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PSYCHROMETRY AND AIR HANDLING UNITS. CONCEPTS AND PURPOSES

Class content material

This document is part of a training materials collection developed within the Erasmus+ project “Smart healthcare engineering”, SHEng, project No. 2023-1-RO01-KA220-HED-000159985.

The collection is intended for engineering students and professionals working in the healthcare sector. It covers technical subjects relevant to hospital infrastructure, equipment, materials and support services, helping readers understand how engineering contributes to safe patient care and the reliable operation of healthcare facilities.

These materials support classroom teaching and independent study. They should be used alongside the project handbook and the presentations, courses and other learning resources available on the project website. Each document addresses a specific subject, while the collection provides a broader understanding of the responsibilities and practical challenges of healthcare engineering.

The content is educational. Its application in practice requires consideration of the conditions of each healthcare facility, the applicable standards and the instructions provided by equipment manufacturers.

Project website: www.smarthealtheng.com

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PSYCHROMETRY AND AIR HANDLING UNITS. CONCEPTS AND PURPOSES

Comprehensive Academic Training Manual & Master Course Guide
Smart Healthcare Engineering (SHEng) Group

Carlos J. Sánchez Morales, University Las Palmas de Gran Canaria, Spain

Course Module:	Advanced Thermal Engineering & Healthcare HVAC Systems
Target Audience:	Mechanical Engineers, Healthcare Facility Managers & Biomedical Technicians
Academic Support:	ASHRAE Standards 62.1 & 170, RITE Regulations, Daikin & Lennox Catalogs

Introduction

This educational material introduces the core principles of psychrometry and the functional role of Air Handling Units (AHUs) in maintaining indoor environments. It explores how atmospheric moisture affects human comfort, explaining that high water vapor levels inhibit cooling through sweat while a lack of vapor allows heat to dissipate quickly. Key technical metrics are defined to evaluate air properties, including dry and wet bulb temperatures, relative humidity, enthalpy, and the dew point. By utilizing a psychrometric chart, engineers can design systems that regulate temperature, filtration, and ventilation to ensure optimal air quality. Ultimately, the source highlights how mechanical units manage these variables to create healthy, climate-controlled spaces within modern buildings.

1. Executive Summary & Training Objectives

Atmospheric air control is a fundamental domain within building services engineering, thermal comfort management, and critical infrastructure design. In specialized facilities—particularly hospitals, pharmaceutical cleanrooms, and surgical centers—air is not merely a medium for temperature regulation; it is a vital biological vector that directly impacts patient recovery, infection control, and sterile procedures. This training manual provides an exhaustive, mathematically rigorous, and practical guide to Psychrometry and Air Handling Units (AHUs).

Key Learning Objectives of this Training Manual:

1. Master the thermodynamic properties of moist air mixtures (Dry-Bulb, Wet-Bulb, Relative Humidity, Dew Point, Enthalpy, Specific Humidity).

2. Interpret and execute psychrometric processes using Carrier, ASHRAE, and Mollier charts.
3. Understand the architectural layout and multi-stage components of modern Air Handling Units (AHUs).
4. Calculate supply airflow rates, coil cooling/heating power, water condensation/humidification rates, and bypass factors.
5. Apply international regulatory frameworks (ASHRAE 62.1, ASHRAE 170, Spanish RITE, UNE-EN ISO 14644) to critical hospital environments.

2. Executive Summary & Training Objectives **Understanding the Air Around You.**

Psychrometry is defined as the sub-discipline of thermodynamics concerned with the physical, thermal, and dynamic properties of gas-vapor mixtures, most notably atmospheric air, which consists of dry air mixed with water vapor. Under normal atmospheric conditions, moist air can be modeled with high accuracy as a mixture of ideal gases governed by Dalton's Law of Partial Pressures:

$P_{atm} = P_{da} + P_v$

Where P_{atm} represents total barometric pressure (101.325 kPa at standard sea level), P_{da} is the partial pressure of dry air, and P_v is the partial pressure of water vapor.

To understand why this matters, let's look at some real-life scenarios:

- **Humidity and Comfort:** Why do you sweat more in high humidity? It's because too much water in the air makes us feel 'sticky' as our sweat cannot evaporate effectively.
- **The Desert Effect:** Why can a desert be so cold at night? Without water vapor to trap heat, energy escapes rapidly into the atmosphere once the sun goes down.
- **Common Questions:** We also need to understand why it feels colder right after it rains or why air conditioning systems must actively remove water from the air to maintain comfort.

To quantify these effects, we use several key concepts.

2.1 Key Thermodynamic State Parameters

- **Dry-Bulb Temperature (T_{db}):** The true sensible temperature of the air measured by a standard thermometer shielded from direct radiation. It measures the mean kinetic energy of air molecules.
- **Wet-Bulb Temperature (T_{wb}):** The lowest temperature achievable by evaporative cooling alone. Measured by a thermometer whose bulb is covered by a water-wetted wick exposed to rapid air stream (> 4 m/s).
- **Dew-Point Temperature (T_{dp}):** The threshold temperature at which moist air reaches 100% saturation ($P_v = P_{sat}$) upon cooling at constant pressure, initiating moisture condensation.
- **Specific Humidity / Humidity Ratio (w):** The absolute mass of water vapor per unit mass of dry air, expressed in grams of water per kilogram of dry air (g_w / kg_da) or kg_w / kg_da:
  - **$w = 0.622 * (P_v / (P_{atm} - P_v))$**

- **Relative Humidity (phi or RH):** The ratio of the actual partial vapor pressure (P_v) to the saturation vapor pressure (P_sat) at the exact same dry-bulb temperature, expressed as a percentage:
  - $\mathbf{RH\ (\%) = (P_v / P_{sat}(T_{db})) * 100}$
- **Specific Enthalpy (h):** The total thermal energy contained in moist air per unit mass of dry air, incorporating both sensible heat (temperature) and latent heat (phase-change water vapor content):
  - $\mathbf{h = c_{p,da} * T_{db} + w * (h_{fg} + c_{p,v} * T_{db})\ [kJ/kg_{da}]}$

Using standard sea-level coefficients: $c_{p,da}$ = 1.006 kJ/kg·°C (specific heat of dry air), h_{fg} = 2501 kJ/kg (latent heat of vaporization at 0°C), and $c_{p,v}$ = 1.86 kJ/kg·°C (specific heat of water vapor), the practical equation becomes:

$$\mathbf{h = 1.006 * T_{db} + w * (2501 + 1.86 * T_{db})}$$

All these variables are plotted on the Psychrometric Chart, which allows us to visualize how air properties change during different treatments. Our ultimate goal is to achieve Room Comfort Conditions, which require balancing dry temperature, relative humidity, air filtration, renovation, and even noise levels through proper ductwork and dampers."

3. Psychrometric Charts and Air Transformations

To evaluate complex thermodynamic air transformations graphically, engineers rely on psychrometric charts. The standard ASHRAE / Carrier psychrometric chart plots Dry-Bulb Temperature along the horizontal X-axis and Specific Humidity Ratio along the vertical Y-axis. Curved lines represent constant Relative Humidity, sloped lines indicate constant Enthalpy and Wet-Bulb temperature, and steep diagonal lines denote Specific Volume.

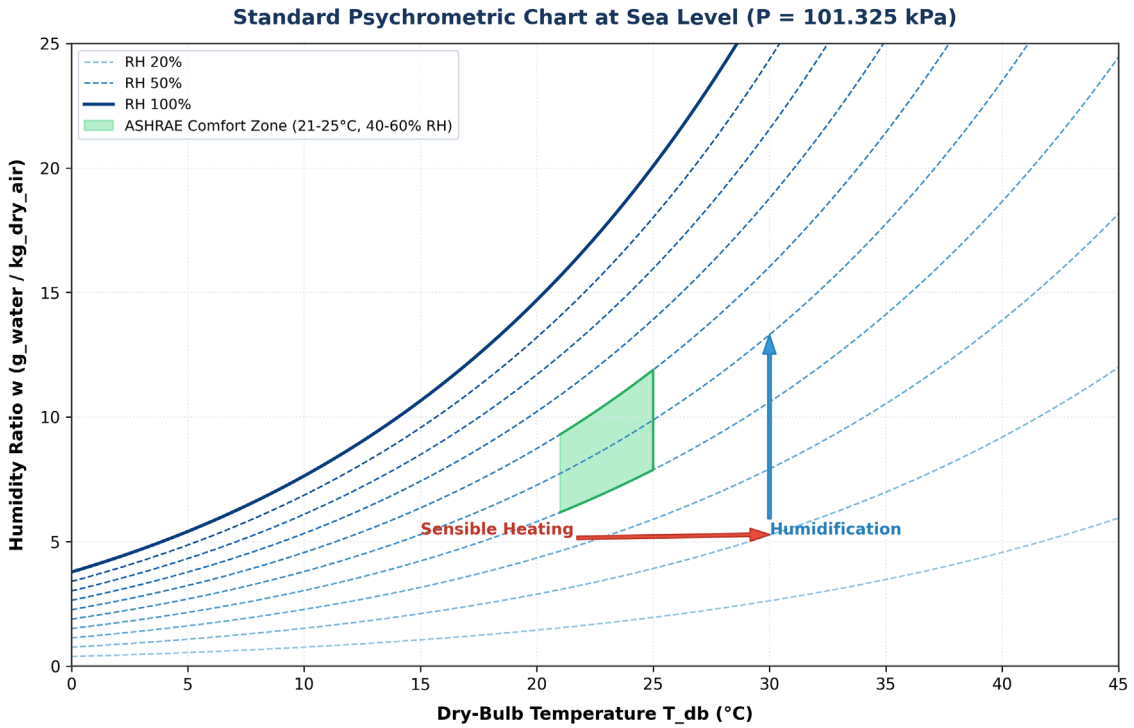

Figure 3.1: Standard Psychrometric Chart at Sea Level displaying Relative Humidity curves, ASHRAE Comfort Zone, and Sensible Heating / Humidification vectors.

3.1 Core Psychrometric Transformations in Air Handling Units

Air Transformation	Δ T_{db}	Δ w (Moisture)	Thermodynamic Vector Direction
Sensible Heating	Increases (+)	Constant (0)	Horizontal arrow to the right
Sensible Cooling	Decreases (-)	Constant (0)	Horizontal arrow to the left
Cooling & Dehumidification	Decreases (-)	Decreases (-)	Diagonal arrow down-left (below dew point)
Isothermal Humidification	Constant (0)	Increases (+)	Vertical arrow straight up (steam injection)

3.2 Sensible Heat Factor (SHF) and Bypass Factor (FB)

The Sensible Heat Factor (SHF) defines the ratio of sensible heat gain to total heat gain (sensible + latent) in a conditioned space:

$$SHF = Q_{sensible} / (Q_{sensible} + Q_{latent})$$

The Bypass Factor (F_B) of a cooling/heating coil accounts for the fraction of air that passes through the coil fins without contacting the tube surfaces. The air leaving the coil is a mixture of completely treated air at the apparatus dew point (ADP) and untreated entering air:

$$F_B = (T_{db,leaving} - T_{ADP}) / (T_{db,entering} - T_{ADP})$$

4. Air Handling Units (AHUs): Engineering & Architecture

Once we understand the air, we need the machinery to treat it. This is where Air Handling Units, or AHUs, come in.

An Air Handling Unit (AHU) is the primary mechanical assembly in centralized HVAC systems responsible for drawing in outdoor and recirculated air, conditioning it to strict thermal and hygienic specifications, and distributing it via ductwork. Modern AHUs utilize modular casing built from double-skin insulated panels (typically 50 mm polyurethane foam or mineral wool) to minimize thermal bridging and acoustic transmission.

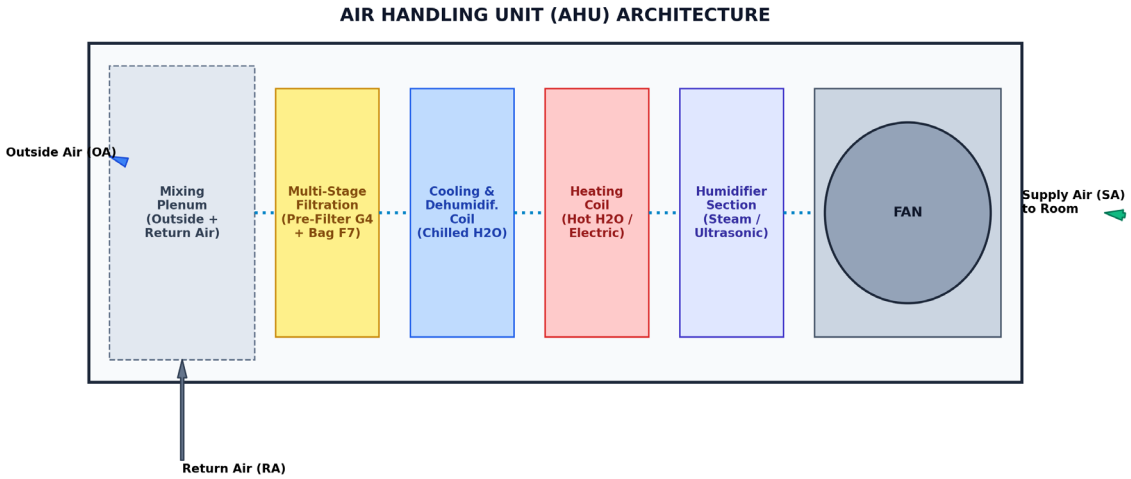

Figure 4.1: Schematic Architecture of a Modular Air Handling Unit showing component sequence from Mixing Plenum to Supply Blower.

AHUs are designed to improve Indoor Air Quality (IAQ) and maintain comfortable temperatures. Their primary functions include:

- Ventilation: Drawing in fresh outside air and mixing it with recirculated air.
- Filtration: Removing airborne particles to keep the environment clean.
- Temperature and Humidity Control: Heating, cooling, humidifying, or dehumidifying the air as needed.
- Efficiency: Modern units offer energy efficiency and integration with Building Management Systems (BMS) for precise control.

4.1 Breakdown of Key AHU Subsystems

Inside a typical AHU, you will find several critical components:

1. Mixing Plenum & Motorized Dampers: Combines fresh outside air (OA) with return air (RA). Low-leakage opposed-blade dampers modulate ratios according to economizer control and air quality demand.

2. Multi-Stage Filtration Section: Protects internal coils and ensures indoor air quality. Standard sequence includes ISO Coarse pre-filters (G4 class), ePM1 high-efficiency bag filters (F7-F9 class), and terminal Absolute HEPA filters (H13-H14 class, 99.995% efficiency at 0.3 µm) for surgical cleanrooms.

3. Thermal Exchange Coils: Copper tube / aluminum fin heat exchangers connected to chilled water central plants (7/12°C), hot water boilers (45/40°C), or direct expansion (DX) heat pumps.

4. Humidification Equipment: Includes dry steam injectors for sterile hospital environments or high-efficiency ultrasonic piezo-atomizers for energy-efficient moisture control.

5. Supply & Exhaust Fan Arrays: Direct-drive Electronically Commutated (EC) plug fans equipped with variable frequency drives (VFDs) for continuous static pressure control and high energy efficiency.

These units can be found in various applications, from commercial offices and retail spaces to highly specialized industrial cleanrooms and hospitals. Depending on the need, they can be modular or rooftop units.

Designing these systems requires precise mathematical calculations to ensure performance.

- Air Flow Rate: Calculated based on room thermal load, air density, and the temperature difference between mixed and supply air.
- Power Calculation: Determining the power needed for evaporators or condensers based on the change in air enthalpy.
- Moisture Control: Calculating the water flow rate required for humidification or dehumidification.

Finally, all designs must adhere to applicable regulations, such as the RITE (*Reglamento de Instalaciones Térmicas en los Edificios*) in Spain, or international standards.

5. Engineering Design Calculations & Formulas

The design of an AHU requires rigorous mass and energy balance calculations. The following engineering equations dictate supply air volume, thermal coil capacity, and moisture removal/addition rates.

5.1 Airflow Rate Calculation (V_i)

The supply airflow volume rate (V_i in m^3/h or m^3/s) is determined by the room sensible thermal load ($Q_{sensible}$ in kW), air density (rho = 1.2 kg/m^3), specific heat (c_p = 1.006 kJ/kg·°C), and the temperature differential between supply air (T_{supply}) and room setpoint (T_{room}):

$$V_i\ (m^3/s) = Q_{sensible} / (\rho * c_p * (T_{room} - T_{supply}))$$

5.2 Thermal Power Calculation for Coils (P_B)

The total thermal capacity required for a cooling or heating coil (P_B in kW) depends on the mass flow rate of dry air ($m_{da} = \rho * V_i$) and the enthalpy change across entering air ($h_{entering}$) and leaving air ($h_{leaving}$):

$$P_B\ (kW) = m_{da} * | h_{entering} - h_{leaving} | = \rho * V_i * | h_{entering} - h_{leaving} |$$

5.3 Water Condensation / Humidification Mass Flow Rate (V_{H2O})

The mass flow rate of water condensed during dehumidification or injected during humidification (m_{H2O} in kg/h or L/h) is calculated using the specific humidity difference:

$$m_{H2O}\ (kg/h) = \rho * V_i\ (m^3/h) * | w_{entering} - w_{leaving} |\ (kg_w / kg_{da})$$

5.4 Application Matrix: Bypass Factor (F_B) and Fresh Air Requirements

Facility Type	Target Bypass (F_B)	Fresh Air Intake (%)	Primary Design Priority
Commercial Offices	0.20 – 0.30	15% – 25% (Economizer)	Occupant Thermal Comfort & Energy Efficiency
Industrial Cleanrooms	0.10 – 0.20	20% – 50% Positive Press.	Particulate Control & High Air Changes (ACH > 30)
Hospital Operating Rooms	0.05 – 0.10	100% Outdoor Air (100% OA)	Ultra-Clean Air (HEPA H14), Zero Cross-Contamination
IVF & Birthing Rooms	0.05 – 0.10	100% Outdoor Air (100% OA)	VOC Elimination, Precise RH (45-55%), Ultra-Quiet

6. Application in Specialized Environments

In highly regulated spaces like hospitals, the psychrometric chart is used to ensure air meets strict safety and comfort standards for areas such as operating rooms, birthing rooms, and in-vitro fertilization rooms. In these cases, the chart ensures that temperature and humidity are precisely controlled to support clinical outcomes while maintaining occupant comfort.

The customization of Air Handling Units (AHUs) differs significantly between hospitals and offices, primarily focusing on the level of air treatment, fresh air requirements, and the precision of environmental control.

1. Technical Design Parameters (Bypass Coefficient)

A key technical difference is the bypass coefficient (), which represents the fraction of air that does not come into contact with the treatment coils.

- Offices: These are designed primarily for comfort conditions, with a higher bypass coefficient typically ranging from 0.20 to 0.30.
- Hospitals: Specialized environments like hospitals, manufacturing plants, and cleanrooms require much lower bypass coefficients, often between 0.10 and 0.30. In cases requiring only fresh air (common in critical hospital zones), the coefficient is even stricter, ranging from 0.05 to 0.10.

2. Fresh Air and Ventilation Requirements

- Offices: Focus on a mix of outside air and recirculated air to maintain standard comfort and energy efficiency.
- Hospitals: Often prioritize air renovation and the intake of fresh air to prevent cross-contamination. This is particularly critical in "clean" zones where the AHU must ensure high indoor air quality (IAQ) through intensive filtration.

3. Specialized Zone Customization

While offices generally use AHUs for broad commercial spaces, hospitals require units tailored to the specific clinical needs of different rooms:

- Operating Rooms: Specialized units (like those at C.H.U. Insular) are designed to maintain the sterile environments required for surgery.
- Birthing and IVF Rooms: At the Hospital Materno Infantil, dedicated AHUs are customized for birthing rooms and in-vitro fertilization rooms, where precise control over temperature, humidity, and airborne particles is vital for clinical outcomes.

4. Operational Priorities

- Offices: The goal is comfort, balancing dry temperature and relative humidity with noise control through dampers and ductwork.

- Hospitals: The goal is safety and air purity. This involves more robust filtration stages, such as the combination of pre-filters and bag filters, to ensure the air supplied to sensitive clinical areas is free of contaminants

7. Regulatory Framework & Specialized Healthcare Case Studies

Designers of HVAC systems in Southern Europe and globally must strictly satisfy statutory codes and clinical mandates. Key regulations governing AHUs include:

• **Spanish RITE Regulations (Real Decreto 1027/2007):** Mandates indoor air quality categories (IDA 1 for hospitals to IDA 4 for low requirement), minimum fresh air per person, and strict thermal comfort envelopes (21-23°C winter, 23-25°C summer, 40-60% RH).

• **UNE-EN ISO 14644 & UNE 100713 Standards:** Defines airborne particulate cleanliness classes and specific HVAC requirements for hospital surgical suites, including positive pressure cascades (+15 Pa) to prevent contaminated air infiltration.

• **ASHRAE Standard 170 (Ventilation of Health Care Facilities):** International benchmark dictating air change rates (min 20 ACH for operating rooms), filtration requirements (MERV 14 + HEPA), and humidity bounds.

• **Turkish Standards Institution (TSE) Seismic Standards:** Requires AHUs installed in seismic zones to feature structural anti-vibration spring isolators and reinforced casing integrity.

7.1 Real-World Hospital Implementations (Gran Canaria)

The Smart Healthcare Engineering (SHEng) group has engineered and validated specialized AHU deployments across major healthcare complexes in the Canary Islands:

1. C.H.U. Insular Surgical Complex: Deployment of 100% Outdoor Air AHUs serving surgical operating suites. System features stainless steel 316L internal casing, multi-stage HEPA H14 filtration, precise dry steam humidification, and positive pressure differential monitoring.

2. Hospital Materno Infantil (Birthing & IVF Suites): Customized low-noise AHUs engineered for In-Vitro Fertilization (IVF) laboratories and delivery rooms. Incorporates activated carbon chemical filtration to scrub volatile organic compounds (VOCs) that impair embryo development, maintaining exact 22.0°C ± 0.5°C and 50% ± 2% RH.

8. Integrated Assessment Examination & Master Quiz

This evaluation section contains a 25-question multiple-choice assessment designed to test student comprehension of psychrometric theory, AHU engineering, calculations, and healthcare regulations. A Quick Answer Matrix and Detailed Step-by-Step Solutions follow the exam paper.

Assessment Examination Instructions:

Time Allowed: 45 Minutes | Total Marks: 25 Points | Passing Threshold: 70% (18/25)
Instructions: Select the single best answer (A, B, C, or D) for each question. Show calculation steps on scratch paper for numerical questions.

1. What does Psychrometry primarily study?

A. Liquid dynamics in high-pressure hydraulic pipes
B. Physical and thermodynamic properties of gas-vapor mixtures (moist air)
C. Electrical impedance of microcontrollers
D. Structural resonance of HVAC dampers

2. What is Dry-Bulb Temperature (T_{db})?

A. The temperature of air cooled by pure water evaporation
B. The ambient temperature measured by a standard thermometer shielded from radiation
C. The temperature at which water vapor begins condensing
D. The temperature inside a chilled water boiler

3. How is Wet-Bulb Temperature (T_{wb}) measured?

A. Using an infrared laser directed at a dry wall
B. Using a thermometer covered with a wet wick exposed to rapid air stream
C. By heating air to 100°C and measuring pressure drop
D. Using a piezoresistive pressure transducer

4. What happens when air reaches its Dew-Point Temperature (T_{dp})?

A. Relative Humidity drops to 0%
B. Specific enthalpy becomes zero
C. Air becomes 100% saturated and condensation begins
D. Dry-bulb temperature instantly doubles

5. What is the definition of Specific Humidity / Humidity Ratio (w)?

A. Mass of water vapor per unit mass of dry air (g_w / kg_{da})
B. Volume of dry air divided by room square meters
C. Ratio of steam pressure to fan speed
D. Total weight of AHU casing in kilograms

6. What does Relative Humidity (RH or phi) represent?

A. Total weight of water in the room
B. Ratio of actual partial vapor pressure P_v to saturation vapor pressure P_{sat} at T_{db}
C. Absolute temperature ratio in Kelvin
D. Percentage of fresh air vs return air

7. What is Specific Enthalpy (h) in moist air?

A. Only the sensible kinetic energy of dry air molecules
B. Total thermal energy combining sensible heat and latent heat per kg of dry air
C. The electrical power consumed by the supply fan
D. The static pressure loss across HEPA filters

8. Why do people feel 'sticky' and uncomfortable on high humidity days?

A. Sweat evaporates too fast, chilling the skin
B. High water vapor partial pressure prevents effective sweat evaporation
C. Atmospheric pressure drops to absolute zero

Air density increases by 500%

9. Why does the temperature drop in a desert rapidly at night?

A. High cloud cover blocks radiation
B. Extremely low moisture content (water vapor) prevents trapping infrared radiation
C. Desert sand absorbs all air enthalpy
D. High relative humidity cools the air

10. On a standard Psychrometric Chart, what do curved lines represent?

A. Constant Dry-Bulb Temperature
B. Constant Relative Humidity (RH %)
C. Constant Airflow Velocity
D. Constant Fan Revolutions Per Minute

11. What path does Sensible Heating follow on a psychrometric chart?

A. Vertical arrow pointing straight up
B. Horizontal line moving to the right (increasing T_{db}, constant w)
C. Diagonal line pointing down-left
D. Curved line following 100% RH

12. What path does Isothermal Steam Humidification follow on the chart?

A. Horizontal line to the left
B. Nearly vertical line pointing straight up (increasing w, constant T_{db})
C. Diagonal line pointing down-right
D. Horizontal line to the right

13. What is the Sensible Heat Factor (SHF)?

A. Ratio of Latent Heat to Total Heat
B. Ratio of Sensible Heat Gain to Total Heat Gain (Sensible + Latent)
C. Fan power divided by coil area
D. Bypass factor multiplied by 100

14. What does a low Bypass Factor (F_B = 0.05) indicate for a cooling coil?

A. 95% of air passes through without touching fins
B. High thermal efficiency; 95% of air contacts coil surface at Apparatus Dew Point
C. The coil is blocked by dust
D. Fan speed is too high

15. What is the primary function of an Air Handling Unit (AHU)?

A. Generating high voltage electricity for the facility
B. Conditioning, filtering, and circulating atmospheric air to maintain IAQ and thermal control
C. Pumping hot water in domestic water to showers
D. Storing medical waste

16. Which component controls the mixing ratio of Outside Air and Return Air in an AHU?

A. Centrifugal Blower
B. Motorized Dampers in the Mixing Plenum
C. HEPA Filter
D. Expansion Valve

17. What is the correct sequence of components in a hygienic hospital AHU?

A. Fan -> HEPA Filter -> Damper -> Coil
B. Mixing Damper -> pre-Filter -> Bag Filter -> Cooling/Heating Coils -> Humidifier -> Supply Fan
C. Humidifier -> Damper -> Bag Filter -> Fan
D. HEPA Filter -> pre-Filter -> Damper

18. What class of filter is required for sterile surgical suites (Hospitals)?

A. Coarse G2 filter
B. Absolute HEPA H13/H14 filter (99.995% efficiency at 0.3 µm)
C. Standard insect mesh
D. Cardboard baffle filter

19. Why are EC (Electronically Commutated) Plug Fans preferred in modern AHUs?

A. They consume 10x more energy
B. Direct-drive speed regulation, high energy efficiency, and low maintenance
C. They operate only with steam boilers
D. They require belt drives

20. Why do In-Vitro Fertilization (IVF) rooms require special chemical gas filtration in AHUs?

A. To remove Volatile Organic Compounds (VOCs) that disrupt delicate cellular/embryo growth
B. To increase humidity to 100%
C. To reduce room oxygen concentration
D. To lower air velocity to zero

8.1 Assessment Examination Quick Answer Matrix

Col 1	Col 2	Col 3	Col 4	Col 5
Q1: B	**Q2: B**	**Q3: B**	**Q4: C**	**Q5: A**
Q6: B	**Q7: B**	**Q8: B**	**Q9: B**	**Q10: B**
Q11: B	**Q12: B**	**Q13: B**	**Q14: B**	**Q15: B**
Q16: B	**Q17: B**	**Q18: B**	**Q19: B**	**Q20: A**

8.2 Comprehensive Solutions & Step-by-Step Explanations

• Q1-Q7 (Psychrometric Principles): Moist air is governed by ideal gas laws. Enthalpy combines sensible heat (c_p * T) and latent heat (w * h_fg). Dew point marks 100% saturation.

• Q8-Q9 (Environmental Phenomena): High humidity suppresses sweat evaporation because P_v is near saturation pressure. Desert dry air lacks water vapor (greenhouse gas), allowing radiative heat to escape to space at night.
• Q10-Q14 (Diagram Transformations & SHF): Sensible processes move horizontally (constant moisture w). Isothermal steam humidification moves vertically. Low bypass factor F_B (0.05) means 95% of air intimately contacts coil fins.
• Q15-Q19 (AHU Components & Filtration): Air handling units sequence mixing dampers, G4 pre-filters, F7 bag filters, coils, and terminal HEPA H14 filters (99.995% at 0.3 µm) driven by EC plug fans for sterile surgical air.
• Q20-20 (Hospital Cases): IVF rooms require

Academic Support & Bibliographical References

To provide rigorous academic support, this manual draws upon recognized international HVAC engineering handbooks, statutory codes, and manufacturer technical specifications:

1. ASHRAE Handbook — Fundamentals (2021): American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA. Chapter 1: Psychrometrics.

2. ASHRAE Standard 62.1-2022: Ventilation for Acceptable Indoor Air Quality. ASHRAE Standards Committee.

3. ASHRAE Standard 170-2021: Ventilation of Health Care Facilities. ASHE / ASHRAE Co-published Standard.

4. RITE Regulations (Real Decreto 1027/2007): Reglamento de Instalaciones Térmicas en los Edificios. Ministerio de Industria, Turismo y Comercio, Gobierno de España.

5. UNE-EN ISO 14644-1:2016: Cleanrooms and associated controlled environments — Part 1: Classification of air cleanliness by particle concentration.

6. Daikin Applied Technical Manual (2023): Modular Air Handling Units (AHU) D-AHU Series Technical & Selection Guide. Daikin Europe N.V.

7. Carrier Psychrometric Chart Manual (2020): Handbook of Air Conditioning System Design. McGraw-Hill Book Company.

Acknowledgments

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