Mechanical Study Guide

HVAC & Refrigeration
How to Pass the PE Exam

- Learn key concepts and skills required for the exam
- Simplify and focus your studying
- Over 50 practice problems

Justin Kauwale, P.E.
# HVAC & Refrigeration Technical Study Guide
## How to pass the PE exam

**Table of Contents**

<table>
<thead>
<tr>
<th>Section</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>Introduction</td>
</tr>
<tr>
<td>2.0</td>
<td>Principles - Basic Engineering Practice</td>
</tr>
<tr>
<td>3.0</td>
<td>Principles - Thermodynamics</td>
</tr>
<tr>
<td>4.0</td>
<td>Principles - Psychrometrics</td>
</tr>
<tr>
<td>5.0</td>
<td>Principles - Heat Transfer</td>
</tr>
<tr>
<td>6.0</td>
<td>Principles - Fluid Mechanics</td>
</tr>
<tr>
<td>7.0</td>
<td>Principles - Energy/Mass Balances</td>
</tr>
<tr>
<td>8.0</td>
<td>Applications - Heating/Cooling Loads</td>
</tr>
<tr>
<td>9.0</td>
<td>Applications - Equipment &amp; Components</td>
</tr>
<tr>
<td>10.0</td>
<td>Applications - Systems &amp; Components</td>
</tr>
<tr>
<td>11.0</td>
<td>Applications - Supportive Knowledge</td>
</tr>
<tr>
<td>12.0</td>
<td>Conclusion</td>
</tr>
</tbody>
</table>

[http://www.engproguides.com](http://www.engproguides.com)
SECTION 1
INTRODUCTION
# Section 1.0 - Introduction

Table of Contents

1.0 Introduction ............................................................................................................................. 2
  1.1 Key Concepts and Skills ...................................................................................................... 2
  1.2 Units .................................................................................................................................... 5

2.0 Disclaimer ............................................................................................................................... 5

3.0 How to use this Book .............................................................................................................. 5

4.0 Sample exam tips ................................................................................................................... 6

5.0 Recommended References .................................................................................................... 9
  5.1 Mechanical Engineering Reference Manual ........................................................................ 9
  5.2 Engineering Unit Conversions Book .................................................................................... 9
  5.3 HVAC Equations, Data and Rules of Thumb (Must Have) .................................................. 9
  5.4 ASHRAE Handbooks ........................................................................................................ 10
  5.5 ASHRAE Codes & Standards ........................................................................................... 10
  5.6 NFPA Codes ..................................................................................................................... 10
  5.7 Mechanical PE: HVAC & Refrigeration Technical Study Guide ........................................ 11
  5.8 Common Property Tables and Charts ............................................................................... 11
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 questions)
   i) Units and conversions
   ii) Economic analysis
   iii) Electrical concepts (e.g., power consumption, motor ratings, heat output, amperage)
2 Thermodynamics - (4 questions)
   i) Cycles
   ii) Properties
   iii) Compression Processes
3 Psychrometrics - (8 questions)
   i) Heating/cooling cycles, humidification/dehumidification, heating/cooling loads, sea level and other elevations
4 Heat Transfer - (7 questions)
5 Fluid Mechanics - (4 questions)
6 Energy/Mass Balances (5 questions)
SECTION 2
BASIC ENGINEERING PRACTICE
# Section 2.0 – Basic Engineering Practice

## Table of Contents

1.0 Introduction .................................................................................................................. 3

2.0 Key Terms & Equations ............................................................................................... 4

3.0 Engineering terms, symbols and technical drawings .................................................. 7
   3.1 Terms & Symbols ....................................................................................................... 7
   3.2 Technical Drawings ................................................................................................. 7

4.0 Economic Analysis ....................................................................................................... 10
   4.1 Interest Rate & Time value of Money ...................................................................... 10
   4.2 Annual value/Annuities ......................................................................................... 11
   4.3 Equipment Type Questions .................................................................................... 13
   4.4 Convert to Present Value ........................................................................................ 14
   4.5 Convert to Future Value .......................................................................................... 15
   4.6 Convert to Annualized Value .................................................................................. 15
   4.7 Convert to Rate of Return ....................................................................................... 16
   4.8 Factor Tables .......................................................................................................... 17

5.0 Units and conversions ................................................................................................. 18

6.0 Electrical concepts ..................................................................................................... 19
   6.1 Current, Voltage and Resistance .......................................................................... 19
   6.2 Basic DC Circuits ..................................................................................................... 19
   6.3 D/C Power ............................................................................................................... 23
   6.4 A/C Power ............................................................................................................... 24
   6.5 Mechanical equipment ............................................................................................ 24

7.0 Practice Problems ....................................................................................................... 29
   7.1 Problem 1 - Economics .......................................................................................... 29
   7.2 Solution 1 - Economics .......................................................................................... 30
   7.3 Problem 2 - Economics ......................................................................................... 31
   7.4 Solution 2 - Economics .......................................................................................... 32
   7.5 Problem 3 - Economics .......................................................................................... 33
   7.6 Solution 3 - Economics .......................................................................................... 34
   7.7 Problem 4 - Economics .......................................................................................... 35
   7.8 Solution 4 - Economics .......................................................................................... 36
   7.9 Problem 5 - Economics .......................................................................................... 37
   7.10 Solution 5 - Economics ......................................................................................... 38
1.0 INTRODUCTION

*Basic Engineering Practice accounts for approximately 4 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 terms, symbols and technical drawings, unit conversions and economic analysis. 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. You may also have to decipher a technical drawing and use the information to complete a heat transfer question or you will complete a power cycle question and need to 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.

---

**Basic Engineering Practice**

6 questions

- Engineering terms, symbols and technical drawings
- Economic Analysis
- Units & Conversions
- Electrical Concepts

- Present value
- Future value
- Annual value
- Rate of return
- Interest rate
- Factor tables
2.0 **KEY TERMS & EQUATIONS**

Convert Present Value to Future Value

\[ FV = PV \times (1 + i)^n \] or Multiply PV by \((F/P, i, n)\)

Convert Future Value to Present Value

\[ PV = \frac{FV}{(1+i)^n} \] or Multiply FV by \((P/F, i, n)\)

Convert Present Value to Annual Value

\[ A = PV \times \left(\frac{i(1+i)^n}{(1+i)^n-1}\right) \] or Multiply PV by \((A/P, i, n)\)

Annual Value to Present Value

\[ PV = A \times \left(\frac{1-(1+i)^{-n}}{i}\right) \] or Multiply PV by \((A/P, i, n)\)

Convert Future Value to Annual Value

\[ A = FV \times \left(\frac{i}{(1+i)^n-1}\right) \] or Multiply FV by \((A/F, i, n)\)

Convert Annual Value to Future Value

\[ FV = A \times \left(\frac{(1+i)^n-1}{i}\right) \] or Multiply AV by \((F/A, i, n)\)

**Ohm’s Law**

\[ I = \frac{V}{R} \]

\(I = \text{current [amps]}

\(V = \text{voltage [volts]}

\(R = \text{resistantce [amps]}

**Resistors in series**

\[ R_{eq,\text{series}} = R_1 + R_2 + R_3 + R_n \]

**Resistors in parallel**

\[ \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_n} \]
Figure 3: A side view or elevation view of the same object, with dimension lines.

Figure 4: A side view or elevation view of the same object, with dimension lines.
4.0 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 other alternatives.* 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.

4.1 INTEREST RATE & TIME VALUE OF MONEY

Before discussing interest rate, it is important that the engineer understand that money today is worth more than money in the future. This is the concept of the 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. Most people will choose $1,000 today, but not understand why this option is worth more. The reason $1,000 today is worth more is because of what you could have done with that money and in the financial world this means how much interest could you 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.

\[ $1,000 \times (1 + .04) = $1,040 \]

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

\[ $1,040 \times (1 + .04) = $1,081.60 \]

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

\[ $1,000 \times (1 + .04) \times (1.04) \times (1.04) \times \ldots = \sum_{i=0}^{10} $1,000 \times (1.04)^i = $1,480.24 \]

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

\[ PV \times (1 + i)^{10} = FV \]

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

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

\[ PV = $675.46 \]

- 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 alternatives, cash values will be present at many different times and the best way to make a uniform analysis is to first convert all values to consistent terms, like present value.

For example, if you were asked if you would like $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 question. But with an understanding of present value, the "correct" answer would be to accept $1,500, 10 years from now, because you would only be able to get $1,480, 10 years from now, should you accept the $1,000 today, with the current interest rate of 4%. In this example, the $1,000 today was converted to the future value 10 years from now. Once this value was converted, it was then compared to the future value that was given as $1,500, 10 years later.

4.2 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%.
### 4.8 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.
3. Number of years.

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 have the Mechanical Engineering Reference Manual (MERM), which has tables of these factor values in its Appendices.](http://www.engproguides.com) A summary of the factory values are shown below.

<table>
<thead>
<tr>
<th>Conversion</th>
<th>Formula</th>
<th>Factor Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present Value to Future Value</td>
<td>[ FV = PV \times (1 + i)^n ]</td>
<td>Multiply PV by (F/P, i, n)</td>
</tr>
<tr>
<td>Future Value to Present Value</td>
<td>[ PV = \frac{FV}{(1 + i)^n} ]</td>
<td>Multiply FV by (P/F, i, n)</td>
</tr>
<tr>
<td>Present Value to Annual Value</td>
<td>[ A = PV \times \left(\frac{i \times (1 + i)^n}{(1 + i)^n - 1}\right) ]</td>
<td>Multiply PV by (A/P, i, n)</td>
</tr>
<tr>
<td>Annual Value to Present Value</td>
<td>[ PV = A \times \left(\frac{1 - (1 + i)^{-n}}{i}\right) ]</td>
<td>Multiply A by (P/A, i, n)</td>
</tr>
<tr>
<td>Future Value to Annual Value</td>
<td>[ A = FV \times \left(\frac{i}{(1 + i)^n - 1}\right) ]</td>
<td>Multiply FV by (A/F, i, n)</td>
</tr>
<tr>
<td>Annual Value to Future Value</td>
<td>[ FV = A \times \left(\frac{(1 + i)^n - 1}{i}\right) ]</td>
<td>Multiply A by (F/A, i, n)</td>
</tr>
</tbody>
</table>
5.0 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.

*Use your Engineering Unit Conversions book.*

The Engineering Unit Conversions book is a must have for nearly all questions in the exam. This book has all the common unit conversions used in the PE exam and this book makes it very easy to convert from one unit to the next.

Amazon Link: [Engineering Unit Conversions](http://www.engproguides.com)
7.11 Problem 6 – Unit Conversions

Background: A boiler is sized at 10 boiler horsepower. The input to the boiler is 10 boiler horsepower. It is found that the boiler outputs 300,000 BTUH of heat to produce steam.

Problem: The efficiency of the boiler is most nearly?

(a) 79%
(b) 81%
(c) 84%
(d) 89%
SECTION 3
THERMODYNAMICS
# Section 3.0 – Principles Thermodynamics

## Table of Contents

1.0 Introduction ........................................................................................................................ 3  
2.0 Key Equations .................................................................................................................... 3  
3.0 Thermodynamics Properties .............................................................................................. 7  
   3.1 Pressure ......................................................................................................................... 7  
   3.2 Temperature ................................................................................................................... 8  
   3.2 Enthalpy .......................................................................................................................... 8  
   3.3 Entropy ........................................................................................................................... 9  
   3.4 Specific Heat ................................................................................................................ 10  
4.0 Refrigerants ...................................................................................................................... 12  
5.0 Boiling Pressure/Temperature ......................................................................................... 13  
6.0 Vapor Compression Cycle ............................................................................................... 15  
   6.1 Evaporator .................................................................................................................... 16  
   6.2 Compressor .................................................................................................................. 18  
   6.3 Condenser .................................................................................................................... 19  
   6.4 Expansion Device ......................................................................................................... 20  
7.0 Pressure-Enthalpy Diagram ............................................................................................. 21  
   7.1 Refrigeration Cycle ....................................................................................................... 24  
      7.1.1 Step 1 Evaporator ....................................................................................................... 25  
      7.1.2 Step 2 Compressor ..................................................................................................... 29  
      7.1.3 Step 3 Condenser ....................................................................................................... 31  
      7.1.4 Step 4 Expansion Device ............................................................................................ 33  
      7.1.5 Net Refrigeration/Condenser, Work and COP ............................................................ 34  
8.0 Steam ............................................................................................................................... 37  
   8.1 Pressure enthalpy diagram for steam ........................................................................... 37  
   8.2 Steam Tables ................................................................................................................ 43  
   8.3 Mollier Diagram ............................................................................................................ 46  
   8.4 Determining Properties of Steam ................................................................................. 47  
9.0 Refrigeration Practice Problems ...................................................................................... 49  
   9.1 Problem 1 – Evaporator ................................................................................................ 49  
   9.2 Solution 1 - Evaporator ................................................................................................. 50  
   9.3 Problem 2 – Evaporator ................................................................................................. 51
1.0 INTRODUCTION

*Thermodynamics accounts for approximately 4 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.
2.0 Key Equations

Evaporator Net Refrigeration Effect

\[ Q_{\text{net refrigeration effect}} \ [Btu/hr] = (H_1 - H_4) \ \frac{Btu}{lb} \times (\text{Refrig Flow Rate}) \ \frac{lb}{min} \times (60) \ \frac{min}{hr} \]

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

Compressor Work

\[ W_{\text{compressor}} \ [Btu/hr] = (H_2 - H_1) \ \frac{Btu}{lb} \times (\text{Refrig Flow Rate}) \ \frac{lb}{min} \times (60) \ \frac{min}{hr} \]

\[ H_2 = \text{leaving compressor enthalpy} \ \frac{Btu}{lb}; \ H_1 = \text{entering condenser enthalpy} \ \frac{Btu}{lb} \]

Net Condenser Effect

\[ Q_{\text{net condenser effect}} \ [Btu/hr] = (H_2 - H_4) \ \frac{Btu}{lb} \times (\text{Refrig Flow Rate}) \ \frac{lb}{min} \times (60) \ \frac{min}{hr} \]

\[ H_2 = \text{entering condenser enthalpy} \ \frac{Btu}{lb}; \ H_4 = \text{leaving condenser enthalpy} \ \frac{Btu}{lb} \]

Net Condenser Effect Function of Compressor Work and Net Refrigeration Effect

\[ Q_{\text{net condenser effect}} \ [Btu/hr] = W_{\text{compressor}} \ [Btu/hr] + Q_{\text{net refrigeration effect}} \ [Btu/hr] \]

Coefficient of Performance

\[ COP = \frac{W_{\text{out}}}{W_{\text{in}}} = \frac{Q_{\text{net refrigeration effect}} \ [Btu/hr]}{W_{\text{compressor}} \ [Btu/hr]} \]

Relationship of Enthalpy of Vaporization, Enthalpy of Saturated Vapor and Liquid Water

\[ h_g = h_f + h_{fg} \]

\[ h_g = \text{enthalpy of saturated vapor} \ \frac{Btu}{lbm} \]

\[ h_f = \text{enthalpy of saturated liquid} \]

\[ h_{fg} = \text{enthalpy of vaporization} \]

*all enthalpies at constant temperature & pressure*

Enthalpy of Wet Steam (Mixed Region) as a Function of Steam Quality

\[ h_{\text{mix}} = h_f + x \times h_{fg} \]

\[ h_{\text{mix}} = \text{enthalpy of wet steam (mix of liquid & vapor)} \]

\[ x = \text{steam quality, dryness fraction, % vapor} \]

Relationship of Entropy of Vaporization, Entropy of Saturated Vapor and Liquid Water

\[ s_g = s_f + s_{fg} \]

\[ s_g = \text{entropy of saturated vapor} \]

http://www.engproguides.com
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.

3.4 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.

\[
\text{heat capacity} = c_p \left( \frac{\text{Btu}}{\text{lbm} \cdot ^\circ \text{F}} \right)
\]

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.

Figure 4: The heat capacity on the left is much larger, thus the same input of heat only raises the temperature by a small amount. The heat capacity on the right is smaller, thus the same amount of heat, greatly raises the temperature.
6.1 EVAPORATOR

Step 1: Evaporator. The first step in the vapor compression cycle is the evaporator, which can also be called a liquid cooler. The evaporator is simply a heat exchanger. Heat is exchanged from the warm medium (air or water) to the cold, liquid refrigerant. The heat gained by the liquid refrigerant causes it to change phases to a refrigerant gas. The refrigerant liquid gains the heat necessary to overcome the latent heat of evaporation, in order to change to a gas.

There are two types of evaporators, (1) an air cooled evaporator and (2) a water cooled evaporator. The figure below shows the (1) air cooled evaporator which is most commonly referred to as a direct expansion system. In this evaporator, warm air from an air conditioned space is cooled and redistributed to the space. The figure below shows the water cooled system, where chilled water return is cooled and supplied to the chilled water distribution system.

![Direct expansion and water cooled system](http://www.engproguides.com)

*Figure 7: Direct expansion on the left and water cooled on the right*

The most common system is the direct expansion system. This system is prevalent throughout smaller systems, like those serving residential systems. In this system, the hot air from the space is used to directly evaporate the refrigerant to a hot gas. Note that the hot air from the space is roughly ~75 °F and the refrigerant liquid is typically 40 °F. The 75 °F room air is cooled down to ~55 °F and then distributed back to the space. In a water-cooled system, which is more common for larger commercial systems, chilled water typically at 55 °F is cooled by the evaporator down to ~45 °F. The colder chilled water is then supplied to another heat exchanger, where air is cooled and then distributed to the space.
7.1 **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 get a copy of the P-H diagram for R-134a and the other common refrigerants. These diagrams can be found in the ASHRAE Fundamentals book. 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.

![Sample R-134a P-H diagram](http://www.engproguides.com)

*Figure 12: Sample R-134a P-H diagram*
The following figure shows the points that are selected for the steam tables. This figure shows the values as a function of temperature.

![Steam Tables Diagram](image)

**Figure 28: Steam tables as a function of temperature**

<table>
<thead>
<tr>
<th>T</th>
<th>P</th>
<th>v = specific volume</th>
<th>h = enthalpy</th>
<th>s = entropy</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>.951</td>
<td>.01613</td>
<td>349.8</td>
<td>68.03</td>
</tr>
<tr>
<td>212</td>
<td>14.7</td>
<td>.01671</td>
<td>26.80</td>
<td>180.2</td>
</tr>
<tr>
<td>300</td>
<td>67.03</td>
<td>.01745</td>
<td>64.66</td>
<td>269.7</td>
</tr>
<tr>
<td>400</td>
<td>247</td>
<td>.01864</td>
<td>1.864</td>
<td>375.1</td>
</tr>
<tr>
<td>500</td>
<td>681</td>
<td>.02044</td>
<td>0.6756</td>
<td>487.9</td>
</tr>
</tbody>
</table>
9.11 PROBLEM 6 – CONDENSER

Background: A chiller operates with a R-134a refrigerant flow rate of 250 lb/min. The suction pressure is 40 PSIA and the discharge pressure is 200 PSIA. The evaporator provides 0 F of superheat and the condenser provides 10 F of sub-cooling.

Problem: What is net condenser effect?

(a) 62 tons
(b) 76 tons
(c) 89 tons
(d) 100 tons
9.12 **SOLUTION 6 – CONDENSER**

Step 1: A is found by the intersection of the suction pressure line and the saturated vapor line, since there is no superheat.

Step 2: Follow the constant entrop line at A to the intersection of the discharge pressure line, to get point B and $H_4$

$$H_2 = entering\ condenser\ enthalpy = 122 \frac{Btu}{lb}$$

Step 3: Follow the discharge pressure line, to the intersection of the saturated liquid line, then move 10 F left to the sub-cooled region

$$H_4 = leaving\ condenser\ enthalpy = 50.5 \frac{Btu}{lb}$$

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

$$Q_{net\ condenser\ effect} = (122 - 50.5) \left( \frac{Btu}{lb} \right) \times (250) \times 60 = 1,072,050\ Btu\ or\ 89.4\ Tons$$
9.13 PROBLEM 7 – CONDENSER

Background: A chiller operates with a suction pressure of 35 PSIA and a discharge pressure of 225 PSIA. The refrigerant flow rate is 100 lb/min of R-134a. The compressor provides 200,000 BTUH of work. The COP of the chiller is 4.0. What is the net condenser effect?

Problem: What is the net condenser effect?

(a) 83.3 Tons

(b) 93.6 Tons

(c) 120.3 Tons

(d) 139.3 Tons
SECTION 4
PSYCHROMETRICS
# Section 4.0 – Principles Psychrometrics

## Table of Contents

1.0 Introduction ........................................................................................................................ 3  
2.0 Key Terms .......................................................................................................................... 4  
3.0 Key Equations .................................................................................................................... 6  
4.0 Psychrometric Chart ........................................................................................................... 8  
   4.1 Properties of Moist Air .................................................................................................... 9  
      4.1.1 Dry Bulb Temperature ........................................................................................... 10  
      4.1.2 Wet Bulb Temperature .......................................................................................... 11  
      4.1.3 Relative Humidity ............................................................................................... 12  
      4.1.4 Humidity Ratio ..................................................................................................... 13  
      4.1.5 Enthalpy ................................................................................................................ 14  
      4.1.6 Specific Volume ..................................................................................................... 15  
      4.1.7 Dew Point .............................................................................................................. 16  
   4.2 Movement on Psychrometric Chart .............................................................................. 17  
      4.2.1 Sensible Heating/Cooling ...................................................................................... 17  
      4.2.2 Latent Heating/Cooling ......................................................................................... 21  
      4.2.3 Sensible Heat Ratio ............................................................................................... 26  
      4.2.4 Mixing of Two Air Streams .................................................................................... 29  
5.0 Different Elevations .......................................................................................................... 31  
6.0 Practice Problems ............................................................................................................ 32  
   6.1 Problem 1 - Navigating Psychrometric Chart ............................................................... 32  
   6.2 Solution 1 - Navigating Psychrometric Chart ............................................................... 33  
   6.3 Problem 2 - Condensation on Surfaces ........................................................................ 34  
   6.4 Solution 2 – Condensation on Surfaces. ...................................................................... 35  
   6.5 Problem 3 - Change in Enthalpy/Humidity Ratio .......................................................... 36  
   6.6 Solution 3 - Change in Enthalpy/Humidity Ratio ........................................................... 37  
   6.7 Problem 4 - Air Mixtures ............................................................................................... 38  
   6.8 Solution 4 - Air Mixtures ............................................................................................... 39  
   6.9 Problem 5 - Electric Heater .......................................................................................... 40  
   6.10 Solution 5 - Electric Heater ........................................................................................ 41  
   6.11 Problem 6 - Cooling Coil ............................................................................................... 42  
   6.12 Solution 6 - Cooling Coil ............................................................................................. 43
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 8 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 please refer to ASHRAE website for required Psychrometric Charts.
Step 1: Find initial location, 55° F DB/53° F DB.
Step 2: Show sensible heating movement.
Movement right at constant humidity ratio, by 11.1° F DB.
Step 3: Read properties at final location.
Dry Bulb = 66.1° F DB
Wet Bulb = 57.5° F WB
Relative Humidity = 60%
Humidity Ratio = .0082
4.2.2 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 and outdoor air.

The amount of latent heating/cooling is determined through the following two ways [constants shown for standard conditions]:

1. $\Delta W_{GR} \rightarrow \text{Change in grains of water vapor per pound of dry air.}$

   **Step 1:** $Q_{latent} = \dot{m} * H_v$

   Latent Energy is equal to change in mass flow rate of water multiplied by the heat of vaporization.

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

   $\dot{m} = \text{mass flow rate of water } \left[ \frac{\text{lb of H}_2\text{O}}{\text{hr}} \right]$

   $H_v = \text{heat of vaporization, } 1060 \left[ \frac{\text{Btu}}{\text{lb of H}_2\text{O}} \right]$

2. $\dot{m} = CFM \left[ \frac{\text{ft}^3}{\text{min}} \right] * .075 \left[ \frac{\text{lbs of dry air}}{\text{ft}^3} \right] * 60 \left[ \frac{\text{min}}{\text{hr}} \right] * \Delta W_{GR} \left[ \frac{\text{grain of H}_2\text{O}}{\text{lb of dry air}} \right] * \left[ \frac{1 \text{ lb of H}_2\text{O}}{7000 \text{ grains of H}_2\text{O}} \right]$

   Find the mass flow rate of water in air, using the specific volume of air and the specific humidity.

   $.075 \left[ \frac{\text{lbs of dry air}}{\text{ft}^3} \right] = \text{Density of air at } 60^\circ \text{F/58^\circ F at 1 atm}$

   $60 \left[ \frac{\text{min}}{\text{hr}} \right] = \text{conversion minutes to hour}$

   $\Delta W_{GR} \left[ \frac{\text{grain of H}_2\text{O}}{\text{lb of dry air}} \right] = \text{change in specific humidity}$

   $\left[ \frac{1 \text{ lb of H}_2\text{O}}{7000 \text{ grains of H}_2\text{O}} \right] = \text{conversion lb to grains}$

   **Step 3:** $Q_{latent} = 0.68 * \Delta W_{GR} * CFM$

   Consolidated constants.
Problem: What is the Enthalpy $\frac{B_{\text{tuh}}}{\text{lbm of dry air}}$?

(c) 35

Problem: What is the Humidity Ratio $\frac{\text{lbm of water vapor}}{\text{lbm of dry air}}$?

(a) .014

Problem: What is the Wet Bulb (°F)?

(c) 71 °F

Problem: What is the Specific Volume $\frac{\text{ft}^3}{\text{lbm of dry air}}$?

(d) 14
6.16 SOLUTION 8 - DEHUMIDIFIER

Since the de-humidifier only provides latent cooling, the following equation can be used.

\[ Q_{\text{latent}} = 4770 \times \Delta W_{LB} \times CFM \]

10,000 = \[ Q_{\text{latent}} = 4770 \times \Delta W_{LB} \times 1000 \]

\[ \Delta W_{LB} = .0021; \ W_{\text{initial}} = .0151 \]

\[ W_{\text{final}} = .0151 - .0021 = .013 \]

Dry bulb temperature does not change, 80°F DB/.013 lbm H2O/lbm dry air.
SECTION 5
HEAT TRANSFER
4.0 CONVECTION

Convection is the second mode of heat transfer and is defined as the transfer of heat through the movement of fluids. In the HVAC & Refrigeration field, convective heat transfer can be found in heating and air conditioning systems, whenever a moving fluid passes over a surface at a different temperature.

One of the most common examples of convection is natural convection. As people enter a building, the lights get turned on and the sun heats the building. These various heat sources cause the air in the building to get warmer. The warm air is less dense than the air around it and begins to rise up and out of the building. The empty space left by the warm air is then replaced by cooler outside air and the cycle continues. This convective heat transfer through the movement of air is called natural convection. It is referred to as natural because it does not rely on a mechanical source, like a fan to move the air.

![Figure 2: Example of natural convection](http://www.engproguides.com)

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

\[ Q = h_{\text{conv}} \times A \times \Delta T \]

\[ h_{\text{conv}} = \text{convective heat transfer coefficient} \left[ \frac{\text{Btu}}{\text{hr} \times \text{ft}^2 \times ^\circ\text{F}} \right] \]

\[ A = \text{area of heat transfer} \ [\text{ft}^2] \]

\[ \Delta T = \text{temperature difference between hot and cold areas of heat transfer} \ [^\circ\text{F}] \]
5.0 RADIATION

The third and final mode of heat transfer is radiation. Radiation heat gains for a typical building’s window or skylight must be calculated with a computer program like Trane Trace 700, Carrier HAP or a similar load calculation program, because the calculation is iterative and complex. However, calculations for heat gains from radiation are simplified in hand calculated applications and it is the opinion of the writer that the simplified equations for radiation are what can be tested on during the PE exam. Thus only the simplified equations will be discussed in this section and the subsequent sections.

Radiation is the mode of heat transfer that requires no substance to transmit heat. All objects above absolute zero radiate or project heat from its surface. For HVAC & Refrigeration the primary heat gain due to radiation is from solar radiation. Heat is radiated from the sun and transmitted to a building either by heating up the building envelope or transmitting heat directly through windows and skylights. These specific examples of solar radiation are described further in the Cooling Load Calculations part of this section.

\[ Q = h_{rad} \cdot A \cdot \Delta T \]

\[ h_{rad} = \text{radiation heat transfer coefficient} \left[ \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot \circ \text{F}} \right] \]

\[ A = \text{area of heat transfer} \left[ \text{ft}^2 \right] \]

\[ \Delta T = \text{temperature difference between hot and cold areas of heat transfer} \left[ \circ \text{F} \right] \]
6.0 Calculating Overall Heat Transfer Coefficient

A must have skill for the aspiring professional engineer is to be able to calculate the overall heat transfer coefficient (U-factor) for a wall, roof, duct or pipe. This skill will be described and explained through the following example.

It is important to be able to follow the flow of heat from the beginning to the end of this diagram [from left to right]. The diagram shows how the temperature starts from a high temperature of 87 °F down to 75 °F.

1. The first method of heat transfer is due to convection. Warm outdoor air moves across the outer surface of the concrete wall causing the outer surface of the wall to heat up. In reality, there would also be radiation loads acting upon the surface of the wall, but for simplicity it is assumed that there are no radiation loads.

2. Next the heat travels from the outer surface of the concrete wall to the inside surface.

3. The heat then moves from the outer surface of the insulation and through the insulation.

4. Next, the heat moves from the outer surface of the gypsum board and through the board.

5. Finally the outer surface of the gypsum board transmits heat via convection and radiation to the indoor air.

In order to find the overall heat transfer coefficient, all of the resistances must be summed. It is recommended that each method of heat transfer should be converted to its equivalent R-Value in order to simplify the calculation, because R-Values in series are simply added together.

\[
R_{\text{series}} = R_1 + R_2 \ldots + R_n
\]

http://www.engproguides.com
R-Values in parallel follow a different equation which is highlighted below.

\[
\frac{1}{R_{\text{parallel}}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}
\]

First, convert all resistances to R-values.

\[
R_{\text{conv.outdoor}} = \frac{1}{h_{\text{conv.outdoor}}}
\]

\[
R_{\text{conc}}, R_{\text{ins}} \text{ and } R_{\text{gyp}} \text{ do not need to be converted.}
\]

\[
R_{\text{conv.indoor}} = \frac{1}{h_{\text{conv.indoor}}}
\]

\[
R_{\text{rad}} = \frac{1}{h_{\text{rad}}}
\]

Next, notice that the radiation and convection heat transfer modes are arranged in parallel. Convert these two items to a single term.

\[
\frac{1}{R_{\text{combined.indoor}}} = \frac{1}{R_{\text{conv.indoor}}} + \frac{1}{R_{\text{rad}}}
\]

\[
R_{\text{combined.indoor}} = \frac{R_{\text{conv.indoor}} \cdot R_{\text{rad}}}{R_{\text{conv.indoor}} + R_{\text{rad}}}
\]

Now that all terms are in series, the terms can be summed together.

\[
R_{\text{total}} = R_{\text{conv.outdoor}} + R_{\text{conc}} + R_{\text{ins}} + R_{\text{gyp}} + \frac{R_{\text{conv.indoor}} \cdot R_{\text{rad}}}{R_{\text{conv.indoor}} + R_{\text{rad}}}
\]

In order to find the overall heat transfer coefficient (U-factor), simply take the inverse of the total R-value.

\[
U_{\text{overall}} = \frac{1}{R_{\text{total}}}
\]
7.0 THERMAL INSULATION

Insulation is provided in HVAC & Refrigeration systems on pipes, ducts, walls and roofs. Insulation for walls and roofs was discussed in the Heat Transfer section. The primary purpose of insulation is to limit heat transfer. For example, in chilled water pipes, insulation is provided to limit heat transfer to the chilled water and to keep the water cold. In hot air ducts, insulation is provided to limit heat loss to the surrounding areas.

Insulation is characterized by its ability to conduct heat transfer and is rated by either a k-value, U-factor or an R-value. K-values are often used when rating pipe, duct or equipment insulation where R-values and U-factors are typically used to describe roof and wall insulation. Please refer to the Heat Transfer section for more detail on insulation for roofs and walls. This section primarily deals with insulation for pipes and ducts, specifically being able to determine the insulation requirements for a pipe or duct, in order to (1) Control Surface Temperature.

Controlling Surface Temperature: One important skill that the professional engineer must attain is the ability to determine the insulation required to keep the surface temperature of a pipe, duct, wall, roof or other piece of equipment within a set range. A common problem encountered in the HVAC & Refrigeration field is determining the required insulation for a chilled water pipe in order to stop condensation from forming on the surface.

![Figure 4: Surface temperature problems](http://www.engproguides.com)

The governing equation for this problem is that the heat transfer from the chilled water pipe through the insulation and to the outer surface is equal to the heat transfer from the outer surface to the ambient air.

\[
Q_{\text{pipe to surface}} = Q_{\text{surface to OAIR}}
\]

**Heat transfer in the system is constant.**
\[ Q_{pipe\ to\ outer\ surface} = \frac{k}{h} \left( \frac{Btu}{ft^2*in\ ^\circ F} \right) \frac{A[ft^2]}{X[in]} * (T_{outer\ surface} - T_{pipe})[\circ F] \]

Where \( k \) is equal to the conductivity of the insulation and \( X \) is equal to the thickness of the insulation. \( K \) can vary depending on the temperature of the pipe.

\[ Q_{outer\ surface\ to\ air} = \frac{h}{f t^2*h*\circ F} \left( \frac{Btu}{ft^2*\circ F} \right) A[ft^2] * (T_{ambient} - T_{outer\ surface})[\circ F] \]

Where \( h \) is equal to the surface coefficient of the insulation. This value is a measure of how well the surface of the material in question is at conducting heat to the ambient air. The value can increase for higher wind speeds and varying surface and air temperatures.
8.1 Practice Problem 1: Calculate Overall Heat Transfer Coefficient

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

\[ a) 0.12 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot ^\circ \text{F}} \]

\[ b) 0.25 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot ^\circ \text{F}} \]

\[ c) 3.12 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot ^\circ \text{F}} \]

\[ d) 8.7 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot ^\circ \text{F}} \]
8.2 **SOLUTION 1: CALCULATE OVERALL HEAT TRANSFER COEFFICIENT**

The overall heat transfer coefficient is found by first converting all values to R-values.

\[
R_{oair} = \frac{1}{h_{oair}} = \frac{1}{3} = 0.33 \frac{hr \cdot ft^2 \cdot ^\circ F}{Btu}
\]

\[
R_{ins} = \frac{t}{k_{ins}} = \frac{2}{0.3} = 6.67 \frac{hr \cdot ft^2 \cdot ^\circ F}{Btu}
\]

\[
R_{brick} = \frac{t}{k_{brick}} = \frac{8}{9} = 0.89 \frac{hr \cdot ft^2 \cdot ^\circ F}{Btu}
\]

Sum up all R-values that are in series.

\[
R_{total} = R_{oair} + R_{brick} + R_{ins} + R_{gyp}
\]

\[
R_{total} = 0.33 + 0.89 + 6.67 + 0.8
\]

\[
R_{total} = 8.69 \frac{hr \cdot ft^2 \cdot ^\circ F}{Btu}
\]

The overall heat transfer coefficient is simply the inverse of the total resistance.

\[
U_{overall} = \frac{1}{R_{total}} = \frac{1}{8.69}
\]

\[
U_{overall} = 0.12 \frac{Btu}{hr \cdot ft^2 \cdot ^\circ F}
\]
SECTION 6
FLUID MECHANICS
3.0 FLUID PROPERTIES

A fluid is a substance that is continually changing its shape when under a shear stress. In engineering application, fluids include gases and liquids. Gases include air, steam, compressed air, medical gases like nitrogen, oxygen, etc. and industrial gases like natural gas, ethane, acetylene, etc. Liquids include domestic water, chilled water, hot water and industrial liquids like diesel fuel, propane and oil. This section describes the various explicit properties of fluids and other implicit properties of non-moving fluids.

During the exam you will need to be able to find and use fluid properties to complete many problems. You should be very familiar with your resources and where to find these fluid properties. As you go through these descriptions of the important fluid properties, look through your Mechanical Engineering Reference Manual and your HVAC & Refrigeration Data and Rules of Thumb book. Tag the appendices that contain these properties and recognize the units. The key is not to waste time looking for fluid properties and to not make mistakes when solving a problem due to incorrect units.

3.1 DENSITY/SPECIFIC VOLUME

The density of a substance is its mass per unit volume, basically how heavy is something in one cubic foot or one cubic meter.

The specific volume of a fluid is measured as a weight per unit volume. Specific volume is the inverse of density and is measures as a volume per unit mass.

3.2 VISCOSITY

![Figure 1: Varying liquids and their viscosities](image)

GASOLINE 9.4x10^-6 ft^2/s  WATER 1.2x10^-5 ft^2/s  OLIVE OIL 4.6x10^-4 ft^2/s  HONEY 7.9x10^-4 ft^2/s

The viscosity of a fluid describes the fluids resistance to flow. Viscosity is measured in cP or centipoises and is represented by the variable, μ or mu. Viscosity is measured with a device called a viscometer. There are many different types of viscometers but each typically has the fluid moving past/through an object or it has the object moving through the fluid. The time of
4.4 SOLUTION 2 - REYNOLDS NUMBER

A 3" Schedule 80 steel pipe has 100 GPM of 50 F water flowing through it. What is the Reynolds number?

For this equation use the Reynolds Number equation below:

\[ Re = \frac{V \frac{ft}{sec} \cdot d [ft]}{v \frac{ft^2}{sec}} \]

First find the velocity, which requires the inner diameter of Schedule 80 pipe. Refer to your Mechanical Engineering Reference Manual (MERM) to find the inner diameter.

\[ D = 0.2417 \text{ ft} \]

Next find the inner area, which is also shown in the MERM.

\[ A = 0.04587 \text{ ft}^2 \]

Next convert GPM to ft^3.

\[ 100 \text{ GPM} \cdot \frac{1}{448.83} = 0.223 \text{ FT}^3/\text{sec} \]

Next find the velocity.

\[ V = \frac{0.223 \text{ FT}^3/\text{sec}}{0.04587 \text{ ft}^2} = 4.86 \text{ ft/sec} \]

Next find the kinematic viscosity for water at 50 F which is also found in the MERM.

\[ v = .0000141 \text{ ft}^2/\text{sec} \]

Plug the values in to the equation.

\[ Re = \frac{4.86 \cdot 0.2417}{.0000141} = 83,343 \]
SECTION 7
ENERGY/MASS BALANCES
## Section 7.0 – Principles Energy/Mass Balance

### Table of Contents

1.0 Introduction ........................................................................................................................ 2  
2.0 Important Terms & Equations ............................................................................................ 3  
3.0 Conservation of Mass ........................................................................................................ 4  
4.0 Conservation of energy ...................................................................................................... 5  
  4.1 Turbines, Pumps & Compressors: .................................................................................. 5  
  4.2 Boilers, Condensers, Evaporators: ................................................................................. 6  
  4.3 Heat exchangers ............................................................................................................ 6  
  4.4 Mixing ............................................................................................................................. 6  
5.0 Evaporation ........................................................................................................................ 7  
  5.1 Latent heat of evaporation .............................................................................................. 7  
  5.2 Convert liquid to vapor .................................................................................................... 7  
6.0 Condensation ..................................................................................................................... 7  
7.0 Dehumidification & Humidification ...................................................................................... 8  
8.0 Mixing ................................................................................................................................. 9  
  8.1 Gas-gas mixing mass balance ....................................................................................... 9  
  8.2 Liquid-liquid mixing mass balance ................................................................................ 11  
9.0 Practice Problems ................................................................................................................. 12  
  9.1 Problem 1 - Humidifier .................................................................................................. 12  
  9.2 Solution 1 - Humidifier .................................................................................................. 13  
  9.3 Problem 2 – Dehumidifier ............................................................................................. 14  
  9.4 Solution 2 - Dehumidifier .............................................................................................. 15  
  9.5 Problem 3 – Air Mixtures .............................................................................................. 16  
  9.6 Solution 3 – Air Mixtures ............................................................................................... 17  
  9.7 Problem 4 – Condensation ........................................................................................... 18  
  9.8 Solution 4 – Condensation ............................................................................................. 19
1.0 INTRODUCTION

Energy/Mass Balance accounts for approximately 5 questions on the HVAC & Refrigeration Mechanical PE exam.

This section focuses on the energy and mass balance equations that govern various HVAC and Refrigeration processes. These processes include evaporation, condensation, and mixing. The important concept to understand is that in each process, energy and mass of the fluid is conserved, even if the fluid is changing from gas to liquid or liquid to gas.
4.0 CONSERVATION OF ENERGY

Conservation of energy is a law in nature and states that energy cannot be created or destroyed. Therefore, when transfers of states or changes in phases occur in a system, an energy 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

\[ \sum \text{energy}_{in} = \sum \text{energy}_{out} \]

This equation is used throughout the exam just in different forms. The following shows examples of energy balances on various pieces of equipment.

4.1 TURBINES, PUMPS & COMPRESSORS:

Turbines, pumps and compressors change the amount of energy of the incoming fluid by changing the pressure of the fluid. Pumps and compressors increase the pressure of the fluid, while turbines reduce the pressure of the fluid. In a pump and compressor, energy is transferred from a power source to the fluid. In a turbine, energy is transferred from a fluid to provide a power source. In both cases, this power source is called Work. Essentially work is transferred to or from these pieces of equipment.

\[ W_{\text{work, pump, compressor}} = \dot{m}_{\text{fluid}} \times (h_{\text{leaving}} - h_{\text{entering}}) \]
9.3 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 H2O/lbm dry air
(b) 80°F DB/.011 lbm H2O/lbm dry air
(c) 80°F DB/.013 lbm H2O/lbm dry air
(d) 80°F DB/.015 lbm H2O/lbm dry air
9.4 SOLUTION 2 - DEHUMIDIFIER

Since the de-humidifier only provides latent cooling, the following equation can be used.

\[ Q_{\text{latent}} = 4,770 \times \Delta W_{LB} \times CFM \]

\[ 10,000 = Q_{\text{latent}} = 4,770 \times \Delta W_{LB} \times 1000 \]

\[ \Delta W_{LB} = .0021; \ W_{\text{initial}} = .0151 \]

\[ W_{\text{final}} = .0151 - .0021 = .013 \]

Dry bulb temperature does not change, 80°F DB/.013 lbm H2O/lbm dry air.
SECTION 8
HEATING/COOLING LOADS
Section 8.0 – Principles Heating & Cooling Loads

Table of Contents
1.0 Introduction .................................................................................................................................. 2
2.0 Important Terms & Equations ......................................................................................................... 3
3.0 Cooling Load Calculations .............................................................................................................. 5
   3.1 Thermal Mass & Time Lag Factor ............................................................................................... 6
   3.2 Uncertainty ................................................................................................................................... 6
   3.3 Roof & Wall ............................................................................................................................... 7
   3.4 Skylight & Window ..................................................................................................................... 9
   3.5 People ....................................................................................................................................... 10
   3.6 Lighting .................................................................................................................................... 10
   3.7 Miscellaneous Equipment ......................................................................................................... 12
   3.8 Infiltration ............................................................................................................................... 13
4.0 Heating Loads ................................................................................................................................. 15
5.0 Practice Problems ........................................................................................................................... 16
   5.1 Practice Problem 1: Calculate Heat Load Through Wall ....................................................... 16
   5.2 Solution 1: Calculate Heat Load Through Wall ................................................................. 17
   5.3 Practice Problem 2: Calculating Heat Load From People .................................................... 18
   5.4 Solution 2: Calculating Heat Load From People .................................................................. 19
   5.5 Practice Problem 3: Calculating Heat Load From Motors ................................................... 20
   5.6 Solution 3: Calculating Heat Load From Motors ................................................................. 21
   5.7 Practice Problem 4: Calculating Heat Load From Motors ................................................... 22
   5.8 Solution 4: Calculating Heat Load From Motors ................................................................. 23
   5.9 Practice Problem 5: Calculating Heat Load From Windows ................................................ 24
   5.10 Solution 5: Calculating Heat Load From Windows ............................................................ 25
   5.11 Problem 6 – Cooling Load Calculation ............................................................................... 26
   5.12 Solution 6 – Cooling Load Calculation ................................................................................ 27
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.
2.0 IMPORTANT TERMS & EQUATIONS

Convert U-Factor to R-Value

\[ U = \frac{1}{R} \]

\[ U = \text{heat transfer coefficient} \left[ \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot \circF} \right] \]

\[ R = \text{thermal resistance} \left[ \frac{\text{hr} \cdot \text{ft}^2 \cdot \circF}{\text{Btu}} \right] \]

Addition of R-Values

\[ R_{\text{total}} = R_1 + R_2 + R_3 \ldots + R_n \]

Addition of U-Factors

\[ \frac{1}{U_{\text{total}}} = \frac{1}{U_1} + \frac{1}{U_2} + \frac{1}{U_3} \ldots + \frac{1}{U_n} \]

Thermal Conductivity Units

\[ k = \frac{\text{Btu}}{\text{hr} \cdot \text{ft} \cdot \circF} \]

Convert Thermal Conductivity to R-Value and U-Factor

\[ R = \frac{t}{k} \]

\[ t = \text{thickness of material [ft]} \]

\[ k = \text{thermal conductivity} \left[ \frac{\text{Btu}}{\text{hr} \cdot \text{ft} \cdot \circF} \right] \]

\[ U = \frac{k}{t} \]

Heat Transfer Equation

\[ Q = U \cdot A \cdot \Delta T \]

\[ U = \text{overall heat transfer coefficient} \left[ \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot \circF} \right] \]

\[ A = \text{area of heat transfer [ft}^2] \]

\[ \Delta T = \text{temperature difference between hot and cold areas of heat transfer [\circF]} \]
3.0 COOLING LOAD CALCULATIONS

Cooling load calculations are typically one of the first calculations completed by a HVAC & Refrigeration engineer. These calculations serve as the basis for determining air conditioning equipment sizes. In order to determine the mechanical equipment sizes, the engineer must first determine what heat is being transferred into the building. The summation of the heat gained by the building will determine the size of the air conditioning equipment.

The various heat gains and losses into a building can be characterized as either external or internal loads. External loads include the conduction and radiation heat loads transferred through roofs, walls, skylights and windows. In addition, outside air can be brought into a building through ventilation requirements or infiltration, which will cause a cooling load upon the system. Internal loads include heat loads from people, lighting and miscellaneous equipment like computers, televisions, motors, etc.

---

![Figure 1: Various heat gains in a building](http://www.engproguides.com)

<table>
<thead>
<tr>
<th>External</th>
<th>Internal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roofs/Walls – Conduction</td>
<td>Lights</td>
</tr>
<tr>
<td>Roofs/Walls – Radiation</td>
<td>People</td>
</tr>
<tr>
<td>Skylights/Windows – Conduction</td>
<td>Miscellaneous Equipment</td>
</tr>
<tr>
<td>Skylights/Windows – Radiation</td>
<td></td>
</tr>
<tr>
<td>Ventilation/Infiltration</td>
<td></td>
</tr>
</tbody>
</table>
3.5 PEOPLE

The heat loads from a person depend on the activity level of the person. ASHRAE has tabulated heat, loads both sensible and latent heat gains, from people based on their activity levels, refer to ASHRAE Fundamentals. The loads from people can be calculated using these heat gain values, the number of people and the cooling load factor. The cooling load factor takes into account the time lag factor and if it is not given it should be assumed to be 1.0.

Sensible loads

\[ Q = N \times SHG \times CLF \]

\[ N = \text{number of people} \]

\[ SHG = \text{sensible heat gain, activity dependent} \left[ \frac{Btu}{hr} \right] \]

\[ CLF = \text{cooling load factor} \]

Latent loads

\[ Q = N \times LHG \times CLF \]

\[ N = \text{number of people} \]

\[ LHG = \text{latent heat gain, activity dependent} \left[ \frac{Btu}{hr} \right] \]

\[ CLF = \text{cooling load factor} \]

3.6 LIGHTING

The heat load from lighting in a building is found by summing up the number of lights of each type and wattage, then converting the watts to Btu/hr, multiplying this number by the usage factor and the special allowance factor.

\[ Q = N \times \frac{Watts}{watts} \times 3.412 \frac{Btu}{hr} \times UF \times SAF \times SF \]

\[ \text{where } N = \text{number of light type.} \]

\[ UF = \text{usage factor} \]

\[ SAF = \text{special allowance factor} \]

\[ SF = \text{space fraction} \]

The wattage of the light is based on the manufacturer reported value for the lamps in the lighting fixture, without taking into account the ballast. The lighting use factor is the ratio of the time the lights will be in use. This factor is typically 1.0 for most applications like offices, classrooms, stores, hospitals, etc. The usage factor may vary for a movie theater or inactive storage space. The special allowance factor takes into account the heat from ballasts. This factor is typically
5.0 PRACTICE PROBLEMS

5.1 PRACTICE PROBLEM 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 at peak load. The indoor temperature is 75 F and the outdoor temperature is 87 F.

a) 125 $\frac{Btu}{hr}$
b) 300 $\frac{Btu}{hr}$
c) 350 $\frac{Btu}{hr}$
d) 500 $\frac{Btu}{hr}$
5.2 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

\[ U_{overall} = \frac{1}{\frac{1}{R_{concrete}} + \frac{1}{R_{insulation}} + \frac{1}{R_{gypsum}}} \]

\[ U_{overall} = \frac{1}{\frac{1}{2} + 8 + 0.8} = 0.093 \text{ Btu/hr*ft}^2*{\circ}F \]

Second calculate the area.

\[ 8' \times 20' = 160 \text{ ft}^2 \]

Third calculate the heat.

\[ Q = U \times A \times (CLTD) \]

\[ Q = 0.093 \text{ Btu/hr*ft}^2*{\circ}F \times 160 \text{ ft}^2 \times 20{\circ}F \]

\[ Q = 296 \text{ Btu/hr} \]
SECTION 9
EQUIPMENT & COMPONENTS

http://www.engproguides.com
Section 9.0 – Application Equipment & Components

Table of Contents

1.0 Introduction ........................................................................................................................ 4
2.0 Key Equations and Terms .................................................................................................. 5
3.0 Cooling towers ................................................................................................................... 8
   3.1 Characterizing Cooling Towers ...................................................................................... 9
   3.2 Cooling Tower Performance ......................................................................................... 12
   3.3 Cooling Tower Water Loss and Make-up ..................................................................... 13
4.0 Boilers & furnaces ............................................................................................................ 14
   4.1 Steam Boilers ............................................................................................................... 14
   4.2 Furnaces ....................................................................................................................... 15
      4.2.1 Types of Furnaces ................................................................................................. 15
      4.2.2 Efficiency ............................................................................................................... 16
5.0 Heat exchangers .............................................................................................................. 16
   5.1 Log Mean Temperature Difference (LMTD) ................................................................. 18
   5.2 Heat Balance ................................................................................................................ 19
6.0 Condensers & Evaporators .............................................................................................. 19
   6.1 Chillers .......................................................................................................................... 19
   6.2 Variable Refrigerant Flow ............................................................................................. 20
   6.3 Heat Pump .................................................................................................................... 21
7.0 Pumps .............................................................................................................................. 22
   7.1 Types of pumps ............................................................................................................ 22
   7.2 Reading Pump Curves ................................................................................................. 24
   7.3 Using the Affinity Laws ................................................................................................. 26
8.0 Fans ................................................................................................................................... 27
   8.1 Important Terms ............................................................................................................ 27
   8.2 Types of Fans .............................................................................................................. 28
      8.2.1 Axial Fans .............................................................................................................. 28
      8.2.2 Propeller Fans ....................................................................................................... 28
      8.2.3 Tube-Axial Fans .................................................................................................... 28
      8.2.4 Centrifugal Fans .................................................................................................. 29
   8.3 Fan Curves ................................................................................................................... 31
   8.4 Fan Affinity Laws ......................................................................................................... 33
3.2 COOLING TOWER PERFORMANCE

The professional engineer must be able to properly design and select a cooling tower to fit the HVAC & Refrigeration application. Cooling towers are characterized by two terms the approach and the range. The range of the cooling tower is the difference between the entering and exiting temperatures of the cooling tower water.

\[ \text{Range} = T_{\text{water, in}} [^\circ F] - T_{\text{water, out}} [^\circ F] \]

The approach or approach to wet bulb is the temperature difference between the water out and the wet bulb temperature of the air.

\[ \text{Approach} = T_{\text{water, out}} [^\circ F] - T_{\text{in, WB}} [^\circ F] \]

The approach is important because it describes the level of performance of the cooling tower. The smaller the approach the better the cooling tower is at providing cooling. The wet bulb temperature of the entering air is the lowest the temperature of the exiting water can reach. If a cooling tower has a 0 degree approach then the cooling tower is using all of the available heat exchange from the air to cool the water. Typical approaches are in the range of ~10 °F.

![Figure 8: approach, effectiveness and range](http://www.engproguides.com)

Approach also leads to another important term in determining the performance of cooling towers, called effectiveness. Effectiveness is a term used to describe how effective the cooling tower is at cooling the water or how close the actual temperature difference between the water
temperatures in and out is to the maximum temperature difference. The maximum temperature difference that a cooling tower can produce is the difference between the water temperature in and the air wet bulb temperature.

\[
\text{Effectiveness} = \frac{\text{Range}}{\text{Range} + \text{Approach}}
\]

The range is important because when used in conjunction with the water flow rate, the capacity of the cooling tower can be found. The capacity and the amount of cooling provided by the cooling tower are found by multiplying the flow rate of the cooling water by the difference in temperature at the inlet and outlet of the cooling tower, using the following equation, \( Q = mc\Delta T \) and for a simplified equation to use during the test, follow the derivation below.

\[
Q[\text{Btu}] = \dot{m} \left[ \frac{\text{lbm}}{\text{hr}} \right] \cdot c_p \left[ \frac{\text{Btu}}{\text{lbm} \cdot \degree F} \right] \cdot \Delta T[\degree F]
\]

Where, \( \dot{m} = \text{mass flow rate} \) and \( c_p = \text{heat capacity of water} \) and \( \Delta T = \text{the difference in temperature} \).

*Substituting volumetric flow rate [GPM] and density of water for mass flow rate, results in the following equation.*

\[
Q[\text{Btu}] = 8.33 \frac{\text{lbm}}{\text{gal}} \cdot 60 \frac{\text{min}}{\text{hr}} \cdot \text{flow rate} \left[ \frac{\text{gal}}{\text{min}} \right] \cdot 1.00 \frac{\text{btu}}{\text{lbm} \cdot \degree F} \cdot (T_{\text{water,in}} - T_{\text{water,out}})
\]

*Simplifying the constants, results in the following equation.*

\[
Q[\text{Btu}] = 500 \cdot \text{flow rate} \left[ \frac{\text{gal}}{\text{min}} \right] \cdot (T_{\text{water,in}} - T_{\text{water,out}})
\]

### 3.3 Cooling Tower Water Loss and Make-Up

In a cooling tower, water is lost due to multiple sources such as evaporation, drift and blow-down. The first term, evaporation, is calculated through the following equation, where the assumption is made that the total heat loss is due to the heat loss through evaporation.

\[
\text{Water Heat Loss} = Q[\text{Btu}] = \dot{m}_{\text{water}} \left[ \frac{\text{lbm}}{\text{hr}} \right] \cdot c_p \left[ \frac{\text{Btu}}{\text{lbm} \cdot \degree F} \right] \cdot \Delta T[\degree F]
\]

\[
\text{Heat Gain through Evaporation} = Q[\text{Btu}] = \dot{m}_{vp} \left[ \frac{\text{lbm}}{\text{hr}} \right] \cdot H_{vp} \left[ \frac{\text{Btu}}{\text{lbm}} \right]
\]

where \( H_{vp} \left[ \frac{\text{Btu}}{\text{lbm}} \right] \) is equal to the latent heat of vaporization

\[
\dot{m}_{water} \left[ \frac{\text{lbm}}{\text{hr}} \right] \cdot c_p \left[ \frac{\text{Btu}}{\text{lbm} \cdot \degree F} \right] \cdot (T_{\text{water,in}} - T_{\text{water,out}}) = \dot{m}_{vp} \left[ \frac{\text{lbm}}{\text{hr}} \right] \cdot H_{vp} \left[ \frac{\text{Btu}}{\text{lbm}} \right]
\]

\[
500 \cdot \text{cooling tower flow rate} \left[ \frac{\text{gal}}{\text{min}} \right] \cdot (T_{\text{in}} - T_{\text{out}}) = 500 \cdot \text{evaporation rate} \left[ \frac{\text{gal}}{\text{min}} \right] \cdot 1,060 \left[ \frac{\text{Btu}}{\text{lbm}} \right]
\]
8.0 FANS
Fans are provided in HVAC & Refrigeration systems to distribute conditioned air, to provide ventilation or to exhaust un-wanted air.

8.1 IMPORTANT TERMS

Mechanical Horsepower (MHP): Mechanical horsepower is the measure of the power produced by the fan. Mechanical horsepower is a function of the air flow rate measured in cubic feet per minute (CFM) and the total static pressure (TSP) measured in inches water gauge (in. wg). The term “in. wg” is representative of the pressure due to an inch of water column.

\[
MHP = \frac{CFM \times TSP[\text{in. wg}]}{6,356}
\]

Brake Horsepower (BHP): Brake horsepower is the measure of the power drawn by the motor to turn the fan. BHP is a function of the fan efficiency and the mechanical horsepower.

\[
BHP = MHP \times \left( \frac{1}{\text{fan efficiency}} \right)
\]

Horsepower (HP): Horsepower is the size of the motor. Motors come in standard sizes. [1, 1.5, 2, 3, 5, 7.5, 10, 15, 20, 25, 30, 40, 50, etc] Horsepower is calculated through the following equation and then rounded up to nearest motor size. In the P.E. exam, if the question explicitly asks for the motor horsepower in standard size then calculate the motor horsepower through the below equation and then round up to the nearest motor size. If the question does not ask for standard motor size, then simply provide the output of the below equation.

\[
HP = BHP \times \left( \frac{1}{\text{motor efficiency}} \right)
\]

*upsize HP to nearest motor size

Velocity Pressure (VP): Velocity pressure is defined as the pressure caused solely by moving air.

\[
VP = \frac{FPM}{4005} \text{ [in. wg]}
\]

Static Pressure (SP): Static pressure is the pressure caused solely by compression, the outward force on a duct.

Total Pressure (TSP): Total static pressure is the sum of the velocity pressure and the static pressure at any point.
8.2 TYPES OF FANS

8.2.1 AXIAL FANS
Axial fans consist of a fan shaft with fan blades attached around the shaft. Air travels along the axis of the fan and is blown out. These fans are not as common in the residential and commercial HVAC & Refrigeration fields and are more common in industrial ventilation type situations. Within the family of axial fans there are also different types of fans, like the propeller, tube axial and vane axial fans.

8.2.2 PROPELLER FANS
Propeller type axial fans consist of a propeller fan in fan housing. This fan, similar to all axial type fans is only suitable for lower pressures.

![Propeller Blades]

Figure 17: Axial Fans - Propeller

8.2.3 TUBE-AXIAL FANS
The tube axial fan consists of a propeller fan placed in a tube. This type of fan is more efficient than the propeller fan and can handle higher pressures.

![Fan Tubular Housing]

Figure 18: Axial Fans – Tube Axial
Section 10.0 – Application Systems & Components

Table of Contents

1.0 Introduction ........................................................................................................................ 3
2.0 Key Equations and Terms ................................................................................................. 4
3.0 Air distribution .................................................................................................................... 7
  3.1 Air Handling Units ........................................................................................................... 8
  3.2 Fan/Duct ......................................................................................................................... 9
    3.2.1 Darcy Weisbach Equation ....................................................................................... 9
    3.2.2 Determining Velocity in Ducts for Pressure Calculations ....................................... 9
    3.2.3 Determining Diameter of Duct ................................................................................. 9
    3.2.4 Determining Volumetric Flow Rate [CFM] ............................................................. 10
    3.2.5 Determining Total Static Pressure [in. wg] ............................................................. 11
  3.3 Terminal Units .............................................................................................................. 13
  3.4 Supply air diffusers ....................................................................................................... 13
4.0 Fluid Distribution .............................................................................................................. 15
  4.1 Pumps .......................................................................................................................... 15
  4.2 Determining Total Head or pressure loss ..................................................................... 15
  4.3 Determining Net Positive Suction Head Available ........................................................ 26
5.0 Refrigeration ..................................................................................................................... 28
6.0 Energy Recovery Devices ................................................................................................ 29
7.0 Basic control concepts ..................................................................................................... 35
  7.1 Economizer ................................................................................................................... 35
  7.2 Temperature reset ........................................................................................................ 36
8.0 Practice problems ............................................................................................................ 37
  8.1 Problem 1 – Duct Design .............................................................................................. 37
  8.2 Solution 1 – Duct Design .............................................................................................. 38
  8.3 Problem 2 – Duct Design .............................................................................................. 39
  8.4 Solution 2 – Duct Design .............................................................................................. 40
  8.5 Problem 3 – Diffusers ................................................................................................. 41
  8.6 Solution 3 – Diffusers ................................................................................................. 42
  8.7 Problem 4 – Energy Recovery Device .......................................................................... 43
  8.8 Solution 4 – Energy Recovery Device .......................................................................... 44
  8.9 Problem 5 – Pressure loss ........................................................................................... 45
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 18 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

<table>
<thead>
<tr>
<th>Air Distribution Systems</th>
<th>Fluid Distribution Systems</th>
<th>Refrigeration Systems</th>
<th>Energy Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Air handlers</td>
<td>• Hydronic</td>
<td>• Food storage</td>
<td>• Enthalpy wheels</td>
</tr>
<tr>
<td>• Duct design</td>
<td>• Oil</td>
<td>• Cooling</td>
<td>• Heat pipes</td>
</tr>
<tr>
<td>• System type</td>
<td>• Fuel gas</td>
<td>• Freezing</td>
<td>• Run-around systems</td>
</tr>
<tr>
<td>• Terminal devices</td>
<td>• Compressed air</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Steam</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• System type</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Basic control concepts**
  - Economizer
  - Temperature reset

18 questions

http://www.engproguides.com
2.0  **Key Equations and Terms**

**Rectangular Duct**

\[ D_e = 1.30 \ast \left( \frac{(a \ast b)}{(a + b)^{0.250}} \right)^{0.625} \]

*where* \(a\) and \(b\) are the width[ft] and height[ft] of the duct

**Oval Duct**

\[ D_e = 1.55 \ast \left( \frac{(A \ast \text{Area})^{0.625}}{(\text{Perimeter})^{0.250}} \right)^{0.625} \]

*Perimeter* = \(\pi \ast a + 2 \ast (A - a)\)

*where* \(A\) is the major axis and \(a\) is the minor axis

**Velocity Pressure as a Function of Air Velocity**

\[ VP = \left[ \frac{FPM}{4005} \right]^2 \text{[in.wg]} \]

*FPM* = *air velocity in feet per minute*

*VP* = *velocity pressure [in.wg]*

**Friction loss due to length of duct**

\[ F_{duct}[\text{in.wg}] = L[ft] \ast f\left[\frac{\text{in.wg}}{100 \text{ ft}}\right] \]

**Energy Recovery Device Efficiency Equations**

\[ \varepsilon_{\text{sensible}} = \frac{q_{\text{sensible, actual}}}{q_{\text{sensible, max}}} \]
\[ \varepsilon_{\text{latent}} = \frac{Q_{\text{latent, actual}}}{Q_{\text{latent, max}}} \]
\[ \varepsilon_{\text{total}} = \frac{q_{\text{total, actual}}}{q_{\text{total, max}}} \]

**Energy Recovery Device Determine Actual Sensible Heat Transferred**

\[ q_{\text{sensible, actual}} = 1.08 \ast CFM_{\text{outdoor}} \ast (T_{\text{outdoor}} - T_{\text{supply}}) \]
\[ q_{\text{sensible, actual}} = 1.08 \ast CFM_{\text{return}} \ast (T_{\text{return}} - T_{\text{exhaust}}) \]

**Energy Recovery Device Determine Maximum Possible Sensible Heat Transferred**

\[ q_{\text{sensible, max}} = 1.08 \ast CFM_{\text{min}} \ast (T_{\text{outdoor}} - T_{\text{return}}) \]

**Energy Recovery Device Determine Actual Latent Heat Transferred**
\[ q_{\text{latent,actual}} = 4.770 \times \text{CFM}_{\text{outdoor}} \times (W_{\text{outdoor}} - W_{\text{supply}}) \]
\[ q_{\text{latent,actual}} = 4.770 \times \text{CFM}_{\text{return}} \times (W_{\text{return}} - W_{\text{exhaust}}) \]

Energy Recovery Device Determine Maximum Possible Latent Heat Transferred

\[ q_{\text{latent,max}} = 4.770 \times \text{CFM}_{\text{return}} \times (W_{\text{outdoor}} - W_{\text{return}}) \]

Energy Recovery Device Determine Actual Enthalpy Transferred

\[ q_{\text{total,actual}} = 4.5 \times \text{CFM}_{\text{outdoor}} \times (h_{\text{outdoor}} - h_{\text{supply}}) \]
\[ q_{\text{total,actual}} = 4.5 \times \text{CFM}_{\text{return}} \times (h_{\text{return}} - h_{\text{exhaust}}) \]

Energy Recovery Device Determine Maximum Possible Enthalpy Transferred

\[ q_{\text{total,max}} = 4.5 \times \text{CFM}_{\text{outdoor}} \times (h_{\text{outdoor}} - h_{\text{return}}) \]

Darcy Weisbach Equation

\[ h = \frac{fLv^2}{2Dg} \quad \text{[Darcy Weisbach Equation]} \]

where \( h = \text{ft of head}; f = \text{Darcy friction factor}; v = \text{velocity} \quad \text{[ft/sec]}, \]
\[ D = \text{inner diameter [ft]}, g = \text{gravity} \quad [32.2 \text{ ft/sec}^2] \]

Darcy Weisbach Equation

\[ h = \frac{12 \times L[\text{ft}]}{D[\text{in}] \times \rho[\text{lb/ft}^3] \times \frac{V[\text{ft/min}]}{1097}} \quad \text{[Darcy Weisbach Equation]} \]

where \( h = \text{ft of head}; f = \text{Darcy friction factor} \)

Net Positive Suction Head Available

\[ NPSHA = P_{\text{abs}} \pm P_{\text{elev}} - P_{\text{fric}} - P_{\text{vapor}} \]

or

\[ NPSHA = P_{\text{gauge}} + P_{\text{velocity}} - P_{\text{vapor}} \]

Pressure Drop due to Velocity Equation [Pump]

\[ \frac{V^2}{2g} \quad [\text{ft of head}]; \ \text{velocity in} \quad \text{ft/sec}; \]
\[ gravity = 32.2 \frac{ft}{sec^2} \]
3.0 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.
3.1 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 components is discussed throughout this book. It is simplest to think of an AHU as pieced together or built up by various building blocks or components. Components that most often comprise an AHU are shown below:

1. Mixing Box: Typically the first component in an AHU is a mixing box, which mixes the correct amounts of outdoor air with return air through the use of dampers.

2. Air Filter: An air filter is then provided prior to the next devices, in order to protect the following devices and to keep them clean.

3. Heating and/or Cooling Coil: A heating and/or cooling coil is then provided to condition the air to the correct leaving temperature.

4. Humidifier or Dehumidifier: If required a humidifier and/or dehumidifier is provided to condition the air to the correct humidity level.

5. Fan: A fan may either be provided ahead or behind devices, depending on the engineer's decision. If the fan is placed last, then the configuration is deemed a draw-thru fan, because the fan draws the air thru the other devices. A blow-thru fan is located before the other components and blows the air thru them.

6. Energy Recovery Device: If there is an opportunity for energy recovery, then an ERV like a heat pipe may be provided.

Figure 1: Sample Air handling unit with draw-thru fan
\[ V = \text{velocity of fluid} \left( \frac{ft}{sec} \right) \]

\[ D = \text{diameter of pipe} \ [ft] \]

These two values (a) Relative Roughness and (b) Reynold's Number, determine the friction factor, which can be found by finding the intersection of the vertical Reynold's number line shown in black and the Relative Roughness factor curves shown in red.

Now, that all the variables of the Darcy Weisbach equation have been determined, simply plug in the variables into the equation to determine the friction head.

\[ h = \frac{fLv^2}{2Dg} \quad \text{[Darcy Weisbach Equation]} \]
8.0 PRACTICE PROBLEMS

8.1 PROBLEM 1 – DUCT DESIGN

Background: The pressure at the outlet of a 2,000 CFM fan is 0.75 in. wg. The fan discharges into a 12” x 18” duct. The duct runs for an equivalent length of 125’ to a supply diffuser. What is the pressure at the supply diffuser?

Assume standard conditions, density = 0.75 lbm/ft^3 and roughness factor of 0.003 ft.

(a) 0.62 in. wg
(b) 0.53 in. wg
(c) 0.41 in. wg
(d) 0.25 in. wg
8.2 SOLUTION 1 – DUCT DESIGN

Since standard conditions are used, the friction chart is applicable.

First calculate the equivalent diameter.

\[
D_e = \frac{1.30 \times (a \times b)^{0.625}}{(a + b)^{0.250}}
\]

\[
D_e = \frac{1.30 \times (12'' \times 18'')^{0.625}}{(12'' + 18'')^{0.250}}
\]

\[D_e = 16''\]

Or refer to ASHRAE Fundamentals Table – Equivalent Rectangular Duct Dimensions for converting Rectangular Dimensions to Equivalent Diameter.

Next navigate the friction chart in ASHRAE Fundamentals to the intersection of equivalent diameter equal to 16'' and a flow rate of 2,000 CFM.

Pressure Loss = 0.18 in. wg per 100'

Next calculate the total pressure loss due to the duct.

Total Pressure Loss = 125' * 0.18 in. wg per 100'

Total Pressure Loss = 0.225 in. wg

The pressure at the diffuser is found below:

Pressure at Diffuser = 0.75 – 0.225 = 0.525 in. wg
8.18 SOLUTION 9 – NET POSITIVE SUCTION HEAD

A cooling tower is located such that the fluid level in the basin is 10 ft above the centerline for the suction of the condenser water pump. The water is at an average temperature of 86 F. The friction loss from the cooling tower basin to the suction of the pump is approximately 15 ft of head. What is the net positive suction head available at the suction side of the pump with a flow rate of 400 GPM?

Assume sea level.

For this question use the Net Positive Suction Head Available equation:

\[ NPSHA = h_{\text{pressure}} + h_{\text{elevation}} - h_{\text{friction}} - h_{\text{vapor pressure}} \]

The pressure at the basin is simply atmospheric pressure.

\[ h_{\text{pressure}} = 14.7 \text{ psi or } 33.96 \text{ ft of head} \]

The elevation pressure is the difference in height between the top of the fluid and the centerline of the pump.

\[ h_{\text{elevation}} = 10 \text{ ft of head} \]

The friction loss is given.

\[ h_{\text{friction}} = 15 \text{ ft of head} \]

Refer to your references MERM or ASHRAE for the vapor pressure. The vapor pressure was also earlier in this section.

\[ h_{\text{vapor pressure}} = 1.4 \text{ ft of head} \]

Find NPSHA

\[ NPSHA = 33.96 + 10 - 15 - 1.4 = 27.6 \text{ ft of head} \]
SECTION 11
SUPPORTIVE KNOWLEDGE
# Section 11.0 – Application Supportive Knowledge

## Table of Contents

1.0 **Introduction** ........................................................................................................................ 3  
2.0 Equations/Terms......................................................................................................................... 4  
3.0 Codes/Standards ........................................................................................................................ 6  
   3.1 ASHRAE 15 ........................................................................................................................ 6  
   3.2 ASHRAE 34 ........................................................................................................................ 7  
   3.3 ASHRAE 55 ........................................................................................................................ 7  
   3.4 ASHRAE 62.1 ....................................................................................................................... 7  
   3.5 ASHRAE 90.1 ....................................................................................................................... 7  
   3.6 NFPA 90A ......................................................................................................................... 8  
   3.7 NFPA 90B ......................................................................................................................... 8  
   3.8 NFPA 96 ........................................................................................................................... 8  
   3.9 Montreal Protocol ............................................................................................................. 8  
4.0 Air quality and ventilation ........................................................................................................ 10  
5.0 Vibration control .................................................................................................................... 10  
6.0 Acoustics ............................................................................................................................... 12  
   6.1 Sound Level as a Function of Distance ........................................................................ 13  
   6.2 NC Rating ....................................................................................................................... 15  
7.0 Practice Problems .................................................................................................................. 17  
   7.1 **PROBLEM 1 - REFERENCES/CODES** ........................................................................ 17  
   7.2 Solution 1 - References/Codes......................................................................................... 18  
   7.3 Problem 2 - References/Codes ....................................................................................... 19  
   7.4 Solution 2 - References/Codes ....................................................................................... 20  
   7.5 Problem 3 - References/Codes ....................................................................................... 21  
   7.6 Solution 3 - References/Codes ....................................................................................... 22  
   7.7 Problem 4 - References/Codes ....................................................................................... 23  
   7.8 Solution 4 - References/Codes ....................................................................................... 24  
   7.9 Problem 5 - References/Codes ....................................................................................... 25  
   7.10 Solution 5 - References/Codes ...................................................................................... 26  
   7.11 Problem 6 – Refrigeration Codes ................................................................................. 27  
   7.12 Solution 6 – Refrigeration Codes ................................................................................. 28  
   7.13 Problem 7 – Refrigerants .............................................................................................. 29
Background: A new chiller is being installed in a mechanical room. The chiller has two separate refrigerant circuits. One refrigerant circuit has 100 lbs of R-134a and the second circuit has 200 lbs of R-134a.

Problem: What value is most nearly the minimum refrigerant exhaust system capacity in CFM?

Take the largest refrigerant circuit (LBS) and use the following formula.

\[
Q = 100 \times G^{0.5}
\]

\(G = \text{weight (lbs) of largest refrigerant circuit}\)

\[
Q = 100 \times 200^{0.5} = 1,414 \text{ CFM}
\]

Correct Answer: C, 1,400 CFM
SECTION 6
CONCLUSION
If you have any questions on this sample exam or any other Engineering Pro Guides product, then please contact:

Justin Kauwale at contact@engproguides.com

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!