16 Oktober 2021

Prinsip-prinsip Pengelolaan Udara di RS dalam Era Endemi Covid-19 dan Revolusi Industri 4.0

Budihardjo

Hospital Engineering Forum 2021

Indonesian Association Hospital Engineering

Curriculum Vitae

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1. S1-Teknik Mesin FTUI, 1977
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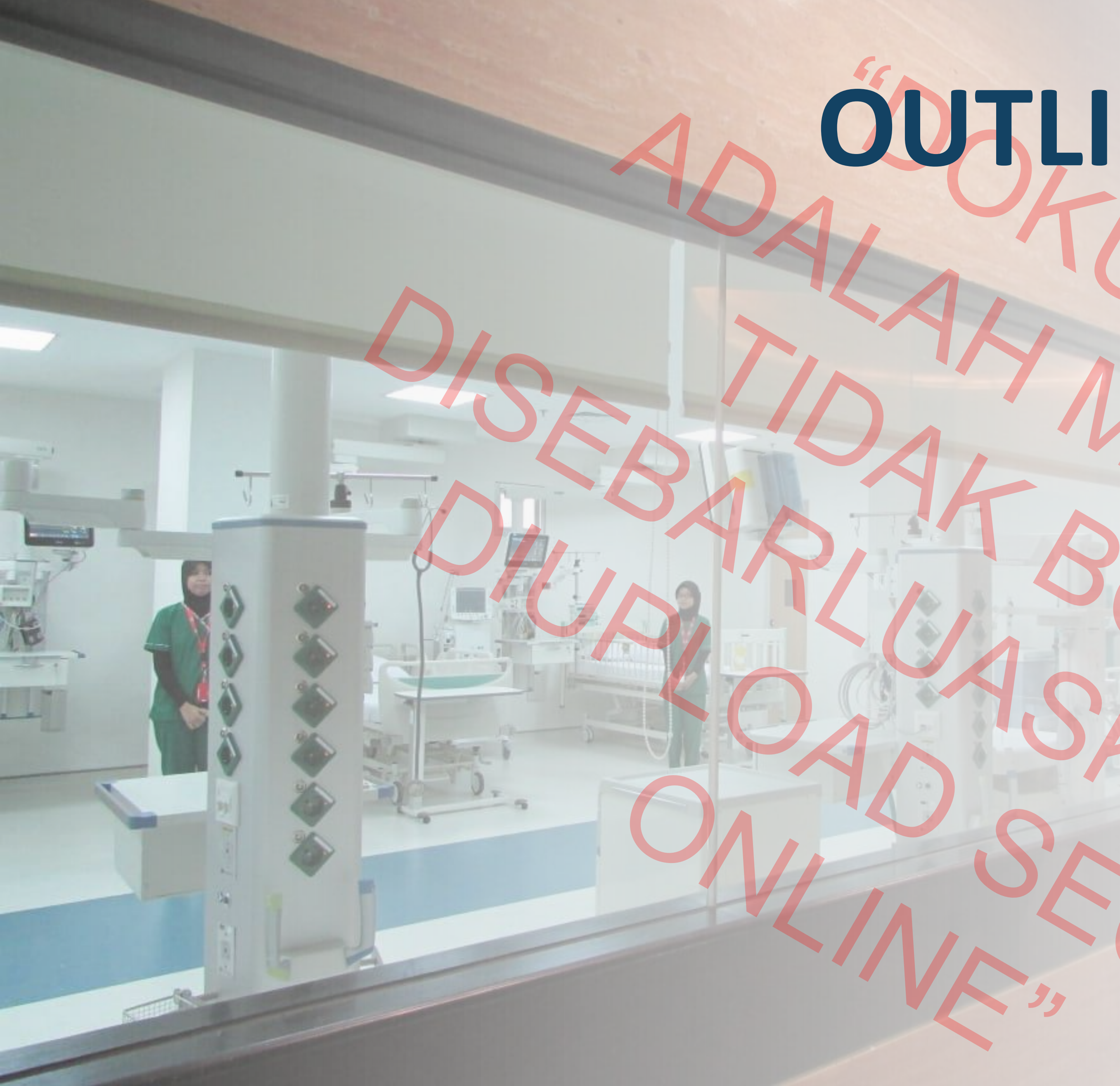


OUTLINE

01 Standard, Peraturan dan Pedoman
02 Kriteria dan Pedoman Perancangan
03 Ruang Isolasi
04 Ruang Operasi
05 Implementasi HVAC Rumah Sakit
06 Kesimpulan

1

Standard, Peraturan dan Pedoman

Sistem Tata Udara

- **Pengkondisian udara (*air conditioning*),** usaha mengolah udara untuk mengendalikan temperatur ruangan, kelembaban relatif, kualitas udara, dan penyebarannya.

- **Sistem tata udara**, keseluruhan sistem yang mengkondisikan udara di dalam gedung dengan mengatur besaran termal seperti temperatur dan kelembaban relatif, serta kesegaran dan kebersihannya, sedemikian rupa sehingga diperoleh kondisi ruangan yang nyaman.

Sistem Tata Udara Pada Bangunan Rumah Sakit

- Rumah sakit adalah bangunan yang penuh dengan sumber penyakit dan sumber infeksi. Bakteri, virus, mikroorganisme yang berada di udara (*airborne microorganism*), jamur, dan sumber-sumber penyakit lainnya yang dapat menular merupakan hal yang harus menjadi perhatian pada sistem tata udara.
- Untuk mencegah berkembang biak dan tumbuh suburnya mikroorganisme penyebab penyakit, maka diperlukan *sistem tata udara khusus* untuk menghindarkan penularan penyakit dan memperoleh tingkat kenyamanan termal.
- Pengaturan temperatur, kelembaban relatif, tekanan udara, ventilasi serta kualitas udara di dalam ruangan serta distribusi udara didalam ruangan secara keseluruhan merupakan parameter-parameter perlu mendapatkan perhatikan khusus.
- Konservasi energi perlu dipertimbangkan pada pemilihan sistem tata udara

Peran Sistem Tata Udara

Dapat mempengaruhi penanganan suatu penyakit, antara lain dengan cara :

- Mendistribusikan udara bersih kedalam ruang melalui filtrasi
- Mengeluarkan udara terkontaminasi keluar ruangan
- Mengatur dan mengendalikan temperatur, kelembaban relatif, tekanan udara
- Melarutkan udara dalam ruang dengan udara yang lebih bersih dari luar ruangan

Peraturan, Standard, Pedoman Teknis Sistem Tata Udara dan Ventilasi Rumah Sakit

1. Peraturan Menteri Kesehatan Nomor 24 Tahun 2016 Tentang Persyaratan Teknis Bangunan dan Prasarana Rumah Sakit
2. Direktorat Jenderal Pelayayanan Kesehatan Kementerian Kesehatan Republik Indonesia Tahun 2020, Pedoman Teknis Bangunan dan Prasarana Ruang Isolasi Penyakit Infeksi Emerging (PIE)
3. Direktorat Bina Pelayanan Penunjang Medik dan Sarana Kesehatan Direktorat Bina Upaya Kesehatan Kementerian Kesehatan RI Tahun 2012 :
   a. Pedoman Teknis Prasarana Rumah Sakit Sistem Instalasi Tata Udara
   b. Pedoman Teknis Bangunan Rumah Sakit Ruang Operasi
4. SNI 6390:2020 Konservasi energi sistem tata udara pada bangunan Gedung
5. ISO 14644-1 2015 Cleanrooms and associated controlled environments
6. ANSI/ASHRAE/ASHE Standard 170 – 2021 Ventilation of Health Care Facilities
7. ANSI/ASHRAE Standard 62.1-2019 Ventilation for Acceptable Indoor Air Quality

2

Kriteria dan Pedoman Perancangan

INTERNATIONAL STANDARD

ISO 14644-1

Cleanrooms and associated controlled environments —

Part 1: Classification of air cleanliness by particle concentration

This International Standard covers the classification of air cleanliness in cleanrooms and associated controlled environments. Classification in accordance with this standard is specified and accomplished exclusively in terms of concentration of airborne particles and is limited to a designated range of considered particle sizes for determination of particle concentration limits.

Table 1 — ISO Classes of air cleanliness by particle concentration

ISO Class number (*N*)	Maximum allowable concentrations (particles/m³) for particles equal to and greater than the considered sizes, shown below[a]					
	0,1 µm	0,2 µm	0,3 µm	0,5 µm	1 µm	5 µm
1	*10*[b]	[d]	[d]	[d]	[d]	[e]
2	100	*24*[b]	*10*[b]	[d]	[d]	[e]
3	1 000	237	102	*35*[b]	[d]	[e]
4	10 000	2 370	1 020	352	*83*[b]	[e]
5	100 000	23 700	10 200	3 520	832	[d, e, f]
6	1 000 000	237 000	102 000	35 200	8 320	293
7	[c]	[c]	[c]	352 000	83 200	2 930
8	[c]	[c]	[c]	3 520 000	832 000	29 300
9[g]	[c]	[c]	[c]	35 200 000	8 320 000	293 000

[a] All concentrations in the table are cumulative, e.g. for ISO Class 5, the 10 200 particles shown at 0,3 µm include all particles equal to and greater than this size.

[b] These concentrations will lead to large air sample volumes for classification. Sequential sampling procedure may be applied; see Annex D.

[c] Concentration limits are not applicable in this region of the table due to very high particle concentration.

[d] Sampling and statistical limitations for particles in low concentrations make classification inappropriate.

[e] Sample collection limitations for both particles in low concentrations and sizes greater than 1 µm make classification at this particle size inappropriate, due to potential particle losses in the sampling system.

[f] In order to specify this particle size in association with ISO Class 5, the macroparticle descriptor M may be adapted and used in conjunction with at least one other particle size. (See C.7.)

[g] This class is only applicable for the in-operation state.

Kondisi Perancangan Udara Luar

SNI 6390:2020 Konservasi energi sistem tata udara pada bangunan gedung

Contoh untuk kota Jakarta

Tabel 1 – Kondisi perencanaan udara luar ruang untuk sistem tata udara (3 dari 7)

Lokasi			*Cooling* DB/MCWB (°C)						*Evaporation* WB/MCDB (°C)						*Dehumidification* DP/MCDB dan HR (°C dan $g_{catran}/kg_{udara\ kering}$)								
			0.4%		1%		2%		0.4%		1%		2%		0.4%			1%			2%		
Kabupaten/ Kota	Koordinat	Stasiun Cuaca	DB	MC WB	DB	MC WB	DB	MC WB	WB	MC DB	WB	MC DB	WB	MC DB	DP	HR	MC DB	DP	HR	MC DB	DP	HR	MC DB
Jakarta Pusat	6.183S, 106.833E	Jakarta Observatory	34,2	25,7	33,7	25,7	33,3	25,7	27,2	32,3	26,9	32,0	26,7	31,6	25,7	21,0	30,2	25,5	20,7	29,9	25,2	20,4	29,6
Jakarta Utara	6.100S, 106.867E	Jakarta Tanjung Priok	33,8	25,8	33,2	25,8	32,9	25,8	27,2	32,0	27,1	31,8	26,8	31,4	26,0	21,3	30,2	25,7	21,0	30,0	25,5	20,7	29,8

ANSI/ASHRAE/ASHE Standard 170-2021 Ventilation of Health Care Facilities

Table 7-1 Design Parameters—Inpatient Spaces

Function of Space (ee)	Pressure Relationship to Adjacent Areas (n)	Minimum Outdoor ach	Minimum Total ach	All Room Air Exhausted Directly to Outdoors (j)	Air Recirculated by Means of Room Units (a)	Unoccupied Turndown	Minimum Filter Efficiencies (cc)	Design Relative Humidity (k), %	Design Temperature (l), °F/°C
Operating room *(FGI 2.2–3.3.3)* (m), (o)	Positive	4	20	NR	No	Yes	MERV-16 (hh)	20–60	68–75/20–24
Patient care area corridor	NR	NR	2	NR	NR	Yes	MERV-14	NR	NR
Patient room *(FGI 2.1–2.3.2)*	NR	2	4 (y)	NR	NR	Yes	MERV-14	Max 60	70–75/21–24
Patient toilet room *(FGI 2.1–2.3.5 & 2.1–2.3.6)*	Negative	NR	10	Yes	No	Yes (ff)	MERV-8	NR	NR
Class 1 imaging room *(FGI 2.2–3.4.1.2 & Table 2.2-2)*	NR (jj)	2	6	NR	NR	Yes	MERV-8	Max 60	72–78/22–26
Class 2 imaging room *(FGI 2.2–3.4.1.2 & Table 2.2-2)* (d), (p)	Positive	3	15	NR	No	Yes	MERV-14	Max 60	70–75/21–24
Class 3 imaging room *(FGI 2.2–3.4.1.2 & Table 2.2-2)* (m), (o)	Positive	4	20	NR	No	Yes	MERV-16 (hh)	20–60	68–75/21–24

cc. Table entries are the minimum filter efficiencies required for the space. Refer to Section 6.4 of this document for further clarification of filtration requirements. The minimum efficiency reporting value (MERV) is based on the method of testing described in ASHRAE Standard 52.2

ANSI/ASHRAE/ASHE Standard 170-2021 Ventilation of Health Care Facilities

Table 8-1 Design Parameters—Specialized Outpatient Spaces

Function of Space (f)	Pressure Relationship to Adjacent Areas (n)	Minimum Outdoor ach	Minimum Total ach	All Room Air Exhausted Directly to Outdoors (j)	Air Recirculated by Means of Room Units (a)	Minimum Filter Efficiencies (c)	Design Relative Humidity (k), %	Design Temperature (l), °F/°C
DIAGNOSTIC AND TREATMENT								
Class 1 imaging room *(FGI 2.1–3.5.2.4[1][b][i])* (ff)	NR	2	6	NR	NR	MERV-8	Max 60	72–78/22–26
Class 2 imaging room *(FGI 2.1–3.5.2.4[1][b][ii])* (d), (p), (ff)	Positive	3	15	NR	No	MERV-14	20–60	70–75/21–24
Class 3 imaging room *(FGI 2.1–3.5.2.4[1][b][iii])* (m), (o), (ff)	Positive	4	20	NR	No	MERV-16 (dd)	20–60	68–75/20–24
Diagnostic imaging waiting *(FGI 2.1–3.5.10.4)* (g)	Negative	2	12	Yes (q), (r)	NR	MERV-8	Max 60	70–75/21–24
AII anteroom *(FGI 2.1–3.3.2.3)* (i)	(e)	NR	10	Yes	No	MERV-8	NR	NR
AII room *(FGI 2.1–3.3.2)* (i)	Negative	2	12	Yes	No	MERV-8	Max 60	70–75/21–24

c. Table entries are the minimum filter efficiencies required for the space. Refer to Section 6.4 of this document for further clarification of filtration requirements. The minimum efficiency reporting value (MERV) is based on the method of testing described in ASHRAE Standard 52.2

Table 8-2 Design Parameters—General Outpatient Spaces (q)

Table 9-1 Design Parameters for Residential Health, Care, and Support-Specific Spaces

ANSI/ASHRAE Standard 62.1-2019 Ventilation for Acceptable Indoor Air Quality

Table 6-1 Minimum Ventilation Rates in Breathing Zone *(Continued)*

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Default Values Occupant Density	Air Class	OS (6.2.6.1.4)
	cfm/ person	L/s· person	cfm/ft^2	L/s·m^2	#/1000 ft^2 or #/100 m^2		
Outpatient Health Care Facilities [a,b]							
Birthing room	10	5	0.18	0.9	15	2	
Class 1 imaging rooms	5	2.5	0.12	0.6	5	1	
Dental operatory	10	5	0.18	0.9	20	1	

6.2.6.1.4 For DCV zones in the occupied standby mode, breathing zone outdoor airflow shall be permitted to be reduced to zero for the occupancy categories indicated "OS" in Table 6-1, provided that airflow is restored to *Vbz* whenever occupancy is detected.

a. Outpatient facilities to which the rates apply are freestanding birth centers, urgent care centers, neighborhood clinics and physicians offices, Class 1 imaging facilities, outpatient psychiatric facilities, outpatient rehabilitation facilities, and outpatient dental facilities.

b. The requirements of this table provide for acceptable IAQ. The requirements of this table do not address the airborne transmission of airborne viruses, bacteria, and other infectious contagions.

Four fundamental rules apply to cleanrooms

1) **First**, contaminants must not be introduced into the controlled environment from the outside.
2) **Second**, the apparatus or equipment within the controlled environment must not generate or otherwise give rise to contaminants (for example as a result of friction, chemical reactions, or biological processes).
3) **Third**, contaminants must not be allowed to accumulate in the controlled environment.
4) **Fourth**, existing contaminants must be eliminated to the greatest extent possible, and as rapidly as possible.

A clean room differs from an ordinary ventilated conditioned room mainly in :

1. Increased air supply:The increased air supply is an important aspect of particle control. Normal air-conditioning systems are designed for 0.5 to 2 air changes per hour. A clean room would have at least 10 air changes per hour and could be as high as 600 for absolute cleanliness.

2. The use of high efficiency filters: High efficiency filters are used to filter the supply air into a clean room to ensure the removal of small particles.

3. Room pressurization: The clean room is positively pressurized with respect to the adjacent areas. This is done by supplying more air and extracting less air from the room than is supplied to it.

The four variables specifically affecting the design of the HVAC system

Temperature
Control for:
- Worker Comfort
- Protect Product, Process

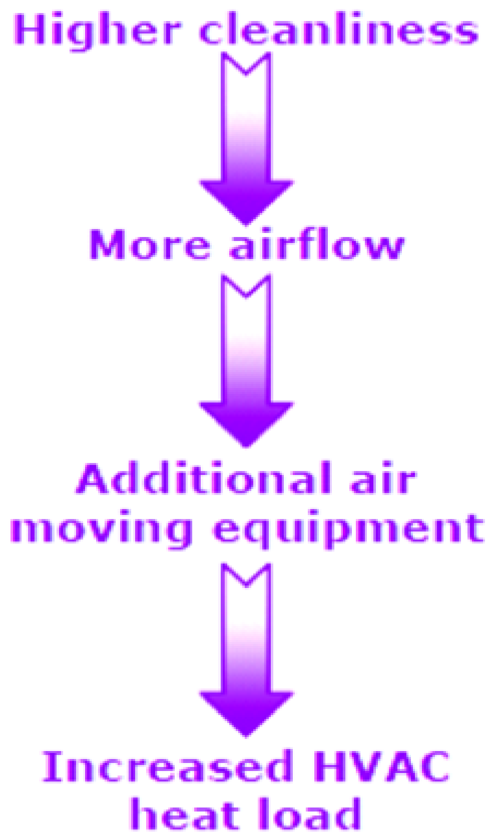
Humidity
Can affect:
- product Yields
- operation of equipment

Cleanroom too dry?
Allows excessive static electrictybuild up

Cleanroom too humid?
Microbial growth in system and in

Cleanliness
- Key determinant for overall amount of airflow.

Pressure Relationships
- Combat infiltration of contaminentsbetween clean/ non-clean space



3

Ruang Isolasi

Persyaratan Ruang Isolasi

Ada 5 Persyaratan yang harus dipenuhi untuk ruang Isolasi:

1. Negative Pressure (Tekanan ruangan yang negatif). → untuk mencegah udara ruangan yang infectious tidak keluar ke ruangan lainnya.
2. Jumlah udara luar yang dimasukkan untuk melarutkan→ minimum 2 x ACH s/d 100% udara luar. → untuk melarutkan konsentrasi bakteri/virus didalam ruangan.
3. Distribusi aliran udara tidak boleh dari Pasien ke Dokter/Suster.
4. Temperatur ruangan, RH ruangan dan kebersihan ruangan terjaga → Units HVAC harus bisa mengatur Temperatur, RH ruangan dan dilengkapi dengan HEPA filter apabila tidak memakai 100% udara luar serta pengaturan jumlah aliran udara constant secara automatic. Hepa filter → mengurangi konsentrasi bakteri/virus dengan cara filtration.
5. Memasang exhaust grille di belakang ranjang/kepala pasien (dikanan kiri kepala) dan exhaust fan nya dipasang Hepa filter. → mengurangi konsentrasi bakteri/virus dari sumbernya.

ISOLATION ROOM

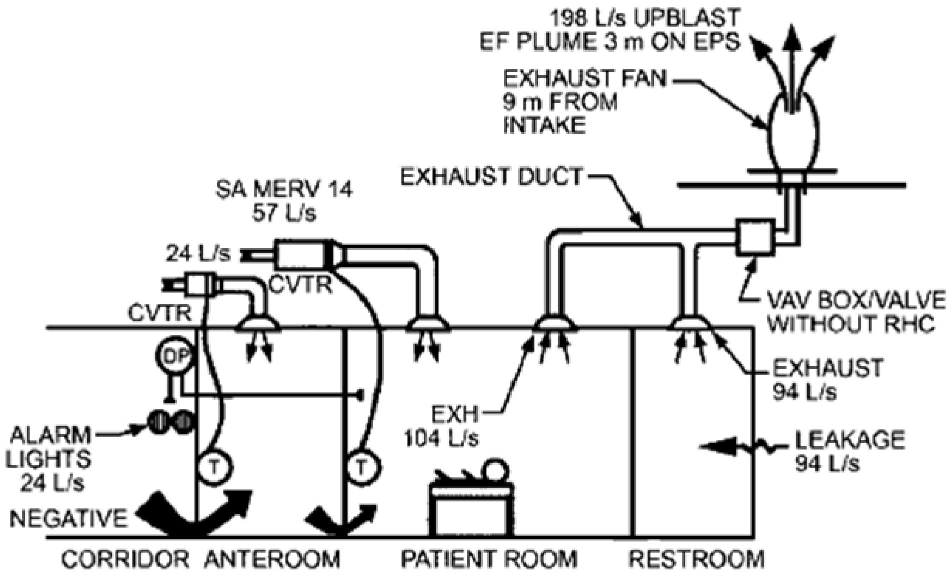


Fig. 4 Airborne Infection Isolation Room

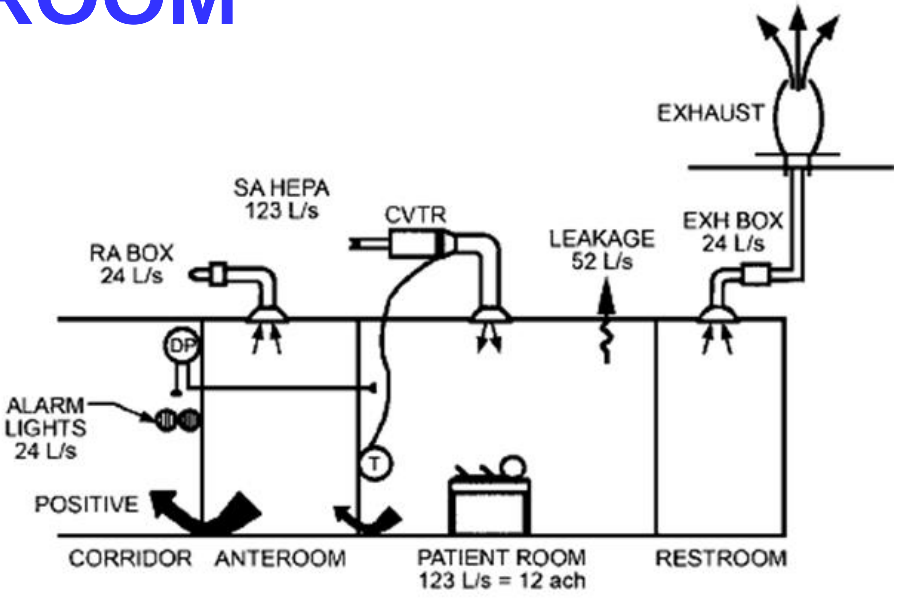
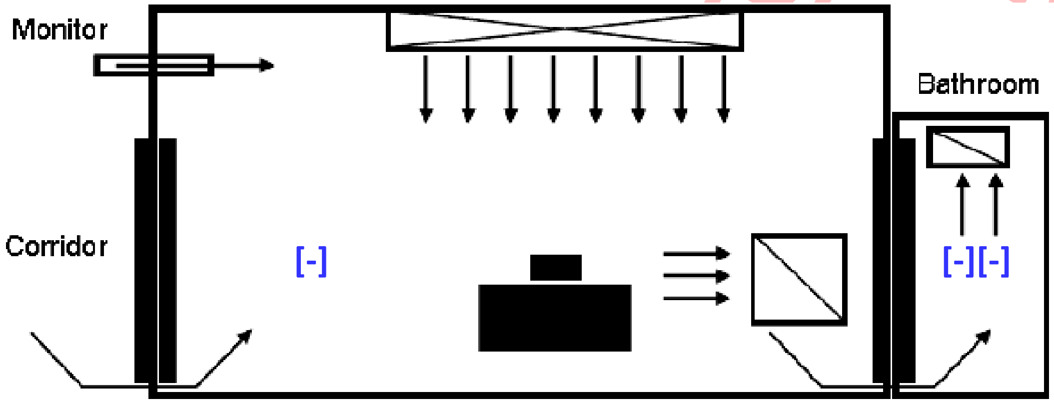
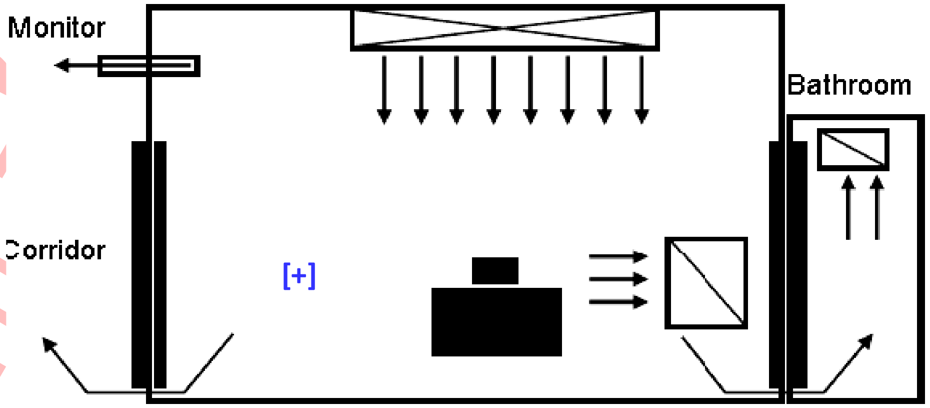


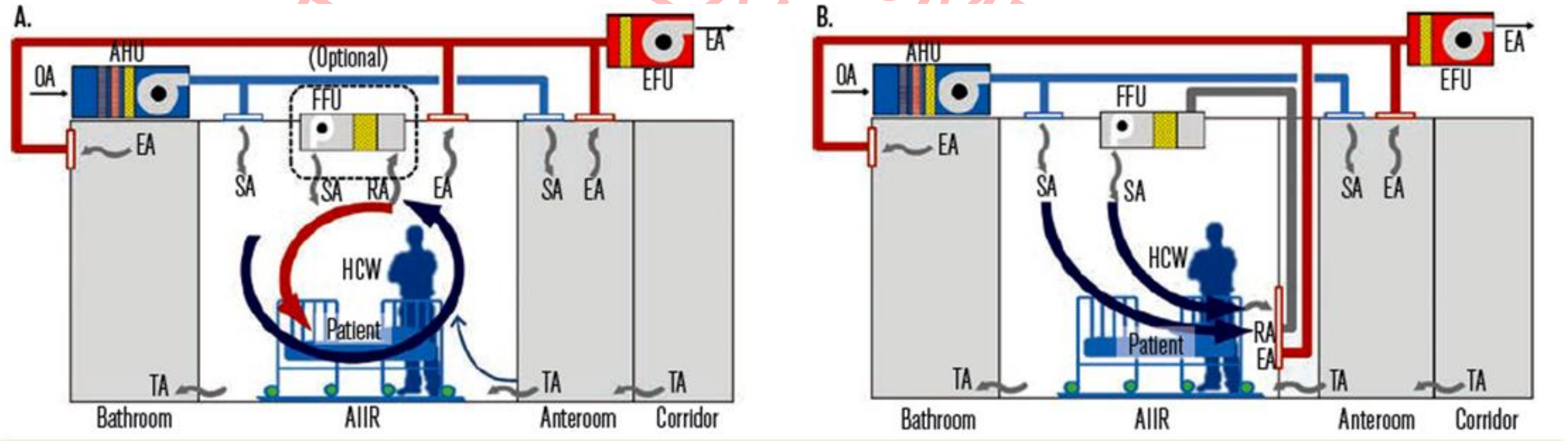
Fig. 3 Protective Environment Room Arrangement





2019 ASHRAE Handbook—HVAC Applications (SI) & CDC (2003) updated 2019

Ventilation strategies of the AIIR;
(A) typical ventilation system and (B) improved ventilation system.



AIIR : Airborne Infectious Isolation Room

ASHRAE JOURNAL, February 2019

From CDC Guidelines (Centers for Disease Control and Prevention)

Table 6. Engineered specifications for positive- and negative pressure rooms*

	Positive pressure areas (e.g., protective environments [PE])	Negative pressure areas (e.g., airborne infection isolation [AII])
Pressure differentials	> +2.5 Pa§ (0.01″ water gauge)	> -2.5 Pa (0.01″ water gauge)
Air changes per hour (ACH)	>12	≥12 (for renovation or new construction)
Filtration efficiency	Supply: 99.97% @ 0.3 µm DOP¶ Return: none required**	Supply: 90% (dust spot test) Return: 99.97% @ 0.3 µm DOP¶ †
Room airflow direction	Out to the adjacent area	In to the room
Clean-to-dirty airflow in room	Away from the patient (high-risk patient, immunosuppressed patient)	Towards the patient (airborne disease patient)
Ideal pressure differential	> + 8 Pa	> - 2.5 Pa

* Material in this table was compiled from references 35 and 120. Table adapted from and used with permission of the publisher of reference 35 (Lippincott Williams and Wilkins).

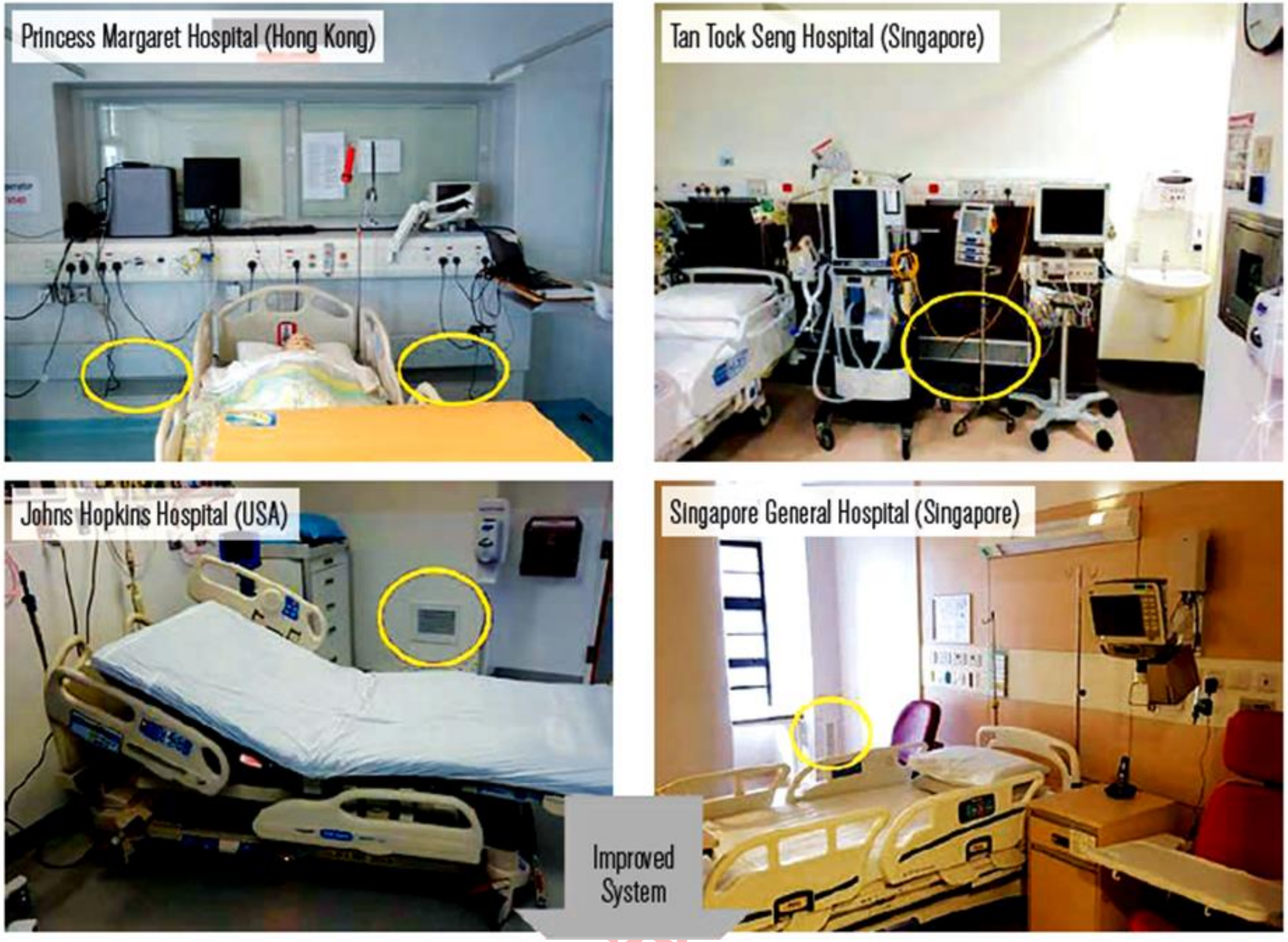
§ Pa is the abbreviation for Pascal, a metric unit of measurement for pressure based on air velocity; 250 Pa equals 1.0 inch water gauge.

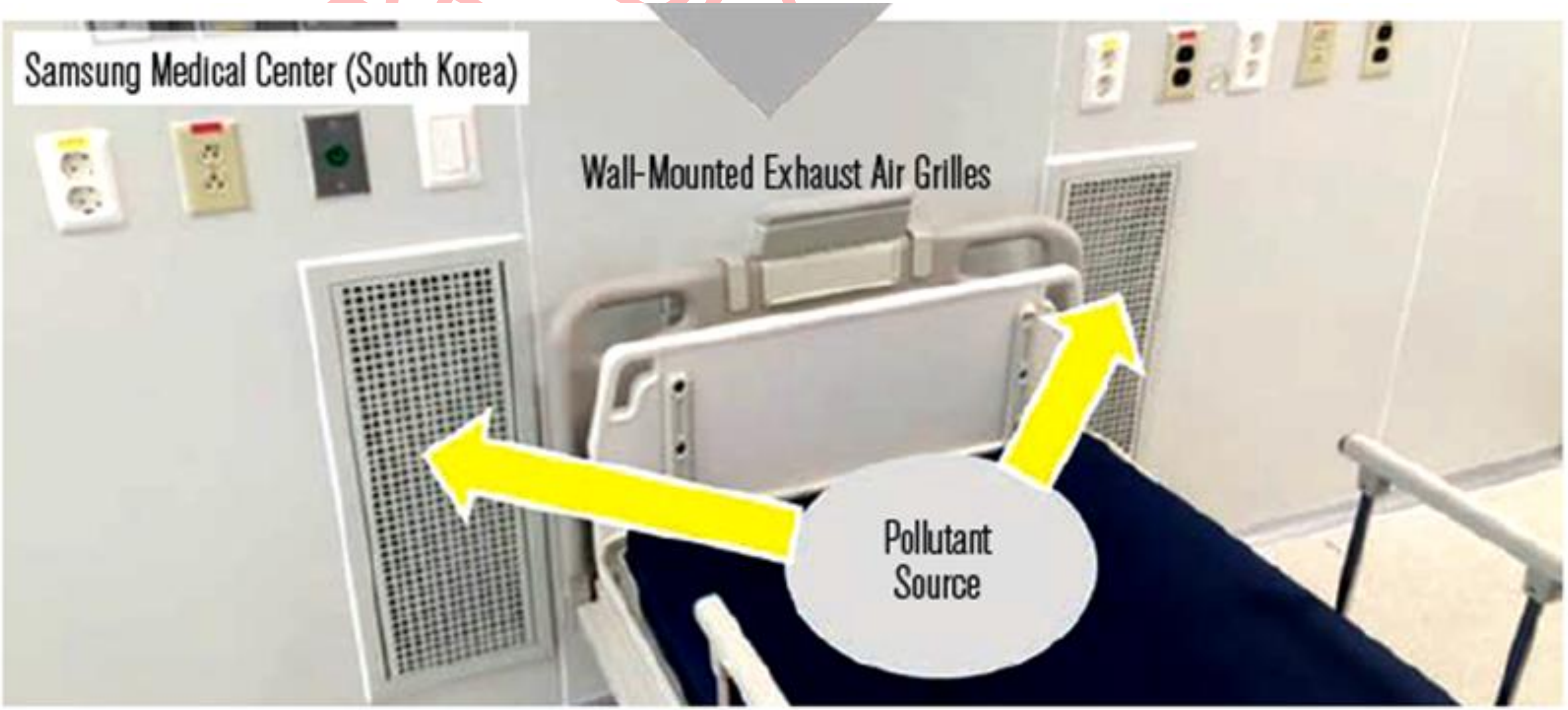
¶ DOP is the abbreviation for dioctylphthalate particles of 0.3 µm diameter.

** If the patient requires both PE and AII, return air should be HEPA-filtered or otherwise exhausted to the outside.

† HEPA filtration of exhaust air from AII rooms should not be required, providing that the exhaust is properly located to prevent re-entry into the building.

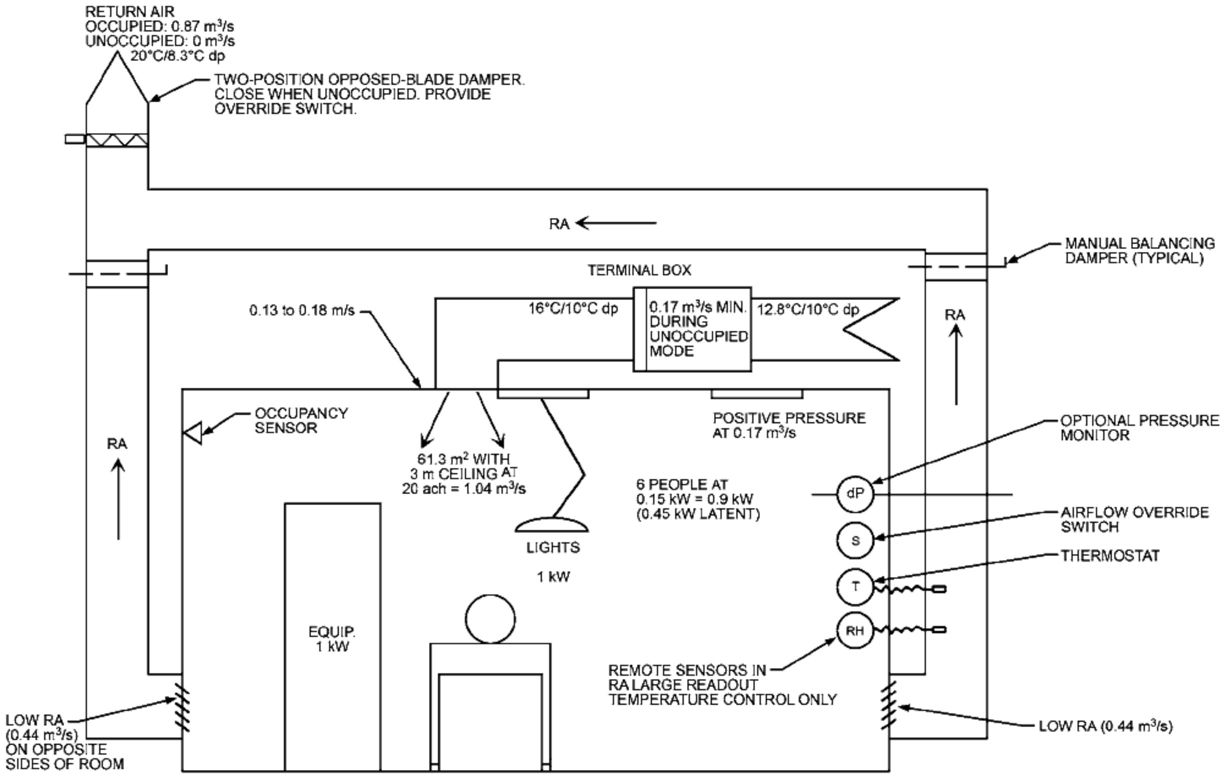
Berbagai konfigurasi ruang isolasi diberbagai negara



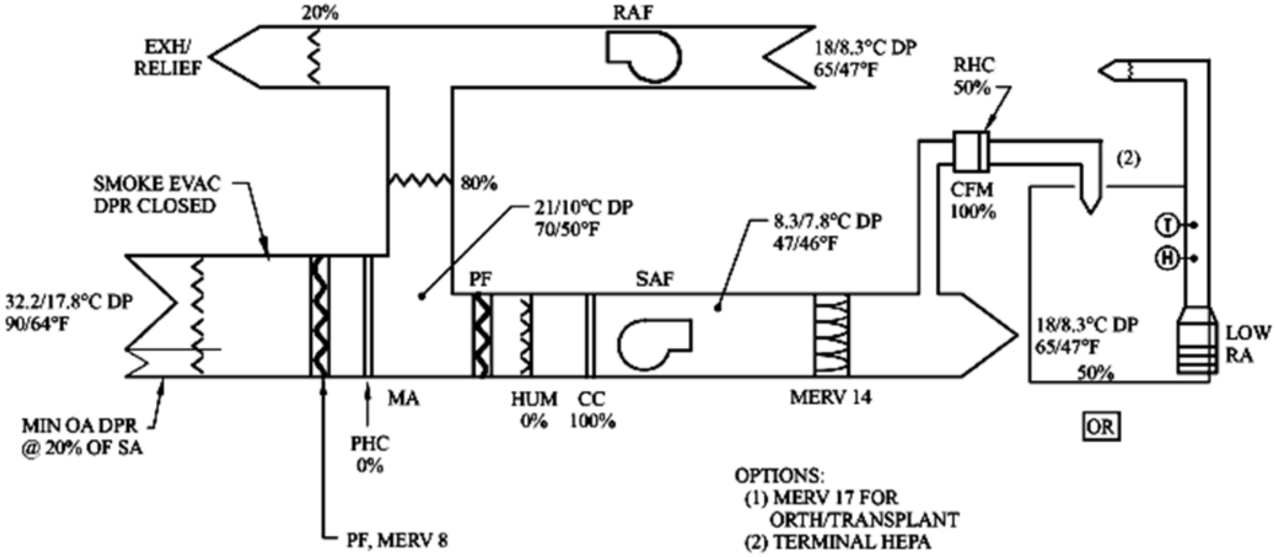

Samsung Medical Center (South Korea)
Wall-Mounted Exhaust Air Grilles
Pollutant Source

4 Ruang Operasi

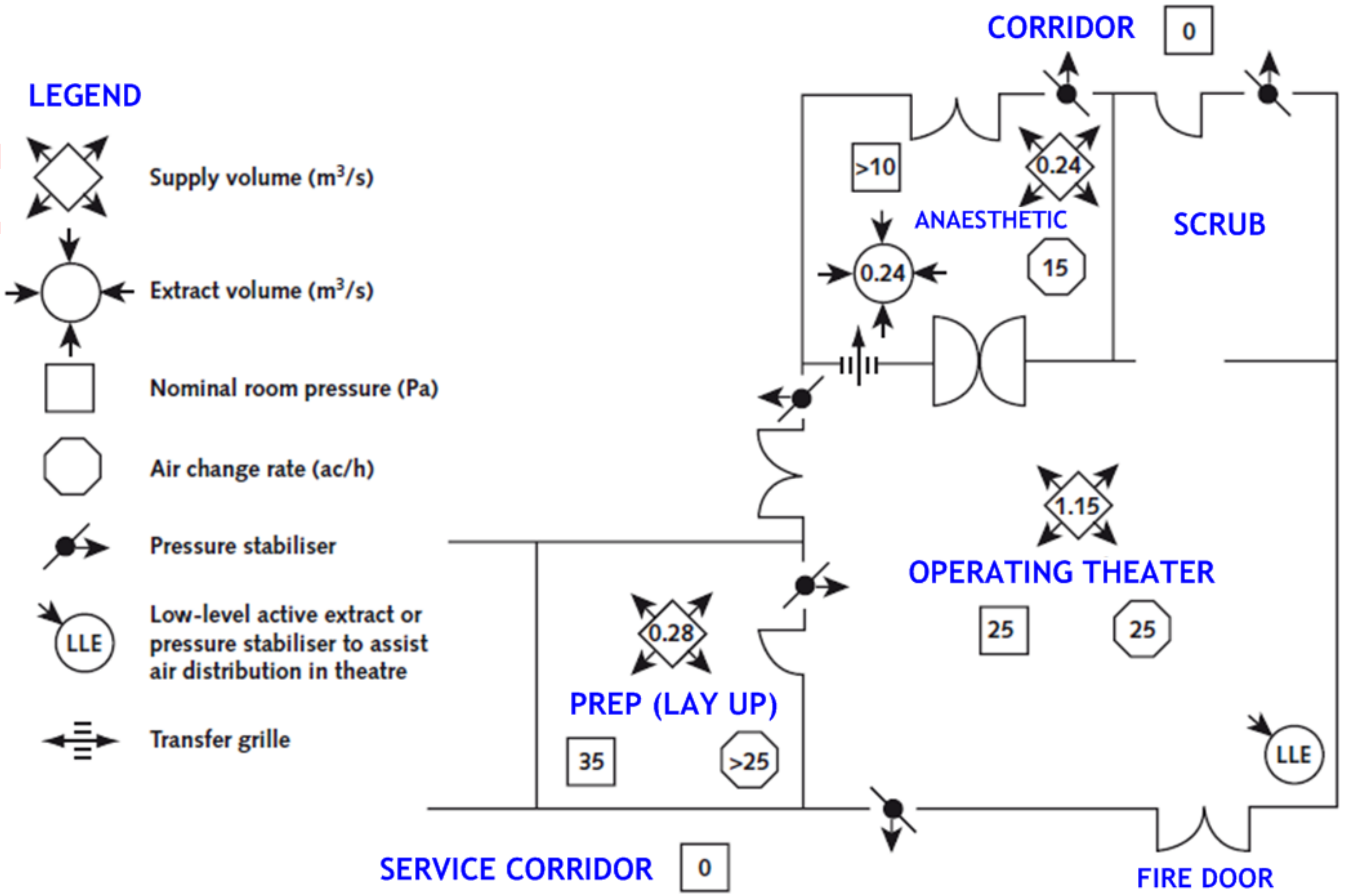
Gambar potongan Ruang Operasi tipikal



AHU Ruang Operasi - Tipikal



Gambar denah ruang operasi



Department of Health (UK) : Health Technical Memorandum 03-01: Specialised ventilation for healthcare premises Part A, 2007

Lampiran Permenkes No. 24 tahun 2016 tentang Persyaratan Teknis Bangunan dan Prasarana Rumah Sakit

1. Ventilasi di ruang operasi harus pasti merupakan ventilasi tersaring dan terkontrol
2. Pertukaran udara dan sirkulasi memberikan udara segar
3. Tekanan udara dalam ruangan lebih besar/positif dari ruangan-ruangan yang bersebelahan.
4. Temperatur ruangan 19^o-24^oC
5. Kelembaban relatif 40-60%

6. Total pertukaran udara minimal 4 kali per jam pada saat ruangan tidak digunakan, dan 20 kali per jam pada saat ada operasi.
7. Ruangan ini merupakan ruangan steril dengan HEPA filter (high efficiency particulate air) (tingkat resiko sangat tinggi), yang mempunyai jumlah maksimal partikel debu ukuran dia. 0,5 µm per m^3 yaitu 35.200 partikel (ISO 6-ISO 14644-1 *cleanroom standards*, 2015) Intensitas cahaya minimal 200 lux.
8. Meja operasi berada dibawah aliran udara laminer, dengan distribusi udara dari langit-langit, dengan gerakan ke bawah menuju inlet pembuangan (*return air*) yang terletak di 4 sudut ruangan yang dibuat plenum.

Persyaratan Teknis Ruang Operasi RS

1. Pengaturan ***FLOW*** barang "bersih" dan "kotor" dan lalu lintas orang
2. Pengaturan ***ZONASI***
3. Persyaratan khusus ***KOMPONEN BANGUNAN***
4. **SOP** → pencegahan & pengendalian infeksi silang
5. Keamanan Sistem Utilitas → sistem kelistrikan, gas medis, penanganan limbah, tata udara, dll
6. Pengaturan ***ALIRAN UDARA*** → mencegah kondisi potensial dari kotaminasi

ASHRAE DESIGN GUIDE

Fundamentals, Systems and Performance

Cleanroom HVAC System Configuration

HVAC configuration:

- Not only meets heating and cooling loads but also satisfies space air cleanliness requirements.

- How to configure an HVAC system when airflow rate required by dilution is significantly higher than that required by heating and cooling loads.

<u>Example:</u>
Commercial buildings : 250–600 cfm (120–280 L/s) per ton
ISO Class 7 cleanroom: 2500 cfm (1200 L/s) per ton,
ISO Class 3 cleanroom: 25,000 cfm (12000 L/s) per ton.

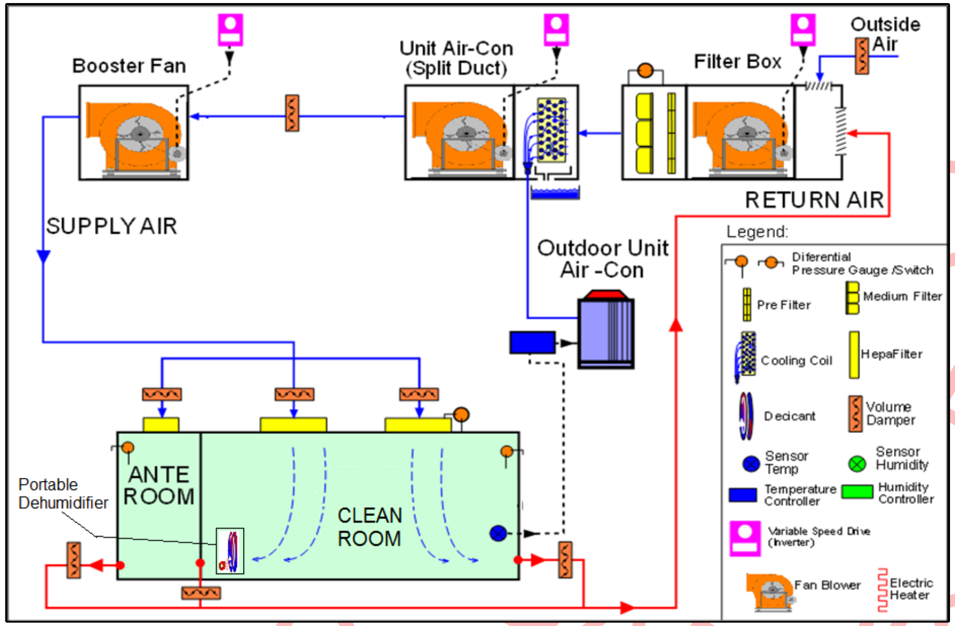
- A typical AHU is commonly designed and manufactured at around 400 cfm (200 L/s) per ton, which can be stretched to a possible range of 300–600 cfm (140–280 L/s) per ton.

  - ► Therefore, it is clear that a single AHU system in the later cases (ISO 7 and 3 cleanrooms) is not capable of achieving both dilution and cooling objectives.

- Cleanroom design engineers commonly use multiple AHUs and RFUs to handle this challenge based on cleanliness classes. RFU (Recirculating Fan Unit)

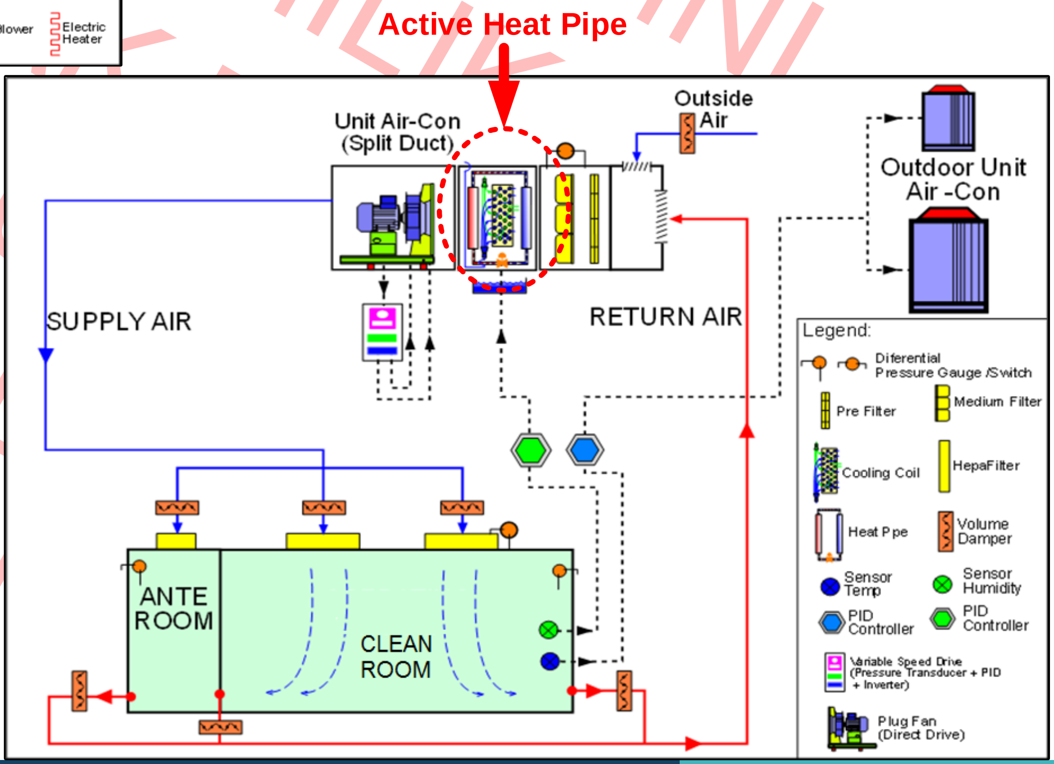
5

Implementasi Mesin HVAC Rumah Sakit



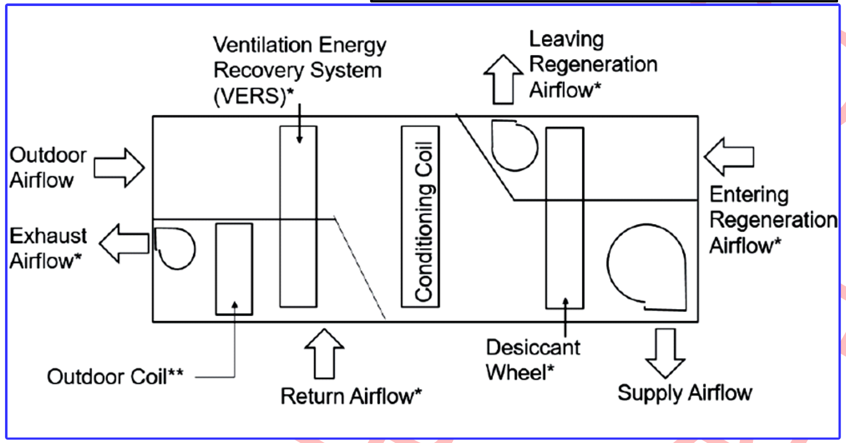
Mesin Tata Udara
DX system + Active Heat Pipe
Clean Room Class > 100.000

Mesin Tata Udara
DX system + Dehumidifier
Clean Room Class > 100.000

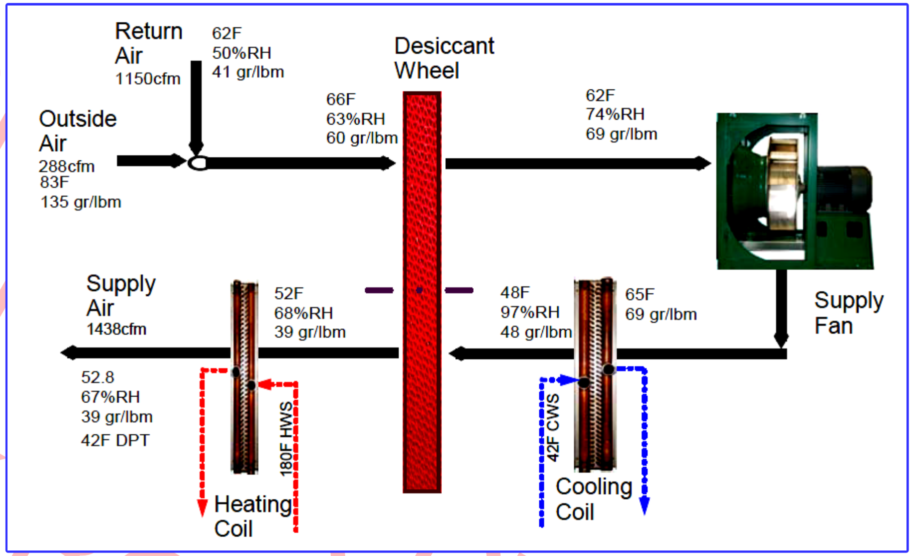


Dedicated Outdoor Air System (DOAS) Units

AHRI Standard 920-2020



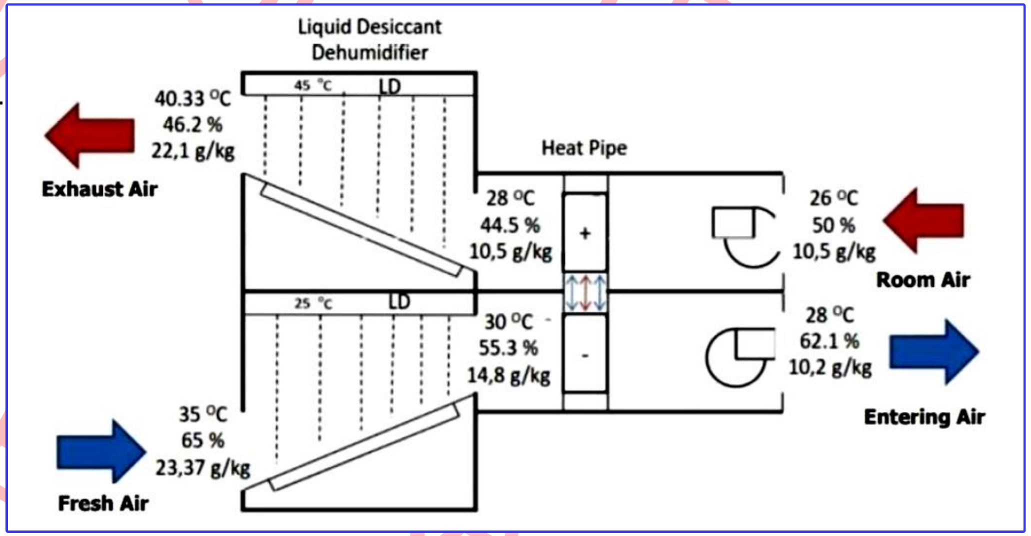
Desiccant Wheel



Fungsi dari DOAS

1. MemperbaikiIAQ (Indoor Air Quality)
2. Mengatur kelembaban udara didalam ruangan (RH ruanganterkendali).
3. Mengatur/menurunkan kadar konsentrasi CO_2 didalam ruangan dan menaikkan kadar O_2 yang kita butuhkan didalam ruangan.
4. Mengatur/menurunkan kadar VOC dan HVOC didalam Ruangan.
5. Melarutkangas/zat/bakteri/virus didalam ruangan.
6. Menghemat energy dalam pemakaian HVAC di bangunan gedung.
7. Membuat tekanan ruangan menjadi lebih positif dibandingkan udara luar → Mencegah infiltrasi udara luar.

Liquid Desiccant



Existing Hospital Air Cooled Chiller

Kesimpulan

Kinerja ruang operasi dan isolasi di Rumah Sakit sangat tergantung pada :

1. Proses perancangan ruang bersih yang mengikuti peraturan, standard dan pedoman nasional dan internasional yang berlaku.
2. Metoda untuk mempertahankan temperatur, kelembaban relatif, tekanan dan kualitas udara dalam ruang.
3. Penentuan tekanan positif atau negatif ruangan, misalnya untuk mencegah udara ruangan yang infectious tidak keluar menuju ruangan lain.
4. Pemilihan dan pemasangan mesin HVAC yang sesuai dengan fungsi ruang yang dapat menghasilkan temperatur, kelembaban relatif dan suplai udara sesuai dengan kebutuhan ruang serta hemat energi.

Thank You