaust Outlet
and Damper
Return
Damper
Mixing
Chamber
Air
Filters
Humidifier/
Cooling Unit
Return
Fan
Supply
Fan
Heating
Unit
Room
Supply
Diffuser
Return
Grille


Plenum
Evaporator coil
Evaporator
drain lines
Fan
Condenser
unit
Condenser
coil
Filter
Blower
Coolant lines
Compressor
Cold air
return duct

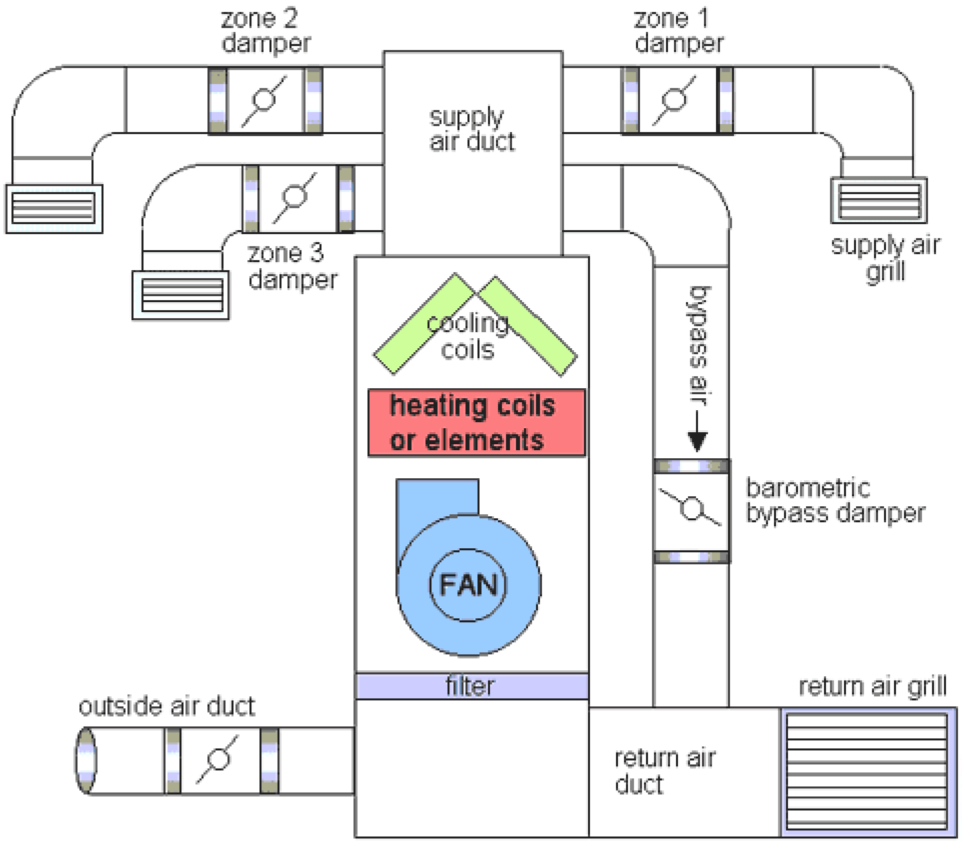


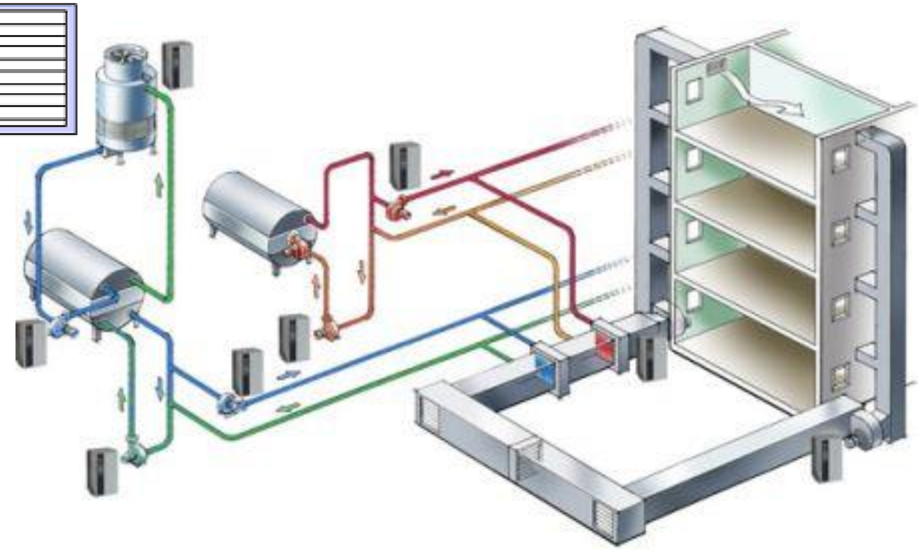
Cool air circulated through house
Evaporator
Refrigerant
Refrigerant vapor
House wall
Furnace
Fan
Condenser
Warm air
Outside air
Air filter or cleaner
Blower
Compressor

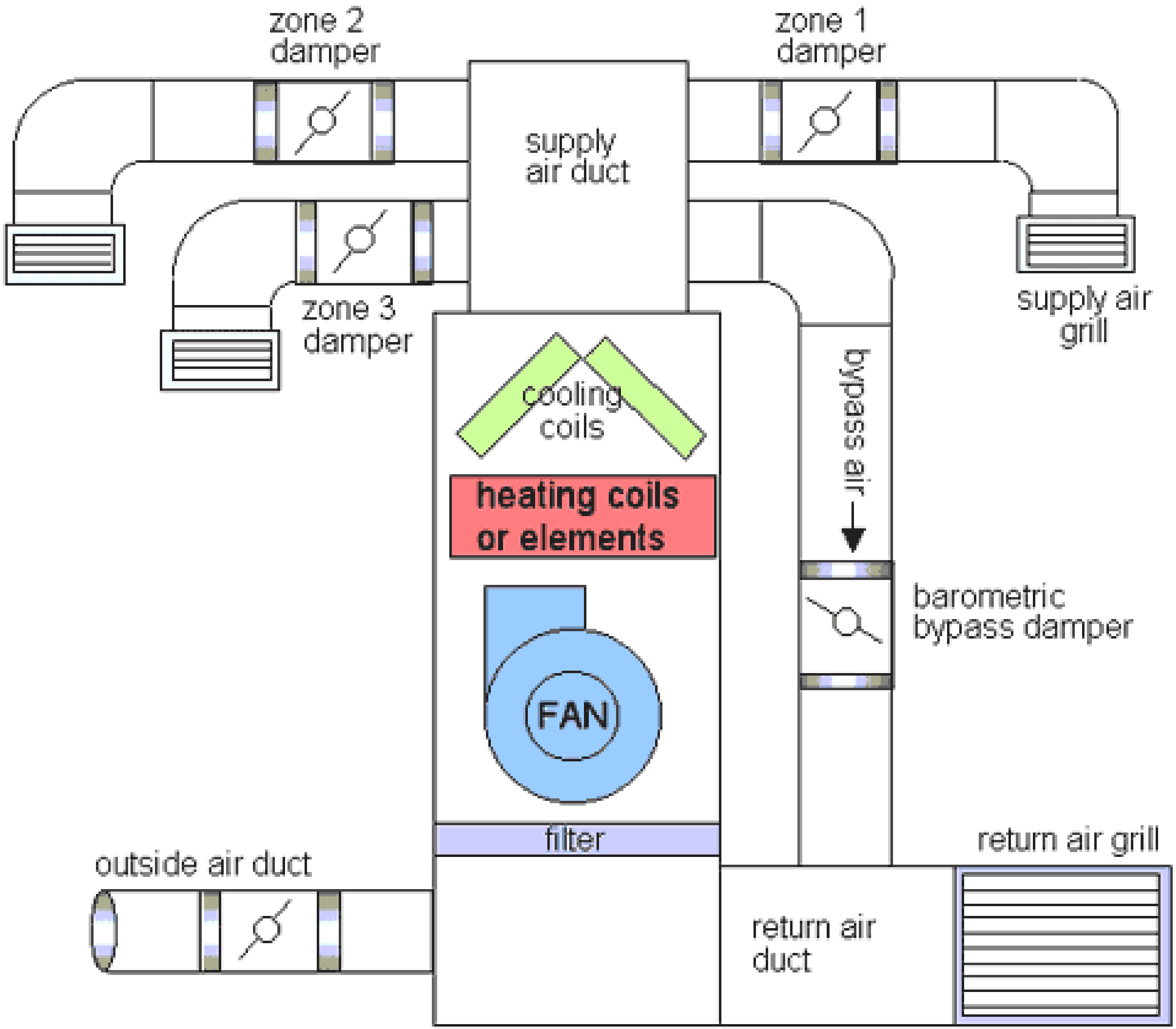


Simplified psychrometric chart at 1 atm total pressure
Psychrometric chart (separate wet bulb temperature and enthalpy lines)
Izzi Urieli - March 2008
Enthalpy kJ/kg dry air
20
30
40
50
60
70
80
90
100
110
Wet bulb temp
5°C
10°C
15°C
20°C
25°C
30°C
80%
60%
40%
30%
20%
10%
60%
40%
Relative humidity
comfort zone
Specific volume m3/kg
0.79
0.81
0.83
0.85
0.87
0.90
0.92
Dry bulb temperature °C
22
27
Specific humidity (ω) grams moisture / kilogram dry air

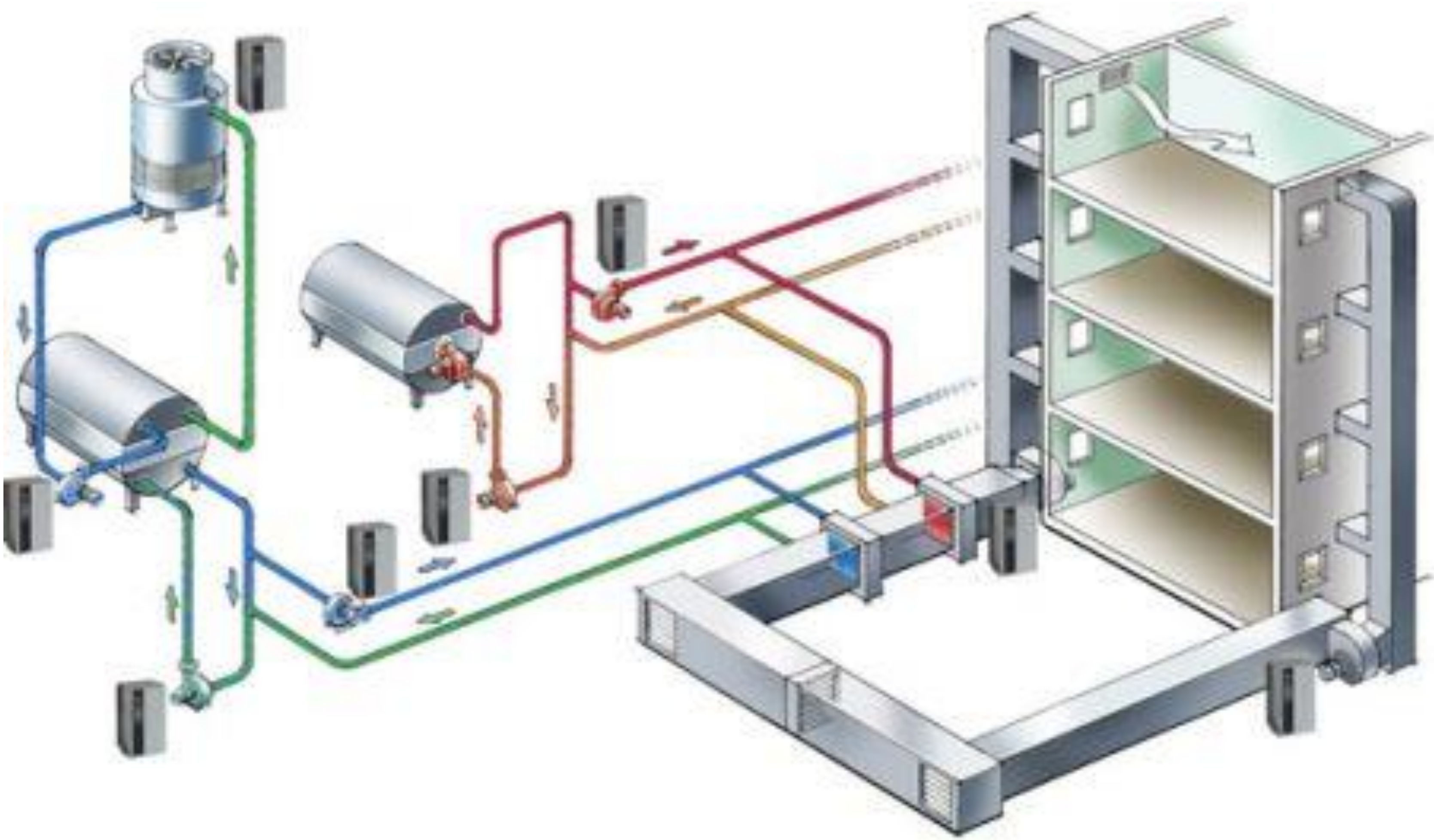
Air Conditioning System






zone 2 damper
zone 1 damper
supply air duct
supply air grill
zone 3 damper
cooling coils
heating coils or elements
bypass air
barometric bypass damper
FAN
filter
outside air duct
return air grill
return air duct

Air Conditioning System



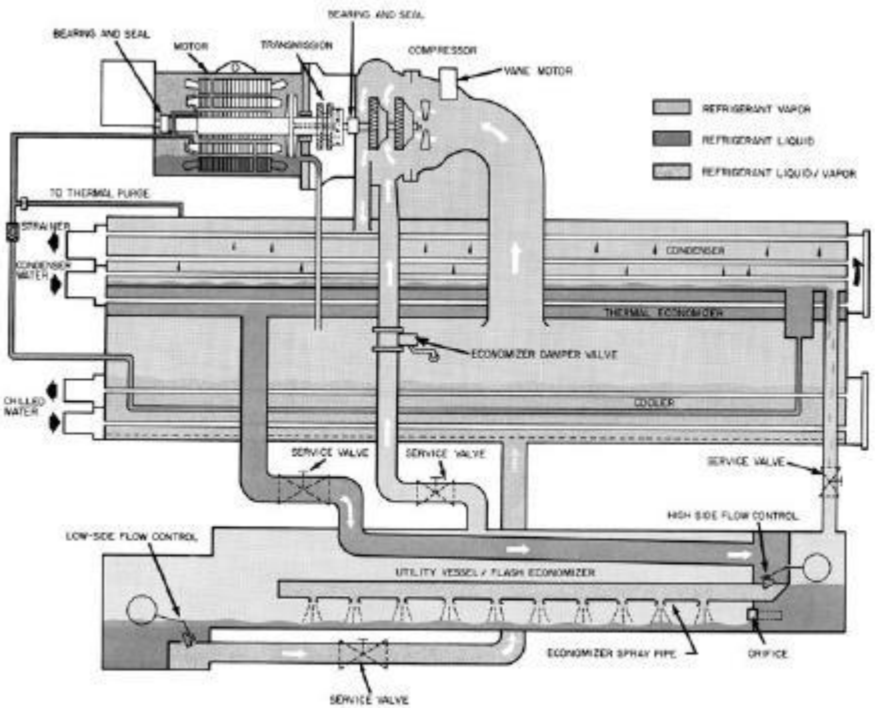
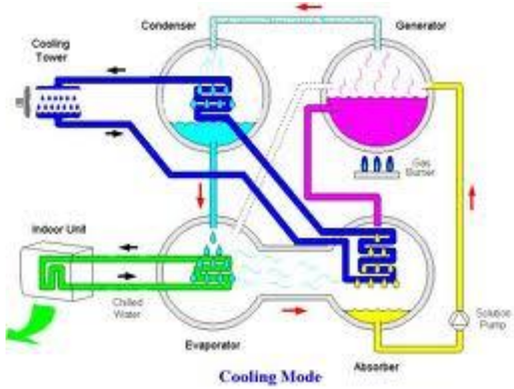
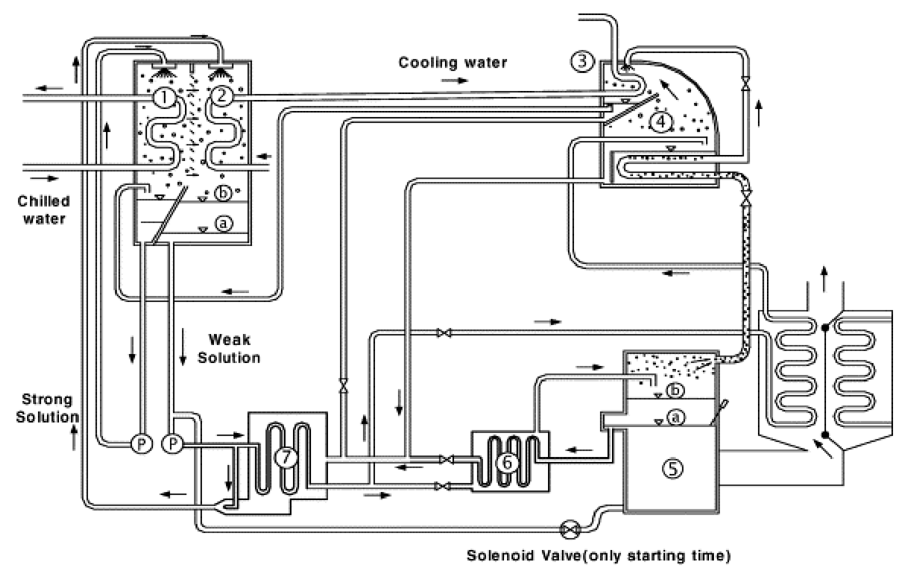
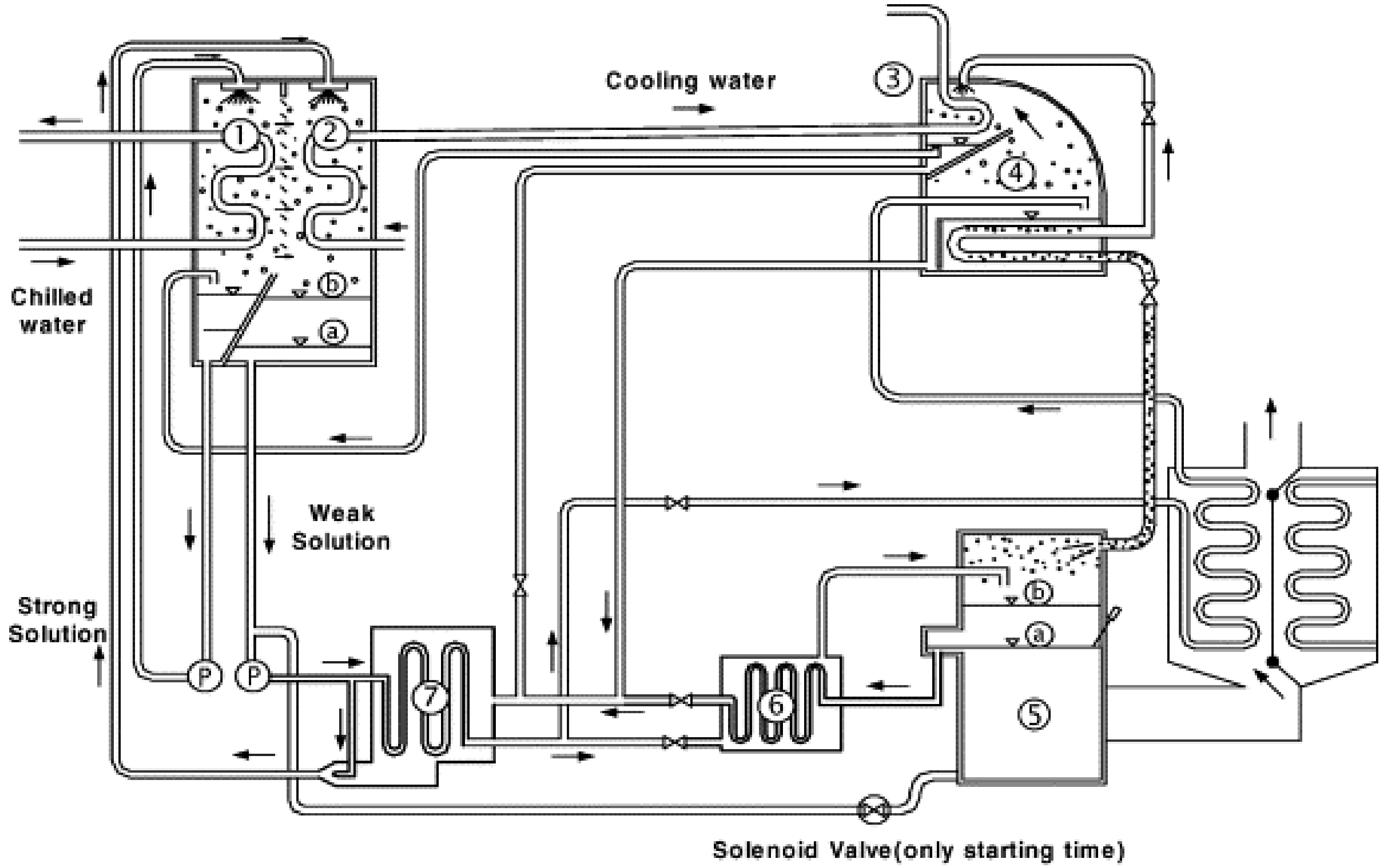


Figure 10-5 Complete operation of a shell-and-tube chiller. (*Courtesy of Carrier.*)





① Evaporator
② Absorber
③ Condensor
Ⓟ Pump
④ Low temperature generator
⑤ High temperature generator
⑥ High temperature heat exchanger
⑦ Low temperature heat exchanger



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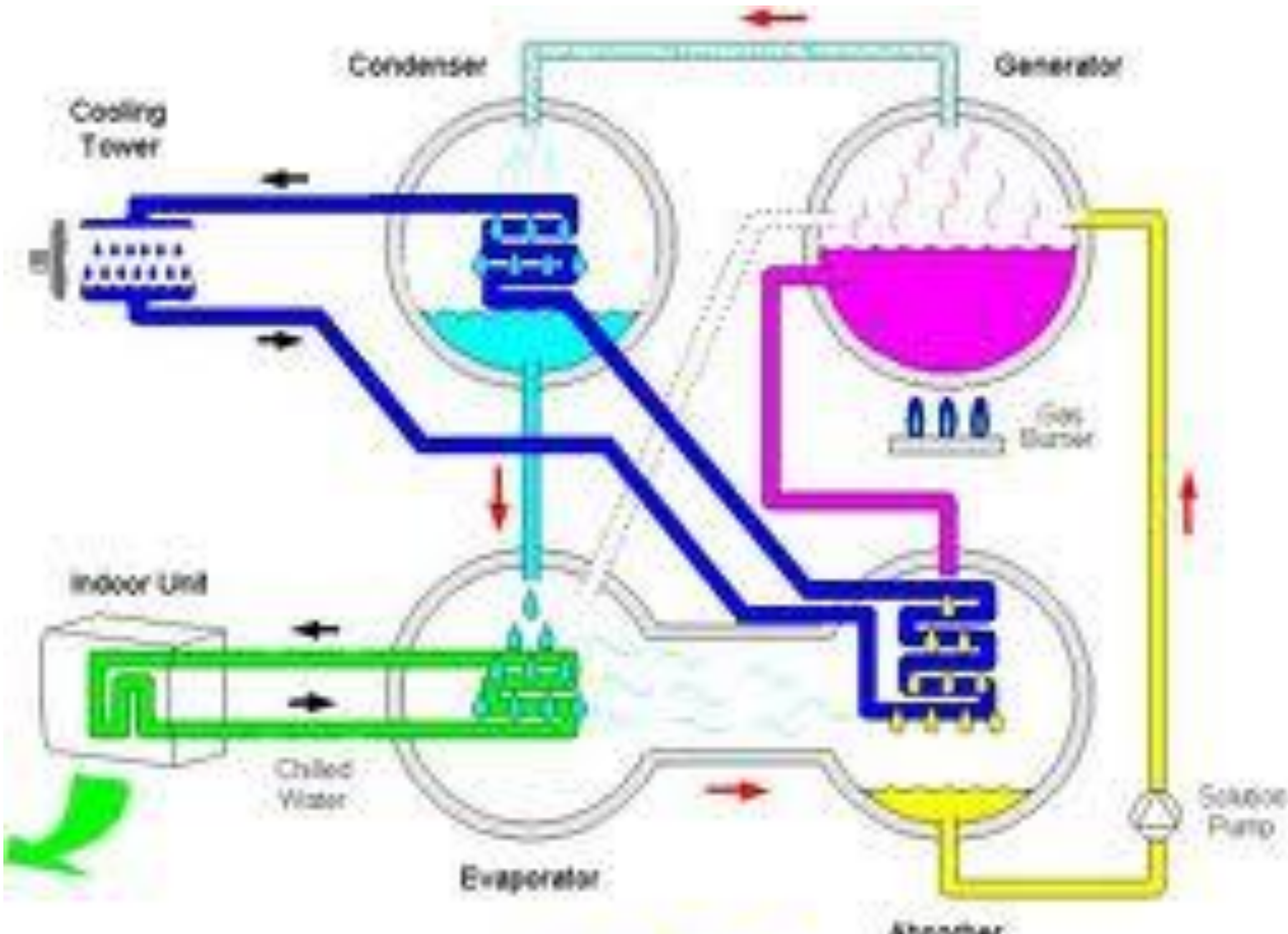
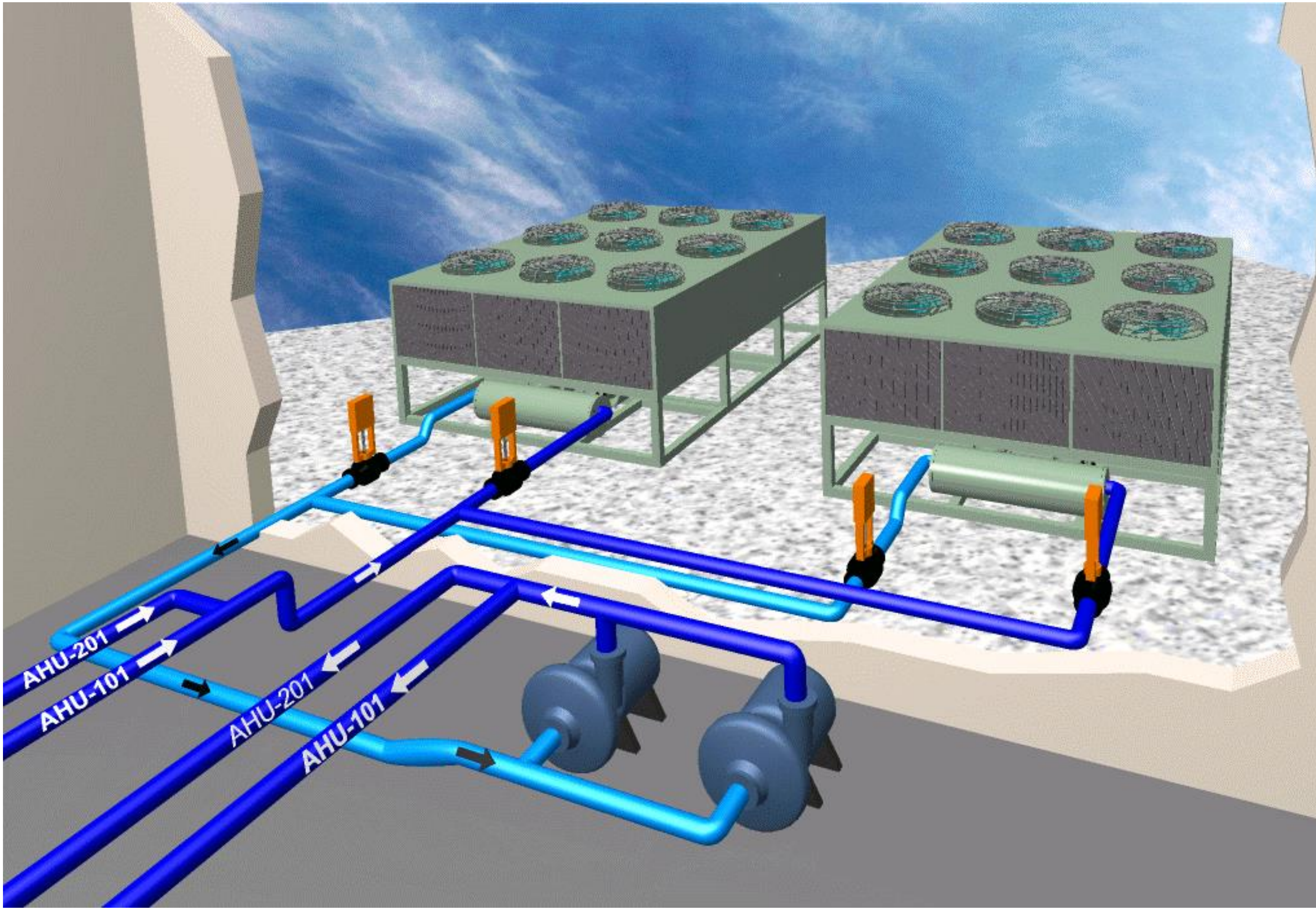
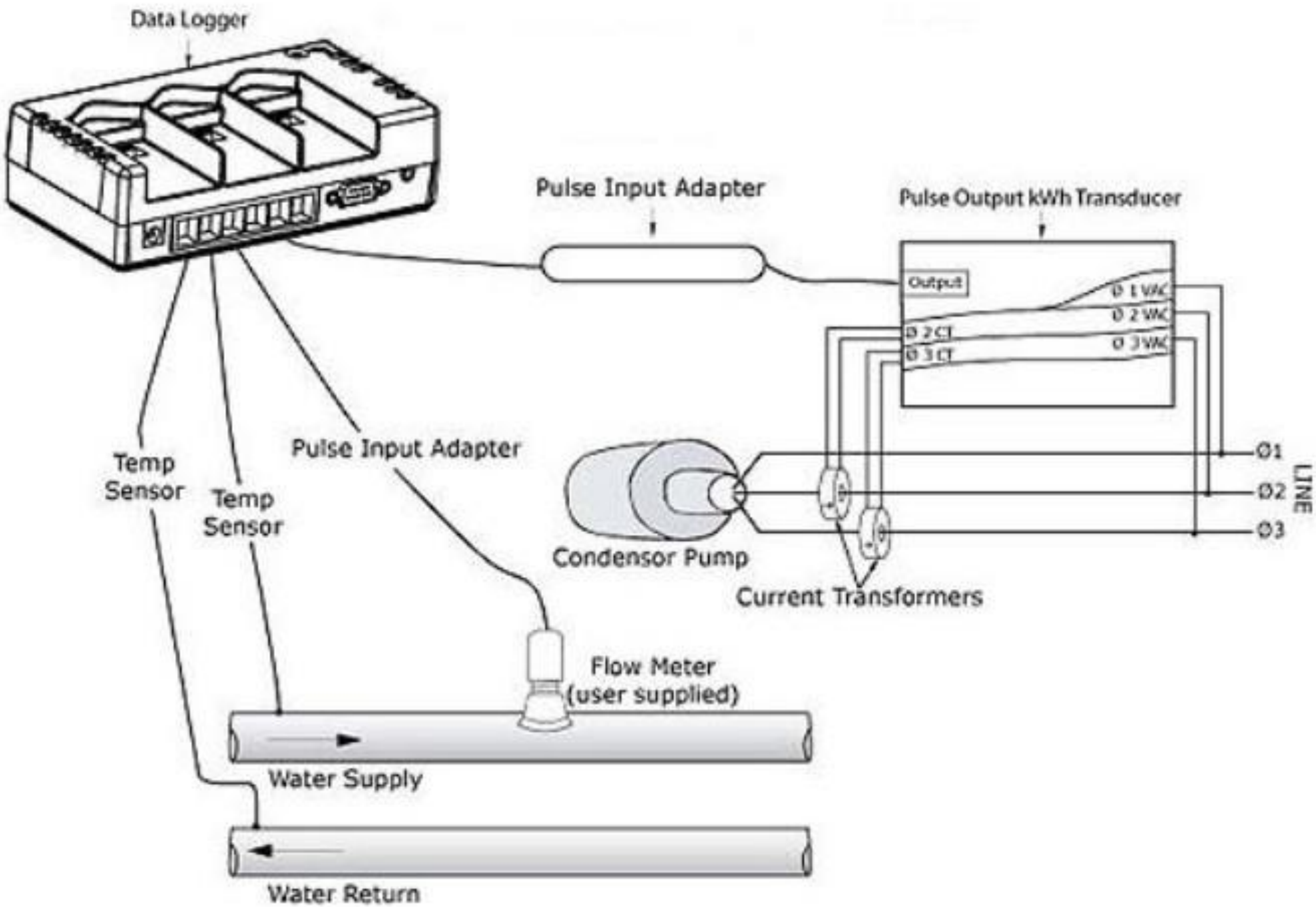


Cooling Mode

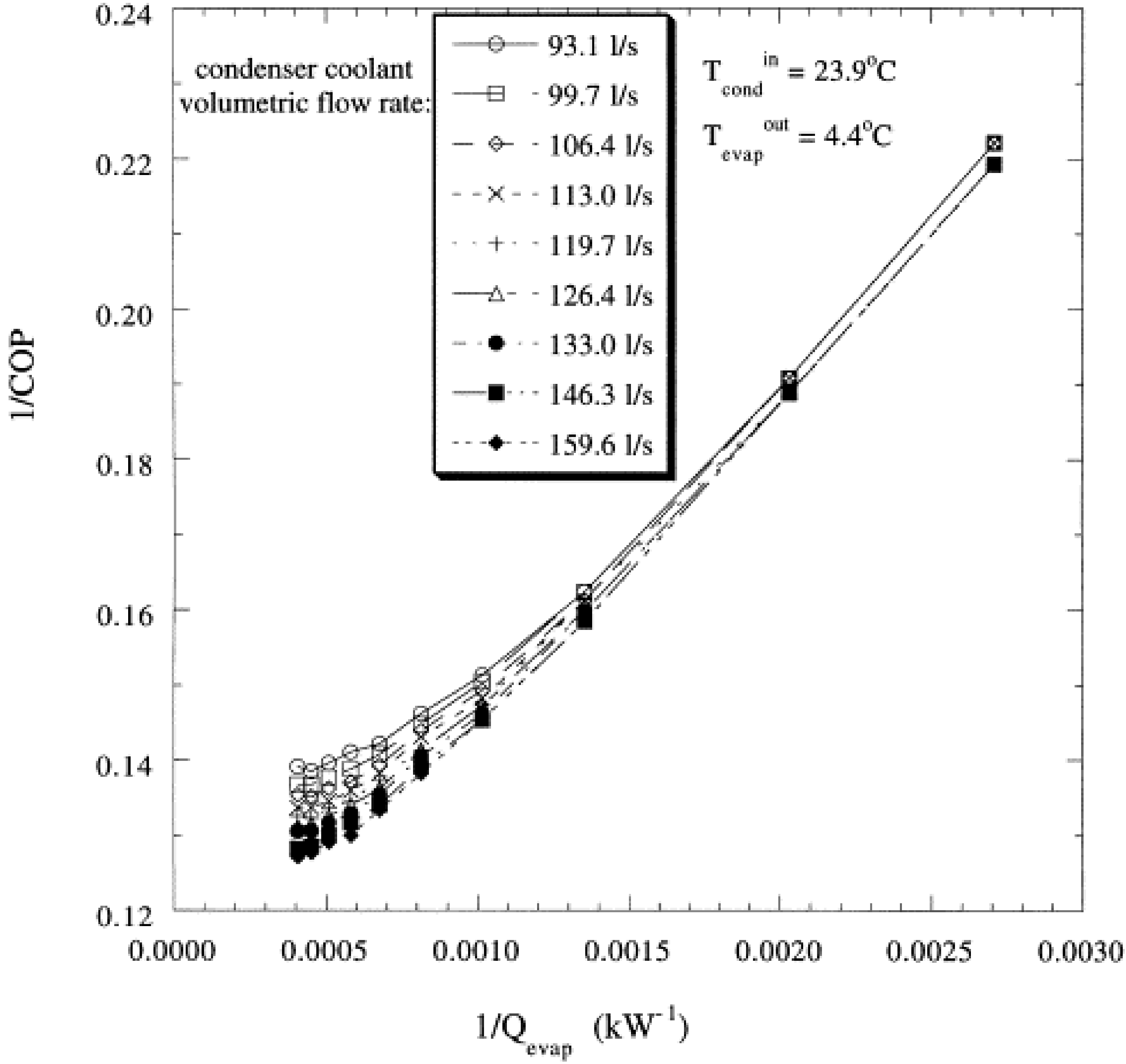

AHU-201
AHU-101
AHU-201
AHU-101



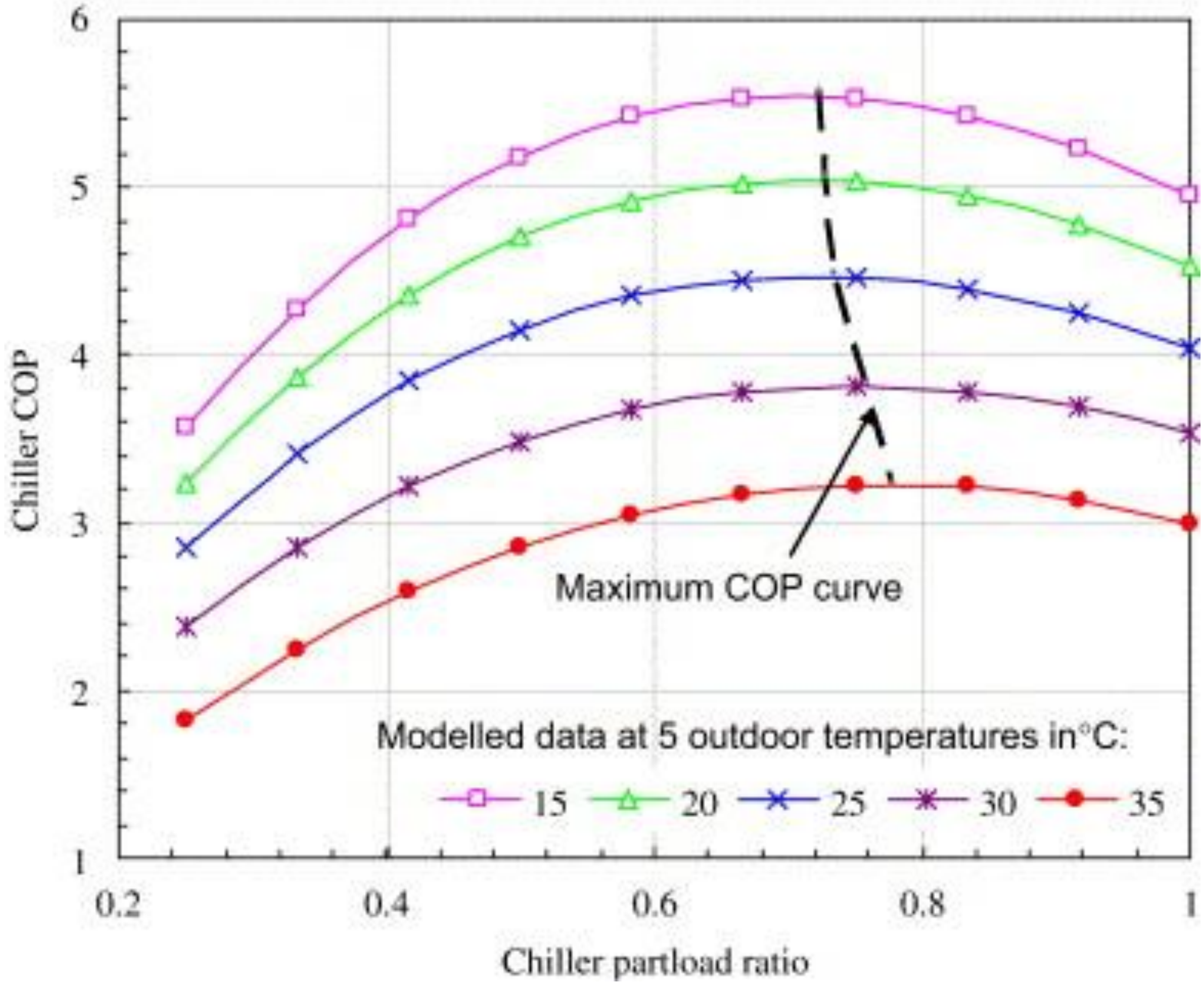
Data Logger
Pulse Input Adapter
Pulse Output kWh Transducer
Output
Ø 1 VAC
Ø 2 VAC
Ø 2 CT
Ø 3 CT
Ø 3 VAC
Temp Sensor
Temp Sensor
Pulse Input Adapter
Condensor Pump
Current Transformers
Ø1
Ø2
Ø3
LINE
Flow Meter (user supplied)
Water Supply
Water Return

Table . Systems and Sensors

System to be Evaluated	Measurement	Accuracy
Whole Building	Power	+/- 1.50%
Chillers	Differential Pressure (water)	+/- 0.25% FS
	Water Temperatures	+/- 0.01 ° F
	Flows (water)	+/- 0.50%
	Power (to chillers)	+/- 0.50 %
Pumps	Differential Pressure (water)	+/- 0.25% FS
	Power	+/- 0.20%
Cooling Tower	Dry Bulb Temperature	+/- 0.01 ° F
	Wet Bulb Temperature	+/- 0.01 ° F
	Water Temperatures	+/- 0.01 ° F
	Power	+/- 0.50%
	Flow	+/- 0.50%
Local Micro-Climate	Dry Bulb Temperature	+/- 0.01 ° F
	Wet Bulb Temperature	+/- 0.01 ° F



condenser coolant
volumetric flow rate:
93.1 l/s
99.7 l/s
106.4 l/s
113.0 l/s
119.7 l/s
126.4 l/s
133.0 l/s
146.3 l/s
159.6 l/s
T_{cond}^{in} = 23.9°C
T_{evap}^{out} = 4.4°C
1/COP
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.0000
0.0005
0.0010
0.0015
0.0020
0.0025
0.0030
$1/Q_{evap}$ (kW^{-1})



Chiller COP
Chiller partload ratio
Maximum COP curve
Modelled data at 5 outdoor temperatures in°C:
15
20
25
30
35
6
5
4
3
2
1
0.2
0.4
0.6
0.8
1

Understanding Water-Chiller Efficiency Ratings

A clear understanding of two measures of chiller efficiency—**the design-efficiency rating** and **the Non-standard Part Load Value (NPLV) rating**—can help organizations obtain the best capital cost and energy efficiency when acquiring new chillers. It also may help facility managers understand why they may not be getting the level of energy efficiency they expect from existing chillers.

Table 1 shows what the ARI found. Specifically, **99% of chiller operating hours are spent at off-design conditions.**

Table 1 — NPLV Operating-Condition Assumptions

Load	Head		Operating Hours
	Air-cooled	Water-cooled	
100%	95°F ECAT	85°F ECWT	1%
75%	80°F ECAT	75°F ECWT	42%
50%	65°F ECAT	65°F ECWT	45%
25%	55°F ECAT	65°F ECWT	12%
0%	55°F ECAT	65°F ECWT	0%

ECAT = entering-condenser-air temperature
ECWT = entering-condenser-water temperature

A second misconception is that a chiller with good efficiency at design conditions will automatically have a good NPLV rating. In fact, chillers can have the same design efficiency but have NPLV ratings that vary widely, depending on capital cost. That's because chillers can have different *off-design* efficiencies.

Comparing NPLV and Design Efficiency in Two Different Chillers

Consider an example of what happens when both the design-efficiency and NPLV ratings are applied by comparing two 1,000 TR chillers (see Table 2).

Table 2 —1,000 TR Chiller Comparisons

	Specified Chiller	Option A Chiller
NPLV Rating	0.466 kW/TR	0.466 kW/TR
Design Efficiency	0.562 kW/TR	0.576 kW/TR
Annual Energy	Base	Base
Capital Cost	$250,000	$240,000

Option A Chiller, which costs less than the Specified Chiller, has the same NPLV rating, but a higher design efficiency. Because both chillers have equal NPLV ratings, they will have equal annual energy consumption.

If the specification contained only the NPLV rating, Option A Chiller might be an attractive choice. However, if the specification requires that a chiller meet *both* the NPLV rating and the design-efficiency rating, Option A Chiller can't meet both ratings and, therefore, can't be bid. The manufacturer of Option A Chiller will usually need to modify it by adding more heat-exchanger surface to meet the design-efficiency rating. The performance of this new chiller is shown in Table 3 as Option B Chiller.

Table 3 – Impact of Specifying Both NPLV and Design Efficiency

	Specified Chiller	Option B Chiller
NPLV Rating	0.466 kW/TR	0.448 kW/TR
Design Efficiency	0.562 kW/TR	0.562 kW/TR
Annual Energy	Base	- 4%
Capital Cost	$250,000	$271,000

The additional heat-exchanger surface improves the NPLV rating of Option B Chiller, resulting in Annual Energy that is four percent better than the Specified Chiller. But, it has also become more expensive, costing $31,000 more than Option A Chiller. This demonstrates how specifying a chiller's design efficiency in addition to its NPLV may complicate matters. Instead of equalizing energy consumption as a basis for comparing costs, now both annual energy consumption and pricing are unequal.

Does a chiller's design-efficiency rating impact electric-demand charges?
Consider the aforementioned Option A Chiller, which has a design efficiency of 0.576 kW/TR. At first glance, that chiller would appear to cause higher electric-demand charges than the Specified Chiller, which has a design efficiency of 0.562 kW/TR. But is that really the case?
Chiller peak kW usually has little impact on building demand because of heat-load timing. The building's kW and the chiller's kW typically peak at different times of the day. This phenomenon is illustrated in Figure 1.

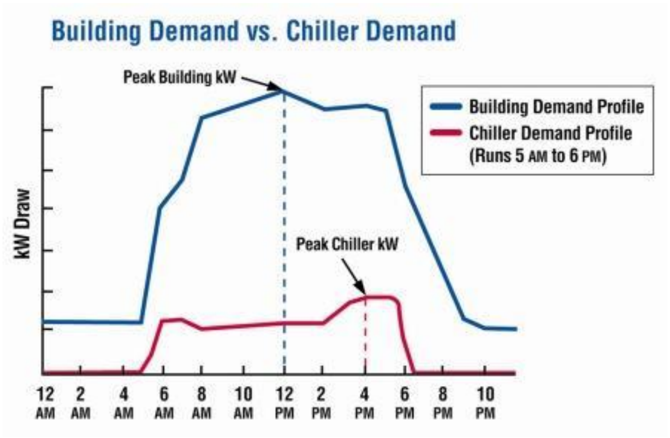
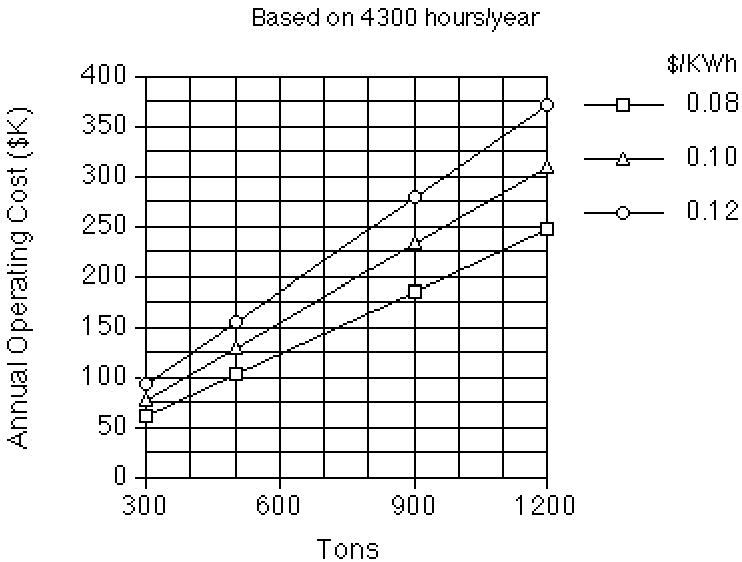
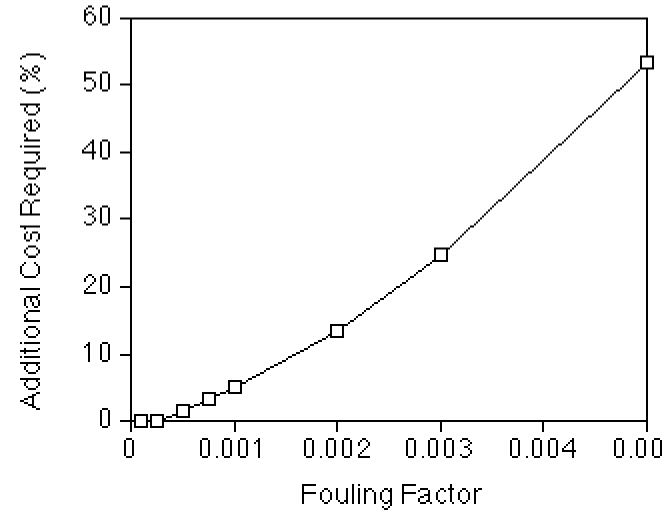
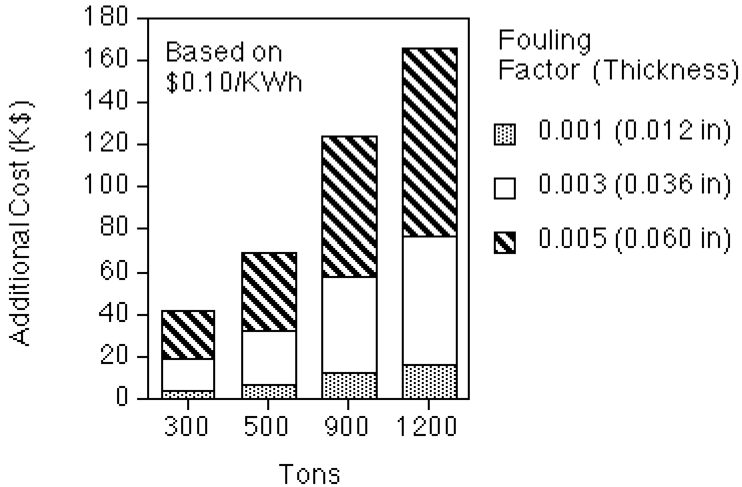
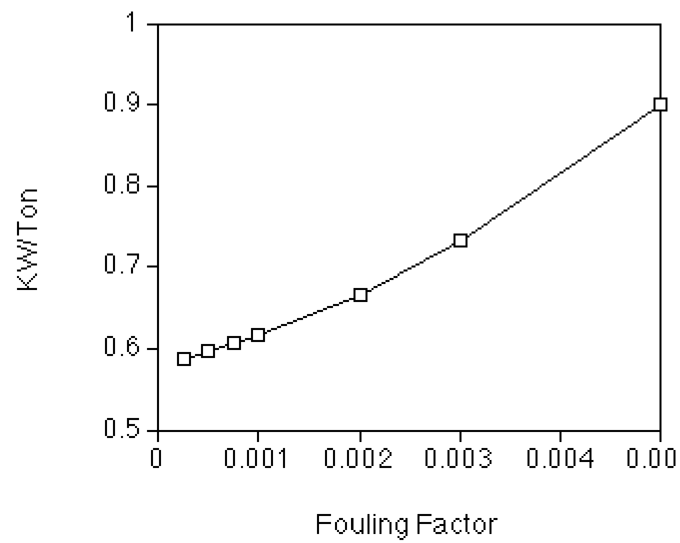


Figure 1: This curve shows building demand vs. chiller demand and the typical time-of-day offset between the two
Most air-conditioned buildings reach their peak electric demand between 10 a.m. and 3 p.m. when occupancy is usually at its highest. Higher occupancy also translates into more heat generated by lights, elevators, cafeterias, office equipment, etc.
Surprisingly, most chillers reach peak electric demand between 3 p.m. and 7 p.m. Why so late? At about 12 p.m., the sun's rays strike the ground at the most direct angle. Through convection, the ground then heats the ambient air to its highest dry-bulb temperature at about 2 p.m. Once the air temperature is at its maximum, the heat is slowly conducted through the building skin, a process that peaks building heat load around 4 p.m. In parallel, the wet-bulb temperature of the ambient air also reaches its maximum later in the day.
The higher wet-bulb temperature raises the entering-condenser-water temperature, which raises the head pressure against which chillers must work, hurting energy efficiency. When these factors combine, the chiller sees its peak load, peak head, and, therefore, peak kW in late afternoon.


Based on 4300 hours/year
$/KWh
0.08
0.10
0.12
Annual Operating Cost ($K)
400
350
300
250
200
150
100
50
0
300
600
900
1200
Tons

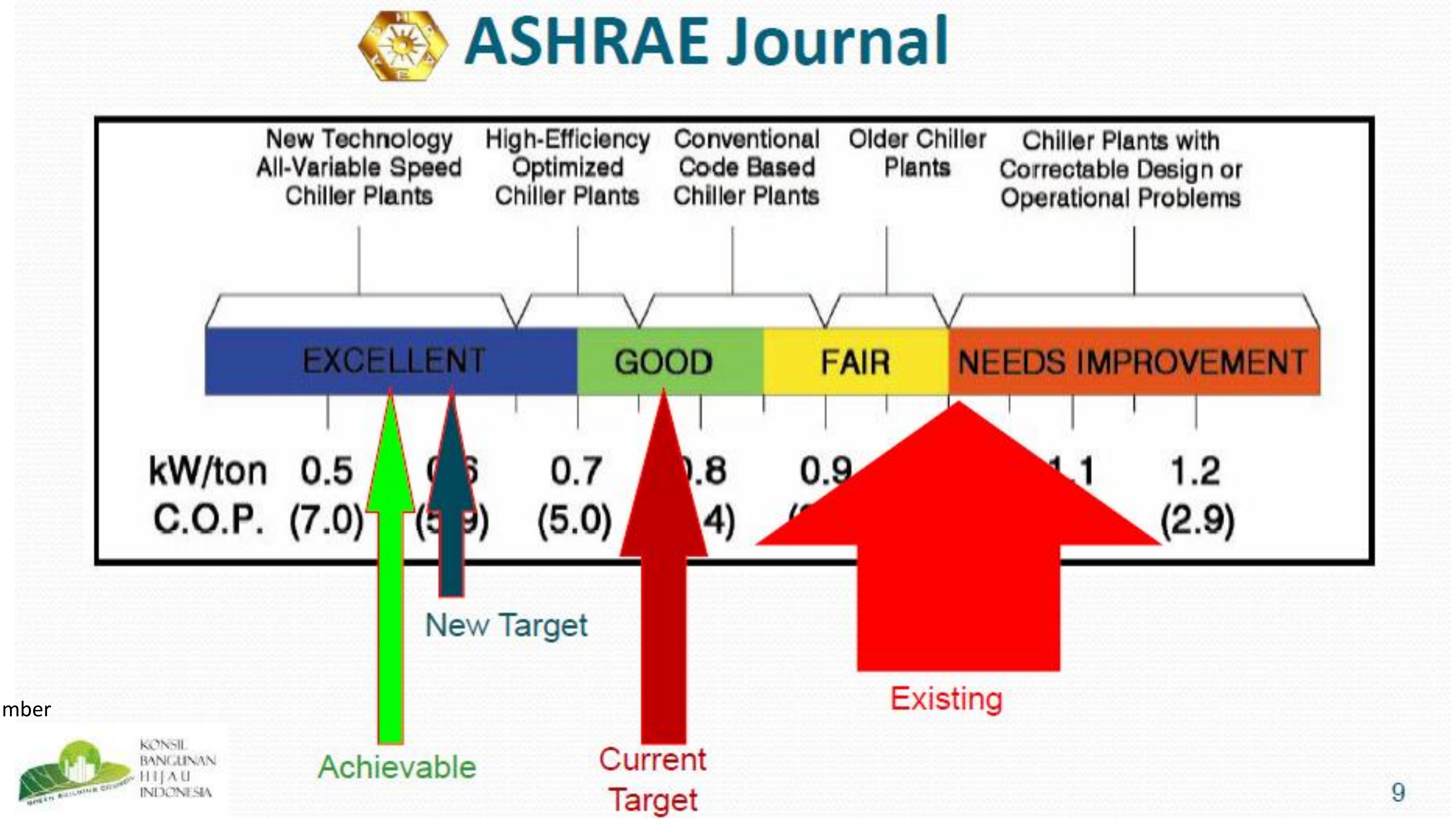

Additional Cost Required (%)
60
50
40
30
20
10
0
0
0.001
0.002
0.003
0.004
0.005
Fouling Factor


Based on
$0.10/KWh
Fouling
Factor (Thickness)
0.001 (0.012 in)
0.003 (0.036 in)
0.005 (0.060 in)
Additional Cost (K$)
180
160
140
120
100
80
60
40
20
0
300
500
900
1200
Tons


KW/Ton
1
0.9
0.8
0.7
0.6
0.5
0
0.001
0.002
0.003
0.004
0.005
Fouling Factor

Chiller Plant

- Water cooled chiller
- Chilled water pump
- Condenser water pump
- Cooling tower



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