Online Instructor's Manual

Mechanical and Electrical Systems in Buildings

Sixth Edition

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Overview and Questions/Answers

A MESSAGE

To colleagues and instructors,

The instructor's manual contains answers to questions that appear at the end of each chapter in the text. In addition, there is an overview page pertaining to each chapter. Hopefully, these will assist you in preparing your class lectures.

This book is arranged along five basic disciplines-HVAC, Plumbing and Fire Protection, Electrical, Illumination and Noise and Vibration Controls. Each discipline may be taught separately or as a whole. As college courses, the entire book with supplemental references should be for a two-semester course with 3 credit-hours for each semester.

When taught separately, the following credit hours are recommended:

- As a Mechanical Course 3 credit hours
  (Chapters 1 through 11 + Chapters 20 and 21)
- As an Electrical Course 3 credit hours
  (Chapters 12 through 15 + Chapters 1 and 21)
- As an Acoustic and Vibration Course 1 credit hour
  (Chapters 20 and 21)
- As a Lighting Course 1 to 2 credit hours
  (Chapters 16 through 19 + Chapter 1)

We thank you for choosing this book for your class or to use in your professional practice.

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CHAPTER 1
INTRODUCTION TO MECHANICAL AND ELECTRICAL SYSTEMS: ENERGY, SUSTAINABILITY, AND ECONOMICS

OVERVIEW

Chapter 1 covers topics that are relevant for all the mechanical and electrical systems covered in subsequent chapters. These materials are essential background and context for subsequent chapters.

Mechanical systems involve the transfer of energy and fluids. Understanding the basic physics of energy is a prerequisite for building load estimating, systems selection and energy conservation. Chapter 1 describes heat, thermal properties of materials, the conversion of energy from one form to another, and the thermal values of commonly used fuels. Transfer of fluids is covered so that students understand the units of flow and pressure that are used to specify and measure the performance of systems and equipment.

Simple example problems are included, and the instructor is encouraged to work them and similar exercises on the board to insure that students are prepared to go on to subsequent chapters.

Mechanical and electrical systems affect the design of buildings. Architectural students especially should appreciate why modern buildings are different in form and dimension to older buildings. This understanding is useful if future buildings are to use less energy by using passive climate control strategies.

Resource conservation, comfort, and habitability are all part of sustainable design, and this topic is discussed in Chapter 1 because it applies to the entire building design process, including all systems. The most important message in these sections, and perhaps in the entire book, is that good building design certainly affects occupant performance. Furthermore, improved occupant performance is worth a larger investment in design and construction than is usually made.

Commissioning is another topic that applies to virtually all systems and equipment discussed in subsequent chapters, so an overview of commissioning is included in Chapter 1.

All systems present many options for design, and selecting among these options relies on evaluation tools to assess quality. Several methods are presented including the decision matrix, which is useful in documenting subjective criteria, and various economic evaluation tools, such as payback analysis and life cycle costing.

CHAPTER 1
INTRODUCTION TO MECHANICAL AND ELECTRICAL SYSTEMS: ENERGY, SUSTAINABILITY, AND ECONOMICS

QUESTIONS AND ANSWERS

1.1 What are the benefits of buildings with shallow floor depths?

Buildings with shallow floor depths have more access to day light, views, and natural ventilation.

1.2 How much CO_2 will be liberated to the atmosphere in a year's time due directly to a lighting system consuming 300,000 kWh per year?

The amount will depend on how the electric is generated. Assume a coal fired power plant, 2.4 lbs. of CO_2 will be generated per kWh; therefore, 2.4 x 300,000 = 720,000 lb. will produced. If the plant uses natural gas, only 1.4 lbs. of CO_2 will be generated per kWh; 1.4 x 300,000 = 420,000 lbs.

1.3 If a corporation is concerned with its carbon footprint and accepts a value of $25 per ton to account for societal costs, what is their perceived economic impact of this much CO_2?

For coal fired power - 720,000 lbs. / 2000 lb./ton = 360 tons. 360 tons x $25/ton = $9,000
For gas fired power - 420,000 lbs. / 2000 lb./ton = 210 tons. 210 tons x $25/ton = $5,250

1.4 What will the relative impact be on CO_2 for heating and for cooling, assuming the buildings in Question 1.1 are located in the Midwest (hot summers, cold winters)?

Buildings with shallow floor depths will use more heating and cooling energy, resulting in higher CO2 liberation from electric and gas. There may, however, be a partial offset if controls are used to turn lights off when daylight is sufficient.

1.5 How does "sustainable" design differ from energy-effective design?

Energy efficiency is only one aspect of the many qualities that comprise sustainable design. Sustainable design includes indoor environmental quality, water conservation, and environmental impact as well as energy conservation.

1.6 What factors should the architect and engineer consider to produce a high performance environment for building occupants?

Healthful indoor air quality, thermal comfort and individual control, good lighting, and connection with the outdoors are the main issues cited in Chapter 1.

1.7 How does saving energy help to protect the environment?

Using less energy reduces air pollution from burning fossil fuels.

1.8 What is the role of maintainability in sustainable buildings?

Solutions must be maintainable to last long term and perform as intended.

1.9 How could building site selection affect the environment?

Chapter 1 cites daylight, views and natural ventilation, which are all affected by site selection. However, students may go beyond these answers and cite many other issues such as infrastructure loads, pollution due to auto traffic and other issues related to building site.

1.10 What factors should interior designers consider in terms of indoor air quality? Architects? HVAC engineers?

Indoor air pollution comes from finish materials and furniture, which are selected by interior designers. Architects are responsible for locating fresh air intakes appropriately to avoid bringing exhaust or polluted air into the building. Architects are also responsible for detailing to control moisture, thereby preventing mold growth. HVAC engineers are responsible for proper ventilation rates and humidity control and working with the architect to locate intakes and exhausts.

1.11 What design features would you suggest to allow personal climate control in a single-story residence? A high-rise office building? A classroom building?

A single story residence might use operable windows as well as the ability to adjust HVAC airflow. Operable windows are not advisable in high rise buildings, but personal control might be achieved by system features such as the task cooling device, or by adjustable floor registers. In a classroom building, personal control can be achieved by any of the means listed, plus the choice of seating location.

1.12 Compare the importance of commissioning for a data center versus a classroom building.

The scope of commissioning will depend on how simple or complicated the systems are and on the relative importance of proper system operation. In general, a classroom building will have simpler, less energy-intensive systems than a data center. A shortened commissioning process might be quite satisfactory for a classroom building. For a data center, the commissioning process will be extensive.

1.13 What sustainable design issues should architects consider in deciding window materials and locations?

Architects should consider daylight and view when selecting window materials and locations. Insulating qualities, solar effects on heating and air conditioning, glare and downdrafts are also considerations which affect energy usage and comfort, which are factors in sustainable design.

1.14 Name a few quantitative factors involved in the analysis of a building HVAC system. Name a few qualitative factors.

Quantitative factors, such as system cost, energy consumption, and space requirements have a basis for numerical measurement and comparison of alternative systems. Qualitative factors, such as comfort, maintainability, and visual impact can be evaluated as better or worse, but have no standardized basis for numerical measurement.

1.15 Is there ever a time when energy conservation is unwise? If so, give examples.

Yes, energy conservation is unwise if it is achieved at the expense of indoor environmental quality. For example, setting thermostats up in summer and down in winter can save energy, but might result in discomfort and reduce occupant productivity. The productivity loss can have a much higher economic impact than the utility savings by energy conservation measures. Decreases in lighting can also adversely affect indoor environmental quality and occupant performance.

1.16 Prepare three decision matrices to evaluate operable windows versus fixed

windows in an office building. Use the process described in Section 1.4.3. Fill out the matrices as an occupant, a maintenance staffer, and a building owner.

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How an Occupant Might think of Operable Windows					
		Operable Windows		Fixed Sash	
Criteria	**Weight**	**Score**	**Weighted**	**Score**	**Weighted**
Comfort	9	8	72	7	63
Connection with outdoors	9	9	81	3	27
Initial Cost	2	4	8	6	12
Energy consumption	2	8	16	4	8
Water hazard	2	3	6	9	18
Freeze hazard	2	3	6	9	18
Security	2	3	6	9	18
Total score			**195**		**164**
% score (normalized)			**100%**		**84%**

How a Maintenance Staffer Might think of Operable Windows					
		Operable Windows		Fixed Sash	
Criteria	**Weight**	**Score**	**Weighted**	**Score**	**Weighted**
Comfort	3	8	24	7	21
Connection with outdoors	2	9	18	3	6
Initial Cost	2	4	8	6	12
Energy consumption	5	8	40	4	20
Water hazard	8	3	24	9	72
Freeze hazard	8	3	24	9	72
Security	8	3	24	9	72
Total score			**162**		**275**
% score (normalized)			**59%**		**100%**

How a Building Owner Might think of Operable Windows					
		Operable Windows		Fixed Sash	
Criteria	**Weight**	**Score**	**Weighted**	**Score**	**Weighted**
Comfort	6	8	48	7	42
Connection with outdoors	3	9	27	3	9
Initial Cost	8	4	32	6	48
Energy consumption	8	8	64	4	32
Water hazard	8	3	24	9	72
Freeze hazard	8	3	24	9	72
Security	8	3	24	9	72
Total score			**243**		**347**

% score (normalized)			**70%**		**100%**

1.17 Will a commercial building developer use a higher or lower discount rate than an institutional building owner? Why?

Developers generally have a higher expectation for rate of return, so they would use a higher discount rate.

1.18 An energy conservation option has a first cost of $50,000. It requires $4000 per year maintenance and saves $10,000 per year in utilities. What is the simple payback period for the option?

Simple payback is $50,000 / ($10,000 - $4,000) = 8.3 years.

1.19 The system in Question 1.18 will last 15 years with no salvage value. What is the 15-year life-cycle cost assuming energy cost escalation of 4% annually, maintenance cost escalation of 2% annually, and a 5% discount rate? What if the discount rate is 15%?

5% discount rate

Year	Invest	Save	Maint	Cash flow	Pres. Value
0	(50,000)	-	-	(50,000)	(50,000)
1	-	10,000	(4,000)	6,000	5,714
2	-	10,400	(4,080)	6,320	5,732
3	-	10,816	(4,162)	6,654	5,748
4	-	11,249	(4,245)	7,004	5,762
5	-	11,699	(4,330)	7,369	5,774
6	-	12,167	(4,416)	7,750	5,783
7	-	12,653	(4,505)	8,149	5,791
8	-	13,159	(4,595)	8,565	5,797
9	-	13,686	(4,687)	8,999	5,801
10	-	14,233	(4,780)	9,453	5,803
11	-	14,802	(4,876)	9,926	5,804
12	-	15,395	(4,973)	10,421	5,803
13	-	16,010	(5,073)	10,937	5,800
14	-	16,651	(5,174)	11,476	5,796
15	-	17,317	(5,278)	12,039	5,791
		15 year life cycle net present value			**36,700**

15% discount rate

Year	Invest	Save	Maint	Cash flow	Pres. Value
0	(50,000)	-	-	(50,000)	(50,000)
1	-	10,000	(4,000)	6,000	5,217
2	-	10,400	(4,080)	6,320	4,779
3	-	10,816	(4,162)	6,654	4,375
4	-	11,249	(4,245)	7,004	4,004
5	-	11,699	(4,330)	7,369	3,664
6	-	12,167	(4,416)	7,750	3,351
7	-	12,653	(4,505)	8,149	3,063
8	-	13,159	(4,595)	8,565	2,800
9	-	13,686	(4,687)	8,999	2,558
10	-	14,233	(4,780)	9,453	2,337
11	-	14,802	(4,876)	9,926	2,134
12	-	15,395	(4,973)	10,421	1,948
13	-	16,010	(5,073)	10,937	1,778
14	-	16,651	(5,174)	11,476	1,622
15	-	17,317	(5,278)	12,039	1,480
		15 year life cycle net present value			**(4,891)**

1.20 Assume the option in Question 1.18 is installed in a building with 200

occupants, with average personnel cost of $60,000 per year. If the device interferes with temperature control, resulting in a 2% decrease in productivity, what would the simple payback be?

Productivity loss will be 200 occup. x $60,000 / yr-occup. x 2% = $240,000
Simple payback is $50,000 / ($10,000 - $4,000 - $240,000) = NEVER

1.21 What would the payback be if the option in Question 1.18 improved temperature control and resulted in a 2% increase in productivity?

Simple payback is $50,000 / ($10,000 - $4,000 + $240,000) = 0.2 years
(VIRTUALLY IMMEDIATELY)

1.22 Calculate the life-cycle costs for the two cases (2% decrease, 2% increase in productivity) using data from Questions 1.19 and 1.20 for a 5% discount rate and a 15% discount rate.

5% discount rate (assuming 2% escalation for productivity)

1

Year	Invest	Save	Maint	Productivity	Cash flow	Pres. Value
0	(50,000)	-	-	-	(50,000)	(50,000)
1	-	10,000	(4,000)	(240,000)	(234,000)	(222,857)
2	-	10,400	(4,080)	(244,800)	(238,480)	(216,308)
3	-	10,816	(4,162)	(249,696)	(243,042)	(209,948)
4	-	11,249	(4,245)	(254,690)	(247,686)	(203,772)
5	-	11,699	(4,330)	(259,784)	(252,415)	(197,774)
6	-	12,167	(4,416)	(264,979)	(257,229)	(191,948)
7	-	12,653	(4,505)	(270,279)	(262,130)	(186,291)
8	-	13,159	(4,595)	(275,685)	(267,120)	(180,797)
9	-	13,686	(4,687)	(281,198)	(272,199)	(175,462)
10	-	14,233	(4,780)	(286,822)	(277,369)	(170,281)
11	-	14,802	(4,876)	(292,559)	(282,632)	(165,249)
12	-	15,395	(4,973)	(298,410)	(287,989)	(160,363)
13	-	16,010	(5,073)	(304,378)	(293,441)	(155,618)
14	-	16,651	(5,174)	(310,466)	(298,989)	(151,010)
15	-	17,317	(5,278)	(316,675)	(304,636)	(146,535)
				15 year life cycle net present value		**(2,784,214)**

5% discount rate (assuming 2% escalation for productivity)

Year	Invest	Save	Maint	Productivity	Cash flow	Pres. Value
0	(50,000)	-	-	-	(50,000)	(50,000)
1	-	10,000	(4,000)	240,000	246,000	234,286
2	-	10,400	(4,080)	244,800	251,120	227,773
3	-	10,816	(4,162)	249,696	256,350	221,445
4	-	11,249	(4,245)	254,690	261,694	215,296
5	-	11,699	(4,330)	259,784	267,153	209,321
6	-	12,167	(4,416)	264,979	272,730	203,515
7	-	12,653	(4,505)	270,279	278,428	197,873
8	-	13,159	(4,595)	275,685	284,249	192,391
9	-	13,686	(4,687)	281,198	290,197	187,064
10	-	14,233	(4,780)	286,822	296,275	181,887
11	-	14,802	(4,876)	292,559	302,485	176,857
12	-	15,395	(4,973)	298,410	308,831	171,969
13	-	16,010	(5,073)	304,378	315,315	167,218
14	-	16,651	(5,174)	310,466	321,942	162,603
15	-	17,317	(5,278)	316,675	328,714	158,117
				15 year life cycle net present value		**2,857,615**

15% discount rate (assuming 2% escalation for productivity)

Year	Invest	Save	Maint	Productivity	Cash flow	Pres. Value
0	(50,000)	-	-	-	(50,000)	(50,000)
1	-	10,000	(4,000)	(240,000)	(234,000)	(203,478)
2	-	10,400	(4,080)	(244,800)	(238,480)	(180,325)
3	-	10,816	(4,162)	(249,696)	(243,042)	(159,804)
4	-	11,249	(4,245)	(254,690)	(247,686)	(141,615)
5	-	11,699	(4,330)	(259,784)	(252,415)	(125,495)
6	-	12,167	(4,416)	(264,979)	(257,229)	(111,207)
7	-	12,653	(4,505)	(270,279)	(262,130)	(98,545)
8	-	13,159	(4,595)	(275,685)	(267,120)	(87,322)
9	-	13,686	(4,687)	(281,198)	(272,199)	(77,376)
10	-	14,233	(4,780)	(286,822)	(277,369)	(68,561)
11	-	14,802	(4,876)	(292,559)	(282,632)	(60,750)
12	-	15,395	(4,973)	(298,410)	(287,989)	(53,827)
13	-	16,010	(5,073)	(304,378)	(293,441)	(47,692)
14	-	16,651	(5,174)	(310,466)	(298,989)	(42,256)
15	-	17,317	(5,278)	(316,675)	(304,636)	(37,438)
				15 year life cycle net present value		**(1,545,692)**

15% discount rate (assuming 2% escalation for productivity)

Year	Invest	Save	Maint	Productivity	Cash flow	Pres. Value
0	(50,000)	-	-	-	(50,000)	(50,000)
1	-	10,000	(4,000)	240,000	246,000	213,913
2	-	10,400	(4,080)	244,800	251,120	189,883
3	-	10,816	(4,162)	249,696	256,350	168,555
4	-	11,249	(4,245)	254,690	261,694	149,624
5	-	11,699	(4,330)	259,784	267,153	132,822
6	-	12,167	(4,416)	264,979	272,730	117,909
7	-	12,653	(4,505)	270,279	278,428	104,671
8	-	13,159	(4,595)	275,685	284,249	92,922
9	-	13,686	(4,687)	281,198	290,197	82,492
10	-	14,233	(4,780)	286,822	296,275	73,235
11	-	14,802	(4,876)	292,559	302,485	65,017
12	-	15,395	(4,973)	298,410	308,831	57,723
13	-	16,010	(5,073)	304,378	315,315	51,248
14	-	16,651	(5,174)	310,466	321,942	45,500
15	-	17,317	(5,278)	316,675	328,714	40,397
15 year life cycle net present value						**1,535,909**