Worked-out answers to IRP Manual Exercises.

1.1

Steam generator operating at 80% efficiency uses fuel oil at a rate of 65.78 kg/hr. Therefore, if it were operating at 100% efficiency, it would use 65.78 * 0.8, or 52.62 kg/hr.

From Appendix 1, fuel oil has a heating value of 43.24 GJ/ton. Assuming that this refers to *metric* tons, 43.24 GJ/ton ÷ 1000 kg/ton = 0.04324 GJ/kg.

Assuming that the steam generator is successfully meeting the 1 ton of steam requirement, the actual heat requirement of the industrial process is:

52.62 kg/hr * 0.04324 GJ/kg = 2.275 GJ/hr.

Therefore,

a.) For natural gas with a steam generator of 88% efficiency:

From Appendix 1, the heating value of natural gas is 41.23 MJ/m^3 (= 0.04123 GJ/m^3).

2.275 GJ/hr ÷ 0.04123 GJ/m^3 ÷ 0.88

= 62.70 m^3/hr = natural gas requirement.

b.) Firewood (10.56 GJ/ton), steam generator of 70% efficiency:

2.275 GJ/hr ÷ 0.01056 GJ/kg ÷ 0.70

= 307.8 kg/hr = firewood requirement.

c.) Electricity, with steam generator of 95% efficiency:

From Appendix 1, 1 joule = 0.278 x 10^{-6} kWh.

Therefore, (2.275 GJ/hr) * (10^9 J/GJ) * (0.278 x 10^{-6} kWh/J) ÷ 0.95

= 666 kWh/hr = electricity requirement.

Alternatively, assume electricity is generated from coal, and assume that coal-to-electricity conversion efficiency is 33%.

From Appendix 1, coal heating value = 28.46 GJ/ton. Therefore, coal electricity heating value = 28.46 * 0.33 = 9.39 GJ/ton.

2.275 GJ/hr ÷ 9.39 GJ/ton ÷ 0.95

= 0.255 tons/hr = coal requirement.

1.2

Converting from standard fluorescent lamps to efficient fluorescent lamps:

Conventional fluorescent: 67 lumens/W * 40 W = 2680 lumens.
Efficient fluorescent: 90 lumens/W * 32 W = 2880 lumens.

This is therefore a good replacement, with similar lumen output.

Annual savings = 8 W * 3 hr/day * 365 days/yr ÷ 1000 W/kW = **8.76 kWh/yr**.

Some other replacement possibilities:

Conventional 60 W incandescent: 10 lumens/W * 60 W = 600 lumens.
Efficient 54 W incandescent: 13 lumens/W * 54 W = 702 lumens.
Annual savings = 6 W * 3 hr/day * 365 days/yr ÷ 1000 W/kW = **6.57 kWh/yr**.

Conventional 25 W incandescent: 10 lumens/W * 25 W = 250 lumens.
Compact fluorescent 5 W: 57 lumens/W * 5 W = 285 lumens.
Annual savings = 20 W * 3 hr/day * 365 days/yr ÷ 1000 W/kW = **21.9 kWh/yr**.

2.1

Annual energy use can be calculated by multiplying the number of households (N) for each city by each end-use's saturation and each end-use's consumption.

For example, for incandescent lights in Manaus,
201,000 homes x 0.98 saturation x 15 kWh/yr-home = 2,954,700 kWh/yr or 2955 MWh/yr.

Results are provided below.

Annual MWh Consumption by End-Use								
City	Incand Light	Fluor. Light	TV b/w	TV color	Refrig	Elec H2O Heat	Air Cond	Clothes Wash
Beijing	31903	58441	176628	323819	1604374	10417	53897	538006
Manila	19392	34798	108502	145551	1079225			
Pune	4169	7059	22494	21370	98639	57112	7207	6852
Thailand	12366	36851			904868	31167	241887	76652
Nanning					118057			57708
Hong Kong			3588	175794	770866	75536	586237	243144
Manaus	2955	3136	10492	29378	128825	52845	112058	6924

Some possible problems with the above:

1. It is highly unlikely that each of the cities would have the same unit energy consumption (kWh per year per end-use for each household which possesses the appliance). In other words, Table 2.3 is too general to be applied to so many different cities.

2. The TV unit energy consumption of 174 kWh/yr in Table 2.3 is not specified as being for color or black&white (B&W) TVs. In the answers above, the same 174 kWh/yr number was

applied to both color and B&W. This is not really appropriate. Because color and B&W TVs have different efficiency levels, Table 2.3 should have separate entries for color and B&W.

If the 174 kWh/yr figure in Table 2.3 is an average of color and B&W, then perhaps all TV numbers should be presented as an average of the two. However, this would also not be very accurate because different cities would have very different relative ratios of color-to-B&W.

3. The incandescent lighting energy use number in Table 2.3 is extremely low. 15 kWh/yr is the equivalent of using one 40W bulb for 1 hr/day. This may be appropriate for some very poor locations but is surely not correct for somewhere like Hongkong. Again, this points back to the general problem discussed in point 1 above that Table 2.3 is too general to be used for multi-country purposes.

2.2

a. Motors would perhaps be the most appropriate program, as motors comprise a very significant portion of all countries' industrial energy use. This end-use is therefore likely to yield large energy savings. Commercial lighting would be another good candidate for the same reason.

b. The two above-mentioned end-uses would still be appropriate for all countries. However, there may be specific additional end-uses which would be appropriate in individual countries. For example, residential ventilation fans and commercial air conditioning in India may yield large savings because they are responsible for such a large portion of residential and commercial energy use in India. These two end-uses would not be appropriate for the other countries. For Thailand, commercial refrigeration is likely to be a very attractive candidate for a program.

2.3

Refrigerators:

Because the sales between 1985 and 1989 are relatively consistent, we will assume that the market is not growing and that all refrigerator sales are replacements. Therefore, using Eq. 2.23,

Total annual energy consumption = L * S * UEC.

L = 35,000 hours = 4.0 years.
S = 1,828,000 units/yr
Assume continuous operation of 8760 hrs/yr. Therefore, UEC = 210 W/unit * 8760 hr/yr = 1839.6 kWh/unit-yr.

Therefore, total annual refrigerator energy consumption
= 4yr * 1,828,000 units/yr * 1839.6 kWh/unit-yr = **13.45 TWh/yr**.

If we are fairly sure that the refrigerator market size is not growing, then we can be reasonably confident that our estimate of total annual energy consumption is not too far off, especially because refrigerators are almost never turned off. Does that mean, though, that they draw a constant 210 W, or does their power consumption vary depending on whether the compressor is running? As long as the 210 W is an average consumption rate, the numbers should be okay. However, the assumption of a 4 year life for a refrigerator seems very short. If the lifetime of the average refrigerator were longer, this would significantly increase annual electricity consumption. For example, assuming an 8 year life instead of 4 years would double the annual electricity consumption because it would imply a doubling of the market size.

Air Conditioners:

If we again assume that the total air conditioner market size is not increasing, then we can again use Eq. 2.23:

Total annual energy consumption = L * S * UEC.

Suppose we assume that the average air conditioner operates for 300 hr/yr. Then the UEC = 1415 W/unit * 300 hr/yr = 424.5 kWh/unit-yr; and lifetime L = 2400 hr ÷ 300 hr/yr = 8 years. S = 408,000 units/yr (average).

Therefore, total annual energy consumption = 8 yr * 408,000 units/yr * 424.5 kWh/unit-yr = **1.39 TWh/yr**.

Note that if we were to assume that the average air conditioner operated for 600 hr/yr instead of 300 hr/yr, then the UEC would be 1415 * 600 = 849 kWh/unit-yr, and the lifetime L would be 2400 ÷ 600 = 4 years. So total annual energy consumption would then be 4 yr * 408,000 units/yr * 849 kWh/unit-yr = **1.39 TWh/yr**, i.e., the same as the previous case.

Therefore, as long as the market size is not growing and all sales are due to replacement units, it does not matter how many hours we assume the equipment operates per year, because the corresponding change in UEC would be completely compensated for by the resulting change in the assumed market size.

However, if not all sales are of replacement units and the market is in fact growing, then our assumptions of equipment operating hours per year and the market size are critically important to our results.

For example, let us assume that of the 408,000 units sold per year, half (204,000 units) are due to market growth, and half are due to replacements of existing units. Then we would use Eq. 2.22 to solve for total annual energy consumption:

$$\textit{Total Annual Energy Consumption} = \left[L(S - MG) + \left(MG \cdot 1\,yr\right)\right] \cdot UEC$$

First, let us assume 300 operating hours per year. Then, L = 8 years, and UEC = 424.5 kWh/unit-yr.

Total annual energy consumption = [8 yr * (408,000-204,000 units/yr) + (204,000 units)] * 424.5 kWh/unit-yr = **0.779 TWh/yr**.

But if we assume 600 operating hours per year, then total annual energy consumption = [4 yr * (408,000-204,000 units/yr) + (204,000 units)] * 849 kWh/unit-yr = **0.866 TWh/yr**.

So, in the case of air conditioners, the trend of sales in Table 2.8 would lead one to believe that the total market size is probably growing. In that case, the assumptions we make as to what portion of the sales are due to market growth vs. replacements, and how many hours the average air conditioner operates per year, are vitally important. These assumptions will have a very significant effect on the results of our calculations.

2.4

The baseline refrigerator has a capital cost of $800 and an annual operating cost of $54/yr. Over a 25 year life, with a discount rate of 60%, the net present worth (NPW) of the total stream of costs is $890 (assuming operating costs are paid at the end of each year). The efficient refrigerator has a capital cost of $880 and an annual operating cost of $38.25/yr, resulting in an NPW of costs of $944. Therefore, with the 60% discount rate, the efficient refrigerator is not cost-effective to the customer because the present worth of the total costs is higher in the efficient case than in the baseline case.

If the utility subsidizes the purchase of efficient refrigerators by paying the $80 incremental cost per refrigerator, then the utility faces, in addition to the up-front $80 capital cost, lost revenues of $15.75/yr per refrigerator (i.e., [600 kWh/yr - 425 kWh/yr] * $0.09/kWh). However, at the same time the utility saves $30.19/yr per refrigerator in reduced marginal costs, including reduced transmission and distribution losses (i.e., [(600 kWh/yr - 425 kWh/yr) * $0.15/kWh * 1.15 T&D loss reduction]). Taking the present value of the capital cost, lost revenues, and marginal cost savings, the total NPW (with 12% discount rate) of the stream of cash flows for the utility is +$33.24 per refrigerator, showing that the utility does indeed save money by subsidizing the purchase of the efficient refrigerator.

2.5

For the customer, the baseline lighting kit has a capital cost of $20 and an annual operating cost of $13.82/yr, while the efficient kit has a capital cost of $24 and an annual operating cost of $11.06/yr (actually these operating cost numbers ignore the energy consumption of the ballast, which is not known; but assuming that the ballasts in both kits consume the same amount of energy, they cancel each other out, thereby not affecting the answer). At a 60% discount rate and 5 year equipment life, the present value of costs is $40.84 for the baseline kit and $40.67 for the efficient kit, making the efficient kit slightly more cost-effective.

For the utility, the utility faces costs of $4 per kit for the incremental capital cost, and $2.76/yr per kit in lost revenues. However, the marginal cost savings are $5.30/yr per kit including T&D loss reductions, providing an overall net present value to the utility of +$5.14 per kit, making the investment very cost-effective.

The baseline kit produces 5360 lumens of light (40 W/bulb * 67 lumens/W * 2 bulbs), while the efficient kit produces 5760 lumens (32 W/bulb * 90 lumens/W * 2 bulbs). Therefore, the efficient kit actually improves lighting energy service.

2.6

The baseline kit has a capital cost of $1, an annual equipment replacement cost of $1/yr at the end of years 1-4 (not year 5), and an annual energy cost of $17.28/yr. The net present value of these costs over 5 years with a 60% discount rate is $28.47. The efficient kit has an initial capital cost of $15 and an annual energy cost of $6.91/yr, assuming zero energy use by the ballast, resulting in a net present value of $25.42. The efficient kit is therefore cost-effective to the school. If one assumes that the efficient kit's energy use is increased by 20% due to the ballast, then the annual energy cost would be $8.29/yr, resulting in a net present value of $27.51; so the efficient kit would still be cost-effective.

If the utility subsidized the entire $14 incremental cost per kit, and assuming zero energy use by the efficient kit's ballast, then the utility would face $10.37/yr of lost revenues but $19.87/yr of marginal cost savings including T&D loss reductions. The net present worth to the utility would then be +$20.26 per kit, making the investment cost-effective.

The lighting output of the baseline kit would be 1400 lumens, while the efficient kit would provide 2680 lumens. The efficient kit therefore not only saves energy but provides a significantly increased output of lighting service as well.

Chapter 2, Brakimpur: Point 6.

a. Air conditioning, refrigerators, and incandescent lamps are the three end-uses with the highest MWh consumption. Air conditioners do not have a particularly high penetration rate (particularly in the low income classes), but their intensity (wattage) is fairly high, and their annual hours of usage are very high. Refrigerators also have high annual hours of usage, combined with high penetration and moderate intensity. Incandescent lamps very high penetration and high annual hours of use, overcoming their low intensity to account for substantial MWh.

The lowest annual consumption comes from fluorescent lamps, clothes washing machines, and irons. Fluorescent lamps have high penetration but very low intensity and fairly low hours of use. Clothes washing machines have high intensity but very low penetration and low hours of use. Irons have high penetration and very high intensity, but extremely low annual hours of use.

b. The most interesting end-uses for which to implement a conservation plan would be those with the following two characteristics: 1.) high overall MWh, 2.) available high efficiency technology to cost-effectively replace existing technology. The three end-uses with the highest annual MWh consumption (air conditioning, refrigerators, and incandescent lamps) would all be suitable candidates, as cost-effective high-efficiency models exist for all three.

c.

Table F -	Socio-Economic Scenario for projected year (X+10)		
- Only Population Growth and change in income distribution; no change in P, M, or I			
			vg. annual growth rate
A'1 - population		14111122	3.00%
A'2 - people/household		4.0	-0.44%
A'3 -Income Classes (Minimum Wage Units)		total **N_{x+10}**	
0-2	15%	**529167**	
2-5	32%	**1128890**	
5-10	28%	**987779**	
+10	25%	**881945**	
TOTAL	100%	3527780	

Table G -Frozen Efficiency Scenario **(MWh/year)**
Brakimpur: End-Use Total Households Energy Consumption by Income Class
Unchanged efficiency and usage (M and I): $E_{X+10} = N_{X+10} * P * M * I$

end use	*0-2*	*2-5*	*5-10*	*+10*	*Total*
LAMP_INC	**105728**	**406400**	**592667**	**617362**	**1722157**
LAMP_FLU	**13229**	**28222**	**61736**	**79375**	**182563**
IRON	**12658**	**46269**	**83038**	**89659**	**231622**
TV	**51594**	**118533**	**159526**	**197556**	**527209**
CLTH WASH	**0**	**0**	**74054**	**136647**	**210701**
AIR_COND.	**0**	**158045**	**829734**	**1508126**	**2495905**
FREEZER	**0**	**60974**	**177840**	**370417**	**609230**
REFRIG.	**222276**	**624178**	**655836**	**793742**	**2296032**
FAN	**75142**	**240454**	**269664**	**343959**	**929217**
WATER HTR	**14288**	**270934**	**296334**	**370417**	**951972**
OTHERS	**10589**	**67733**	**266700**	**423334**	**768356**
Total	**505502**	**2021741**	**3467128**	**4930592**	**10924963**

Shown above are Tables F and G which would occur if no changes in income distribution took place between year X and year X+10. Compared to the total MWh energy use in year X+10 in Table 2.12, total MWh in the current Table G above is approximately 7% lower. This is because, as households' incomes rise, their appliance ownership and usage rates both increase. Therefore, in the table above, with incomes kept lower, energy use stays low as well. This is particularly noticeable in the air conditioning end use, where the above table's consumption is roughly 12% lower than that in Table 2.12.

d. I would probably choose refrigerators and incandescent lamps for a conservation program. As outlined in part b above, these two end-uses have high energy use and available cost-effective efficient technologies to implement. Another benefit of these end-uses is that they have very high market penetration, allowing for a potentially large program and a way to minimize the fixed administrative costs as a percentage of overall program costs. Also, with high market penetration across all income classes, a program in these areas would be able to benefit the entire socio-economic spectrum, thus making political support more likely. On the other hand, if the poor have highly subsidized electricity and/or do not pay their bills, then targeting the poor for a conservation program may not be very effective. In that case, maybe an air conditioner efficiency program might be more practical, as air conditioners' penetration (and energy consumption) is strongly concentrated in the upper-income sectors.

e.

Chapter 2, Brakimpur: Point 9.

The projected commercial electricity consumption in year X+10, assuming constant P, M, and I, is as follows:

Year X+10 MWh Energy Consumption Assuming Unchanged P, M, and I Between Year X and X+10

Market Segment	Illumination	Air conditioning	Electric cooking	Refrigeration	Equipment	TOTAL MWh	TOTAL MWh per m^2 of floor area
Small commerce	378,542	5,979	2,562	172,189	9,395	568,666	3.33
Shopping center	1,711,875	181,563	46,688	1,045,800	129,688	3,115,613	30.03
Hotels	332,473	382,534	1,701	380,832	11,334	1,108,875	14.68
Bank	291,173	17,470	851	156,534	9,706	475,734	6.13
Schools	3,812,802	992,918	20,426	915,072	181,562	5,922,781	6.52
TOTAL MWh	6,526,864	1,580,464	72,228	2,670,428	341,685	11,191,668	8.38

a. Based on the above projection, schools have the highest total MWh consumption, followed by shopping centers and hotels. Banks have the lowest total MWh consumption. However, in terms of MWh consumption per unit of floor area, shopping centers and hotels are by far the highest. On a per-floorspace basis, school consumption is quite low, though small commerce's consumption is the lowest on this basis. Shopping centers are the most attractive market segment to target for conservation because they are easily the most energy-intensive and also have the second highest total electricity consumption. Small commerce, though significant in terms of floor area, is not very energy intensive and would not be a likely target for a conservation program.

b. Illumination would probably be the best end-use for implementing a conservation plan, given that illumination accounts for a very significant percentage of total electricity use in each of the five market segments.

c. I would choose illumination and refrigeration. These two end-uses account for a very large proportion of electricity use, and there are cost-effective energy-efficient alternatives available for both end-uses.

Chapter 2, Brakimpur: Point 13.

a. The electrical/electronics market segment has the highest total electricity consumption, and the wood market segment has the lowest overall. However, in terms of electricity consumption per unit of GDP produced, electrical/electronics has by far the lowest MWh/$ consumption, making it the least energy-intensive market segment, even if it uses the most electricity in total. In terms of MWh/$, textiles and metallurgy are the most energy-intensive segments. In addition, the electrical/electronics segment (i.e., the least energy-intensive) is growing the most rapidly in terms of product output ("GDP") growth, while the metallurgy segment (one of the most energy-intensive) is growing the slowest. This indicates that the economy is likely to be becoming less energy-intensive over time. This is in fact the case. The energy intensity of the industrial sector declines from 576 MWh/$million in year X to 497 MWh/$million in year X+10.

b. The 10-40 Hp motors and the 40-100 Hp motors have the greatest overall electricity consumption in both year X and year X+10. This is because these motors are the most prevalent sizes in the market. These are therefore likely to be the most interesting motor sizes to try to make more energy-efficient.

c. Table D is created from the top down by taking the overall electricity consumption in each market segment and then allocating this total consumption down into different end-uses and further down into different motor types. Table H is created from the bottom up by taking the number of motors of each type, the average wattage of each motor type, and the average annual usage hours, and multiplying these quantities together to build up the total estimate of overall electricity consumption. If the numbers have been correctly determined, then these two approaches should provide the same results. It is in fact a very useful check to develop estimates using both methods and make sure that the results agree.

d. See responses to part b. above.

e.

3.1

In cases of uniform cash flow, simple payback = 1/crf. From Appendix 3,

$$CRF = Capital\ Recovery\ Factor = A/P = \frac{r}{\left[1-(1+r)^{-t}\right]}$$

For all three agents (customer, utility, government), the equipment lifetime t is 15 years. Knowing the simple payback (=1/crf), we can solve the CRF equation iteratively for r, which will equal the implicit discount rate, or IRR.

a. t = 15, SPB = 2.5, CRF = 1/SPB = 0.4. **r = 39.735%**

b. t = 15, SPB = 10, CRF = 1/SPB = 0.1. **r = 5.556%**

c. t = 15, SPB = 20, CRF = 1/SPB = 0.05 Note, the lifetime is only 15 years, but the required payback is 20 years. In other words, at the expected payback rate, the equipment would cease operating 5 years before its savings ever match its incremental cost; so the equipment would never pay itself off. Therefore, it is impossible to calculate a meaningful value of r. The calculated value of r, -3.398%, has no meaning.

3.2

As outlined in question 3.1 above, the capital recovery factor is equal to 1/simple-payback. Therefore, the discount rate r at which CRF = 1/SPB is the internal rate of return IRR.

3.3

3.4

Lamp Model A.

Up-Front Capital Cost = \$1.00
Annual Energy Cost = 100 W * 1000 hr/yr * \$80/MWh * (1 MWh/10^6 W-hr) = \$8/yr.
Annual Equipment Replacement Cost (at end of years 1-4 only) = \$1/yr.

Assuming energy costs are paid at the end of each year,
Total Net Present Worth of Model A costs = \$19.21 as shown below, using the customer's discount rate of 39.735%.

Lamp Model A	Capital Cost	Energy Cost	Equipment Replacement Cost	Total Cost
Discount Rate	39.735%	39.735%	39.735%	
NPV	\$1.00	\$16.35	\$1.86	**\$19.21**
Year 0	\$1.00			
End of Year 1		\$8.00	\$1.00	
End of Year 2		\$8.00	\$1.00	
End of Year 3		\$8.00	\$1.00	
End of Year 4		\$8.00	\$1.00	
End of Year 5		\$8.00		
Lamp Model B				
Discount Rate	39.735%	39.735%	39.735%	
NPV	\$15.94	\$3.27	\$0.00	**\$19.21**
Year 0	\$15.94			
End of Year 1		\$1.60	\$0.00	
End of Year 2		\$1.60	\$0.00	
End of Year 3		\$1.60	\$0.00	
End of Year 4		\$1.60	\$0.00	
End of Year 5		\$1.60		

Lamp Model B.

Up-Front Capital Cost = \$???
Annual Energy Cost = 20 W * 1000 hr/yr * \$80/MWh * (1 MWh/10^6 W-hr) = \$1.60/yr.
Annual Equipment Replacement Cost (at end of years 1-4 only) = \$0/yr.

With the customer's discount rate of 39.735%, the maximum price for Lamp Model B at which Model B would still be cost-effective would be **\$15.94**. At this price, the total net present worth of Model B's costs would equal those of Model A at \$19.21, as shown in the above table.

Similarly, with the utility's discount rate of 5.556%, Lamp Model B could cost as much as **\$31.79** and still be cost-effective. This is because, with the utility's lower discount rate, Model B's savings in annual energy and replacement costs are valued much higher.

3.5

Labor costs are \$8000/month regardless of the tariff schedule chosen.

Monthly energy costs would be as follows:

Tariff A:	\$2628/month
Tariff B:	\$3081/month
Tariff C:	\$2668/month

Therefore, under the current operating conditions, it would be most advantageous for the factory to select Tariff A, resulting in total costs of **\$10,628/month**.

3.6

Under the night time production schedule, labor costs rise to \$9440/month.

However, now under Tariff C, energy costs are reduced to \$1164/month, resulting in total monthly operating costs of **\$10,604/month**, which is less than the lowest costs derived in Exercise 3.5 above.

Therefore, the factory saves money by switching to night time production.

3.7

For the gas-fired water heater:
$E_{gas} = 3.5$ MWh/yr $\div$ 0.65 efficiency = 5.4 MWh/yr
$ER_{gas} = 5.4$ MWh/yr $\cdot$ 0.05 tC/MWh = 0.27 tC/yr
$AC_{gas} = (\$400 \cdot 0.10/\text{yr}) + (5.4\ \text{MWh/yr} \cdot \$18/\text{MWh}) = \$137/\text{yr}$. Same as in the example.

For the electric heat pump water heater:

$E_{electric} = 3.5$ MWh/yr $\div$ 2.1 efficiency = 1.2 MWh/yr

If primary conversion efficiency to produce electricity is 33%, then total primary energy consumption for the heat pump water heater would be 1.2 MWh/yr $\div$ 0.33 = 3.6 MWh/yr, still considerably less than the gas water heater's consumption of 5.4 MWh/yr.

$ER_{electric} = 1.2$ MWh/yr $\cdot$ 0.18 tC/MWh = 0.22 tC/yr

$AC_{electric} = (900 \cdot 0.10/\text{yr}) + (1.2\ \text{MWh/yr} \cdot \$65/\text{MWh}) = \$168/\text{yr}$

Therefore, the electric heat pump water heater has lower energy consumption and lower carbon emissions but is not cost-effective compared to the gas-fired water heater. The electric heat pump water heater costs \$31/yr more than the gas-fired water heater.

3.8

For the **utility**:

Utility discount rate = 12%, lifetime = 20 yr.

Therefore, crf = $0.12/(1-(1+0.12)^{-20}$ = 0.1339

Annualized cost of replaced electric water heating = (\$141 · 0.1339) + (632.0 kWh/yr · \$0.07/kWh · 1.15) = \$69.76/yr = annual benefits

Annualized cost of solar water heating = (\$433 · 0.1339) + (126.4 kWh/yr · \$0.07/kWh · 1.15) = \$68.15/yr = annual cost

Therefore, benefit/cost ratio to the utility = 69.76/68.15 = 1.02. The measure is therefore just barely cost-effective to the utility.

For the **customer**:

Customer discount rate = 35%, lifetime = 20 yr.

So crf = $0.35/(1-(1+0.35)^{-20}$ = 0.3509

Annualized cost of replaced electric water heating = (\$141 · 0.3509) + (632.0 kWh/yr · \$0.09/kWh) = \$106.36/yr = annual benefits

Annualized cost of solar water heating = (\$433 · 0.3509) + (126.4 kWh/yr · \$0.09/kWh) = \$163.32/yr = annual cost.

So benefit/cost ratio to the customer = 106.36/163.32 = 0.65. The measure is not cost-effective to the customer.

3.9

For the electric heating system:

E = 20 MWh / 0.95 efficiency = 21.05 MWh/yr.

Annual cost AC =(\$1000 · 0.08/yr) + (21.05 MWh/yr · \$65/MWh) = **\$1448/yr** per household.

Annual emissions = 21.05 MWh/yr · 0.18 tC/MWh = 3.79 tC/yr per household.

For the district heat dedicated gas plant:

E = 20 MWh / 0.8 efficiency = 25.0 MWh/yr.

Annual cost AC = (\$3000 · 0.08/yr) + (25.0 MWh/yr · \$30/MWh) = **\$990/yr** per household.

Annual emissions = 25.0 MWh/yr · 0.05 tC/MWh = 1.25 tC/yr per household.

Therefore, the dedicated gas plant district heating system has both considerably lower annual costs and annual emissions than the electric heating system. However, this dedicated gas plant district heating system still has considerably higher annual costs and emissions than the cogenerated district heat system analyzed in the example, which costs only \$540/yr per household and emits only 1.0 tC/yr per household for the equivalent amount of space heat.

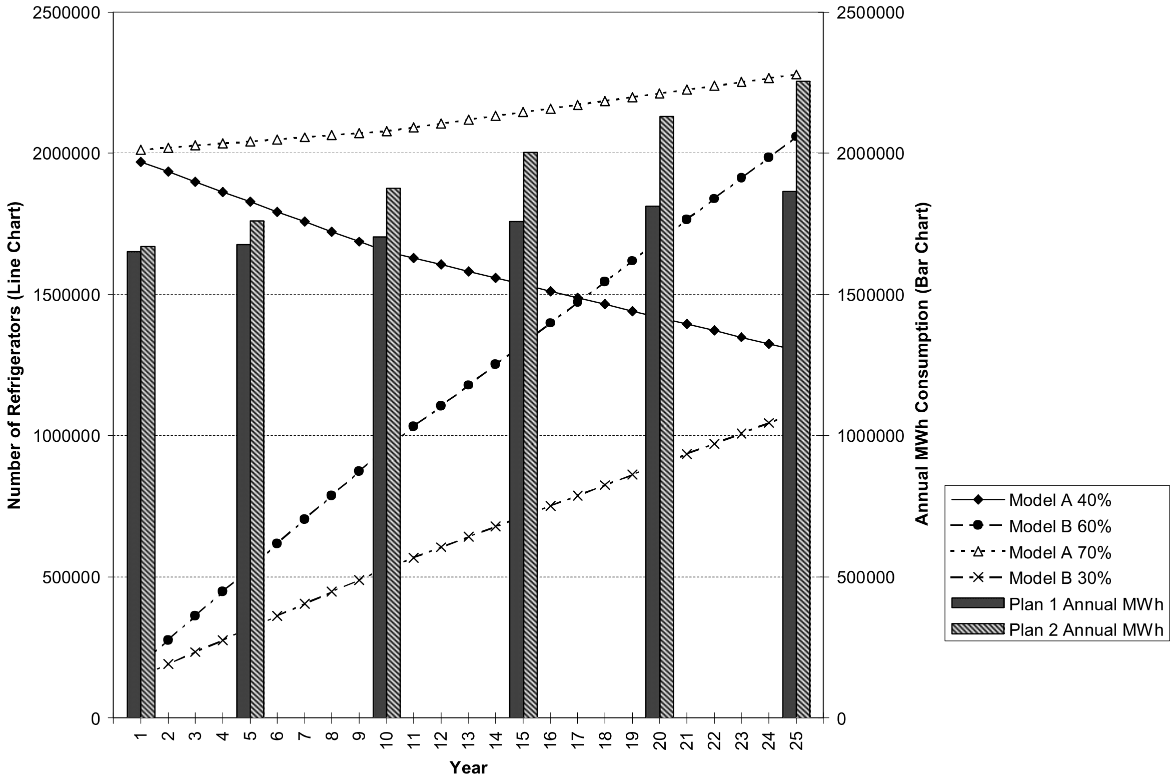
3.10

The number of Model A and Model B refrigerators and total refrigerator electricity consumption are projected in the following table and are shown graphically in the following chart.

In Plan 1, Model A goes from 1,969,684 refrigerators in Year 1 to 1,302,009 refrigerators in Year 25, while Model B goes from 190,866 in Year 1 to 2,058,541 in Year 25. Total annual refrigerator consumption is 1,652,094 MWh in Year 1 and 1,865,024 MWh in Year 25.

In Plan 2, Model A goes from 2,012353 refrigerators in Year 1 to 2,278,516 refrigerators in Year 25, while Model B goes from 148,197 in Year 1 to 1,082,034 in Year 25. Total annual refrigerator consumption is 1,669,161 MWh in Year 1 and 2,255,626 MWh in Year 25.

	Plan 1			Plan 2		
Year	Model A 40%	Model B 60%	MWh/yr	Model A 70%	Model B 30%	MWh/yr
1	1,969,684	190,866	1,652,094	2,012,353	148,197	1,669,161
2	1,934,345	276,205		2,019,684	190,866	
3	1,899,007	361,543		2,027,015	233,535	
4	1,863,668	446,882		2,034,345	276,205	
5	1,828,330	532,221	1,675,552	2,041,676	318,874	1,760,891
6	1,792,991	617,559		2,049,007	361,543	
7	1,757,652	702,898		2,056,338	404,213	
8	1,722,314	788,237		2,063,668	446,882	
9	1,686,975	873,575		2,070,999	489,551	
10	1,651,636	958,914	1,704,875	2,078,330	532,221	1,875,552
11	1,628,328	1,032,222		2,091,675	568,875	
12	1,605,019	1,105,531		2,105,021	605,529	
13	1,581,711	1,178,839		2,118,367	642,183	
14	1,558,402	1,252,148		2,131,713	678,838	
15	1,535,094	1,325,456	1,758,258	2,145,058	715,492	2,002,243
16	1,511,786	1,398,765		2,158,404	752,146	
17	1,488,477	1,472,073		2,171,750	788,800	
18	1,465,169	1,545,382		2,185,096	825,455	
19	1,441,860	1,618,690		2,198,441	862,109	
20	1,418,552	1,691,999	1,811,641	2,211,787	898,763	2,128,935
21	1,395,243	1,765,307		2,225,133	935,417	
22	1,371,935	1,838,616		2,238,479	972,072	
23	1,348,626	1,911,924		2,251,824	1,008,726	
24	1,325,318	1,985,233		2,265,170	1,045,380	
25	1,302,009	2,058,541	1,865,024	2,278,516	1,082,034	2,255,626



3.13

3.14

The total utility cost, total annual kWh saved, and cost of saved energy are shown below varying the rebate level in 10% increments between 0% and 100%. The program is most cost-effective or the utility at 40% and 50% incentives, where the cost of saved energy is $0.020/kWh.

Rebate Level	Total Utility Cost	Total Annual kWh Saved (kWh/yr)	Cost of Saved Energy ($/kWh)
0.0%	$85,000	0	-
10.0%	$88,900	372,000	0.063
20.0%	$105,280	967,200	0.029
30.0%	$138,820	1,711,200	0.021
40.0%	$194,200	2,604,000	0.020
50.0%	$272,200	3,571,200	0.020
60.0%	$370,480	4,538,400	0.022
70.0%	$483,580	5,431,200	0.023
80.0%	$590,440	6,026,400	0.026
90.0%	$702,760	6,547,200	0.028
100.0%	$810,400	6,919,200	0.031

4.1

Coal plant: [(10 GJ/MWh) · ($1/GJ) / 1000 kWh/MWh] + $0.02 /kWh = **$0.03/kWh.**
Gas plant: [(12 GJ/MWh) · ($2/GJ) / 1000 kWh/MWh] + $0.016 /kWh = **$0.04/kWh.**
CT plant: [(15 GJ/MWh) · ($2/GJ) / 1000 kWh/MWh] + $0.023 /kWh = **$0.053/kWh.**
Hydro plant: **$0.020/kWh.**
Wind plant: **$0.010/kWh.**

Coal plant is marginal resource for 4560 hr/yr
Gas plant is marginal resource for 3000 hr/yr
CT plant is marginal resource for 1200 hr/yr

Therefore, annual system marginal cost = ($0.03/kWh · 4560 hr/yr ÷ 8760 hr/yr) + ($0.04/kWh · 3000 hr/yr ÷ 8760 hr/yr) + ($0.053/kWh · 1200 hr/yr ÷ 8760 hr/yr) = **$0.0366/kWh.**

4.2

$0.03/kWh ÷ (1 - 0.08) = $0.0326/kWh
$0.04/kWh ÷ (1 - 0.09) = $0.0440/kWh
$0.053/kWh ÷ (1 - 0.10) = $0.0589/kWh

Therefore, annual system marginal cost = ($0.0326/kWh · 4560 hr/yr ÷ 8760 hr/yr) + ($0.0440/kWh · 3000 hr/yr ÷ 8760 hr/yr) + ($0.0589/kWh · 1200 hr/yr ÷ 8760 hr/yr) = **$0.0401/kWh.**

4.3

Hydro:
Capital cost: $55/(1.06)^3 + 55/(1.06)^4$ = $89.7 million. 89.7 million ·$(1.06)^4$ = $113.3 million.
crf = 0.063
Fixed cost: $0.5 million ÷ 0.063 = $7.9 million
Present Value of MCC = **$121.2 million** ÷ 100 MW = **$1212/kW**.
Annualized MCC = $1212/kW · 0.063 = **$76/kW/yr**.

Gas:
Capital cost: $70/(1.06)^2 + 70/(1.06)^3 + 70/(1.06)^4$ = $176.5 million. 176.5 million ·$(1.06)^4$ = $222.8 million.
crf = 0.073
Fixed cost: $3.4 million ÷ 0.073 = $46.6 million
Present Value of MCC = **$269.4 million** ÷ 150 MW = **$1796/kW**.
Annualized MCC = $1796/kW · 0.073 = **$131/kW/yr**.

Coal:
Capital cost: $60/(1.06)^0 + 60/(1.06)^1 + 60/(1.06)^2 + 60/(1.06)^3 + 60/(1.06)^4$ = $267.9 million.
267.9 million ·$(1.06)^4$ = $338.2 million.

crf = 0.073
Fixed cost: \$5.0 million ÷ 0.073 = \$68.5 million
Present Value of MCC = **\$406.7 million** ÷ 200 MW = **\$2034/kW**.
Annualized MCC = \$2034/kW · 0.073 = **\$148/kW/yr**.

CT:
Capital cost: \$40.0 million.
crf = 0.087
Fixed cost: \$2.1 million ÷ 0.087 = \$24.1 million
Present Value of MCC = **\$64.1 million** ÷ 80 MW = **\$801/kW**.
Annualized MCC = \$801/kW · 0.087 = **\$70/kW/yr**.

4.4

From equation 4.21: $MCOE = \frac{MCC \cdot crf}{8760 \cdot CF} + MEC$

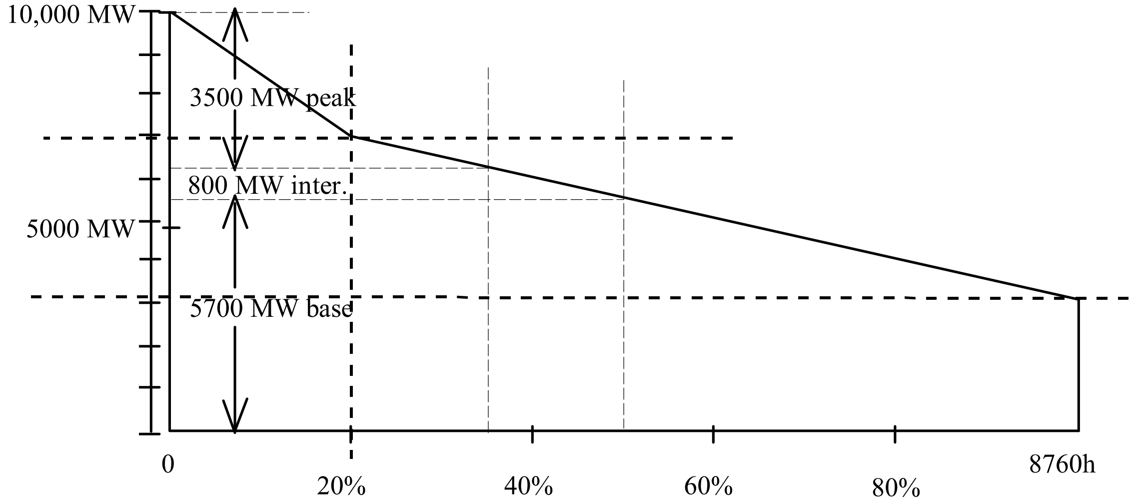
The variable cost in the table represents the MEC in equation 4.21. The marginal capacity cost in the table represents MCC · crf in equation 4.21.

Therefore, for the New Gas plant, MCOE = (\$130/kW-yr) ÷ (8760 hr/yr · 0.75) + \$0.035/kWh = \$0.055/kWh.

MCOE values for each plant are calculated similarly and are presented in the right hand column of the table below:

Power Source	Capacity (MW)	Capacity Factor	Variable Cost (\$/kWh)	Marginal Capacity Cost (\$/kW-yr)	**Marginal Cost of Energy (\$/kWh)**
Hydro Existing	1200	0.50	0.020	0	**0.020**
Gas Existing	600	0.50	0.040	0	**0.040**
Coal Existing	420	0.75	0.030	0	**0.030**
Coal Retrofit	400	0.75	0.040	50	**0.048**
New Gas	200	0.75	0.035	130	**0.055**
New Coal	200	0.75	0.030	150	**0.053**
New Coal w/Scrubbers	200	0.75	0.040	180	**0.067**
Wind Farm	500	0.30	0.010	150	**0.067**
Combustion Turbines	50	0.20	0.055	70	**0.095**

4.5



The above load duration curve can be broken up into the following components:

Rectangle with base 8760 hrs and height approximately 3000 MW = 26,280 GWh;
Triangle with base (80% x 8760) hrs and height approximately 4000 MW = 14,016 GWh;
Rectangle with base (20% x 8760) hrs and height approximately 4000 MW = 7008 GWh;
Triangle with base (20% x 8760) hrs and height approximately 3000 MW = 2628 GWh.

Total = approximately **49,932 GWh**.

Load Factor = (49,932,000 MWh) ÷ [(8760 hr) x (10,000 MW)] = **57%**

4.6

Marginal cost of energy has already been calculated in Exercise 4.4 and is also provided in Table 4.2. The calculation method is reviewed below.

$$MCOE = \frac{MCC \cdot crf}{8760 \cdot CF} + MEC$$

MEC = Variable cost
MCC * crf = Marginal capacity cost {$/kW-yr}

So, MCOE = (Marginal capacity cost {$/kW-yr} ÷ 8760 ÷ CF) + Variable cost

e.g., For New Gas, MCOE = ($130/kW-yr ÷ 8760hr/yr ÷ 0.75) + $0.035/kWh = $0.055/kWh

Similar calculations can be done to develop MCOE for each plant. For the load management program, we assume that there are no variable costs, so the MCOE is calculated strictly on the basis of the capacity cost portion: MCOE = ($50/kW-yr ÷ 8760hr/yr ÷ 0.05) = $0.114/kWh. **(???)**

The revenue requirements for each plant can be calculated either as a single present value, on an annualized basis, or on an annualized per-kWh basis. Given the numbers provided in this problem, revenue requirements can be calculated most readily on an annualized per-kWh basis.

For the new power plants and the DSM and load management programs, the revenue requirements are the same as the MCOE. For the existing power plants, we must calculate the capacity cost portion of the revenue requirements using the sunk capacity and fixed costs of $35 million and by calculating the crf.

Knowing the present value capacity cost, the crf, CF, and MEC, we can use the same MCOE formula to calculate the annualized per-kWh revenue requirements for the existing power plants.

$$CRF = \frac{r}{\left[1-(1+r)^{-t}\right]}$$

Hydro plant:
t = 13 yr, r = 0.06: crf = 0.1130
Annualized capacity cost = ($350 million) · (0.1130/yr) = $39,550,000/yr ÷ 1200 MW = $33/kW-yr

Since CF = 0.50 and MEC = $0.020/kWh,
Revenue Requirements = $33/kW-yr ÷ 8760 hr/yr ÷ 0.5 + $0.020/kWh = **$0.028/kWh**

Coal plant:
t = 17 yr, r = 0.06: crf = 0.0954
Annualized capacity cost = ($350 million) · (0.0954/yr) = $33,390,000/yr ÷ 420 MW = $80/kW-yr

Since CF = 0.75 and MEC = $0.030/kWh,
Revenue Requirements = $80/kW-yr ÷ 8760 hr/yr ÷ 0.75 + $0.030/kWh = **$0.042/kWh**

Gas plant:
t = 12 yr, r = 0.06: crf = 0.1193
Annualized capacity cost = ($350 million) · (0.1193/yr) = $41,755,000/yr ÷ 600 MW = $70/kW-yr

Since CF = 0.50 and MEC = $0.040/kWh,
Revenue Requirements = $70/kW-yr ÷ 8760 hr/yr ÷ 0.5 + $0.040/kWh = **$0.056/kWh**

The following table provides the final results. The variable cost, marginal cost of energy, and revenue requirements are provided in the 3 right-hand columns.

Power Source	Capacity (MW)	Capacity Factor	Annual GWh	**Variable Cost $/kWh**	**MCOE $/kWh**	**Revenue Requirements $/kWh**
Hydro	1200	0.50	5256	**0.020**	**0.020**	**0.028**
Existing Gas	600	0.50	2628	**0.040**	**0.040**	**0.056**
Existing Coal	420	0.75	2759	**0.030**	**0.030**	**0.042**
Retrofit Coal	400	0.75	2628	**0.040**	**0.048**	**0.048**
New Gas	200	0.75	1314	**0.035**	**0.055**	**0.055**
New Coal	200	0.75	1314	**0.030**	**0.053**	**0.053**
New Coal with Scrubbers	200	0.75	1314	**0.040**	**0.067**	**0.067**
DSM 1	375	0.40	1314	**-0.001**	**0.028**	**0.028**
DSM 2	750	0.20	1314	**-0.001**	**0.056**	**0.056**
Wind Farm	500	0.30	1314	**0.010**	**0.067**	**0.067**
Combustion Turbines	50	0.20	88	**0.055**	**0.095**	**0.095**
Load Mgmt.	100	-0.05	-44	**0.000**	**0.114**	**0.114**

4.7

$$CAE = (MCOE_A - MCOE_B) / (MER_B - MER_A)$$

Hydro vs. Existing Coal: (\$0.020/kWh - \$0.030/kWh) · (10^6 kWh/GWh) ÷ (5.0 tSO_2/GWh - 0.0 tSO_2/GWh) = -\$2000/ton

Hydro vs. New Coal: (\$0.020/kWh - \$0.053/kWh) · (10^6 kWh/GWh) ÷ (5.0 tSO_2/GWh - 0.0 tSO_2/GWh) = -\$6600/ton

These calculations are similarly carried out for all plants, and their CAE values are provided in the two right-hand columns in the table below. Note, the values in the table below differ fairly substantially from those shown in Table 4.2. This is due to rounding errors. It is therefore important to not round the numbers too early in the calculations.

For example, looking at DSM1 without rounding:
MCOE = (\$100/kW-yr ÷ 8760 hr/yr ÷ 0.40) - \$0.001/kWh = \$0.027539/kWh,
CAE (vs. Existing Coal) = (0.027539 - 0.03) · 10^6 ÷ (5.0 - 0.0) = -\$492/ton

Looking at DSM1 with rounding:
MCOE = \$0.028/kWh,
CAE (vs. Existing Coal) = (0.028 - 0.03) · 10^6 ÷ (5.0 - 0.0) = -\$400/ton

Power Source	MCOE $/kWh	Emissions tSO2/GWh	**CAE vs New Coal $/ton**	**CAE vs Exist Coal $/ton**
Hydro	0.02	0	**-6600**	**-2000**
Existing Gas	0.04	0	**-2600**	**2000**
Existing Coal	0.03	5		
Retrofit Coal	0.048	0.5	**-1111**	**4000**
New Gas	0.055	0	**400**	**5000**
New Coal	0.053	5		
New Coal with Scrubbers	0.067	0.5	**3111**	**8222**
DSM 1	0.028	0	**-5000**	**-400**
DSM 2	0.056	0	**600**	**5200**
Wind Farm	0.067	0	**2800**	**7400**
Combustion Turbines	0.095	0	**8400**	**13000**
Load Managment	0.114	0	**12200**	**16800**

??

4.8

The calculations are done the same way as in Exercise 4.6. However, the emission charge is added to the variable cost.

For example, for the new coal plant and the \$600/tNO_x emission charge:

> The new coal plant emits 10 tons of NO_x per GWh, so the emission charge would be \$600/ton * 10 tons/GWh = \$6000/GWh = \$0.006/kWh. The additional emission charge of \$0.006 /kWh is added to the original variable cost of \$0.0300/kWh to yield a new variable cost of \$0.036/kWh.
>
> With this new variable cost, the marginal cost of energy and the revenue requirements are computed in an identical manner as in Exercise 4.6.

	No Emission Charges			$600/tSO2 Emission Charge			$600/tNOx Emission Charge		
Power Source	Variable Cost ($/kWh)	Marginal Cost of Energy ($/kWh)	Revenue Requirements ($/kWh)	Variable Cost ($/kWh)	Marginal Cost of Energy ($/kWh)	Revenue Requirements ($/kWh)	Variable Cost ($/kWh)	Marginal Cost of Energy ($/kWh)	Revenue Requirements ($/kWh)
Hydro	0.0200	0.0200	0.0275	0.0200	0.0200	0.0275	0.0200	0.0200	0.0275
Existing Gas	0.0400	0.0400	0.0559	0.0400	0.0400	0.0559	0.0436	0.0436	0.0595
Existing Coal	0.0300	0.0300	0.0421	0.0330	0.0330	0.0451	0.0366	0.0366	0.0487
Retrofit Coal	0.0400	0.0476	0.0476	0.0403	0.0479	0.0479	0.0472	0.0548	0.0548
New Gas	0.0350	0.0548	0.0548	0.0350	0.0548	0.0548	0.0380	0.0578	0.0578
New Coal	0.0300	0.0528	0.0528	0.0330	0.0558	0.0558	0.0360	0.0588	0.0588
New Coal w/Scrubbers	0.0400	0.0674	0.0674	0.0403	0.0677	0.0677	0.0466	0.0740	0.0740
DSM 1	-0.0010	0.0275	0.0275	-0.0010	0.0275	0.0275	-0.0010	0.0275	0.0275
DSM 2	-0.0010	0.0561	0.0561	-0.0010	0.0561	0.0561	-0.0010	0.0561	0.0561
Wind Farm	0.0100	0.0671	0.0671	0.0100	0.0671	0.0671	0.0100	0.0671	0.0671
Combustion Turbines	0.0550	0.0950	0.0950	0.0550	0.0950	0.0950	0.0592	0.0992	0.0992
Load Management	0.0000	0.1142	0.1142	0.0000	0.1142	0.1142	0.0000	0.1142	0.1142

4.9

Cost of Avoided Emissions: SO_2					
Power Source	MCOE ($/kWh)	Annual GWh	CAE: static base ($/ton)	CAE: dynamic base ($/ton)	
			vs new coal (1314 GWh/yr)	vs new coal (1314 GWh/yr)	vs existing coal (2759 GWh/yr)
DSM 1	0.028	1314	-5059	-5059	
Retrofit Coal	0.048	2628			3913
New Gas	0.055	1314	391	391	
DSM 2	0.056	1314	649		5216
Wind farm	0.067	1314	2849		7416
Combustion Turbines	0.095	88	8420		12992

In the static case, since the new coal plant is always assumed to be the marginal baseline resource, the CAE values can be simply copied from Table 4.2.

For the dynamic case, the cheapest option is to replace one new coal plant with the DSM 1 option. The next cheapest option is to replace the second new coal plant with the new gas plant.

At this point, both new coal plants will have been replaced, so the existing coal plant becomes the marginal baseline resource. Replacement of the existing coal plant with the retrofit coal plant becomes the next cheapest option. This would eliminate almost all SO_2 emissions, but not quite all. In order to eliminate all SO_2 emissions, we would forego the retrofit coal plant and would instead implement DSM 2, the wind farm, and the combustion turbines, in that order.

4.10

Power Source	Capac. (MW)	CF	Annual GWh	Variable Cost ($/kWh)	Marginal Capacity Cost ($/kW-yr)	Marginal Capacity Cost ($/kWh)	MCOE ($/kWh)	Sunk Capacity Cost ($/kW-yr)	evenue Requirements ($/kWh)	Revenue Requirements (@13315 GWh/yr) ($million/yr)	Revenue Requirements (@13000 GWh/yr) ($million/yr)
Hydro	1200	0.5	5256	0.0200	0	0	0.0200	33	0.0275	144.7	144.7
DSM 1	375	0.4	1314	-0.0010	100	0.02854	0.0275	0	0.0275	36.2	36.2
Existing Coal	420	0.75	2759	0.0300	0	0	0.0300	80	0.0421	116.2	116.2
Existing Gas	600	0.5	2628	0.0400	0	0	0.0400	70	0.0559	146.9	129.3
New Coal	200	0.75	1314	0.0300	150	0.02283	0.0528	0	0.0528	69.4	69.4
Load Mgmt	100	-0.05	-44	0.0000	50	0.11416	0.1142	0	0.1142	5.0	5.0
Combustion Turbines	50	0.2	87.6	0.0550	70	0.03995	0.0950	0	0.0950	8.3	8.3
Total	2945		13315							526.6	509.1
									Average Rate ($/kWh):	0.0396	0.0392

Marginal Resource = Combustion Turbine
Marginal Cost = **0.0950 $/kWh**

If we all assume that each plant is producing its full annual GWh per year (13315 GWh/yr), then: Annual Revenue Requirements = **$526.6 million/yr**
Average Rate = **$0.0396/kWh**

If only 13000 GWh/yr are required, then we must decide how the dispatch is done. The combustion turbine has the highest variable cost, but we will assume that its generation cannot be reduced because it is operated only at peak times when it is needed. Therefore, we will assume that the resource with the next highest variable cost, the existing gas plant, will be the marginal resource under economic dispatch.
Then, Annual Revenue Requirements = **$509.1 million/yr**
Average Rate = **$0.0392/kWh**

Brakimpur Chapter 4

Question 6a.

Incandescent lamps' energy use goes down the most. This is due to the combined fact that the appliance ownership of incandescent lamps dropped substantially in the high income classes, and the average intensity per bulb dropped substantially as well. Fluorescent lamps' energy use goes up substantially due to the greatly increased ownership as fluorescent lamps replace incandescents.

Air conditioners were the largest consuming end-use in the Frozen Efficiency Scenario, and remain so in the Technical Scenario. Nevertheless, air conditioning energy consumption drops drastically due to the reduced energy intensity. Refrigerators show a similar drop.

6b.

Between the Frozen Efficiency Scenario and the Technical Scenario, total annual energy consumption drops from 11,775,436 MWh/yr to 9,891,105 MWh/yr. This represents a drop of 1,884,331 MWh, or 16%.

6c.

Reduction in the intensity of incandescent lamps and in air conditioners are the most attractive options because they achieve the largest energy savings and have the lowest cost (US$27/MWh each).

6d.

The total residential energy consumption in DSM1 is 10,029,191 MWh/yr, and in DSM2 it is 9,986,088 MWh/yr. Compared to the Frozen Efficiency Scenario, this is a savings of 1,746,245 MW (14.8%) and 1,789,348 MWh (15.2%), respectively.

9a.

Segment\End-Use	Illumination	Air Conditioning	Electric Cooking	Refrigeration	Equipment	TOTAL MWh
Small commerce	227,125	4,723	2,562	146,360	9,395	390,166
Shopping center	1,027,125	143,434	46,688	888,930	129,688	2,235,864
Hotels	199,484	302,202	1,701	323,708	11,334	838,428
Banks	174,704	13,802	851	133,054	9,706	332,116
Schools	2,287,681	784,406	20,426	777,812	181,562	4,051,886
TOTAL MWh	3,916,118	1,248,566	72,228	2,269,864	341,685	7,848,461

The technical potential scenario and the economic potential scenarios all result in a total commercial sector electricity consumption of 7,848,461 MWh/yr in year X+10. Compared to the frozen efficiency scenario of 11,191,668 MWh/yr, this is a reduction of 3,343,207 MWh/yr, or 30%.

The reason that the economic potential scenarios save as much energy as the technical scenario is that the all DSM options with a cost of saved energy of less than US$30/MWh are to be implemented for DSM1, and less than US$35/MWh for DSM2. Therefore, with the most expensive commercial option costing only US$19/MWh, all commercial DSM options are implemented under the criteria for the economic scenarios.

9b.

Illumination still has the largest MWh consumption even after implementation of the DSM program, but its share is reduced drastically. Before DSM, illumination accounted for 58% of commercial electricity consumption, but after DSM, this is reduced to only 50%. 78% of all energy savings come from the illumination program.

Brakimpur 13a. and b.

In the absence of other restrictions, the cheapest MCOE options are implemented first. DSM1 and DSM 2 are both cheaper than the supply options, so they get implemented first. However, DSM2 already includes the DSM1 measures, so we cannot choose both DSM1 and DSM2. Therefore, DSM2 is the first resource selected.

The next cheapest option is the retrofit coal plant. As outlined in the Chapter, we have assumed that only 1 coal plant is available for retrofit, and that the retrofit does not replace an existing coal plant but simply adds capacity to it.

The next cheapest options to be implemented are the new coal plants. However, implementing too many of these would cause emissions to increase per kWh in year X+10 compared to year X. Therefore, we cannot build more than 3 new coal plants.

New gas plants are the next cheapest resource, so they provide the remainder of the resources except for the wind farm, which is implemented to meet the Brakimpur government's committment to wind. Note that one 500 MW wind farm meets the 2% wind energy requirement.

So, with selection of DSM2, 1 retrofit coal, 3 new coal, 3 new gas, and 1 wind farm represents the cheapest (in terms of MCOE) resource plan which meets the various restrictions set out.

13 c.

The greatest simplification made was that we only considered energy requirements and did not consider peak capacity. Therefore, the resources we selected would not necessarily be optimal or even sufficient for meeting peak demand. Note that we did not choose to implement any combustion turbines (CTs) due to their high MCOE. However, CTs are highly effective at meeting peak demand, so if we had taken peak demand considerations into account, we probably would have chosen some CTs.

Also, the DSM2 and wind farm options might not provide much reliable peak capacity value, so a greater reserve margin would most likely be necessary if peak demand were considered. As it stands, the minimum 4% required reserve margin for energy is very low.

Also, as mentioned in the chapter, the retrofit coal plant was assumed to not displace any existing coal plants but rather add to them. This may not have been realistic but simplified the calculations and presentation.