Professional Engineering Exam

Heating, Ventilation, and Air-Conditioning (HVAC) and Refrigeration Engineering

Study Guide

Education and Training Evaluation Commission (ETEC)
National Center for Assessment (NCA)

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1. Aim:

The objective of this Instruction Manual is to provide guidelines for the NCA proposed Professional Engineers Exam. These guidelines cover the eligibility conditions, the grading and passing conditions, the structure of the exam and the distribution of exam questions among various areas. In essence, this Instruction Manual represents a "bridge" between the developed exam standards and the actual phrased questions. It is designed to help item writers prepare questions for the HVAC and Refrigeration Engineering Discipline Exam as well as a study guide for the examinees.

2. Exam Structure:

2.1 Exam Type

The exam is initially paper-based with questions being a combination of multiple- choice questions (MCQ) and essays.

2.2 Exam Organization

The exam will be conducted in two sessions during one day. The duration of the first session is 2.5 hours while the second section is 4 hours long. There is one-hour break between the two sessions.

2.2.1. Session #1

The first session is the common part to be taken by all the examinees from all disciplines. This part includes seven topics: (Ethics – Professionalism - Laws for Professional Practice, Professional Laws and Regulation - Environment and Natural Resources - Engineering Management - Engineering Economics - Health, Safety & Security (HSS)).

The total duration of this session is 2.5 hours and the total number of questions is 30 MCQ and 2 essays.

2.2.2. Session #2

The second session is the Discipline Part. The following engineering disciplines are considered:

Code	Discipline
STE	Structural Engineering
GTE	Geotechnical Engineering
TRE	Transportation Engineering
WREE	Water Resources and Environmental Engineering
PE	Power Engineering
HVAC	Heating, Ventilation, and Air Conditioning (HVAC) and Refrigeration Engineering
TFSE	Thermal and Fluids Systems Engineering
CHE	Chemical Engineering
FPE	Fire Protection Engineering
ARCH	Architecture

The total duration of this session is 4 hours and the total number of questions is 30 MCQs and 5 essays. The examinee must answer all the MCQs and two essays (one compulsory and one to be chosen out of 4).

2.3 Eligibility for the Exam

The eligibility to register for the exam is according to the Saudi Council of Engineers (SCE) requirements.

2.4 Grades

Each part (common part and discipline part) carries a total grade of 100. The MCQs carry a grade of 60% while the essays carry a grade of 40%. Each MCQ has 4 choices for the answer. There is no negative marking for wrong answers.

2.5 Passing Rules

- The eligible candidate must take in his/her first sitting the two exam parts (common part and discipline part).
- In order to pass the exam, the candidate must obtain a grade of 60% or above in each part of the exam.
- If the candidate fails both parts of the exam (by receiving in each part a grade less than 60%), he/she can take the two parts of the exam but only when one full year has passed.
- If the candidate fails only one part of the exam (common part or discipline part), he/she must repeat only the part he/she failed, but he/she must pass this part within one year.
- If a year passed and the candidate did not succeed in passing the part he/she failed, then he/she has to take both parts of the exam.

2.6 Exam Rules

- No printed or electronic material is allowed during the exam. All necessary reference materials will be provided by NCA
- Calculators approved by NCA are allowed.
- Comprehensive exam rules will be provided by the examination authority, NCA, in a separate manual.

3. Table of Specifications for HVAC and Refrigeration Professional Engineering Exam:

Topic Area	Multiple Choice Questions (MCQs)		Essay Questions # Q	Engineering Standard
	% of Test	# Q		
1. Introduction to HVAC	3.3%	1		HVAC-T1
2. Air Conditioning Systems	6.7%	2	1 (Compulsory)	HVAC-T2
3. Comfort Conditions and Air Quality	3.3%	1		HVAC-T3
4. Air Conditioning Processes	10%	3	I	HVAC-T4
5. HVAC Load Estimation	10%	3	I	HVAC-T5
6. HVAC Equipment Selection	6.7%	2		HVAC-T6
7. Air Distribution System Design	10%	3		HVAC-T7
8. Chilled and Hot water Piping Systems Design	3.3%	1		HVAC-T8
9. Sustainability of HVAC Systems	3.3%	1		HVAC-T9
10. Ventilation	3.3%	1		HVAC-T10
11. Refrigeration Systems	10%	3	2	HVAC-T11
12. Refrigerants	6.7%	2		HVAC-T12
13. Equipment of Refrigeration Systems	6.7%	2		HVAC-T13
14. Cold Stores	6.7%	2		HVAC-T14
15. Codes and Standards	6.7%	2		HVAC-T15
16. HVAC Control Principles	3.3%	1		HVAC-T16
Total	100%	30	1 Compulsory and Choose 1 out of 4	

4. Standards for HVAC and Refrigeration:

The Engineering Standards for the Mechanical Engineering Discipline PE exam is structured around three core specializations (Fire Protection Engineering, Thermal-Fluid Systems, and Heating, Ventilating, Air-Conditioning and Refrigeration (HVAC)). The exam in each specialization has to satisfy a number of indicators to measure the practicing engineer's competency in that specialization. This particular section covers the HVAC and Refrigeration specialization.

HVAC & Refrigeration Engineers are expected to possess and demonstrate command of the following Engineering Competencies.

T1: Introduction to HVAC

HVAC-T1: HVAC&R engineers should be able to recognize and use special terminology, units, measurements and concepts that are particular to this specialization. The following Indicators are addressed in the Exam Questions on this topic.

T1- Indicators

HVAC-T1-01 Be familiar with basic components present in heating and cooling systems.

HVAC-T1-02 Recognize definition of HVAC, special units used in HVAC to measure cooling capacity (Ton Refrigeration, Btu/h, kW cooling) and their conversion factors, other units common in HVAC: GPM, Lit/Sec, cfm, m^3/h, temperature Celsius (C), Fahrenheit (F).

HVAC-T1-03 Recognize the difference between kW power and kW cooling/heating.

HVAC-T1-04 Measure current and voltage of compressor motor and calculate its power consumption considering the power factor (phase angle) and recognize the reactive power, real power and the difference between kW, kVA, kVAr.

HVAC-T1-05 Recognize Energy Efficiency Ratio (EER) of HVAC equipment and how it is related to Coefficient of Performance (COP), Performance Factor (PF).

HVAC-T1-06 Recognize that the highest ceiling (maximum possible even under ideal conditions) for COP/PF of any HAVC system as compared to actual values.

HVAC-T1-07 Recognize the effect of temperature limits (heat sink/ambient and cold reservoir) on performance of HVAC equipment.

HVAC-T1-08 Recognize common terms used in submissions including: Approved as Noted, Revise and Resubmit, Disapproved or Rejected, and Submit as Specified.

HVAC-T1-09 Recognize common terms used in receiving an HVAC installation including Pre-Final Inspection or Observation, Final Inspection or Observation, Balancing, Commissioning … etc.

HVAC-T1-10 Recognize Psychrometric terms: dry bulb temperature, wet bulb temperature, dew point, moisture content, relative humidity, enthalpy, specific volume, partial pressure of water vapor and total pressure according to sea level.

HVAC-T1-11 Recognize the following concepts: Sensible Heat factor (SHF), Coil Bypass Factor (BPF), Apparatus Dew Point (ADP), Coil surface temperature (t_s).

T2: Air Conditioning Systems

HVAC-T2: HVAC&R engineers should be able to understand how different air conditioning systems work, the advantages, disadvantages and the architectural requirements of each system. Also the engineer should be able to select the most appropriate system for a given application (project).

T2- Indicators

HVAC-T2-01 Recognize the differences between different type of AC systems such as: All-Air, All-water, Air-water, VFR and mini-split systems.

HVAC-T2-02 Apply the conservation laws (conservation of mass and conservation of energy to HVAC systems).

HVAC-T2-03 Understand the concepts of variable air volume (VAV) and constant air volume (CAV) systems, their control strategy and their suitable applications.

HVAC-T2-04 Understand single-zone systems and their control strategy and be able to determine the condition of air at various points in the system.

HVAC-T2-05 Understand multi-zone systems and how terminal reheat and / or zone VAV and individual zone control works.

HVAC-T2-06 Recognize different types of Unitary Systems, their advantages, disadvantages, and architectural requirements.

HVAC-T2-07 Recognize different types of Heat pumps: air-source, water-source, ground-source.

HVAC-T2-08 Understand how VRF (variable refrigerant flow) systems work and their merits.

HVAC-T2-09 Understand how Evaporative Coolers (single-stage and two-stage) work, their advantages, disadvantages and limitations as well as their merits.

HVAC-T2-10 Understand the Testing and Balancing (TAB) techniques.

T3: Comfort Conditions and Air Quality

HVAC-T3: HVAC&R engineers should be aware of the different factors that affect human comfort and the effects of indoor air quality on the wellbeing of building occupants. They should consider these factors when selecting indoor design conditions together with their effect on energy consumption, whenever appropriate.

T3- Indicators

HVAC-T3-01 Recognize the impact of indoor design conditions on the thermal load.

HVAC-T3-02 Understand the different parameters affecting human thermal comfort and recognize the impact of indoor design conditions (temperature and humidity) on the level of human thermal comfort.

HVAC-T3-03 Be able to use the comfort zone to determine the level of human comfort in both winter and summer for a given indoor conditions (DBT and RH).

HVAC-T3-04 Realize the impact of indoor air quality on the health and comfort of humans occupying the built environment with reference to ASHRAE 55 and 62.

T4: Air Conditioning Processes

HVAC-T4: HVAC&R engineers should be able to select the appropriate air conditioning processes to achieve required indoor conditions. Also they should be able to represent these processes on the psychrometric chart and do the necessary calculations.

T4- Indicators

HVAC-T4-01 Demonstrate ability to use the Psychrometric chart to obtain various air-vapor mixture properties.

HVAC-T4-02 Recognize the difference between sensible and latent heat transfer in HVAC.

HVAC-T4-03 Understand various classical air-conditioning processes including sensible cooling, sensible heating, humidification by water spray and by steam injection, dehumidification by cooling, by absorbing salts (solid and liquid desiccant) and by mixing fresh and return air.

HVAC-T4-04 Represent the above classical processes on the psychrometric chart and be able to do simple calculations for these processes for summer air conditioning in dry and humid regions as well as for winter air conditioning.

HVAC-T4-05 Represent the evaporative cooler process on the psychrometric chart and determine the condition of leaving air using the cooler's effectiveness. (Note effectiveness is sometimes called efficiency which is not proper).

HVAC-T4-06 Carry out air-conditioning processes calculations for single zone central system to determine the condition of mixed air (recirculated + fresh), the condition of air before and after coil as well as the coil load.

HVAC-T4-07 Carry out air-conditioning processes calculations on any approved Software.

T5: HVAC Load Estimation

HVAC-T5: HVAC&R engineers should be able to calculate the air-conditioning (thermal) load in a building manually or by using computer software such as Energy Plus, HAP or equivalent. Load calculation involves calculating heat gain through building envelope, solar heat gain, internal heat gain (lighting, people and equipment) and heat gain due outdoor air (ventilation/infiltration). Engineers should be familiar with ASHRAE standard 90.1 or equivalent.

T5- Indicators

HVAC-T5-01 Recognize different factors affecting the cooling/heating load.

HVAC-T5-02 Recognize the different methods for calculating HVAC loads in buildings and differentiate between block load and peak load.

HVAC-T5-03 Understand different measures of "Outdoor air design conditions" for load calculations and be able to select them as well as indoor air design conditions for a particular location/ project.

HVAC-T5-04 Demonstrate the ability to estimate walls, roofs and windows properties such as U-coefficients or and R-values based on the building construction plans set by the architect.

HVAC-T5-05 Understand different HVAC zoning strategies and be able to divide building into zones according to the most relevant strategy.

HVAC-T5-06 Understand different methods to reduce HVAC loads in buildings such as using thermal insulation, shading, efficient glazing, efficient lighting, and efficient equipment with relevance to the Energy Conservation part of the Saudi Building Code.

HVAC-T5-07 Estimate heat transmission through building envelope (composite walls, roofs, windows, and ground) employing proper mechanisms of heat transfer, and using the concept of the overall heat transfer coefficient (U) or thermal resistance (R-value) and the cooling load temperature difference (CLTD) of building elements.

HVAC-T5-08 Estimate solar radiation through glazing considering the optical properties of glazing (shading coefficient).

HVAC-T5-09 Estimate Internal heat gains from lighting, people and heat producing equipment, and recognize different types of lighting and their relative energy efficiency using schedules reflecting the local life style.

HVAC-T5-10 Determine fresh air volume flow rate as required by codes and standards (ASHARE, SASO and SBC).

HVAC-T5-11 Estimate fresh air heat gains and recognize the difference between outdoor ventilation and infiltration.

HVAC-T5-12 Recognize the difference between sensible and latent gains and calculate the zone sensible heat factor (SHF) and differentiate between space and equipment loads.

HVAC-T5-13 Apply different methods for calculating thermal loads in buildings.

HVAC-T5-14 Carry out air-conditioning load calculations on any approved Software.

T6: HVAC Equipment Selection

HVAC-T6: HVAC&R engineers should be able to select different equipment required to achieve the required condition of air in various spaces.

T6- Indicators

HVAC-T6-01 Demonstrate ability to select single-zone and multi-zone air handling units for a given HVAC load.

HVAC-T6-02 Demonstrate ability to select chillers for a central station cooling plant including their number and chiller capacity considering back-up and maintenance for system reliability.

HVAC-T6-03 Demonstrate ability to select control strategy for chilled water system.

HVAC-T6-04 Understand how energy recovery (sensible and total) systems work and how they affect the overall performance of an HVAC system.

HVAC-T6-05 Select suitable energy recovery (sensible and total) systems (Runaround coils or Enthalpy wheel between outside air and exhaust air).

HVAC-T6-06 Recognize different types of filters (Sand Trap, Coarse Filters, Fine Filters, HEPA Filters, Gaseous filters and their applications.

HVAC-T6-07 Understand how District cooling systems work and recognize their equipment.

HVAC-T6-08 Understand control strategies for multi chillers arrangement in parallel or in series.

HVAC-T6-09 Recognize the concept of common pipe for flow control of hydronic system.

T7: Air Distribution System Design

HVAC-T7: HVAC&R engineers should be able to design the air distribution system including determining air volume flow rates, duct system layout, duct sizing, determining pressure loses, and fan selection.

T7- Indicators

HVAC-T7-01 Recognize different air flow pattern for different applications.

HVAC-T7-02 Determine air volume flow rate required to carry space heat gain.

HVAC-T7-03 Sketch duct system to distribute air to different spaces and zones of a building.

HVAC-T7-04 Determine duct sizes and calculate pressure drop (including main and secondary losses and static regain) in the duct system.

HVAC-T7-05 Determine location of volume dampers in order to balance the network.

HVAC-T7-06 Select suitable room air distribution system and select supply air outlets (diffusers) and air return grilles.

HVAC-T7-07 Select suitable fan of the AHU for the duct systems based on volume flow rate and maximum pressure loss in duct system and estimate power required to operate it.

HVAC-T7-08 Understand different means of measurements of air volume flow rate in ducts and from diffusers and outlets.

HVAC-T7-09 identify the suitable instruments to measure dry bulb and wet bulb temperatures, dew point temperature and relative humidity.

HVAC-T7-10 Be familiar with testing and balancing the air conditioning system of a building considering ASHRAE standard 111.

HVAC-T7-11 Demonstrate the ability to diagnose and service air conditioning systems based on load calculations, equipment selection, and air duct flow.

T8: Chilled and Hot Water Piping Systems Design

HVAC-T8: HVAC&R engineers should be able to design chilled water and hot water piping systems for HVAC. This includes determining required water flow rates, piping layout, pipe sizing, determining pressure loses, and pump selection.

T8- Indicators

HVAC-T8-01 Be familiar with piping standards, fittings and symbols.

HVAC-T8-02 Be familiar with types of piping insulation and how to prepare piping external surface for insulation.

HVAC-T8-03 Recognize the necessity of expansion tank (open or closed types) in piping networks.

HVAC-T8-04 Recognize the importance of piping network flushing before starting and the necessity of chemical dosing during operation.

HVAC-T8-05 Recognize the necessity of balancing valves at network branches and devices.

HVAC-T8-06 Be familiar with using 3-way or 2-way valves with Air Handling Units and Fan/Coil Units.

HVAC-T8-07 Estimate major and minor pressure losses in single-pass and multi-path pipes, create piping system curve and estimate the energy and cost required to operate a piping system.

HVAC-T8-08 Be familiar with types of pumps commonly used in piping systems, pump H-Q curve and efficiency vs Q characteristics at different speeds.

HVAC-T8-09 Select a suitable pump for the piping system based on volume flow rate and maximum pressure loss in the system.

HVAC-T8-10 Recognize procedures for operating of different types of pumps including start up, planned shutdown and emergency shutdown.

HVAC-T8-11 Recognize methods to control flow in a pipeline, select appropriate valves and recognize how to avoid water hammer.

HVAC-T8-12 Understand how chilled/hot water flow rate in pipes are measured, using orifice, nozzle and Venturi meters.

T9: Sustainability of HVAC Systems

HVAC-T9: HVAC&R engineers should be able to make sure that Buildings and HVAC systems and equipment conform to energy efficiency and sustainability regulations and codes.

T9- Indicators

HVAC-T9-01 Be familiar with the common terms used in sustainability design such as green buildings, zero energy buildings, sustainable design, global warming, carbon emissions, energy star rating.

HVAC-T9-02 Be familiar with thermal characteristics of buildings and strategies for minimizing loads.

HVAC-T9-03 Ability to explore ways, and familiarity with techniques, to reduce the energy requirements such as natural ventilation, thermal-mass storage, radiant cooling and passive solar control.

HVAC-T9-04 Be familiar with computer-based energy analysis tools and understand how to create energy simulation model for the building.

HVAC-T9-05 Be familiar with energy efficiency codes, standards and labels used in Saudi Arabia.

HVAC-T9-06 Carry out engineering, economic and feasibility studies for solutions proposed to improve the energy efficiency in buildings, estimate payback period for proposed solutions, either by hand or by appropriate software such as Energy Plus.

HVAC-T9-07 Understand how to select, install and utilize appropriate equipment to measure energy consumption and efficiency in buildings.

HVAC-T9-08 Recognize the impact of energy efficiency measures on environmental aspects.

HVAC-T9-09 Be familiar with how to measure actual cooling capacity of a chiller from chilled water flow rate and temperature difference.

HVAC-T9-10 Determine COP and kW per Ton Refrigeration of a chiller plant and compare with recognized values for efficient operation.

HVAC-T9-11 Determine the heat removal rate in the condenser from cooling water flow rate and temperature difference across the condenser.

HVAC-T9-12 Balance the cooling capacity of the chiller (cooler) plus the compressor power with the heat removal rate in the condenser.

HVAC-T9-13 Determine the heat rejection ratio and compare with what is expected under the same operating conditions.

HVAC-T9-14 Compare actual cycle obtained from refrigerant pressure and temperature measurements at various points in the system with the ideal cycle to find out if there are potential improvements.

HVAC-T9-15 Be familiar with the various renewable energy strategies and how to incorporate them whenever possible into the design.

T10: Ventilation

HVAC-T10: HVAC&R engineers should be able to determine the required or recommended ventilation rates for various applications and ensure that HVAC systems provide such ventilation rates.

T10- Indicators

HVAC-T10-01 Understand common contaminants in conditioned air, their source and acceptable levels.

HVAC-T10-02 Design air conditioning systems that provides outdoor air volumes that comply with ASHRAE standard 62.

HVAC-T10-03 Design pressurized air systems required for stair shafts and elevator wells to prevent spread of smoke in buildings.

HVAC-T10-04 Design ventilation systems for underground car parking garages, industrial installations, kitchens, bathrooms, labs, clean spaces and data processing spaces.

HVAC-T10-05 Recognize how to build up pressure inside a zone over nearby one.

HVAC-T10-06 Recognize how to create an Air Lock zone (hospital and Pharmaceutical Applications).

HVAC-T10-07 Recognize the value of using outdoor air control module in conjunction with Air-Handling units.

T11: Refrigeration Systems

HVAC-T11: HVAC&R engineers should understand how vapor-compression and absorption refrigeration systems operate and the function of their various components. Moreover, they should understand the merits and shortcomings of each of these systems and consequently would be able to select the most appropriate system in a given project considering the particulars/limitations of that project.

T11- Indicators

HVAC-T11-01 Understand the thermodynamics of the vapor-compression system (VCS) and its components.

HVAC-T11-02 Analyze performance of vapor compression cycles and estimate the refrigerating capacity, compressor power, coefficient of performance COP, and condensing capacity for the standard and real cycles.

HVAC-T11-03 Recognize the effect of evaporator and condenser temperatures on system performance.

HVAC-T11-04 Recognize the effect of refrigerant type on system performance.

HVAC-T11-05 Decide when a multi-pressure system is warranted, determine intermediate pressure, analyze the performance of these systems and estimate total refrigerating capacity, total compressor power, and coefficient of performance.

HVAC-T11-06 Recognize the effect of the type of refrigerant in deciding on the use of multistage compressor.

HVAC-T11-07 Interpret the data collected from measurement at various points in the system and estimate its real performance and analyze and interpret data collected to set up a maintenance plan.

HVAC-T11-08 Understand how the absorption systems work and the function of its components.

HVAC-T11-09 Determine Lithium-Bromide solution properties (p-t-x chart and h-t-x chart).

HVAC-T11-10 Carry out thermal analysis for absorption refrigeration systems, determine refrigerant or solution flow rates from mass balance on various system components, determine cooling capacity in evaporator, heat input in generator and system COP.

HVAC-T11-11 Check for the likelihood of crystallization and recognize how to mitigate its occurrence.

HVAC-T11-12 Recognize the use of waste heat or solar energy to operate absorption systems.

HVAC-T11-13 Compare the merits and shortcomings of Lithium Bromide absorption system vs. Ammonia absorption system vs. vapor-compression and be able to select the best system for a particular application.

T12: Refrigerants

HVAC-T12: HVAC&R engineers should know the differences between various categories of refrigerants (CFCs, HCFCs, HFCs and natural refrigerants. They should be familiar with the Montreal Protocol, phase out of CFCs and HCFCs, Ozone depletion potential and global warming potential of various refrigerants, and should be able to make the most suitable choice of a refrigerant for a given application considering safety, energy efficiency and regularity requirements.

T12- Indicators

HVAC-T12-01 Recognize different types of refrigerants and know refrigerant numbering system.

HVAC-T12-02 Recognize common refrigerants used in commercial applications and the outline for the accepted procedures for safe handling and disposal of these refrigerants.

HVAC-T12-03 Know the desired properties of refrigerants as related to thermal performance, safety (flammability, toxicity), interaction with piping materials, and miscibility with oil.

HVAC-T12-04 Understand merits of natural refrigerants and their shortcomings.

HVAC-T12-05 Understand merits of Halocarbons, and their shortcomings (ozone-depletion and/or global warming).

HVAC-T12-06 Be familiar with phase out schedule for CFCs and HCFCs.

HVAC-T12-07 Recognize some of the common new refrigerants and their merits and shortcomings.

HVAC-T12-08 Be familiar with Zeotropic and Azeotropic refrigerant blends.

HVAC-T12-09 Recognize hazards related to refrigerant leaks and procedure to withdraw refrigerants from refrigeration systems for maintenance or dismantle purpose.

T13: Refrigeration System Equipment

HVAC-T13: HVAC&R engineers should be able to specify the appropriate type of compressor, condenser and evaporator most suitable for a given application and ambient conditions.

T13- Indicators

HVAC-T13-01 Recognize different types of compressors used in HVAC and select the best compressor type for a given application.

HVAC-T13-02 Determine volumetric efficiency, flow rate and work of the reciprocating compressors.

HVAC-T13-03 Understand energy transfer in the impeller of the centrifugal compressor and energy transformation in diffuser.

HVAC-T13-04 Estimate tip speed and impeller diameter of a centrifugal compressor, recognize limits on tip speed and when it is necessary to use 2 stages instead of one stage.

HVAC-T13-05 Recognize how a screw compressor works, its efficiency range and the best range of cooling capacity for its application.

HVAC-T13-06 Recognize methods of capacity control of compressors.

HVAC-T13-07 Recognize the role of condensers in refrigeration systems and calculate required condensing capacity.

HVAC-T13-08 Understand the difference between air-cooled and water-cooled condensers.

HVAC-T13-09 Recognize when to select air-cooled condensers versus water-cooled condensers.

HVAC-T13-10 Estimate U-coefficient of condensers and determine the heat transfer area for both air-cooled and water-cooled condensers.

HVAC-T13-11 Recognize the role of the evaporator in a refrigeration system and calculate its required evaporating (refrigerating) capacity.

HVAC-T13-12 Recognize different types of evaporators used in refrigeration systems and recognize the differences between flooded and dry evaporator.

HVAC-T13-13 Recognize the effect of temperature difference between room and evaporator on the required RH and the evaporator size.

HVAC-T13-14 Recognize different types of expansion devices and their advantages and disadvantages and appropriate application for each type.

HVAC-T13-15 Recognize the evaporator starvation and flooding in relation to type and operation of expansion device.

HVAC-T13-16 Recognize the role of cooling towers in chiller plants and how they work.

HVAC-T13-17 Recognize different types of cooling towers and their components.

HVAC-T13-18 Recognize the definitions of approach and range, and cooling tower efficiency.

HVAC-T13-19 Estimate water consumption and blow down of a cooling tower.

T14: Cold Stores

HVAC-T14: HVAC&R engineers should be able to select appropriate design conditions, calculate the air-conditioning load (heat transmission through envelope, internal, ventilation and product loads) and select needed refrigeration system.

T14- Indicators

HVAC-T14-01 Understand "Outdoor design conditions" for load calculations and specify them for a particular cold store project.

HVAC-T14-02 Specify the "Indoor design conditions" for a particular cold store application based on ASHARE standards and divide the cold store to the required zones.

HVAC-T14-03 Understand Perishables storage (Normal Storage +5/0 C), pre-frozen storage (Deep Freezing -20 C), Freezing Tunnel (-30 to -40 C), Pre-cooling Tunnel (5 C).

HVAC-T14-04 Determine thermal insulation thickness needed in the external walls, floors and roofs and determine R-values of these elements based on their construction.

HVAC-T14-05 Estimate heat transmission through cold store envelope: composite walls, roofs, and ground employing proper mechanisms of heat transfer, and using the concept of the overall heat transfer coefficient (U) or thermal resistance (R-value) of building elements.

HVAC-T14-06 Estimate Internal heat gains from product, lighting and people and recognize different types of lighting and their relative energy efficiency recognizing their schedules.

HVAC-T14-07 Select refrigeration equipment for the cold store.

T15: Codes and Standards

HVAC-T15: HVAC&R engineers should be familiar with the following codes; SASO, SBC (Saudi Building Code) and ASHRAE. In particular, applicant should be aware of the following requirements in the Saudi standards/codes.

T15- Indicators

HVAC-T15-01 Be aware of the recommended R-value or U-coefficient for building walls and roofs (Saudi Building Code, SBC).

HVAC-T15-02 Be aware of the amount of fresh air (ventilation) required for various applications (ASHRAE 62 or equivalent).

HVAC-T15-03 Be aware of the minimum energy efficiency ratio (EER) for mini-split and window units, (SASO 2663).

HVAC-T15-04 Recognize the requirements for duct work: tightness, supports, materials etc. (SMACNA 006).

T16: HVAC Control Principles

HVAC-T16: HVAC&R engineers should be familiar with HVAC control Systems and how they work.

T16 - Indicators

HVAC-T16-01 Understand the principles of control of HVAC systems so that desired comfort and performance criteria are met.

HVAC-T16-02 Recognize the role of control set point, local loop and supervisory control.

HVAC-T16-03 Be able to identify main control strategies.

Useful Literatures:

- Saudi Building Code (SBC)
- SASO
- ASHRAE (Handbooks and Standards)

5. Sample Questions Table

Q. No.	Major Area	Code	Question Statement (Answer's Choices)	Key Answer	Expected Time (min.)	Supplied Reference
1	Introduction to HVAC	HVAC-T1-02 HVAC-T1-04	An air-cooled chiller is driven by a 3-phase motor draws 200 amps at voltage = 460 v with a power factor is 0.9. The actual coefficient of performance is 3. The input power and the cooling capacity are: A) 122.3 kW and 400 TR B) 143.4 kW and 122.3 TR C) 430.2 kW and 122.3 TR D) 200.2 kW and 143.3 TR	(B)	4.0 - 5.0	See Reference
2	Introduction to HVAC	HVAC-T1-02 HVAC-T1-03 HVAC-T1-05	If EER of a 2 TR mini-split unit is 8, the power input is approximately: A) 2 hp B) 3 hp C) 4 hp D) 5 hp	(C)	2.0 - 3.0	See Reference
3	Codes and Standards	HVAC-T15-03	A vendor is claiming that his mini-split unit can achieve EER=10 under T3 (46 °C ambient and 24 °C indoor). Does this achieve the Saudi Minimum Energy Performance Standard (MEPS)? And is the claim possible if air leaves the unit at 12 °C? A) Yes, and Yes B) No, and Yes C) No and No D) Yes and No	(A)	2.0 - 3.0	See Reference
4	Refrigerants	HVAC-T12-05 HVAC-T12-07	Arrange (Rank) the following refrigerants: R-11, Ammonia, R134a, R22, R12, CO_2, according to their ODP (Ozone Depletion Potential) starting from the most damaging to the least damaging. A) R11, R22, R12, Ammonia, R134a, CO_2 B) R11, R12, R22, R 134a, Ammonia, CO_2 C) R11, R134a, R22, Ammonia, R12, CO_2 D) R22, CO_2, R12, R134a, Ammonia, R11	(B)	1.0 – 2.0	None

Q. No.	Major Area	Code	Question Statement (Answer's Choices)	Key Answer	Expected Time (min.)	Supplied Reference
5	**Air Conditioning Processes**	HVAC-T4-02	Air is very dry in Riyadh. One method to humidify air is by adiabatic water spray. In this process: A) DBT increases while WBT stays roughly unchanged. B) DBT and WBT do not change. C) Relative humidity (RH) increases while DBT decreases. D) RH and enthalpy increase.	(C)	2.0 – 3.0	None
6	**Refrigeration Systems**	HVAC-T11-08 HVAC-T11-13	For an ice making plant, I will choose an Ammonia absorption system over a Lithium Bromide Absorption system because: A) The evaporating temperature must be below zero B) The ammonia system is more efficient C) The ammonia system is cheaper D) The evaporating pressure in the ammonia system is above atmospheric	(A)	1.0 – 2.0	None
7	**Air Conditioning Processes**	HVAC-T4-04	Air at atmospheric pressure, 27 °C dry-bulb temperature (DBT) and 50% relative humidity (RH), enters an air-conditioning unit at a rate of 3.5 m^3/s. The air leaves the unit at 13 °C DBT and 90% RH. Using properties from the psychrometric chart, the refrigerating capacity and the rate of moisture removal are found to be: A) 87 kW and 0.011 kg/s B) 98.48 kW and 0.11 kg/s C) 56.36 kW and 0.029 kg/s D) 87 kW and 0.029 kg/s.	(A)	6.0 – 7.0	See Reference
8	**Air Distribution System Design**	HVAC-T7-04	Air at 20 °C and near atmospheric pressure flows through a circular sheet-metal duct with a diameter of 400 mm and a length of 20 m under the effect of a pressure differential of 100 Pa. The air velocity and volume flow rate in the duct are approximately: A) 14 m/s and 1.7 m^3/s B) 20 m/s and 2.5 m^3/s C) 14 m/s and 1.0 m^3/s D) 5 m/s and 0.7 m^3/s	(A)	3.0 – 4.0	See Reference

Q. No.	Major Area	Code	Question Statement (Answer's Choices)	Key Answer	Expected Time (min.)	Supplied Reference
9	**Air Distribution System Design**	HVAC-T7-02	The total heat gain in a large hall in Riyadh is 15 TR. The room sensible heat factor is 0.7. Air is supplied at a temperature 10 °C below room temperature. Assuming that the specific volume and specific heat of air are 0.83 m^3/kg dry air and 1.0 kJ/kg.°C, the supply volume flow rate is approximately: A) 6 m^3/s B) 10 m^3/s C) 2 m^3/s D) 3 m^3/s	(D)	4	None
10	**HVAC Load Estimation**	HVAC-T5-04 HVAC-T5-07	A simple exterior wall (10 m wide and 3 m high) is made of 3 layers: 50 mm Concrete block outer layer, 75 mm polystyrene insulation and a 50 mm concrete block inner layer. The outside and inside air film coefficients are 17 W/m^2.C and 8.3 W/m^2.°C. The thermal conductivities (k) of concrete block and polystyrene are: 1.04 W/m.°C and .033 W/m.°C, respectively. The Cooling load temperature difference across the wall (CLTD) is 25 °C. The overall heat transfer coefficient (U-coefficient) and the transmission heat load are found under these conditions to be: A) 0.42 W/m^2. °C , 315 W B) 0.63 W/m^2. °C , 473 W C) 0.82 W/m^2. °C , 715 W D) 0.39 W/m^2. °C , 294 W	(D)	6.0 – 7.0	None
11	**Air-Conditioning Systems**	HVAC-T2-09	An evaporative cooler draws outdoor air in Riyadh at 42 °C DBT and 20 °C WBT. If the effectiveness of the cooler is 80%, the leaving air condition is: A) 24.4 °C DBT and 75% RH B) 28 °C DBT and 67 % RH C) 24.4 °C DBT and 67% RH D) 25 °C DBT and 67% RH	(C)	5.0 – 6.0	See Reference

Q. No.	Major Area	Code	Question Statement (Answer's Choices)	Key Answer	Expected Time (min.)	Supplied Reference
Essay 1	**Air Conditioning Systems**	HVAC-T2-01 HVAC-T2-02 HVAC-T2-03	A single zone central air conditioning system draws outdoor air in Riyadh at 44 °C DBT and 10% RH. Outdoor air is mixed with return air with a ratio of 1:1 on mass basis. The condition of air in the conditioned space is 24 °C and 50 % RH. Mixed air passes over a cooling coil where it undergoes sensible cooling only and leaves at 90% RH and enters the space at a rate of 6 kg/s. Assume the condition of the return air is the same as room air. Sketch the above processes on the psychrometric chart and calculate: A) The properties of the mixed air (h, DBT, w) B) The properties of the supply air (h, DBT, w) C) The cooling capacity of the coil in kW. D) The supply volume flow rate in l/s. E) The space cooling heat gain. F) The outdoor air load G) The room sensible heat factor	----	40 – 45	See Reference
Essay 2	**Refrigeration Systems**	HVAC-T11-01 HVAC-T11-02 HVAC-T11-07	Actual test measurements of a vapor-compression refrigeration system that uses R-134a as a refrigerant and employs a reciprocating compressor are as follow: - Evaporating and condensing temperatures are 0 °C and 40 °C, respectively. - The heat load (heat input) on the evaporator under equilibrium is 210 kW - The compressor input power is 52 kW. The compressor has 6 cylinders and each cylinder has a diameter of 120 mm and a stroke of 100 mm. The compressor has a percent clearance 4% and rotates at 1500 rpm. i. Calculate the mass flow rate of the refrigerant, ii. Calculate the clearance volumetric efficiency, iii. Find compressor displacement rate and hence calculate the actual volumetric efficiency, iv. Calculate the actual compressor work and its adiabatic efficiency v. Calculate the actual COP of the system and compare it to ideal cycle COP. vi. What are the reasons for the difference between actual and ideal COP?	----	40 – 45	See Reference

References

The following equations may be helpful in some problems.

Power = V x I x $\sqrt{3}$ x P.F

Where,

V: Voltage (volt)

I: Current (ampere)

P.F.: Power factor (--)

EER= Cooling capacity (Btu/hr) / Power (W)

Where,

EER: Energy Efficiency ratio

$\varepsilon = \{(DBT_1 - DBT_2) / (DBT_1 - WBT)\} \times 100$

Where,

ε: effectiveness (-)

DBT: Dry Bulb Temperature (°C)

WBT: Wet Bulb Temperature (°C)

$COP)_{Carnot} = T_L / (T_H - T_L)$

Where,

COP: Coefficient of Performance (--)

T_L: Low Temperature (K)

T_H: High Temperature (K)

Extracted Page from SASO2663/2017

SAUDI ARABIAN STANDARD SASO 2663/2017

4. MINIMUM ENERGY PERFORMANCE STANDARD (MEPS)

4.1 General

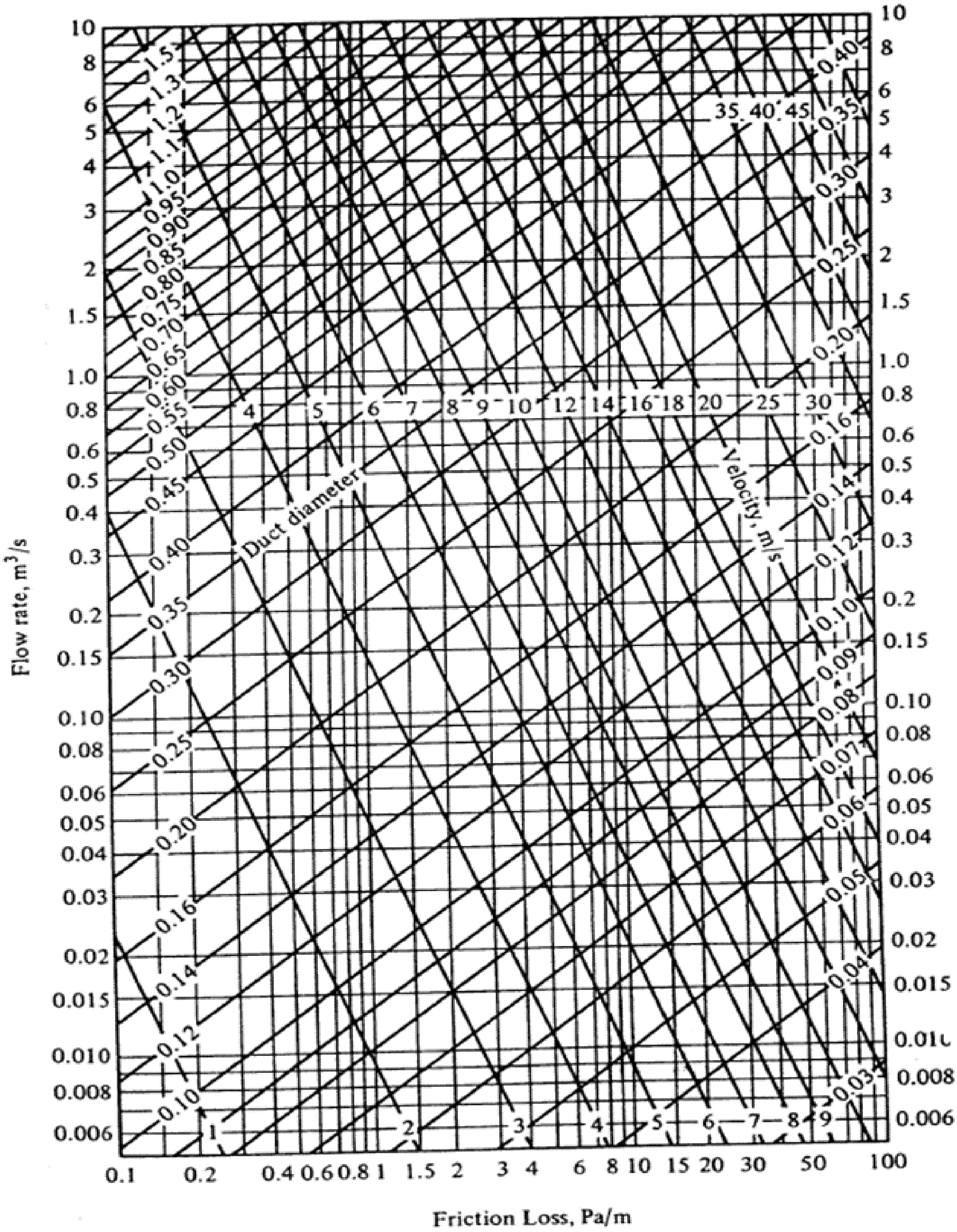
The value of the Energy Eficiency Ratio (EER) for the rated values, shall be greater than or equal to the minimum energy performance standard (MEPS) value for the air conditioners in the scope of this standard. MEPS are based on the rated cooling capacity for the rated EER at rating conditions (T1) and (T3), according to Table 1 and Table 2.

Table 1 – REFERENCE TESTING CONDITIONS FOR COOLING AND HEATING

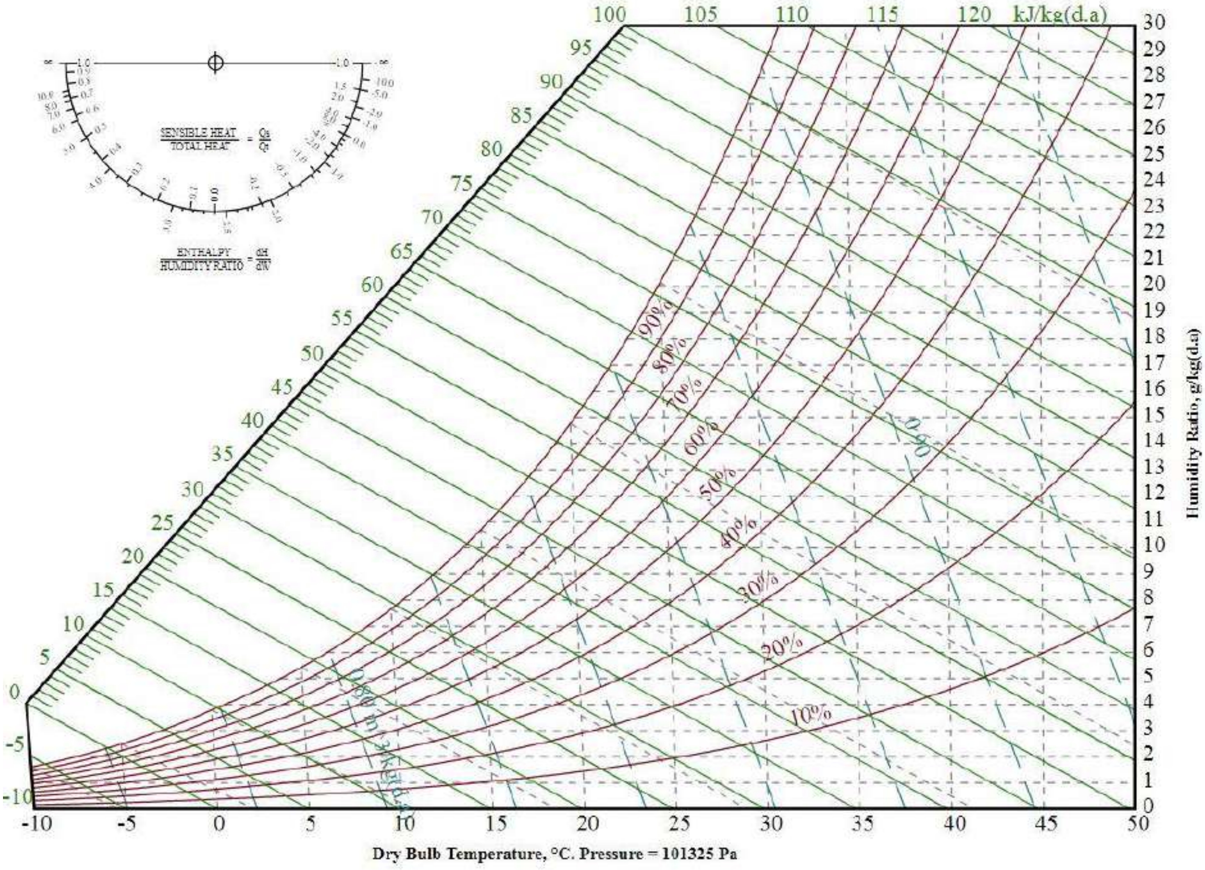
Testing conditions	Indoor section		Outdoor section	
	Dry-Bulb °C	Wet-Bulb °C	Dry-Bulb °C	Wet-Bulb °C
Temperature T_1	27.0	19.0	35.0	24.0
Temperature T_3	29.0	19.0	46.0	24.0
Temperature H_1	20.0	15.0	7.0	6.0

Table 2 – MINIMUM REQUIRED EER (MEPS) APPLICABLE

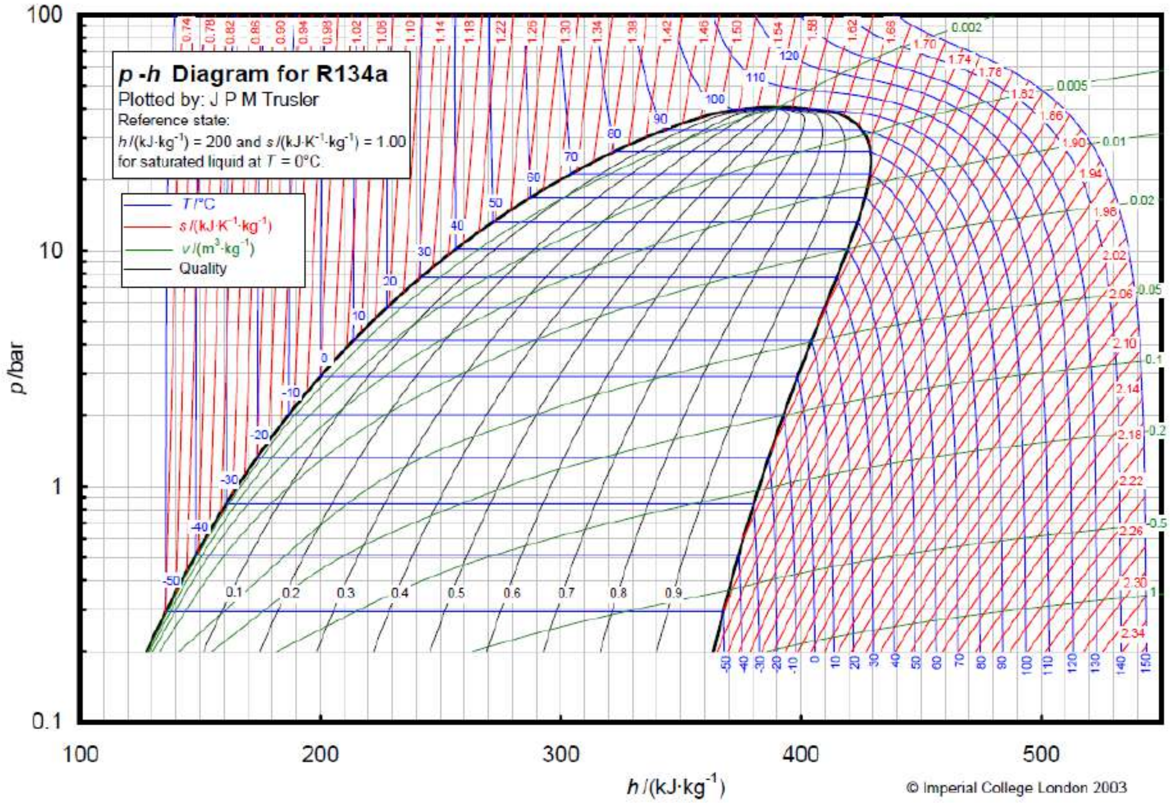
Air conditioner appliance type	Rated Cooling Capacity (CC) categories at test condition (T1) in Btu/h (or W)	EER Values (Btu/h)/W	
		T1	T3
Single package of Window type – category A	CC ≤ 24,000 (7,050W)	9.80	7.00
Single package of Window type – category B	24,000 (7,050W) < CC ≤ 65,000 (19,050 W)	9.00	6.20
Split type ducted and non-ducted using air-cooled condensers, heat pumps using air cooled condensers	CC ≤ 65,000 (19,050 W)	11.80	8.30


Flow rate, m³/s
Friction Loss, Pa/m
Duct diameter
Velocity, m/s
10
8
6
5
4
3
2
1.5
1.0
0.8
0.6
0.5
0.4
0.3
0.2
0.15
0.10
0.08
0.06
0.05
0.04
0.03
0.02
0.015
0.010
0.008
0.006
0.1
0.2
0.4
0.6
0.8
1
1.5
2
3
4
6
8
10
15
20
30
50
100
1
2
3
4
5
6
7
8
9
10
12
14
16
18
20
25
30
35
40
45
1.5
1.3
1.2
1.1
1.0
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.16
0.14
0.12
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03

Psychrometric Chart



P-h Chart for 134a



6. Solutions of Sample Questions

Multiple Choice Questions (MCQs)

Question # 1

Indicator HVAC-T1: HVAC engineers should be able to recognize and use special terminology, units, measurements and concepts that are particular to this specialization.

HVAC-T1-02: Recognize definition of HVAC, special units used in HVAC to measure cooling capacity (Ton Refrigeration, Btu/h, kW cooling) and their conversion factors, other units common in HVAC: GPM, Lit/Sec, cfm, Mt3/h, temperature Celsius (C), Fahrenheit (F).

HVAC-T1-04: Measure current and voltage of compressor motor and calculate its power consumption considering the power factor (phase angle).

Example on HVAC-T1-2 & 4:

An air-cooled chiller is driven by a 3-phase motor draws 200 amps at voltage = 460 v with a power factor is 0.9. The actual coefficient of performance is 3. The input power and the cooling capacity are:

A) 122.3 kW and 400 TR

B) 143.4 kW and 122.3 TR

C) 430.2 kW and 122.3 TR

D) 200.2 kW and 143.3 TR

Solution of example on HVAC-T1-2 & 4

The input power = V x I x $3^{0.5}$ x power factor

= 460x200x1.73x0.9= 143.4 kW

$COP)_{actual}$ = Cooling capacity (kW) / Power (kW)

3 = Cooling capacity / 143.4

Cooling capacity = 430.2 kW= 430.2/3.518= 122.3 TR

Answer: (B)

Question # 2

Indicator HVAC-T1: HVAC engineers should be able to recognize and use special terminology, units, measurements and concepts that are particular to this specialization.

HVAC-T1-02: Recognize definition of HVAC, special units used in HVAC to measure cooling capacity (Ton Refrigeration, Btu/h, kW cooling) and their conversion factors, other units common in HVAC: GPM, Lit/Sec, cfm, Mt3/h, temperature Celsius (C), Fahrenheit (F).

HVAC-T1-03: Recognize the difference between kW power and kW cooling or heating.

HVAC-T1-05: Recognize Energy Efficiency Ratio (EER) of HVAC equipment and how it is related to Coefficient of Performance (COP), Performance Factor (PF).

Example on HVAC-T1-02 & 03 & 05:

If EER of a 2 TR mini-split unit is 8, the power input is approximately:

A) 2 hp

B) 3 hp

C) 4 hp

D) 5 hp

Solution of example on HVAC-T1-02, 03 & 05:

EER= Cooling capacity (Btu/hr) / Power (W)

Power = 2 x 12000 / 8 = 3000 W = 3 kW

1 hp = 0.746 kW

Power = 3/.746 = 4.02 hp

Answer: (C)

Question # 3

Indicator HVAC-T15: **Codes and Standards,** HVAC engineers should be familiar with the following codes; SASO, SBC (Saudi Building Code) and ASHRAE. In particular, applicant should be aware of the requirements in the Saudi standards/codes.

HVAC-T15-03: The minimum energy efficiency ratio for mini-split and window units, (SASO 2663).

Example on HVAC-T15-03:

A vendor is claiming that his mini-split unit can achieve EER=10 under T3 (46 ^{o}C ambient and 24 ^{o}C indoor). Does this achieve the Saudi Minimum Energy Performance Standard (MEPS)? And is the claim possible if air leaves the unit at 12 ^{o}C?

A) Yes, and Yes

B) No, and Yes

C) No and No

D) Yes and NO

Solution of example on HVAC-T15-03:

MEPS for split units under T3 test conditions per SASO 2663 (2017): Energy Labeling and Minimum Energy Performance Requirements for Air-Conditioners is EER= 8.3 minimum. So the answer to this part is YES, unit achieves minimum requirements.

$COP)_{Carnot} = T_L / (T_H - T_L)$ = (12+273) / (46-9) = 8.38 assuming 5^{o}C temperature differentials.

$EER)_{Carnot}$ = 8.38 x 3.412 = 28.6

Since reported EER is less $EER)_{Carnot}$, then YES the claim is possible.

Answer: (A)

Question # 4

Indicator HVAC-T12: **Refrigerants,** HVAC engineers should know the differences between various categories of refrigerants (CFCs, HCFCs, HFCs and natural refrigerants). They should be familiar with the Montreal Protocol, phase out of CFCs and HCFCs, Ozone depletion potential and global warming potential of various refrigerants, and should be able to make the most suitable choice of a refrigerant for a given application considering safety, energy efficiency and regularity requirements.

HVAC-T12-05: Understand merits of Halocarbons, and their shortcomings (ozone-depletion and/or global warming).

HVAC-T12-07: Recognize some of the common new refrigerants and their merits and shortcomings.

Example on HVAC-T12-05 & 07:

Arrange (Rank) the following refrigerants: R-11, Ammonia, R134a, R22, R12, CO_2, according to their ODP (Ozone Depletion Potential) starting from the most damaging to the least damaging.

A) R11, R22, R12, Ammonia, R134a, CO_2

B) R11, R12, R22, R 134a, Ammonia, CO_2

C) R11, R134a, R22, Ammonia, R12, CO_2

D) R22, CO_2, R12, R134a, Ammonia, R11

Solution of example on HVAC-T12-05 and 07

R-11 and R-12 are the most damaging to the ozone layer (highest number of chlorine atoms in their molecules) with ODP=1, R-22 comes next with much less damage. These three are followed by R 134a, Ammonia and CO_2, which do not cause any damage to the ozone layer (ODP=0).

Answer: (B)

Question # 5

Indicator HVAC-T4: Air Conditioning Processes, HVAC engineers should be able to select the appropriate air conditioning processes to achieve required indoor conditions. Also they should be able to represent these processes on the psychrometric chart and do the necessary calculations.

HVAC-T4-02: Understand various simple air-conditioning processes including sensible cooling, sensible heating, humidification by water spray and by steam injection, dehumidification by cooling, by absorbing salts and by mixing fresh and return air.

Example on HVAC-T4-02:

Air is very dry in Riyadh. One method to humidify air is by adiabatic water spray. In this process:

A) DBT increases while WBT stays roughly unchanged

B) DBT and WBT do not change

C) Relative humidity (RH) increases while DBT decreases

D) RH and enthalpy increase

Solution of example on HVAC-T4-02

The enthalpy (and therefore the wet bulb temperature) stay constant during spraying water into the air since there is no external heat transfer. The sensible heat content of air drops to compensate for increasing latent heat content in the form of increased moisture in the air. Thus DBT drops and RH increases.

Answer: (C)

Question # 6

Indicator HVAC-T11: **Refrigeration Systems,** HVAC engineers should understand how vapor-compression and absorption refrigeration systems operate and the function of their various components. Moreover, they should understand the merits and shortcomings of each of these systems and consequently would be able to select the most appropriate system in a given project considering the particulars/limitations of that project.

HVAC-T11-08: Understand how the absorption systems work and the function of its components.

HVAC-T11-13: Compare the merits and shortcomings of Lithium Bromide absorption system vs. Ammonia absorption system vs. vapor-compression and be able to select the best system for a particular application.

Example on HVAC-T11-08 & 13:

For an ice making plant, I will choose an Ammonia absorption system over a Lithium-Bromide absorption system because:

A) The evaporating temperature must be below zero

B) The ammonia system is more efficient

C) The ammonia system is cheaper

D) The evaporating pressure in the ammonia system is above atmospheric

Solution of example on HVAC-T11-08 & 13

The Lithium Bromide system cannot achieve ZERO cooling temperature because it uses water as the refrigerant, while the Ammonia system can achieve cooling temperatures below ZERO, which is necessary for making ice.

Answer: (A)

Question # 7

Indicator HVAC-T4: Air Conditioning Processes, HVAC engineers should be able to select the appropriate air conditioning processes to achieve required indoor conditions. Also, they should be able to represent these processes on the psychrometric chart and do the necessary calculations.

HVAC-T4-04: Represent the above processes on the psychrometric chart and be able to do simple calculations for these processes for summer air conditioning in dry and humid regions as well as for winter air conditioning.

Example on HVAC-T4-04:

Air at atmospheric pressure, 27 ºC dry-bulb temperature (DBT) and 50% relative humidity (RH), enters an air-conditioning unit at a rate of 3.5 m3/s. The air leaves the unit at 13 ºC DBT and 90% RH. Using properties from the psychrometric chart, the refrigerating capacity and the rate of moisture removal are found to be:

A) 87 kW and 0.011 kg/s

B) 98.48 kW and 0.11 kg/s

C) 56.36 kW and 0.029 kg/s

D) 87 kW and 0.029 kg/s

Solution of HVAC-T4-04:

From the psychrometric chart: v_1= 0.865 m^3/kg dry air,

h_1= 55.5 kJ/kg dry air, w_1= 0.011 kg vapor/kg dry air

h_2 = 34 kJ/kg dry air, w_2= 0.0083 kg vapor/kg dry air

m_a= 3.5/0.865 = 4.05 kg dry air/s

Q= 4.05 x (55.5-34) = 87 kW

$m_{condensate}$ = 4.05 x (0.011-.0083) = 0.011 kg/s of water

Answer: (A)

Question # 8

Indicator HVAC-T7: **Air Distribution System Design,** HVAC engineers should be able to design the air distribution system including determining air volume flow rates, duct system layout, duct sizing, determining pressure loses, and fan selection.

HVAC-T7-03 & 04: Sketch duct system to distribute air to different spaces and zones of a building and determine duct sizes as well as pressure losses in the duct system.

Example HVAC-T7-03 & 04:

Air at 20 ºC and near atmospheric pressure flows through a circular sheet-metal duct with a diameter of 400 mm and a length of 20 m under the effect of a pressure differential of 100 Pa. The air velocity and volume flow rate in the duct are approximately:

A) 14 m/s and 1.7 m^3/s

B) 20 m/s and 2.5 m^3/s

C) 14 m/s and 1.0 m^3/s

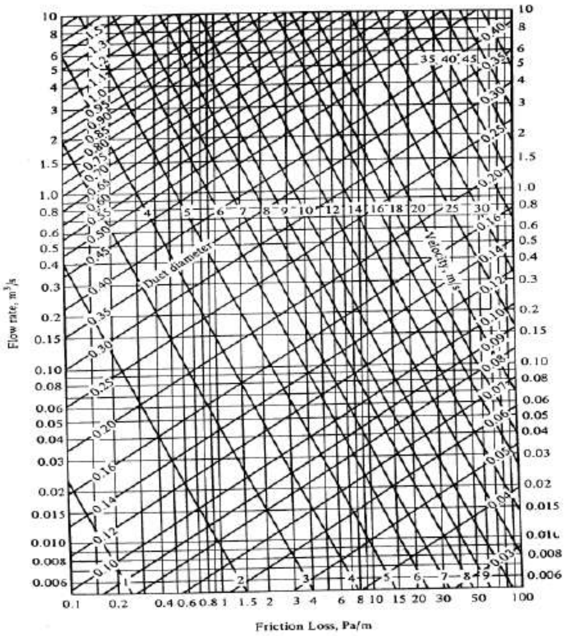
D) 5 m/s and 0.7 m^3/s

Solution of example on HVAC-T7-03 & 04:

$\Delta p / L = 100 / 20 = 5$ Pa/m

Enter the chart below at $\Delta p / L = 5$ Pa/m and D= 0.4 m, we get V= 14 m/s,

and flow rate = 1.7 m^3/s



Answer: (A)

Question # 9

Indicator HVAC-T7: **Air Distribution System Design,** HVAC engineers should be able to design the air distribution system including determining air volume flow rates, duct system layout, duct sizing, determining pressure loses, and fan selection.

HVAC- T7-02: Determine air volume flow rate required to carry space heat gain.

Example HVAC-T7-02:

The total heat gain in a large hall in Riyadh is 15 TR. The room sensible heat factor is 0.7. Air is supplied at a temperature 10 ºC below room temperature. Assuming that the specific volume and specific heat of air are 0.83 m^3/kg dry air and 1.0 kJ/kg.ºC, the supply volume flow rate is approximately:

A) 6 m^3/s

B) 10 m^3/s

C) 2 m^3/s

D) 3 m^3/s

Solution HVAC-T7-02:

Sensible gain q_s= 0.7 x 15= 10.5 TR= 10.5 x 3.518 = 36.94 kW

$= m_a C_{p,a} (\Delta t) = m_a 1.0 (10) = 36.94$

m_a = 3.694 kg dry air / s

Supply volume flow rate = 3.694 x 0.83 = 3.07 m^3/s

Answer: (D)

Question # 10

Indicator HVAC-T5: **HVAC Load Estimation,** HVAC engineers should be able to calculate the air-conditioning (thermal) load in a building manually or by using computer software such as Energy Plus, HAP or equivalent. Load calculation involves calculating heat gain through building envelope, solar heat gain, internal heat gain (lighting, people and equipment) and heat gain due outdoor air (ventilation/infiltration).

HVAC-T5-04: Demonstrate the ability to estimate walls, roofs and windows properties such as U-coefficients or and R-values based on the building construction plans set by the architect.

HVAC-T5-07: Estimate heat transmission through building envelope (composite walls, roofs, windows, and ground) employing proper mechanisms of heat transfer, and using the concept of the overall heat transfer coefficient (U) or thermal resistance (R-value) and the cooling load temperature difference (CLTD) of building elements.

Example on HVAC-T5-04 & 07:

A simple exterior wall (10 m wide and 3 m high) is made of 3 layers: 50 mm Concrete block outer layer, 75 mm polystyrene insulation and a 50 mm concrete block inner layer. The outside and inside air film coefficients are 17 $W/m^2.C$ and 8.3 $W/m^2.^oC$. The thermal conductivities (k) of concrete block and polystyrene are: 1.04 $W/m.^oC$ and .033 $W/m.^oC$, respectively. The Cooling load temperature difference across the wall (CLTD) is 25 ^oC. The overall heat transfer coefficient (U-coefficient) and the transmission heat load are found under these conditions to be:

A) 0.42 $W/m^2.\ ^oC$, 315 W

B) 0.63 $W/m^2.\ ^oC$, 473 W

C) 0.82 $W/m^2.\ ^oC$, 715 W

D) 0.39 $W/m^2.\ ^oC$, 294 W

Solution of HVAC-T5-04 & 07:

The total resistance is the sum of the resistances of all layers. Thus,

$R_{total} = 1/17.0 + .05/1.04 + 0.075/0.033 + .05/1.04 + 1/8.3 = 2.548\ m^2.C / W$

U coefficient = $1/ R_{total} = 0.392\ W/ m^2.C$

Q = U x A x CLTD

= 0.392 x (10x3) x (25) = 294.3 W

Answer: (D)

Question # 11

Indicator HVAC-T2: **Air Conditioning Systems,** HVAC engineers should be able to understand how different air conditioning systems work, the advantages, disadvantages and the architectural requirements of each system. Also the engineer should be able to select the most appropriate system for a given application (project).

HVAC-T2-09: Understand how Evaporative Coolers (single-stage and two-stage) work, their advantages, disadvantages and limitations as well as their merits.

Example on HVAC-T2-09:

An evaporative cooler draws outdoor air in Riyadh at 42 ^oC DBT and 20 ^oC WBT. If the effectiveness of the cooler is 80%, the leaving air condition is:

A) 24.4 ^oC DBT and 75% RH

B) 28 ^oC DBT and 67 % RH

C) 24.4 ^oC DBT and 67% RH

D) 25 ^oC DBT and 67% RH

Solution of HVAC-T2-09:

Effectiveness= $\{(DBT_1 – DBT_2) / (DBT_1 – WBT)\} \times 100$

$80= \{(42 – DBT_2) / (42 – 20)\} \times 100$

$DBT_2 = 24.4\ ^oC$

By locating point (2) on the psychrometric chart at DBT= 24.4 ^oC and WBT= 20 ^oC, we get

$RH_2 = 67\ \%$

Answer: (C)

Essay Question

Essay Question # 1

Indicator HVAC-T2: Air Conditioning Systems (HVAC-2-02)

Indicator HVAC-T4: Air Conditioning Processes (HVAC-T4-01, 02, 03 & 04)

A single zone central air conditioning system draws outdoor air in Riyadh at 44 ºC DBT and 10% RH. Outdoor air is mixed with return air with a ratio of 1:1 on mass basis. The condition of air in the conditioned space is 24 ºC and 50 % RH. Mixed air passes over a cooling coil where it undergoes sensible cooling only and leaves at 90% RH and enters the space at a rate of 6 kg/s. Assume the condition of the return air is the same as room air.

Sketch the above processes on the psychrometric chart and calculate:

A) The properties of the mixed air (h, DBT, w)

B) The properties of the supply air (h, DBT, w)

C) The cooling capacity of the coil in kW.

D) The supply volume flow rate in l/s.

E) The space cooling heat gain.

F) The outdoor air load

G) The room sensible heat factor

Answer of Essay Question 1.

a. Using the psychrometric chart:

Locate outdoor air condition "1" and room air condition "2" on the chart. Connect the points "1" and "2" and locate the condition of mixed air "3" at midpoint. Read the properties from the chart:

h_3= 54 kJ/kg, t_{db3}= 34 C, w_3= 0.0072 kg vapor/kg dry air

Since cooling is completely sensible, draw a horizontal line from point "3" to the left until it intersects with the 90% humidity line at point "4". This is the condition after the coil. Read the properties at this point: h_4 = 30.5 kJ/kg dry air, t_{db4}= 11.5 C, w_4= 0.0073 kg vapor/kg dry air

b. The cooling capacity of the coil= m_a x C_p x (t_{db3}-t_{db4})

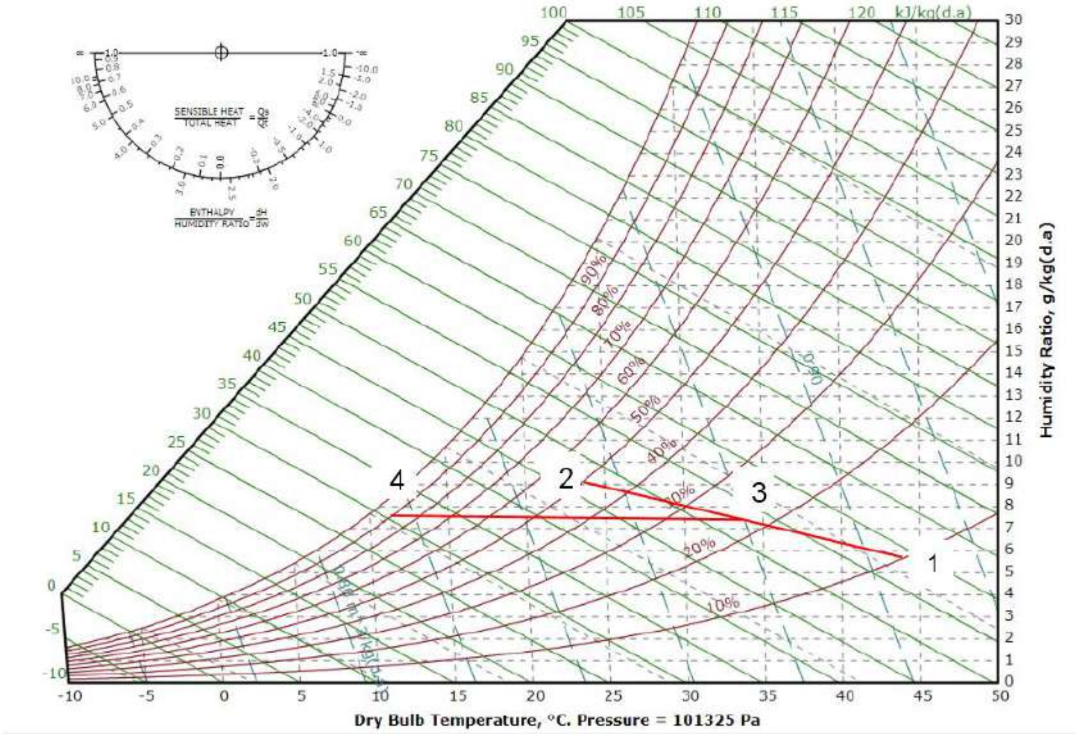
Q_{coil} = 6 x 1.0 x (34. -11.5) = 135 kW

c. Volumetric supply rate = m_a x v_4= 6x0.817 = 4.9 m^3/s

d. Space heat gain = m_a x (h_{db2}-h_{db4}) = 6x (47.5-30.5) = 102 kW

e. Outdoor air load = $Q_{coil} - Q_{room}$ = 135-102= 33 kW

f. Room SHF= $Q_s / Q_{total} = C_p (t_{db2}-t_{db4}) / (h_{db2}-h_{db4})$ = 1x (24-11.5) / (47.5-30.5) = 0.735



Essay Question # 2

Indicator HVAC-T11: Refrigeration Systems (HVAC-T11-01, HVAC-T11-02, HVAC-T11-07)

Actual test measurements of a vapor-compression refrigeration system that uses R-134a as a refrigerant and employs a reciprocating compressor are as follow:

- Evaporating and condensing temperatures are 0 oC and 40 oC, respectively.
- The heat load (heat input) on the evaporator under equilibrium is 210 kW
- The compressor input power is 52 kW.

The compressor has 6 cylinders and each cylinder has a diameter of 120 mm and a stroke of 100 mm. The compressor has a percent clearance 4% and rotates at 1500 rpm.

i. Calculate the mass flow rate of the refrigerant,

ii. Calculate the clearance volumetric efficiency,

iii. Find compressor displacement rate and hence calculate the actual volumetric efficiency,

iv. Calculate the actual compressor work and its adiabatic efficiency

v. Calculate the actual COP of the system and compare it to ideal cycle COP.

vi. What are the reasons for the difference between actual and ideal COP?

Answer Essay Question 2; HVAC-T11:

First we obtain properties for the ideal vapor compression cycle from the p-h chart for R-134a. Please note that state "1" represents evaporator exit / compressor suction; state "2" represents compressor discharge / condenser inlet; state "3" represents condenser exit / expansion valve inlet and state "4" represents valve exit / evaporator inlet.

h1 = 250.5 kJ/kg h2 = 276.3 kJ/kg h3 = h4=108.3 kJ/kg

v1= 0.069 m^3/kg, v2i= 0.021 m^3/kg

i. qe = h1-h4= 142.2 kJ/kg

m= LOAD / qe = 210 / 142.2 = 1.477 kg/s

ii. Eta_c= 100 – 4 (v1/v2i-1) %

= 100 – 4 (.069/.021-1) = 90.55 %

iii. DR= π/4 D^2 L N z = π/4 $(0.12)^2$ x 0.1 x 1500/60 x 6

= 0.1696 m^3/s

V_{suv}= m x v1 = 1.477x 0.069 = 0.10228 m^3/s

Eta_a= 0.10228/0.1696= 0.6= 60%

iv. $wc_a = W/me = 52/1.477 = 35.2$ kJ/kg

$wc_i = h2_i - h1 = 25.8$ kJ/kg

$\eta c = wc_i/wc_a = 25.8/35.2 = 73.3$ %

v. $COP_a = LOAD/POWER = 210/52 = 4.04$

$COP_i = qe/wc_i = 142.2/25.8 = 5.51$

vi. Reasons for the Difference:

- pressure drops in condenser and evaporator
- compression process is approximately adiabatic but not reversible or non-isentropic, (needs more power than ideal process)
- Actual volumetric efficiency of compressor is less than clearance volumetric efficiency
- Possibility of slight superheat at evaporator exit (at compressor suction)

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