Cairo University
Faculty of Engineering
Mech. Power Department

دبلوم تطبيقات التحكم الأوتوماتيكي
في نظم القوى الميكانيكية

Automatic Control Diploma

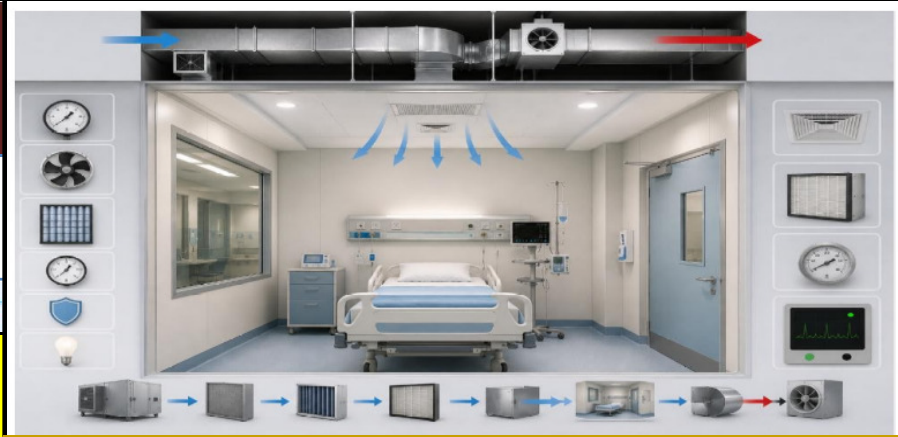
ACC Virtual Labs
Automatic Control Circuits & Virtual Labs for Mechanical Power Systems
معمل التحكم الاوتوماتيكي و المعامل الافتراضية لانظمة القوى الميكانيكية

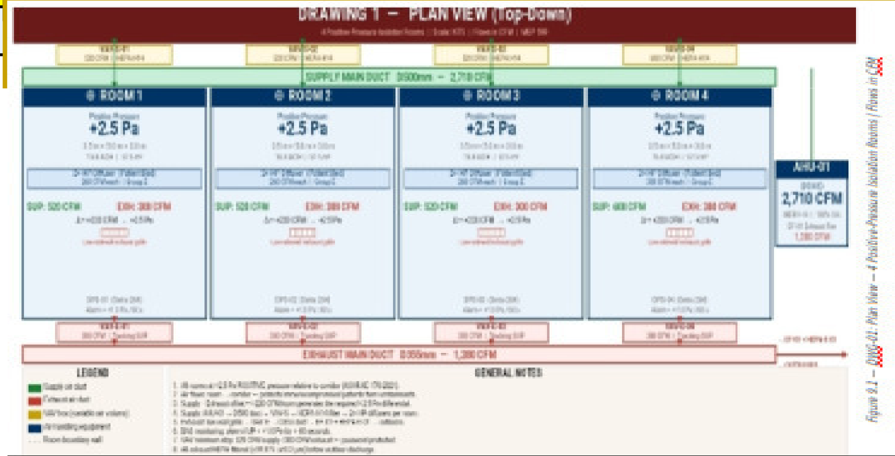
Design of Isolation - Ward-Healthcare Positive Pressure - HVAC System

Prepared by: Eng. Mohamed Mahmoud Radwan eissa & Eng. Ahmed Abu El-Aref Hassn metwaly

Report Submitted to: Dr. Mohsen Sayed Soliman
Director of ACC Lab.& Coordinator of the Automatic Control Diploma Program
Mechanical Power Engineering Deportment

MEP 599 | Diploma Design Project | Academic Year 2025 / 2026



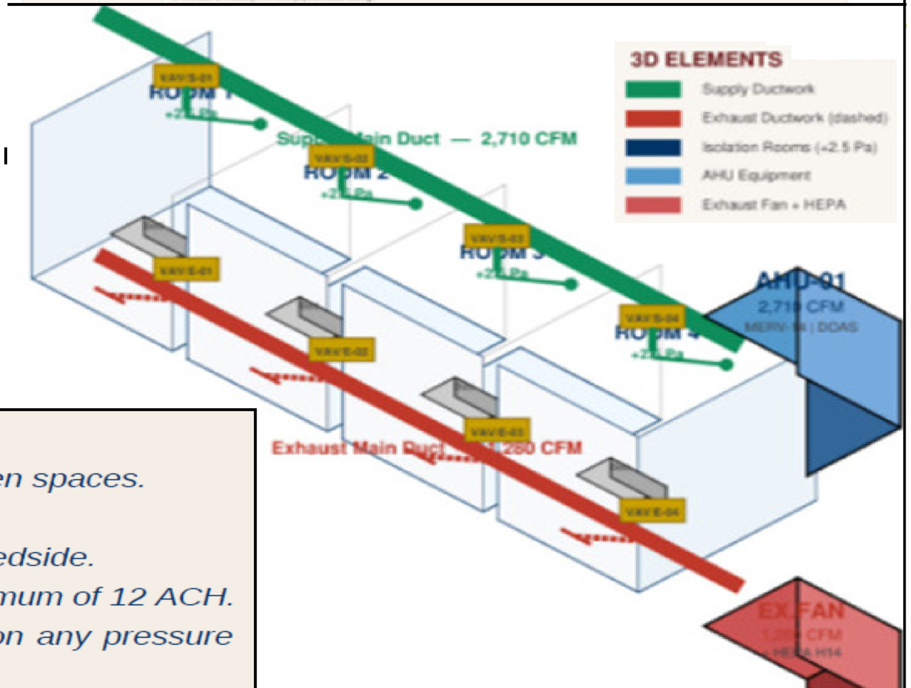


ABSTRACT & PROJECT OVERVIEW

This study presents the complete HVAC engineering design of a four-room Protective Environment (PE) isolation ward — a clinical space conceived for the most fragile patients a hospital ever admits. Bone-marrow transplant recipients, oncology patients enduring aggressive chemotherapy, and severe-burn cases all share one condition: their immune defences are suppressed to the point where the ordinary air of a hospital corridor becomes a genuine threat. For such a patient, a single airborne Aspergillus spore drifting in from an adjacent space can be the difference between recovery and a fatal opportunistic infection.

The design philosophy answers that risk with engineering rather than procedure. Clean, precisely conditioned air is treated as a clinical instrument — a continuous, invisible line of defence that works every hour of every day, long before any drug or physician intervenes. Every parameter in the ward is therefore derived from one governing document: ANSI/ASHRAE/ASHE Standard 170-2021, the international benchmark for the ventilation of health-care facilities.

The thermal sizing of the system was established from a ready set of design-load assumptions — Cairo summer design conditions applied to four identical rooms of 52.5 m³ each, conditioned entirely on outdoor air. Fixing the loads in advance allowed the study to concentrate on what truly distinguishes a healthcare design from a commercial one: the air-side architecture of infection control. The result is a system that is simultaneously code-compliant, clinically robust, energy-aware, and — as the later sections show — genuinely buildable on site.



Design at a glance

A dedicated 100% outdoor-air (DOAS) air-handling unit — no recirculation between spaces.
Each room held at a continuous +2.5 Pa positive pressure relative to the corridor.
Triple-stage filtration culminating in HEPA H14 (≥ 99.995% per EN 1822) at the bedside.
16.8 air changes per hour — about 40% above the ASHRAE 170 mandatory minimum of 12 ACH.
Continuous BMS pressure monitoring with an instant audible and visual alarm on any pressure loss.

ASHRAE 170-2021 — Mandatory Requirements for PE Rooms

Minimum 12 ACH

12 total air changes per hour; ≥2 must be outdoor air. This design achieves 16.8 ACH — 40% above the mandatory minimum.

+2.5 Pa Positive Pressure

Room at higher pressure than all adjacent spaces at all times. Air always flows outward, blocking corridor contaminants.

HEPA Filtration at Terminal

HEPA H14 (≥99.97% at 0.3 µm) at each room supply terminal plus MERV-14 at AHU — two-stage defence-in-depth.

100% Exhaust to Outdoors

No recirculation without HEPA. All room air discharged to atmosphere via dedicated HEPA-filtered exhaust fan.

Temperature 21–24°C / RH 30–60%

Controls pathogen viability, aerosol persistence, and prevents mould growth while maintaining patient thermal comfort.

Continuous Pressure Monitoring

Permanent ΔP sensor visible from corridor. BAS alarm if pressure <+1.0 Pa for >60 s. Emergency generator backup.

Key Engineering Calculations — 3 Equations

01 Supply Airflow Rate (ACH Model)

$$Q_s = (V \times ACH) / 60$$

Inputs: V = 1,857 ft³ (3.5m × 5.0m × 3.0m) ACH = 16.8

→ Qs = 520 CFM per room → VAV minimum stop set at 520 CFM

02 Mass Balance — Pressure Generation

$$Q_s = Q_e + Q_{leak}$$

Inputs: Supply = 520 CFM Exhaust = 300 CFM Exfiltration = 220 CFM

→ Net offset +220 CFM → creates and sustains +2.5 Pa positive differential

03 Orifice Flow Model — Pressure Validation

$$Q_{leak} = C \times A \times \sqrt{2 \times \Delta P / \rho}$$

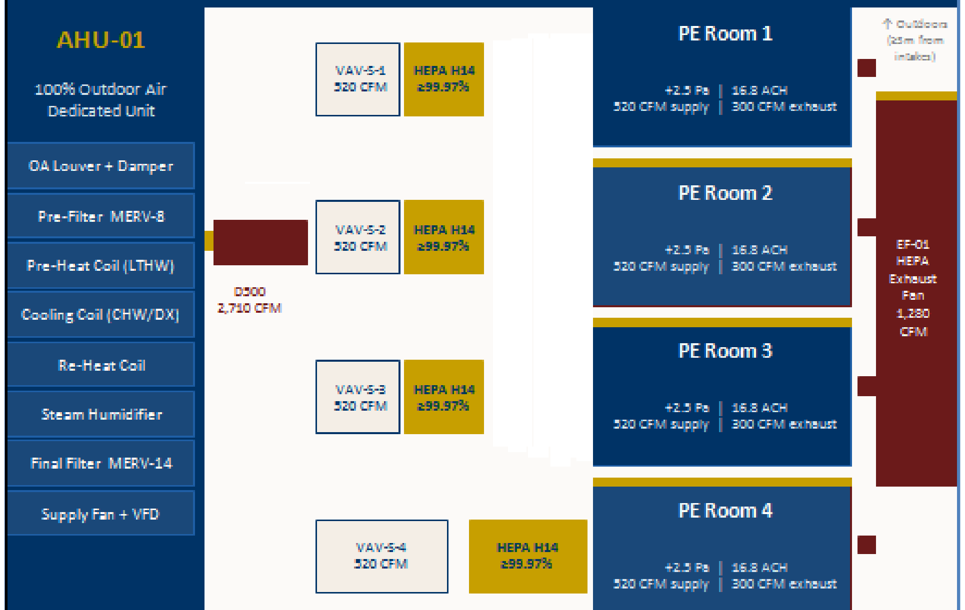
Inputs: C = 0.60 A = 0.342 ft² ρ = 0.075 lb/ft³

→ ΔP = +2.5 Pa ✓ validated by Bernoulli orifice model

Equipment Selection

AHU Internal Components

System Architecture — DOAS Configuration

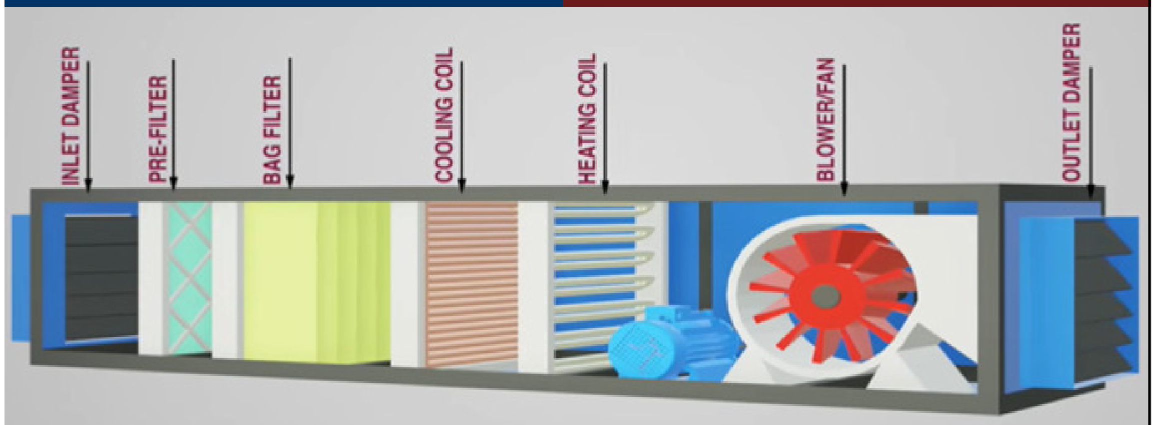


Cooling Load & Fan Selection — Sample Calculations

Cooling Load (Carrier HAP — Cairo, Egypt)		Supply Fan (Greenheck CAPS)	
OA design condition:	38°C DB / 23°C WB (ASHRAE 0.4% summer)	Design flow:	Q = 2,710 CFM = 1.28 m³/s
Mass flow rate:	ṁ = 1.53 kg/s	Total static pressure:	TSP = 1,100 Pa (4.4 in.wg)
Sensible load:	Q_s = 1.53 × 1.005 × (38−14) = 36.9 kW	Fan efficiency:	η_fan = 78%
Latent load:	Q_L = 1.53 × 2500 × (0.017−0.0095) = 28.7 kW	Shaft power:	P = (1.28 × 1100) / (1000 × 0.78) = 1.81 kW
Total load:	65.6 kW (18.7 TR)	Motor (90%, SF 1.15):	P_motor = 1.75 kW
Heat recovery (60%):	−17.6 kW recovered	Selected motor:	2.2 kW | 3-phase | with VFD

Selected: 48 kW (13.7 TR) after heat recovery

Selected: Greenheck BCSW-220 | 2.2 kW | 78% efficient



Conclusions — System Performance Summary

2,710 CFM Total Supply Flow

16.8 ACH Achieved (min 12)

+2.5 Pa Positive Pressure

48 kW Cooling Capacity

5 HEPA Units (4+1 exhaust)

DOAS — Only Compliant Configuration

100% outdoor air, 100% exhaust. No recirculation risk. Energy offset by run-around coil heat recovery at 60% effectiveness (−17.6 kW recovered).

Defence-in-Depth Filtration

MERV-14 at AHU + HEPA H14 at each room terminal. Independent stages: if one degrades the other still protects. Annual integrity test per IEST-RP-CC001.

VAV with Hardwired Minimum Stops

DDC controller password-protected: 520 CFM supply / 300 CFM exhaust minimum per room. Cannot be overridden during commissioning or

Continuous Monitoring & Emergency Power

Setra 264 sensors + BAS alarm if ΔP <+1.0 Pa for >60s. All life-safety HVAC on emergency generator via 10-second automatic transfer switch.

Equipment Schedule — Selected Items

Tag	Equipment	Specification	Qty
AHU-01	Dedicated Outdoor Air Handling Unit	2,710 CFM / 100% OA / MERV-14 final	1
VAV-S-1 to 4	Supply VAV box (room) + DDC	520 CFM min / 600 CFM max	4
VAV-E-1 to 4	Exhaust VAV box (room)	300 CFM / Tracks supply +220 CFM	4
VAV-S-1A to 4	Supply VAV box (anteroom)	70 CFM / Pressure-independent	4
HEPA-S-1 to 4	HEPA H14 supply filter (per room)	≥99.97% at 0.3 µm / 520 CFM rated	4
EF-01	Centrifugal exhaust fan + VFD	1,280 CFM / BC-AF impeller / 1.5 kW motor	1
HEPA-E-01	HEPA H14 filter — exhaust fan inlet	≥99.97% / 1,280 CFM rated	1
DPS-1 to 4	Diff. pressure sensor (Setra 264)	−25 to +25 Pa / 0.25% accuracy / 4-20 mA	4

ASHRAE 170-2021 Compliance Matrix

Parameter	ASHRAE 170 Minimum	This Design	Status
Pressure Relationship	+2.5 Pa to all adjacent	+2.5 Pa continuous (Setra 264 sensor)	✓ COMPLIANT
Min. Pressure Diff.	+0.01 in.w.g. (+2.5 Pa)	+2.5 Pa — hardwired minimum	✓ COMPLIANT
Min. Total ACH	12 ACH	16.8 ACH (520 CFM / 52.5 m³)	✓ EXCEEDS
Min. Outdoor ACH	2 ACH	16.8 ACH (100% OA DOAS)	✓ EXCEEDS
Supply Filtration	HEPA at terminal device	MERV-14 (AHU) + HEPA H14 (room)	✓ COMPLIANT
Exhaust Discharge	100% to outdoors	100% OA, HEPA exhaust fan, rooftop	✓ COMPLIANT
Volume Control	Constant-volume (CV)	VAV + hardwired password-protected sto	✓ COMPLIANT
Temperature	21–24°C	Setpoint 22°C ±1°C	✓ COMPLIANT
Relative Humidity	30–60% RH	Steam humidifier / 30–60% RH	✓ COMPLIANT
Pressure Monitoring	Permanent device + alarm	BAS alarm if <+1.0 Pa for >60 seconds	✓ COMPLIANT
Recirculation	Not permitted w/o HEPA	None — 100% OA DOAS system	✓ COMPLIANT
Anteroom	Recommended	Provided at each room (0 Pa neutral)	✓ EXCEEDS

TOOLS, RECOMMENDATIONS & CONCLUSION

Software as the Designer's Reference Instruments

The design rests on a toolkit of industry-standard software, recommended here as a practical reference for any engineer building on this work. Carrier HAP performs a full 8,760-hour load simulation against Cairo weather data, producing accurate and defensible cooling and heating loads. The McQuay Duct Sizer applies the equal-friction method to size a balanced, low-noise duct network. These are supported by the ASHRAE Psychrometric tool for state-point analysis and by manufacturer selection tools (such as TROX and Greenheck) for terminals and fans — together turning engineering judgement into traceable, reviewable numbers.

An Economic Recommendation: Energy Recovery

Conditioning 100% outdoor air all year round is, honestly, the most energy-hungry consequence of the ASHRAE 170 philosophy — and it is the design's one true cost. The strong recommendation is to install an energy-recovery device, such as a run-around coil loop, between the exhaust and supply air streams. Because the two streams never physically mix, it recovers roughly 60–70% of the sensible energy with zero cross-contamination risk — turning the largest operating cost of the ward into a manageable one and making the whole system markedly more sustainable.

Closing statement

Healthcare HVAC is one of the few branches of building engineering where the quality of a design is measured in patient outcomes. A correctly designed and commissioned Protective Environment ward is preventive medicine built into the walls and ceiling — the engineer acting, quietly and continuously, as the doctor before the doctor. The system presented here is compliant with ASHRAE 170-2021, robust against real-world disturbances, economically responsible, and — above all — buildable.

Reference Standards

ANSI/ASHRAE/ASHE Standard 170-2021 — Ventilation of Health Care Facilities (primary standard).

ASHRAE Standard 52.2 — MERV filter performance rating (MERV 8 / MERV 14).

EN 1822:2019 — HEPA classification (H13 / H14, ≥ 99.995% at MPPS).

ASHRAE 62.1 · EN 1886 · NFPA 90A — outdoor-air rates, AHU casing/leakage class, and HVAC fire-safety.