HVAC & Refrigeration

Mechanical PE

Exam Textbook

April 2021 Exam Edition
Updated for Latest CBT Exam

Learn the key concepts and skills necessary to pass the PE Exam

Engineering Pro Guides

by **Justin Kauwale, P.E.**

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HVAC & Refrigeration Textbook

How to pass the PE exam

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1 - Introduction

How to Study for and Pass the PE Exam

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Section 1.0 - Introduction

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1.0 INTRODUCTION

One of the most important steps in an engineer's career is obtaining the professional engineering (P.E.) license. It allows an individual to legally practice engineering in the state of licensure. This credential can also help to obtain higher compensation and develop a credible reputation. In order to obtain a P.E. license, the engineer must first meet the qualifications as required by the state of licensure, including minimum experience, references and the passing of the National Council of Examiners for Engineering and Surveying (NCEES) exam. Engineering Pro Guides focuses on helping engineers pass the NCEES exam through the use of free content on the website, http://www.engproguides.com and through the creation of books like sample exams and guides that outline how to pass the PE exam.

The key to passing the PE exam is to learn the key concepts and skills that are tested on the exam. There are several issues that make this key very difficult. First, the key concepts and skills are unknown to most engineers studying for the exam. Second, the key concepts and skills are not contained in a single document. This technical guide teaches you the key concepts and skills required to pass the Mechanical - HVAC & Refrigeration Mechanical P.E. Exam in a single document.

1.1 KEY CONCEPTS AND SKILLS

How are the key concepts and skills determined?

The key concepts and skills tested in the sample exams and taught in this technical study guide were first developed through an analysis of the topics and information presented by NCEES. NCEES indicates on their website that the P.E. Exam will cover an AM exam (4 hours) followed by a PM exam (4 hours) and that the exam will be 80 questions long, 40 questions in the morning and 40 questions in the afternoon. The HVAC & Refrigeration Mechanical PE exam will focus on the following topics as indicated by NCEES. (http://ncees.org/engineering/pe/):

A) Principles

1 **Basic Engineering Practice - *(4-6 questions)***
    i) Units and conversions
    ii) Economic analysis
    iii) Electrical concepts (e.g., power consumption, motor ratings, heat output, amperage)
2 **Thermodynamics - *(4-6 questions)***
    i) *Cycles*
    ii) *Properties*
    iii) *Compression Processes*
3 **Psychrometrics - *(7-11 questions)***
    i) *Heating/cooling cycles, humidification/dehumidification, heating/cooling loads, sea level and other elevations*
4 **Heat Transfer - *(6-9 questions)***
5 **Fluid Mechanics - *(3-5 questions)***
6 **Energy/Mass Balances *(4-6 questions)***

B) Applications

1 **Heating/Cooling Loads - *(7-11 questions)***
2 **Equipment and Components - *(16-24 questions)***
    i) *Cooling towers and fluid coolers*
    ii) *Boilers and furnaces*
    iii) *Heat exchangers*
    iv) *Condensers/evaporators*
    v) *Pumps/compressors/fans*
    vi) *Cooling/heating coils*
    vii) *Control systems components*
    viii) *Refrigerants*
    ix) *Refrigeration components*
3 **Systems - *(16-24 questions)***
    i) *Air distribution*
    ii) *fluid distribution*
    iii) *refrigeration*
    iv) *energy recovery*
    v) *control concepts*
4 **Supportive Knowledge - *(3-5 questions)***
    i) *Codes and standards*
    ii) *Air quality and ventilation*
    iii) *Vibration control*
    iv) *Acoustics, economic analysis, electrical concepts*

Each of these broad topics were investigated and filtered for concepts and skills that met the following criteria:

(1) First, the concept and skill must be commonly used in the HVAC & Refrigeration field. For example, the Fluid Mechanics topic includes skills (e.g., determining the force on a surface due to a jet and the siphon concept), that are *not* used in the HVAC & Refrigeration field. In comparison, pump and fan sizing, determining friction losses and calculating net positive suction head *are* regular occurrences in the HVAC & Refrigeration field.

(2) Second, the skill and concept must be testable in roughly 6 minutes per problem. There are (40) questions on the HVAC & Refrigeration afternoon exam and you will be provided with 4 hours to complete the exam. This results in an average of 6 minutes per problem. This criterion limits the complexity of the exam problems and the resulting solutions. For example, pressure drop calculations are common in the HVAC & Refrigeration field, but the calculation is often very lengthy because of the number of steps involved, especially if a unique fluid and flow condition is used. Thus, common fluids like water/air and common pipe/duct materials are used.

(3) Third, the key concept and skill must be used by practicing HVAC & Refrigeration engineers. This criterion is similar to the first criterion. However, this criterion filters the concepts and skills further by limiting the field to material encountered and used by practicing engineers. The HVAC & Refrigeration field is vast and there are many different avenues an engineer can take. Two diverging paths are those engineers involved in research and those who practice. Research engineers are pushing the boundaries of the field and are highly focused in their specific area of the field. The Professional Engineering exam does not cover innovative material or highly focused material.

(4) The P.E. Exam must test the application of the skill and concept and not the background knowledge of the topic or concept. The exam also does not cover background information on the NCEES topics. The P.E. Exam is meant to prove that the test taker is minimally competent to practice in the HVAC & Refrigeration field. The exam is less concerned with theory and more with the application of the theory, skill or concept. For example, the P.E. exam is less concerned with the theory of evaporation in a cooling tower and more with the performance and selection of a cooling tower.

In summary, this book is intended to teach the necessary skills and concepts to develop a minimally competent, practicing professional engineer in the HVAC & Refrigeration field, capable of passing the P.E. exam. This book and the sample exam do this through the following means:

(1) Teaching commonly used skills and concepts in the HVAC & Refrigeration field.

(2) Providing sample problems that can be completed in roughly 6 minutes per problem.

(3) Teaching skills and concepts used by practicing HVAC & Refrigeration engineers.

(4) Teaching the application of the skill and concept.

1.2 UNITS

The primary units that are used in the P.E. Exam are United States Customary System Units (USCS). As such, this guide focuses exclusively on the USCS. However, it is recommended that the test taker have a conversion book, because certain areas of the P.E. Exam may use the International System of Units (SI).

1.3 COMPUTER BASED TEST (CBT)

As of April 2020, the exam will be converted from the paper-pencil/scantron testing method to a computer based platform. This allows the test to be offered year round instead of twice per year. This also means you will not have the same set of the questions as the next person. The style of the testing interface will be very similar to the fundamentals of engineering (FE) exam that is also administered by NCEES. If you have gone through the computer based version of the FE exam, you should be familiar with the format. The main difference is the number and difficulty of

2 - Basic Engineering Practice

Units and Conversions | Economic Analysis | Electrical Concepts

STUDY GUIDE
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Section 2.0 – Basic Engineering Practice

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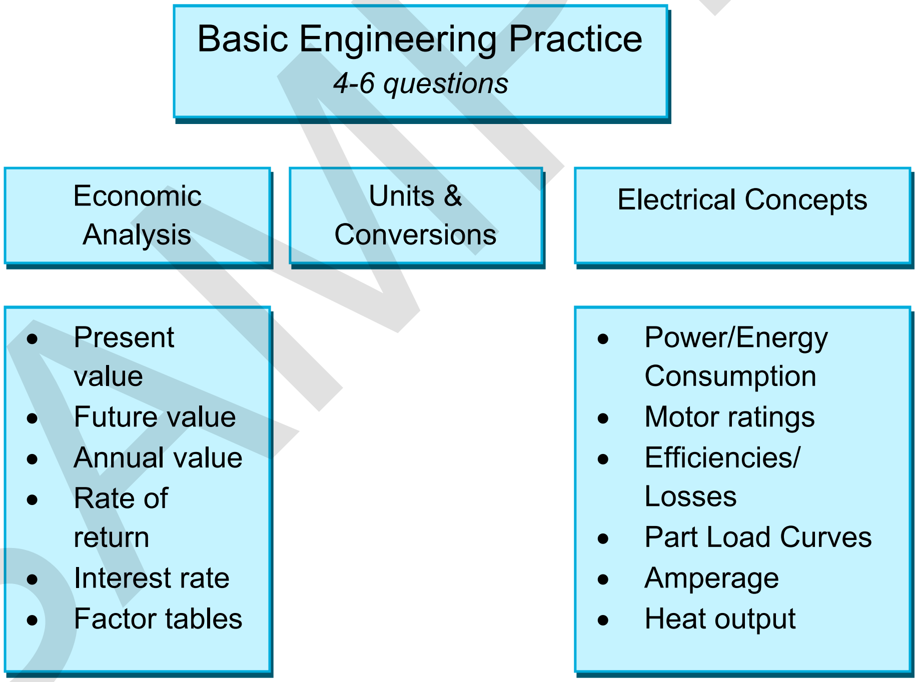
1.0 INTRODUCTION

Basic Engineering Practice accounts for approximately 4-6 questions on the HVAC & Refrigeration Mechanical PE exam.

The HVAC & Refrigeration Mechanical PE exam is designed to ensure that a passing engineer is minimally competent to practice engineering. Being minimally competent does include understanding engineering unit conversions, performing basic economic analyses, and understanding electrical concepts that are required for supporting mechanical equipment. However, many of these tasks can be completed without an engineering background and thus the PE exam should provide questions that are more complex than just questions in one of these topics. The questions may include an economic analysis but also with thermodynamics. It may include power consumption and integrate fluids first to size a pump or fan. You may also have to complete an energy-mass balance problem and convert units to match the selected answers.

Based on the above reasoning, you should focus your studying on other sections of this book, with the exception of the *Economic Analysis* section. The skills learned in the Economic Analysis and Electrical Concepts sections are necessary of a HVAC engineer.



2.0 ECONOMIC ANALYSIS

As a professional engineer, you will be tasked with determining the course of action for a design. Often times this will entail choosing one alternative instead of several other design alternatives. *Engineers need to be able to present engineering economic analysis to their clients in order to justify why a certain alternative is more financially sound than another.* The following sub-sections will present the engineering economic concepts that should be understood by the engineer for the PE exam and does not present a comprehensive look into the study of engineering economics.

2.1 INTEREST RATE & TIME VALUE OF MONEY

Before discussing interest rates, it is important that the engineer understands that money today is worth more than money in the future. This is the concept of "time value of money." For example, if you were given the option to have $1,000 today or to have $1,000 10 years from now, you should choose $1,000 today. Why is that? The reason $1,000 today is worth more is because of what you could have done with that money now. In the financial world this is the amount of interest you could have earned with that money. If you took $1,000 today and invested it at 4% per year, you would have $1,040 dollars at the end of the first year.

$$\$1{,}000 * (1 + .04) = \$1{,}040$$

- If you kept the $1,040 in the investment for another year, then you would have $1,081.60.

$$\$1{,}040 * (1 + .04) = \$1{,}081.60$$

- At the end of the 10 years the investment would have earned, $1,480.24.

$$\$1{,}000 * (1 + .04) * (1.04) * (1.04) \ldots\ldots = \$1{,}000 * (1.04)^{10} = \$1{,}480.24$$

  This means $1,000 today is worth $1,480.24 ten years from now, assuming a yearly interest rate of 4%.

- An important formula to remember is the Future Value (FV) is equal to the Present Value (PV) multiplied by (1 + interest rate, i), raised to the number of years, n.

$$PV * (1 + i)^n = FV$$

- As an example, what would be the present value of $1,000, 10 years from now, if the interest rate is 4%?

$$PV * (1 + .04)^{10} = \$1{,}000$$

$$PV = \$675.46$$

- Thus in the previous example, receiving $1,000, 10 years from now, is only worth $675.46 today.

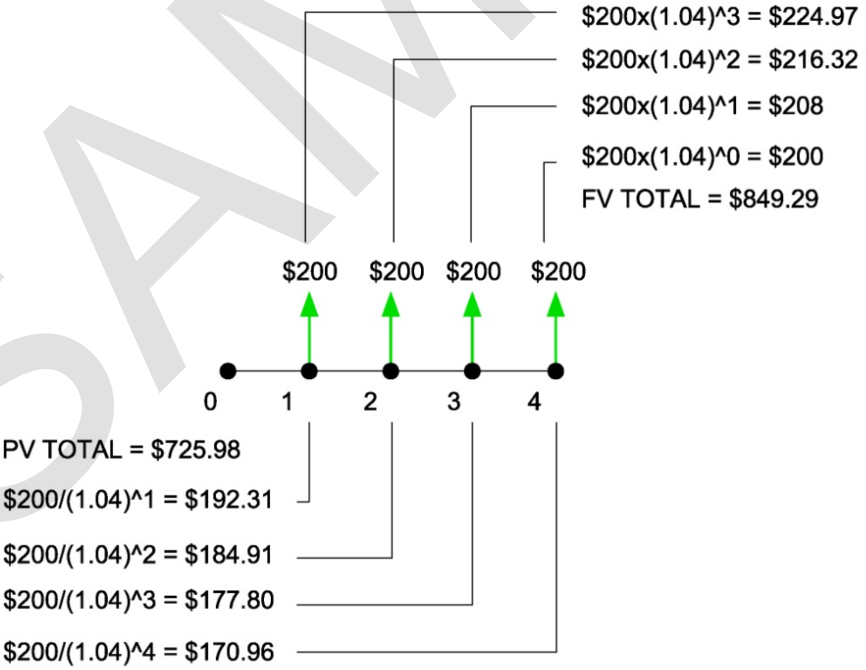
It is important to understand present value because when analyzing engineering alternatives, cash values will be presented at many different times. The best way to make a uniform analysis is to *first convert all values to consistent terms, like present value.*

For example, if instead your options were $1,000 today or $1,500 in 10 years (interest rate at 4%), then it would be a much more difficult question than the previous one. With an understanding of present value, you can derive that it is better to accept $1,500 10 years from now, because $1,000 at present value is only worth $1,480 10 years from now, at 4% interest. In this example, the $1,000 today was converted to the "future value," 10 years from now. Once this value was converted, it can then be compared to the future value that was given as $1,500, 10 years later.

2.2 ANNUAL VALUE/ANNUITIES

The previous section described the difference between present value and future value. It also showed how a lump sum given at certain times are worth different amounts in present terms. In engineering, there are often times when annual sums are given in lieu of one time lump sums. An example would be annual energy savings due to the implementation of a more efficient HVAC system. Thus, it is important for the engineer to be able to determine the present/future value of future **annual** gains or losses.

For example, let's assume that a solar hot water project provides an annual savings of $200. Using the equations from the previous section, each annual savings can be converted to either present or future value. Then these values can be summed up to determine the future and present value of annual savings of $200 for four years at an interest rate of 4%.



$$AV_{total} = AV_{salvage\ value} + AV_{initial\ cost} + AV_{O\&M+energy\ savings}$$

$$AV_{total} = \$249.71 - \$4{,}497.06 + \$4{,}000 = \$-247.35$$

For an even faster method on how to do these calculations with tables, see the following section: Factor Tables.

2.7 FACTOR TABLES

When conducting engineering economic analyses, factor values are used in lieu of formulas. Factor values are pre-calculated values that correspond to:

(1) A specific equation (convert present value to annual, convert present value to future, etc.)

(2) An interest rate, i.

(3) Number of years, n.

Looking up these values in a table is sometimes quicker than using the equations and lessens the possibility of calculator error. It is recommended that the *engineer practice using the factor tables in the NCEES PE Mechanical Reference Handbook*. A summary of the factor values are shown below.

Conversion	Formula	Factor Value (from table)
Present Value to Future Value	$FV = PV * (1+i)^n$	Multiply PV by (F/P, i, n)
Future Value to Present Value	$PV = \frac{FV}{(1+i)^n}$	Multiply FV by (P/F, i, n)
Present Value to Annual Value	$AV = PV * \left(\frac{i*(1+i)^n}{(1+i)^n - 1}\right)$	Multiply PV by (A/P, i, n)
Annual Value to Present Value	$PV = AV * \left(\frac{1-(1+i)^{-n}}{i}\right)$	Multiply AV by (P/A, i, n)
Future Value to Annual Value	$AV = FV\left(\frac{i}{(1+i)^n - 1}\right)$	Multiply FV by (A/F, i, n)
Annual Value to Future Value	$FV = AV * \left(\frac{(1+i)^n - 1}{i}\right)$	Multiply AV by (F/A, i, n)

4.0 UNITS AND CONVERSIONS

Many of the problems on the PE exam will require you to convert units and will have incorrect answers that use different units or wrong conversion techniques. Double check your work and make sure you use the correct units. Make sure you are very familiar with the unit conversions available in the *NCEES Mechanical PE Reference Handbook*.

5.0 ELECTRICAL CONCEPTS

Mechanical and electrical engineers work closely together and there is often a lot of coordination between the two disciplines. Most of the equipment that a HVAC & Refrigeration engineer designs will require power. It is important for the HVAC & Refrigeration engineer to understand the basics of electrical engineering.

5.1 CURRENT, VOLTAGE AND RESISTANCE

There are three basic terms that mechanical engineers should understand about electrical engineering, current, voltage and resistance.

Current is the measure of the flow of electrons and is measured in terms of amperes (A). Current is represented by the variable (I).

Voltage is best described in mechanical terms as the pressure at which current (flow) is supplied. Voltage is often represented by the variable (V).

Resistance is the opposition to flow. It controls the amount of flow or voltage in a circuit. Resistance is represented by the variable (R) and is measured in ohms (Ω).

These three terms are related by the following equation. In order to solve for another variable, simply re-arrange the equation to solve for the desired variable. This equation is called Ohm's Law.

$$Ohm's\ Law: V = IR$$

5.2 BASIC DC CIRCUITS

A basic direct current circuit consists of a voltage source [battery] and a resistor. The voltage source provides the "pressure" to drive the current (flow) through the circuit.

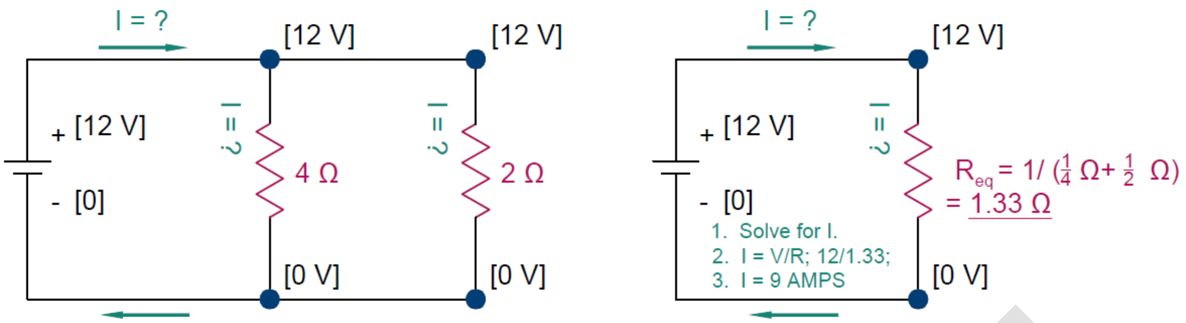


Figure 10: Basic dc circuit for equivalent resistance for resistors in parallel

5.3 D/C Power

The next important electrical equation to remember is the DC electric power equation as shown below. Real power is typically expressed in units, Watts and apparent power is expressed in units volt-amperes. Current is represented by the variable "I" and is expressed in amperes and voltage is represented by the variable "V" and is expressed in volts.

$$Real\ Power \rightarrow P = IV * PF\ (volt - amperes);$$

$$Apparent\ Power \rightarrow S = IV\ (volt - amperes);$$

Variations of the equation can be shown by substituting I and V, through the use of Ohm's law.

$$P = \left(\frac{V}{R}\right) * V * PF = \frac{V^2}{R} * PF$$

$$P = I * IR * PF = I^2 * R * PF$$

5.4 A/C Power

The previous electrical sections have dealt with DC power or direct current electricity. This allows for a basic understanding of common electrical terms. However, for the P.E. exam, the mechanical engineer should also be aware of alternating current (AC) power terms and equations.

Power Factor: When electricity is supplied to a piece of equipment, it is supplied with a certain amount of amps (current) at a designated voltage. However, not all of the power supplied (apparent power) is useful. Some of its power is lost, because the current and voltage are out of phase. [The explanation of phase is out of the scope of this section and is more representative of the material found in the Electrical Power P.E. Exam] The degree at which the current and voltage are out of phase is reported as the power factor. The total amount of real (useful) power supplied to the equipment is found by multiplying the total power supplied (S = IV) by the power factor. Typical power factors are around ~0.85.

$$Total\ Electricity\ Supplied \rightarrow Apparent\ Power \rightarrow S = I * V\ (volt - amperes)$$

$$Total\ Useful\ Power \rightarrow Real\ Power \rightarrow P = I * V * PF\ (watts)$$

The above equations are only for single phase motors. The following sections will show the difference for 3-phase motors.

5.5 MECHANICAL EQUIPMENT MOTOR RATING

When selecting mechanical equipment, the mechanical engineer must coordinate the power requirements with the electrical engineer. This is done through the following steps: (1) Determine Mechanical Horsepower, (2) Determine Fan/Pump Brake horsepower, (3a) Determine Motor Horsepower, (3b) Determine Electrical Input Power, and finally (4) Apparent Power.

1) Determine Mechanical Horsepower. Mechanical HP is defined as the amount of power required to meet the needs of the system in question. For example, if the mechanical equipment was a pump, then the mechanical HP would be the amount of power generated by a certain GPM at a certain pressure. For a fan, the mechanical work would be the amount of power generated by a certain amount of CFM at a certain pressure. These equations can be found below.

$$\boldsymbol{P_{mech\,work,pump[HP]}} = \frac{\boldsymbol{h_{ft} * Q_{gpm} * (SG)}}{\boldsymbol{3956}};$$

$$h = hydraulic\ head[ft], Q = flow\ rate\ [gpm], SG = specific\ gravity$$

$$\boldsymbol{P_{mech\,work,fan[HP]}} = \frac{\boldsymbol{Q_{cfm} * TP_{in\,wg}}}{\boldsymbol{6356}};$$

$$TP = total\ pressure\ [in\ wg], Q = flow\ rate\ [cfm]$$

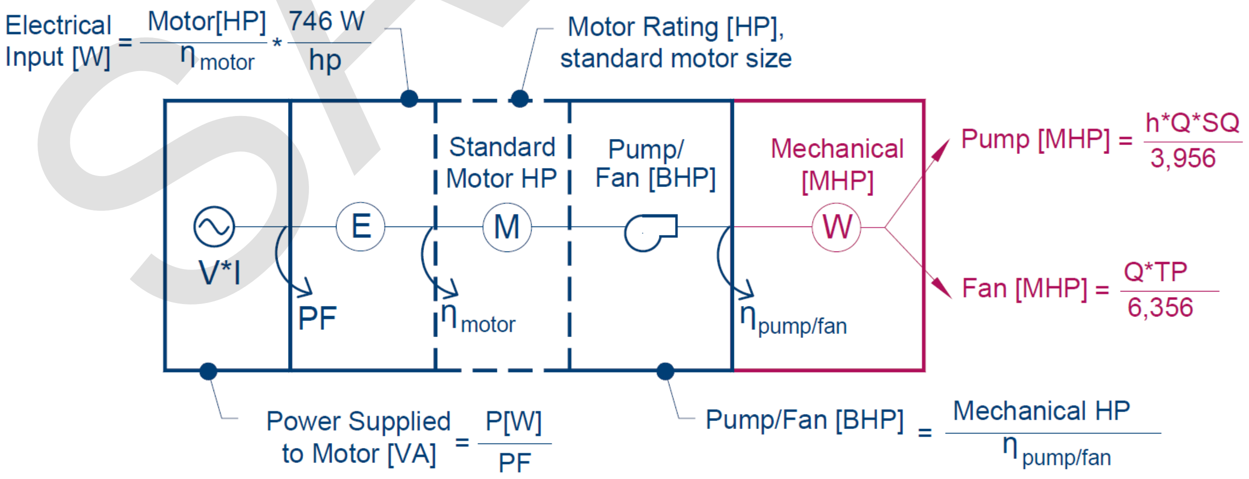


Figure 11: Determining mechanical horsepower

6.0 PRACTICE PROBLEMS

6.1 PROBLEM 1 - ECONOMICS

Background: A client is contemplating on purchasing a new high efficiency pump and motor, with an initial cost of $10,000. The pump has a lifetime of 15 years and is estimated to save approximately $1,000 per year. There is an additional maintenance cost of $300 per year associated with this new pump. The pump will have a salvage value of $0 at the end of its lifetime. Assume the interest rate is 4%.

Problem: What is the annual value of the pump?

(a) -$499

(b) -$199

(c) $199

(d) $499

6.2 PROBLEM 2 - ECONOMICS

Background: A client is contemplating between two separate turbines. Turbine 1 has a life of 25 years, an initial cost of $50,000, an ongoing maintenance/electricity cost totaling $1,000 per year. Turbine 2 has a life of 25 years, an initial cost of $35,000 and an ongoing maintenance/electricity cost totaling $1,500 per year. Assume interest rate is equal to 4%.

Problem: What is the present worth of the two turbines?

(a) Turbine 1 = -$48,099 ; Turbine 2 = -$39,651

(b) Turbine 1 = -$55,278 ; Turbine 2 = -$47,455

(c) Turbine 1 = -$61,222 ; Turbine 2 = -$49,469

(d) Turbine 1 = -$65,622 ; Turbine 2 = -$58,433

6.9 PROBLEM 9 - ELECTRICAL

Background: A new electrical circuit has 3 resistors in series. Each resistor has a resistance of 4 Ω. The circuit is powered by a 12 V battery.

Problem: What is the current through the circuit?

(a) 0.5 amps

(b) 1.0 amps

(c) 2.0 amps

(d) 3.0 amps

6.10 PROBLEM 10 - ELECTRICAL

Background: A new electrical circuit has 2 resistors in parallel. One resistor has a resistance of 4 Ω. The resistance of the other resistor is unknown. The circuit is powered by a 12 V battery.

Problem: If the total current through the circuit is 8 amps, what is the resistance of the 2nd resistor?

(a) 1.2

(b) 1.6

(c) 2.0

(d) 2.4

7.0 SOLUTIONS

7.1 SOLUTION 1 - ECONOMICS

Background: A client is contemplating on purchasing a new high efficiency pump and motor, with an initial cost of \$10,000. The pump has a lifetime of 15 years and is estimated to save approximately \$1,000 per year. There is an additional maintenance cost of \$300 per year associated with this new pump. The pump will have a salvage value of \$0 at the end of its lifetime. Assume the interest rate is 4%.

Problem: What is the annual value of the pump?

First convert all terms to annual values.

Maintenance cost and cost savings are already annual values.

$$A_{maint} = -\$300$$

$$A_{savings} = \$1{,}000$$

Convert initial cost (present value) to annual value.

$$A_{initial\ cost} = -\$10{,}000 * (\frac{A}{P}, 4\%, 15)$$

Refer to the NCEES Mechanical PE Reference Handbook for I= 4.0% economics table. Then navigate down to n = 15 and then to the A/P term to convert P to A.

$$A_{initial\ cost} = -\$10{,}000 * (.0899)$$

$$A_{total} = A_{maint} + A_{savings} + A_{initial\ cost}$$

$$A_{total} = -\$300 + \$1{,}000 - \$899$$

$$A_{total} = -\$199$$

The correct answer is most nearly, (b) -\$199.

(a) -\$499

(b) -\$199

(c) \$199

(d) \$499

7.2 SOLUTION 2 - ECONOMICS

Background: A client is contemplating between two separate turbines. Turbine 1 has a life of 25 years, an initial cost of $50,000, an ongoing maintenance/electricity cost totaling $1,000 per year. Turbine 2 has a life of 25 years, an initial cost of $35,000 and an ongoing maintenance/electricity cost totaling $1,500 per year. Assume interest rate is equal to 4%.

Problem: What is the present value of the two turbines?

First convert all terms to present value, Turbine 1.

$$P_{turbine\ 1} = P_{initial\ cost} + A_{maint/elec} * (\frac{P}{A}, 4\%, 25)$$

$$P_{turbine\ 1} = -\$50{,}000 - \$1{,}000 * 15.6221$$

$$P_{turbine\ 1} = -\$65{,}622$$

Second convert all terms to present value, Turbine 2.

$$P_{turbine\ 2} = P_{initial\ cost} + A_{maint/elec} * (\frac{P}{A}, 4\%, 25)$$

$$P_{turbine\ 2} = -\$35{,}000 - \$1{,}500 * 15.6221$$

$$P_{turbine\ 2} = -\$58{,}433$$

The correct answer is most nearly, (d) Turbine 1 = -$65,622 ; Turbine 2 = -$58,433.

(a) Turbine 1 = -$48,099 ; Turbine 2 = -$39,651

(b) Turbine 1 = -$55,278 ; Turbine 2 = -$47,455

(c) Turbine 1 = -$61,222 ; Turbine 2 = -$49,469

(d) Turbine 1 = -$65,622 ; Turbine 2 = -$58,433

7.3 SOLUTION 3 - ECONOMICS

Background: An existing A/C control system is inefficient and you are researching whether or not to replace system. You develop a new system that will cost $30,000 and require an ongoing maintenance of $1,000 per year, but it will save $4,000 per year in energy savings. The new A/C control system will have a lifetime of 30 years.

Problem: If the minimum rate of return is 8%, what will be the annual value of the new system? Economically, should the new system be installed?

3 - Thermodynamics

Cycles | Properties | Compression Processes

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Section 3.0 – Principles Thermodynamics

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1.0 INTRODUCTION

Thermodynamics accounts for approximately 4-6 questions on the HVAC & Refrigeration Mechanical PE exam.

Thermodynamics includes the principles used in the vapor compression cycle. Also the properties discussed in this section are used in the sections, Heating/Cooling Loads, Equipment, Systems, Psychrometrics and Energy/Mass Balance.

A professional engineer should be able to properly navigate a refrigeration diagram and have a deep understanding of the vapor compression cycle. In addition, this guide also focuses on the (4) main parts of refrigeration systems, which are the evaporator, compressor, condenser and expansion device. The refrigerant used in this cycle is also discussed in this section.

Also introduced in this section are the Thermodynamics properties, pressure, temperature, enthalpy, entropy and specific heat. These properties are used throughout the vapor-compression cycle and also in many other sections on the HVAC & Refrigeration PE exam.

At the end of this section, steam is covered. Steam is used heavily in the HVAC & Refrigeration field for heating. Although there is no specific category in the NCEES outline, you should be familiar with the skills presented in this section since it may appear in a heating question.

Thermodynamics
4-6 questions

Cycles

- Vapor-Compression Cycle
  - Evaporator
  - Compressor
  - Condenser
  - Expansion

Properties

- Pressure
- Temperature
- Enthalpy
- Entropy
- Specific heat

Compression Process

- Discussed in cycles

highest entropy in this example. At any given time, the configuration of the gas can be one of many different configurations.

$$S_{SOLID} < S_{LIQUID} < S_{GAS}$$

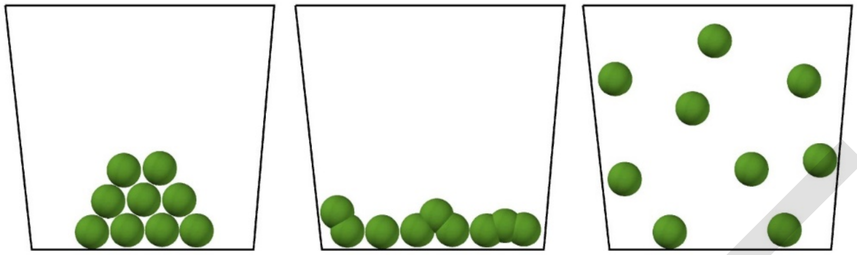


Figure 4: Entropy in a solid increases from solid to liquid to gas.

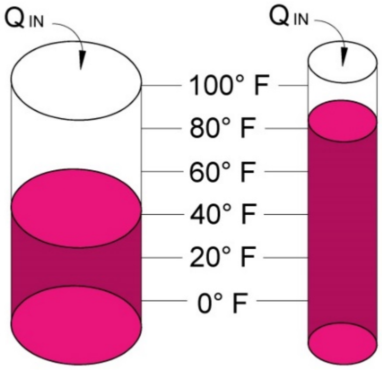
Entropy is mostly known for its use in the 2nd law, which states that a system's entropy never decreases. Also entropy is used to describe thermodynamic transitions. If there is no change in entropy then the process is determined to be isentropic. Also a process is reversible if the entropy is not increased and the process is irreversible if the entropy increases.

2.4 SPECIFIC HEAT

The specific heat describes the ease of a fluid or solid to increase in temperature, when heat is applied. Specific heat is also known as heat capacitance and can be thought of as an objects ability to hold and gain heat. For solids and liquids, specific heat is shown as the variable.

$$heat\ capacity = c_p \left(\frac{Btu}{lbm\ °F}\right)$$

Water has a specific heat of 1.0, while aluminum has a specific heat of 0.23. As heat is added to water, water will increase in temperature at a slow rate. Since aluminum has a lower specific heat, it needs less energy to raise its temperature.



the refrigerant. A refrigerant liquid's boiling point is a function of the vapor pressure of the refrigerant vapor that is in equilibrium with the refrigerant liquid. If the pressure is low, then there is a smaller force acting upon the refrigerant liquid, thus it will take a lower temperature to boil the refrigerant liquid. For example, water at a pressure of 1 atmosphere or 14.696 PSI will boil at 212°F. However, if the water was at a pressure of 0.122 PSI, then the water will boil at 40°F. This principle is important to understand: *Low pressure refrigerants boil at a lower temperature, high pressure refrigerants condense at a higher temperature.*

For more detail refer to the following table and figure.

Water Temperature [F] Boiling Point	Pressure [PSI]
212	14.696
190	9.340
160	4.742
130	2.224
100	0.950
70	0.363
40	0.122
10	0.031

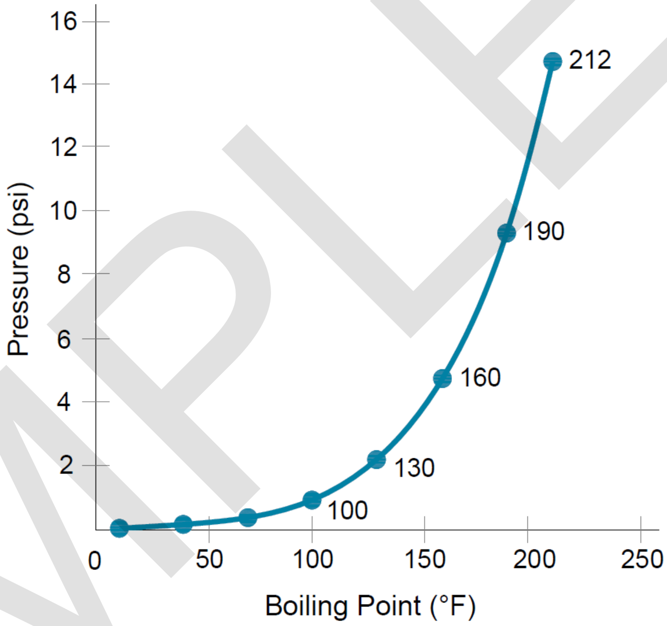


Figure 6: Relationship between boiling point and pressure

When a low pressure refrigerant changes from its liquid phase to a gas phase, it can absorb much more heat than if it were to simply increase in temperature. The same is also true when a high pressure refrigerant changes phase from its gas phase to a liquid phase; it releases much more heat than if it were to decrease in temperature. The energy required to change the phase of a liquid from a liquid to a gas is called the latent heat of evaporation. The energy released to change the phase of a gas to a liquid is called the latent heat of condensation.

The x-y axes of the P-H diagram are the pressure lines running from left to right. The enthalpy lines are the vertical lines. The skeletal graph shown in the figure above shows the pressure-enthalpy lines.

The next important lines on the pressure-enthalpy diagram are those describing lines of constant entropy, which are used and discussed in section 6.1.2 Compressor.

6.1 REFRIGERATION CYCLE

One of the most important skills needed for the professional engineer in the HVAC & Refrigeration field is navigating the refrigeration cycle on a pressure-enthalpy diagram. The following sections will show each specific part of the refrigeration cycle on the pressure-enthalpy diagram and it will also highlight the important points and calculations needed.

Throughout this explanation the refrigerant R-134a is used as an example. It is recommended that the engineer be familiar with the P-H diagram for R-134a and the other common refrigerants. These diagrams can be found in the NCEES Mechanical PE Reference Handbook. A sample R-134a diagram is shown below, with a sample refrigeration cycle, identifying (Step 1) Evaporator, (Step 2) Compressor, (Step 3) Condenser and (Step 4) Expansion Device.

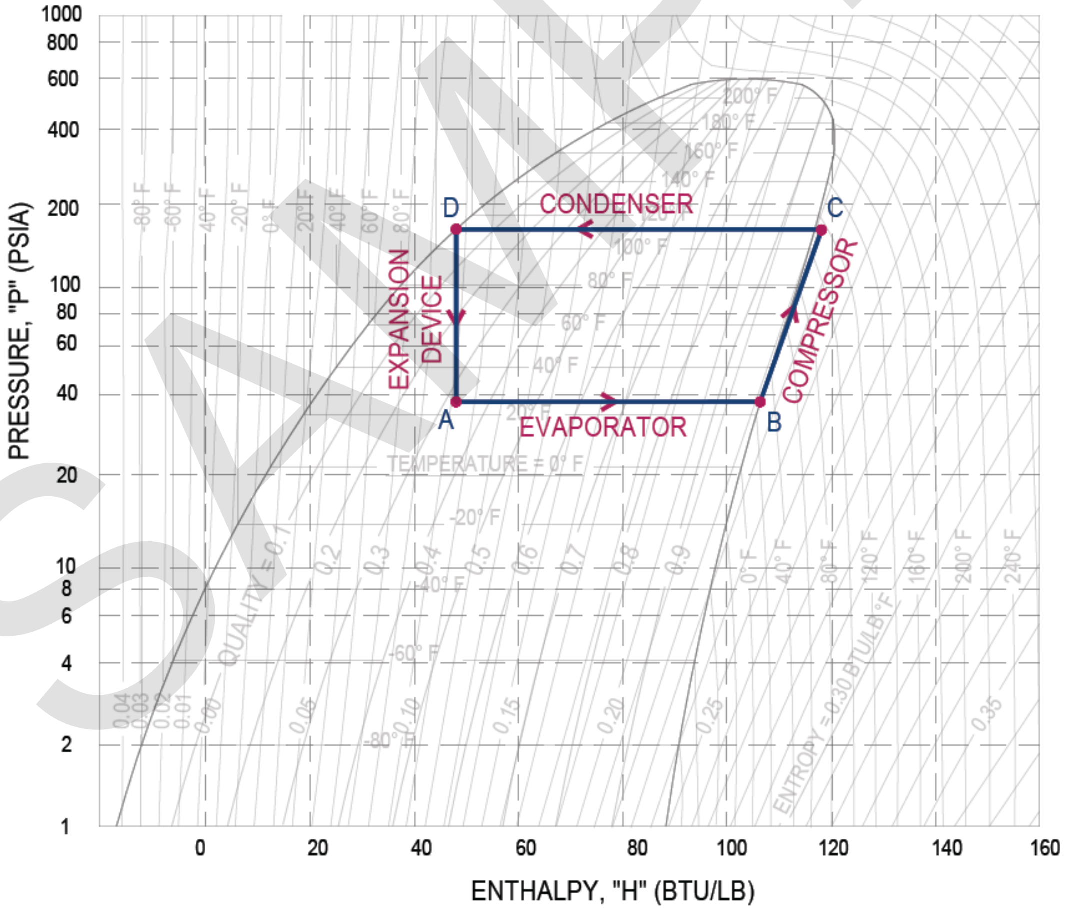


Figure 13: Sample R-134a P-H diagram

6.1.3 Step 3 Condenser

The refrigerant entering the condenser is now a hot, high pressure refrigerant gas. The condenser is shown on the pressure-enthalpy diagram as a horizontal line. This horizontal line is a line of constant pressure, corresponding to the discharge pressure of the compressor. The condenser proceeds from right to left in the following three steps:

(1) The superheated gas cools down to saturation temperature [C' 160 °F to D' 140 °F]. Cooling takes place as heat flows from the hot refrigerant gas to the condenser cooling medium.

(2) Next, the100% saturated vapor at D' is converted to 100% saturated liquid at D''. Heat is lost to the condenser cooling medium as the vapor is condensed to a liquid.

(3) Finally, the 100% saturated liquid is sub-cooled from D'' to D'''[140 °F to 115 °F]. In an ideal condenser, no sub-cooling occurs. Once the refrigerant is a fully saturated liquid, any additional heat loss results in a decrease in temperature. This cooling of the saturated liquid is referred to as sub-cooling. In this example, the refrigerant has gone through 25 °F of sub-cooling and resulted in a sub-cooled temperature of 115 °F.

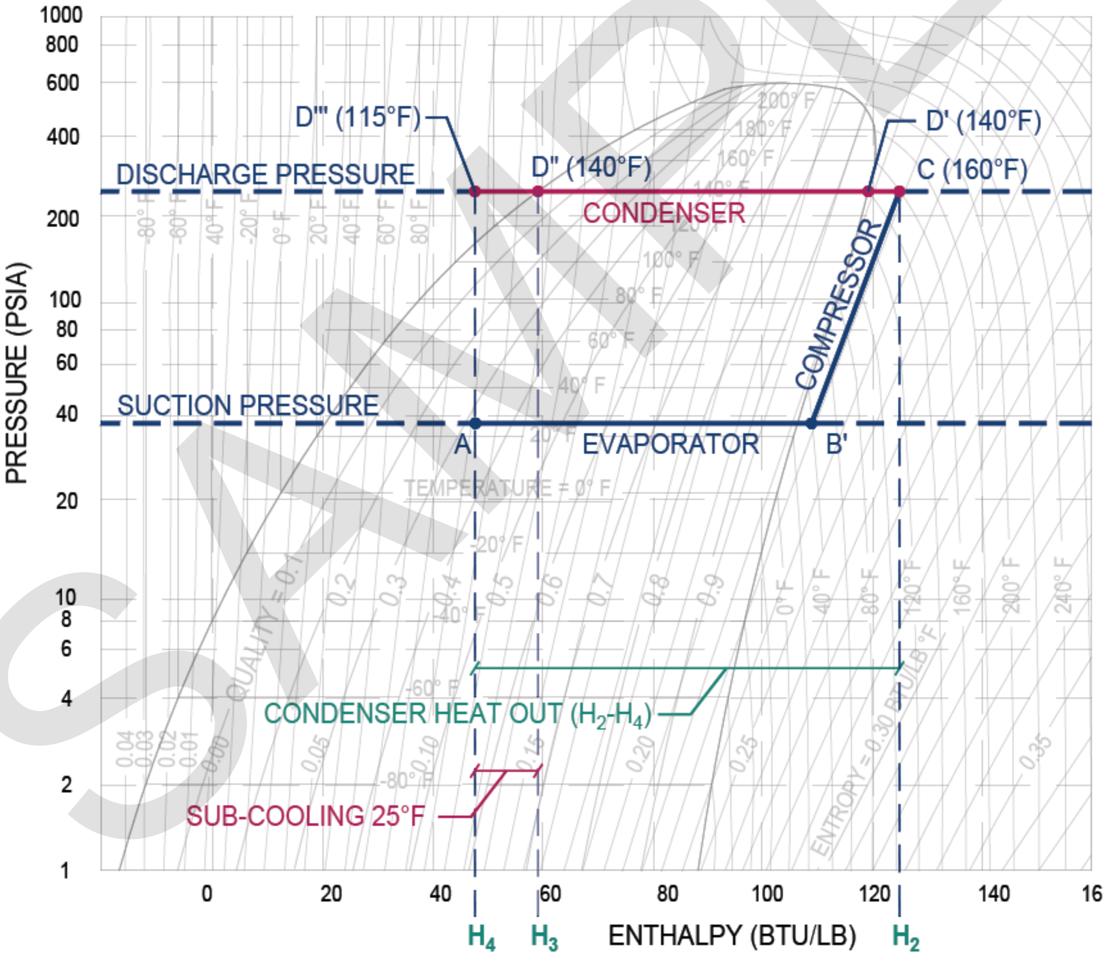


Figure 20: R134a pressure-enthalpy diagram – condenser

Equation 1: Evaporator Net Refrigeration Effect

$$Q_{net\ refrigeration\ effect}\ [Btuh] = (H_1 - H_4)\left[\frac{Btu}{lb}\right] * (Refrig\ Flow\ Rate)\left[\frac{lb}{min}\right] * (60)\left[\frac{min}{hr}\right]$$

$$H_1 = leaving\ evaporator\ enthalpy\ \left[\frac{Btu}{lb}\right];\ H_4 = entering\ evaporator\ enthalpy\ [\frac{Btu}{lb}]$$

Equation 2: Compressor Work

$$W_{compressor}\ [Btuh] = (H_2 - H_1)\left[\frac{Btu}{lb}\right] * (Refrig\ Flow\ Rate)\left[\frac{lb}{min}\right] * (60)\left[\frac{min}{hr}\right]$$

$$H_2 = leaving\ compressor\ enthalpy\ \left[\frac{Btu}{lb}\right];\ H_1 = entering\ condneser\ enthalpy\ [\frac{Btu}{lb}]$$

Equation 3: Net Condenser Effect

$$Q_{net\ condenser\ effect}\ [Btuh] = (H_2 - H_4)\left[\frac{Btu}{lb}\right] * (Refrig\ Flow\ Rate)\left[\frac{lb}{min}\right] * (60)\left[\frac{min}{hr}\right]$$

$$H_2 = entering\ condenser\ enthalpy\ \left[\frac{Btu}{lb}\right];\ H_4 = leaving\ condneser\ enthalpy\ [\frac{Btu}{lb}]$$

Equation 4: Net Condenser Effect

$$Q_{net\ condenser\ effect}\ [Btuh] = W_{compressor}\ [Btuh] + Q_{net\ refrigeration\ effect}\ [Btuh]$$

The next term that the engineer should understand is Coefficient of Performance or COP. COP is the ratio of the amount of “Work Out” divided by the amount of “Work In”. In the refrigeration cycle, “Work Out” is equal to the net refrigeration effect. “Work In” is equal to the Compressor Work, this is the only point at which outside work is put into the system.

Equation 5: COP

$$COP = \frac{W_{out}}{W_{in}} = \frac{Q_{net\ refrigeration\ effect}\ [Btuh]}{W_{compressor}\ [Btuh]}$$

COP is a term used to describe the efficiency of a piece of equipment. Another common term is the Energy Efficiency Ratio or EER. The EER term describes the ratio of the cooling capacity in units [Btu/hr] to the input electrical power in units [Watts]. The conversion of COP to EER is shown below.

Equation 6: Relationship between COP and EER

$$COP = \frac{EER}{3.412}$$

7.0 STEAM

This section on steam provides background information on the steam pressure enthalpy diagram and the Mollier Diagram and various pieces of steam equipment. The professional engineer in the HVAC/R industry must have a deep understanding of steam systems, because it is often used in the heating of both water and air. This guide teaches the key concepts and skills that are often used in dealing with steam systems.

7.1 PRESSURE ENTHALPY DIAGRAM FOR STEAM

The pressure enthalpy diagram for steam is an excellent tool to gain an understanding of the steam tables. The pressure-enthalpy diagram describes the liquid, vapor and mix region of water. As shown in the following figure, the P-H diagram consists of Pressure (PSIA) on the y-axis and Enthalpy (Btu/lbm) on the x-axis. It is important to note that pressure is shown on a logarithmic scale while enthalpy is shown in a normal scale. In the middle of the diagram is the vapor dome. This dome separates the sub-cooled liquid (aka water) on the left side, super-heated vapor (aka steam) on the right side and the liquid-vapor mix region (aka mixed region or wet region) in the middle.

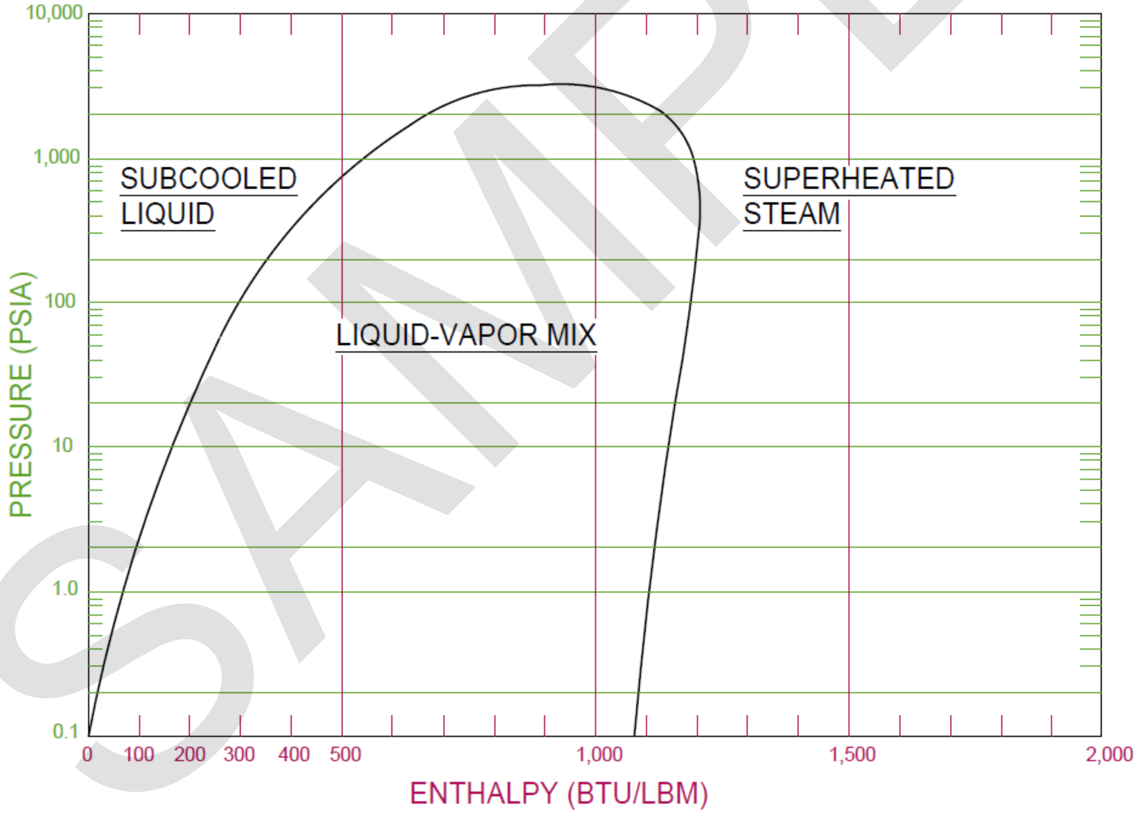


Figure 23: Pressure-enthalpy (p-h) diagram: phases of water

The mixed region is cut by upward sloping lines that represent the percentage of vapor, as shown

8.13 PROBLEM 13 - STEAM AIR COILS

50 lbm/hr of steam enters a heating coil at a pressure of 15 PSIA. 700 CFM of air enters the coil at 60 F. Assume 100% efficient heat transfer. What is the resulting exiting temperature of the air?

a) 105 °F

b) 110 °F

c) 115 °F

d) 125 °F

8.14 PROBLEM 14: STEAM - HOT WATER COILS

A hot water coil has an incoming water temperature of 70 F and an outgoing temperature of 140 F. Hot water is flowing through the coil at a rate of 40 GPM. What steam flow rate is required to properly heat the water [lb/hr]? Assume saturated steam at a pressure of 15 PSIA, with no super heat and sub-cooling and 100% effective heat exchange.

a) $1{,}320 \frac{lb}{hr}$

b) $1{,}440 \frac{lb}{hr}$

c) $1{,}560 \frac{lb}{hr}$

d) $1{,}800 \frac{lb}{hr}$

9.0 SOLUTIONS

9.1 SOLUTION 1 - EVAPORATOR

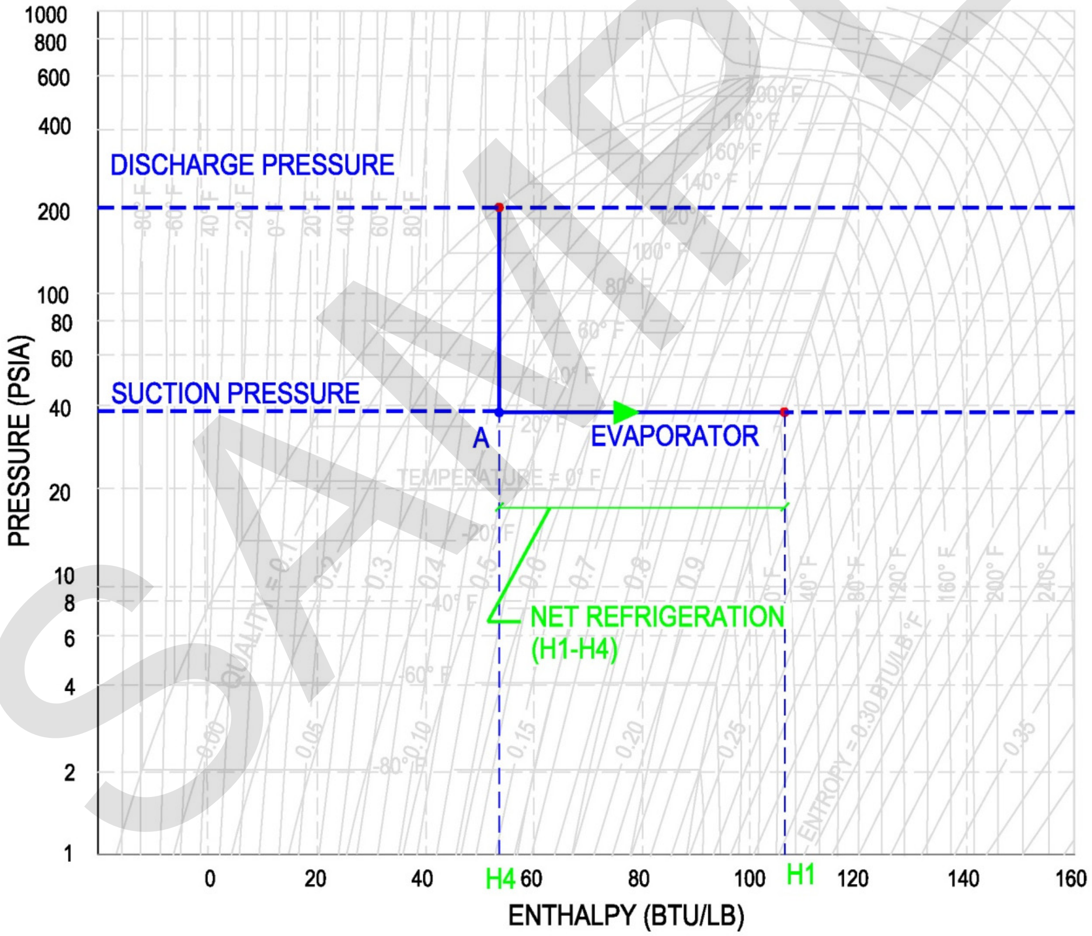
$$Q_{net\ refrigeration\ effect}\ [Btuh] = (H_1 - H_4)\left[\frac{Btu}{lb}\right] * (Refrig\ Flow\ Rate)\left[\frac{lb}{min}\right] * (60)\left[\frac{min}{hr}\right]$$

$$H_1 = leaving\ evaporator\ enthalpy\left[\frac{Btu}{lb}\right] = 107\ Btu/lb$$

$$H_4 = entering\ evaporator\ enthalpy\left[\frac{Btu}{lb}\right] = 54\ Btu/lb$$

$$Q_{net\ refrigeration\ effect}\ [Btu] = (107 - 54)\left[\frac{Btu}{lb}\right] * 50\left[\frac{lb}{min}\right] * 60\left[\frac{min}{hr}\right]$$

$$Q_{net\ refrigeration\ effect} = 159{,}000\ Btuh * \frac{1\ ton}{12{,}000\ Btuh} = 13.25\ Tons$$



4 - Psychrometrics

Moist Air Properties | Movement on Chart | Various Elevations | Heating/Cooling | Humidification/Dehumidification

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Section 4.0 – Principles Psychrometrics

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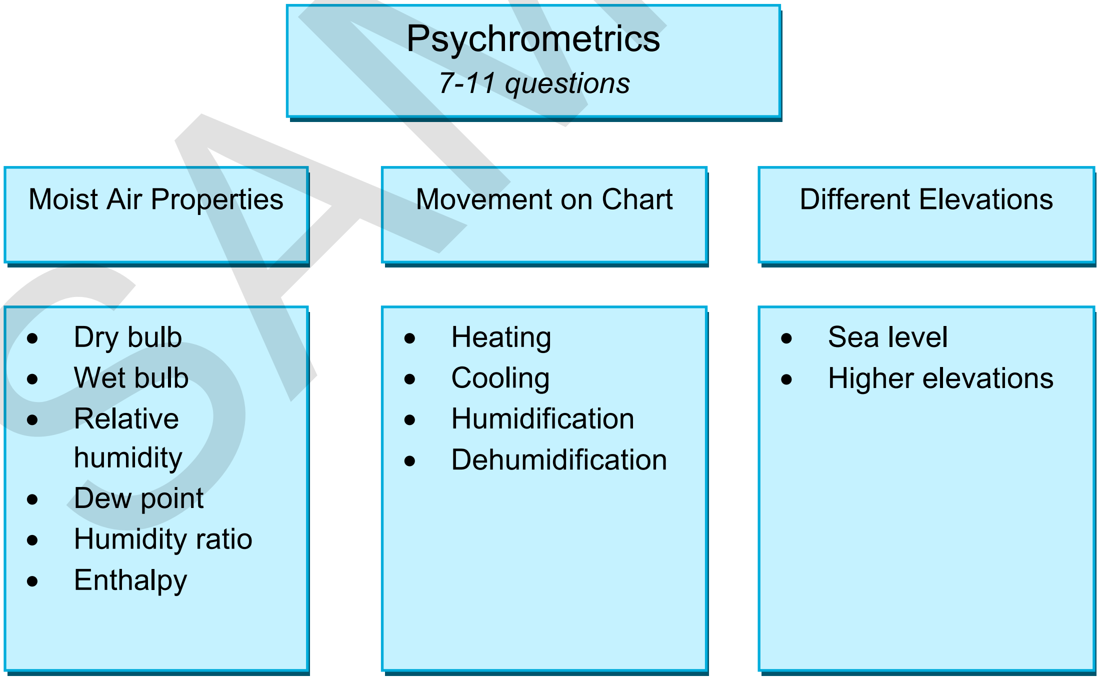
1.0 INTRODUCTION

This section focuses on the skills and concepts related to the **Psychrometric Chart.** The Psychrometric Chart is a key tool used by HVAC & Refrigeration engineers in many situations. It is used in calculating cooling loads and selecting mechanical equipment like enthalpy wheels, heat exchangers (air), air handlers and fan coils. *Psychrometrics counts for 7-11 questions on the Mechanical HVAC & Refrigeration PE exam.*

This guide focuses on constant atmospheric pressure at sea level, which is the most common situation encountered by most Mechanical Engineers in the HVAC field. However, if a question indicates a different pressure or extreme temperatures, then you will need to use the other charts in the NCEES Mechanical PE Reference Handbook.

Exam Tip: Do not spend enormous amounts of time trying to interpolate the exact value on the psychrometric chart.

The psychrometric chart is provided as part of the NCEES exam, but the chart is small and unclear compared to the ones typically used in practice. It is the opinion of the writer that this fact should indicate to the test taker that it is not important to get the values to the nearest 0.0001 (exaggeration) because it is impossible. In addition, the exam writer would not provide possible multiple choice answers that are fairly close together because of the confusion that would arise. You need to get used to using the psychrometric chart on a computer with the Adobe PDF program.



Psychrometrics

7-11 questions

Moist Air Properties

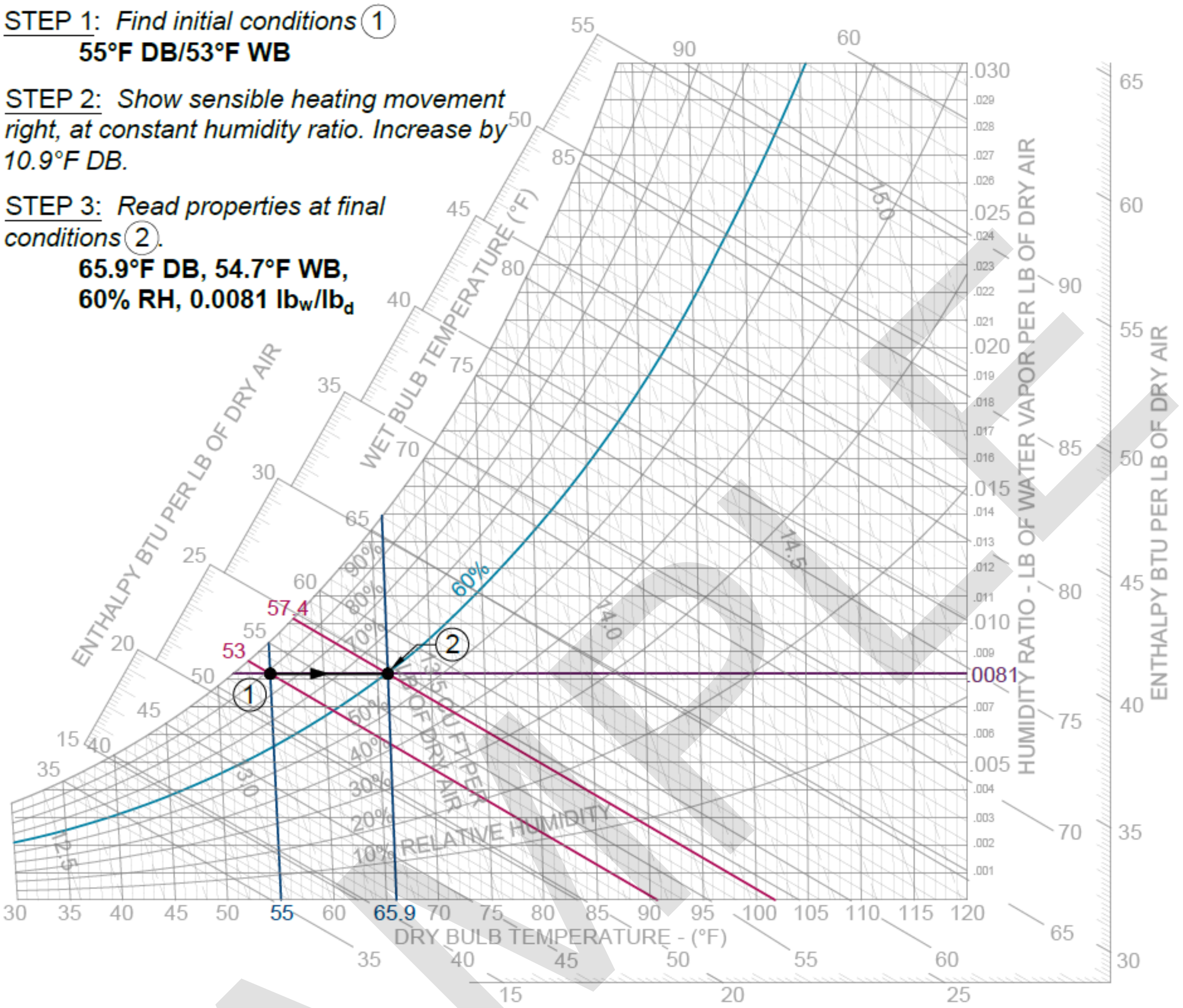
- Dry bulb
- Wet bulb
- Relative humidity
- Dew point
- Humidity ratio
- Enthalpy

Movement on Chart

- Heating
- Cooling
- Humidification
- Dehumidification

Different Elevations

- Sea level
- Higher elevations



STEP 1: *Find initial conditions* ①
55°F DB/53°F WB

STEP 2: *Show sensible heating movement right, at constant humidity ratio. Increase by 10.9°F DB.*

STEP 3: *Read properties at final conditions* ②.
65.9°F DB, 54.7°F WB, 60% RH, 0.0081 lb_w/lb_d

Figure 14: Sensible heating example

2.2.2 LATENT HEATING/COOLING

Latent heat energy is the amount of energy required to produce a phase change, water (liquid) to water (vapor).

Latent heating and cooling is defined as the removal or addition of moisture (water vapor) to an air mixture. Latent heating is more commonly known as humidification and latent cooling is known as dehumidification. In HVAC, common latent heat sources include people, equipment (kitchen or industrial equipment, steamers, anything that produced water vapor) and outdoor air.

Latent heating and cooling is calculated with the latent heat of vaporization, or the energy required to change phases from liquid to vapor. It does not account for actual temperature

2.2.3 SENSIBLE HEAT RATIO

The sensible heat ratio (SHR) is used when there is diagonal movement on the psychrometric chart. Diagonal movement would indicate both sensible heating/cooling and latent heating/cooling. SHR is defined as the ratio of sensible heat to total heat.

$$SHR = \frac{Sensible\ heat\ \left(\frac{Btu}{h}\right)}{Total\ heat\ \left(\frac{Btu}{h}\right)} = \frac{Sensible\ heat\ \left(\frac{Btu}{h}\right)}{Sensible+Latent\ heat\ \left(\frac{Btu}{h}\right)}$$

The sensible heat ratio (SHR) is used in HVAC to describe the ratio of the sensible space cooling to total cooling required for a space. Typically, there will be more sensible cooling required than latent cooling. On the psychrometric chart it describes the slope of the line as shown in the figure below. If the ratio is known, this slope can also be plotted using the compass provided with the psychrometric chart. This slope is a tool to finding the final air conditions due to the cooling or heating loads.

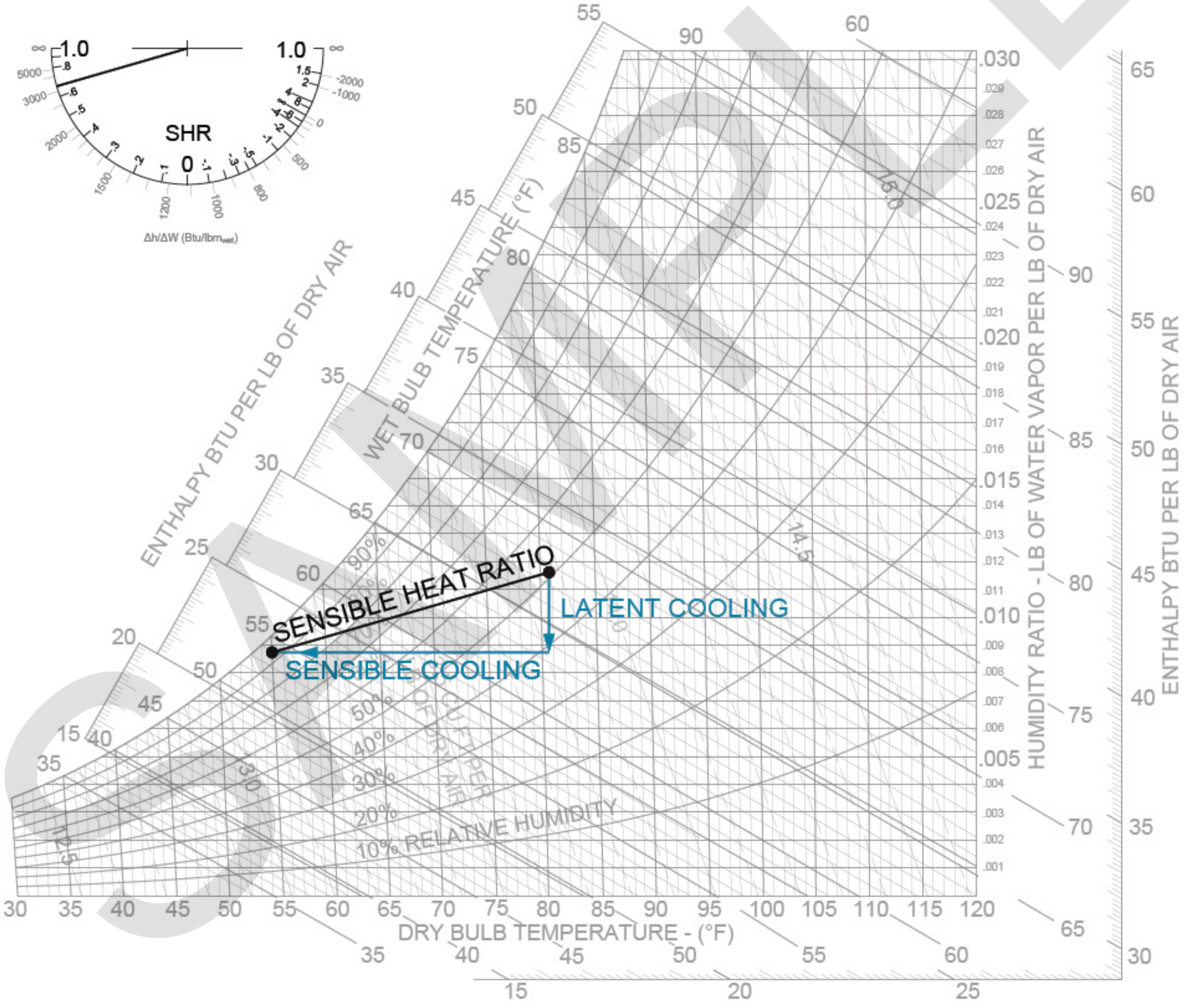


Figure 18: Sensible Heat Ratio (SHR)

transferred at a higher elevation will be less than at sea level for the same volumetric flow rate (CFM).

Do not use the quick and easy key equations for higher elevations. The values assume the standard density. In order to complete the psychrometric problems at higher elevations, you must use the following equations and your *NCEES Mechanical PE Reference Handbook* for the density, specific heat and latent heat of vaporization values. If only the density changes, the density factor can be used to quickly adjust the quick equations for a given elevation. This data can be found in the *NCEES Mechanical PE Reference Handbook* during the exam.

Sensible Heat Equation at all Conditions

$$Q_{sensible} = \left(\rho * c_p * 60\frac{min}{hr}\right) * \Delta T_{DB} * CFM$$

$$where,\ \ Q_{sensible} = sensible\ heat\ \left[\frac{Btu}{hr}\right]$$

$$\Delta T_{DB} = difference\ in\ dry\ bulb\ temperature\ between\ entering\ and\ leaving$$

$$CFM = volumetric\ flow\ rate, cubic\ feet\ per\ minute$$

$$\rho = density\ of\ air\ \left(\frac{lb}{ft^3}\right); c_p = specific\ heat\ of\ air\ \left(\frac{Btu}{lb * {}^\circ\mathrm{F}}\right)$$

Latent Heat Equation at all Conditions

$$Q_{latent} = \left(\rho * \Delta h_{vap} * 60\frac{min}{hr}\right) * \Delta W_{LB} * CFM$$

$$where,\ \ Q_{latent} = latent\ heat\ \left[\frac{Btu}{hr}\right]$$

$$\Delta W_{LB} = change\ in\ humidity\ ratio\ \left[\frac{lb\ of\ water\ vapor}{lb\ of\ dry\ air}\right]$$

$$CFM = volumetric\ flow\ rate, cubic\ feet\ per\ minute$$

$$\Delta h_{vap} = latent\ heat\ of\ vaporization; \rho = density\ of\ air\ \left(\frac{lb}{ft^3}\right);$$

Total Heat Equation at all Conditions

$$\mathrm{Q_{total}} = \left(\rho * 60\frac{min}{hr}\right) * (\Delta \mathrm{h}) * \mathrm{CFM}$$

$$where,\ \ Q_{total} = total\ heat\ \left[\frac{Btu}{hr}\right]$$

$$\Delta \mathrm{h} = change\ in\ enthalpy\ between\ entering\ and\ leaving$$

$$CFM = volumetric\ flow\ rate, cubic\ feet\ per\ minute$$

$$\rho = density\ of\ air\ \left(\frac{lb}{ft^3}\right);$$

Quick Equations at Standard Temperature, Revised for Density

$$\mathrm{Q_{total,@\ new\ elevation\ d}} = \mathrm{DF} * (4.5 * \mathrm{CFM} * \Delta \mathrm{h})$$

4.8 PROBLEM 8 – DEHUMIDIFIER

Background: A desiccant dehumidifier most often has a silica gel medium, which absorbs moisture from air as it is passed over the medium. For the purposes of this problem, it is assumed that the dry bulb temperature is not affected and the dehumidifier only provides latent cooling (dehumidification).

1,000 CFM of air at 80°F DB/72°F WB passes through a de-humidifier with 10,000 Btu/h of latent heat, assume that the de-humidifier is 100% effective. What is the resulting state of air?

(a) 80°F DB/.009 lbm H20/lbm dry air

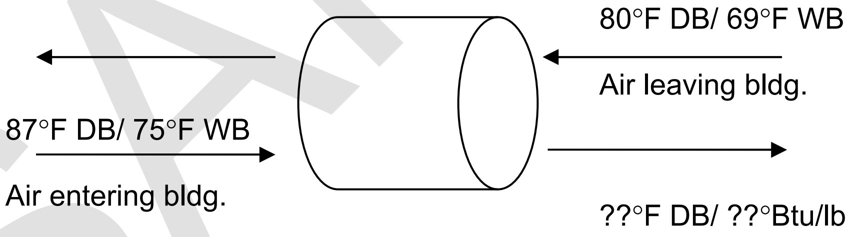
(b) 80°F DB/.011 lbm H20/lbm dry air

(c) 80°F DB/.013 lbm H20/lbm dry air

(d) 80°F DB/.015 lbm H20/lbm dry air

4.9 PROBLEM 9 - ENTHALPY WHEEL

Background: An enthalpy wheel is used to transfer energy (enthalpy) from one air stream to another. 2,000 CFM of air leaving a building at 80°F DB/69°F WB is used to pre-cool and pre-dehumidify 2,000 CFM of air at 87°F DB/75°F WB prior to the air entering the building HVAC system. Assume the enthalpy wheel is 80% effective. What is the resulting temperature of the air entering the building HVAC system after the enthalpy wheel?



(a) 80°F DB/32.5 Btu/lb

(b) 81.4°F DB/34.2 Btu/lb

(c) 85.6°F DB/35.8 Btu/lb

(d) 87°F DB/37.1 Btu/lb

5.2 SOLUTION 2 – CONDENSATION ON SURFACES.

(A) Given 55 °F DB, .007 $\frac{lbm\ of\ water\ vapor}{lbm\ of\ dry\ air}$? Using the psychrometric chart, we find that the dew point of the air is approximately 47°F DB. If the temperature of the window is 50°F, then no condensation will occur.

Answer: No.

(B) Given 60°F DB, 20 $\frac{Btu}{lbm\ of\ dry\ air}$? Using the psychrometric chart, we find that the dew point of the air is approximately 41°F DB. If the temperature of the window is 52°F, then no condensation will occur.

Answer: No.

(C) Given 80 °F DB, 60°F WB? Using the psychrometric chart, we find that the dew point of the air is approximately 45.5°F DB. If the temperature of the window is 40°F, then condensation will occur.

Answer: Yes.

(D) Given 75 °F DB, 50% RH? Using the psychrometric chart, we find that the dew point of the air is approximately 55°F DB. If the temperature of the window is 56°F, then no condensation will occur.

Answer: No.

5.3 SOLUTION 3 - CHANGE IN ENTHALPY/HUMIDITY RATIO

Enthalpy Change $\left[\frac{Btuh}{lbm\ of\ dry\ air}\right]$:

$$\Delta \boldsymbol{h} = \boldsymbol{h}_{\boldsymbol{final}} - \boldsymbol{h}_{\boldsymbol{initial}}$$

From psychrometric chart, $\boldsymbol{h}_{\boldsymbol{final}} \approx \mathbf{22.6}$; $\boldsymbol{h}_{\boldsymbol{initial}} \approx$ **33.7 ;**

$$\Delta \boldsymbol{h} = \boldsymbol{h}_{\boldsymbol{final}} - \boldsymbol{h}_{\boldsymbol{initial}} = -\mathbf{11.1}\ \frac{Btuh}{lbm\ of\ dry\ air}$$

Answer - (b) –11.1

Humidity Ratio Change $\left[\frac{lbm\ of\ water\ vapor}{lbm\ of\ dry\ air}\right]$:

$$\Delta \boldsymbol{W}_{\boldsymbol{LB}} = \boldsymbol{W}_{\boldsymbol{final}} - \boldsymbol{W}_{\boldsymbol{initial}}$$

5 - Heat Transfer

Conduction | Convection | Radiation

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Section 5.0 – Principles Heat Transfer

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1.0 Introduction

Heat transfer is the topic centering on the movement of heat from one system to the next system. In this section, the three modes of heat transfer will first be discussed in order to give a background into the concepts of heat transfer. The three modes of heat transfer are (1) Conduction, (2) Convection and (3) Radiation. This section leads to determining overall heat transfer coefficients, which is an important and practical skill and can be used for determining the resistances of walls and roofs. Following this discussion, this section will delve into the thermal insulation topic.

It is important to note that this section discusses the basic principles of heat transfer. The application of these principles and the incorporation of factors to estimate the additional elements at play in real life situations are further discussed in the heating and cooling load section. The best resources for Heat Transfer is ASHRAE Fundamentals 2017, Chapter 4 Heat Transfer and Chapter 23 Insulation.

Heat Transfer

6-9 questions

Conduction

- U-value
- R-value
- Overall heat transfer coefficient
- Temperature transitions through materials
- Required insulation
- Conductive heat

Convection

- Find convective heat transfer coefficient
- Convective heat

Radiation

- Radiative heat
- Radiative heat between objects

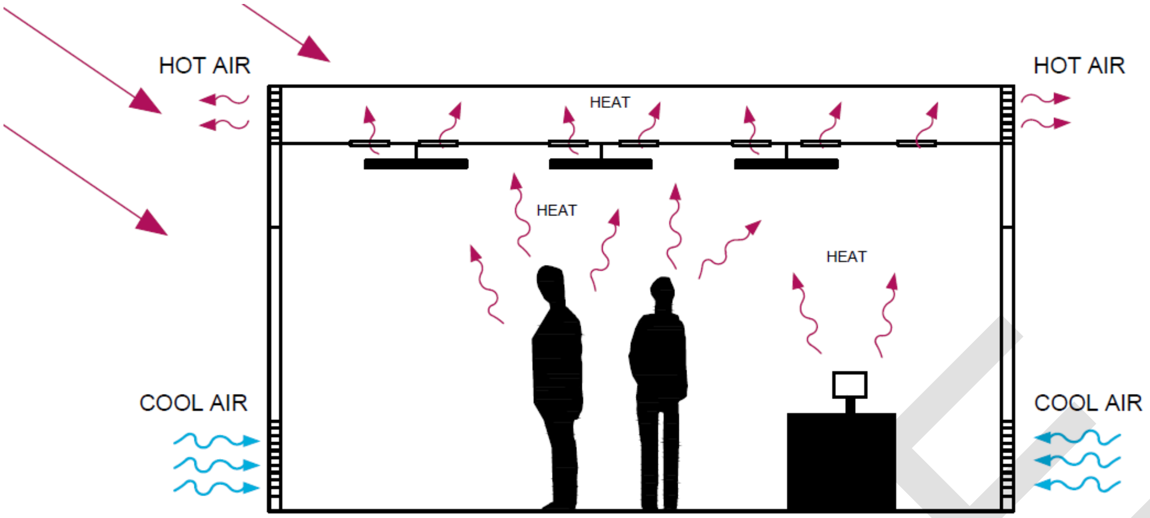


Figure 3: Example of natural convection

Convective heat transfer has a similar equation to conductive heat transfer, except the U-Factor or R-Value is replaced with the convective heat transfer coefficient. This convective heat transfer coefficient characterizes the moving fluid by taking into account its viscosity, thermal conductance, temperature, velocity and it also characterizes the surface that the fluid is moving upon. The derivation of this coefficient for various situations is not part of the scope of this section and is more suited to the Thermal and Fluids Depth Exam.

Convective Heat Transfer Equation

$$Q_{convection} = h_{conv} * A * \Delta T$$

$$h_{conv} = convective\ heat\ transfer\ coefficient \left[\frac{Btu}{hr * ft^2 * °\mathrm{F}}\right]$$

$$A = area\ of\ heat\ transfer\ [ft^2]$$

$$\Delta T = temperature\ difference\ between\ hot\ and\ cold\ areas\ of\ heat\ transfer\ [°\mathrm{F}]$$

This equation is used in the Heating/Cooling Loads section. It is used to determine the convective heating/cooling load that affects a building.

3.1 Heat Transfer For Pipes

When including the convective heat transfer in pipes with the conductive heat transfer, add $\frac{1}{r_n h_{conv}}$ into the denominator of the conductive heat transfer equation for pipes. The resulting heat transfer (conductive + convective) through pipes is found by the following equation.

$$Heat\ Transfer\ through\ Pipes$$

$$Q_{cond+conv} = \frac{2\pi L * \left(T_{fluid} - T_{ambient}\right)}{\frac{\ln\left(\frac{r_2}{r_{inner}}\right)}{k_i} + \frac{\ln\left(\frac{r_3}{r_2}\right)}{k_{ii}} + \cdots + \frac{\ln\left(\frac{r_{outer}}{r_n}\right)}{k_m} + \frac{\mathbf{1}}{\boldsymbol{r_{inner}h_{inner}}} + \frac{\mathbf{1}}{\boldsymbol{r_{outer}h_{outer}}}}$$

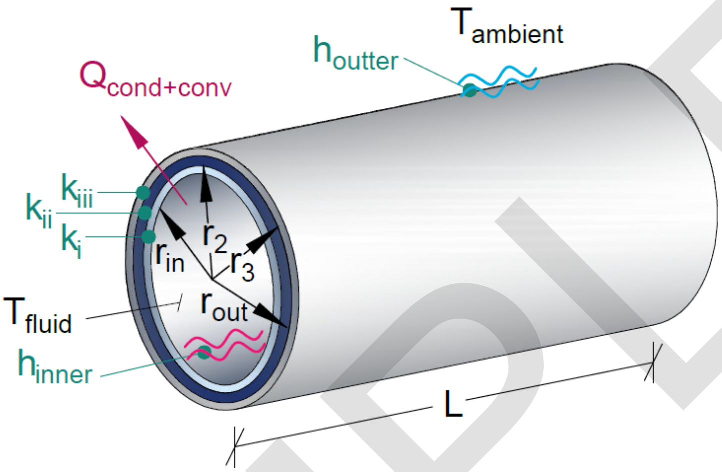


Figure 4: Conductive and convective heat transfer through pipe

The following discussion describes how to find the convective coefficient and will most likely not be on the HVAC & Refrigeration PE exam, because it is too detailed and not normally encountered in practice. Please do not spend a lot of time on the following discussion, it is only provided here in the very rare situation that the PE exam will have one question on the convective heat transfer in the pipes of a heat exchanger.

3.2 Forced convective heat transfer in pipe flow

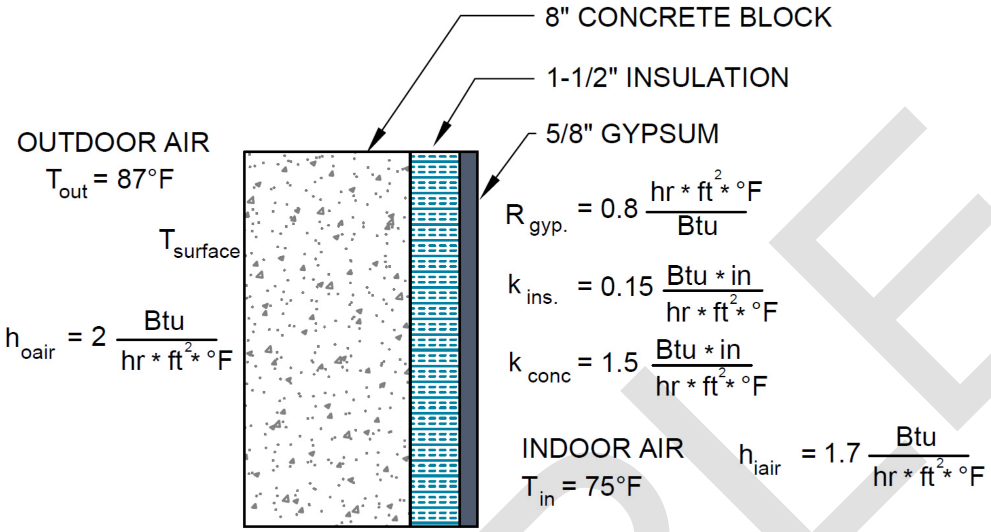
To find the convective heat transfer coefficient for fluids inside the pipe, several factors must first be determined to know which equation to use. The first step in finding the convective heat transfer coefficient is to find the Reynolds number. The Reynolds number is the ratio of the inertial forces to the viscous forces. The Reynolds number describes whether or not a fluid is turbulent or laminar. A higher number implies a turbulent flow, typically above 2,300.

$$Re = \frac{D * v}{\nu}$$

$$D = diameter\ of\ pipe\ (ft); v = velocity\ \left(\frac{ft}{s}\right); \nu = kinematic\ viscosity\ \left(\frac{ft^2}{s}\right)$$

7.2 Problem 2 - Calculate Overall Heat Transfer Coefficient

Calculate the overall heat transfer coefficient for the following wall conditions.



a) $0.06 \frac{Btu}{hr*ft^2*°F}$

b) $.11 \frac{Btu}{hr*ft^2*°F}$

c) $.21 \frac{Btu}{hr*ft^2*°F}$

d) $15 \frac{Btu}{hr*ft^2*°F}$

The correct answer is most nearly, (c) 650,000 W.

(a) 50,000 W

(b) 300,000 W

(c) 650,000 W

(d) 1,520,000 W

8.5 Solution 5 – Pipe Resistances

A pipe has an outer diameter of 1.315 inches and an inner diameter of 1.049 inches. The thermal conductivity of the pipe material is 20 Btu/h-ft-°F. The inner convective heat transfer coefficient between the fluid within the pipe and the inner pipe walls is 150 Btu/h-ft^2-°F. The outer convective heat transfer coefficient between the outer pipe wall and ambient air is 50 Btu/h-ft^2-°F. What is the overall heat transfer coefficient? What is the overall heat transfer coefficient per length of pipe?

The heat transfer area changes with the pipe radius. Therefore, the area is kept integral to each layer of pipe and the composite heat transfer coefficient is taken over a generic area, U*A. The question is asking for the heat transfer coefficient per length of pipe, so solve for U*A/L.

First, convert all heat transfer coefficients to resistances.

$$R_{inner,convective} = \frac{1}{150} = 0.0067 \left(\frac{h - ft^2 - {}^\circ F}{Btu}\right)$$

$$R_{outer,convective} = \frac{1}{50} = 0.02 \left(\frac{h - ft^2 - {}^\circ F}{Btu}\right)$$

For the conductivity through the pipe, you need the equivalent thickness of a pipe.

$$t_{equiv} = r_2 \ln\left(\frac{r_2}{r_1}\right) = \left(\frac{1.315\ in}{2}\right) \ln\left(\frac{\frac{1.315\ in}{2}}{\frac{1.049\ in}{2}}\right) = 0.1486\ in = 0.01238\ ft$$

$$R_{pipe,conductive} = \frac{0.01238\ ft}{20 \frac{Btu}{h - ft - {}^\circ F}} = 0.000619\ \frac{h - ft^2 - {}^\circ F}{Btu}$$

Finally, add up all the resistances, since all the materials are in series. You need to be sure to multiply the resistance by the inverse of the applicable area per unit length of pipe.

$$Inner\ Area\ per\ ft\ of\ pipe = 2\pi r_{inner} L = 2\pi * (0.5245\ in)\left(\frac{1}{12}\right)(1\ ft) = 0.275\ ft^2/ft$$

6 - Fluid Mechanics

Fluid Properties

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Section 6.0 – Principles Fluid Mechanics

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$$B_{rising}\ when, \qquad \rho_{fluid} * V_{fluid\ displaced} * g > \rho_{object} * V_{object} * g$$

4.0 INCOMPRESSIBLE FLUIDS

The HVAC & Refrigeration PE exam focuses only on incompressible fluids and primarily covers pressure drop & friction loss through ducts and pipes. This discussion on friction loss is included in the Systems & Components section. This section will cover some basic Fluid Mechanics topics under incompressible fluids, besides friction loss.

You do not need to study compressible fluids, since this topic is not regularly covered in practice in the HVAC & Refrigeration field. The Thermal & Fluids PE exam covers compressible fluids, since compressed air is a common topic in the Thermal & Fluids field.

Incompressible fluids do not occur in the real world. Incompressible fluids were created to describe a range of fluids, in order to make calculations simpler. The calculations are simpler because incompressible fluids are assumed. An incompressible fluid is a fluid that does not change in volume of the fluid due to external pressure. Most of the basic calculations done in fluid mechanics are done assuming the fluid is incompressible. The approximation of incompressibility is acceptable for most of the liquids as their compressibility is very low. However, the compressibility of gases is high, so gases cannot be approximated as incompressible fluids. The compressibility of an incompressible fluid is always zero.

4.1 BERNOULLI'S EQUATION

The fundamental equation for incompressible, steady flow fluids, is Bernoulli's equation, which essentially says that the energy will be conserved between two points in a system. The fluid energy will either be present as pressure, kinetic, or potential energy. The total energy in state 1 will equal the energy in state 2 plus any losses due to friction in the fluid.

$$[Pressure_1 + Kinetic_1 + Potential_1] = [Pressure_2 + Kinetic_2 + Potential_2] + Friction\ Losses$$

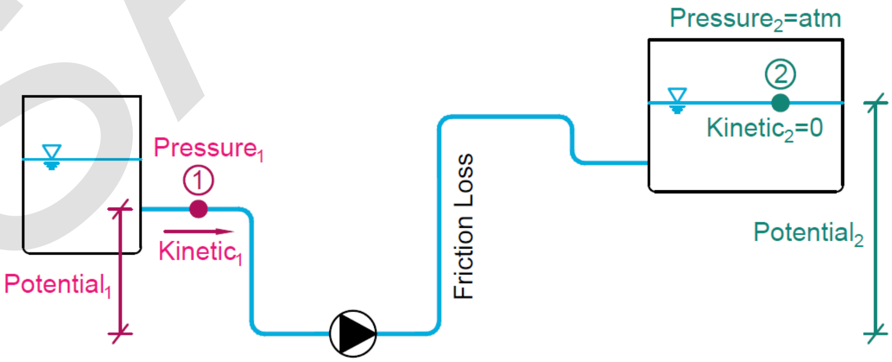

Figure 11: Illustration of Bernoulli's Principle. Energy in state 1 is conserved in state 2 in the form of pressure, kinetic, or potential energy after any losses due to friction.

This equation and its principles are the basis of many equations used in this chapter. The full equation is written out as follows. The exam and this book will focus on the English units (IP) version.

$$\frac{P_1}{\rho g}+\frac{v_1^2}{2g}+z_1=\frac{P_2}{\rho g}+\frac{v_2^2}{2g}+z_2+h_f+h_{f,fitting}\ \ [SI]$$

$$\frac{P_1 g_c}{\rho g}+\frac{v_1^2}{2g}+z_1=\frac{P_2 g_c}{\rho g}+\frac{v_2^2}{2g}+z_2+h_f\ +h_{f,fitting}\ \ [IP]$$

Notice that the IP version requires the gravitational constant conversion factor, g_c, in order to convert lbf in the pressure units (lbf/in^2) to lbm in the density units (lbm/ft^3). Since g=32.2 ft/s^2 and g_c=32.2 (lbm/lbf)*(ft/s^2), the g term essentially cancels out to P/ρ.

$$\frac{P_1}{\rho}+\frac{v_1^2}{2g}+z_1=\frac{P_2}{\rho}+\frac{v_2^2}{2g}+z_2+h_f+h_{f,fitting}\ \ [IP, simplified]$$

$$where\ P=psi(lbf/in^2), \rho=lbm/ft^3$$

However, for completeness the g_c values will be written out in this book.

4.2 FRICTION LOSS: DARCY WEISBACH

Friction loss in a fluid system, the h_f term in the Bernoulli's equation, is found through the use of either the Darcy Weisbach equation or the Hazen-Williams equation. The Darcy Weisbach equation is slightly more involved and will be explained below, starting with the equation. The Hazen-Williams equation is explained in an upcoming topic.

$$h_f=\frac{fLv^2}{2Dg}\ [Darcy\ Weisbach\ Equation]$$

$$where\ h_f=pressure\ loss\ [ft\ of\ head]; f=Darcy\ friction\ factor; v=velocity\ \left[\frac{ft}{sec}\right],$$

$$L=Pipe\ Length\ (ft);\ D=inner\ diameter\ [ft], g=gravity\ \left[32.2\frac{ft}{sec^2}\right]$$

For laminar flow through a circular tube, the friction factor is simply found as 64 divided by the Reynold's number.

$$f_{pipe,laminar}=\frac{64}{Re}$$

For turbulent flow, the calculations require a few more steps and are discussed below. During the exam, in order to quickly complete a friction loss question using the Darcy Weisbach Equation, know where all the necessary tables, graphs, and equations are in the *NCEES Mechanical PE Reference Handbook*.

5.3 PROBLEM 3 – PITOT TUBE

A duct with air flowing at 0.075 lb/ft3 has a pitot tube connected to a manometer. The manometer liquid has a density of 900 kg/m^3. The pressure differential is measured as a height of 4 centimeters. What is the velocity of air in the duct?

(a) 27 m/s

(b) 41 m/s

(c) 57 m/s

(d) 81 m/s

5.4 PROBLEM 4 – VENTURI METER

A Venturi meter has the following diameters, D_1 = 200 mm and D_2 = 100 mm. A manometer is connected between the two locations. The manometer has a delta reading of 100 mm. The density of the manometer liquid is 5,000 kg/m^3. What is the volumetric flow rate of water (density = 1,000 kg/m$^{3)}$ through the meter?

(a) $1.056\frac{m^3}{s}$

(b) $0.194\frac{m^3}{s}$

(c) $0.059\frac{m^3}{s}$

(d) $0.0254\frac{m^3}{s}$

7 - Energy Mass Balance

Evaporation | Condensation | Dehumidification | Mixing

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Section 7.0 – Principles Energy/Mass Balance

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2.0 CONSERVATION OF MASS

Conservation of mass is a law in nature and states that mass cannot be created or destroyed. Therefore, when transfers of states or changes in phases occur in a system, a mass balance equation can be created to solve for the unknown properties in a system or cycle.

Essentially, the equations are derived from the law that

$$\sum \text{mass}_{\text{in}} = \sum \text{mass}_{\text{out}}$$

Similarly the flow of mass entering the system will be equal to the flow leaving the system, like in a condenser or a boiler.

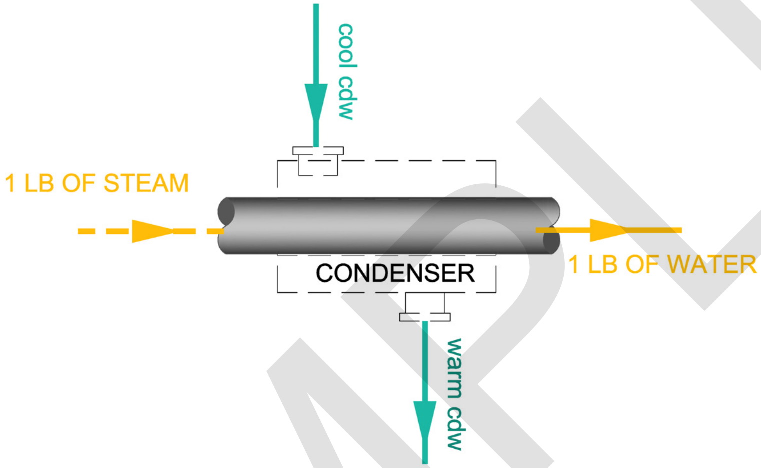

Figure 1: This figure shows one pound of steam entering a condenser and leaving as one pound of water.

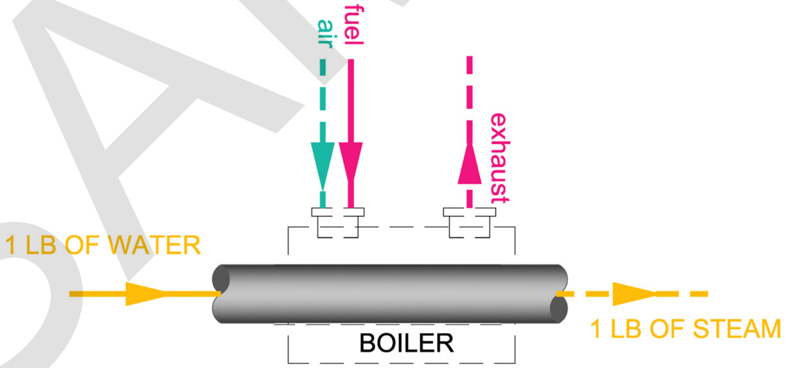

Figure 2: This figure shows one pound of water entering a boiler and leaving as one pound of steam.

8.0 PRACTICE PROBLEMS

8.1 PROBLEM 1 - HUMIDIFIER

Background: An evaporative humidifier works by blowing air over a wet medium, evaporating the water in the medium into the air, thereby increasing the humidity ratio of the air. This will reduce the dry bulb temperature of the air since the air lost heat to evaporate the water in the medium. For the purposes of this problem, this effect will not be taken into account.

1,000 CFM of air at 75°F DB/20% relative humidity passes through a humidifier with 8,000 Btu/h of latent heat, assume that the humidifier is 100% effective. What is the resulting state of air?

(a) 70°F DB/22.4% Relative Humidity

(b) 72°F DB/33.2% Relative Humidity

(c) 75°F DB/29.3% Relative Humidity

(d) 75°F DB/35.1% Relative Humidity

8.2 PROBLEM 2 – DEHUMIDIFIER

Background: A desiccant dehumidifier most often has a silica gel medium, which absorbs moisture from air as it is passed over the medium. For the purposes of this problem, it is assumed that the dry bulb temperature is not affected and the dehumidifier only provides latent cooling (dehumidification).

1,000 CFM of air at 80°F DB/72°F WB passes through a de-humidifier with 10,000 Btu/h of latent heat, assume that the de-humidifier is 100% effective. What is the resulting state of air?

(a) 80°F DB/.009 lbm H20/lbm dry air

(b) 80°F DB/.011 lbm H20/lbm dry air

(c) 80°F DB/.013 lbm H20/lbm dry air

(d) 80°F DB/.015 lbm H20/lbm dry air

8 - Heating & Cooling Loads

Envelope | Fenestration | People | Lighting | Miscellaneous | Ventilation

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Section 8.0 – Application Heating & Cooling Loads

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1.0 INTRODUCTION

Calculating heating and cooling loads is one of the first skills that a practicing HVAC engineer learns on the job. A cooling and heating load calculation serves as the basis for the selection of all key HVAC equipment like, cooling/heating coils, pumps, cooling towers, chillers, etc.

On the PE exam you should be able to complete a cooling and heating load calculation. This involves understanding the key aspects that make up the cooling and heating loads. The following are the loads from external sources, roof, wall, skylight and windows. Internal loads include people, lighting and miscellaneous equipment. The final two loads are from ventilation and infiltration. Each of these loads will be discussed in detail in this section.

Heating & Cooling Loads
7-11 questions

Cooling Loads

- Roof/wall
- Skylight/window
- People
- Lighting
- Miscellaneous equipment
- Ventilation/infiltration

Heating Loads

- Roof/wall
- Skylight/window
- Ventilation/infiltration

$$U_{total,window} = \frac{U_{center}A_{center} + U_{edge}A_{edge} + U_{frame}A_{frame}}{A_{total,window}}$$

$$where\ \ U_{center} = center\ of\ glass\ heat\ transfer\ coefficient; U_{edge} = center\ of\ glass$$

$$heat\ transfer\ coefficient;\ U_{frame} = window\ frame\ heat\ transfer\ coefficient$$

In the above equation, there are three different areas of heat transfer rates. The center of glass, U_{center}, uses the properties of the glass. The edge of glass, U_{edge}, takes into account the heat from the frame that is conductively transferred to the outer edge of the glass. This value based on the frame and glass type. Finally, the frame material will have its own heat transfer rate.

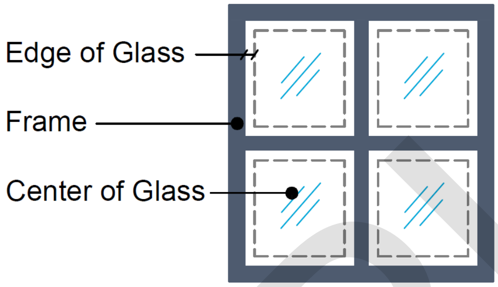

Figure 4: The overall U-value calculation for fenestration includes the frame, glass, and outer edge of the glass in parallel. The frame will affect the heat transfer rate through the outer edge of the glass.

2.4.2 SOLAR RADIATION LOADS

The radiant time series method is used to calculate the solar radiation, i.e. solar transmission loads through a window or skylight. Normally the radiant time series method can be lengthy, but if enough variables are provided for you in the problem, the calculation can be simplified. The solar radiation is calculated by multiplying the area of the window or skylight by the total incident irradiance (E_t) , the solar heat gain coefficient (SHGC), and the indoor solar attenuating factor (IAC), which is used if there is interior shading. The IAC is optional, and may be excluded if it is not indicated in the problem.

$$Q_{solar,window} = A * SHGC * E_t * IAC$$

$$where\ SHGC = solar\ heat\ gain\ coefficient, varies\ by\ solar\ incident\ angle/framing;$$

$$E_t = Total\ Incident\ Irradiance \left[\frac{Btu}{h - ft^2}\right];\ IAC = indoor\ solar\ shading, optional$$

The SHGC, E_t, and IAC all vary based on the solar incident angle, θ, which is the angle that the sun is hitting the window or skylight. The solar incident angle varies by building orientation, latitude of the earth, the day, and the time. Thus, the SHGC, E_t, and IAC be unique for each wall direction, location, and time, and must be given.

5.0 SOLUTIONS

5.1 SOLUTION 1 - CALCULATE HEAT LOAD THROUGH WALL

An east facing exterior wall consists of 8” concrete (R-Value = 2.0), with 2” insulation (R-Value = 8.0) and 5/8” gypsum board (R-Value = 0.8). The wall has dimensions of 8’ height by 20’ long. If the CLTD at peak load is 20 F, calculate the total heat load through the wall. The indoor temperature is 75 F and the outdoor temperature is 87 F.

First calculate the U-Value

$$U_{overall} = \frac{1}{R_{conc} + R_{ins} + R_{gyp}}$$

$$U_{overall} = \frac{1}{2 + 8 + 0.8} = .093 \frac{Btu}{hr * ft^2 * °F}$$

Second calculate the area.

$$8' X\ 20' = \ 160\ ft^2$$

Third calculate the heat.

$$Q = U * A * (CLTD)$$

$$Q = 0.093 \frac{Btu}{hr * ft^2 * °F} * 160\ ft^2 * 20°F$$

$$Q = 296 \frac{Btu}{hr}$$

5.2 SOLUTION 2 - CALCULATING HEAT LOAD FROM PEOPLE

An office is maintained at space conditions of 75 °F and 50% RH. There are fifteen office workers located in a 2,000 SF office building. Each worker has their own computer with flat screen. What is the total heat load from the people to the space?

The total load from each individual person depends on the person's activity level. Refer to ASHRAE Fundamentals to find the total heat gain from an office worker.

$$Heat\ gain\ per\ person = \frac{450 \frac{Btu}{hr}}{person}$$

9 - Equipment and Components

Cooling Towers/Fluid Coolers | Boilers/Furnaces | Heat Exchangers | Condensers/Evaporators | Pumps/Compressors/Fans | Cooling/Heating Coils | Control System Components | Refrigerants | Refrigeration Components

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Section 9.0 – Application Equipment & Components

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1.0 INTRODUCTION

This section of the exam guide book focuses on the Mechanical Equipment and Components used in the HVAC & Refrigeration field. *This section accounts for approximately 16-24 questions on the HVAC & Refrigeration Mechanical PE exam.*

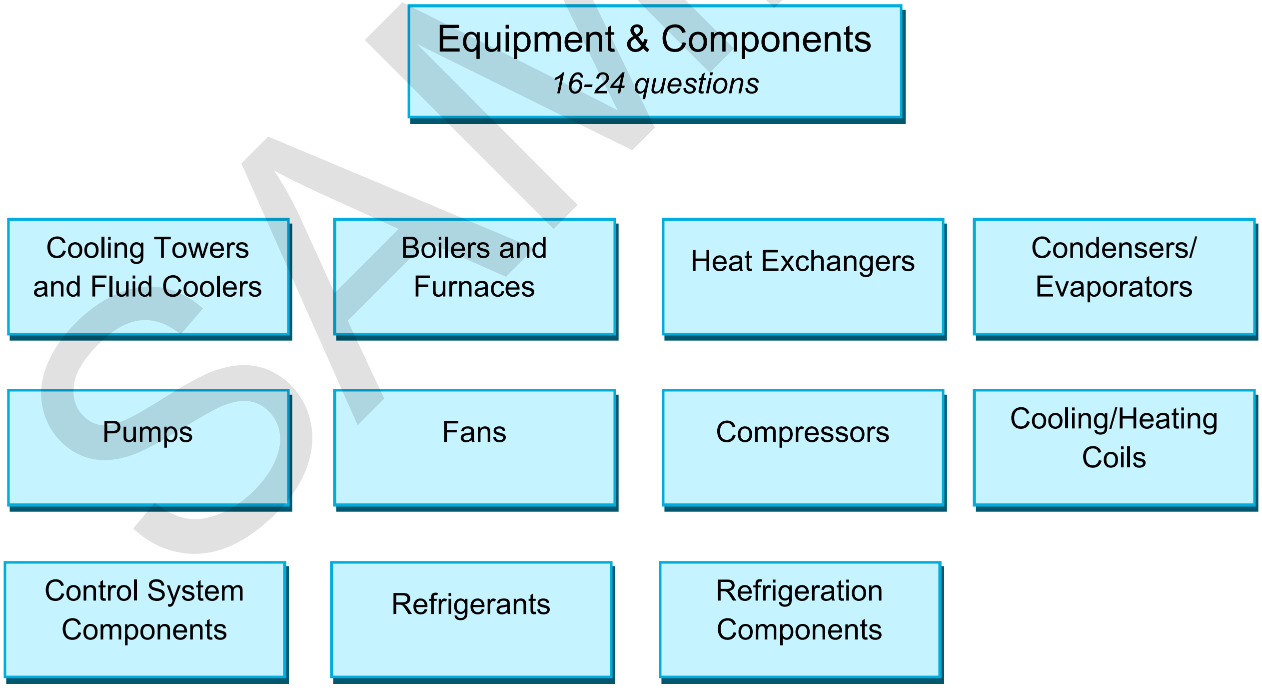
The equipment discussed in this section includes the most common pieces of equipment and systems that are on the PE exam. The next section uses the equipment and components and puts them together into various systems.

Air handling and distribution equipment: fans, dampers, cooling/heating coils and heat exchangers.

Fluid handling and distribution equipment: pumps, cooling towers, fluid coolers, heat exchangers and valves.

Refrigerant handling and distribution equipment: chillers, condensers, evaporators and compressors.

Heating handling and distribution equipment: boilers and furnaces.



2.0 COOLING TOWERS

Cooling towers are mechanical pieces of equipment that function on the principle of evaporative cooling. Evaporative cooling is the process by which a liquid is cooled to a lower temperature by evaporating a small portion of the liquid into an airstream. Relatively dry air moves through a falling liquid and as the air moves it picks up water vapor from the liquid, thereby increasing the air's moisture content. In order for the liquid to evaporate, the liquid needs a heat source to meet the latent heat of vaporization. This heat source is the sensible heat loss from the remaining liquid. The fluid running through the cooling tower is cooled either by direct or indirect contact with the evaporation process. In this section, direct contact, also known as open circuit cooling towers, is described. Indirect contact is discussed in the fluid cooler section at the end of this topic.

An open circuit cooling tower consists of two fluid flows, the air flow and the water flow. The water flow starts from the top of the cooling tower. Warm water is pumped to a series of nozzles. The nozzles' purpose is to break up the water into tiny droplets to increase the surface area of the water that is in contact with the air stream. The droplets then fall through a fill material, which also serves to break up the droplets further to increase the surface area of the water. As the water moves downward it steadily decreases in temperature as heat is lost due to evaporation. Finally, the water collects at the basin, where it is sucked out and distributed to its required location.

The air flow starts at the bottom of the tower, where cold dry air is brought into the cooling tower where it comes into contact with the water droplets. As the air moves upward through the tower it picks up water vapor and slightly increases in temperature. Prior to exiting the cooling tower, the air must travel through the drift eliminators, which is a series of baffles. The purpose of the drift eliminators is to catch any suspended water droplets in the air stream and return them to the fill.

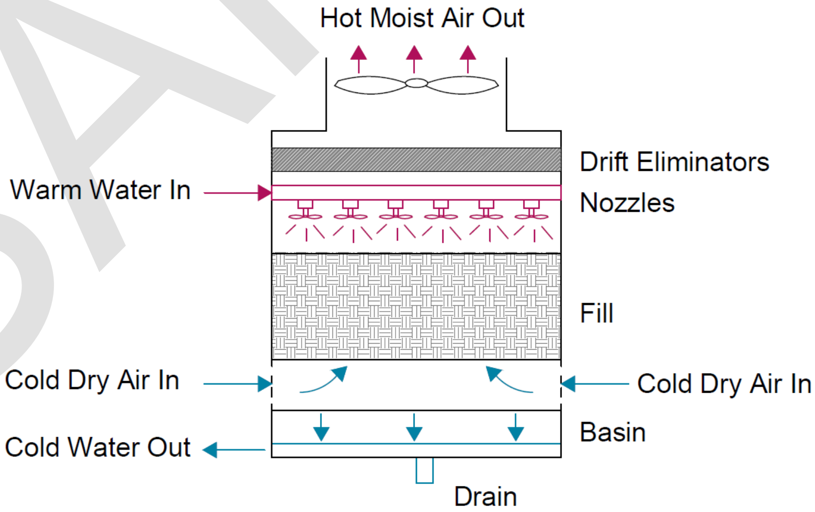


Figure 1: Cooling tower schematic

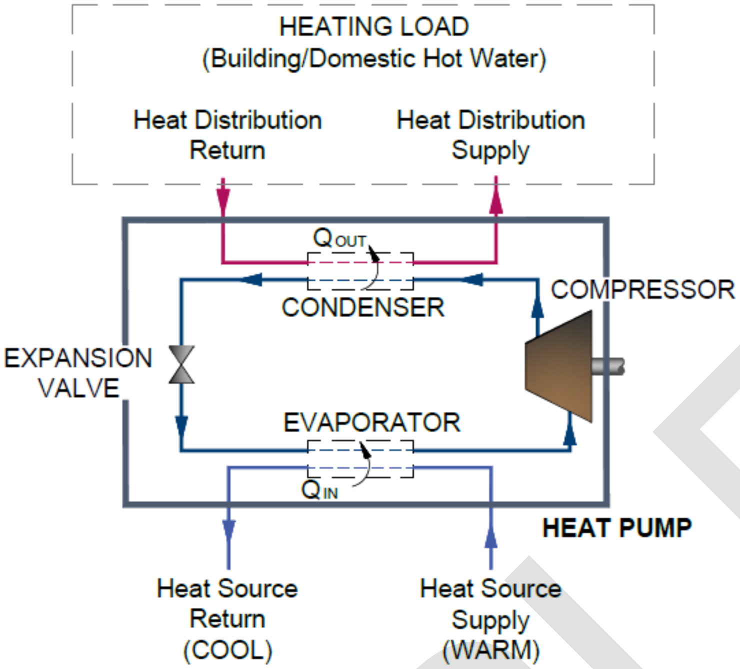


Figure 37: Heat Pump Vapor Compression Cycle

Heat pumps are also commonly integrated within the VRF system, allowing the units to switch between heating and cooling. A four way valve, called the reversing valve, will redirect the refrigerant flow to swap the outdoor and indoor coils between condenser and evaporator modes, effectively switching the indoor unit between a heating and cooling coil.

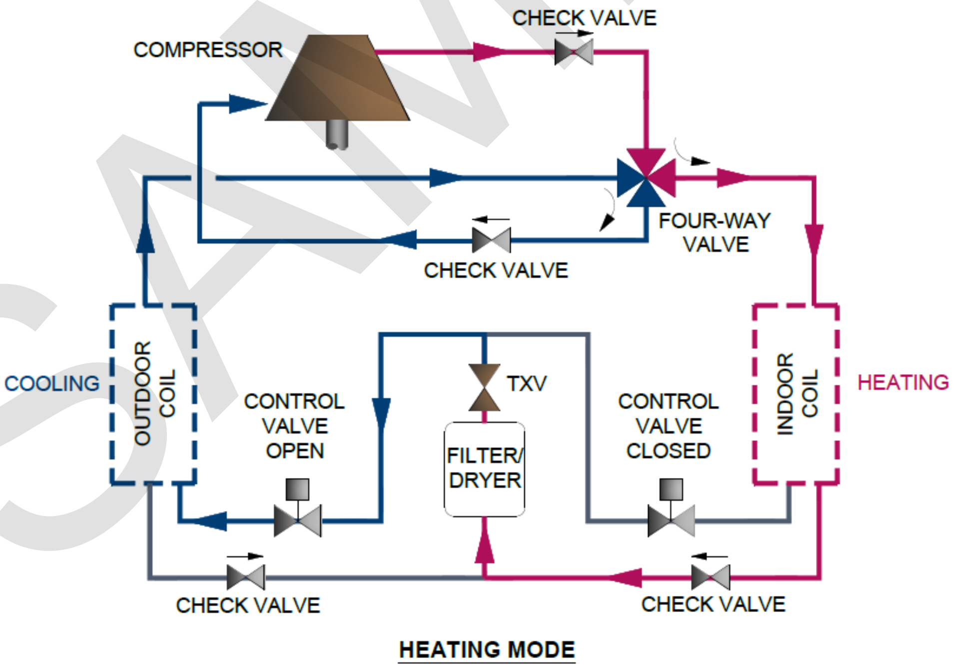


Figure 38: The VRF is set to heat pump, heating mode. The four way reversing valve directs the refrigerant to flow from the compressor to the indoor coil, setting the indoor coil acts as the condenser and the outdoor coil as the evaporator.

$$\frac{BHP_1}{BHP_2} = \frac{N_1^3}{N_2^3}; if\ diameter\ is\ held\ constant$$

7.4.1 PUMP SIMILARITY LAWS

You may come across these formulas, if you encounter a question that compares two similar pumps. These formulas are called the similarity laws. These laws compare similar pumps within the same series of pumps. The previous formulas compared the original condition and new condition of the same pump. These formulas compare two similar pumps, with different diameters. In order to best understand what is meant by same series of pumps, visit a manufacturer's website and you will see various pump series that have varying sizes within the same series. Within a series of pumps, a pump with "x" diameter impeller and "y" diameter volute can be compared to another pump in the same series of pumps, but with "2x" diameter impeller and "2y" diameter volute. The second pump is similar but has twice the diameter of the first pump.

$\frac{Q_1}{Q_2}$	=	$\left(\frac{D_1}{D_2}\right)^3 \left(\frac{N_1}{N_2}\right)$
$\frac{H_1}{H_2}$	=	$\left(\frac{D_1}{D_2}\right)^2 \left(\frac{N_1}{N_2}\right)^2$
$\frac{BHP_1}{BHP_2}$	=	$\left(\frac{D_1}{D_2}\right)^5 \left(\frac{N_1}{N_2}\right)^3 \left(\frac{\rho_1}{\rho_2}\right)$
$\frac{Q_1}{Q_2}$	=	$\left(\frac{D_1}{D_2}\right)^2 \left(\frac{H_1}{H_2}\right)^{.5}$
$\frac{N_1}{N_2}$	=	$\left(\frac{D_2}{D_1}\right) \left(\frac{H_1}{H_2}\right)^{.5}$
$\frac{BHP_1}{BHP_2}$	=	$\left(\frac{D_1}{D_2}\right)^2 \left(\frac{H_1}{H_2}\right)^{1.5} \left(\frac{\rho_1}{\rho_2}\right)$
$\frac{N_1}{N_2}$	=	$\left(\frac{D_2}{D_1}\right)^3 \left(\frac{Q_1}{Q_2}\right)$
$\frac{H_1}{H_2}$	=	$\left(\frac{D_2}{D_1}\right)^4 \left(\frac{Q_1}{Q_2}\right)^2$
$\frac{BHP_1}{BHP_2}$	=	$\left(\frac{D_2}{D_1}\right)^4 \left(\frac{Q_1}{Q_2}\right)^3 \left(\frac{\rho_1}{\rho_2}\right)$

$$where\ Q = flow\ rate, D = diameter, N = speed, H = head\ pressure, BHP = power, \rho = density$$

7.5 PUMP WITH A MODULATING VALVE

A pump with a modulating valve will change the system resistance curve but it will not change the pump curve. The decrease and increase of system pressure as the modulating valve opens and closes, respectively, causes the system curve to change as shown in the figure below.

and Powell Valves. However another good source is at the control valve webpage at Emerson Process's website. If the link is not functional, please email me. You will find my contact information at the end of this book and the beginning of this book. Please read through these resources to increase you knowledge, so you can answer the experience type problems on the actual exam.

http://www.documentation.emersonprocess.com/groups/public/documents/book/cvh99.pdf

The various types of valves are good to understand but they are difficult to test on an exam, the sizing of the valves and the flow characteristics of a control valve is something that does fit this type of exam.

- Globe valve
  A globe valve consists of a plug and a seat. The plug is raised and lowered to increase and decrease flow through the valve.

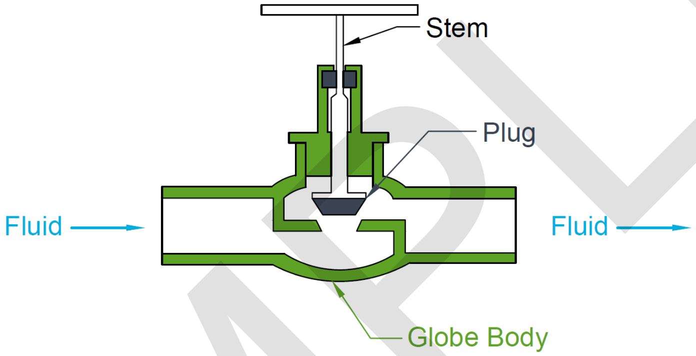
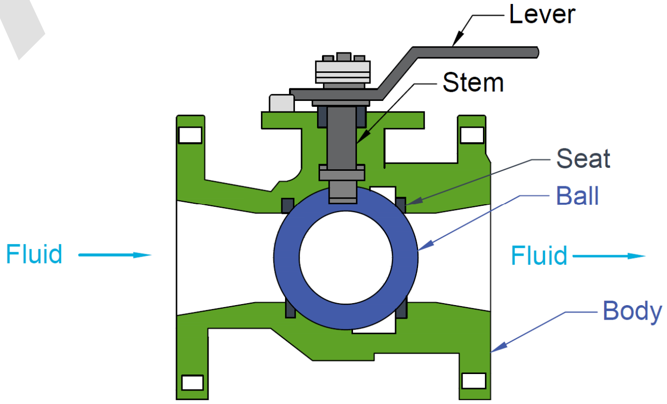


Figure 83: A section view of a globe valve. As the valve is closed, the plug is lowered into the seat, which blocks the fluid flow from moving up and to the right of the valve.

- Ball valve
  A ball valve is called a ball valve due to the ball shape in the center of the valve. This ball has an opening on sides 180 degrees opposite of each other. The rest of the valve is solid. When the valve is aligned such that the openings are in line with the fluid flow, then the valve is 100% open. When the valve is aligned such that the openings are perpendicular to the fluid flow, then it is 100% closed.



15.0 SOLUTIONS

15.1 SOLUTION 1 – FANS

Background: Two fans are placed in parallel. Each fan has the following performance, 2,000 CFM at 1.5 in. wg. If the fans are combined into a single 26” X 12” duct, then what is the resulting pressure at the end of an equivalent length of duct of 100’?

Assume standard conditions, density = 0.075 lbm/ft^3 and roughness factor of 0.0007 ft. $Kinematic\ Viscosity\ of\ Air \rightarrow 1.5\,x10^{-4}\frac{ft^2}{s}$

First calculate the equivalent diameter of the duct:

$$D_e = \frac{1.30*(a*b)^{0.625}}{(a+b)^{0.250}}$$

$$D_e = \frac{1.30*(12"*26")^{0.625}}{(12"+26")^{0.250}}$$

$$D_e = 19" = 1.5833\,ft$$

Next recognize that the fans are in parallel, thus the resulting flow rate is 4,000 CFM. Also the pressure at the outlet of the fan is assumed to be 1.5 in. wg.

On the PE exam, you will not have access to ASHRAE Fundamentals, so the other way to complete this problem is to use the equation from the NCEES Mechanical PE Reference Handbook.

$$Pressure\ Loss = \frac{12f}{D_e}L(\rho)\left(\frac{v}{1097}\right)^2$$

First, you need to find the friction factor from the Moody Diagram.

$$Velocity = 4{,}000\frac{ft^3}{min} \div \left(\frac{\pi D_e^2}{4}\right) = 4{,}000\frac{ft^3}{min} \div \left(\frac{\pi 1.5833^2}{4}\right) = 2{,}032\frac{ft}{min} = 33.88\frac{ft}{s}$$

$$Kinematic\ Viscosity = 1.5\,x10^{-4}\frac{ft^2}{s}$$

$$Re = \frac{33.88\frac{ft}{s}x1.5833}{1.5\,x\,10^{-4}\frac{ft^2}{s}} = 357{,}565$$

$$Relative\ Roughness = \frac{\varepsilon}{D} = \frac{0.0007\,ft}{19"/12} = 0.00044$$

From the Moody Diagram, you will see that the friction factor is equal to .018

10 - Systems and Components

Air Distribution | Fluid Distribution | Refrigeration | Energy Recovery | Basic Control Concepts

STUDY GUIDE
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Section 10.0 – Application Systems & Components

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1.0 INTRODUCTION

This section of the exam guide book focuses on the Mechanical Systems used in the HVAC & Refrigeration field. *The systems and components section accounts for approximately 16-24 questions on the HVAC & Refrigeration Mechanical PE exam.*

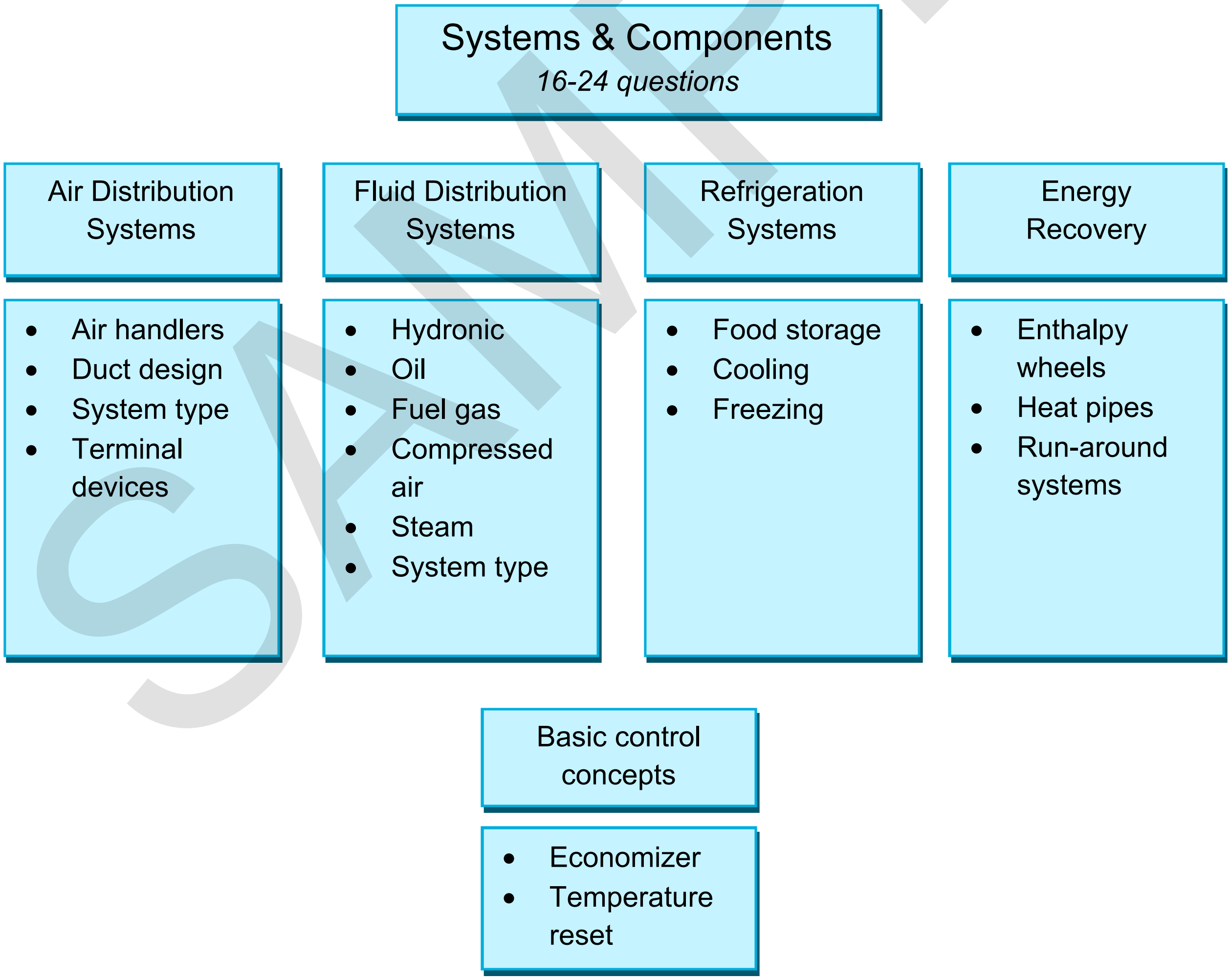
The systems discussed in this section include the most common systems that are on the PE exam. The previous section described the equipment that make up these systems in more detail. Also at the end of this section is a brief discussion on controls.

Air Distribution Systems: The air distribution systems consist of an air handler (coil and fan), ducting, air, and terminal devices.

Fluid Distribution Systems: A fluid distribution system consists of a pump, piping and the fluid.

Refrigeration Systems: Refrigeration systems are primarily used to cool and freeze food.

Energy Recovery: Energy recovery systems are additions onto an air distribution or fluid distribution system that make the air or fluid distribution system more efficient.



Systems & Components
16-24 questions

Air Distribution Systems
- Air handlers
- Duct design
- System type
- Terminal devices

Fluid Distribution Systems
- Hydronic
- Oil
- Fuel gas
- Compressed air
- Steam
- System type

Refrigeration Systems
- Food storage
- Cooling
- Freezing

Energy Recovery
- Enthalpy wheels
- Heat pipes
- Run-around systems

Basic control concepts
- Economizer
- Temperature reset

2.0 AIR DISTRIBUTION

In the HVAC field, air distribution systems are used to supply cold/hot air to various spaces to keep the occupants comfortable and/or to keep equipment at optimum conditions. Fresh air is also provided through the air distribution system to provide appropriate ventilation levels, in order to alleviate carbon dioxide (CO2) levels.

An air distribution system consists of a supply air system, return air system, outside air and exhaust air system. The supply air system consists of an air handling unit, supply ducting, dampers, terminal units and diffusers. An air handling unit is a fan with cooling/heating coils. The air handling unit cools/heats supply air and then distributes it through the ducting system, which consists of ducts, dampers and duct fittings. Once the air reaches the space, it is then directed to a terminal unit, which controls the amount and conditions of air distributed to that specific space. Next the air is delivered to the space through a supply air diffuser, this piece of equipment controls the way the air is distributed throughout the space. The return air system consists of return air registers, ducts, dampers and duct fittings. The return air system also exhausts air via the exhaust air system, before sending the return air back to the air handler, where the cycle begins again. At the air handling unit, the exhaust air is replaced with new outside air.

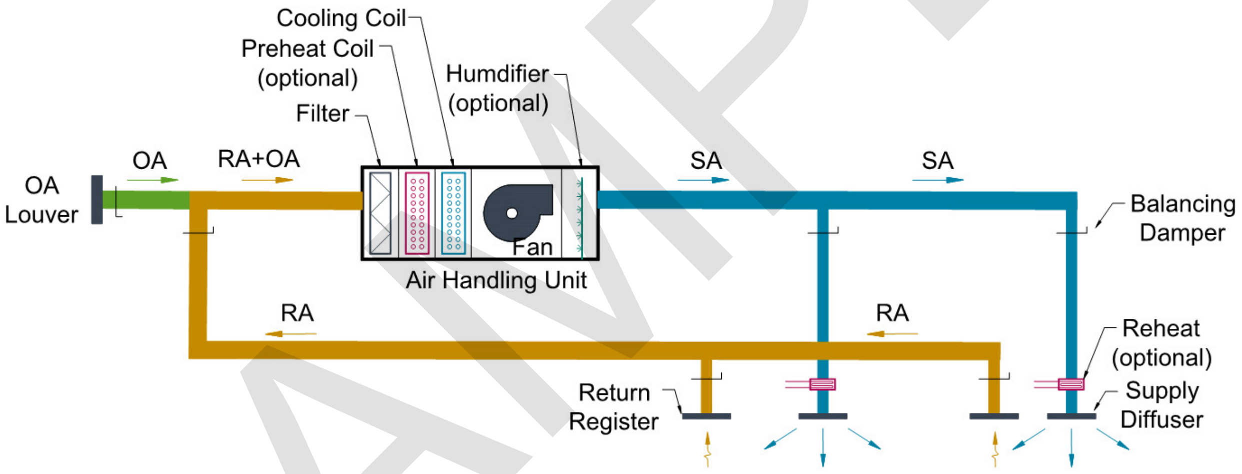


Figure 1: A typical air distribution system has an outside air and return air system that supply air to the air handler. The air handler will cool or heat and filter the air. Humidification may also be provided if needed at the air handler. The fan at the air handler will push the air through the supply air ducting system. Dampers and terminal units will be provided to control the airflow, in order to ensure that just the right amount of air is provided to each diffuser. Supply diffusers are provided to ensure proper distribution within the space.

2.1 AIR HANDLING UNITS

Air handling units or AHUs are a common piece of equipment in the HVAC & Refrigeration field. An AHU is a built-up, air moving and conditioning device. It is typically constructed of metal framing with a multitude of individual air handling components. Each of the individual

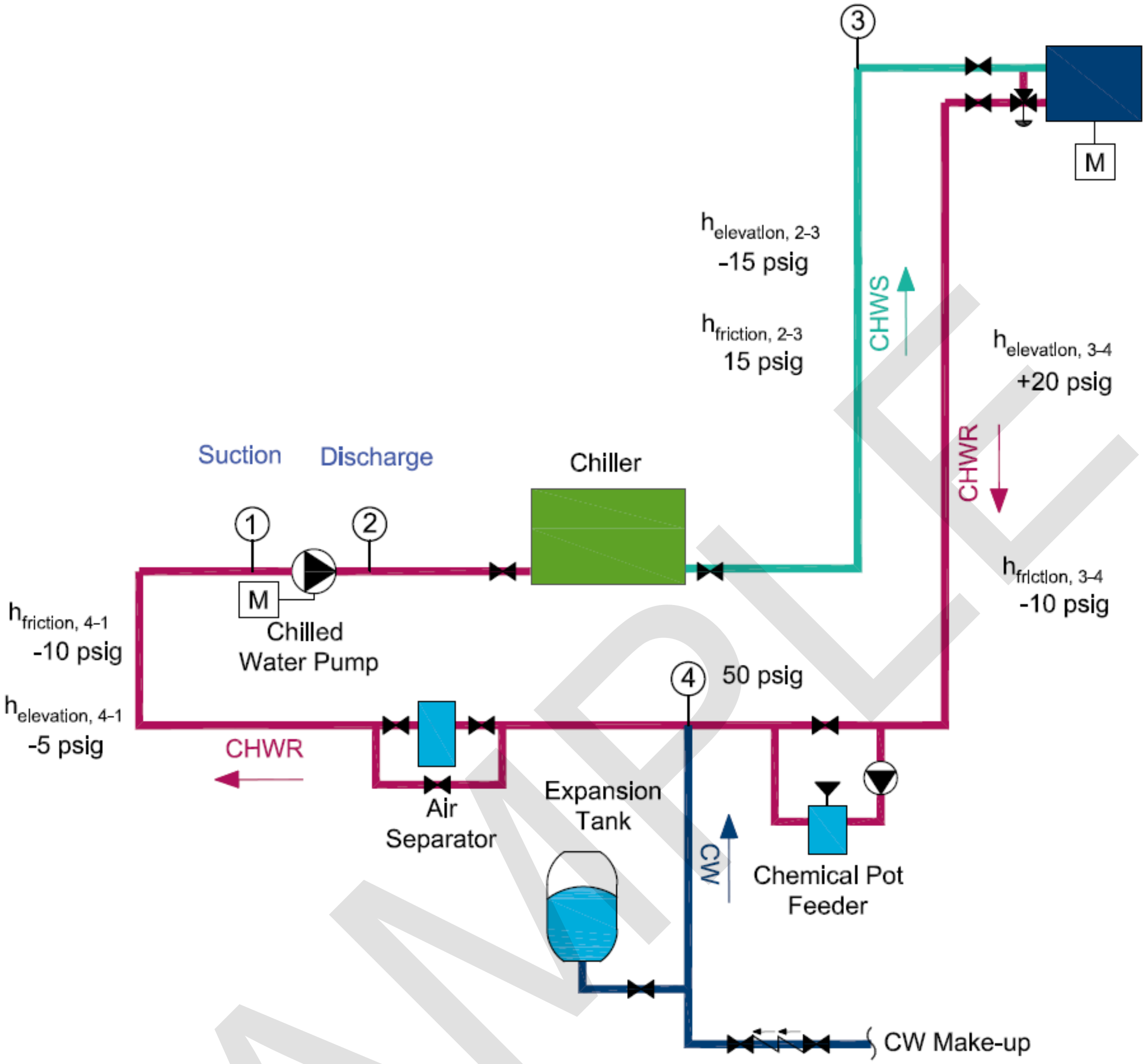


Figure 18: The typical closed system in the HVAC field is the chilled water system. In these types of systems, there is typically an expansion tank which is the location of constant pressure. You typically take this point and then calculate the suction pressure and the discharge pressure, in order to determine the total dynamic head or total pressure that the pump must provide.

The typical example of a *closed* system in the HVAC & Refrigeration field is the chilled water system serving the air handlers and chillers. The pump moves chilled water to and from the chiller and through the air handlers. The total dynamic head required at the pump accounts for only the *friction head* through the piping, chiller, fittings, other equipment and appurtenances. There is no static/elevation head because the system is closed.

7.21 PROBLEM 21 – CONTROLS

A cooling tower relief control scheme accomplishes which of the following?

(A) Increases condenser water temperature to the chiller, in order to relieve the cooling tower.

(B) Decreases condenser water temperature to the chiller, in order to relive the chiller.

(C) Cycles cooling tower fans off, to relieve the stress on the cooling tower.

(D) Decreasing condenser water flow rate, in order to relieve the cooling tower.

11 - Supportive Knowledge

Codes and Standards | Air Quality and Ventilation | Vibration Control | Acoustics

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Section 11.0 – Supportive Knowledge

Table of Contents

1.0 INTRODUCTION

In engineering many design issues are regulated by codes and references. These codes govern the minimum requirements for mechanical design and the engineer must be familiar with these codes in order to avoid making a legal mistake. Also the engineer should keep handy a set of references to solve typically encountered problems. This section will introduce the engineer to the must-have references for the HVAC & Refrigeration Engineer.

This section accounts for approximately 3-5 questions on the HVAC & Refrigeration Mechanical PE exam.

Additionally, HVAC design requires an understanding of supplementary concepts that include air quality, vibration and noise. These supportive tools are necessary for the health and comfort of the building occupant. In mechanically conditioned buildings, air quality is an essential design component to ensure proper ventilation of CO2 or hazardous substances and an overall safe building environment. It is also important to understand how to mitigate the noise and vibrations from rotating equipment and the sound transmissions through ductwork for privacy or security reasons.

Since the Mechanical PE Exam is computer based, you will not be allowed to bring in these references to the exam. So you will need to have these codes memorized. This section, along with the other Application based problems gives engineers with more experience an advantage. If you don't have experience, I suggest reading the recommended references and using flash cards to remember the general concepts, names and descriptions of codes. The equations for acoustics and vibration are included in the handbook.

Supportive Knowledge

3-5 questions

Codes and Standards	Air Quality and Ventilation	Vibration Control	Acoustics
• ASHRAE • NFPA • Montreal Protocol	• Filtration • Dilution	• Transmission effect • Isolation	• Sound control • Absorption • Attenuators • Noise-level criteria

2.0 CODES/STANDARDS

An engineer should be aware of the codes/standards that apply to their line of work. The primary codes and standards that apply to the HVAC & Refrigeration engineer revolve around American Society of Heating, Refrigerating and Air Conditioning (ASHRAE). The primary focus of the ASHRAE Standards are in mechanical building equipment and systems, like cooling towers, air handlers, boilers, chillers, air distribution, water distribution, etc.. The standards govern minimum requirements for these systems and equipment in the areas of energy efficiency (ASHRAE 90.1), indoor air quality (ASHRAE 62.1), thermal comfort (ASHRAE 55) and refrigeration safety (ASHRAE 15 & ASHRAE 34).

The following sections go into more detail in the specific ASHRAE standards. It is recommended that the HVAC & Refrigeration engineer be familiar with each of the codes and standards listed below at a minimum.

2.1 ASHRAE 15

ASHRAE 15 is titled, "Safety Standard for Refrigeration Systems". Refrigerants are dangerous and in some cases highly flammable and toxic. This standard recognizes the danger that refrigerants pose to humans and the environment. It creates minimum safety requirements for Refrigeration Systems and the locations of these systems. The HVAC & Refrigeration engineer should be familiar with the ventilation requirements for evacuating a refrigerant leak. There are also other safety requirements of a room that hold refrigerant, like a mechanical chiller room.

Table 1: ASHRAE 15 Table of Contents and brief descriptions of each chapter.

Chapter	Description
1	Purpose - Safe design, construction, installation operation of a refrigeration system.
2	Scope – Compressor and absorption refrigerant systems
3	Definitions
4	Occupancy Classifications – Institutional, Commercial, Residential, etc.
5	Refrigerating System Classifications – Direct or indirect. High or low probability.
6	Refrigerant Safety Classifications – Single compound or blend.
7	Restrictions on Refrigerant Use – Limit pounds in occupied spaces, ducts, etc.
8	Installation Restrictions – Minimize safety concerns, damage to pipes/seals, etc.
9	Design & Construction of Equipment & Systems – Materials are chemically compatible, can withstand system pressure, pressure relief safely,
10	Operation & Testing – Conduct pressure tests.
11	General Requirements – Safeguard the equipment during maintenance and secure access.
12	Precedence with Conflicting Requirements – No applicable information.

$$Critically\ Damped \rightarrow \zeta = 1$$

$$Characterizing\ Function \rightarrow y(t) = C_1 e^{rt} + t * C_2 e^{rt}$$

$$r = \omega_n; C_1 and\ C_2\ are\ constants$$

4.4.4 OVERDAMPED

The final classification occurs when the damping ratio is greater than 1. The machine design system will decay exponentially back to equilibrium but not as fast as the critically damped classification.

$$Overdamped \rightarrow \zeta > 1$$

$$Characterizing\ Function \rightarrow y(t) = C_1 e^{r_1 t} + C_2 e^{r_2 t}$$

$$r_1 = -\left(\zeta - \sqrt{\zeta^2 - 1}\right)\omega_n; r_2 = -(\zeta + \sqrt{\zeta^2 - 1})\omega_n;$$

$$C_1 and\ C_2\ are\ constants$$

The equations for the constants are not shown because this would make the equations take longer than 6 minutes to solve on the PE exam. The constants are a function of initial displacement and velocity. In most problems, you will be given the constants in order to focus on the more critical concepts in these equations like damping ratio, natural frequency and damped frequency.

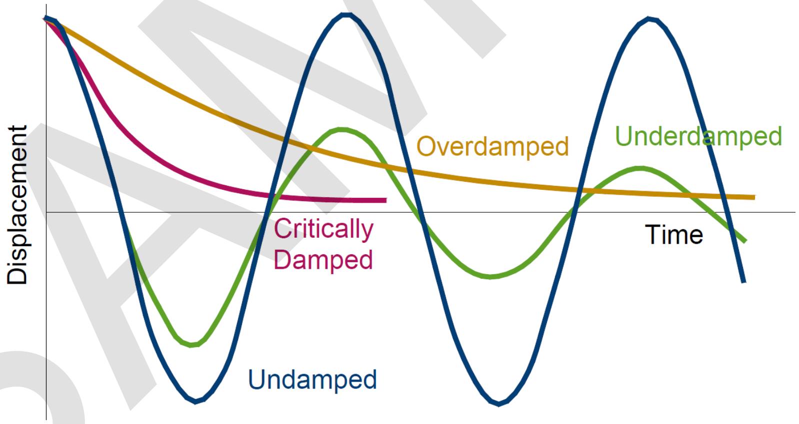

Figure 5: There are four classifications of damped systems that depend on the damping ratio. This graph shows the different effects of the different damping classifications.

4.5 TRANSMISSIBILITY

Transmissibility is a term used to describe the effectiveness of the damping. Transmissibility is the ratio of the vibrational force that is measured after damping to the ratio of the vibrational

6.7 PROBLEM 7 – REFRIGERANTS

Problem: Which of the following best ranks refrigerants from most to least harmful to the ozone, from left to right?

(a) R-11 - Ammonia - R-134a - R-22

(b) R-11 - R-134a - R-22 - Ammonia

(c) R-22 - Ammonia - R-134a - R-11

(d) R11 - R-22 - R-134a – Ammonia

6.8 PROBLEM 8 – SOUND

The current sound level is 90 decibels. If the sound pressure is halved, then what will be the new sound level?

(a) 45 dB

(b) 75 dB

(c) 84 dB

(d) 87 dB

R-11 is the most harmful refrigerant because it is a CFC and was banned, R-134a is a HFC and does not contain chlorine and has an ODP of 0, however R-22 does contain chlorine since it is a HCFC. Thus this ranking is incorrect.

(c) R-22 - Ammonia - R-134a - R-11

R-22 is a HCFC and contains chlorine. Ammonia and R-134a both do not contain chlorine and both have an ODP of 0. However, R-11 is a CFC and has a high ODP. Thus this ranking is incorrect.

(d) R11 - R-22 - R-134a - Ammonia

R-11 is the most harmful refrigerant because it contains chlorine, R-22 does contain chlorine since it is a HCFC, but to a lesser extent than R-11. Ammonia and R-134a both do not contain chlorine and both have an ODP of 0. Thus this ranking is correct.

Correct Answer: D

7.8 SOLUTION 8 – SOUND

The current sound level is 90 decibels. If the sound pressure is halved, then what will be the new sound level?

First, find the sound pressure, with the decibel equation.

$$20\log\left(\frac{P_{current}}{P_{ref}}\right) = 90\ dB$$

$$\frac{P_{current}}{P_{ref}} = 10^{\frac{90}{20}}$$

$$P_{current} = 31{,}622.8\ P_{ref}$$

After the sound pressure is halved, then find the new decibel level.

$$P_{new} = 15{,}811\ P_{ref}$$

$$20\log\left(\frac{15{,}811\ P_{ref}}{P_{ref}}\right) = 84\ dB$$

12 - Conclusion

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12.0 CONCLUSION

If you have any questions on this product or any other Engineering Pro Guides product, then please contact me at any of the websites or at my email address below.

Justin Kauwale at contact@engproguides.com

Company Facebook: https://www.facebook.com/engineeringproguides/

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Person LinkedIn: https://www.linkedin.com/in/justin-kauwale/

Personal Facebook: https://www.facebook.com/justin.kauwale

I also make updates and changes to this product and all other Engineering Pro Guides products. The errata for this product is located at the following webpage.

https://www.engproguides.com/hvacguideerrata.pdf

Hi. My name is Justin Kauwale, the creator of Engineering Pro Guides. I will be happy to answer any questions you may have about the PE exam. Good luck on your studying! I hope you pass the exam and I wish you the best in your career. Thank you for your purchase!

13 - Checklists

COMMON MISTAKES

Double check before you submit your exam!

☐ Answer all questions before submitting

☐ Check your units!
  - Inches vs Feet
  - Minutes vs Hour: *GPM, CFM, ACH, lb/min, lb/hr, Btu/h*
  - Month vs Year: *Economics questions*
  - lbm vs lbf vs slugs

☐ Correct decimal place?

☐ Diameter vs Radius
  - Insulation Thickness + Radius - OR - 2x Insulation Thickness + Diameter
  - Calculating Area/Flow rate/Velocity

☐ Absolute vs Relative
  - PSIA vs PSIG – *NPSH in PSIA*
  - Fahrenheit vs Rankine – *Reynolds # in Rankine*

☐ Refrigeration Charts
  - Did you use the correct refrigerant?
  - Lookup with Temperature or Pressure column
  - hf vs hfg

☐ Psychrometric Chart
  - Correct Density (*other than STP, 60F & 14.7 psia*)
  - Correct Elevation

☐ Heat Transfer
  - K value (conductivity, use thickness) vs R value (thickness included)
  - K value per inch or per ft
  - Windows – Conductive + Radiative Heat

☐ Does your answer make logical sense?

Review the Basics!

I. Principles (28-43)

A. Basic Engineering Practice (4-6)

1. Units and conversions
    - Gravitational Constant: $g_c = 32.2\frac{ft\cdot lbm}{lbf\cdot s^2}$
        - *Convert between lbm and lbf*
    - Common conversions
        - 12,000 Btuh = 1 cooling ton
        - 15,000 Btuh = 1 nominal cooling tower ton
        - 3.412 Btuh = 1 Watt
        - 1 gallon = 8.34 pound water
        - 1 HP = 0.7457 kW
        - 1 psi = 2.31 ft head
    - Common Constants
        - Air density @STP = 0.075 lb/ft^3
        - STP of Air: 60F, 14.7 psia
        - Specific Heat Capacity
            - $c_{p,water} = 1.0\frac{Btu}{lbm*R}$
            - $c_{p,air} = 0.240\frac{Btu}{lbm*R}$ @constant pressure
            - $c_{v,air} = 0.171\frac{Btu}{lbm*R}$ @constant volume (less used)
2. Economic analysis
    - Interest Rate Table
    - Simple Payback
    - Straight Line Depreciation
    - MACRS
3. Electrical concepts (e.g., power consumption, motor ratings, heat output, amperage)
    - Power Consumption:
        - Demand (kW) * hours = Energy (kWh)
    - Building Energy Indices:
        - Energy Utilization Index (EUI) = Total Yearly Energy/Building Area
        - Cost Utilization Index (CUI) = Total Yearly Energy Cost/Building Area
    - Motor Ratings
        - **Power** (comes in set increments): *0.5 HP, 0.75 HP, 1 HP, 2 HP, 3 HP, 5 HP, 7.5 HP, 10 HP, 15, HP 20 HP, 25 HP, 30 HP, 40 HP, 50 HP, 60 HP, 75 HP, 100 HP*
        - **Amperage**
            - FLA = Full Load Current (Operating Amps, use in apparent power calc)
            - RLA = Running Load Amps (Similar to FLA)
            - LRA = Locked Rotor Amps (startup current, disconnect sizing)

14 - Index