Air Conditioning Unit
Chiller & Absorption Chiller

2018.01

KOREA ENERGY AGENCY

Contents

1. Air Conditioner

A. Air Conditioner Outline

➢ What is the Air Conditioner?

Air conditioning is the process of altering the properties of air (primarily temperature and humidity) to more favourable conditions.

- Temperature
- Humidity
- Ventilating
- Cleanliness
- Air Movement

Air Conditioner

<u>Adjusted by the purpose of use</u>

▶ Clean Room

-. Temp : 23℃(20~26℃)
-. humidity : 50%(40~60%)
-. Ventliating : 40~300/hr
-. Cleaniness : Class 10~10,000
-. Air Movement : vertical laminar flow

▶ Office Zone

-. Temp : 18~26℃
-. Humidity : 30~70%
-. Ventliaing : 7~10/hr

▶ etc.

-. Parts storage
-. CCSS R'm
-. Gas R'm
:
:

➢ Air Conditioner Components

-**Pre-heating Coil**: Preheating outdoor air in order to prevent coil freeze in winter season

-**Cooling Coil/Heating Coil**: Coil to warm/cool the Air, using hot water (steam) and cold water.

-**Re-Heating Coil**: Partially rise the temperature of the air in Cooling Coil that temperature is dropped up to the dew point in summer season by using hot water or steam.

- **Humidifier**: Be used to increase absolute humidity of the air in winter season. It uses steam or water

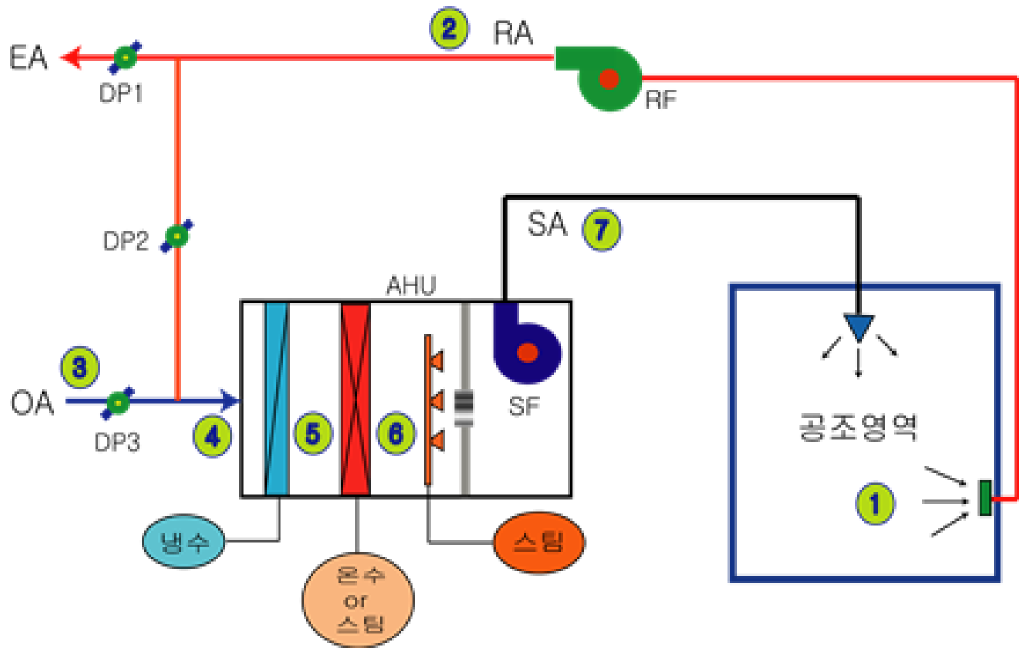
-**Supply and Exhaust Fan**: Fan for transporting supply and exhaust

-**Air Conditioner**: Room HVAC main devices including Coil, Fan, humidifier for air conditioning

1. Air Conditioner

A. Air Conditioner Outline

➢ Composition of general air conditioning system



-Composition of general air conditioning system is shown above. Air conditioning area's temperature, humidity, and air flow is managed by AHU.

- Driving process of AHU is the RA which came back from the area (RA : Return Air) mixed with (OA : Outdoor Air), and processed through heating/cooling coil, and humidifier.
- Processed Air (SA : Supply Air) is sent to air conditioning area through (SF : Supply Fan)
- AHU is comprised of cooling coil, heating coil, humidifier, fan, and rest of accessory equipment such as filter and damper.

1. Air Conditioner

A. Air Conditioner Outline

➢ Major Air handling terminology and equations

- Relative Humanity

Ratio between partial pressure of water vapor among Humid air (Pw) and Partial pressure of water vapor in saturated vapor at that temperature(Pws).

$$\psi = \frac{Pw}{Pws} \times 100$$

- Absolute Humidity

Mass of vapor in dry air(DA) of 1kg among Humid air, its Standard Unit is kg/kg(DA).

$x = \gamma w/\gamma a = 0.622\ Pw \div (P-Pw)$

x : absolute humidity(kg/kg') γ_w : weight of vapor in air (kg/m3)

γ_a=: weight of dry air (kg/m3) P : air pressure(mmHg)

P_w : water vapor pressure(mmHg)

$x = \gamma_w/\gamma_a = 0.622\ P_w \div (P-P_w)$

$P_w = \Psi P_s$, $x = 0.622\ \Psi P_s \div (P-\Psi P_s)$

P : air pressure(mmHg), P_s : saturated moist air vapor pressure (mmHg), Ψ : Relative Humidity(%)

- Sensible Heat Factor (SHF)

Indicates status of air flow supplied to room, which is the ratio between change of entropy(active heat + dormant heat) and active heat Air supply flow supplied by the fan needs to be along to the SHF status.

1. Air Conditioner

A. Air Conditioner Outline

-State transition of humid air in air conditioning

a) Energy equilibrium equation

$G_1.\ i_1 + G_2.\ i_2 = (G_1 + G_2).\ i_3$

G_1 = Interior recycled air (kg/h) G_2 = Exterior flow-in air (kg/h)

i_1 = Interior recycled air entropy (kcal/h)

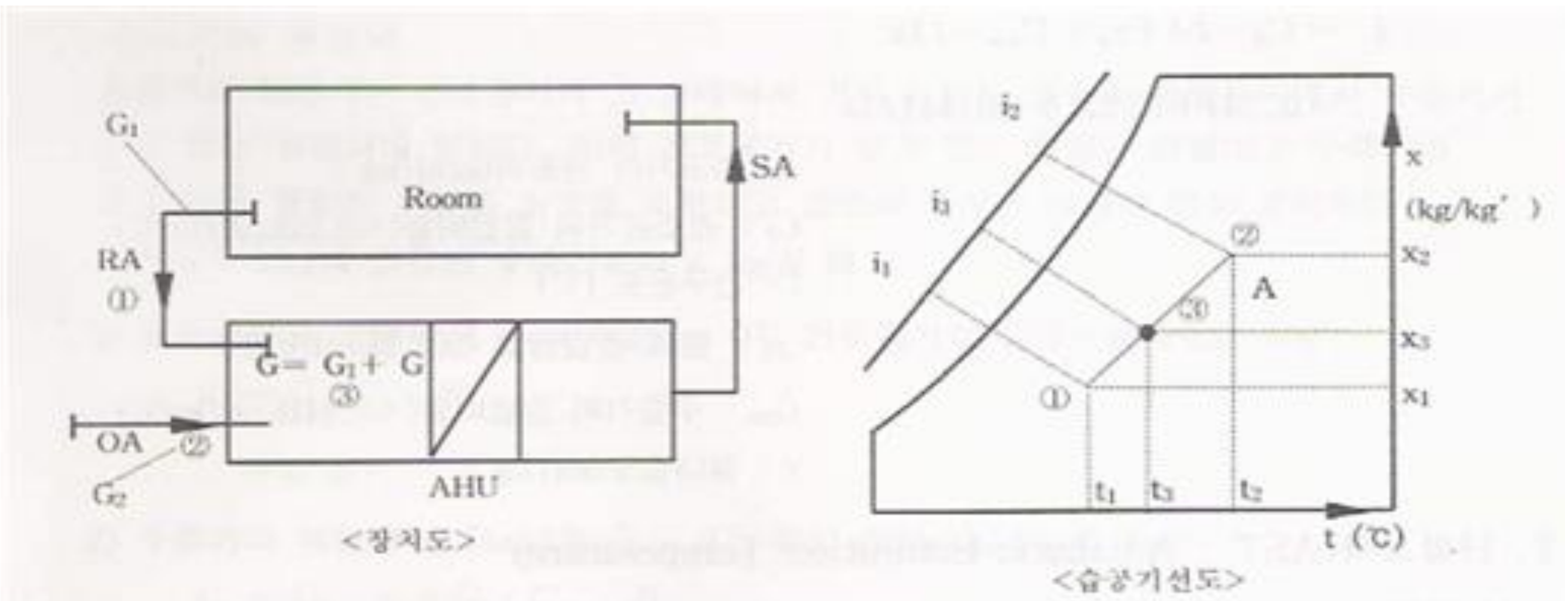
i_2 = Introduced entropy (kcal/h) i_3 = mixed air entropy (kcal/h)

b) Mass equilibrium equation

$G_1.\ x_1 + G_2.\ x_2 = (G_1 + G_2).\ x_3$

x_1 = absolute humidity of inside air (kg/kg')

x_2 = absolute humidity of outside air (kg/kg') x_3 = absolute humidity of outside air (kg/kg')



➢ Air Conditioner Types and Characteristics

▣ Packaged Air Conditioner

- Purpose of installation is to be heat and cool for compact space, but humidity control is not possible.

- PAC type can be divided into refrigerant circulating type, hot and cold water circulating type.

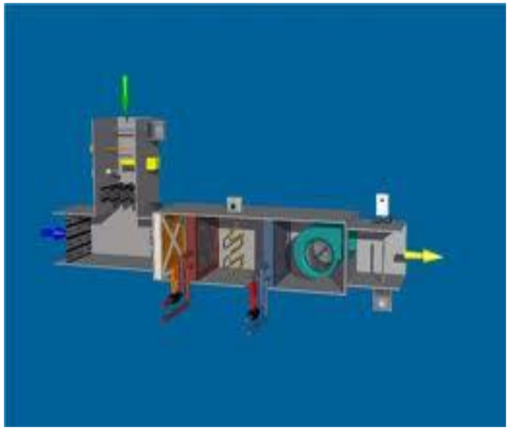
▣ Air Handling Unit, AHU

- Purpose of installation is supplying air to large space for altering the temperature and humidity.

- AHU type can be divided into Outdoor Air Conditioner (OAC) and normal Air Conditioner, Energy consumption (Cold Water, Hot Water, Steam) is greater.

[Packaged Air Conditioner]

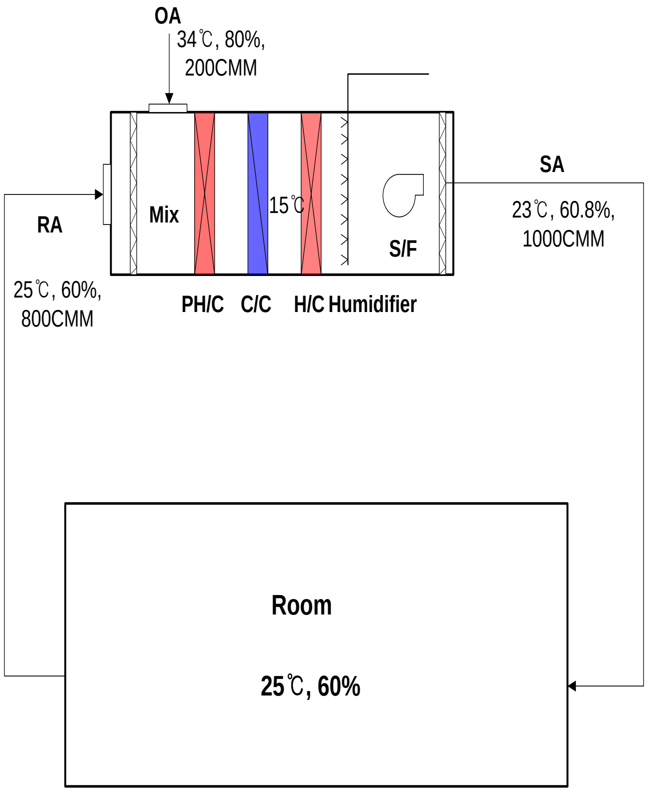
[AHU]



[OAC structure]

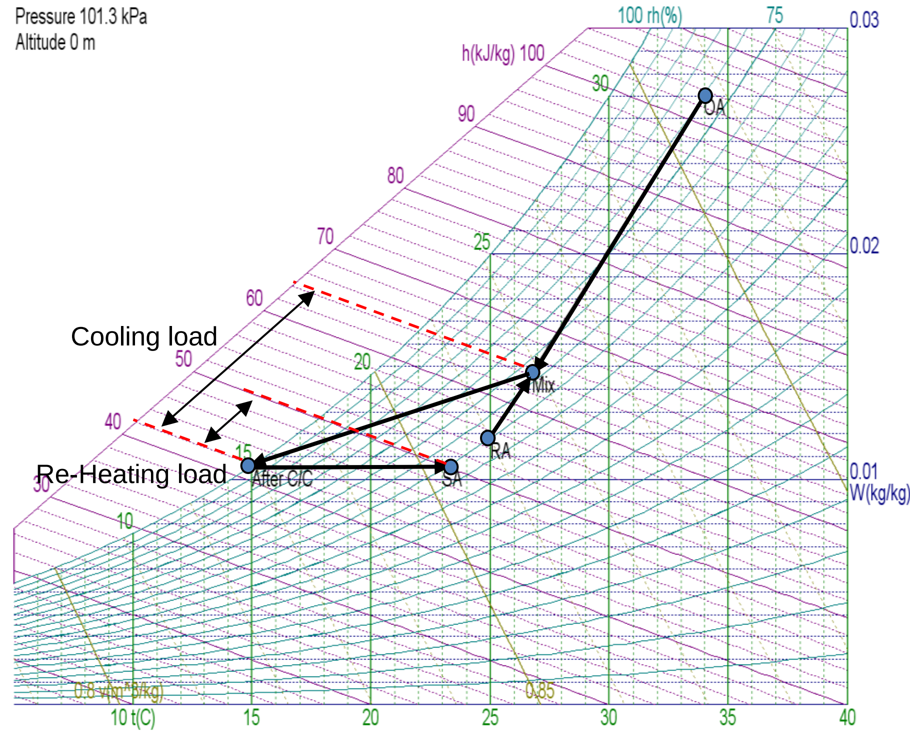
B. Psychometric Chart of Air Conditioner at Summer

- Supply air at Summer through a process of OA and RA mixed → C/C→ Heating coil, that will maintain a constant temperature / humidity.



	W	t	rh	v	h	td	tw	Vtot	m	ma	mw
	kg/kg	C	%	m^3/kg	kJ/kg	C	C	m^3	kg	kg	kg
RA	0.0118	25*	60*	0.8601	55.19	16.7	19.4	800*	941.1	930.1	11.01
OA	0.0271	34*	80*	0.9074	103.5	30	30.8	200*	226.4	220.4	5.971
Mix	0.0148	26.8*	67.1	0.8692	64.45	20.1	22.1*	1000*	1168	1151	16.98
After C/C	0.0106	15*	100	0.8296	41.85	15*	15	954.5*	1163	1151	12.21
SA	0.0106	23*	60.8	0.8527	50.02	15*	17.8	981*	1163	1151	12.21

Pressure 101.3 kPa
Altitude 0 m



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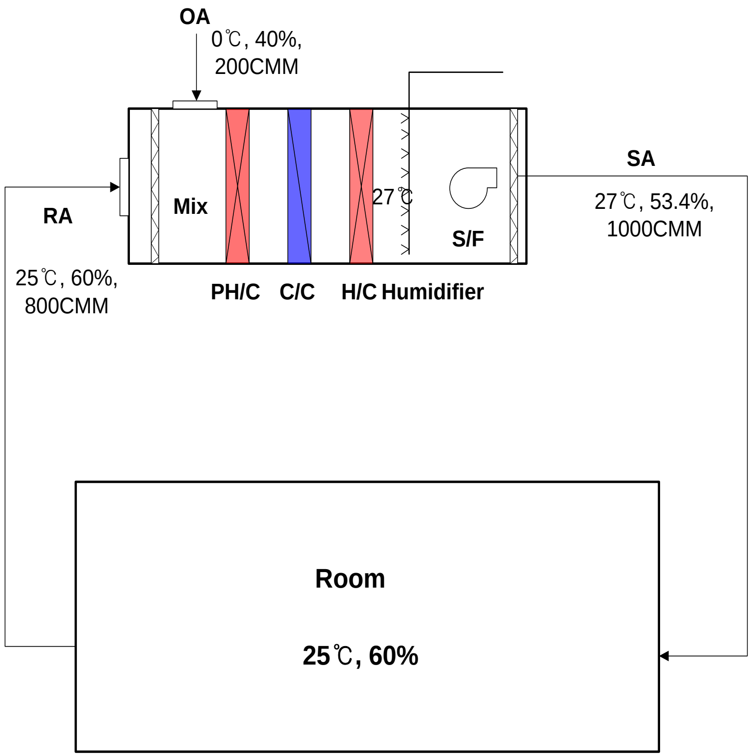
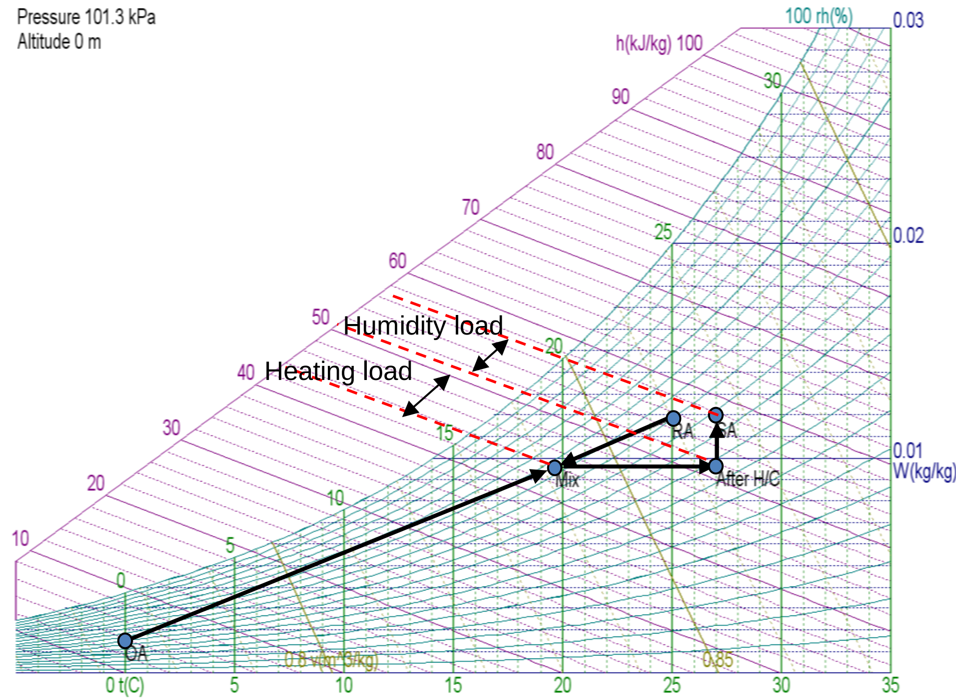
C. Psychometric Chart of Air Conditioner at Winter

-Supply air at Winter through a process of OA and RA mixed → H/C→ Humidifier, and that will maintain a constant temperature / humidity.



	W	t	rh	v	h	td	tw	Vtot	m	ma	mw
	kg/kg	C	%	m^3/kg	kJ/kg	C	C	m^3	kg	kg	kg
RA	0.0118	25*	60*	0.8601	55.19	16.7	19.4	800*	941.1	930.1	11.01
OA	0.00148	0*	40*	0.7751	3.711	-10.8	-3.32	200*	258.4	258	0.383
Mix	0.00959	19.7*	67.4	0.8417	44.01	13.5	15.8*	1000*	1200	1188	11.39
After H/C	0.00961	27*	43.5	0.8628	51.58	13.5*	18.3	1025*	1200	1188	11.42
SA	0.0119	27*	53.4	0.8659	57.28	16.7*	20	1029*	1202	1188	14.08

Pressure 101.3 kPa
Altitude 0 m



D. Air Conditioner Audit Procedure

- Scope Confirmation → AHU Equipment specifications and identify status of the operation → Humidity and temperature Measurement(SA, RA, OA, after C/C, after H/C) → Airflow Measurement (OA, RA, SA) → Psychometric Chart construction → Loss factors Measurement

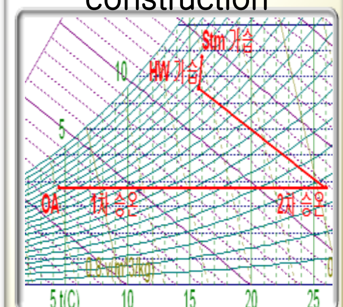
Scope Confirmation

Specificatio
n
Check

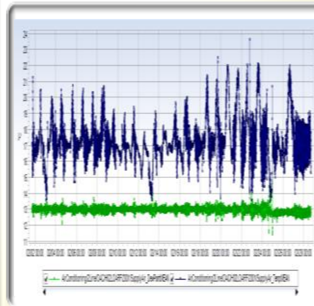
Humidity
and
temperature
Measuremen

Airflow
Measurement

Psychometric
Chart
construction



Loss factors
Measurement

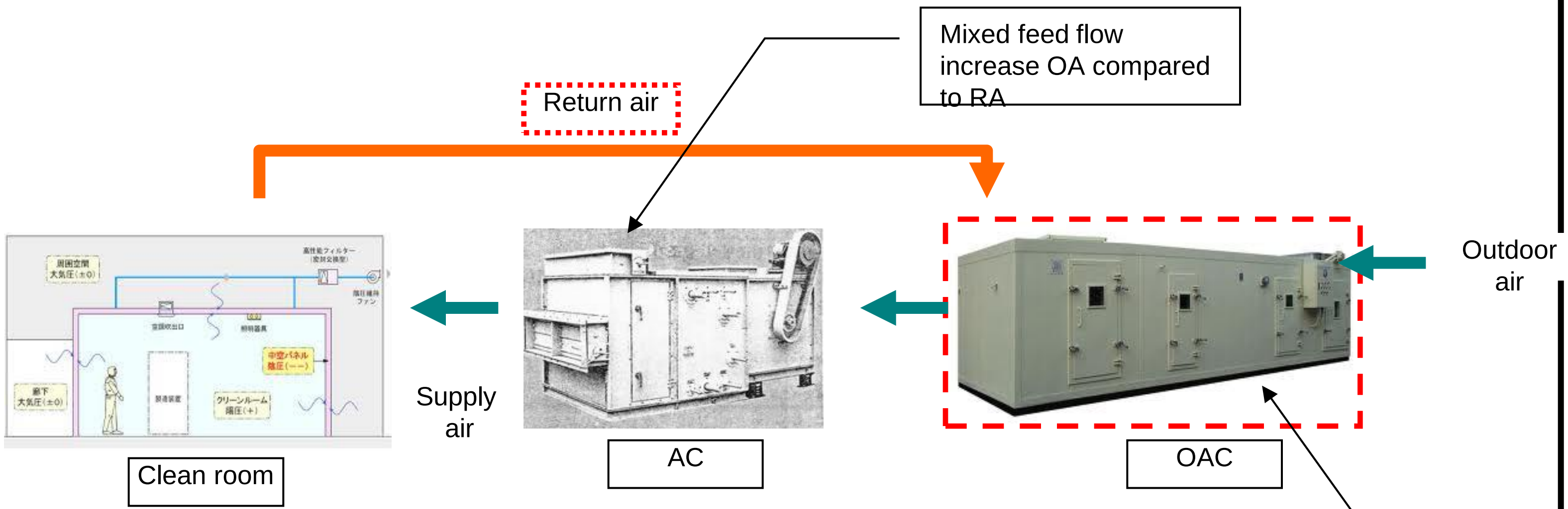


D. Air Conditioner Audit Procedure

- **Grasp AHU distribution diagram**: Find out Supply Air, Return Air, Outdoor Air, Mixed Air duct line, Room air conditioning condition through PFD or AHU distribution diagram etc.
- **Grasp AHU design condition**: with air conditioning load bill's AHU plan condition or installed nameplate of the AHU on site, find out planned air flow, planned temperature/humidity, coil capacity of hot/cold water, humidifier steam capacity, airing fan's power capacity, interior temperature/humidity condition.
- **Measure state point of each air**: Using thermometer and hygrometer, measure temperature/humidity of exterior air, Return Air, Mixed Air, Supply Air through measurement hole. Find out average value for one minute using thermometer and hygrometer which automatically saves for 1~2 sec . When measuring, make sure measure with no external air flow-in or disturbances.
- **Measure air flow**: Using hot-wire and windmill type of anemometer, measure air flow of external air, Return Air, Supply Air. Measure point is centered to the middle of the duct, and find out average of multiple measurements. Measure point is measuring average wind speed of chosen points in grid where total wind flow is secured. (Be advised that measure point with whirlpool can cause inaccurate data)
- **Air volume(m3/h)= air speed (m/s) × cross sectional area of the duct(m2) × 3,600 (s/h)**
- **Psychometric chart drawing** : After getting operating status of each points using psychometric program, Find out coil load and reason for energy loss

E. Air Conditioner Energy Saving Factor

- Energy-saving factors are OA heating by waste heat, Steam humidification changing to water humidification, reducing cooling load and heating load by prevent overcooling, OAC installation.

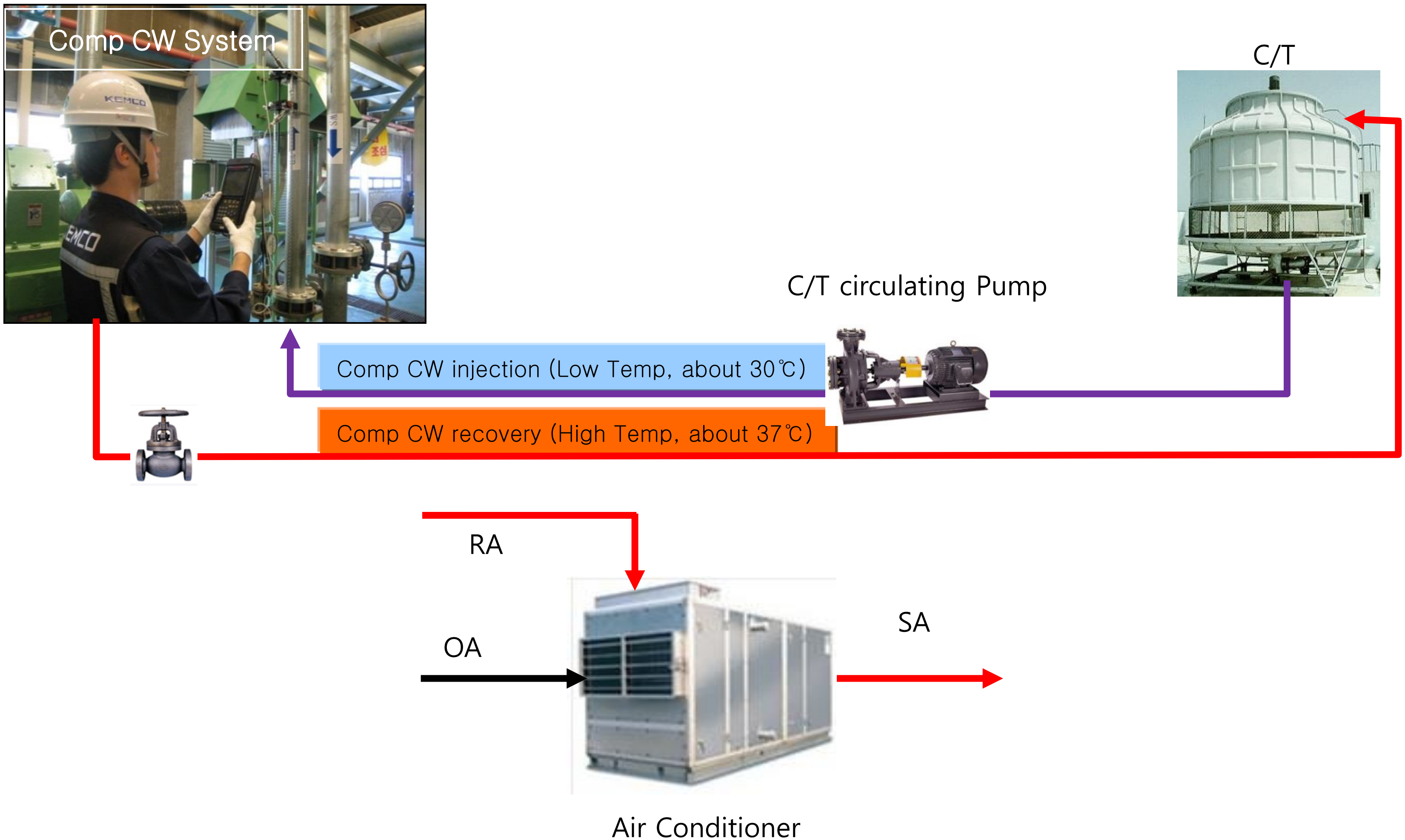


1. Preheating OA by waste heat
2. Changing steam humidification to water humidification
3. Reducing cooling and heating load by prevent overcooling
4. OAC installation

Case1. AHU Inlet OA is heated by waste heat of the Air Comp CW

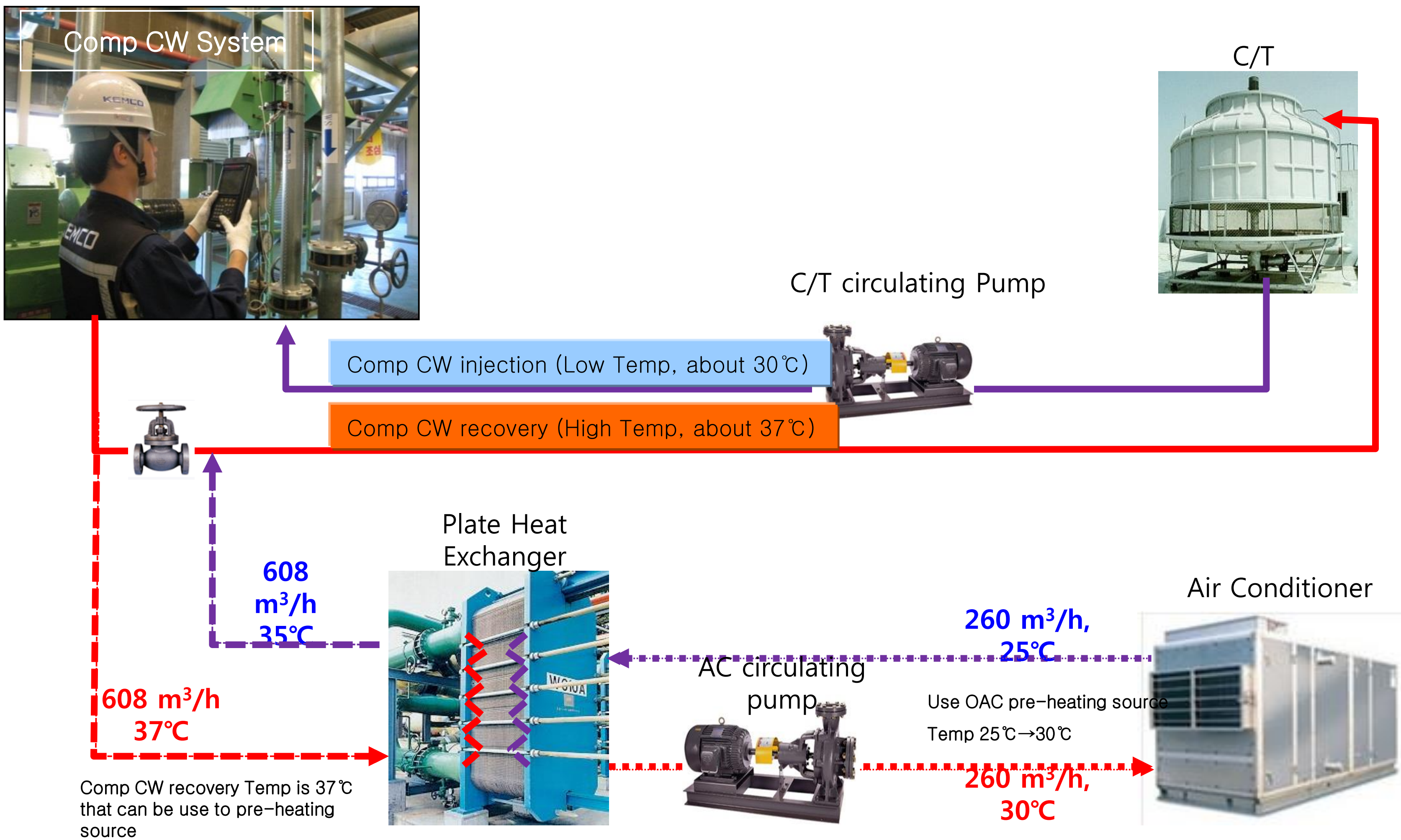
A. Operation Status

- Air Comp CW is cooled by C/T, OA is heated by AHU Steam.



B. Improvement

- Install Heat Exchanger for waste heat recovery of the Air Comp CW and AC Preheating coil will be using recovery heat



B. Improvement

Saved Cost equation

1) Saved fuel amount (fuel/h)= Preheating Coil retrieval calories(kcal/h)/{fuel calories (kcal/fuel) ×boiler efficiency(%)}

Where, Preheating Coil ‘s retrieval calories (kcal/h)=circulated amount (m3/h)×specific heat of the water (kcal/kg·℃) × In & out temperature difference (℃)

152 Nm3/h = (260,000 kg/h × 1 kcal/kg·℃ × 5℃)/(9450kcal/Nm3 × 0.9)

2) Saved cost ($/year)= Saved fuel amount(fuel/h) × operating hours(h/yr) × Unit price for fuel($/fuel)

410k$/yr = 152Nm3/h × 3,000h/yr × 0.9 $/Nm3 ÷ 1000 $/k$

3) Investment cost($)= set through material of construction companies or price calculating website

Investment cost(k$)= 70k$

Piping cost: 20k$, Heat exchanger cost: 50k$

4) Payback period (year)= Investment cost($) /Saved cost($/year)

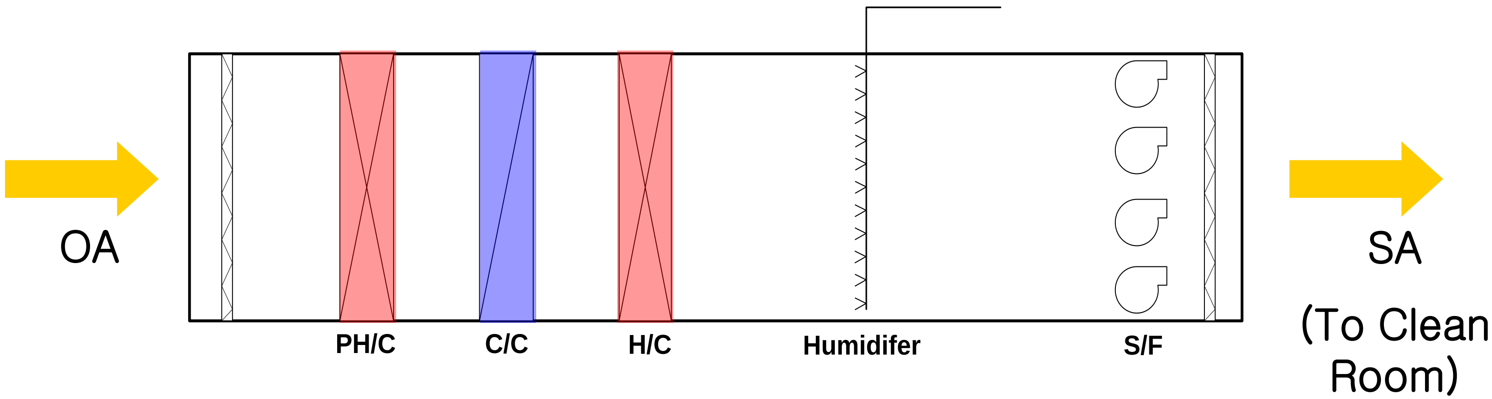
0.17 yr = 70k$/410k$/yr

Calculate simple payback period with pay-off period method of investment. Generally, 2~3 years of payback period is considered feasible for investment.

Case2. Steam type humidification changed to Spray type humidification

A. Operation Status

- OA through a process of PH/C (Preheating Coil) → H/C (Heating Coil) → Humidifier (Steam humidification), and that will be supplying C/R after heating/humidifying.
- currently way of Increasing moisture in the air by steam injection.



Process	OAC	Supply Air flow (m3/h)	OA condition		After P/H Temp(℃)	After H/C Temp(℃)	Dew point (℃)	Humidification flow (kg/h)
			Temp(℃)	Humidity (%)				
K-1	OAC-101	160,242 (design:153,000)	-5.2	62.3	11.8	18.8	17.7	2,158
K-3	OAC-102	78,619 (design:96,000)	-5.2	62.3	13.1	18	16.4	962
K-2	OAC-201	177,840 (design:171,900)	-5.2	62.3	11.8	21.2	19.8	2,785

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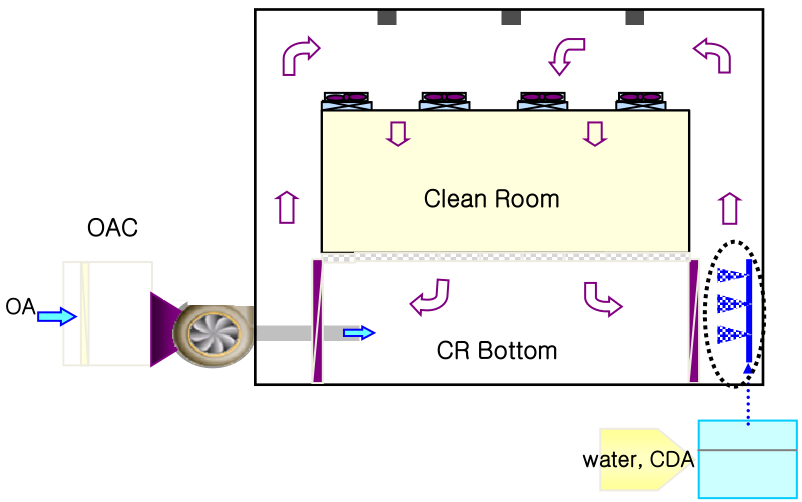
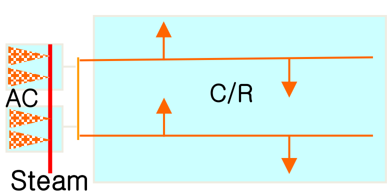
B. Improvement

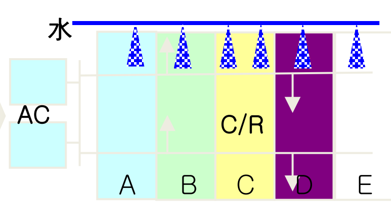
- Spray humidifier is installed at C/R that is altering humidity at C/R, so OAC Steam reduced.



<Clean Room water Spray humidification >



<Steam humidification control>



<water humidification control>

<C/R water humidification >

B. Improvement

- Saved cost equation

1) Annual steam usage (ton-steam/yr)= {absolute humidity in back of humidifier (kg/kg'-dry air) – absolute humidity in front of humidifier (kg/kg'-dry air)} × amount of dry air (kg'-dry air/h) × operating hours(h/yr)

   6,870 ton-steam/yr=(0.0119 kg/kg'-dry air - 0.00961 kg/kg'-dry air)×1,000,000 kg'-dry air/h × 3000 h/yr ÷ 1,000 kg/ton

2) DI usage amount when humidified with water (ton-water/yr) = 6,870ton-water/yr(assumed to use same amount of water, used heat emission of the device's heat source for evaporation)

3) Saved Cost ($/year)

   = Annual steam usage (ton-steam/yr) × steam unit price ($/ton-steam) - DI usage(ton-water/yr) × DI production cost($/ton-water)

   = 6,870ton-steam/yr × 70$/ton-steam - 6,870 ton-water/yr × 2 $/ton-water

   = 467,160 $/yr

3) Investment cost($)=set through material of construction companies or price calculating website.

   Investment Cost(k$)= 800k$

   Piping cost: 300k$, water humidifier device 500k$(DI generating system in the process, and considered extra investment cost of separate DI generating device)

4) Payback Period(year)= Investment cost($) /Saved cost($/년)

   1.7 yr = 800k$/467k$/yr

   Calculate simple payback period with pay-off period method of investment. Generally, 2~3 years of payback period is considered feasible for investment.

Contents

1. Chiller & Absorption Chiller

A. Chiller Outline

➢ What is the Chiller?

Chiller is to maintain a lower temperature than the ambient temperature, by removing heat, artificially.

➢ Principle

- Cooling system using refrigerant heat of vaporization of most commercial freezer.

➢ Classification

- Chiller: Machine lowering the temperature from room temperature to 0°C.
- Refrigerator : Machine lowering the temperature from room temperature to below freezing point.

➢ Chiller Classification

▣ Mechanical refrigeration methods (Chiller Classification)

▶ Vapor Compression type (Mechanical Compression type)

- Reciprocating
- Screw
- Rotary
- Turbo

▶ Absorption

- Single Effect Absorption
- Double Effect Absorption

▶ Compressed air, steam injection, vacuum, desiccant, Magnetic. . .

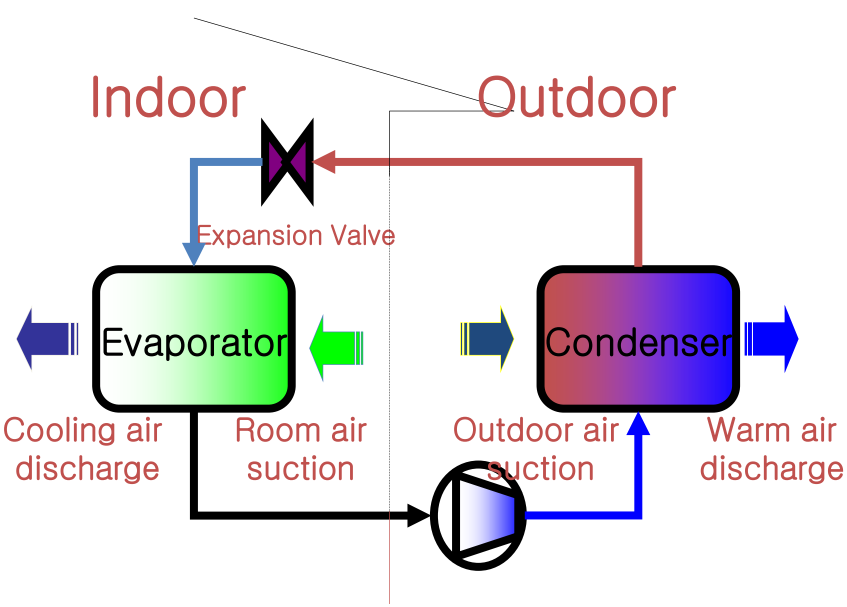
B. Compression Chiller Property

- Compression Chiller Cycle : Compression (Compressor) → Condensation (Condenser) → Expansion (Expansion Valve) → Evaporation (Evaporator)

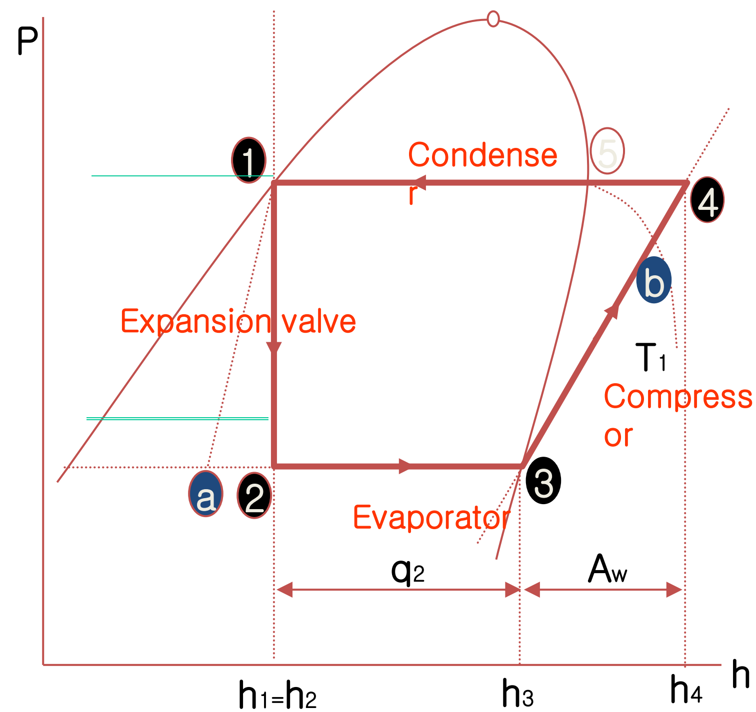
  ※ Cooling water from the Evaporator

- Compression Chiller COP = Chiller Water Heat(kcal/h) ÷ (Compressor power(kW)×860(kcal/kWh))

  = (h3-h2)÷(h4-h3)



[Compression Chiller Cycle]



[Compression Chiller P-h Diagram]

B. Compression Chiller Property

☞ **EVAPORATOR**

Low temperature, low pressure Refrigerant absorbs heat from the cooled products to have actual freeze effect.

☞ **COMPRESSOR**

Transform Low temperature, low pressure gas absorbed from evaporator into high temperature and pressure gas to emit heat in the air or water more easily. Power is used to operate compressor.

☞ **CONDENSER**

Emit heat to air(air-cooled) or water (water-cooled) of High temperature and pressure refrigerant gas provided from compressor to make high temperature and pressure liquid.

☞ **EXPANSION VALVE**

Expand valve for High temperature and pressure liquid provided from condenser to easily evaporate in evaporator, making it low temperature and pressure liquid.

C. Absorption Chiller Property

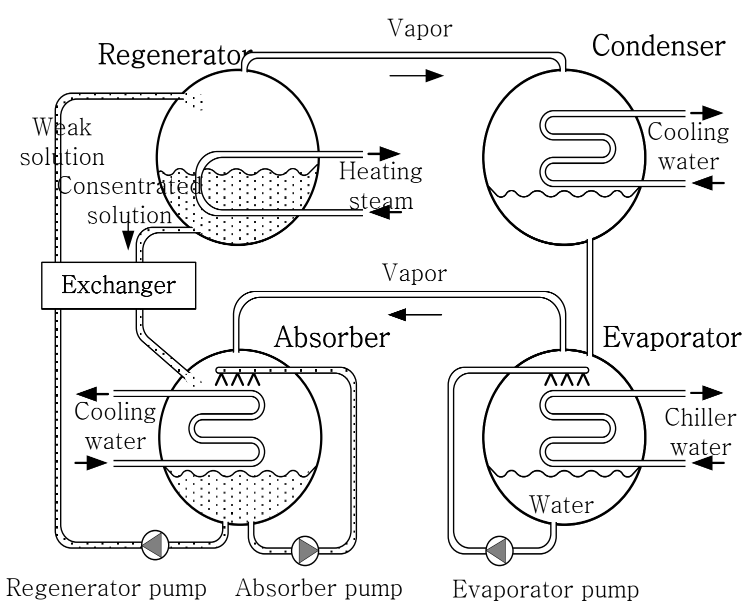
- Absorption Chiller Cycle : Evaporation → Absorption → Regeneration → Condensation

  ※ Cooling water from the Evaporator

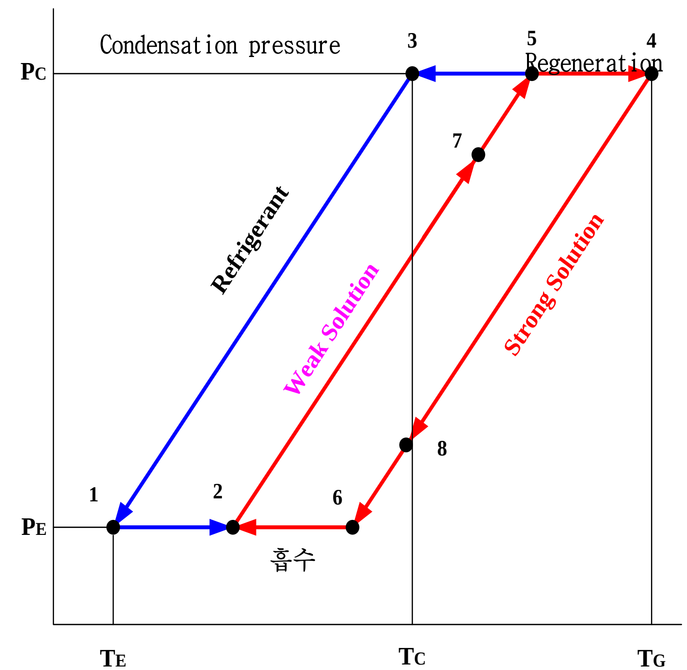
  ※ Refrigerant : water, Absorbent : LiBr

- Absorption Chiller COP = Heat of Evaporator (kcal/h) ÷ Input Energy (kcal/h)

  = Chiller Water Supply Heat (kcal/h) ÷Input Energy (kcal/h)



[Single Absorption Chiller Cycle]



[Single Absorption Chiller During Diagram]

C. Absorption Chiller Property

☞ EVAPORATOR

Refrigerant of evaporators are precipitated by refrigerant's pump of the refrigerant's tank through special nozzle above the heat pipe. Vacuum state (6～7mmHg) inside of evaporator refrigerant evaporates, cold water through heat pipe is frozen by refrigerant's dormant heat. Evaporated refrigerant's steam is sent to absorber.

☞ ABSORBER

Refrigerant steam evaporated from the evaporator is absorbed to absorber's Lithium Bromide solution. While evaporated pressure and temperature is maintained steady, absorption heat created when absorbing Refrigerant steam is removed by coolant flowing through heat pipe inside of absorber. Thin solution of the absorber is sent to high・low temperature regenerator by solution pump.

☞ REGENERATOR

Continued absorption of refrigerant causes thinner Lithium Bromide solution, making it unable to absorb the steam. In order to regenerate, thinned Lithium Bromide solution is sent to high・low pressure regenerator, and refrigerant steam coming from high-temperature regenerator is condensed to thinned solution from low temperature regenerator, and thinned solution from the absorber is condensed by refrigerant steam.

☞ CONDENSER

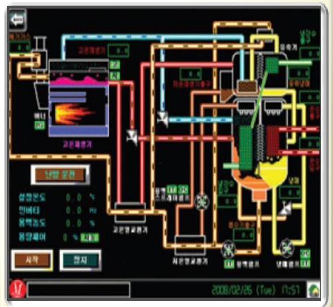
Refrigerant steam caused by low temperature generator and refrigerant condensed inside of the heat pipe are sent to condenser, frozen by coolant flowing inside of the condenser's heat pipe, concentrated, sent to evaporator. Refrigerant sent back to evaporator evaporates again to freeze.

D. Chiller Audit Procedure

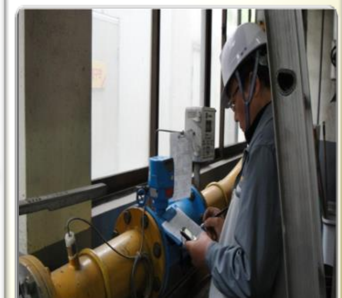
- Scope Confirmation → Design/Working Grasp→Heat/Power source Measurement →CHW/CW Measurement → Refrigerant Pressure & Temperature Measurement → COP Calculation → COP degradation factor grasp → Final Improvement Suggestion

Scope Confirmation

Design/Working Grasp



Heat/Power source Measurement



CHW/CW Measurement

Refrigerant Pressure & Temperature Measurement

COP Calculation

$$\text{성적계수} = \frac{\text{증발기에서 흡수한 열량(kcal/h)}}{\text{입력 에너지 (kcal/h)}} = \frac{\text{냉수 공급 열량}}{\text{입력 에너지}}$$

$$= \frac{\text{냉수유량(kg/h)} \times [\text{출구온도-입구온도}]\ ℃}{\text{증기소비량(kg/h)} \times [\text{증기엔탈피 - 응축수엔탈피}]\ \text{kcal/kg} + [\text{용액펌프 + 흡수액펌프 + 냉매펌프}]\text{kW} \times 860\ \text{kcal/kW}}$$

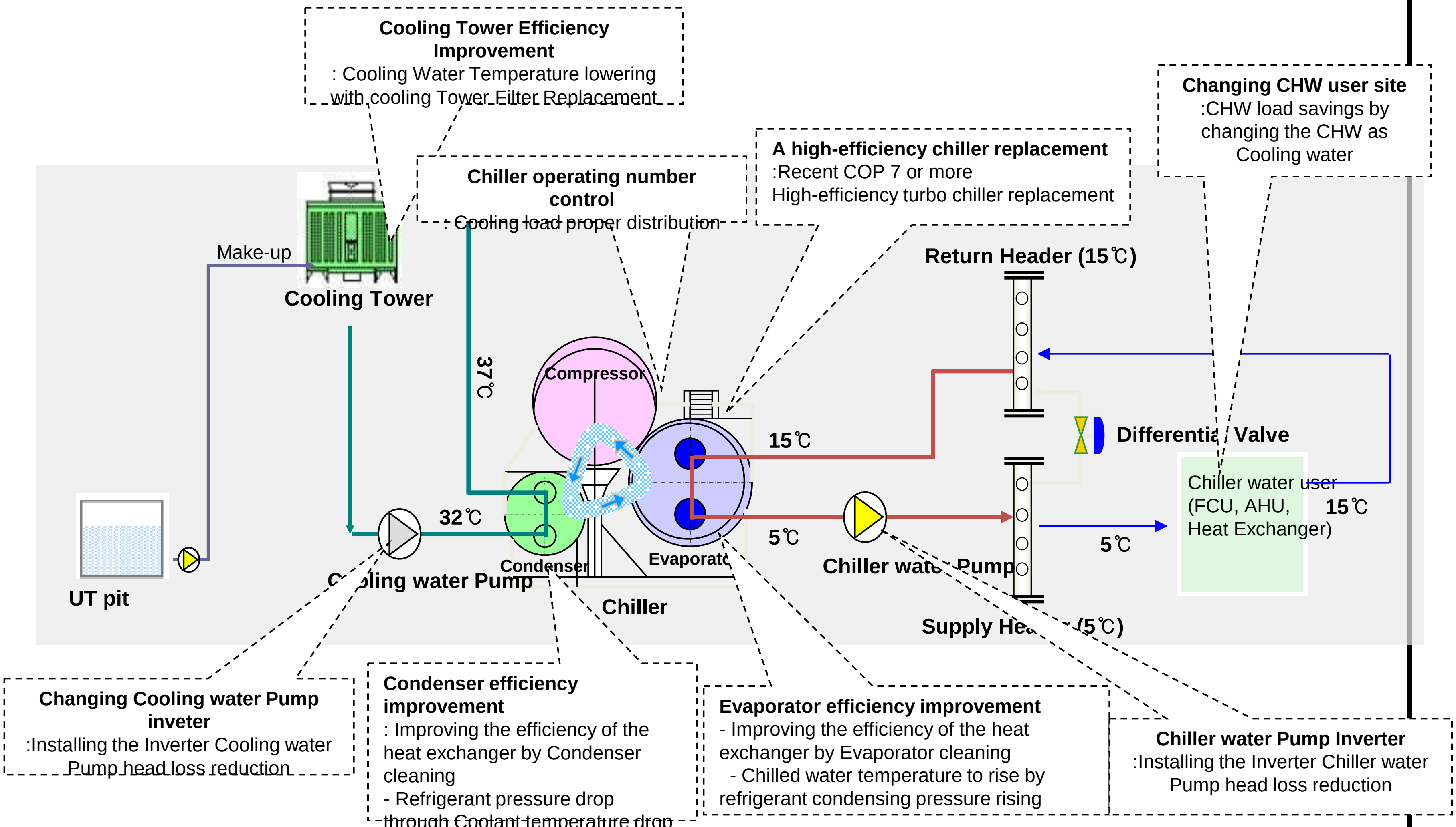
$$= \frac{\text{냉수유량(kg/h)} \times [\text{출구온도-입구온도}]\ ℃}{\text{증기소비량(kg/h)} \times [\text{중온수 입구온도 - 중온수 출구온도}]\ ℃ + [\text{용액펌프 + 흡수액펌프 + 냉매펌프}]\text{kW} \times 860\ \text{kcal/kW}}$$

COP degradation factor grasp

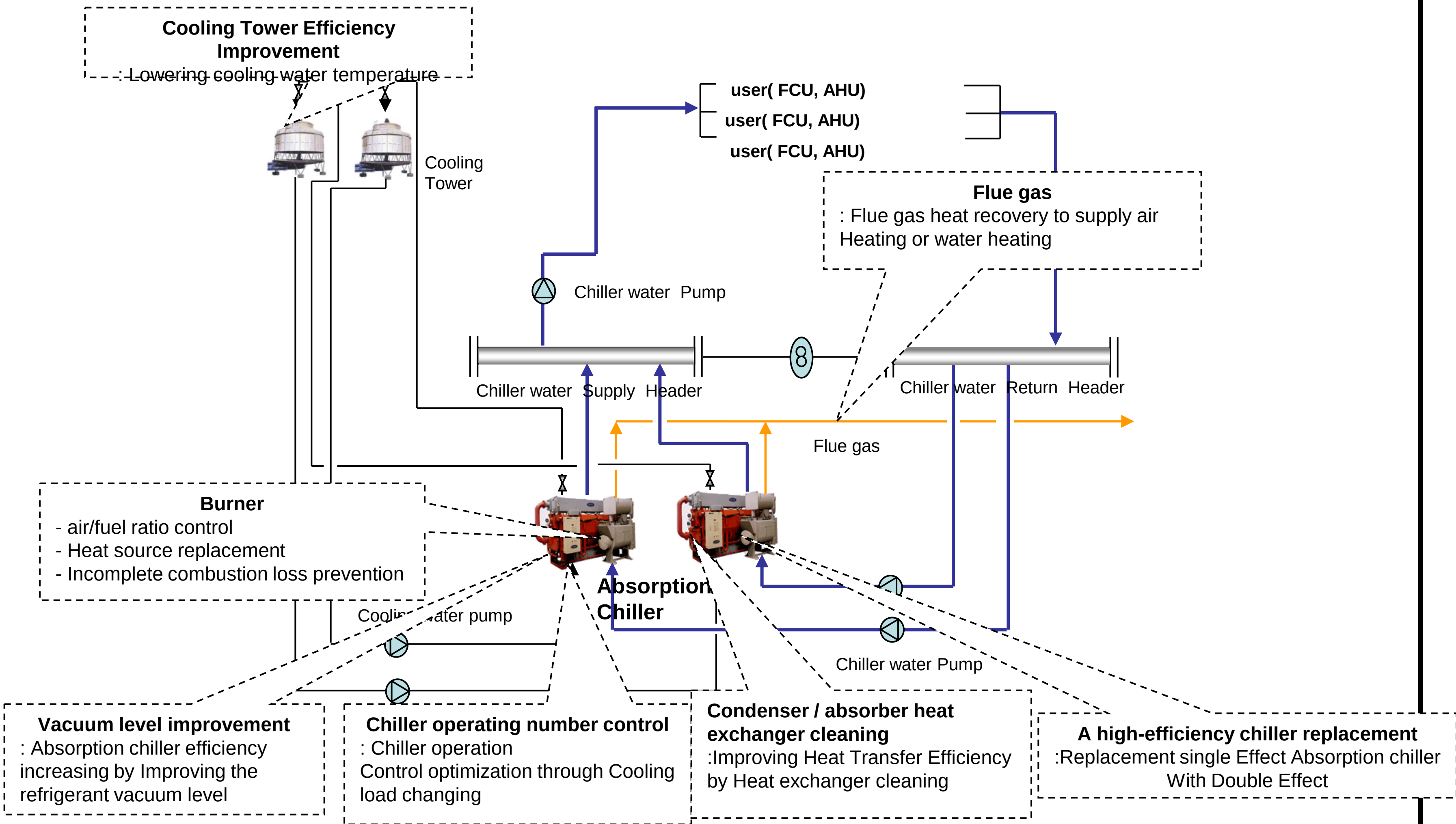
D. Air Conditioner Audit Procedure

- **Grasp Freeze distribution diagram**: through distribution diagram of freezer PFD, cold water pipe, coolant pipe, cold water/coolant circulation pump, cooling tower, usage of cold water, heat exchanger, freezer's installed location.
- **Grasp Freezer's design condition**: through freezer's Design Spec Data in equipment list and name plate installed in freezer on-site, refrigerant type, coolant condense, planned evaporation pressure, planned flow of cold water/coolant, planned temperature of cold water/coolant, rated power usage, rated COP, planned condition for cooling tower, etc.
- **Measuring cold water/coolant temperature**: measure temperature from surface temperature of the pipe or water discharged outside of the pipe. There is a possibility danger from pressure of the pipe when water leaks outside of the pipe, so cooperation with manager is necessary. Surface temperature is measured by making a direct contract of sensor to the surface to measure. When logging the data, use the data saving thermometer, and auto save temperature by 1 minute to analyze change of temperature.
- **Measuring flow of cold water/coolant**: uses ultrasonic flow meter by attaching sensor to the surface of the pipe, flow is calculated by time delayed caused by fluid flow. Measured point is where total flow is maintained (4D~6D apart from curve). If it has logging function, flow is calculated by 1 minute to analyzer the change of flow pattern.
- **Measuring freezer's power**: measured by power meter from electric distribution board. The value is instantaneous, but use logging measurement when required. If it is high pressure, use PT and CT to measure power. When taking a measurement, confirm it is high or low voltage, and manager is obliged to present for measurement.
- **Freezer COP = Cold Water Flow (kg/h) × Cold water specific heat (kcal/kg·℃) × temperature difference of cold water(℃)/{power usage(kW) × 860 (kcal/kWh)}**

E. Compression Chiller Energy Saving Factor



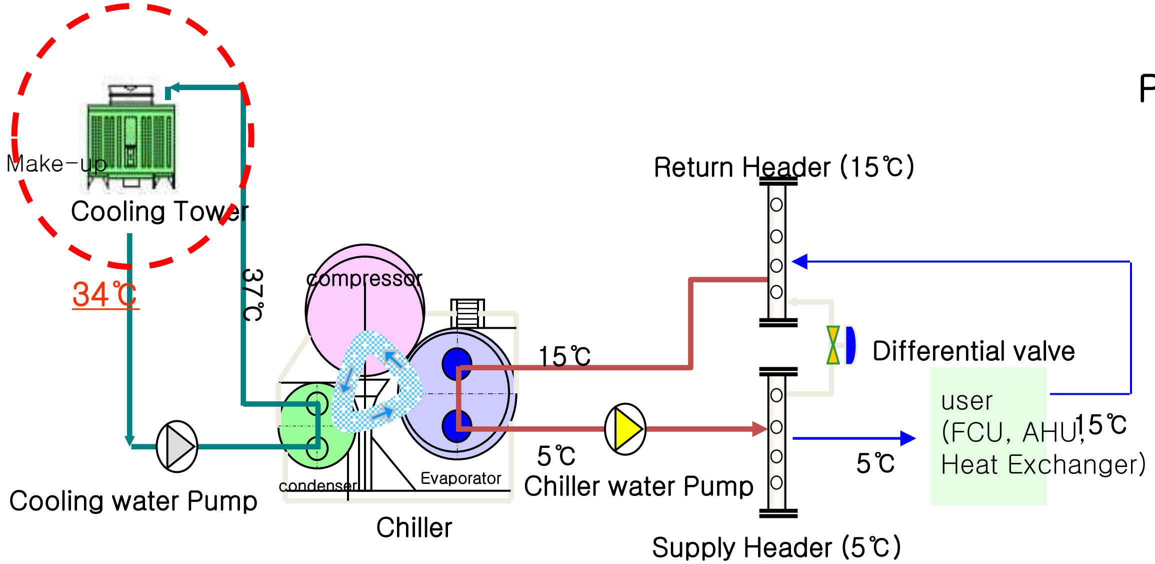
F. Absorption Chiller Energy Saving Factor

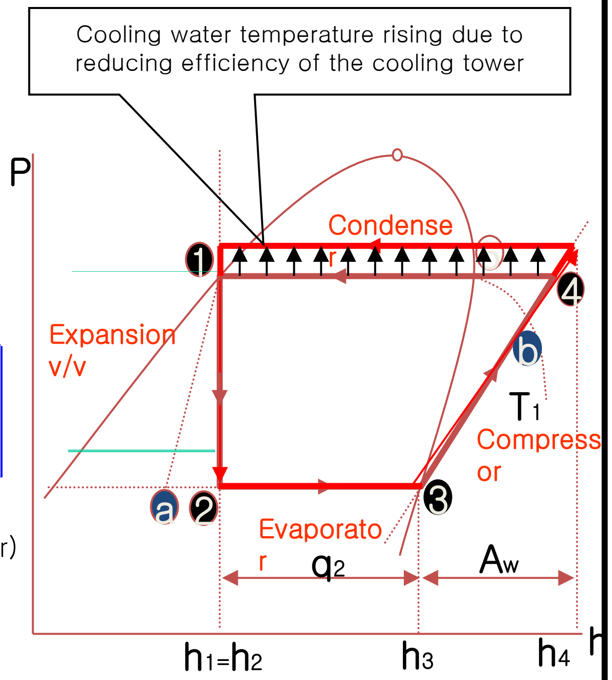


Case 1. Improving chiller efficiency by Cooling water temperature lowering due to the replacement of the cooling tower filler

A. Operation status

- Condenser refrigerant pressure rise increases the compressor power and coolant temperature remains high due to contamination of cooling tower filler.
- Cooling Water feed Temp: 32℃(design) → 34(present)

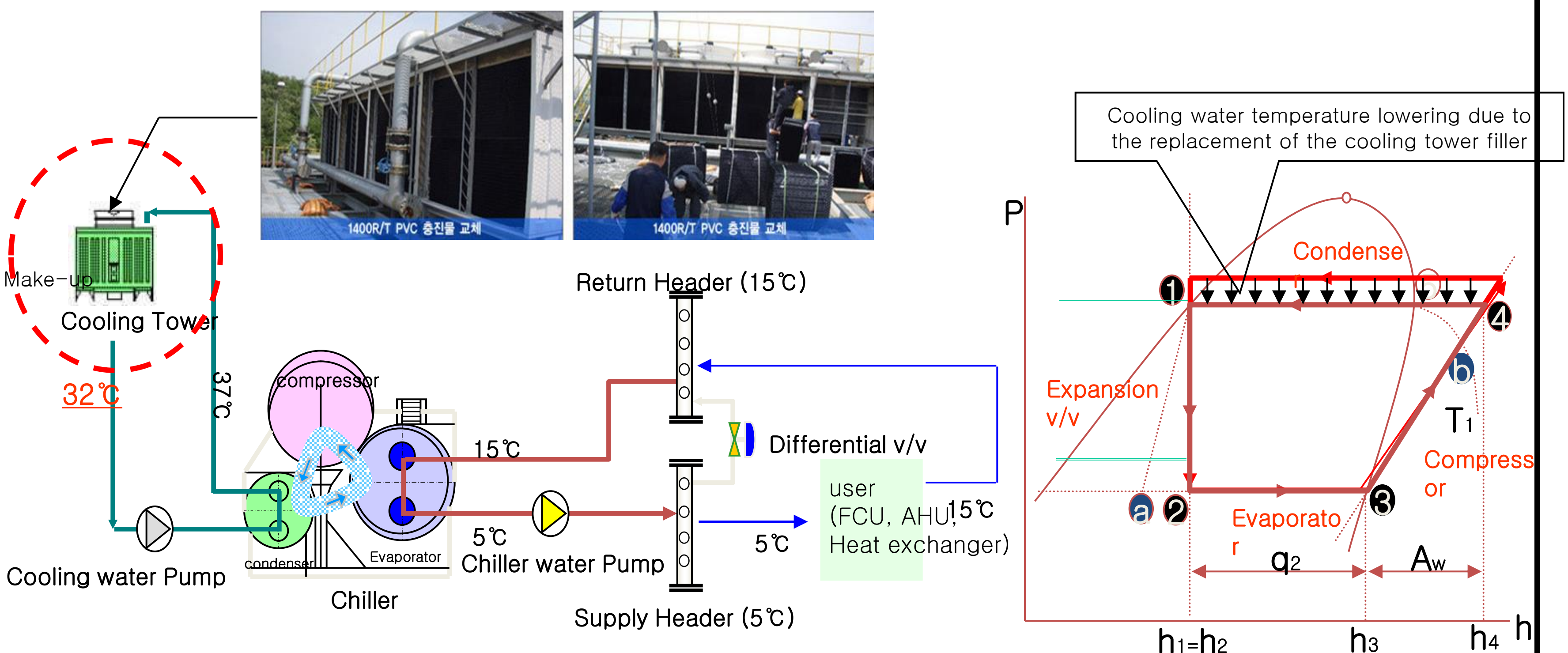




B. Improvement

●The cooling water temperature and condenser refrigerant pressure drop with replacing Cooling tower filler high efficiency fillers ☞ Compressor power savings.

- After cooling tower filler replacement, Cooling water supply temperature: 34℃ (before) → 32℃ (after)



B. Improvement

Energy saved equation.

1) Power usage of the freezer after improvement (kW)= entropy of compressor after improvement (h'4-h3)(kcal/kg)/entropy of compressor before improvement (h4 –h3)(kcal/kg) × power usage of the freezer before improvement (kW)

   482.8kW=(169 kcal/kg – 141 kcal/kg)/(170 kcal/kg -141 kcal/kg) × 500 kW

2) Saved Cost ($/year)= {power usage of freezer before improvement (kW)- power usage of freezer after improvement (kW)}× operating hours(h/yr) × Power Unit Price($/kWh)

   51.6 k$/yr = (500 kW – 482.8kW)×3,000h/yr × 1$/kWh

3) Investment Cost($)= set through material of construction companies or price calculating website

   Investment Cost(k$)= 50k$

   Cooling tower Filler Replacement cost 50k$

4) Payback period (year)= Investment cost($) /saved cost($/year)

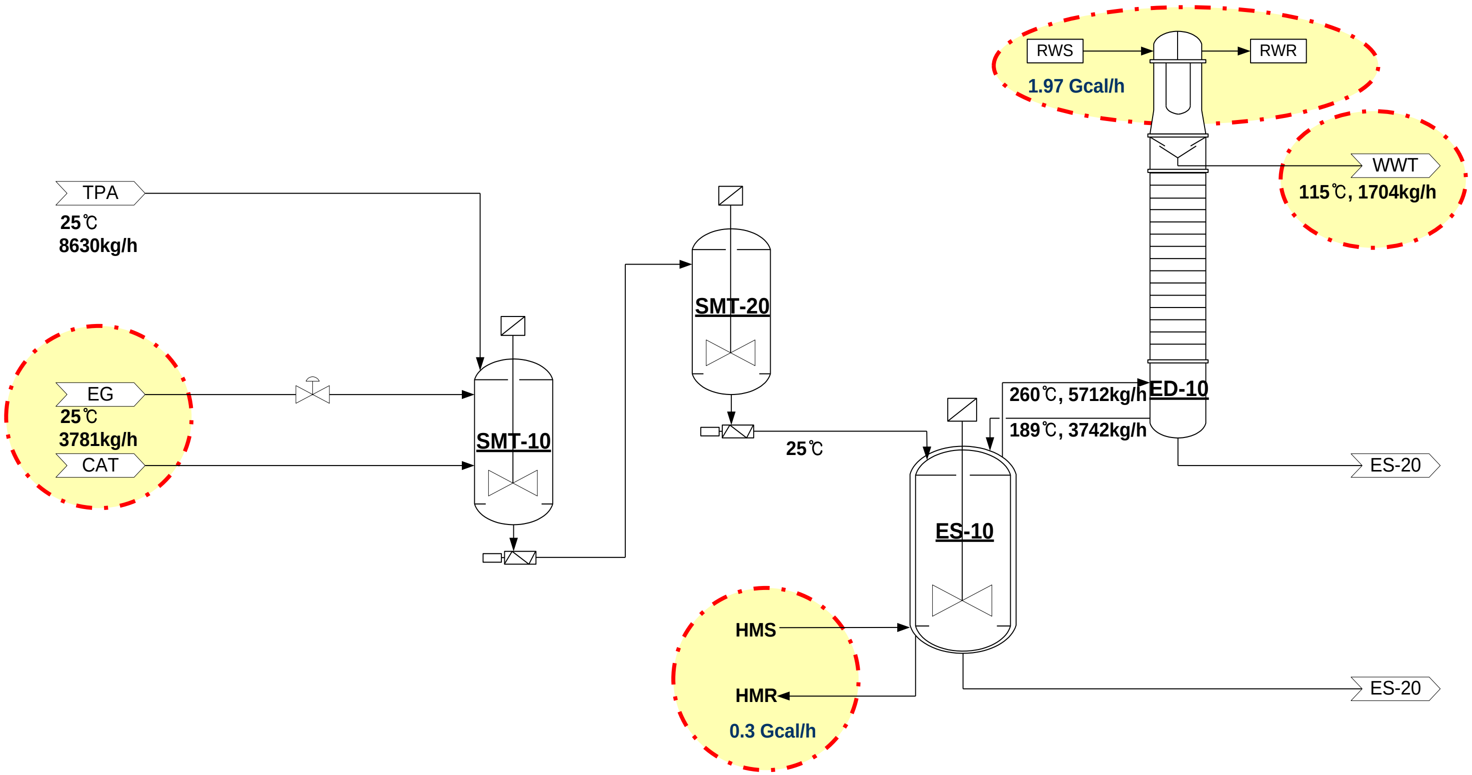
   1.0 yr = 50k$/51.6k$/yr

   Calculate simple payback period with pay-off period method of investment. Generally, 2~3 years of payback period is considered feasible for investment.

Case 2. Using Hot water with ES Tower OVHD Heat recovery to Chiller Heat source

A. Operation status

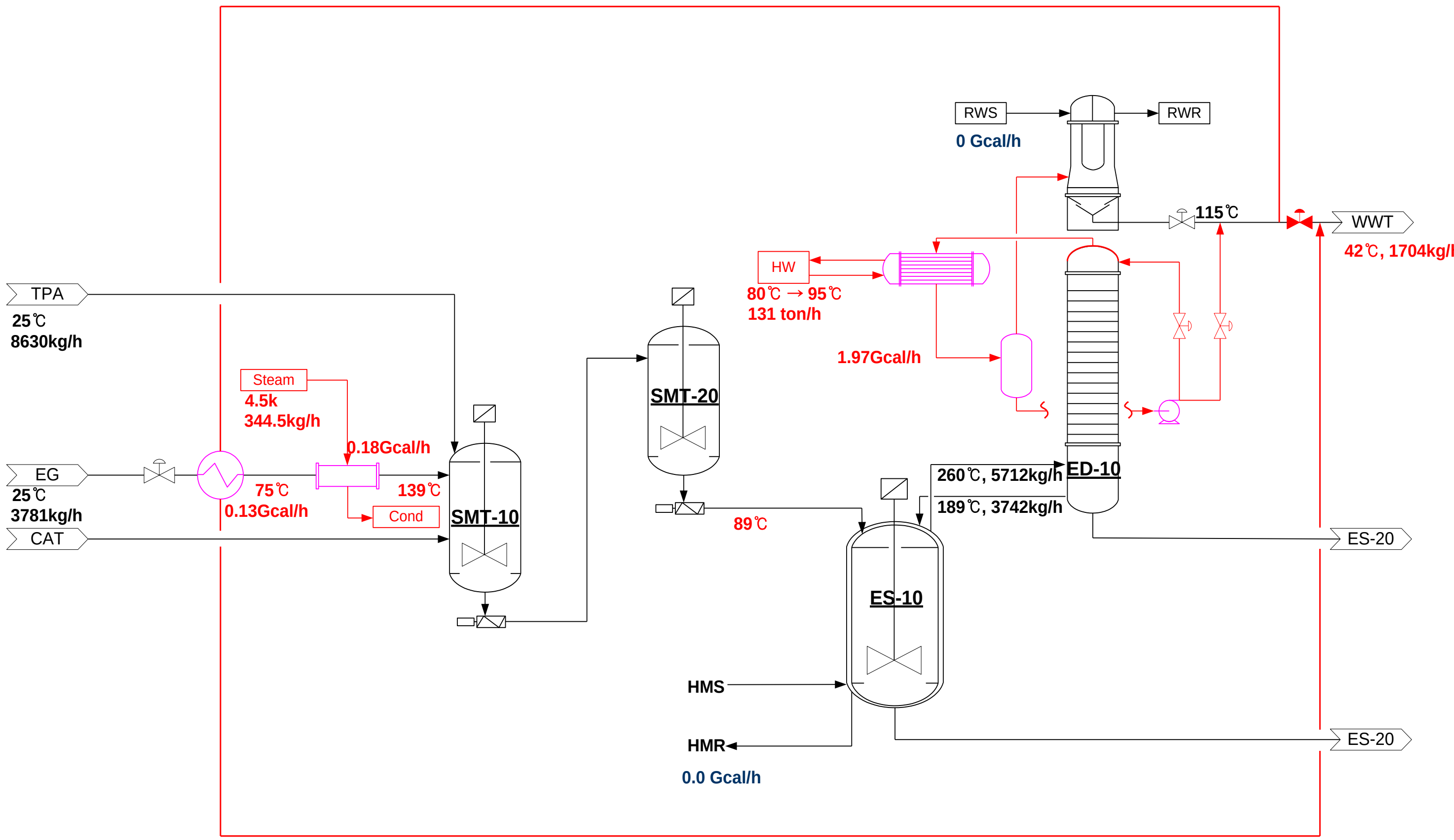
- ES Tower Over Head Vapor flow :1,170kg/h(115℃) Condensing with Cooling water Heat Exchanger
- ES Tower Condenser Cooling load: 1.97Gcal/h



KOREA ENERGY AGENCY

B. Improvement

- Using the ES Tower Vapor Heat (New Hot water Heat Exchanger)
  - Hot water : 80℃ → 95℃, flow: 131ton/h ☞ Heat source of Absorption Chiller
- Existing compression chillers power savings and Peak Load drop



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B. Improvement

Energy saved equation

1) Saved freezer power (kW)= waste heat recovery (kcal/h)×absorption refrigeration machine COP /3024 (kcal/RT)×unit freezer power (kW/RT)

   331kW = 1,965,000 kcal/h× 0.85 / 3024 kcal/RT × 0.6 kW/RT

   Where, waste heat calories(kcal/h)= circulated hot water flow (kg/h) × temperature difference (℃) × specific heat (kcal/kg·℃)

   1,965,000 kcal/h = 131,000 kg/h × (95-80)(℃) × 1kcal/kg·℃

2) Saved Cost ($/년)= Saved freezer power (kW)}× operating hours (h/yr) × Unit power price ($/kWh)

   99.3 k$/yr = 331kW×3,000h/yr × 0.1$/kWh

3) Investment cost($)= set through material of construction companies or price calculating website.

   Investment cost(k$)= 550k$

   Absorption refrigeration machine :200k$, heat exchanger:200k$, Column line separation cost: 100k$, pipe and other costs : 50k$

4) Payback period (year)= Investment cost($) /saved cost($/year)

   5.5 yr = 550 k$/99.3k$/yr

   Calculate simple payback period with pay-off period method of investment. Generally, 2~3 years of payback period is considered feasible for investment.

Thank You
감사합니다

Emblem Name : SeSe

"Save energy, Save earth"