Energ Efficienct Designs of TFT-LCD Panel Fabs

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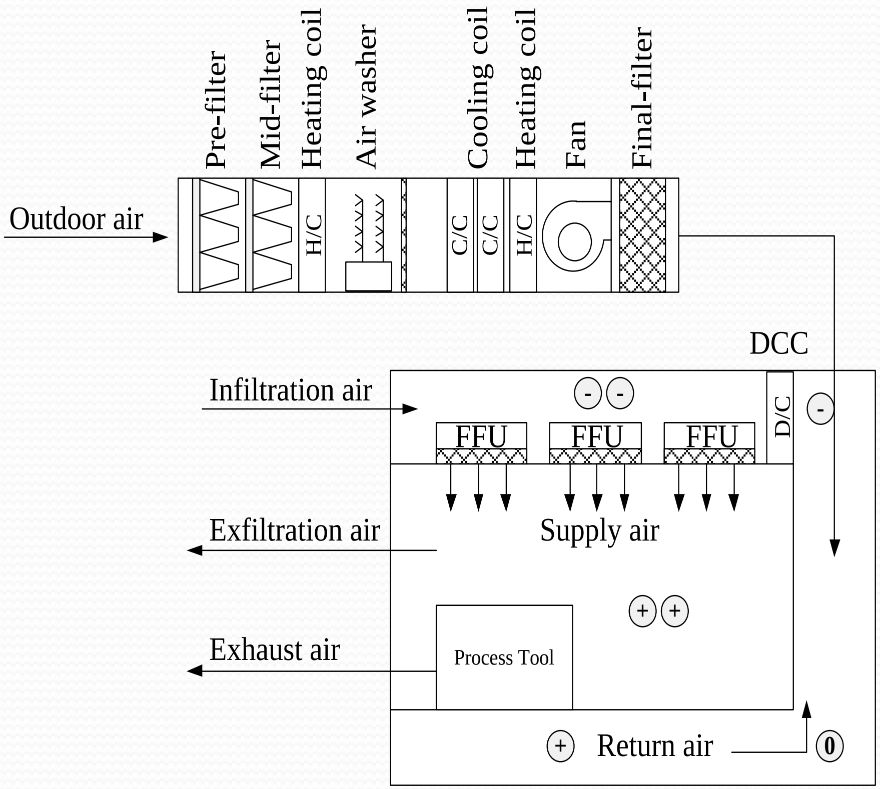
Abstract

- This study employs the a dedicated fab energy simulation (FES) software by our group to examine six energy-saving approaches for the make-up air unit (MAU) of a TFT-LCD (thin-film transistor liquid-crystal display) fab.
- Approach-1: adjust the set point of dry bulb temperature and relative humidity in the cleanroom
- Approach-2: lower the flow rate of supply air volume in the MAU
- Approach-3: use draw through type instead of push through type MAU
- Approach-4: combine the two stage cooling coils in MAU to a single stage coil
- Approach-5: reducing the original MAU exit temperature from 16.5˚C to 14.5˚C
- Approach-6: avoid excessive increase in pressure drop over the filter by replacing HEPA filter more frequently
- The simulated results showed that Approach-1 and 6 exhibits more significant influence on annual power consumption than the other approaches. The advantage/disadvantage of each approach is elaborated.

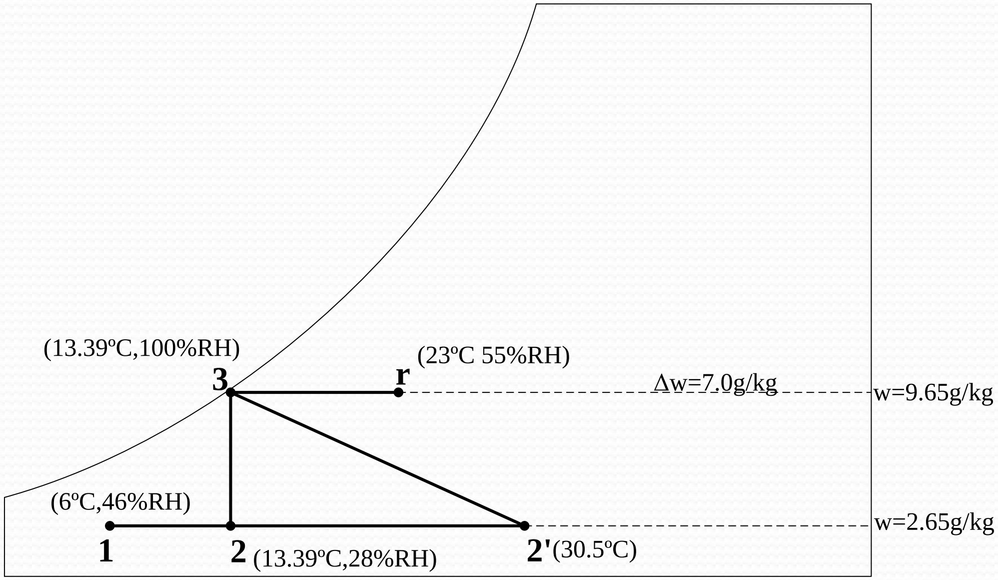
Introduction

- Humidity in large-scale high-tech cleanrooms is often controlled by a dedicated MAU which consists of a fan, two stage cooling coils, a heating coil (or heater), filters and a humidifier
- Methods of humidification include mist humidification and steam humidification. The steam humidification process is a quasi isothermal process, which needs heat energy to generate steam. The mist humidification process is an isenthalpic process, which draws evaporation energy from the air.

- MAU output air has a temperature range of 14–17°C, and the humidity is controlled at 9.65 x 10-3 kg/kg for TFT-LCD fab. The make-up air (MA) is mixed with return air (RA) to maintain temperature at 23±1°C and humidity at 55±5% for most TFT-LCD industries.
- The temperature in cleanroom can be controlled by a dry coil but this does not regulate humidity, thus the MAU output humidity becomes very important, as it is the only mechanism to control humidity in the cleanroom.



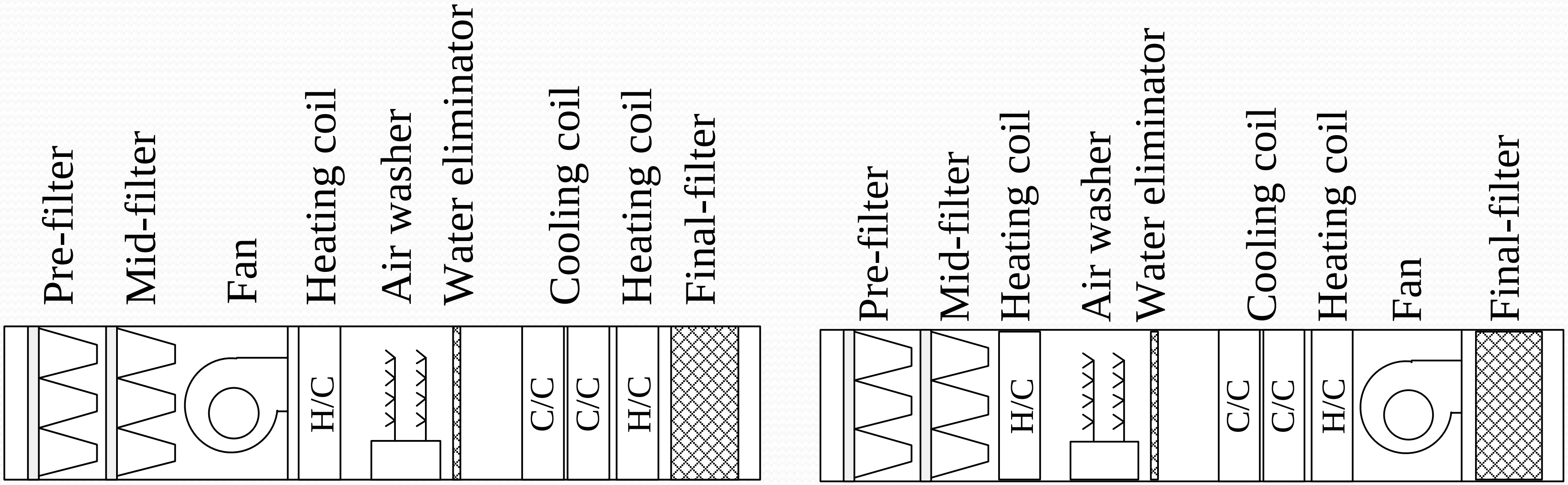
A typical schematic diagram for MAU and clean room HVAC system.



The psychrometric process of humidification: steam-humidification (1-2-3) and mist-humidification (1-2'-3), where r is the room condition.

- the supply water temperature for cooling coil inside MAU is typically 5–7°C. This low temperature of the supply water reduces water chiller’s efficiency. In general, a rise of 1°C in evaporator temperature of water chiller can increase chiller efficiency by about 3%.
- Heat sources of heating coil generally are steam, hot water or electric heater. However, replacing these high energy consumption components with heat recovery chiller helps reduce energy consumption of heating coil.

- Dividing one cooling coil with low supply water temperature into two cooling coils with different supply water temperatures (i.e. 9°C for first cooling coil and 6°C for second cooling coil), total energy consumption of water chillers can be reduced.
- Heat sources of heating coil generally are steam, hot water or electric heater. However, replacing these high energy consumption components with heat recovery chiller helps reduce energy consumption of heating coil.
- Mounting the MAU fan after the cooling coils can replace some of the energy required for reheating.



(a) A push-through type MAU

(b)A draft-through type MAU

Components arrangement of MAUs with mist humidifier

- Generally, power consumption for air-conditioning in a high-tech facility is about 30–40% of the total power consumption [3-6], around 50% of which is accounted for by the chiller.
- Standard chiller plant design of cleanrooms provides chilled water at 5–6°C. While this temperature is required for dehumidification, the low set point imposes an efficiency penalty on the chillers. Typically, heat exchangers and/or mixing loops are used to convert the low temperature, energy intensive chilled water into warmer chilled water for sensible or process cooling loads.

- Chiller efficiency is a function of the chilled water supply temperature. Other things being equal, higher chilled water temperatures resulted in improved chiller efficiency. For example, instead of both chillers operating at 6 ° C, if one chiller in a dual chiller plant provides water at 12.5 ° C, 20–40% of energy consumption and peak power can be saved. The chilled water temperature is 5 ° C for a single-temperature chiller plant system and 5 ° C/9 ° C for a "dual-temperature" chilled water system.

Methods

- In the present study, we use the simulation software (namely Fab Energy Simulation, FES) to analyze the energy use of the fab. Design parameters or operating conditions such as the room temperature, relative humidity, supply/return temperature of the chilled water, and so on can be inputted via the user interface of the FES.
- The energy uses in the fabs generally come from several parts, including the HVAC system, exhaust system, process cooling water (PCW), ultra-pure water (UPW), clean dry air (CDA), fan-filter unit (FFU) vacuum, fans (mainly used in the HVAC and exhaust system), pumps (for hot or chilled water), process tools, and lighting system. The detailed description, used models, and validation of the developed FES have been conducted in our recent study.

Basic conditions of the fab

The fab is located in the Science Park in Hsinchu, Taiwan. In the studied fab, the cleanroom area is 59,760 m2 (core fabrication area is 49,031 m2). The product is a 3.5 generation small/medium-size display panel with monthly production volume of 75,000 pieces.

(a) Design conditions

Temperature	23±2°C
Relative humidity	55±5%
Cleanliness	
Process area	Class 10@0.3 μm : 8,293 m^2 Class 100@0.3 μm : 16,438 m^2
Tool maintenance area	Class 1,000@0.5 μm : 22,226 m^2 Class 10,000@0.5 μm : 2,074 m^2

(b) Outdoor air conditions (Hsinchu, Taiwan)

Temperature	35°C (Summer)	5°C (Winter)
Relative humidity:	80 % (Summer)	20% (Winter)

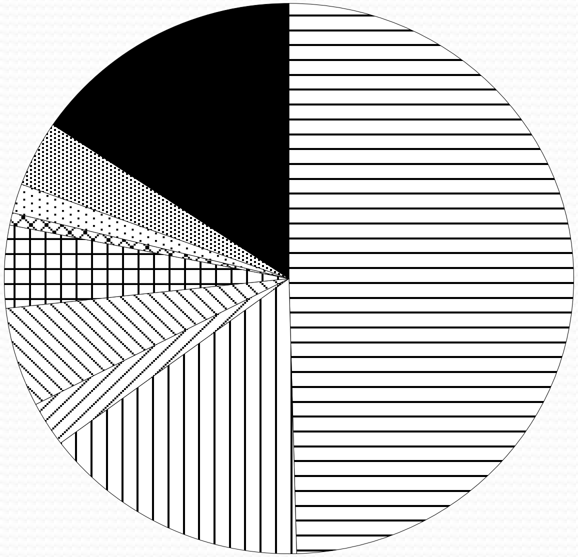
(c) Utility matrix

Item	Supply pressure	Temperature	Remarks
General exhaust	–650 Pa	23.5°C	Use point –250 Pa
Alkaline exhaust	–550 Pa	23.4°C	Use point –250 Pa
Acid exhaust	–600 Pa	23.3°C	Use point –250 Pa
Flammability exhaust	–1000 Pa	35.5°C	Use point –250 Pa
Solvent exhaust	–600 Pa	23.6°C	Use point –250 Pa
Compressed dry air	6.5 kg/cm^2		DP = –70°C
Process Cooling water	5 kg/cm^2	18°C	Back pressure 0 kg/cm^2 and $\triangle t$ = 5°C
Pure water	2 kg/cm^2	23°C	Power to production = 10 kWh/m^3
Process Vacuum	–600 mmAq		Use point flow rate = 250 m^3/h

Operating conditions of the cleanroom.

Baseline of energy use of the fab & *energy-saving approaches*

- Combined chiller and MAU system is the largest energy consumption component in the fab.
- The following approaches were selected because they significantly influence the energy use and only related to the operational mode, without any extra expenditure. Note that process tool relates to production and is normally very sensitive to the fab management .



Energy-saving approaches.

(1)Adjusting the set point of dry bulb temperature and relative humidity in the cleanroom.

(2)Lower the supply flow rate of make-up air unit.

(3)Use draw through type instead of push through type MAU.

(4)Combine two stage cooling coils in MAU to a single stage coil.

(5)Reduce the original MAU exit temperature from 16.5˚C to 14.5˚C.

(6)Reduce pressure drop across HEPA filters in MAU by increasing frequency of HEPA filter replacement.

Approach	Original condition	Modified condition	Remark
1	T_{db} = 23°C, RH = 55%, and w = 9.6 g/kg	(A) T_{db} = 24°C, RH = 52%, and w = 9.6 g/kg (B) T_{db} = 24°C, RH = 55%, and w = 10.2 g/kg (C) T_{db} = 22°C, RH = 58%, and w = 10.2 g/kg (D) T_{db} = 22°C, RH = 55%, and w = 9.1 g/kg	(A) Increasing T_{db} and decreasing RH. (B) Increasing T_{db} and keep the same RH. (C) Decreasing T_{db} and increasing RH. (D) Decreasing T_{db} and keep the same RH
2	Q_{MAU} = 1,260,000 m^3/h	Q_{MAU} = 1,200,000 m^3/h	This approach generally combines with reducing exhaust gas flowrate.
3	Push-through	Draft-through	The location of fan affects the degree of reheating required.
4	Two stage cooling coil	Single stage coil.	This related to the cost and also energy performance.
5	Exiting temperature = 16.5°C and static pressure (Ps) = 1,182 Pa	Exiting temperature = 14.5°C and Ps = 1,382 Pa	Motor efficiency = 80% and fan efficiency = 83%.
6	Ps = 1,182 Pa	(A) Ps = 1,232 Pa (B) Ps = 1,282 Pa (C) Ps = 1,332 Pa	Motor efficiency = 80% and fan efficiency = 83%.

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Results and Discussion

Approach-1

- **This approach is acceptable for most of the area in a fab, except the photolithography area, which is a process very sensitive to temperature variation. Approach-1B exhibits highest energy saving effect, up to 1.01% of annual fab energy consumption, majorly due to a lower cooling load of MAU. Approach-1D has a negative effect; it consumes 0.94% more of energy.**
- **It is noted that the setting on room temperature results a very significant impact on energy-saving. Increasing 1 ℃ of fab temperature can almost save 1% of fab energy consumption. On the other hand, increasing 3% of RH value in the fab can reduce about 0.65% of fab energy consumptio**n.

Item	**Base (kWh)**	**Approach-1A (kWh)**	**Approach-1B (kWh)**	**Approach-1C (kWh)**	**Approach-1D (kWh)**
High temp. chiller	21,668,692	20,915,272	20,872,416	22,272,119	22,362,851
Low temp. chiller	10,631,363	10,631,330	9,248,430	10,631,363	11,953,912
MAU Cooling load	80,546,944	80,546,751	72,512,100	80,546,944	88,230,952
MAU Re-Heating load	9,739,383	9,739,189	6,671,003	9,739,383	12,757,970
Total	214,786,230	214,032,777	212,607,021	215,389,657	216,802,938
Power saved (%)	-	0.35%	1.01%	–0.28%	0.94%

Electric power consumption difference of Base case and Approach-1

Results and Discussion

Approach-2

- **Reducing the flow rate of supply air of MAU can reduce the cooling load of the cooling coil in MAU during summertime and reduce the heating load of pre-heating coil during wintertime. Thus, the total power consumption is reduced. The energy saving of entire Fab is 0.34%.**

Item	**Base (kWh)**	**Approach-2 (kWh)**
High temp. chiller	21,668,692	21,602,271
Low temp. chiller	10,631,363	10,228,825
MAU/RCC Fan	5,472,802	5,212,193
MAU Cooling load	80,546,944	76,711,375
Humidification (kg)	6,263,319	5,965,065
MAU Pre-Heating load	2,190,983	2,086,650
MAU Re-Heating load	9,739,383	9,275,602
Total	214,786,230	214,056,662
Power saved (%)		0.34%

Electric power consumption difference of Base case and Approach-2.

Results and Discussion

Approach-3

- **For the draft-through type MAU, as the fan is located downstream of cooling coils, the air temperature (also the specific volume) upstream of fan is lower than outdoor air temperature.**
- **For the draft-through type MAU, airflow rate across the fan is less than that in the MAU inlet.**
- **For the same MAU inlet flow rate, the fan power consumption of the draft-through type MAU is less than that of push-off type**
- **The fan heat load of the draft-through MAU becomes part of the heat source of the re-heating coils, while that of the push-through MAU becomes additional heat load.**

	Push-off type	**Draft-through type**
Air flow rate (CMH)	105,170	97,127
Fan power consumption (kW)	52.00	40.96
Power saved (%)	Base	21.23%

Fan power consumption of draft-through type and push-off type MAU.

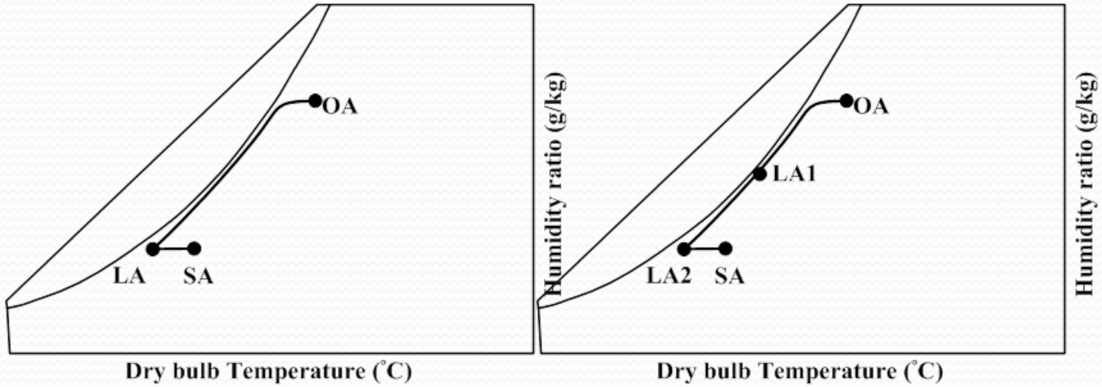
Item	**Base (kWh)**	**Approach-3 (kWh)**
High temp. chiller	21,912,119	21,668,692
Low temp. chiller	10,701,543	10,631,363
MAU Cooling load	82,206,784	80,546,944
Humidification (kg)	6,632,341	6,263,319
MAU Pre-Heating load	1,983,789	2,190,983
MAU Re-Heating load	11,608,959	9,739,383
Total	215,099,837	214,786,230
Power saved (%)	-	0.15%

Electric power consumption difference of Base case and Approach-3.

Results and Discussion

Approach-4

- **In terms of the initial cost, this approach uses one stage of cooling coil instead of two-stage cooling coils. As only low temperature chilled water is used, energy consumption in low temperature chiller increases, resulting in an increase of 0.2% in total energy consumption. However, the difference between initial costs of single cooling coil and two stage cooling coil is little. Therefore, the increase in operational cost of MAU with single cooling coil easily exceeds the initial cost saving.**



(a) Single cooling coil

(b) Two stage cooling coils

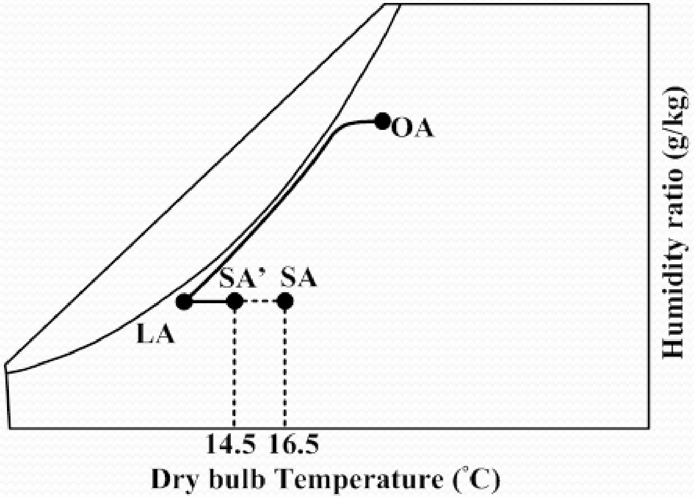
Item	Base (kWh)	Approach-4 (kWh)
High temp. chiller	21,668,692	16,658,491
Low temp. chiller	10,631,363	16,065,633
MAU Cooling load	80,546,944	80,686,831
Humidification (kg)	6,263,319	15,663,913
MAU Re-Heating load	9,739,383	9,682,892
Total	214,786,230	215,210,299
Power saved (%)		–0.20%

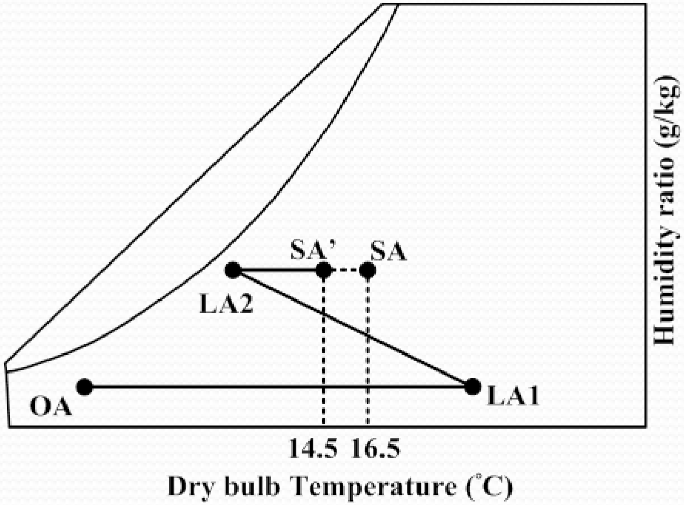
Electric power consumption difference of Base case and Approach-4.

Results and Discussion

Approach-5

- **As the chillers are with heat recovery function, i.e. the so-called heat-recovery chillers, which provide warm water (up to about 37˚C) from condensing side, the warm water may be used for reheating.**
- **If the hot water generated by heat-recovery chillers is enough for re-heating, no heating facility such as a boiler is required and the energy-saving is mostly from the high temperature chillers.**
- **Successive lowering of the air temperature can cause increase of fan power consumption due to higher pressure loss in HEPA filters, caused by the high humidity air. In this case, reducing exit air temperature by 1˚C of MAU saves about 0.1% of fab energy consumption.**





Item	Base (kWh)	Approach-5 (kWh)
High temp. chiller	21,668,692	20,262,409
MAU/RCC Fan	5,472,802	6,398,827
MAU Re-Heating load	9,739,383	1,877,907
Total	214,786,230	214,305,972
Power saved (%)		0.22%

Results and Discussion

Approach-6

- The increase of power consumption is mostly from the fan. The re-heating load is slightly reduced due to a slightly higher temperature rise by the fan power.
- By frequently replacing HEPA filter, the pressure drop increase may be maintained to a very low level. Therefore, great fan power increase may be saved.
- Approach-1B reduces annual operations energy consumption by 1.01%. This is due to the increase of humidity ratio from 9.6 g/kg to 10.2 g/kg. The worst case is Approach-1D, which increases the annual energy consumption by 0.94%. This is due to the decrease of humidity ratio from 9.6 g/kg to 9.1 g/kg.

Item	Base (kWh)	Approach-6A (kWh)	Approach-6B (kWh)	Approach-6C (kWh)
High temp. chiller	21,668,692	21,667,301	21,665,109	21,662,974
MAU/RCC Fan	5,472,802	5,704,308	5,935,814	6,167,320
MAU Re-Heating load	9,739,383	9,663,613	9,584,141	9,504,666
Total	214,786,230	215,016,346	215,245,660	215,475,031
Power saved (%)		–0.11%	–0.21%	–0.32%

Case	Energy saving (%)
Approach-1A	0.35
Approach-1B	1.01
Approach-1C	–0.28
Approach-1D	–0.94
Approach-2	0.34
Approach-3	–0.15
Approach-4	–0.20
Approach-5	0.22
Approach-6A	0.11
Approach-6B	0.21
Approach-6C	0.32

Approaches 1A and 6C are perferable!

Conclusions

- The simulated results demonstrate that the setting on room temperature results a very significant impact on energy-saving. Specifically, increasing 1°C of fab temperature can almost save 1% of fab energy consumption, increasing 3% of RH value in the fab can reduce about 0.65% of fab energy consumption.
- Using a single stage coil or push-off type MAU surprisingly consumes more energy. Reducing exit air temperature of MAU by 1°C saves about 0.1% of fab energy consumption.
- Avoiding excessive increase in pressure drop over the filter by more frequently, replacing HEPA filter is economically possible and its effect on reducing energy consumption is notable, about 0.2% of fab energy consumption can be saved by reducing 100 Pa of pressure drop over the filter.

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