Energy Efficiency in New Office Buildings: An Investigation of Market Failures and Corrective Policies

By

Jonathan Garo Koomey

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Robert G. 5/1/90

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CHAPTER I: DISCOUNT RATES AND EFFICIENCY INVESTMENTS

Engineering analyses typically conclude that current practice for new office buildings is significantly more energy intensive than is technically feasible and economically optimal. Economists respond that the marketplace will choose that level of energy efficiency that is justified based on an assessment of transaction costs, information costs, and risk. Both views may be correct, and there still may be justification for policies to increase energy efficiency beyond the levels that the market would otherwise choose.

This research examines the justifications for policies to promote energy efficiency in new office buildings. It investigates the technical evidence for market failures and other sources of divergence of observed from optimal energy efficiency, and explores design, construction, and leasing processes to determine key leverage points for policies. It uses a financial model to examine the effectiveness of different structures for incentive policies.

This chapter summarizes estimates of the payback times used by commercial sector customers, converts them to discount rates, and compares them to the real discount rates used by utilities to evaluate supply side investments (derived from aggregate utility financial statistics). It also summarizes the consequences of the divergence in discount rates. The last part of this chapter summarizes the rest of the dissertation.

CHARACTERIZING THE PROBLEM

The calculation and use of discount rates has always engendered controversy. Recently, many people have compared supply and demand-side discount rates (in the form of simple payback times (SPTs)[1]) and concluded that large differences exist between them.[2] This section summarizes published estimates of discount rates for the commercial building sector and compares them to an internal rate of return derived for the electric utility sector.

The rate of return from investments is most precisely characterized in terms of an implicit discount rate, which is equivalent to what the business economist calls "internal rate of return (IRR)" or "return on investment (ROI)". (These three terms will be used interchangeably herein.) The demand or supply-side investment will yield a stream of future benefits with a present value that will exactly equal the initial cost of the investment when discounted at the ROI. ROI must be determined through an iterative process, and has the advantage of being relatively independent of accounting practice and the cost of capital. The ROI of both supply and demand-side investments can be compared to the returns available from savings accounts or treasury bonds.

Implicit discount rates can either characterize *investor choice* or the behavior of the *entire market* for energy efficiency, including manufacturers, wholesalers, retailers, and other middlemen. The first type of discount rate I refer to as an *investor* discount rate, while the second I refer to as a *market* discount rate. Investor discount rates are typically

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[1] The simple payback time and the costs of conserved energy are related. The payback time of an conservation investment with a cost of conserved energy (CCE) equal to the fuel price is equal to the present worth factor, calculated at some discount rate (r) over some time period (n). This result follows from the definitions of SPT and CCE. See Appendix B.

[2] See, for example, Ralph Cavanagh's comments in Cavanagh 1987, p. 204.

determined by asking investors about their time preferences, while market discount rates are calculated using engineering-economic models and information about the energy-efficiency of past market decisions (Ruderman et al. 1987). When used to calculate life-cycle costs using a capital cost vs. energy consumption curve, the market discount rate will yield minimum life-cycle cost at the energy consumption currently being chosen by the market.

Market discount rates contain more information than investor discount rates, since they implicitly contain the effects of both the weighted average investor discount rates of all consumers and the market failures affecting efficiency choice[3]. The market discount rate is a convenient way to characterize the extent of market imperfections, but it should be used with care. In principle, market discount rates should be higher than investor discount rates for the same device. However, neither of these quantities is known with sufficient precision to make such a generalization valuable.

It is important to distinguish these two types of discount rates when analyzing policy implications of such studies, since it may be misleading to design policies that rely on rational builders/developers/consumers using high market discount rates. Investor discount rates are not subject to this caveat, since they represent the consumer's explicit characterization of the discount rate used in assessing cost-effectiveness.

Investor Discount Rates in the Commercial Sector

A survey completed in 1986 for the Potomac Electric Co., serving Washington, D.C., yielded striking results for the payback times demanded for energy efficiency improvements by commercial customers (Barker et al. 1986). **Table I.1** shows the maximum payback period these customers require when evaluating energy efficiency improvements, broken down by customer peak demand level. About 1/3 of the respondents were unable to answer this question, and of those who answered it, more than 3/4 indicated payback periods of three years or less. Those users with higher peak demand clustered closer to three year payback, while those with lesser peak demand (and presumably less expertise and greater cash-flow constraints) clustered around one and two year paybacks. A three year payback in this context is equivalent to about a 39% real consumer discount rate (see Appendix A). There is no reason to believe that new building purchasers are any more inclined to install efficiency improvements than the surveyed group.

Table I.1 also shows the real discount rates implied by these simple payback times (assuming a 30 year measure lifetime), which range from almost 20% real to over 160%. The weighted average real discount rate for all customers is either 44.5% if we ignore those respondents who didn't know, or 72% assuming that those who didn't know use first cost as their only decision criterion.

A survey of 610 commercial customers in Niagara Mohawk's commercial sector found that 16.8% used lowest first cost as their decision criterion to select space conditioning or lighting equipment replacement (Xenergy 1988, p.3-14). Schon et al. (1987, p.1-70) interviewed commercial customers in the service territory of Consolidated Edison Co, in New York City. They found that of 54 electric customers who occupied office buildings, 80-90% required simple payback times of three years or less . The results

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[3] Market failures such as risk aversion may affect both market discount rates and investor discount rates.

for retail stores, schools, supermarkets, and other small buildings showed similarly high proportions of respondents indicating required paybacks of 3 years or less. NEEPC (1987) describes the results of a relatively informal survey of landlords and tenants in Boston's commercial sector, which found that three year simple payback was the upper limit of acceptability for those interviewed.

Table I.2 shows that the results of the surveys cited above are more the rule than the exception.[4] EPRI (1988b) cites nine other surveys of commercial sector payback times, eight of which are included in Table I.2 (Burnett 1981, Energy Research Group Inc. 1986, Leahy ??, MI PSC 1982, Mueller Associates 1985, Portland Energy Conservation 1985, Train, 1985 #455, Rocky/Marsh Public Relations 1985).[5] Six of the eight studies found payback times of three years or less, with four of the eight indicating paybacks of two years or less.

The investor discount rates implicit in simple payback criteria of 3 years or less are much higher than the cost of capital to the commercial sector, which indicates that the market for efficiency is not operating in an optimal fashion. The historical average real cost of capital for commercial loans is 4-6%. Investor discount rates higher than this amount must indicate other factors at work, such as hidden costs, risk premia, satisficing behavior, or cash-flow constraints.

Market Discount Rates

The market discount rates characterizing energy efficiency in the commercial sector are difficult to calculate. There are some examples that suggest the approximate size of these discount rates, but the sector is so heterogeneous and the conservation measures so numerous that precise characterization is impossible. This section examines the implications of several engineering economic analyses, and calculates a market discount rate for the flourescent ballasts that are found in almost every new office building.

A supply curve of conserved energy represents the conservation potential that could be achieved if ALL market failures are overcome (Meier et al. 1983). Such "supply curves" are derived by calculating the cost of conserved energy (CCE) from engineering principles, and ranking various efficiency options in order of increasing CCE (using a discount rate approaching the societal optimum). It is a "snapshot" of the conservation potential at a particular point in time, and it is similar to what economists call a "production function" for energy efficiency. It is a *technical* potential because it assumes no constraints on implementing specific measures and no implementation or program costs. A separate curve is usually used to represent *achievable* potential, based on program experience and total costs.

Supply curves of conserved energy are of necessity an aggregate measure of the conservation potential. In a world in which this potential could be exactly quantified, the existence of only one societally cost-effective conservation measure would be sufficient evidence to indicate a market discount rate that is higher than the societal rate of interest.

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[4] Industrial decisionmakers, who according to theory should be profit maximizers, also use paybacks for energy efficiency investments that are usually range from six months to two years (Peters 1988, Peters and Gustafson 1986)

[5] One of the studies was inadequately referenced, giving neither author nor date. I therefore do not include it here.

Since we do not know the conservation potential with such precision, we must be more circumspect in the conclusions we draw from these curves.

These studies typically conclude that there are large reserves of conserved energy in the commercial sector, at costs of conserved energy (CCEs) of roughly 0.5-2¢/kwh (Hunn et al. 1986, Lovins 1987, Miller et al. 1989, NEEPC 1987). If the market would not implement these low cost measures and the calculations are correct, the market discount rates must be substantially higher than current interest rates. **Table I.3** shows the market discount rates implied if the market turns down savings with costs less than the electricity price (Appendix B describes how to calculate the numbers in this table). CCEs of $0.005-0.02/kWh imply real market discount rates of 36.3 to 225%, assuming that all costs are included in the calculations and that the more efficient devices are perfect or superior substitutes for the devices they replace. Chapter III describes in more detail the conditions under which such technical evidence can be used to infer market failures.

The *market* discount rate characterizing overall efficiency choice in the commercial sector must be greater than or equal to the weighted average *investor* discount rate in this sector, since market discount rates include the effects of both high investor discount rates (due to risk) and market failures. The exact value of these discount rates will always be uncertain. However, the results of engineering economic studies cited above are consistent with typical investor discount rates that are substantially larger than utility ROIs and the cost of capital to the commercial sector.

To accurately calculate a market discount rate, it is necessary to have examples of two devices that supply the same service, both of which are currently commercially available, one of which uses less energy than the other at calculable cost. Residential appliances present the most convenient examples of such situations (Meier and Whittier 1982, Ruderman et al. 1987). In the office building sector, discount rates may be calculated for users who purchase the ubiquitous two lamp flourescent ballast.

Table I.4 shows the characteristics of such ballasts. According to Geller and Miller (Geller and Miller 1988), standard core-coil ballasts would have accounted for about 90% of all flourescent ballast sales in 1987 (after correcting for efficiency standards in five states that prohibited the sale of inefficient ballasts). The table shows that the efficient core-coil ballast offers energy savings at a CCE of $0.0142/kWh. In this example, no cooling energy savings have been credited to the ballasts, even though one kWh of electricity savings in commercial buildings also results in 0.1 to 0.25 kWh of savings in cooling energy, and associated savings in Heating, Ventilating, and Air-Conditioning (HVAC) capital costs (Usibelli et al. 1985). This example also assumes operating hours that are lower than those in almost all commercial buildings (see Table II.4, in Chapter II). This CCE implies a real market discount rate of about 60% for those who purchase the standard core-coil ballasts. Since the efficient core-coil ballasts are indentical to the standard models except that the core winding is more efficient, I conclude that the market is acting *as if* purchasers of standard ballasts are using high discount rates.[6]

The situation is more complicated for electronic ballasts, since they are a relatively new technology that experienced reliability problems when first introduced (these problems have been overcome). They offer superior service than their core-coil counterparts,

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[6] The fact that consumers have purchased the less efficient model does not necessarily imply that they actually performed a life-cycle cost calculation using a high discount rate. It does strongly indicate that cost-effective efficiency measures can be ignored by substantial numbers of purchasers.

eliminating flicker and hum. Some models allow use of daylighting sensors to dim the lights when outside light is plentiful and occupancy sensors to turn lights off when rooms are unoccupied. It may be difficult for purchasers to find electronic ballasts in certain areas, though they are available by mail in large quantities for those who know where to look. Purchasers of efficient core-coil ballasts who do not purchase solid state ballasts are acting as if they are using real discount rates of about 26%. This estimate is a lower bound, since the service level is actually improved (the benefits are larger than just the energy savings).

Calculations thus confirm that the market for flourescent ballasts is ignoring inexpensive improvements in energy efficiency. Since these ballasts are used in all office buildings, it is plausible to argue that other energy-using devices in offices are evaluated using similar decision criteria and suffer from similar market failures.

Utility Investments

The real IRR for supply-side investment decisions, on the other hand, is typically 4 to 6%. The discount rate used by these companies for evaluating economic choices is usually the weighted average cost of capital (WACC). Since electric and gas utilities' rates of return are regulated, the WACC should be close to the ROI. In fact, if the utility is allowed to recover all costs plus the rate of return, the ROI should be exactly equal to the rate of return (Kihm 1988).

A 1977 survey of electric, gas, and telephone utilities gives one indication of the discount rates used by these companies. The average WACC estimated by this survey was 11.2%, while the 1976 inflation rate (as represented by the consumer price index) was about 6%. Thus, the real discount rate used was approximately 5% (Corey 1982).

The method for calculating IRR for individual projects based on financial statistics is quite well known (see Appendix A). A method for approximating the IRR for an entire firm or industry is developed in R.A. Peters' book *ROI: Practical Theory and Innovative Applications* (Peters 1974). This technique divides the annual cash flow of a business, (which usually equals net after-tax profit plus depreciation) by the total capital investment, adjusted for depreciation. This ratio yields the cash flow as a percentage of total capital invested, which is converted to an IRR by using a fractional breakdown of wasting and current assets, an average lifetime for the wasting assets, an infinite lifetime for the current assets, and a standard annuity table. The method assumes that the current capital structure of a business is "typical" and so this measure is unreliable during periods of rapid change and substantial investment.

A time series of IRRs calculated for the utility industry using this method is shown in **Table I.5**. Aggregate utility financial statistics from which this table was derived are contained in the *Statistical Yearbook of the Electric Utility Industry*, published annually by the Edison Electric Institute (EEI 1988). The IRR is quite stable over this period. Those years in which it changes provide insights into the events buffeting the utility industry. In 1974, it decreased from 5.1% to 4.7%, reflecting the increase in fuel prices due to the oil shock. The early 1980's show an increasingly healthy industry reaping the benefits of decreasing fuel prices and the capital investment program of the 1970's. The decline of ROI after 1984 is caused by slower revenue growth, reduced Allowance for Funds Used During Construction (AFUDC), and a drop in Other (Non-operating) Net Income.

The 1976 value of 5.4% is close to that calculated from the utility survey above. Table I.5 shows that 6% real is a reasonable round-numbered estimate of utility ROIs, and it is the discount rate I will use to represent the utility or societal perspective in the rest of the dissertation. For a 30 year lifetime, this IRR corresponds to a simple payback time of 14.2 years.

Effect of the Divergence in Discount Rates

High discount rates affect both the *responsiveness* of developers to changes in electricity prices, and the *level* of energy efficiency chosen. Many analysts argue that as long as price is set equal to marginal cost, all cost effective conservation will be installed. Krause and Eto (1988), following Plunkett and Chernick (1988), show that a customer using a 2 year payback criterion will evaluate a \$0.023/kWh efficiency investment as if it cost \$0.136/kWh. Alternatively, this customer will ignore all conservation investments with societal costs greater than \$0.012/kWh (if electricity costs \$0.07/kWh). If policymakers wanted to influence this customer to install all conservation costing less than \$0.07/kWh using price signals alone, they would have to add an additional tax of \$0.34 for every kWh.[7] Therefore, up-front incentives may be more effective (per unit of incentive) than price signals in influencing customers with short payback times to invest in conservation. This assertion will be explored further in Chapter VI, when incentive policies are compared from the perspective of the purchaser of a new office building.

CONCLUSIONS

Discount rate comparisons indicate that the market for energy efficiency in commercial buildings apparently does not promote installation of devices that are extremely cost effective from society's perspective. As discussed in Chapter III, inefficient investment in energy-using devices may be the result of hidden costs, incorrect parameter specification, time lags, or market failures/regulatory distortions. The rest of this dissertation investigates which of these factors, if any, can account for the divergence in discount rates and the corresponding inefficiency in energy use. Once identified, the contributing factors are used to derive lessons for policies to improve the functioning of the market and increase energy efficiency.

PLAN OF DISSERTATION

Chapter II analyzes characteristics of the office building sector, including energy intensity, growth in floorspace, peak demand, vacancy rates, rates of return, and other factors. Chapter II also compares the commercial and office sector contributions to growth in energy use, peak demand, CO_2 emissions, NO_X emissions, and SO_X emissions to those of the U.S. utility sector and the country as a whole. This comparison illustrates that commercial buildings are important contributors to key environmental insults and electric utility demand growth.

Chapter III presents the technical evidence for market failures affecting the energy efficiency of new office buildings. It investigates the conditions under which technical evidence (engineering calculations of cost-effectiveness) can be used to infer the existence of market failures, reviews previous studies of the potential for efficiency improvements in new offices, assesses specific technologies for exceeding the energy efficiency of "current-practice" buildings, defines baseline prototypes for small, medium, and large office

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[7] Krause and Eto's calculation assumes a real discount rate of 7% and a lifetime of 20 years, but I have adjusted the numbers to reflect my convention of a 6% real discount rate. Price signals of slightly smaller magnitude may influence the purchaser to *use a longer payback time*, but this outcome is by no means certain.

buildings, and derives a plausible estimate for the efficiency potential (30% savings, three year simple payback time). This estimate is used in Chapter VI when assessing investor response to different incentive policies.

Chapter IV explores how economists explain the divergence in discount rates, by using the existing general literature on market failures and specific studies of the new office building development process. Buildings are not often optimally efficient because of information costs, asymmetric information, lack of information, bounded rationality, satisficing behavior, risk aversion, externalities, split incentives, public goods, imperfect capital markets, and other market failures. Important regulatory distortions are caused by conventional ("cost-plus") utility regulation (which encourages electricity sales), average cost pricing, income taxes, property taxes, and subsidies to conventional energy sources (Blumstein et al. 1980, Fisher and Rothkopf 1988, Griffin and Steele 1986, Kempton and Neiman 1987, Marnay and Comnes 1989, Oster and Quigley 1978, Plunkett and Chernick 1988, Stern and Aronson 1984).

Chapter V examines policies to correct specific market failures and regulatory distortions identified in Chapter IV. These policies include energy taxes, hookup charges, utility rebates, building energy rating systems, design assistance, energy education, time-of-use pricing, shared savings, minimum efficiency standards for buildings and equipment, government purchase programs, government-sponsored research and development, and others. The Chapter reviews experience with each policy (if any), and uses the analysis in Chapter IV to propose a minimum set of policies for substantially mitigating market failures affecting the efficiency of new office buildings.

Chapter VI analyzes four incentive policies from Chapter V, using a discounted cash-flow model and baseline building prototypes (from Chapter III) to calculate real IRRs and to estimate the present value of one dollar of first-year operating-cost savings for small, medium, and large offices. The incentive policies are 1) a fifteen percent externality tax on all energy (which is the basis for the size of the other incentives as well), 2) a front-ended externality tax, 3) a front-ended rebate, and 4) front-ended revenue-neutral fees and rebates. Chapter VI uses the estimate for efficiency potential derived in Chapter III when calculating the value of energy-efficiency to the new building owner. Then each of the incentives are applied in turn, and the results are compared.

Chapter VII summarizes important results and conclusions.

Appendix A derives the relationship between simple payback time and implicit discount rates. Appendix B derives relationships between CCE, internal rate of return demanded for conservation, electricity price and simple payback times. Appendix C presents technical details of calculations performed in Chapter II. Appendix D contains a printout of the spreadsheet model used to perform the calculations in Chapter VI. Appendix E contains the outputs from the spreadsheet model in Appendix D.

Table I.1. Payback Periods Used By Commercial Customers (Potomac Electric Power Company)

Preferred Period Years	*Total* %	*Peak Demand Level (kW)* *Under 100* %	 *100-500* %	 *Over 500* %	*Implied Real IRR* %
One	17	19	20	10	*161.8*
Two	17	16	16	20	*64.0*
Three	18	10	15	30	*39.3*
Four	6	5	6	6	*28.3*
*>Four**	10	8	10	13	*19.8*
Don't Know	33	42	34	22	*- or ∞*
Total	100	100	100	100	-
Sample Size	659	192	283	184	-
Avg SPT (Yrs)*	2.71	2.50	2.63	2.98	
Implied IRR (%)	*44.4*	*48.7*	*46.0*	*39.7*	
Avg SPT(Yrs)**	1.82	1.45	1.74	2.33	
Implied IRR (%)	*72.0*	*97.0*	*76.5*	*53.0*	

*Assumes that > 4 year paybacks = 5.5 years. Ignores "Don't Knows".

**Assumes that > 4 year paybacks = 5.5 years and that "Don't Know" implies a zero year payback criterion.

Measure lifetime assumed to be 30 years to calculate IRRs.

Source: Barker et al. (1986).

Table I.2. Simple Payback Times Used by Commercial Sector Investors

Source	*Simple Payback Time (Years)*
Train, Ignelzi and Kumm 1985	2.0
Leahy	1.5
Portland Energy Conservation, Inc 1985	6.8
Mueller Associates 1985	0.8-1.5
Rocky/Marsh Public Relations 1985	6.5
MI Public Service Commission 1982	1.4
Energy Research Group, Inc. 1986	2.0
Burnett 1981	2.0-3.0

Source: EPRI (1988b).

Table I.3. Market Discount Rates Implied if Measures with a Certain Cost Are Not Being Implemented in the Commercial Sector

CCE (¢/kWh)	*Implied Discount Rate*
0.5	224.7%
1	84.7%
2	36.3%
3	22.6%
4	15.9%
5	11.8%
6	8.9%
7	0.0%

Assumptions: Discount rate = 6% real, device lifetime=20 yrs , and 1988 commercial sector electricity price = $0.0736/kWh (1989 $); Also assumes that all costs are included in the calculations, and that the device in question is a perfect substitute for the one it replaces.

Table I.4. Market Discount Rates of People and Institutions Who Do Not Purchase Efficient Flourescent Ballasts

	Approximate Adjusted Market Share ca 1987	*Capital Cost 1989 $*	*Power Savings W*	*Energy Savings kWh/yr*	*Marginal CCE 89$/kWh*	*Implied IRR*
Standard	90%	11.05	0	0	-	-
Eff. Core coil	9%	15.47	11	28.6	0.0142	60.3%
Electronic ballast	1%	33.15	33	85.8	0.0284	26.3%

Assumptions: Operation time for offices = 2600 hrs/yr, ballast lifetime=45k hrs=17.3 yrs, discount rate=6% real , CRF=0.0917, and 1988 U.S. average commercial sector electricity price of $0.0736/kWh. Capital costs are from Geller and Miller (1988), and have been adjusted from 1987$ to 1989$ using the Consumer Price Index from 1987 to 1988, and 5% inflation from 1988 to 1989.

Market Shares have been adjusted by Geller and Miller to represent market shares if state standards did not exist in 1987. By the end of 1987, standards prohibiting sale of inefficient core-coil ballasts existed in five states representing about one quarter of the U.S. population (California, New York, Massachusetts, Connecticut, and Florida).

The market share of Electronic Ballasts has been growing extremely rapidly, and the small share estimated for 1987 will swell to surpass even standard ballasts by the mid-1990s (if industry forecasts are accurate).

Table I.5. Real IRRs for the Investor-Owned Electric Utility Industry 1969-1988 (in billions of dollars and %)

Year	*NI*	*DEPR+ DEPL*	*CF*	*WA*	*DD+CA*	*TA*	*CF/TA %*	*ROI %*
1969	3.13	2.20	5.33	72.80	4.99	77.79	6.9%	5.5%
1970	3.33	2.40	5.74	81.44	5.78	87.22	6.6%	5.2%
1971	3.77	2.63	6.41	91.61	6.44	98.05	6.5%	5.1%
1972	4.36	2.91	7.26	103.04	7.58	110.62	6.6%	5.2%
1973	4.85	3.27	8.12	116.08	8.72	124.80	6.5%	5.1%
1974	5.15	3.63	8.78	129.10	13.31	142.41	6.2%	4.7%
1975	6.00	4.10	10.11	140.71	14.90	155.61	6.5%	5.1%
1976	6.99	4.55	11.54	154.79	17.11	171.90	6.7%	5.4%
1977	7.31	5.00	12.31	170.42	20.32	190.73	6.5%	5.1%
1978	8.57	5.49	14.06	187.99	21.69	209.68	6.7%	5.4%
1979	9.30	6.04	15.35	209.65	26.11	235.76	6.5%	5.2%
1980	10.53	6.55	17.08	230.62	30.99	261.62	6.5%	5.2%
1981	12.66	7.22	19.88	253.08	34.63	287.72	6.9%	5.7%
1982	15.15	7.86	23.00	277.91	39.29	317.20	7.3%	6.1%
1983	17.59	8.61	26.20	300.62	45.20	345.81	7.6%	6.5%
1984	19.67	9.48	29.15	323.50	55.89	379.39	7.7%	6.7%
1985	18.49	10.45	28.94	345.95	56.62	402.57	7.2%	6.0%
1986	20.24	11.42	31.66	363.26	60.46	423.72	7.5%	6.4%
1987	18.05	12.85	30.89	373.44	66.43	439.87	7.0%	5.9%
1988	15.77	14.14	29.91	379.57	68.91	448.48	6.7%	5.4%

KEY: NI = Net Income; Depr + Depl = Depreciation + Depletion;
CF = Cash Flow = NI + Depr + Depl; WA = Wasting Assets
(i.e., assets that can be depreciated);
CA = Current Assets (assets that cannot be depreciated);
DD + CA = Deferred Debits + Current Assets;
TA = Total Assets = WA + DD + CA; ROI = Return on Investment.

Sources: Data: EEI (1979, 1983, 1987, 1988);
Method: Peters (1974)

CHAPTER II: THE IMPORTANCE OF OFFICE BUILDINGS

INTRODUCTION

Commercial buildings are important contributors to key environmental insults and electric utility demand growth. This Chapter compares the commercial and office building sectors' contributions to growth in energy, peak demand, CO_2, NO_X, and SO_X emissions, to those of the U.S. utility sector and the country as a whole. The chapter also presents a detailed characterization of the office building sector, including energy intensity, electricity intensity, distribution of floor area by census division and building size, vacancy rates, and growth rates in these quantities.

The U.S. Department of Energy (U.S. DOE) forecasts that the commercial sector's primary energy use will grow more quickly than will the residential or industrial sectors, in large part because of the large and increasing electricity intensity of buildings in this sector. The efficiency of new buildings is easier and cheaper to improve than that of existing buildings, and about half of all commercial buildings existing in 2010 will have been built between now and then. There are therefore large foregone opportunities if inefficient buildings are built today that need to be retrofitted in ten years. Office buildings are more electricity intensive than the average for all commercial buildings, and are forecasted to comprise about 1/5 of all additions to commercial floorspace in the period 1987-2010.

COMMERCIAL SECTOR CHARACTERIZATION

The Commercial sector is the smallest sector in terms of total primary energy consumption, as shown in **Figure II.1**. Commercial buildings consumed 12.7 Quadrillion Btus (Quads) in 1988, while the residential, industrial, and transport sectors consumed 16.5, 29.0, and 21.9 Quads, respectively. **Figure II.2** shows that the commercial sector was the most electricity intensive, with about 70% of its total primary energy consumption in the form of electricity.[1] This high electricity intensity results in the commercial sector consuming about 30% of all U.S. electricity, as shown in **Figure II.3**.

The U.S. DOE has published forecasts of growth rates in energy consumption for the period 1988-2000. The DOE forecasts that the commercial sector will experience the most rapid growth in total primary energy consumption, as shown in **Figure II.4**. Even though electricity demand in the industrial sector is forecasted to increase more rapidly than in the commercial sector[2], the electricity intensity of the commercial sector (70%) is twice that of the industrial sector (35%), which leads to total forecasted growth rates in primary energy consumption of 2% per year for the commercial sector and 1.5% per year for the industrial sector. These growth rates are in part the result of modest price changes forecast

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[1] Throughout this dissertation, I have adopted the convention that 1 kWh of direct (site) electricity consumption equals 11,156 Btus of primary energy (except where otherwise noted), which includes losses in generation, transmission, and distribution. This assumption corresponds to the average generation + T&D loss factor for the U.S. utility industry in 1988 (U.S. DOE 1989).

[2] There is significant uncertainty in the forecast of industrial electricity sales by utilities, since industrial customers can often easily and profitably cogenerate. Many utilities are concerned about the potential for such self-generation (or "bypass") in the industrial sector.

for electricity and large increases in prices forecast for other fuels, as shown in **Figure II.5**.

These growth rates represent the continuation of long-standing trends. **Figure II.6** shows how quickly electricity has grown to dominate primary energy consumption in the commercial sector. This growth has come largely at the expense of coal and petroleum, although natural gas consumption has been declining slightly in recent years as well. **Figure II.7** is Figure II.6 redrawn to show the change in market shares even more dramatically.

Figure II.8 shows fuel market shares in the commercial sector if electricity is counted as site energy (without losses). Electricity is less obviously dominant from this perspective. Electricity plus gas comprise 80% of total site energy and 90% of total primary energy in 1986.

Figure II.9 shows a breakdown of energy consumption in the commercial sector by principal building activity. This figure represents the average intensity of commercial floorspace in 1986, based on the Non-Residential Buildings Energy Consumption Survey (US DOE 1988b, US DOE 1989d). Office Buildings are the second-most energy and electricity intensive building type, with a primary energy intensity about 40% higher than the average. **Figure II.10** shows that electricity represents about 85% of total primary energy consumed in office buildings, which means that offices are about 21% more electricity intensive than the sector average.

The energy intensities for buildings built 1980-86 are shown in **Figure II.11**.[3] Averaged over all building types, the total primary energy intensity of the 1980-86 buildings is about 2% higher than average existing buildings, while the total primary energy intensity of 1980-86 offices is 7% higher than that in average existing offices. This higher office energy intensity was caused principally by a 15% higher electricity intensity (253 kBtus/sf for 80-86 offices vs. 220 kBtus/sf for average existing offices). More than 90% of primary energy for office buildings built 1980-86 is in the form of electricity, as shown in **Figure II.12**. Other building types are also increasing in electricity intensity.

Figure II.13 shows the breakdown of commercial floorspace existing in 1960 and 1986, and forecasted for the year 2010 (OBCS 1989). It also shows the breakdown of forecasted additions to new commercial floorspace for the period 1987-2010. Total commercial floorspace increased at about 2.7% per year over the period 1960-86, and the U.S. DOE forecasts that it will increase at about a 2% annual rate between 1986 and 2010. Warehouses, Offices, and Mercantile and Service Buildings are growing in importance, while Assembly (churches, meeting halls etc) and Other Building Activities are declining. About half (49%) of all buildings existing in 2010 will have been built between 1987 and 2010, according to the DOE forecast. Of those buildings constructed after 1987, about 20% of the floorspace will be in offices.

Table II.1 shows gross additions to total floor area 1975-1987 for both residential and commercial buildings. The amount of floorspace added each year can be quite volatile, since it is so dependent on national and regional economic cycles. For instance, 43% more

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[3] The energy intensities for buildings built 1980-86 have been imputed using the method described in Appendix C.

non-residential floorspace was added in 1986 than during the 1982 recession year. For comparison, Appendix C contains details concerning the DOE forecast of gross and net commercial floor area additions 1987-2010.

Figure II.14 shows the breakdown of electricity consumption in commercial buildings by end-use (EPRI 1986). Cooling and lighting dominate electricity usage for office buildings, with about 80% of the total. Since some cooling energy is needed to remove the heat from the lights, energy savings in lighting will result in cooling energy savings as well. The dominance of cooling and lighting becomes important when estimating the technical potential for efficiency improvements in new offices in Chapter III.

Summary

The commercial sector is the most electricity intensive of all end-use sectors, and is likely to experience the most rapid growth in total primary energy consumption over the next decade. All commercial buildings are becoming more electricity intensive, as shown by a comparison of the existing stock in 1986 to buildings built from 1980-86. Office buildings are the second-most electricity intensive of all commercial buildings, and they comprise about 20% of all commercial floorspace to be added over the next 20 years.

OFFICE BUILDING CHARACTERIZATION

This section presents more information about office buildings, including distribution of offices by geography and size, energy prices and operating costs, load profiles, and time-series of office vacancy rates for selected cities.

Geographic Distribution of Office Buildings

Table II.2 shows the distribution of existing office building floor area by census division and region.[4] The Southern Census Region contains the most buildings and floor area. This region also has buildings of the smallest average size (about 11 thousand square feet (k sf)/building) compared to the national average (15.5 k sf/building). All other census regions (and all census divisions but the West North Central Division) have average floor areas per building higher than the national average.

Size Distribution of Office Buildings

Table II.3 shows the distribution of office building floor area by size of building. Offices less than 25 k sf comprise 89.4% of the buildings but only 34.3% of the floor area. A small number of buildings (about 15,000 or 2.4% of the total) contain 42% of the floor area.

Energy Prices and Operating Costs

Figure II.15 shows site energy prices for the commercial sector 1970-1988 (OBCS 1989, US DOE 1989c). All fuels increased in price up to the early 1980s, then started declining again. Electricity, the most important fuel in the commercial sector, is also

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[4] For the intended policy purposes of this dissertation, estimates of both geographic and size distribution of offices should be made for *new* buildings. Unfortunately, such data are not available.

about a factor of three more expensive per delivered Btu than other fuels. **Figure II.16** shows that energy and other utilities are the most important single type of operating costs in existing offices, comprising about 32% of operating costs in 1988 (BD&C 1989c).

Load Profiles

Figure II.17 shows the national average load profile for offices and other commercial buildings on the summer peak day (EPRI 1986). Because of the high density of internal loads in offices (e.g., people, lights, equipment) these buildings are often dominated by cooling, even in cold climates. Cooling and lighting are usually well correlated with the time of utility system peak demand, particularly for office buildings, which results in an especially large contribution to peak demand for every kWh of office electricity use. Typical load factors for U.S. utilities are about 62% (see **Tables II.5** and **II.6**), while typical coincident load factors for the commercial sector as a whole are 50-55% (Sorooshian-Tafti 1989). Coincident load factors (LFs) for office buildings are not known with precision, so the calculations in Tables II.5 and II.6 assume that the office coincident load factor is the same as that for the commercial sector as a whole. Every kWh of electricity use in the commercial sector (LF=53%) contributes 17% more to peak demand than 1 kWh of electricity use elsewhere in the utility system.

Vacancy Rates

Figure II.18 shows vacancy rates for leased office space in selected cities and for the U.S. as a whole. The lines for Dallas, Houston, and Denver show the potential volatility of this indicator in the face of regional economic cycles. Because of the oil slump and the 1982 recession, vacancy rates in Texas and Colorado increased from 4-8% in 1980 to 22-27% in 1983, and current vacancy rates in these areas range from 27-32%. The U.S. average vacancy rate increased from about 5% in 1980 to 19.2% in 1988. In general, vacancy rates for new offices will be lower than these averages, since new buildings offer many amenities unavailable in buildings constructed prior to widespread use of computer technology (see Chapter IV for more details).

Operating Hours

Table II.4 shows typical operating hours for commercial buildings of various types (Piette et al. 1988). All commercial buildings operate for more than 2400 hours per year, according to these estimates. Three of the four estimates for offices are approximately 2600-2700 hours, which are well below the average estimates for all commercial buildings (more than 4000-4500 hours).

BASELINE ENERGY USE AND POLLUTANT EMISSIONS

This section explores the contribution of new commercial buildings to growth in energy consumption, peak demand, and key environmental insults, and compares these contributions to current levels. **Table II.5** shows forecasted energy consumption and peak demand in 1990 (and **Table II.6** shows growth in these parameters) for the entire U.S., the U.S. electric power industry, the commercial building sector, and the office building sector.

The forecasted energy consumption in Tables II.5 and II.6 is based on the 1989 *Annual Energy Outlook*, published by the U.S. Department of Energy (US DOE 1989a). The CO_2 emissions factors are taken from Chernick and Caverhill (1989). The NO_x and

SO_X emission factors for direct fuel combustion were derived using the 1985 emissions inventory from the U.S. Environmental Protection Agency (Zimmerman et al. 1988) and energy consumption estimates from the *Monthly Energy Review* (US DOE 1989c). The NO_X and SO_X emission factors for electric utility fossil fuel combustion were derived from the 1988 *Electric Power Annual* (US DOE 1988a). The methodology for deriving these estimates (and the rest of the numbers in Chapter 2) is contained in Appendix C.

Table II.5 indicates that total U.S. primary energy consumption is forecasted to be 81.59 Quadrillion Btus (Quads or Q) in 1990, and 30 Quads, or about 37%, will be consumed to generate electricity. The commercial sector is responsible for sixteen percent of total primary energy consumption (13.39 Q), while offices are responsible for 3.8% of total primary energy (3.08 Q). Table II.6 shows growth in consumption, and it reveals that the power sector contributes the bulk of growth in primary energy consumption (79%). Largely because of growing electricity intensity, the commercial sector contributes 30% of total growth in primary energy consumption. Offices are responsible for 30% of commercial sector growth and 9% of total growth in U.S. primary energy consumption.

Total peak demand in 1990 is about 530 Gigawatts (1 GW=1 Billion kW), with the commercial sector contributing 193 GW or 36% of the total, and offices contributing 10% of the total. Total net generation will be 2850 TWh, of which about 31% (895 Twh) can be attributed to the commercial sector, and 8% can be attributed to offices. Growth in total peak demand and net generation will be about 14 GW (77.7 TWh) or 2.7% annually, while for the commercial sector growth will be about 2.8% per year. The annual percentage growth rates in both peak demand and net generation are higher than the growth rates in primary energy consumption in the electric power sector because new power plants have lower heat rates than existing ones.

Tables II.5 and II.6 also show primary energy consumption broken out by fuel type. Coal and non-fossil resources dominate the electric power sector, while oil, coal, and natural gas contribute almost 90% of total primary energy for the U.S. as a whole. The largest growth will be in non-fossil resources and in oil, for both the U.S. and the utility sector. Estimates of fuel consumption for commercial buildings and offices include the primary energy used to generate electricity used in those buildings.

The emissions estimates for CO_2, NO_X, and SO_X, again reveal the importance of the power sector. Electric utilities are responsible for about 1/3 of CO_2 and NO_X emissions, and 2/3 of SO_2 emissions. Commercial buildings are responsible for about 15% of total CO_2 emissions, 11% of NO_X emissions, and 22% of SO_2 emissions. Offices contribute 3-4% of CO_2 and NO_X emissions, and 5.7% of SO_2 emissions. The electricity sector is the dominant source of growth in these pollutants, contributing about 74% of the growth in CO_2 emissions, 57% of growth in NO_X, and 67% of the growth in SO_X. The commercial sector contributes about 29% of the growth in CO_2, 20% of the growth in NO_X, and 22% of the growth in SO_X. New offices contribute 8% of the growth in CO_2 emissions, 6.1% of the growth in NO_X emissions, and 7% of growth in SO_2 emissions.

CONCLUSIONS

The commercial sector is an important contributor to growth in electricity consumption, peak demand, and emissions of CO_2, NO_X, and SO_X, principally because of this sector's electricity intensity. This sector will be responsible for 1/3 of growth in electricity consumption and peak demand in 1990, and for roughly 20-30% of *total* U.S.

growth in CO_2, NO_X, and SO_X. Offices are responsible for 8-10% of growth in primary energy consumption, electricity consumption, and peak demand, and for 6-8% of growth in pollutant emissions. Many studies have estimated the economically justified energy savings potential in new office buildings. If the technical energy savings potential is 30-60% (see Brambley et al (1988b) and Chapter III), potentially significant reductions are possible in growth of electricity use, peak demand, and environmental insults caused by new commercial buildings.

Table II.1. Gross Additions to U.S. Floor Area 1975-1987 (Million sf)

	Residl	*Comml*	*Manufacturing*	*Educational*	*Hospital*	*Other*	*Total*
1975	1441	409	146	152	63	179	2390
1976	1867	440	152	118	71	172	2820
1977	2440	564	175	112	66	180	3537
1978	2815	758	219	104	53	153	4102
1979	2528	816	243	102	57	160	3906
1980	1892	688	216	95	54	147	3092
1981	1620	733	187	74	60	124	2798
1982	1497	571	119	74	70	112	2443
1983	2349	647	110	74	83	115	3378
1984	2396	808	145	90	70	123	3632
1985	2414	939	159	100	73	137	3822
1986	2578	869	147	116	73	144	3927
1987	2358	849	155	126	79	157	3724

Commercial includes mercantile and service, non-industrial warehouses, and offices. Gross additions are used both to replace demolished buildings and to meet growth in demand for floor area.

Source: Statistical Abstract of the U.S. (Census 1988) Table 1224.

Table II.2. Regional Distribution of Office Buildings 1986

CENSUS DIVISION	*# Buildings Thousands*	*% of Total*	*Floor Area M sf*	*% of Total*	*Area/Building k sf*
New England	30	4.9%	535	5.6%	17.83
Middle Atlantic	61	9.9%	1247	13.1%	20.44
E. N. Central	109	17.8%	1901	19.9%	17.44
W. N. Central	44	7.2%	634	6.6%	14.41
S. Atlantic	105	17.1%	1305	13.7%	12.43
E. S. Central	60	9.8%	620	6.5%	10.33
W. S. Central	73	11.9%	914	9.6%	12.52
Mountain	41	6.7%	671	7.0%	16.37
Pacific	91	14.8%	1720	18.0%	18.90
CENSUS REGION					
Northeast	91	14.8%	1782	18.7%	19.58
Midwest	153	24.9%	2535	26.6%	16.57
South	238	38.8%	2839	29.7%	11.93
West	132	21.5%	2391	25.0%	18.11
TOTAL	614	100%	9547	100%	15.55

N = North, E = East, S = South, W = West.

Source: Non-Residential Buildings Consumption Survey (US DOE 1988b), Tables 13 and 14.

Table II.3. Size Distribution of Office Buildings 1986

BUILDING SIZE	*# Buildings Thousands*	*% of Total*	*Floor Area M sf*	*% of Total*	*Area/Building k sf*
1001-5k sf	343	55.8%	1003	10.5%	2.92
5001-10k sf	133	21.6%	989	10.4%	7.44
10001-25k sf	74	12.0%	1284	13.5%	17.35
25001-50k sf	35	5.7%	1227	12.9%	35.06
50001-100k sf	15	2.4%	1047	11.0%	69.80
100001-200k sf	8	1.3%	1081	11.3%	135.13
200001-500k sf	5	0.8%	1540	16.1%	308.00
>500k sf	2	0.3%	1375	14.4%	687.50
1001-25k sf	550	89.4%	3276	34.3%	5.96
25001-100k sf	50	8.1%	2274	23.8%	45.48
> 100k sf	15	2.4%	3996	41.9%	266.40
TOTAL	615	100%	9546	100%	15.52

Source: Non-Residential Buildings Consumption Survey (US DOE 1988b), Tables 16 and 17.

Table II.4. Four Estimates of Average Annual Operating Hours for Commercial Buildings

Building Type	*Seton et al.*	*SCE*	*PG&E*	*NBECS*
Restaurant	5200	3361	3650	4264
Hospital	6000	6396	5840	--
Retail	4020	2867	5110	3276
Hotel/Motel	6090	7167	--	7904
Office	2730	2610	4380	2652
Warehouse	3120	2631	--	2756
School	2600	2818	3258	2392
Grocery	6240	4514	5110	5044
Average	4440	4395	4558	4041

One Year = 8760 hours

Source: Piette et al. (1988)

Table II.5. Estimated Commercial and Office Building Contribution to Energy Use, Peak Demand, and Environmental Insults 1990

	Totals 1990			
	U.S. Total	U.S. Electric Power Sector	Commercial Sector	Office Sector
ENERGY INDICATORS				
Total Primary Energy (Q)	81.59	30.00	13.39	3.08
Non-Electric Direct Fuel Use	51.59	0.00	3.97	0.558
*Net Generation (Q)**	30.00	30.00	9.42	2.52
Peak Demand (GW)	529	529	193	52
Net Generation (TWh)	2849	2849	895	240
*Primary Energy by Fuel (Q)***				
Natural Gas (Q)	18.48	2.96	3.66	0.66
Oil (Q)	30.44	1.32	1.65	0.26
Coal (Q)	23.18	16.23	5.10	1.37
Non-Fossil (Q)	9.49	9.49	2.98	0.80
ENVIRONMENTAL INSULTS				
CO2 (10e6 t C)	1461	487	215	50
% of U.S. Total	*100%*	*33%*	*15%*	*3.4%*
NOx (10e3 t NOx)***	22885	7081	2563	641
% of U.S. Total	*100%*	*31%*	*11%*	*2.8%*
SOx (10e3 t SO2)***	26027	16880	5816	1482
% of U.S. Total	*100%*	*65%*	*22%*	*5.7%*

Sources: Annual Energy Outlook (US DOE 1989a), NERC (1989), Chernick and Caverhill (1989), Zimmerman et al. (1988), EIA Monthly Energy Review February 1989 (US DOE 1989c), Sorooshian-Tafti (1989)

*T&D losses = 0.06

Average Heat Rate 1990 (Btus/kWh)	10530
with losses	11162

**Primary energy for fuel includes primary energy used for generation of electricity.
Direct fuel use in comml sector (1990) = 2.73Q gas and 1.24Q oil + other.
***US total includes industrial processes that emit ~13% of SOx and ~5% of NOx

ASSUMPTIONS: 1 ton = 2000 lbs. Pollution emission factors are from Appendix C.
Commercial and Office Coincident Load Factor = 0.53 from SCE (Sorooshian-Tafti).
U.S. load factor 1990 = 0.615 from NERC forecast

Table II.6. Estimated Commercial and Office Building Contribution to Energy Use, Peak Demand, and Environmental Insults 1990-91

	Annual Net Growth 1990-91			
	U.S. Total	U.S. Electric Power Sector	Commercial Sector	Office Sector
ENERGY INDICATORS				
Total Primary Energy (Q)	0.87	0.69	0.26	0.08
Non-Electric Direct Fuel Use	0.18	0.00	0.04	0.007
*Net Generation (Q)**	0.69	0.69	0.22	0.07
Peak Demand (GW)	14.1	14.1	5.35	1.71
Net Generation (TWh)	77.7	77.7	24.9	7.94
*Primary Energy by Fuel (Q)***				
Natural Gas (Q)	0.14	0.04	0.043	0.009
Oil (Q)	0.27	0.20	0.074	0.022
Coal (Q)	0.17	0.16	0.051	0.016
Non-Fossil (Q)	0.29	0.29	0.093	0.030
ENVIRONMENTAL INSULTS				
CO2 (10e6 t C)	11.7	8.7	3.4	1.0
% of U.S. Total	*100%*	*74%*	*29%*	*8.4%*
NOx (10e3 t NOx)***	153	87	30.8	9.4
% of U.S. Total	*100%*	*57%*	*20%*	*6.1%*
SOx (10e3 t SO2)***	242	162	54.2	16.9
% of U.S. Total	*100%*	*67%*	*22%*	*7.0%*

Sources: Annual Energy Outlook (US DOE 1989a), NERC (1989), Chernick and Caverhill (1989), Zimmerman et al. (1988), EIA Monthly Energy Review February 1989 (US DOE 1989c), Sorooshian-Tafti (1989)

*T&D losses = 0.06
Marginal HR 1990-91 (Btus/kWh) 9286
with losses 9843

**Primary energy for fuel includes primary energy used for generation of electricity.
Direct fuel use in comml sector (1990-91) = 0.03Q gas and 0.01Q oil + other.
***US total includes industrial processes that emit ~13% of SOx and ~5% of NOx

ASSUMPTIONS: 1 ton = 2000 lbs. Pollution emission factors are from Appendix C. 50% of electricity growth is assumed to be supplied by new plants meeting the New Source Performance Standards, and 50% is supplied by existing plants. Commercial and Office Coincident Load Factor = 0.53 from SCE (Sorooshian-Tafti).
Load factor of growth 1990-91 = 0.627 from NERC forecast

Note: Figures II.1 through II.18 are not included in this PDF file. Contact the author at JGKoomey@lbl.gov or 510/486-5974 to obtain copies.

CHAPTER III: TECHNICAL EVIDENCE FOR MARKET FAILURES AFFECTING ENERGY EFFICIENCY OF NEW OFFICE BUILDINGS

INTRODUCTION

This Chapter examines the technical evidence for the existence of market failures affecting the energy efficiency of new office buildings, based on previous analyses of whole building energy use, as well as studies of individual efficiency technologies. It also derives a rough estimate of the savings potential in new offices, for use in the economic analyses in later chapters. The second section of this Chapter presents the nature of the technical evidence, examining the conditions under which the existence of cost-effective energy conservation implies the existence of market failures. The third section reviews the results of previous studies and regulatory decisions relating to efficiency of new office buildings. The fourth section presents information about a few representative efficiency technologies that allow new office buildings to cost-effectively exceed the efficiency mandated in the new standards for Federal non-residential buildings.

THE NATURE OF THE TECHNICAL EVIDENCE

Technical analyses often indicate substantial potential for cost-effective improvements in the energy efficiency of new office buildings. For instance, Brambley et al. (1988b), who have participated in many such analyses, state that

> at least 15% of the energy now used in new [commercial] buildings could be saved using existing energy-efficient building design knowledge. If additional measures requiring modest additional first cost (with payback periods of less than 3 years) are considered, this estimate increases to approximately 30% to 40%. Early building system integration research suggests that by using building subsystem integration techniques, savings of 60% could be achieved.

Engineering analyses and successful utility programs provide tangible evidence for the existence of such efficiency improvements and the market failures they imply. However, the robustness of this evidence is dependent on the accuracy of the analyst's characterization of current building practice, as well as assumptions about fuel price escalation and discount rates.

What are the conditions under which the existence of untapped energy efficiency implies the existence of market failures? In principle, a single device that offers a cost of conserved energy[1] that is less than the electricity price but is not used in all new office buildings is evidence for market failures affecting the adoption of that investment. However, there are a number of subtleties in using engineering-economic analyses to infer the existence of market failures.

Suppose an extremely cost-effective efficiency investment (e.g., an efficient electromagnetic/core-coil ballast for fluorescent lights) is available off-the-shelf and in large quantities, yet is not being used in all suitable applications. Either there are hidden costs

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[1] CCE equals the annualized cost of an investment divided by the annual kWh savings, and is expressed in \$/kWh. For these calculations, CCE must be a measure of *societal* cost, based on a societal discount rate. The discount rates of consumers are not relevant to this calculation, except to explain why they don't invest in these efficiency measures.

that have not been included in the calculations, parameters that have been incorrectly specified in the calculations, time lags between the introduction and the acceptance of a new technology, or market failures inhibiting the adoption of this option.

Hidden Costs : engineering-economic calculations must include all societal costs of efficiency measures, and should hold the level of service or level of amenity constant in any consistent calculation of the cost of conserved energy. Other costs that may not be included in the calculations include sales taxes, income taxes, property taxes, additional maintenance costs due to the efficiency measure, search costs for the information describing the device, risk costs associated with changing to a new device, or additional installation costs due to unique circumstances.

In the case of the efficient core-coil ballast, none of these conditions are important– this device provides equivalent amenity and longer lifetime than its inefficient counterpart. It is widely available and is based on well-known, proven technology. The similarity between this device and the one it replaces insures that hidden costs are unlikely to be important in this case

Incorrect Parameter Specification : engineering calculations may overstate the benefits of energy efficiency by calculating energy savings with respect to a base case building or device that is less efficient than currently designed new buildings or new devices. Building prototypes based on average characteristics may submerge important details and may not contain all available efficiency technologies, due to limited funding for such analyses. Incorrect estimation of operating hours may also affect these calculations.

Since we know that about 90%[2] of the fluorescent ballasts sold in the U.S. in 1987 would have been of the inefficient core-coil variety without state standards (see Chapter 1), *and* we know that efficient core-coil ballasts are cost effective when operated more than 600 hours/year, *and* we know that all types of commercial buildings operate for thousands of hours every year (Table II.4), we can conclude that incorrect specification of operating hours (within reasonable bounds) will not affect the results from this calculation. The other parameters are irrelevant because efficient core-coil ballasts are perfect substitutes for inefficient ballasts (except with respect to energy savings and lifetime, where they are superior substitutes).

Time Lags : Relatively new technologies may take time to be understood and accepted in the design community.[3] Manufacturers may need years to produce a new technology on sufficient scale to saturate the market. Efficient electromagnetic ballasts have been on the market for many years, so time lags probably do not explain commercial customers' reluctance to purchase them.

The existence of devices that are based on proven technology, which save energy at a cost below the price of energy, which meet the conditions stated above (no hidden costs and correct parameter specification), and have not been adopted over many years, *does* indicate market failures. Since efficient core-coil ballasts satisfy all these conditions,

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[2] This figure includes a correction for sales of efficient ballasts in states with laws prohibiting the sale of inefficient ballasts. States with such laws in place by the end of 1987 comprised about 25% of the U.S. population.

[3] The time and effort needed to learn about new technologies is another hidden cost, which is likely to be greatest when these new technologies are introduced extremely rapidly.

market failures must be inhibiting their adoption.[4] Fluorescent ballasts are found in almost every new commercial building (and are ubiquitous in offices) which suggests that market failures affecting the adoption of efficient core-coil ballasts may be widespread in the commercial sector and may affect the adoption of other cost-effective devices as well. These market failures are explored in Chapter IV.

REVIEW OF PREVIOUS STUDIES

This section explores the studies and building efficiency regulations that indicate substantial potential for improvement in the efficiency of new office buildings in the U.S. The studies span many years, and have been completed for different areas of the U.S. The main purpose of this review is to calculate a rough estimate of the untapped conservation potential in new offices. It also notes where the results of previous studies may indicate market failures.

Redesign of New U.S. Buildings Using Computer Simulations

In the late 1970s, scientists, engineers, and architects participated in the Federal Government's efforts to analyze the economics of Building Energy Performance Standards (BEPS) for new residential and commercial buildings. The first stage of the analysis for commercial buildings involved evaluation of over 1600 buildings that were constructed in the mid-1970s, using computer simulation tools (principally DOE-2) and data supplied by participants in the design and construction process (Stoops et al. 1984).

From this large sample, 168 buildings were chosen for further analysis. Each building was then redesigned by teams of architects who were constrained by the characteristics of the original site and project budget. Passive solar techniques and efficiency options were allowed in these redesigns, while active solar technologies generally were not. The overall energy use was 38 percent less than the original designs, when averaged over all commercial building types.

The redesigned buildings included 22 offices, half of which were smaller than 50 thousand square feet (ksf), and half of which were larger. Savings for offices averaged 50 percent for buildings less than 50 ksf, and 42 percent for those larger than 50 ksf. The capital cost of the office redesigns averaged 3.5 percent higher than the original designs. If the original designs cost $60/sf[5] and used energy costing roughly $1.50/sf/year, the simple payback time of the added investment would be about three years. These redesigns were thus extremely cost effective from the societal perspective.

Improvements in typical new building efficiency have occurred since the mid-1970s, when most of the redesigned buildings were first constructed. Therefore, the results from the BEPS redesign analyses cannot be used to infer the potential size of cost-effective efficiency improvements in *current* new offices. However, they suggest that

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[4] As of January 1990, only efficient core-coil and solid state ballasts may be sold in the U.S. The inefficient core coil ballasts were outlawed by an amendment to the National Appliance Energy Conservation Act of 1987.

[5] Stoops et al. do not give actual cost per sf estimates averaged over all the redesigns, so I chose this plausible estimate to do a rough calculation.

market barriers may have in the past inhibited new buildings from taking advantage of all cost-effective energy efficiency.

Analysis of U.S. Building Prototypes Using Computer Simulations

Related to the BEPS redesign project was concurrent analysis to analyze the feasibility and economic attractiveness of the ASHRAE[6] 90-1975 building efficiency standards. This research, first conducted by the American Institute of Architects and later moved to Pacific Northwest Laboratory (PNL), has continued through the 1980s, and now includes analysis of building standards that exceed 90-1975 in stringency.

Most state building standards in the 1980s are based on 90-1975, 90A-1980, or comparable standards (EPRI 1988c, NCSBCS 1985). Some codes, such as the California Building Standards and the Model Conservation Standards (MCS) in the Pacific Northwest, include requirements similar in stringency (at least in some cases) to the recently published ASHRAE standard (90.1-1989). The Federal Government has just instituted mandatory standards for Federal buildings that exceed 90.1-1989 in some cases (these standards are voluntary for non-Federal buildings).

The analysis of the technical and economic aspects of these building energy performance standards involved computer simulations of the energy use of three office building prototypes, as well as prototypes for other types of commercial buildings (PNL 1983). The office prototypes in the earlier analyses were a 2.5 ksf bank, a 50 ksf suburban office, and a 684 ksf large office building.[7] Detailed capital cost analyses accompanied the building energy simulations, based on engineering cost estimation. Life-cycle costs were then calculated based on energy prices, the energy intensity of each building, and the capital costs needed to reach a given standard level.

Table III.1 shows the essential characteristics of the most recent prototypes defined in the PNL analyses for small, medium, and large office buildings. **Table III.2** shows recent results of the PNL simulation runs for these buildings, in terms of site energy use per square foot[8] (and fraction of the 90A-1980 standard level) for each prototype, at the various standard levels, using Washington, DC weather.[9] The 90.1-1989 standard reduces site energy consumption by 6 percent for the small office, 12 percent for the medium office, and 7 percent for the large office (compared to 90A-1980 levels).

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[6] American Society of Heating, Refrigerating, and Air Conditioning Engineers.

[7] The most recent PNL analyses (1989) used a large office building floor area of 797 ksf, which corresponds to that of the large building included in Tables III.1 and III.2.

[8] For comparison, the NBECS estimate for all offices built between 1980 and 1986 is about 101.6 kBtus/sf of site energy. This number is higher than the site energy of the medium and large offices in Table III.2, and lower than that estimated for small offices. Differences between simulation analyses and actual building energy use can occur because assumptions about internal loads, occupant behavior, and equipment usage can diverge from actual conditions. The results of such analyses, which analyze the *differences* in energy use between different cases, do not depend as heavily on the absolute value of these assumptions as analyses that attempt to estimate *actual energy use* of real buildings using simulation models.

[9] The PNL analyses used different combinations of HVAC systems and building shells. This table shows only one of these combinations for small, medium, and large offices. Washington, DC has weather that is close to the population-weighted average climate for the U.S.

The analysis of standard 90A-1980 for these prototypes determined that the standards were cost-effective in all areas of the country, with payback times usually less than two years compared to 90-1975. The more stringent standards that evolved into 90.1-1989 were found in general to be cost-effective from the societal perspective, often offering payback times of less than two years. In many cases these standards allowed significant down-sizing of Heating, Ventilating, and Air Conditioning (HVAC) equipment, which reduced capital costs (PNL 1983).

Redesign of New California Building Prototypes Using Computer Simulations

The California Energy Commission (CEC) reevaluated the Title 24 minimum efficiency standards for non-residential buildings in the early 1980s. The CEC used prototypical buildings and a methodology similar to that used in the PNL analyses (above) to analyze standards similar in stringency to ASHRAE 90.1-1989. The analysis included a variety of assumptions about discount rates, tax rates, fuel prices, and length of analysis period (Borden et al. 1982).

The CEC analysis found that the new standards under consideration were cost effective to *society* in the base case and in every single sensitivity case. The standards resulted in minimum life-cycle costs (LCCs)[10] for *office building investors* in most cases, using a variety of different discount rates. When the standards did not result in minimum LCC for investors, the difference in life-cycle costs between the minimum LCC and the estimated LCC was a few percent of the minimum LCC.

Redesign of New Northeast U.S. Building Prototypes Using Computer Simulations

Northeast Utilities, based in Hartford, CT, conducted an analysis in the mid-1980s to show that new office buildings can be designed that save significant amounts of energy relative to current practice, but cost no more than conventional buildings to construct (NU 1988, Wajcs and Kroner 1988). Their analysis, which was similar in approach to the BEPS redesign effort (above), used a prototypical 60,000 square foot office building. They calculated energy consumption using the DOE-2 building simulation model, and calculated capital costs using standard cost estimating techniques. The base-case building "exceeded the minimum building envelope standards".

The results of this work are shown in **Table III.3**, which shows that the improved base case building uses 36 percent less electricity and 32 percent less total energy. Natural gas use increased 17 percent to compensate for reduced internal gains in winter. The analysis also found that peak electricity demand fell by 51 percent, and the total energy bill fell by 37 percent (Wajcs Jr. and Kroner 1988).

The overall first cost for the improved base-case building did not increase over the original design. In some cases (e.g. lighting efficiency and controls) the overall capital cost of the building fell slightly, because the more efficient technology allowed the use of a smaller and less expensive HVAC system.

The one measure considered in the Northeast Utilities analysis that might not strictly be considered an energy efficiency measure is that of reducing glazing area. While this

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[10] Life-cycle cost is a term used in engineering economics that is equal to the present value of capital, operating, maintenance, and other costs over the life of the building.

technique does save both electricity and natural gas, it changes the design of the building and may in some cases lead to decreased amenity. If people derive benefit from looking through vast expanses of window, this benefit may be reduced. On the other hand, less window area means more comfort, since the mean radiant temperature of a wall will be closer to the desired room temperature than that of a window. Changing the *orientation* of the window area may also slightly affect amenity, but it can substantially influence energy consumption (see the BEPS redesign work above). In any case, this measure accounts for only a few percent of the total savings.

In summary, the Northeast Utilities analysis shows that typical new office buildings (corresponding to current practice) can be redesigned to save significant amounts of energy at no increase in first cost. This result, which is more recent that those from the BEPS redesign and is based on well known, widely available technology, may indicate that market failures are preventing such efficiency measures from being incorporated into new offices.

Energy Edge Design Assistance Program

In 1984, the Bonneville Power Administration (BPA) instituted the Energy Edge Design Assistance Program. This program offered design assistance and financial incentives to designers of new, all-electric, commercial buildings that use 30 percent less energy than buildings meeting the region's Model Conservation Standards (see below). Twenty nine buildings were chosen, all of which will be monitored for three years from the time they reach 70 percent occupancy. The monitoring will end in 1992 for the last building constructed (Vine and Harris 1988b).

Pre-monitoring estimates indicate that these commercial buildings will reduce energy consumption by 36 percent compared to the Model Conservation Standards, with a range of 30 to 50 percent savings. The average cost of conserved energy for these improvements is $0.023/kWh (based on estimated savings) (Vine and Harris 1988b). This CCE compares favorably to both the 1988 national average electricity price of $0.066/kWh (1989 $), and to electricity prices in the Northwest of about $0.05/kWh.

Measured Data on Energy Use of New Office Buildings

BECA-CN[11] is Lawrence Berkeley Laboratory's ongoing compilation of energy consumption of new commercial buildings. These data are important because they are not based on simulations but on measurement of the energy use of 152 actual buildings. About 2/3 of the buildings in the sample are office buildings. About 3/4 of the offices have floor areas greater than 50 ksf (large offices). Most of these buildings are award-winning "energy-efficient" buildings.

These data clearly show no correlation between construction cost of office buildings and resource[12] energy use. For large offices, buildings with the same capital cost can vary in resource energy intensity by more than a factor of two. Buildings with the same

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[11] BECA = Building Energy Compilation and Analysis

[12] Site energy includes the higher heating value of fuels and the heat value of electricity consumed on site (measured as 3412 Btus/kWh). Resource energy adjusts the heat value of electricity to account for generation, transmission, and distribution losses.

resource energy intensity can vary in capital cost by a factor of more than two and a half. Small offices show even greater variation (Piette and Riley 1986, Piette et al. 1985). These data show that offices with low capital costs can also have low operating costs, and offices with high capital costs can have high operating costs.

Measured Data on Energy Use of Passive Solar Commercial Buildings

The U.S. Department of Energy's (DOE's) Passive Solar Commercial Building Program involved design, construction, and monitoring of nineteen new buildings that used high-efficiency construction and passive solar techniques (there were also major retrofits of four existing buildings) (US DOE 1983). Only two of these buildings were offices--most of the rest were schools, libraries, and community centers. The buildings in the experiment were comparable in cost to ordinary new buildings, but used about half the energy for space conditioning and lighting end-uses. Energy use in the miscellaneous end-use was larger than for comparable buildings in some cases. Total energy use was 45% lower than in comparable conventional buildings (Gordon et al. 1985, Hirst et al. 1986, Vine and Harris 1988b).

Building Efficiency Standards

Federal Standards : In January 1989 the Federal Government established minimum standards for the efficiency of new buildings constructed under government contract. These standards can be either performance-based or prescriptive. They are similar to but more stringent than the ASHRAE 90.1-1989 standards for new commercial buildings, and are mandatory for new federal buildings. The more stringent second phase of the standard will go into effect in 1993. When referring to the Federal standards in the rest of this dissertation, I mean the 1993 standards (unless otherwise specified).

The U.S. government will purchase, own, and operate these buildings, and hence will pay the increased first cost as well as the operating costs. The Interim Rule for these standards indicates that they "have already been analyzed for life-cycle cost effectiveness and have been found to be cost effective for the buildings tested" (US DOE 1989b, p.4539). The government would not need to set minimum efficiency standards for its own new buildings if all contractors were currently meeting those standards. Therefore, the buildings constructed by these contractors in the recent past must not meet these standards, in spite of the cost effectiveness of the efficiency levels mandated by the legislation. As shown in Table III.2, the 1993 Federal Standard reduces site energy consumption by 13 percent for the small office, 19 percent for the medium office, and 17 percent for the large office (compared to 90A-1980 levels).

The Northwest Power Planning Council's MCS : The Northwest Power Planning Council (NPPC) established Model Conservation Standards for new commercial buildings in 1983. These standards were roughly equivalent to the ASHRAE 90A-1980 standards, but included lighting efficiency standards stricter than those in 90.1-1989. NPPC revised these standards in 1989 to tighten the envelope and HVAC requirements to correspond more closely to the more stringent Federal standards and the standards adopted by Oregon, Washington state, and the City of Seattle. The NPPC believes that these more stringent efficiency standards are economically justified from the societal perspective (NPPC 1989c).

Utility Programs

Some utilities now offer programs to improve the efficiency of new construction, either through technical assistance, rebates, or both. After a review of seventeen such programs, Nadel (1990) concludes that some programs "have achieved energy savings in participating buildings as high as 30%. Even higher savings may be possible if incentives are provided for additional cost-effective measures".

Utilities have less experience with programs affecting the efficiency of *new* commercial buildings than with those for existing buildings. About half of the new building programs Nadel surveyed were started in 1988 or 1989, and only two started before 1984. The cost of these programs ranges from less than 1¢/kWh for simple rebate programs to about 8¢/kWh for the most expensive comprehensive programs that deliver both design and financial assistance (not all comprehensive programs are this expensive).

These programs are usually able to purchase energy efficiency at a cost less than the price of electricity, which suggests either that there are market failures or that participants in these programs are misleading the utilities by stating that they will build an inefficient new building if they are not given money (i.e., they are gaming the process). As Nadel points out, many utilities have avoided such "free rider" problems by offering rebates only for those efficiency options that are not in common use in new construction practice. As current practice changes, rebate programs must change also.

Utility programs can provide direct empirical evidence for specific market failures, by assessing market response to incentives and information programs. However, there are not sufficient numbers of carefully documented programs for new offices to draw detailed conclusions about specific market failures in this sector (using this evidence).

COST-EFFECTIVE EFFICIENCY TECHNOLOGIES FOR NEW OFFICES

This section does not attempt detailed engineering-economic analysis in the manner of the BEPS or Northeast Utilities analyses described above. Rather, it seeks to present the cost and rough savings potential for a few commercially-available technologies that allow designers to exceed the 1993 Federal standards, including those affecting space conditioning, lighting, and electric motors. These estimates may be further indication of market failures afflicting energy efficiency investments in new offices, since many of these technologies have been on the market for years.

Referring to the PNL prototypes for small, medium, and large buildings will help structure the discussion when distinctions by building size are warranted. Unless otherwise noted, requirements and energy savings numbers correspond to Washington, D.C. weather, and all costs are national average values in 1989$, adjusted using the consumer price index and a 1989 inflation rate of 5 percent.

Glazing

In new buildings, adjusting glazing orientation or reducing glazing area can often save energy at small cost. The PNL analysis did not consider these options. However, both the BEPS and the Passive Solar redesign exercises reveal that significant reductions in new office energy use may be achieved by using such techniques.

Glazing in all offices can benefit from low-emissivity (low-E) coatings that reflect infrared radiation. These coatings reduce summer heat gain from solar infrared radiation, thereby reducing cooling loads. They are distinct from tinted or reflective glazings, which reflect visible light and are also highly cost effective. In winter, low-E coatings reflect heat back into the building and increase the mean radiant temperature of the window so that occupants feel warmer at any given air temperature.

These glazings can, in conjunction with daylighting controls, result in large savings in building capital costs, because these measures reduce peak cooling demand and required chiller size. Sweitzer et al. (1986) estimate that low-E glazings can reduce total electricity consumption in perimeter zones by a few percent, can reduce heating energy in those zones by more than 30 percent, and can reduce peak electric demand by 3 to 7 percent, depending on climate and other factors.[13] Gilmore (1986) reports that double-paned low-E glazings typically sell for 10-15% more than standard double-paned windows. At $10/sf of glazing area, this amounts to incremental additional costs of $1-1.50/sf.

Lighting Efficiency

In 1993, the Federal standards mandate that lighting power budgets will drop by 26% from 1990 levels, so this analysis proceeds from the lighting efficiency levels mandated in 1993. While the standards' lighting requirements can be met using combinations of lighting controls and more efficient lighting, I assume that the 1993 lighting levels are met using efficient lighting technologies alone.

For large buildings, I assume that designers must use all available efficiency technologies (including electronic ballasts, T-8 or T-10 lamps with thin coat phosphors, and state-of-the-art fixtures) to meet the strict lighting standards (1.1 W/sf). I assume that the more lenient lighting standards for small (1.27-1.4 W/sf) and medium-sized (1.22 W/sf) offices can be met without the electronic ballast but do include the other efficiency measures. Using such efficiency technologies to reach the required lighting power has a simple payback of less than two years (Rubinstein 1990).

The cost effectiveness of electronic ballasts has already been illustrated in Chapter I and has been documented extensively (Piette et al. 1988, Rubinstein et al. 1986). These ballasts usually operate at high frequency (tens of kilohertz) and save energy by reducing losses in the ballast itself, increasing the efficacy of the lamps, and allowing use of sophisticated controls (Lovins and Sardinsky 1988). Piette et al (1988) calculate that in two *retrofit* applications the cost of conserved energy for installing an electronic ballast in place of an efficient core-coil ballast ranges from 2.6 to 3.3 ¢/kwh in their most pessimistic case.[14] Since these costs are lower than the average price of commercial sector electricity in 1988 (7.4¢/kWh in 1989$), and installation of solid state ballasts in new offices will have much lower costs than retrofits, solid state ballasts should be dominating the marketplace.

The case of electronic ballasts is one where the analyst must be circumspect in drawing inferences regarding market failures. These devices were developed in the 1970s but suffered from reliability problems when first introduced in the U.S. in 1979. By the early to mid-1980s, these problems had been substantially reduced or eliminated. Lovins and Sardinsky (1988) report that shipments of electronic ballasts increased at about 60 percent per year from 1982-1986, which indicates rapid acceptance. However, these devices still only account for a few percent of current ballast sales in the U.S. If the growth in electronic ballast sales halts before they completely dominate the market, that

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[13] Assumes double glazing and daylighting. Results as stated hold for Madison, WI and Lake Charles LA, for window to wall ratios from 25% to 75%.

[14] This case assumed that the lights operated 3000 hours per year, the ballasts were purchased at retail cost, and the existing ballasts were replaced in the middle of their useful life. The calculation also assumed 7 percent real discount rate.

slowing of sales will indicate market failures at work (assuming there are no unforeseen manufacturing constraints).

Lighting Controls

The costs and energy savings of lighting controls are as well documented as those for electronic ballasts (Lovins and Sardinsky 1988, PG&E 1989, Rubinstein and Karayel 1984, Rubinstein et al. 1984, Verderber et al. 1989, Verderber and Rubinstein 1984). In fact, the use of solid state ballasts makes sophisticated control strategies less expensive, although electronic ballasts are not necessary for such controls. Controls are used to compensate for lumen depreciation over time, to automatically turn lights off in unoccupied rooms (occupancy sensing or scheduling), to "task-tune" ballasts in specific areas to lower lighting levels when appropriate, and to dim lights in response to incoming daylight (Verderber 1984). The focus here is mostly on daylighting for energy savings and evidence of market failures, but the analysis could apply equally well to other control strategies.

Rubinstein and Karayel (1984) measured savings from daylighting a large San Francisco office building. They found that savings ranged from 25 to 35 percent of *lighting energy* consumption in the daylit area. Table III.2 shows that daylighting adds an additional 4 to 6 percentage points to total energy savings relative to 90A-1980, assuming that the building prototypes are not redesigned. New buildings that are designed specifically for daylighting can achieve even higher savings (Verderber et al. 1989).[15] Usibelli et al. (1985) confirm that this control strategy offers energy savings, peak demand savings, and substantial reductions in HVAC capital cost that offset much of the cost of the controls. Studies that *do not consider* the capital cost savings in HVAC systems find simple payback times for daylighting alone or for daylighting plus other strategies from two to three years (Verderber et al. 1989, Verderber and Rubinstein 1984).

Daylighting is not commonplace in new U.S. offices, but daylit buildings, if properly designed, should offer the same lighting levels as conventional buildings, at substantially lower life-cycle cost. Is this omission an indication of market failures?

Designing buildings to take full advantage of such control strategies requires substantially more skill and effort than designing "current practice" buildings that are similar to the last building designed, since they involve complex interactions between lighting, fenestration, and HVAC systems. Many architects and engineers are not familiar with the technologies involved (even though daylighting and occupancy sensors have been available and cost effective for many years). There is risk involved in implementing an unfamiliar technology, and many architects and engineers are reluctant to specify "innovative" technologies for fear of lawsuits. Chapter IV explores these issues in more detail.

Electric Motor Efficiency

"Energy-efficient" motors are 3-8% more efficient than their standard counterparts, mainly because better materials are used in construction (Usibelli et al. 1985). Efficient motors are similar to efficient core-coil ballasts in that they offer a relatively "clean" case of

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[15] Lighting energy savings for combination strategies using daylighting, lumen depreciation, occupancy sensing, and task tuning can range from 60 to 70 percent (in the daylit area) for offices with daylit areas comprising 10 to 60 percent of total floor area (see Verderber and Rubinstein 1984).

market failures inhibiting the adoption of a proven and cost-effective technology. The efficient motors are identical to the standard motors except for their energy use and their capital cost.

Table III.4 shows the minimum acceptable full-load efficiencies mandated by the Federal Standards for single-speed polyphase motors, and **Table III.5** shows efficiency, capital costs, energy savings, and cost of conserved energy for efficient motors of various sizes in commercial buildings, based on estimates from Miller et al. (1989).[16] Miller et al.'s estimates of the efficiency of *standard* motors are comparable to the efficiencies contained in the Federal Standards (similar estimates for industry average efficiencies are contained in Magnetek (1989)). The Federal Standards therefore do not promote the use of the more efficient motor technology. Efficient motors greater than 5 hp in size save electricity at costs of conserved energy less than $0.032/kWh, indicating that market failures must be inhibiting their adoption.

Electric Motor Controls

Mechanical and electronic adjustable speed drives (ASDs) adjust the speed of electric motors to more closely match the load, while mechanical adjustable speed drives change the speed of the driven load while keeping motor speed constant. They are widely used and highly cost effective in large buildings, both in new and retrofit applications. Medium-sized office buildings can save roughly 5 percent of total electricity consumption by controlling HVAC fan motors with variable speed drives, though under national average conditions (Washington, DC weather and commercial sector electricity prices of 7.4¢/kWh) this application is not cost effective enough in medium-sized buildings to make a compelling case for market failures preventing its adoption.[17] The technology is so cost effective for larger buildings that if some such buildings are not using it, market failures must be at work.

ASDs for small buildings are currently used in packaged heat pump units intended for residential and small commercial use. Small, mass-produced ASDs comprise most of the ASDs currently in use worldwide. They are not standard practice on small HVAC units and they are not required by the Federal Standards.[18] The costs of these ASDs have been reduced drastically through mass production to $25/hp (compared to hundreds of dollars per horsepower for larger units (Miller et al. 1989)). At $25/hp and a 7.4¢/kWh electricity price, the simple payback time is two to three years for 1500 to 2000 operating hours per year, which is typical for small commercial heat pump operation (Greenberg et al. 1988).

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[16] The operating hour estimates have been reduced by 40% to account for the significant part-load operation of most motors (i.e., not all operating hours are full-load operating hours).

[17] Based on the energy savings numbers from Greenberg et al. 1988 and installed costs of VSDS from Miller et al. 1989.

[18] The efficiency improvement from these drives is usually factored into the Seasonal Energy Efficiency Ratio (SEER) and the Heating Season Performance Factor (HSPF) of the heat pump, so a VSD could allow an heat pump system to meet the standards more easily. However, the Federal standards for packaged, air-cooled heat pumps are similar in stringency to those established in the National Appliance Energy Conservation Act of 1987 (SEER 10), which can be cost-effectively met using other methods (see Levine et al. 1987). Therefore, the VSD provides additional cost-effective efficiency improvement.

Thermal Storage

Large and some medium-sized office buildings pay both energy and demand charges in their utility bills. The energy charge is simply based on the number of kWh used, while the demand charge depends on the demand of the building during the utility's peak period. Since a large amount of an office buildings' peak demand is due to cooling, demand charges can be reduced using thermal storage systems. These systems run chillers at night to make ice, chill water, or cool hollow concrete slabs. They use this stored "coolth" to keep the building cool during the day. There are many different configurations of such systems, some that achieve partial reductions of peak demand, and some that eliminate demand charges entirely. Rosenfeld and la Moriniere (1985) found that partial storage systems could reduce peak demand by more than 60%. The additional cost of full and partial storage systems range from zero (for the "Thermodeck" concrete slabs from Sweden) up to $500 per shifted kW. They offer returns on investment that are attractive in many cases. The technology has advanced rapidly in recent years, with several hundred such systems being installed around the U.S., principally in response to financial incentives from electric utilities (Piette and Harris 1988). As microprocessor-based TOU and demand meters become more common in smaller commercial buildings, thermal storage technology will become more widely used.

Energy Management Systems (EMSs)

According to the Electric Power Research Institute, EMSs will achieve energy savings in commercial buildings of ten to twenty percent (EPRI 1988c). These systems control water heating, lighting, and HVAC, allowing optimization to achieve superior performance from this equipment. They also allow temperature setback, demand limiting, economizer control, optional start/stop, timed start/stop, duty cycling, and shut down of unused lighting and equipment (EPRI 1988c, Lytle IV 1989). EMSs rely on microprocessor technology, and have become more widespread and cost effective as such technology has fallen in price. Controls of this sort are available in a large number of different configurations. As with all solid-state technology, prices are dropping and capabilities increasing at a rapid rate, though price reductions will ultimately be limited by the cost of the relays and other mechanical devices the microprocessor needs to control building systems.

TECHNICAL POTENTIAL FOR ENERGY COST REDUCTIONS

The studies and calculations cited above indicate that the conservation/energy cost reduction potential in new office buildings (relative to current practice) implies at least 30 percent savings in annual energy costs. The Federal Standard saves about 15 percent of site energy compared to 90A-1980, and these savings do not include variable speed drives and increased insulation levels for small buildings, electronic ballasts for small and medium-sized buildings, high efficiency motors, daylighting, occupancy scheduling, task tuning, lumen depreciation, high efficiency HVAC systems, low-emissivity glazings, modification of glazing area and orientation, thermal storage, and computerized energy management systems, all of which are commercially available and cost effective in many new buildings (EPRI 1988c, Geller 1988, Lytle IV 1989, Miller et al. 1989, NAHB 1986, Piette et al. 1988, Sweitzer et al. 1986, Usibelli et al. 1985, Verderber and Rubinstein 1984). Brambley et al (1988a) believe that 30-40 percent savings can be achieved using measures with less than three year simple paybacks. The Energy Edge Buildings should reduce energy consumption by more than 30 percent compared to standards that are more stringent in some requirements than 90A-1980, at a CCE of 2.3¢/kWh. Northeast Utilities was able to achieve greater than 30 percent energy savings in their analysis *without* *increasing first cost of the building*, so 30 percent cost savings at three year payback appears to be reasonable.[19]

This number will be used in the financial analysis of market failures and corrective incentive policies in later chapters. It need not be an exact representation of all efficiency options available to the new building designer, only a plausible one. It crudely characterizes the aggregate result of market failures, hidden costs, and regulatory distortions on decision processes affecting energy efficiency of new offices.

CONCLUSIONS

This Chapter explored the technical evidence for the existence of untapped reserves of conserved energy in new office buildings and the market failures these reserves imply. It examined the conditions under which such technical evidence can be used to infer market failures, and analyzed previous estimates of the potential for cost-effective efficiency impovements in new buildings. Finally, it derived an estimate that 30 percent of energy costs in new offices could be saved by additional investments with simple payback times averaging three years. This estimate will be used in Chapters IV and VI in financial analyses of specific market failures and of corrective incentive policies.

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[19] In fact, the choice of an average three year payback is more restrictive than Brambley et al's estimate, which implies an average payback time of less than three years.

Table III.1. Characteristics of PNL Building Prototypes

Attribute	*Small Office*	*Medium Office*	*Large Office*
Floor Area (Gross sf)	2,250*	48,644	797,124
# of Floors	1	3	36
Floor to Ceiling Height (ft)	10	12	13.5
Construction	Wood frame with brick veneer	Steel super-structure, 4" lightweight concrete skin	Steel frame, 4" lightweight concrete skin
Glazing (% of Wall Area)			
North	45%	27%	25%**
South	60%	27%	25%**
East	5%	27%	25%**
West	15%	32%	25%**
HVAC System	Same for core and perimeter zones	Same for core and perimeter zones	Separate systems for core and perimeter zones
Cooling	electric packaged rooftop VAV system (direct expansion)	Single dual-duct VAV. Chilled water supplied by reciprocating chiller with air cooled condensor.	VAV with chilled and heated water coils *Summer*: two hermetic centri-fugal chillers plus a cooling tower *Winter*: double-bundled chiller + one centrifugal chiller
Heating	baseboards supplied by gas hot water generator	Hot water supplied from gas boiler	Heat recovery from double-bundled chiller + 2 hot water generators

*The small office included a 250 Gsf vault that was not included in the analysis. Building is 50 ft by 50 ft.

**The large office is a hexagon with glazing on roughly 25% of each wall (i.e., total window to wall ratio equals 0.25).

The PNL analysis included other HVAC systems as well. I choose these as illustrative.

Source: Crawley--Personal Communications (1989a, 1989b)

Table III.2. Energy Consumption for Different Building Prototypes Based on PNL Analysis

Small Office *Efficiency Level*	*Total Site Electricity* *kBtus/Gsf/yr*	*Gas* *kBtus/Gsf/yr*	*Total Site Energy* *kBtus/Gsf/yr*
90-1975	63.14	68.90	132.04
90A-1980	60.78	69.25	130.03
90.1-1989	51.83	69.51	121.33
Fed. Std 1993	45.36	67.32	112.68
Fed Std + Daylighting	40.68	67.83	108.51
	Index	*Index*	*Index*
90-1975	1.04	0.99	1.02
90A-1980	1.00	1.00	1.00
90.1-1989	0.85	1.00	0.93
Fed. Std 1993	0.75	0.97	0.87
Fed Std + Daylighting	0.67	0.98	0.83
Medium Office *Efficiency Level*	*Total Site Electricity* *kBtus/Gsf/yr*	*Gas* *kBtus/Gsf/yr*	*Total Site Energy* *kBtus/Gsf/yr*
90-1975	70.49	3.76	74.25
90A-1980	63.54	4.38	67.92
90.1-1989	54.58	5.16	59.74
Fed. Std 1993	48.59	6.21	54.80
Fed Std + Daylighting	44.49	6.47	50.97
	Index	*Index*	*Index*
90-1975	1.11	0.86	1.09
90A-1980	1.00	1.00	1.00
90.1-1989	0.86	1.18	0.88
Fed. Std 1993	0.76	1.42	0.81
Fed Std + Daylighting	0.70	1.48	0.75
Large Office *Efficiency Level*	*Total Site Electricity* *kBtus/Gsf/yr*	*Gas* *kBtus/Gsf/yr*	*Total Site Energy* *kBtus/Gsf/yr*
90-1975	52.58	8.64	61.22
90A-1980	51.16	9.03	60.20
90.1-1989	43.63	12.13	55.76
Fed. Std 1993	38.48	11.31	49.79
Fed Std + Daylighting	35.23	11.79	47.02
	Index	*Index*	*Index*
90-1975	1.03	0.96	1.02
90A-1980	1.00	1.00	1.00
90.1-1989	0.85	1.34	0.93
Fed. Std 1993	0.75	1.25	0.83
Fed Std + Daylighting	0.69	1.31	0.78

Note: Large office daylighting analysis was not available, so percentage changes in energy use from medium office analysis were applied to the large office consumption numbers. Daylighting savings are those for ordinary buildings to which daylighting has been applied, and do not include potential savings from designing the building structure to take maximum advantage of daylight. Gsf=gross sq. foot. Weather is that of Washington, DC. Increase in gas use for medium and large offices is due to increasing space heating needs. Internal gains, which dominate shell effects in such buildings, are reduced when more efficient lighting is used. Gas use in the small building did not increase because the shell is more important for this building, and the shell standard is tighter. Source: Crawley (1989a, 1989b).

Table III.3. Northeast Utilities Redesign of Medium Office Building

	Capital Cost Thousand $	Site Electricity kBtus/sf	Gas kBtus/sf	Site Energy kBtus/sf
Base Case	*3860*	*54.08*	*5.02*	*59.10*
Reduced glazing area	3825	53.23	3.84	57.06
Beige color brick	3860	54.02	5.02	59.04
High efficiency VAV*	3878	51.07	5.02	56.08
High efficiency lighting	3850	39.64	8.16	47.79
Daylighting controls	3830	49.99	4.21	54.20
Improved Base Case	*3860*	*34.52*	*5.88*	*40.40*
	Index	Index	Index	Index
Base Case	*1.00*	*1.00*	*1.00*	*1.00*
Reduced glazing area	0.99	0.98	0.76	0.97
Beige color brick	1.00	1.00	1.00	1.00
High efficiency VAV	1.00	0.94	1.00	0.95
High efficiency lighting	1.00	0.73	1.63	0.81
Daylighting controls	0.99	0.92	0.84	0.92
Improved Base Case	*1.00*	*0.64*	*1.17*	*0.68*

*VAV = Variable Air Volume System. Base case includes a relatively inefficient VAV system.

Floor Area = 60 thousand square feet (k sf).

Savings by measure are not additive.

Source: Wajcs and Kroner (1988).

Table III.4. Federal Standards (Non-Residential Buildings): Mandated Minimum Acceptable Full-Load Motor Efficiency for Single-Speed Polyphase Motors

Horsepower	Minimum Efficiency
1-4	78.5
5-9	84.0
10-19	85.5
20-49	88.5
50-99	91.2
100-124	91.7
125 and above	92.4

Source : US DOE 1989b.

Table III.5. Costs and Energy Savings from Efficient Electric Motors in Commercial Buildings

Motor Size HP	*Avg Size HP*	*Assumed Usage Hours/year*	*Std Motor Efficiency*	*Efficient Motor Efficiency*
<1	0.28	400	70.0%	74.5%
1-5	1.34	921	80.5%	85.5%
5.1-20	8.61	2050	85.0%	90.0%
21-50	25.9	3139	89.0%	92.5%
51-125	80.6	3656	91.0%	94.3%
>125	195	3913	93.3%	95.5%

Motor Size HP	*Avg Size HP*	*Std Motor Capital Cost 1989 $*	*Efficient Motor Capital Cost 1989 $*	*Energy Savings kWh/yr*	*60% Load CCE $/kWh*
<1	0.28	46	57	7	0.272
1-5	1.34	188	222	67	0.088
5.1-20	8.61	746	905	861	0.032
21-50	25.9	1708	1964	2578	0.017
51-125	80.6	5123	5806	8454	0.013
>125	195	11953	12978	14055	0.013

CCE = Cost of Conserved Energy,
Discount rate = 6% real, lifetime = 15 years.
Energy savings = HP * 0.746 * Op Hours * 60% *(1/EFFstd - 1/EFFeff)

Operating hours based on DOE-2 simulations for commercial buildings in NY State, with the additional assumption that the motor operates at 60% of full load on average. The formula for energy savings approximates the true effect, which is more complicated because the motor efficiency varies as a function of full or part-load operation.

Source for efficiency, capital costs, average motor size, and operating hours: Miller et al. (1989).

CHAPTER IV: TYPOLOGY OF MARKET FAILURES AND REGULATORY DISTORTIONS

Neoclassical economics shows that a perfectly functioning market will yield an economically efficient outcome in equilibrium. This conclusion is based on the following assumptions about perfect markets (after Harris and Carmen (1983)):

1) *Perfect Competition* : there should be many buyers and sellers, so that no one actor has bargaining power or influence over prices. These buyers and sellers must act without collusion.

2) *Perfect Information* : all characteristics of the objects of exchange (and substitutes for them) must be known to both buyers and sellers.

3) *Absence of Side Effects* : all costs associated with the exchange and the object of exchange must be borne solely by the participants in the transaction.

4) *Divisibility* : The object of exchange must be infinitely divisible, or at least divisible to such small sizes that each transaction is small compared to the total amount of goods exchanged.

5) *Excludability* : those involved in the exchange can prevent those not involved in the exchange from enjoying the benefits from it.

6) *Zero Transactions Costs* : exchange must be instantaneous and costless.

7) *Zero Entry Barriers* : producers must be free to enter and exit the market.

8) *Economic Rationality* : consumers maximize utility, producers maximize profits. Economic actors are able to collect and process all relevant information and make decisions that maximize their objective functions.

9) *Fair Distribution of Wealth and Income* : "Each individual has wealth and income corresponding to his production of economic goods and services" (Harris and Carman 1983)

No real-world markets have all these attributes. The task of this chapter is to determine how closely the market for energy efficiency in new office buildings approximates the economist's requirements for a perfect market, and whether market failures in this sector could cause new offices to use significantly more energy than would be optimal. If market failures or regulatory distortions do exist in this sector (and the analysis in Chapters I and III suggests that they do) a comprehensive framework of such failures can facilitate and organize analysis of the reasons for divergence from economic optimality. While general analyses of this type have been conducted for the energy sector as a whole (Blumstein et al. 1980, Fisher and Rothkopf 1988), I know of no similar analyses for a segment of the marketplace as narrow as new offices.

This Chapter first characterizes the design, construction, and leasing process, then presents a comprehensive market failure framework applied to new offices. For each possible market failure or regulatory distortion, the Chapter analyzes its applicability and potential importance. In most cases where a failure or distortion defies quantification, it is analyzed qualitatively. The most important market failures involve information costs, asymmetric information, lack of information, bounded rationality, risk aversion, externalities, split incentives, public goods, and cash-flow constraints. The most important regulatory distortions involve utility regulation and building codes.

THE DESIGN, CONSTRUCTION, AND LEASING PROCESS

General Characterization

Figure IV.1 illustrates schematically the actors involved in constructing and using a new office building. The number of possible combinations reflects the heterogeneity of the office building sector, which makes such careful specification essential, though difficult. Short-term leases (3 years or less) are not common in new office buildings (especially large offices), which usually house more financially secure companies than existing buildings. Pyhrr and Cooper (1982, p. 568) note that "...a form of filtering takes place in which a[n office] building accomodates lower paying tenants as it ages."

This filtering tendency has become even more pronounced in recent years as rapid improvements in computer and building technology have given new buildings a significant advantage in services provided (BD&C 1989d, BD&C 1989e, McCain 1989). This change in technology has also contributed to an increase in the equilibrium office vacancy rate (BD&C 1989f). Even though high vacancy rates and supply of existing building space have led to decreasing rents, the demand for and construction of new office space has continued, in part because of the perceived superiority of these buildings over their older counterparts.

Table IV.1 shows that more than 2/3 of leased space in existing *large* offices in the Bonneville Power Administration's service territory is associated with leases longer than three years. About half the leased space in *small* offices is associated with short-term leases and half with long-term leases. Ten to forty percent of commercial floor space is owner-occupied in this region.

Competitive office space is that available for lease by the general public, which comprises all those buildings with tenants in Figure IV.1. As shown in **Table IV.2**, about half of the existing office buildings in the U.S. and 63% of the floor space is located in buildings that are non-owner occupied or that house multiple establishments. Competitive space therefore occupies roughly half of total office space, while owner-occupied space comprises the other half. It is unclear whether new buildings differ from existing buildings in this regard.

There are three basic types of leases in commercial buildings: net, gross, and fixed-base (Pyhrr and Cooper 1982). A *net lease* is one in which the tenant pays for utilities and other operating costs, in addition to the monthly rent. A *gross lease* is one in which the tenant pays the monthly rent, which includes all expenses. A *fixed-base lease* is like a gross lease with an escalation clause. The tenant is not responsible for operating costs except if they rise above some fixed dollar level. Unfortunately, there are no statistics on the prevalence of different lease types.

Design and Construction

Figure IV.2 shows a highly stylized representation of the steps and the actors involved in the design and construction process. EPRI (1988a, p. 3-1) points out that "decisions involving the specification and purchase of equipment in commercial firms do not lend themselves to simple characterizations." Figure IV.2 is adequate for this analysis, but no linear characterization can capture the richness and complexity of the interactions inherent to the design process.

Clark et al. (1982) analyze six major classes of participants in this industry: Owners, Occupants, Developers, Builders, Architects/Designers, and Construction Finance Organizations. To this list should be added so-called "take-out lenders" (who finance the buildings after they are constructed), brokers (who arrange the sale of buildings), appraisers (who assess the value of a given building for both sale and tax purposes), equipment suppliers (who manufacture lighting, HVAC, and other energy using equipment), and local government officials (who regulate zoning and other aspects of construction, design, and operation).

Many of the entities involved in this process are groups of individuals whose interactions vary depending on the situation (Twomey 1989), which further complicates analysis. In addition, designing an efficient building is a complicated and interdisciplinary process that requires communication between disciplines that do not speak the same language and may not have the same priorities (Brambley et al. 1988b).

Figure IV.2 shows that heating, ventilation and air conditioning system (HVAC) design is completed early in the construction process, while lighting design is usually completed after buildings are subdivided and leased (Goldstein and Watson 1988, p.3.82). Many medium and large office buildings are forced to run air conditioning all year round, because their space conditioning needs are dominated by internal heat gains from lights and other equipment (see Chapter III). More efficient lighting allows HVAC system capacity and capital costs to be reduced. HVAC design cannot be optimized without information about the lighting system, so substantial cost reductions are sacrificed. The developer thus assumes that the cost reductions available from integration of lighting and HVAC design are less important than the flexibility gained by designing the lighting systems to meet tenant's perceived desires.

A similar timing mismatch exists between the designers of the HVAC system and the future tenant's purchase of personal computers, printers, copiers, and other office equipment. To size the HVAC system, the designer must use some rule of thumb to estimate the level of electric consumption and associated heat generated by these devices. Often she will oversize the system to insure that the system is not overburdened by unforeseen load.

Relevant Transactions

Figures IV.1 and IV.2 are helpful in pinpointing which exchanges are relevant to analysis of market failures:

1) the developer obtaining construction financing

2) the developer purchasing design and construction services (or supplying them "in-house", in so-called "design/build" arrangements (Twomey 1989))

3) the architect or engineer specifying efficient HVAC and lighting technology

4) the developer/builder constructing the building

5) the appraiser assessing the value of the new building

6) the developer selling the building to the new owner

7) the owner obtaining "take-out" financing after construction.

8) the owner leasing the building to the first tenants

9) the tenants' or landlord's purchase of electricity

The developer's *perception* of the nature of each of these exchanges affects her receptiveness to changes in these exchanges. For instance, if the developer thinks energy efficiency won't be important to the new owner or tenants, this perception will affect the developer's choice of building equipment and design. The perceptions of developers who "build-to-hold" will be different from those who "build-to-sell", since the build-to-hold developer knows her own requirements exactly. Because of the long-term nature of the construction process, decisions affecting future exchanges related to energy efficiency are necessarily based on incomplete information.

TYPES OF MARKET FAILURES

Harris and Carmen (1983) developed a framework to analyze market failures that I have adapted for use in the present analysis. **Table IV.3** shows this framework. I have omitted from consideration the issues of income maldistribution, internalities, demerit goods, economic rents, excessive competition, and monopolistic competition as not germane to the analysis. Some categories (risk aversion, split incentives, regulatory distortions, and cash flow constraints) have been added. The examples used in Harris's original table have been changed to correspond to those from the new office building sector.

This taxonomy enumerates a name for each type of failure, the nature of the failure, and specific examples of such failures related to the efficiency of new office buildings. The entries in the table are necessarily brief--more detailed explanations follow below.

Imperfect Competition

Natural monopoly

Natural monopoly is a market failure in the electric utility sector. Until comparatively recently, all aspects of the electric power industry were considered natural monopolies. Now many analysts believe that generation is capable of at least limited deregulation, because of technological progress in alternative generation technology and declining returns to scale in conventional generation units. Transmission and distribution remain natural monopolies without question (Kahn 1988, Kahn 1990).

The principle consequences of these characteristics of the power sector for new office building efficiency are described under the section titled Regulatory Distortions--Utility Bias and Average Cost Pricing. These effects are more the result of the way this industry is regulated than the result of natural monopoly itself.

There are no aspects of the real estate industry that would lead to natural monopoly in this sector.

Market Power (Monopoly and Oligopoly)

If one or a few developers could somehow restrict entry into the market using the political process (see anticompetitive behavior, below), monopoly or oligopoly could conceivably occur in a given region.

Berry (1984) analyzes the concept of monopoly property from the perspective of the real estate appraiser. A monopoly property is one that "through franchise, license, zoning regulation, etc., has the exclusive right to carry on that enterprise". Such properties, because of regulatory decisions, cannot be replaced at any price, and hence represent a challenge to appraisers, whose techniques usually assume that an asset is replaceable.

Berry's definition is quite restrictive, applying to only a small number of cases. However, the more general case of market power related to building location or unique design can be treated as a less extreme example of monopoly property (an "oligopoly property").

Monopolies or oligopolies related to the desirability of a few choice locations could be important in particular circumstances. The developer of a building or the owner of a large amount of land in a particularly favorable location might be able to exercise some degree of market power. Pyhrr and Cooper (1982, p. 568) comment that "...locational obsolescence is an important feature of office building investment. A superior location offering favorable public exposure and proximity to clients maximizes rent-producing capacity." IREM (1981) states "a well-located building can command the highest rents in the market area, even though it may be inefficiently designed and poorly maintained".

Many buildings offer unique features. Gregerson (1989) quotes a developer who states that "Signature buildings with an institutional, headquarters-like feel to them can get $2 to $3 [per square foot per year] over the average [rent] in just about any market. We wouldn't go to the trouble to build them if they didn't." These unique buildings command some market power simply because of their uniqueness.

The market power stemming from a unique location or design may be reflected in bargaining leverage in negotiations with purchasers of the property.[1] Such power could make a developer complacent about the other attributes (e.g., energy efficiency) of the property, since a satisfactory rate of return is likely even for a project meeting the lowest expected standards of efficiency and other attributes. In other words, market power, combined with satisficing behavior (see below), could lead to less efficient new office buildings in particular sites. If it exists, this market failure is likely to be strongly dependent on particular circumstances.

On the other hand, market power may allow a developer to coerce "tie-in" sales, pricing added efficiency measures far above their value, in an attempt to reap a windfall. Without further data collection, it is impossible to know whether market power causes over- or underinvestment in efficiency.

Anti-Competitive Conduct

While not generally a problem in the real estate sector, there have been instances where businesses manipulated local regulatory authorities to their own advantage and to the detriment of their competitors. It is unclear how this failure would affect the efficiency of new office buildings. If it inhibited the entry of new firms with more efficient designs, then it might have a negative effect on efficiency. If these new firms would not build structures of superior energy efficiency, then this failure would have a neutral or possibly

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[1] This argument holds little force if the developer owns and operates the building herself.

positive effect on efficiency. No generalizations are possible in the absence of specific facts.

Information Collection

Information Costs

Information costs include those (1) of collecting information about efficiency measures or the credibility and reliability of new suppliers and subcontractors, (2) of developing expertise, (3) of calculating the costs and benefits of different efficiency levels, (4) of deciding how to alter established design and construction procedures, (5) of demonstrating in a credible way that a new building will reduce prospective tenants' or purchaser's energy costs, (6) of disseminating information about efficiency technologies, and (7) of the architect/engineer incorporating new information about efficiency in her day-to-day work. These failures are among the most important and pervasive affecting energy efficiency. While some of these costs are unavoidable costs of improving efficiency, others can be reduced but not eliminated through centralized information collection and dispersal.

Table IV.4 attributes these information costs to the participants in the design, construction, and leasing process most directly affected by them. This Table reveals that most participants are directly affected by information costs associated with credibly determining the energy consumption of new buildings. It also shows that architects/designers are affected by almost all the information costs considered here. Developers are the participants next most affected by information costs.

In general, the marketplace will produce too little information, because this product is easily replicated (i.e., it is hard for the producing firm to prevent resale of information). The following section addresses each of the information costs in turn:

1) Since information can be replicated at low marginal cost, there are economies of scale if one utility or agency searches for and compiles information on efficiency measures or the qualifications of contractors. This search can be more comprehensive and less costly (per unit of information) than searches undertaken by any single smaller firm (Plunkett and Chernick 1988).

2) Developing expertise is analyzed under public goods (below), since it involves information acquisition unrelated to specific transactions.

3) Calculating conservation's benefits in particular circumstances involves costs such as the cost of computer time and the cost of labor. Once the requisite expertise is obtained, the required calculations are not exceptionally difficult. The number of options analyzed affects these costs, however.

There is evidence that appraisers and other building industry professionals are using computers (particularly microcomputers) much more extensively than in the early 1980s (ACHRN 1989a, Diskin et al. 1988). As sophisticated computer hardware and software become more prevalent (ACHRN 1989a), costs associated with calculating the benefits of efficiency should diminish in importance.

4) Deciding *how* to alter established design and construction procedures (e.g., to integrate lighting and HVAC design) involves analyzing these procedures, comparing them to other procedures used elsewhere, and choosing new procedures

to replicate. Each step in this decision process involves costs (both direct and indirect).

These decisions precede *actually changing* these procedures, which also entails costs (though they cannot be categorized as information costs). Such changes can be inhibited by institutional inertia and transaction costs.

5) The cost of determining the efficiency of a new building is the cost of an *audit* and *energy analysis.*

Audit costs depend strongly on particular circumstances: for many new office buildings, no more than cursory audits will be necessary, since simulations can be based on design specifications and architectural plans. Where buildings are mistakenly built differently than the plans indicate, or documentation is inadequate, walk-through audits will be necessary to verify assumptions about equipment characteristics and building parameters. In the latter case, the cost of the audit depends on the complexity of the HVAC system, the size of the building, and the number of areas of the building with different characteristics. Larger buildings will in general have better documentation than small buildings, but may be characterized by larger variation in the lighting and computer equipment used by different tenants. Rough calculations of audit costs result in numbers of \$0.032/sf for 2.5k square feet (sf) buildings, to \$0.008/sf for 50k sf buildings, to \$0.001/sf for 800k sf buildings.[2] These costs represent 0.03%, 0.007%, and 0.0007% of the total up-front cost of these buildings (based on the costs in Table VI.2 in Chapter VI).

Energy Analyses: In Northern California, where energy efficiency standards have generated demand for such services, detailed computer analyses of energy use in new commercial buildings range in cost from about \$0.16/sf for 2.5k square feet (sf) buildings, to \$0.01/sf for 50k sf buildings, to \$0.002/sf for 800k sf buildings.[3] These costs are 0.16%, 0.009%, and 0.00015% of building first cost (based on the costs in Table VI.2 in Chapter VI). This is a cost to establish compliance with the mandatory California building efficiency standards. An energy analysis of several different design strategies would be more expensive, perhaps costing two to four times as much, depending on complexity. If conducted as a routine part of the design process, the cost for such analysis could be lower.

In regions where a large number of energy consultants do not exist, the cost for a customized audit and energy analysis may be much higher. Some national equipment suppliers (e.g., Trane) are starting to use sophisticated energy analysis programs as marketing tools to demonstrate the economic benefits of more efficient

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[2] These costs are derived assuming that it takes 2 hours to examine and interpret an audit of a 2.5k sf building, 10 hours for a 50 k sf building, and 20 hours for a 800 k sf building, at an hourly cost of \$40/hour.

[3] These calculations are based on data from Martin Dodd of Mike Gabel Associates in Berkeley, CA. He quoted costs of \$100/zone for DOE2 simulations of commercial buildings, with a \$400 minimum charge. A zone is a group of sections of the building with similar thermal characteristics. The estimates per sf assume that the 2.5k sf building pays the minimum, that the 50k sf building has 5 zones (total cost \$500) and that the 800k sf has 15 zones. The number of zones is highly variable and is largely arbitrary, so these numbers should be taken as rough approximations only.

> products (Smithart 1989), which should make the costs drop in regions where local energy consultants are not commonly found.
>
> The size of these information costs is not well known, and has never been compiled in systematic form. This section's rough quantifications indicate that building size will be an important determinant of the cost per square foot of such analyses. Small buildings are likely to face the highest costs per square foot in obtaining such information, though these costs are tiny as a percentage of total building costs.
>
> 6) The cost of disseminating information is a natural cost of doing business for all companies. It includes the cost of advertising and the cost of establishing relationships between suppliers and customers of efficient equipment.
>
> 7) Time for professionals to digest and internalize new information can be substantial. This internalization process may involve admitting that previous work was in error, which can make the recipient of information less eager to seek it out or absorb it in the future (Burnette 1979a, p.8). Education and training (see *Public Goods* below) can substantially reduce the time for professionals to internalize new information.
>
> If the information is not in a form that the professional is used to digesting, it will not be absorbed. Architects, who are accustomed to working conceptually and visually, are not in general comfortable with numbers. Most energy analysis tools have been designed by engineers, for engineers. Recently, some have begun to address this issue by incorporating energy analysis software into sophisticated computer-aided design tools (Brambley et al. 1988b, Schuman 1989).

The cost of efficiency information relative to the costs of gathering other information can be an important factor. The advantages of a building's distinctive design or location are usually obvious and are assessed largely using subjective criteria. Understanding energy efficiency information, on the other hand, requires analysis of technical details about mechanical systems that are often invisible (Stern and Aronson 1984).

Rapid change in efficiency technologies makes every single information cost barrier more severe. NEEPC (1987) interviewed landlords and tenants in the Boston area to assess market failures affecting efficiency in the commercial sector:

> The first theme that emerged in our interviews was confusion. The pace of development in efficient energy-using and energy-conserving technologies has been accelerating in the past few years, and the people we spoke with evinced a certain bewilderment at the array of choices now being touted by vendors and the trade press.

This rapidity of change places greater burdens on costs associated with information collection, professional education, and information dissemination than would a less rapidly evolving industry. In addition, filtering information to distinguish differences and identify useful or attractive designs becomes more costly as the amount of information available increases.

Trust in the source of information also affects information costs and associated risks. The existence of a credible source of information that is perceived as unbiased will reduce information and risk costs (e.g., Consumer Reports). Conversely, the lack of such a source implies higher risk and information costs. Consulting firms meet this need in some areas, but these companies are not large enough to fully capture economies of scale, nor are they always perceived as being unbiased.

Asymmetric Information

The developer knows more about the building than do prospective tenants or building purchasers. Without some credible, effective way of estimating new building energy use before occupancy (or sale), the tenants who will pay the utility bill (or the purchasers) are at a disadvantage in negotiations.[4] They must take the developer's word that the building is more efficient, or they must hire someone they trust to analyze the building's efficiency. In the first case there is added risk, in the second, added cost.

Currently existing institutions and professions are often not capable enough to correct for asymmetric information by themselves. For instance, appraisers, upon whom banks and purchasers depend to assess the value of buildings, must be conversant in many different aspects of real estate (Pearson 1989). It is unrealistic to expect that they be expert enough in energy matters to assess operating cost benefits from specific technologies or a set of such technologies. They would be able to use such information if it were supplied, but it is probably beyond their capabilities to estimate it. Even if they could estimate energy costs on a case-by-case basis, lack of uniformity in assumptions would limit the usefulness of such estimates.

Misinformation

Some developers and tenants believe that there simply isn't much scope for improving energy efficiency (EPRI 1987b, p. C-8). This belief influences what these actors look for when renting office space. Architects and engineers may be misinformed about efficiency's effectiveness, based on a small number of anecdotes about unsuccessful installations of such devices. It is unclear just how pervasive these beliefs may be. However, they could have an effect in certain cases.

Lack of Information

Lack of information is one of the most important barriers, and it shows up in many forms (EPRI 1987b, p. C-11). It is strongly linked to information costs, which inhibit the search for information. Designers and builders often lack current, credible information on the latest and most cost-effective conservation technology. They may not trust energy conservation companies to deliver such information, because of a perceived conflict of interest. Without the help of established, reputable energy consultants (who do not exist in many areas of the country), building purchasers have no credible way to compare the operating cost differences between two new buildings. Purchasers are often unable to "comparison shop" or to assess the chances of recovering their additional initial investment (due to efficiency) upon resale of the building.

EPRI (1987b, p. C-2) found that larger businesses are "more aware of potential [efficiency] measures than smaller ones". Larger utility customers are also more likely to have installed a given efficency measure. However, "awareness of more complicated conservation measures is low for both large and small companies".

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[4] Asymmetric information is not a problem for tenants if the landlord pays the utility bill.

Economic Non-rationality

There has been considerable debate over how well the assumption of economic rationality describes human decisionmakers (Stern and Aronson 1984). Non-rationality refers to differences between the cognitive processes of real economic actors and the assumptions about "rational economic actors" implicit in economic theory. It is not necessarily the same as irrationality, though this category is subsumed under the rubric of non-rationality. Other forms of non-rationality refer to human beings' limited ability to collect and process information and their use of rules of thumb and satisficing behavior.

Bounded Rationality and Satisficing

Humans have limited or "bounded" rationality, since they can only process limited amounts of information. To compensate for these limits, they often resort to rules of thumb that minimize transactions costs at the expense of optimality (March and Simon 1959). James March and Herbert Simon, writing about the application of the theory of satisficing to organizational behavior, state that "finding the optimal alternative is a radically different problem from finding a satisfactory alternative. An alternative is optimal if:

> (1) there exists a set of criteria that permit all alternatives to be compared, and (2) the alternative in question is preferred, by these criteria, to all other alternatives. An alternative is satisfactory if: (1) there exists a set of criteria that describes minimally satisfactory alternatives, and (2) the alternative in question meets or exceeds all these criteria. Most human decision-making, whether individual or organizational, is concerned with the discovery and selection of satisfactory alternatives; only in exceptional cases is it concerned with the discovery and selection of optimal alternatives (March and Simon 1959).

Procedures, routines, and rules of thumb lead to satisfactory solutions, since they screen out alternatives before detailed analysis begins. They will be modified only given sufficient stimulus. *Satisficing* techniques can approximate the optimal outcome when change is slow, but during dynamic periods, rules of thumb may not keep pace, and large disparities can develop between optimality and decisions actually made. Even during quiet periods, rules of thumb may diverge substantially from optimality.

As noted above under *Information Costs*, rapid change has been the rule and not the exception for energy efficency technologies, suggesting that existing rules of thumb are likely to be out of date. For instance, in many sectors of the U.S. economy, the two-to-three year payback rule of thumb is commonly used to assess efficiency investments (Barker et al. 1986, Cavanagh 1987, EPRI 1988b, NEEPC 1987, Peters and Gustafson 1986, Schon et al. 1987) This rule of thumb reduces the time spent analyzing energy issues, and expresses an implicit belief that profits are more likely to be improved by increasing revenues or by cutting costs elsewhere. "Energy must compete for attention with other problems facing the organization and other solutions being offered. Thus, the amount of attention devoted to energy efficiency depends on the number and salience of other, competing issues that demand attention and time." (Stern and Aronson 1984, p.113). The *time* it takes to process all information is an information cost (described above), while humans' inability to *analyze* and *understand* every issue is an indication of bounded rationality.

Wofford and Gitman (1978) state that "many investors believe that the payback period is a good measure of the risk exposure or the liquidity of the proposed investment...the shorter the payback period, the less risky the investment". Short payback periods may therefore be an expression of both satisficing behavior and risk aversion (see below). If only one of the many participants in the design, construction, and leasing process uses short payback times, it can inhibit the other participants from choosing more efficient technology. For instance, if tenants, due to risk aversion or cash flow constraints, use two year simple payback times, landlords who know their market will conclude that the buildings they purchase need not be exceptionally efficient.

"Minimize first costs to maximize profits" is a rule of thumb to which developers continue to adhere (Comerio 1989). It developed before the advent of inexpensive computing power, and has persisted. John Burgee, one of the architects who designed Pennzoil Place in Houston in the mid 1970s (which was a distinctive, "signature" building surrounded by undistinguished glass boxes), learned that "you can make a better profit with better architecture. *The thinking up until that time was that with a spec*[5] *office building, you enclosed the most amount of space the cheapest way possible to make the most amount of money...*" (Gregerson 1989, Italics added). Feinbaum (1981) surveyed architects about the perceived importance of first costs and operating costs savings to their clients. He found that 95% of architects surveyed believed that speculative clients valued first costs more than operating cost savings, while 55-62% of institutional, government, and owner occupant clients were perceived as valuing first costs more than operating cost savings. "Minimize first costs to maximize profits" is a rule of thumb that is probably diminishing in importance as increasingly sophisticated financial analyses become easier to create.

Satisficing behavior could also take the form of tenants demanding efficiency only when energy costs exceed some threshold fraction of total costs (say 1-5 percent). For the prospective tenant, energy costs may be miniscule compared to total business costs. Say the amount of floor area per person in the office is 200-300 sf, and the average salary is $30-40k per year. The cost of salaries is thus $100-200/sf/yr, compared to $1.50-2.00/sf/year for energy costs in typical new office buildings. Savings in energy costs of 50% will thus change total costs by much less than 1%. Management changes that increase productivity by a few percent, or slight reductions in labor expenses, will swamp the potential effect of state-of-the-art efficiency improvements (Lovins and Sardinsky 1988, Smith 1989).

If projected energy costs in the developer's proforma look reasonable or satisfactory (within some broad range) then they may not be subjected to further scrutiny by the lender. The Bank of America bases its lending decisions first and foremost on the credibility and experience of the developer. The second level of analysis is to examine the operating costs assumed in the proforma to determine "if they conform to industry norms". Small variations in operating costs (say less than 10%) will be ignored. Large differences between industry norms and the proforma assumptions will lead to closer scrutiny by the lender (Briggs and America 1989).

Commercial building owners, developers, or tenants may not be profit maximizers. Instead, they may seek satisfactory profits above some minimum hurdle rate.

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[5] A Spec(ulative) office building is one designed for sale to an as yet undetermined purchaser upon or soon after completion of the building.

Other Deviations from Economic Rationality

Interviews with participants in the real estate industry often find a preference for revenue-enhancing measures over cost-reduction measures. EPRI (1988b) cites Bob Butler, former editor of Energy User News, who states:

> cost-cutting is a defensive tactic, a tactic, indeed, that hints of weakness. I believe a major reason upper management is attracted to cogeneration is that it effectively establishes in their mind the connection between an energy project and the more fundamental concerns of production in the industrial sector, or facility operation in the commercial sector. Energy stops being simply a parochial, defensive, cost-cutting approach, and becomes linked to the aggressive, competitive, production and marketing activities that are nearest and dearest to the management heart.

While this sort of assertion is difficult to test, it sounds plausible, and I doubt many executives would disagree with it. If this statement describes the attitudes of some executives in the real estate industry, it is an indication that they are not perfectly rational economic actors.

Risk Aversion

Convincing builders and developers to replace their tried and true technologies with new, more efficient devices is difficult in part because these actors may be more *risk averse* than society may be. The technology may not work as advertised, fuel or electricity prices may not rise as expected, or the real estate market could become depressed, which might make buyers more wary of increased initial cost. In the aggregate, these risks would average out across the entire society and yield a positive economic return. The risk for individual economic actors may be greater than the aggregate risk, and hence individuals may be reluctant to invest. The societal cost associated with such risk (which will be lower than the risk for an individual firm) is the expected value of costs associated with device failure or price drops, averaged over all buildings with similar devices.

Risk Due to Economic Fluctuations

Supply and demand are unpredictable and there are time lags in adding new capacity. For instance, in the middle stages of a real estate boom, many more office buildings are likely to be started than will be needed to meet all the demand. By the time they are all completed, there will be a glut on the market, and returns may be reduced substantially below expectations or acceptable levels (Bon 1989).

Pyhrr and Cooper note that "both the national and the regional supply of office space has tended to follow a boom-and-bust cycle more dramatic than that of any other real estate sector." (1982, p. 568) Consider **Figure IV.3**, which shows the rate of return on equity for office buildings in the U.S. and Western Europe between 1979 and 1988 (Hylton 1989). The returns over this period ranged from over 25% nominal to about 5% for both regions. This sector exhibits large fluctuations in economic returns over relatively short periods, which implies that the office real estate market is almost never in equilibrium.

It is unclear why these boom and bust cycles should be so severe. To understand and reduce the risk of such economic fluctuations, real estate brokers keep track of permits filed with local governments as well as other data affecting the supply of office space. Brokers know whose leases are coming up for renewal and which tenants are growing out of their current office space, but macro-economic and non-regional variables affecting demand are more difficult to predict (DelCasino 1988). O'Conner (1987) attributes the vast overbuilding in the 1980s to an influx of money from thrifts and banks that has continued even though the office market is glutted. Deregulation may have allowed liberalization of loan policies at these institutions. The superiority of new buildings over existing ones may also have played a role.

High risk can lead rational people to discount the future and be proportionately more sensitive to initial costs, which are certain and are not discounted. Market instability increases the risk of investing in new office buildings that will be sold to an as yet undetermined purchaser. Buildings that will be owned by the developer or that are being built for particular tenants will be less risky if their operating costs are lower, regardless of the state of economic cycles. Market instability may contribute to risk aversion, and may make developers reluctant to increase the up-front cost of new buildings in certain cases.

Risk of Delay

Adopting a new conservation technology and changing suppliers entails risk of delay in the construction schedule. The probability of such delay is highly variable and uncertain, but the consequences are well known and substantial. This is the textbook description of a situation that a risk averse actor will seek to avoid. This problem is connected to the credibility of various information sources, which can be established by utility or government certification of products and suppliers.

Risk of Litigation

A related risk of equipment failure is litigation (Clark 1986, Gamble II 1987, Streeter 1988). Burnette (1979a, p.5) points out that "the legal responsibility under license rests on the individual professional...his judgement need not be infallible, just reasonable within the norms established by the judgements and practices of other qualified professionals". This responsibility leads to risk aversion: "Unless their client clearly indicate preferences for innovative systems, architects and engineers are likely to specify equipment known to be reliable and functional. Recent litigation against A/Es for equipment performance failures is causing the professions to become increasingly defensive and cautious in specifying buildings and equipment" (EPRI 1988a, p. 3-7). Burnette (1979a, p.6) also notes that the rate of filing liability claims against insured architects more than doubled from 1960 to 1976, and "tripled in severity". Liability insurance costs have skyrocketed to reflect these claims (Gamble II 1987).

Contractors are legally responsible for following design specifications exactly (ACHRN 1989b): "a contractor has performed adequately if he has followed the specifications, even if they do not produce the desired result". Law thus restricts the contractor's responsibility, which may make innovation less likely. It also makes the legal responsibilities associated with creating specifications more stringent.

In some cases, if the architect/engineer (A/E) knows about (or should have discovered through normal inspections) a violation of specifications by the contractor, but does nothing about it, she can be held liable by the developer who hired the A/E to supervise construction (Lunch 1989). Innovating with an untried efficiency technology will require more inspections of contractor work by the A/E and will take away from inspections of other building components. The fixed fee of the A/E depends on completing the job. Innovation will probably not change the fee, but it will increase the risk of liability and the time spent inspecting contractor work.

Punishing architects and engineers for unsatisfactory performance of devices will encourage installation of technologies that are known to yield satisfactory performance with high reliability. Such punishment stifles innovation, institutionalizes satisficing, and promotes risk aversion.

Risk and Tenant Productivity

The substantial value of productivity compared to energy savings (see Satisficing, above) affects perceived risks and may result in the use of short payback times. If using new technologies risks even minor occupant discomfort, these devices will not be cost effective from the owner's perspective. Equipment failure that reduces productivity by 1% in a year will swamp the energy savings and may result in the loss of tenants.

A 1988 survey by the Building Owner's and Manager's Association (BOMA), as cited in Smithart (1989), discovered that "if a tenant experiences interruption of any basic service--electricity, telephone, or HVAC--three times in a 12 month period, there's a 56% probability the tenant will vacate at lease end". The same survey (BD&C 1989a), cited in Smith (1989), found that tenants who were affected by malfunctioning HVAC systems "predicted an 18% productivity gain if their [thermal discomfort] problems were solved". NEEPC (1987), after surveying landlords and tenants in the Boston area, stated that "landlords in particular, noted that tenants are extremely sensitive to even the smallest alteration in lighting level or quality, or to the appearance of fixtures, and that experiments with new technologies often elicit negative reactions from tenants". This sensitivity may be the result of the importance of labor costs relative to energy, or it may have other causes. In any case, it encourages risk aversion by landlords that will inhibit experimentation with new, more efficient technologies.

Side Effects

Negative Externalities From Power Production

Efficient buildings reduce negative externalities from power production. **Tables IV.5** and **IV.6** show the various environmental insults attributable to use of fossil fuels and the two other most important electricity generation technologies (nuclear and hydroelectric power). This section is concerned only with externalities associated with fuel consumption and operation of *existing* power plants and direct combustion devices, because they are the only ones relevant to an assessment of the size of the market failure currently represented by external costs.

Estimates of the size of currently quantifiable externalities vary between zero and several times the current price of energy, with typical estimates falling between 10% and 60% of the current price of energy (Cavanagh et al. 1982, CEC Staff 1989, Chernick and Caverhill 1989, DeLuchi et al. 1987, Hohmeyer 1988, Koomey 1990a, Marcus 1989, NPPC 1989a, Schilberg et al. 1989). Such quantification is frought with pitfalls (Holdren 1980), which is one reason for the large reported range.

Koomey (1990a) reviews nine different estimates and regulatory determinations relating to external costs associated with the combustion of fossil fuels in new and existing power plants, and for direct combustion. **Table IV.7** shows two estimates for externality costs from existing fossil fuel power plants from that review. One, taken from a report from the electric power industry's research organization (EPRI), is probably an absolute lower bound to external costs from existing fossil fuel-fired power plants. The other corresponds to current regulatory practice in one of the states (New York) that has addressed externality costs in resource planning in a comprehensive manner.

The Electric Power Research Institute's (EPRI's) Technical Assessment Guide for demand side resources includes dollar per pound estimates for external costs associated with emissions of Nitrogen Oxides (NO_X) and Sulfur Dioxide (SO_2). The NOx costs are based on a National Science Foundation Study. The SO_2 estimates are based on direct damage estimation by the National Academy of Sciences in the middle of the 1970s, for emissions of SO_2 in rural West Virginia or Pennsylvania. Damages from pollution in urban areas are likely to be higher than these estimates. The estimate for SO_2 is almost exactly the same as that implied in Consolidated Edison Company's bidding system (below), but the NO_X estimates are more than a factor of thirteen lower (The Con Ed NO_X estimates are themselves a factor of nine to twelve smaller than estimates for polluted urban areas in California (Koomey 1990a)). EPRI does not include an estimate for external costs associated with carbon dioxide or other emissions.

Consolidated Edison Company's proposed bidding process for new resources explicitly differentiates between externalities in conventional power production, and assigns weights ("points") based on the amount and type of externalities imposed by a project on society (NY PSC 1989). It is designed to incorporate externalities into resource planning for *new* power plants. However, Koomey (1990a) derived the dollars per pound figures *implied* in this bidding system and applied them to existing power plants.

The Consolidated Edison system includes NO_X and SO_2 costs, and a preliminary estimate for external costs associated with global warming, based on mitigation cost (the regulators used 20% of the estimated cost of planting trees). Direct damage estimation for the greenhouse effect is unlikely to be meaningful because predicting damages depends on regional forecasts in which scientists have the least confidence (Krause et al. 1989). The NY PSC estimate for global warming is more than a factor of ten lower than other estimates based on similar methodologies (CEC Staff 1989, Chernick and Caverhill 1989, Koomey 1990b, Schilberg et al. 1989).

Table IV.7 contains net generation by fuel in the United States (US DOE 1988a), and assumes that existing nuclear power plants, hydroelectric dams, and other sources of generation have no externalities associated with their operation and decommissioning. While this assumption is not too egregious for existing hydroelectric dams, it neglects potentially important externalities from nuclear power, including the undetermined cost of nuclear waste disposal, the risk of catastrophic accidents, and the risk of nuclear proliferation (Cavanagh et al. 1982, Hohmeyer 1988, Holdren 1987). Nevertheless, assuming zero externalities for other fuels will be a way to estimate the lower bound for externality costs associated with power production in existing power plants.

Using this assumption, 1988 average heat rates for existing fossil steam plants, and emissions factors derived in Appendix C, reveals that EPRI's estimates for external costs of NO_X and SO_2 yield an average cost of $0.0067/kWh, while the NY PSC's estimates for CO_2, NO_X, and SO_2 result in average external costs of almost $0.012/kWh. These costs are 10% and 18%, respectively, of the 1988 average U.S. electricity price ($0.066/kWh in 1989$) and 9.1% and 16% of the 1988 average U.S. commercial sector electricity price ($0.074/kWh in 1989$).

Direct use of natural gas in the commercial sector emits far fewer pollutants than electricity generation. Estimates of these costs range from 0% to 41% of the price of energy, depending on location and methodology (Koomey 1990a).

For the purposes of later analysis of incentive policies, I choose 15% of energy prices as a reasonable, lower-bound estimate for external costs. Recall that the estimates reviewed above did not include all pollutants, and did not include external costs associated with operation and decommissioning of existing non-fossil electric power plants.

Externality costs of this magnitude are significant. The fact that these costs are external to the purchase of elecricity means that they are unrelated to the high market discount rates analyzed in Chapter I. They represent, however, an additional and important market failure that should be corrected. They should be monetized and incorporated into energy prices and avoided costs. While there will always be uncertainty in these estimates, ignoring them is equivalent to assuming they are unimportant.

Negative Externalities from Energy Efficiency

There are some potential negative externalities associated with energy efficiency, including indirect emissions from production of materials, and increased exposure to radon gas in houses that have reduced air infiltration (it is not strictly an externality, since the people who are presumably benefiting from the more efficient house are also the ones suffering from exposure. It is, however, an often uncounted cost). One careful review of the indirect emissions found that they were much smaller than emissions from avoided fossil fuel combustion (Anderson 1987). Radon exposure is relatively easy to mitigate, though it costs some money to do so.

Positive Externalities from Energy Efficiency

Positive externalities associated with efficient building practices include increased economic competitiveness and reduced trade imbalance. These positive externalities are amorphous and difficult or impossible to quantify, so I ignore them here.

Split Incentives

The person buying the equipment or building the office building may not be the person who will be financially responsible for paying the energy bills. If the developer/landlord will pay the bill (gross lease), then the savings from any conservation investment may be negated by wasteful tenant practices. If the tenant will pay the bill (net lease), then the developer/landlord will build an efficient building only if she thinks she can get the money back in increased rents. If the developer plans to sell the building to some currently unknown new owner, then the developer will only install efficiency if she thinks she can get her money back (plus some risk premium) in a larger selling price.

Economists argue that, in general, split incentives of this type should not cause reduced energy efficiency in a perfect market, because the added value of the efficiency should be capitalized in a higher selling price or be reflected in higher rents. If they are not so reflected, then it may or may not be the result of split incentives. Consider the case of a net lease (tenant pays for utilities) or the case of building sale. As discussed under *Asymmetric Information*, above and in Chapter V, reliably determining the energy consumption of a new building before occupancy or purchase can be difficult or impossible without the existence of a standardized building energy rating system that generates consumption estimates that are easily comparable to estimates from other (both new and existing) buildings. Therefore, due to another market failure, energy efficiency will probably not be capitalized in a higher selling price or be reflected in increase rents. In this case, it is not the split incentives that cause the market failure.

In the case of the landlord paying for utilities, it is not clear how she can prevent the tenants from wasting electricity, since the users do not pay for it directly (the marginal cost of increasing energy consumption is zero). Fixed-base leases (described above), in conjunction with new computer metering and monitoring technology (Clepper 1990), can be used to insulate the owner from this problem. It is not known how prevalent these various types of leases are. A detailed assessment of the problem would require some kind of survey and further research.

When the landlord pays the bills, she need convince no one else about the efficiency of the building (although she bears all the risk as well). Tenants prefer lower rental rates and will not require an independent audit and energy analysis in this case. When the tenant pays the bills (in net leases) the landlord must *convince* the prospective tenant that the operating savings will be worth the added rent. In this case, an energy analysis by some credible source or some other way of proving the energy efficiency of the building is needed, which adds to the cost of efficiency. Adopting lease agreements in which tenants pay the utility bills therefore reallocates the risks associated with increasing the energy efficiency of a new building, and adds another step to the process by which energy efficiency is incorporated into rents.

Public Goods

Information is in many ways a public good,[6] which is the chief argument for government- (or utility-) sponsored research and development and information dissemination. Where the information failures discussed above were related to information involved in a given transaction (the purchase or leasing of a new office building), the public goods failure of information concerns development and dissemination of information beyond that related to any specific transaction.

Research and Development

The societal benefits from energy efficiency R&D (as well as R&D in other sectors) are well documented and substantial (Geller et al. 1987). Geller et al. cited a study that found that U.S. appliance manufacturers spent 1-2% of their sales revenue on all R&D. Oster and Quigley (1978) cite "crude" evidence that "the ratio of R&D expenditures to value added is three and a half times as large for the economy as a whole as for the construction industry". Rough estimates by Rosenfeld (1988) indicate that proprietary and government R&D in the buildings sector comprise less than 0.4% of total costs associated with creating new structures or modifying existing structures. For comparison, R&D spending for U.S. industry as a whole was between 3.0% and 4.2% of net sales between 1980 and 1985 (Census 1988).

The perfect marketplace will only produce information until the marginal benefit of the additional unit of information to each economic actor equals the marginal cost of producing it. Individual developers and contractors will not fund the societally optimal level of basic research and development into new energy efficiency technologies, since many of the benefits of such research will flow to their competitors and to other parts of the economy (Mansfield 1982, pp. 454-5). The problem is especially pronounced when an industry is as fragmented as the design and construction industries (Brambley et al.

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[6] My consumption of a public good does not interfere with your enjoyment of it, or that of anyone else in society.

1988b).[7] Oster and Quigley (1978), discussing R&D in the residential construction industry, state that

> Small scale may be particularly problematic if many of the potential innovations in the industry are in organization, systems design, and in the integration of housing components. Here the minimum efficient scale for R&D activity is presumably rather large, and, more importantly, the returns to R&D are not easily capturable by a single firm.

These conclusions might just as well apply to design and construction of commercial buildings.

Expertise and Training

Only 500 to 1000 of the roughly one hundred thousand architects and engineers in the U.S. are qualified to design and construct buildings that utilize state-of-the art efficiency technologies (Deringer 1989). Acquiring the latest skills in energy efficient design would take five to ten years of study and practice (Brambley et al. 1988b). Few small firms have the resources to send their employees for such training, since these employees must be immediately productive and may move to other firms (Olivieri 1989a). Society benefits if the individual receives such training, but individual firms will not reap the entire benefit and will be reluctant to incur the expense. Subsidized education may make an employee happy with her current employer, but it also makes her more marketable.

The cost of losing an employee can be substantial, even without considering the added cost of the additional training. An American Institute of Architects report (cited by Gutman (1988, p.81)) notes that "losing an employee whose time is billable can cost 2-3 times the employees' annual salary in terms of lost time and retraining costs". High turnover rates (also cited by Gutman) make firms reluctant to pay for additional training, since the risk of losing employees is relatively high.[8]

Economic analysis of training finds that if the training is *general* and transferable to other jobs, the employee will pay for the training in reduced wages. If the training is *specific* to the job at hand, the firm will pay (Becker 1980). Gutman is probably referring to specific training and to opportunity and transaction costs associated with hiring a new employee Energy-related training can be both general and specific, and the situation is complicated by the fact that architects and engineers are professionals, and wages in the professions are not as free to fluctuate as in industries characterized by free entry. More study is needed on energy-related training in the professions to determine how much of such training is general and how much is specific.

Another important issue is why professionals won't pay for their own education, if it will allow them to design buildings more efficiently than their fellow professionals. Taking five to ten years off to study efficiency technologies would be a luxury that few

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[7] The bulk of nonresidential construction (80% by value) is completed by the 200 largest builders. The building design industry is much less concentrated, with 80-85% of the roughly forty thousand architecture and engineering firms having less than 25 employees and completing about 50% of the design work (by value) (Brambley 1988, p.B-1).

[8] High turnover rates also characterize employment in the construction industries. Lange and Mills 1979, p.6

people have the means to enjoy. In addition, the benefits from such study would depend on there being a demand for designers of efficient buildings. However, other market failures (risk aversion, information costs, asymmetric information, satisficing behavior, and regulatory distortions) may be preventing employers of professionals from demanding the services of efficient designers.

States and utilities may be reluctant to fund energy education for professionals, since those educated may leave the region. The problem becomes less acute as the geographic region increases in size. The federal government, with its sophisticated research facilities, vast financial resources, and national scope is the logical candidate to fund such education.

The energy-related content of the education of architects, appraisers, and engineers is strongly influenced by professional societies, whose licensing exams, educational guidelines, and other procedures may inhibit adoption of new information and rules of thumb about energy efficiency. Burnette (1979a, pp.4-5) points out that the architect's professional licensing exam "does not test the architect's ability to obtain information relevant to the problems he encounters....Instead it requires that the professional demonstrate an awareness of the norms of his peers--a constraint on the architect's approach to information which is also reinforced in practice by the exercise of law" (see the discussion of liability under *Risk Aversion*, above).

Many efficiency technologies lead to both energy savings AND capital cost savings, but assessing these techniques requires specialized knowledge and analysis of complicated interactions between building subsystems. There is a difference between designing for incremental improvements in efficiency, and redesigning all building systems. It is in the latter situation when capital cost savings are most easily captured but also when demands on design expertise are most intense. Both the computer analysis tools necessary for such analysis and the most efficient technologies that require it have been developed comparatively recently (in the past ten years or so).

Cash-Flow Constraints

Cash-Flow Constraints are an important consideration for developers, since increases in capital costs must often be financed using a loan from the take-out lender or additional capital from the joint venture partner. Increasing debt increases the risk of default, while increasing equity reduces the overall percentage rate of equity return (for a given cash flow). This market failure can also be characterized as a failure in the capital markets.

If the lender does not consider energy efficiency in determining eligibility for and size of the take-out loan, cash-flow constraints may be exacerbated and efficient buildings with higher first costs may be penalized. The owner of an efficient office building with low monthly bills will be able to afford higher monthly loan payments, all other things being equal. The major secondary lending agencies for residential mortgages (Freddie Mac and Fannie Mae) now consider energy efficiency in their lending decisions, although many banks do not. It is unclear to what extent commercial lenders account for energy costs, since these lenders suffer from lack of information about the efficiency of particular buildings and about the potential for cost-effective improvements in efficiency.

Cash-flow constraints may also be important for certain utility customers, principally small businesses (some of whom may be the future tenants of a new office building). EPRI (1987b, p.C-4) notes that many small firms have a high probability of bankruptcy (roughly 50% fail within five years of startup). The energy efficiency of buildings probably "plays only a minor role in the survival of these types of operations" (EPRI 1987b, p.C-4).

In this case, high discount rates are a reflection of the high opportunity cost of displacing consumption now for future returns. They may therefore be the result of rational calculations for businesses just getting by, but may still result in a suboptimal societal outcome. These constraints may also be related to *risk aversion*, since the business owner's perception of cash-flow constraints are affected by how the owner perceives risk.

The most successful businesses tend to locate in new buildings, while the marginal businesses occupy the less expensive older space. Tenant cash-flow constraints (e.g., for small tenants) are probably not a major issue affecting efficiency of new offices, though they may be important in certain cases. Developer cash-flow constraints are more generally a problem, though they also are less severe for the larger buildings that have tenants who have already preleased the space (i.e. promised to occupy it when completed).

Regulatory Distortions

While regulatory distortions are not strictly market failures, I include them here because they define the bounds within which the market is constrained to operate.

Regulatory Bias

Under current regulatory practices (outside of California), the profit of utilities will be reduced if they implement conservation, even if the conservation costs them nothing. This effect occurs because of imperfect regulation. The electricity price set by the regulators is based on forecasts of fixed costs, variable costs, and electricity sales. If the utility sells exactly the amount of electricity assumed in the forecast, it will recover exactly its fixed and variable costs. If, after the rate is set, the utility can increase sales above the forecasted level, it will collect additional revenues. The fixed costs do not increase with an increase in consumption, but the fixed cost portion of the rate continues to accrue to the utility. The variable cost portion of the rate is always offset by the increased variable costs associated with the increase in electricity generation. Under these conditions, two cent per kWh conservation will always be less profitable than two cent per kWh supply, and the utility will therefore favor the supply option (NPPC 1989d).

California instituted the Electric Revenue Adjustment Mechanism (ERAM) in 1982, which corrects for this regulatory failure, but may introduce other regulatory inefficiencies (CPUC 1986, Marnay and Comnes 1989).

Average Cost Pricing

Related to this regulatory bias is that price is set equal to *average cost* for U.S. utilities. Since prices do not reflect the long-run marginal cost (LRMC) of power, the electricity usage choices of electricity customers cannot be optimal from society's perspective. Since prices do not always reflect costs by time of day (especially for smaller commercial customers), consumers use too much electricity at expensive peak times and too little in off-peak periods. Whether this regulatory distortion causes an increase, decrease, or no change in energy use is unclear. It depends on the availability of energy storage technologies and time-varying elasticities of utility customers. This distortion does imply that consumers are not paying the true costs of their usage decisions.

This regulatory failure results in some loss of economic efficiency, but it is politically difficult to correct. Calculating LRMC is problematic and contentious, and there are technical and cost constraints on implementing time-of-use pricing for all customers. Special mechanisms (without precedent in U.S. regulatory history) would have to be established to collect additional revenues when LRMC was below average costs, and to rebate excess money when LRMC exceeded average costs.

Building Codes

Obsolete building codes may inhibit innovation and cost-effective conservation (Oster and Quigley 1978). Local U.S. building codes contain outdated requirements that interfere with efficient construction. Many of these codes are decades old, while most efficiency technologies have been developed in the last ten years and are evolving rapidly.

The number of building codes in the U.S. (thousands) inhibits economies of scale achievable through mass production. Each building is usually custom built to local standards. If codes were standardized, the planning and design process would be simplified, and penetration of new efficient technologies (which benefit from mass production) would be accelerated. There has been some standardization through the model code process, but large variations remain (ACHRN 1989c).

Subsidies for Established Energy Technologies

Subsidies for established energy technologies reduce energy prices below their true cost to society. Unfortunately, there has been little recent work on quantifying the annual size of subsidies for conventional energy sources such as coal, oil, gas, hydroelectric, and nuclear power in the United States. The work completed in 1985 by Heede and Lovins (1985), reports total annual Federal subsidies to conventional energy resources of $46 billion in 1984, but has been criticized as incomplete (Rothkopf 1985). Bezdek and Cone (1980) assessed subsidies in a comprehensive and rigorous fashion, but they only reported cumulative subsidies. They found total cumulative Federal subsidies up until 1977 of $210 billion (1977$). Oil production and electricity transmission and distribution garnered more than 80% of this total. Unfortunately, the work of Bezdek and Cone, and that of Brannon (1974) are not representative of current subsidies in the U.S. More work is needed to quantify subsidies based on current data.

Sales, Income, and Property Taxes

Three types of taxes are relevant here: Sales taxes, income taxes, and property taxes.[9] This section calculates the investor's perceived costs from taxes, assuming a real cost of debt capital for the investor of 8 percent (after Borden et al. (1982)). This cost of capital is also used as the discount rate, when appropriate.

Sales Taxes are usually levied by states, and are calculated as a percent of the sale price of a given device. Such taxes usually increase the cost of energy efficiency and other goods by eight percent or less. If the sales tax applies to energy conservation devices but not to fuels or electricity, a slight bias away from conservation is produced. Twelve

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[9] The initial impetus for the analysis presented in this section came from Marshall (1980) and discussions with Rosalie Ruegg at the National Bureau of Standards.

states[10] tax conservation but not residential fuels, and one state (Rhode Island) taxes fuels but not conservation. No state currently exempts from sales tax energy used in commercial buildings (Mendoza et al. 1989). Sales taxes therefore may be important in affecting investment in residential efficiency improvements in some states, but are not important for those in new offices.

Income taxes are more complicated than sales taxes in their effect upon energy efficiency. The income tax rate affects the perceived benefits from energy efficiency, since energy costs are a tax deductible item. If energy costs are reduced by one dollar, income taxes will increase by $0.28 to $0.34 for marginal tax rates of 28 to 34 percent.

Marginal Federal income tax rates of most real estate investors are 28 or 33 percent, while the corporate tax rate is 34 percent. State income tax rates range from zero to about 9% (Mendoza et al. 1989). Rosen (1989) describes how to calculate an overall marginal tax rate that accounts for the federal deductibility of state and local taxes. The 34% tax rate is close to that of a taxpayer in the 28% Federal bracket paying 8% state and local taxes.

Depreciation, which depends upon capital expenditures, increases tax-deductible costs by some fraction of the capital cost of the efficiency measure, thereby reducing taxes. Straight line depreciation[11] and a tax lifetime of 31.5 years implies an annual depreciation benefit of 3.2 percent of initial capital costs.[12] Interest payments on loans are tax deductible, which is a further tax benefit for capital investment. Finally, a few states have tax credits for energy efficiency and renewable energy investments, though these only rarely apply to offices or other commercial buildings (Mendoza et al. 1989).

The first year effect of these different tax costs and benefits is summarized in **Table IV.8**, for efficiency investments with different simple payback times and a 31.5 year investment lifetime.[13] The income tax system increases the effective cost of short payback time efficiency investments and decreases the effective cost of longer payback time investments. An investment with a pre-tax three year payback has a net after-tax simple payback time to the investor that is 13 percent longer (assuming a 28 percent marginal tax rate). Equivalently, the effective capital cost of the measure has been increased by 13 percent. Assuming a 34 percent marginal tax rate increases the perceived cost of this conservation measure by 19 percent. The perceived increase is more severe for measures with shorter payback times.

Property taxes are perhaps the least understood tax affecting energy efficiency. These taxes are levied annually as a fraction of the assessed value of the building (or are

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[10] Colorado, Kentucky, Maryland, Minnesota, Mississippi, Missouri, Nevada, New York, South Carolina, Tennessee, Virginia, and Wisconsin.

[11] Straight line depreciation means that depreciation costs are allocated evenly over the tax lifetime of a capital investment.

[12] This percentage equals the inverse of the lifetime of the measure. The 1986 tax law requires that for real commercial property (i.e., the building itself and all devices permanently attached to it) the tax life for depreciation purposes will be 31.5 years, which is longer than the depreciation period allowed in the earlier tax law (19 years for most real property). See Shenkman 1987 for more details.

[13] Most efficiency investments are attached permanently to the building and are thus classified as real property.

levied on some fraction of the assessed value). The *effective* annual tax rates are usually less than five percent of the *total* value of the building. Bradbury and Ladd (1987) list the effective city property tax rates for fifty-six U.S. cities as 0.63 percent in 1982. Cities in the Northeast census region have city property taxes that total 1.62 percent in 1982, while the Western census region boasts city property tax rates of 0.22 percent in 1982. These estimates *do not include* property tax assessments for school districts, county government, and other municipal government entities. No information was available on differences in tax rates between residential and commercial buildings. Some states offer property tax exemptions for solar or other alternative energy devices. None offer such exemptions for energy efficiency (Mendoza et al. 1989).

Property taxes appear to be small, but because they are annual and are based on assessed value, they could have a large effect on the perceived cost of an energy efficiency investment. The importance of this effect depends on how the value of the building is assessed. Because the effect of property taxes on the perceived cost of efficiency is extremely complicated to calculate, this section discusses the issues qualitatively. Chapter VI uses a discounted cash-flow model to estimate the effect of different assessment methods on net present value and internal rate of return.

Two separate entities are charged with such assessment: the tax assessor must estimate the building's value for tax purposes, while the real estate appraiser must estimate the building's value for future sale. These assessments need not correspond, though for convenience, this discussion assumes that they do.

Consider two buildings, identical except for energy efficiency. The effect of property taxes on the perceived after-tax return of the more efficient building depends upon how well the tax assessor incorporates the value of energy efficiency. Three cases that span the range of possibilities are

1) *Zero Assessment*: the assessor assigns the building a value that is equivalent to that of comparable office space elsewhere, without considering capital costs or energy efficiency.

2) *Cost Assessment*: the assessor assigns the building a "value" that is based solely on its capital costs. This method is straightforward to implement, but it ignores both the value of equivalent office space and the value of efficiency.

3) *Value Assessment*: the assessor assigns the building a value that is based on the value of comparable space and the additional present value (PV) of future cash flows attributable to the efficiency option. According to theory, the price of the building should be bid up until its price exactly equals this present value, and the assessment tries to approximate this outcome.

If the tax assessor completely ignores the energy efficiency in her assessment, the property taxes will not be increased at all. However, ignoring the energy efficiency understates the true value of the building, since a rational investor should be willing to pay up to PV dollars more for the more efficient building (all other things being equal) since it has lower operating costs. If the tax assessor assesses only the additional capital costs (i.e., focuses solely on the *cost* of the conservation and not on its *value*), the perceived after-tax cost of the energy efficiency will be increased by the present value of the property tax rate times the increase in capital cost.[14] In the case where the tax assessor accurately calculates the true value of the building compared to a comparable building (i.e. adds PV dollars to the value), the perceived after-tax cost of efficiency will be increased by the largest amount, which is equal to the present value of the property tax rate times PV.

Research is needed to determine the actual method used in assessing value for property tax purposes. If neither tax assessors nor real estate appraisers accurately account for the value of efficiency, then the developer who installs such measures can have no guarantee of an increased sale price for the building, which reduces the benefits from the investment. If building energy rating systems are instituted widely (see Chapter V) and building prices change to more fully reflect operating costs, property tax assessments will more closely correspond to the Value Assessment case, which may impute a penalty to the cost savings from such investments.

CONCLUSIONS

Market failures and regulatory distortions can be divided into those that inhibit adoption of conservation with costs less than or equal to the price of energy, and those that justify investment in efficiency beyond the market price of energy. Information costs, asymmetric information, satisficing, taxes, and risk aversion fall into the former category, while externalities and subsidies are examples of the latter.

Some of the failures analyzed above are more important than others in the market for efficiency in new commercial office buildings. The failures related to market structure and perfect competition (with the possible exception of market power related to building location) are not serious. The market failures connected with information, economic rationality, risk aversion, side effects, regulatory distortions and cash flow constraints probably have greater impact and are worthy of further investigation.

Overall themes

Transactions costs are a recurrent problem in the market for energy efficiency. This market involves decisionmakers in every sector of the economy, most of whom are not concerned with energy per se, but with reducing energy *costs*, which are usually a small part of their total costs. The conservation potential is composed of millions of individually small conservation actions and investments that comprise significant savings in the aggregate. These transaction costs inhibit information collection and dissemination, slow institutional changes, and increase risk aversion.

Energy use is of secondary concern to people involved in the real estate industry. Their training and interests focus on building, buying, and selling real estate: not on operating costs but on the profits those operating costs affect. For this reason, transaction costs are likely to be a larger fraction of the potential cost savings than in the case where an institution is devoted to efficiency, and its employees are trained to maximize cost-effective efficiency of buildings. The point is not that developers should make efficiency their main preoccupation, only that under such circumstances, transaction costs will be relatively important.

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[14] Property taxes are also a tax deductible item for income tax purposes, which means they are subject to the same type of analysis as in the previous section. In this case, however, tax deductible costs are increased by energy efficiency.

There are *costs of adjustment or lost opportunities* if new buildings are not as efficient as is cost effective, since it is much less expensive to improve the efficiency of new buildings than to retrofit existing buildings (NPPC 1989b). Market failures affecting energy efficiency of new buildings are thus more pernicious than those preventing retrofit of existing buildings. Once done, the damage from these market failures cannot easily be undone.

Market failures affect every actor in the design and construction process. Many of the market failures and regulatory distortions are interconnected, which reflects the complexity of the phenomena. Chapter V explores the implications of this complexity for the design of policies to combat these failures.

Table IV.1. Total Commercial Floorspace (BPA) Represented by Ownership and Length of Leaseholds (Percent)

Type	*Owner-Occupied*	*Leased Space* *3 Years or Less*	 *More Than 3 Years*
Large Office	20.0	22.4	57.6
Small Office	30.0	35.0	35.0
Small Retail	10.0	43.2	46.8
Warehouse	40.0	24.0	36.0

Source: George (1986)

Table IV.2. Owner and Tenant-Occupied U.S. Office Buildings in 1986, by Number of Buildings and by Floor Area

	Total	*Owner Occupied*	*Non-Owner Occupied*	*Bdgs w/ Tenants*
# Bdgs (thousands)	558	378	180	277
Single Establishment	385	281	104	
Multiple Establishment	173	97	76	
Floor Area (M sf)	8360	5334	3026	5296
Single Establishment	4150	3064	1086	
Multiple Establishment	4210	2270	1940	
Area/Bdg (k sf)	14.98	14.11	16.81	19.12
Single Establishment	10.78	10.90	10.44	
Multiple Establishment	24.34	23.40	25.53	
Percent of Total	*Total*	*Owner Occupied*	*Non-Owner Occupied*	*Bdgs w/ Tenants*
# Bdgs	100%	68%	32%	50%
Single Establishment	69%	50%	19%	
Multiple Establishment	31%	17%	14%	
Floor Area	100%	64%	36%	63%
Single Establishment	50%	37%	13%	
Multiple Establishment	50%	27%	23%	

The NBECS survey does not indicate how much floor area is taken up by owner-occupiers in multi-establishment office buildings. I have added together all buildings that are not owner occupied and all multi-establishment owner-occupied buildings as the best approximation.

Source: Non-Residential Buildings Consumption Survey (US DOE 1988b), Tables 23 and 24.

Table IV.3. Market Failures Affecting The Energy Efficiency of New Office Buildings

Type of Failure	*Nature of Failure*	*Examples of Failure*
Imperfect Competition		
Natural monopoly	Economies of Scale	Electric utilities
Market Power (Monopoly& Oligopoly)	Bargaining Power; Interdependent Conduct	Uniqueness of building location; Few development firms in one area
Anti Competitive Conduct	Collusion; predation	manipulation of permit process to the detriment of competitors
Information Collection		
Information Costs	Transaction costs	high cost of customized audit (cheaper if done en masse); collecting product info; finding credible information sources
Asymmetric Information	Unequal bargaining	developer's superior knowledge of building
Misinformation	Misinformed exchange	belief: "no efficiency increase is possible"
Lack of Information	Uninformed exchange	no knowledge of efficient technologies
Economic NonRationality		
Bounded Rationality, Satisficing	using rules of thumb to reduce transaction costs; not maximizing profits	ignore costs that are < 5% of rent; use a two year payback;seek acceptable profits
Other Non-Rationality	cultural reasons for taking actions that affect business practice	Preferring energy production to cost-cutting because it is more congruent with management culture
Risk Aversion	resistance to change	avoid changes in suppliers and technologies; avoid construction delays; avoid new technologies
Side Effects		
Negative Externalities from Power Production	Overconsumption of power; costs imposed on non-subjects	pollution from power generation; dependence on imported oil; risk of nuclear accidents; risk of nuclear proliferation
Negative Externalities from Energy Efficiency	Overconsumption of conservation; costs imposed on non-subjects	indirect emissions from production of materials in efficiency technologies; exposure to radon gas in tight houses.
Split Incentives	utility costs not paid by purchaser or user of equipment	Landlord-tenant problem
Public Goods		
R&D	Indivisibility, non-excludability, zero MCs;	too little R&D performed
Expertise and Training	Indivisibility, non-excludability, zero MCs	too little training on efficient design; too little information dissemination

Table IV.3. Market Failures (Continued)

Type of Failure	*Nature of Failure*	*Examples of Failure*
Cash Flow Constraints	lack of access to capital	small business tenants on the edge; Developer's reluctance to take on more debt.
Regulatory Distortions		
Regulatory Bias	More utility profits for electricity production than for efficient use	utilities reluctant to install conservation, even when cheaper than new supply
Average Cost Pricing	price signals do not reflect cost, leading to inefficient usage	Utility regulation in the U.S.
Building Codes	obsolete contents of codes inhibits innovation and efficiency; # of inconsistent codes inhibits achieving economies of scale.	local U.S. building codes contain requirements that interfere with efficient construction; thousands of building codes in the U.S.;
Subsidies to Established Energy Technologies	price of energy does not reflect true cost	prices too low
Sales, Income, and Property Taxes	affects perceived cost of energy efficiency	Sales taxes have little effect; Income taxes can increase perceived cost of short SPT investments. Prop. Taxes can increase perceived costs of all investments

Table IV.4. Information Costs Directly Affecting Decisionmaking in the Market for New Office Buildings

	Information Cost Code						
Decisionmaker	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Prospective Building Purchasers	x				x		
Prospective Occupants					x		
Developers	x		x	x	x		
Builders				x			
Architects/Designers	x	x	x	x	x		x
Construction Finance Organizations					x		
Take-Out Lenders					x		
Brokers			x		x		
Appraisers		x	x		x		
Local Government Officials						x	
Utility						x	
Suppliers of Efficient Devices						x	

Information Cost Codes (x = cost directly affects the decisionmaker)
1 = cost of collecting information about efficiency measures or the credibility and reliability of new suppliers and subcontractors,
2 = cost of developing expertise
3 = cost of calculating the costs and benefits of different efficiency levels
4 = cost of deciding how to alter established design and construction procedures
5 = cost of demonstrating in a credible way that a new building will reduce prospective tenants' or purchaser's energy costs
6 = cost of disseminating information about efficiency technologies
7 = cost of the architect/engineer incorporating new information about efficiency in her day to day work.

Table IV.5. Environmental Insults From Fossil Fuels

	All Fuels	Natural Gas	Oil	Coal
Exploration/ Harvesting	CO_2, CH_4, N_2O, NO_x, CO, ROG, HCs, particulates, trace metals, thermal pollution	drilling accidents, drilling sludge disposal	drilling accidents, SO_2, drilling sludge disposal	mining injuries, land degradation, SO_2
Processing/ Refining	CO_2, CH_4, N_2O, NO_x, CO, ROG, HCs, particulates, trace metals, thermal pollution	refinery accidents, refinery waste disposal	SO_2, refinery accidents, refinery waste disposal	SO_2
Transport/ Distribution	CO_2, CH_4, N_2O, NO_x, CO, ROG, HCs, particulates, trace metals, thermal pollution	pipeline accidents, LNG explosions	pipeline and tanker accidents, oil spills, SO_2	train accidents, SO_2
Conversion/ Marketing/ End Use	CO_2, CH_4, N_2O, NO_x, CO, ROG, HCs, particulates, trace metals, thermal pollution		ash disposal, SO_2	ash disposal, SO_2

ROG = Reactive Organic Gases, HC = hydrocarbons

Table IV.6. Environmental Insults From Existing Nuclear Power and Hydroelectric Generation

	Nuclear Power	**Hydro Electric**
Exploration/ Harvesting	mining accidents, radioactive tailing disposal, land degradation, indirect fossil fuel emissions (from fuel used in harvesting)	N/A
Processing/ Refining	processing accidents, indirect fossil fuel emissions	N/A
Transport/ Distribution	truck accidents, risk of proliferation, indirect fossil fuel emissions	N/A
Conversion/ Marketing/ End Use	Risk of catastrophic accidents, creation of low and high level radioactive wastes	may inhibit fish migration
Decommissioning	disposal of low and high level radioactive wastes*, indirect fossil fuel emissions	concrete disposal

*All U.S. nuclear reactors are charged an annual fee to cover decommissioning and disposal of radioactive wastes. However, neither a disposal site or disposal method has yet been chosen, and no large reactor has ever been decommissioned. It is therefore unknown if the actual costs will correspond to the value of this fee.

Table IV.7. External Costs from Existing U.S. Power Plants

	1988 Net Generation GWh	*1988 Net Generation % of Total*	*EPRI NO_X+SO_2 $/kWh*	*Implied by Con Ed Bidding System $NO_X+SO_2+CO_2$ $/kWh*
Natural Gas	252801	9.3%	0.0003	0.0043
Oil	148900	5.5%	0.0055	0.0096
Coal	1540653	57.0%	0.0111	0.0193
Nuclear Power	526973	19.5%	0	0
Hydro	222940	8.2%	0	0
Other	11984	0.4%	0	0
Total/Weighted	2704251	100.0%	0.0067	0.0119

Uses 1988 Average heat rates and emissions factors from Appendix C, external costs of $0.0015/lb of Carbon for Con Ed, damage costs of $0.48/lb of SO_2 for both EPRI and Con Ed, and NO_X damage costs of $0.07/lb for EPRI and $0.94/lb for Con Ed. All numbers are in 1989$. U.S. average electricity price is $0.066/kWh in 1988 (1989 $) and 1988 U.S. commercial sector average electricity price is $0.074/kWh.
Sources: Koomey (1990a), EPRI (1987c), NY PSC (1989).

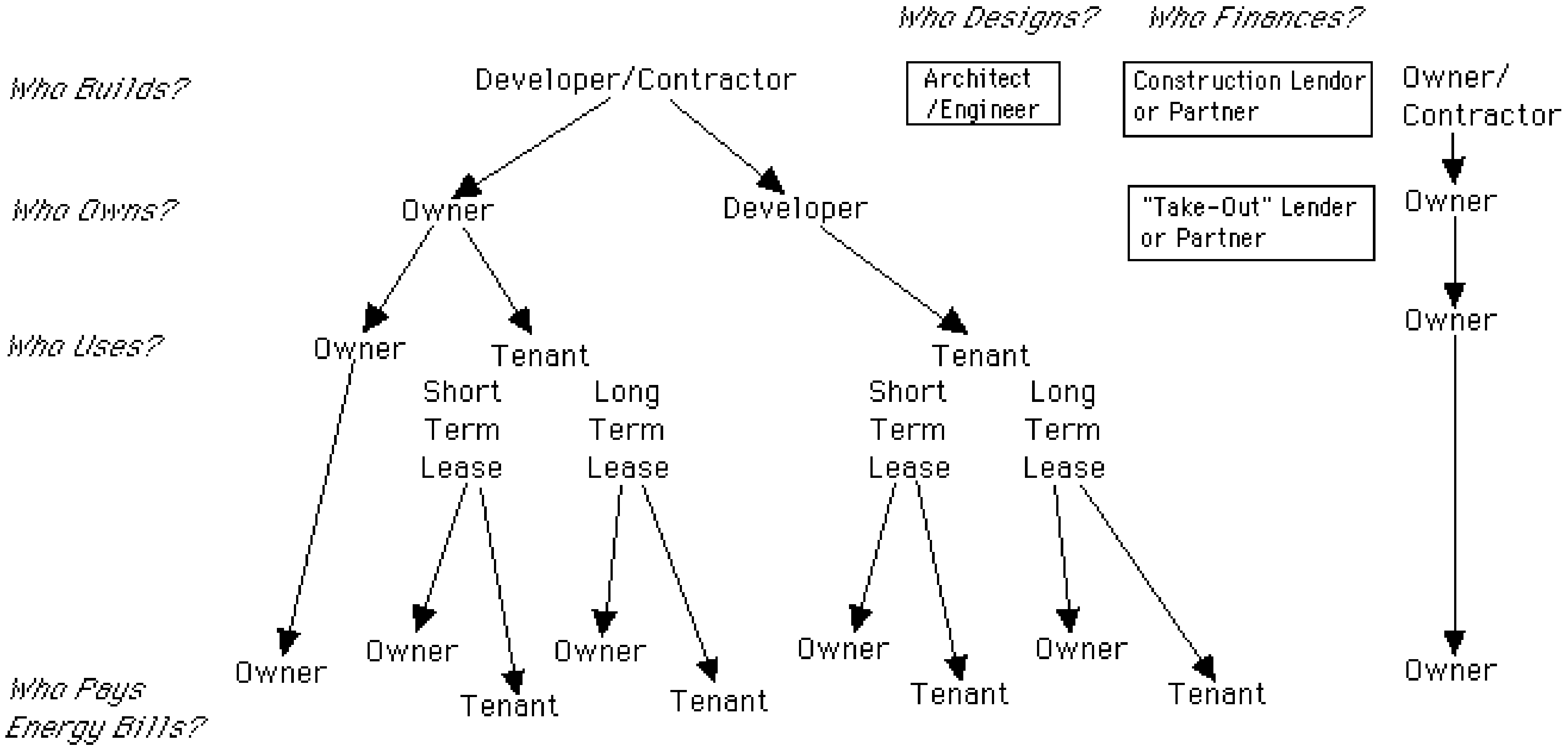
Table IV.8. First-Year Effect of Income Taxes on Perceived Cost of Efficiency

	INCOME TAXES 28%							
Pre-Tax SPT	*Capital Cost* $	*Pre-Tax Svgs* $/yr	*Post-Tax Svgs* $/yr	*Deprec-iation* $/yr	*Interest* $/yr	*Interest Tax Svgs* $/yr	*Net Svgs* $/yr	*Effective Increase in Capital Cost* %
1	1	1	0.72	0.03	0.08	0.02	0.77	29%
2	2	1	0.72	0.06	0.16	0.04	0.83	21%
3	3	1	0.72	0.10	0.24	0.07	0.88	13%
5	5	1	0.72	0.16	0.40	0.11	0.99	1%
7	7	1	0.72	0.22	0.56	0.16	1.10	-9%
10	10	1	0.72	0.32	0.80	0.22	1.26	-21%
15	15	1	0.72	0.48	1.20	0.34	1.53	-35%
20	20	1	0.72	0.63	1.60	0.45	1.80	-45%

	INCOME TAXES 34%							
Pre-Tax SPT	*Capital Cost* $	*Pre-Tax Svgs* $/yr	*Post-Tax Svgs* $/yr	*Deprec-iation* $/yr	*Interest* $/yr	*Interest Tax Svgs* $/yr	*Net Svgs* $/yr	*Effective Increase in Capital Cost* %
1	1	1	0.66	0.03	0.08	0.03	0.72	39%
2	2	1	0.66	0.06	0.16	0.05	0.78	29%
3	3	1	0.66	0.10	0.24	0.08	0.84	19%
5	5	1	0.66	0.16	0.40	0.14	0.95	5%
7	7	1	0.66	0.22	0.56	0.19	1.07	-7%
10	10	1	0.66	0.32	0.80	0.27	1.25	-20%
15	15	1	0.66	0.48	1.20	0.41	1.54	-35%
20	20	1	0.66	0.63	1.60	0.54	1.84	-46%

Interest payments assume that the marginal source of capital is debt, @ 8% real interest rate. The interest payments are for the first year. They would normally decline after this point and become less important, as the principal becomes amortized, which would make efficiency appear even more expensive. Depreciation is straight line and assumes a lifetime of 31.5 years, as required for real commercial property under current tax law (Shenkman 1987).

Figure IV.1: Categorization of Decision Processes



Short Term Lease is < 3 years (Rare in New Offices)

Figure IV.2: Schematic Development, Design, Construction, and Occupancy Process for Typical Office Building

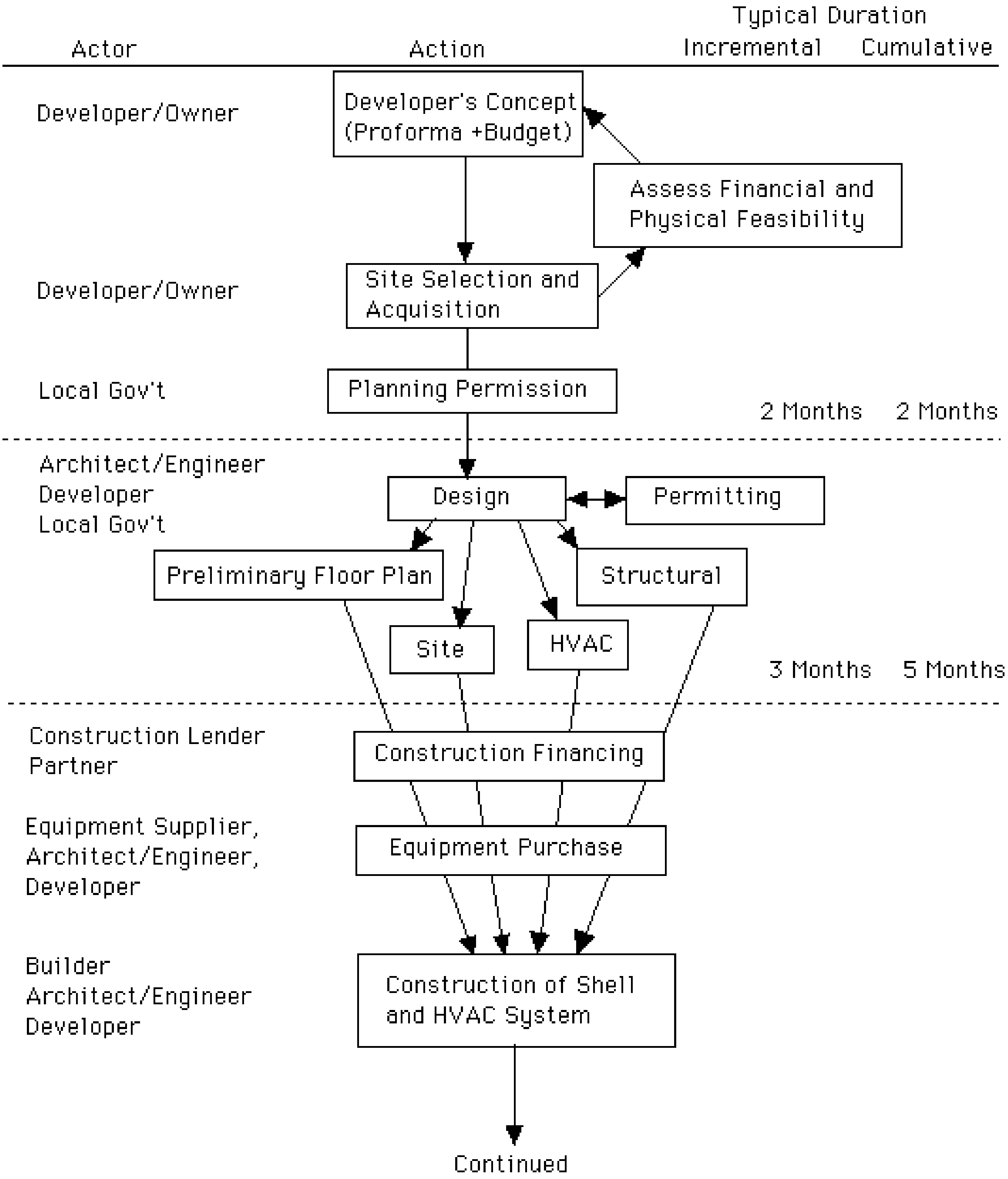


Figure IV.2: Schematic Development, Design, Construction, and Occupancy Process (Continued)

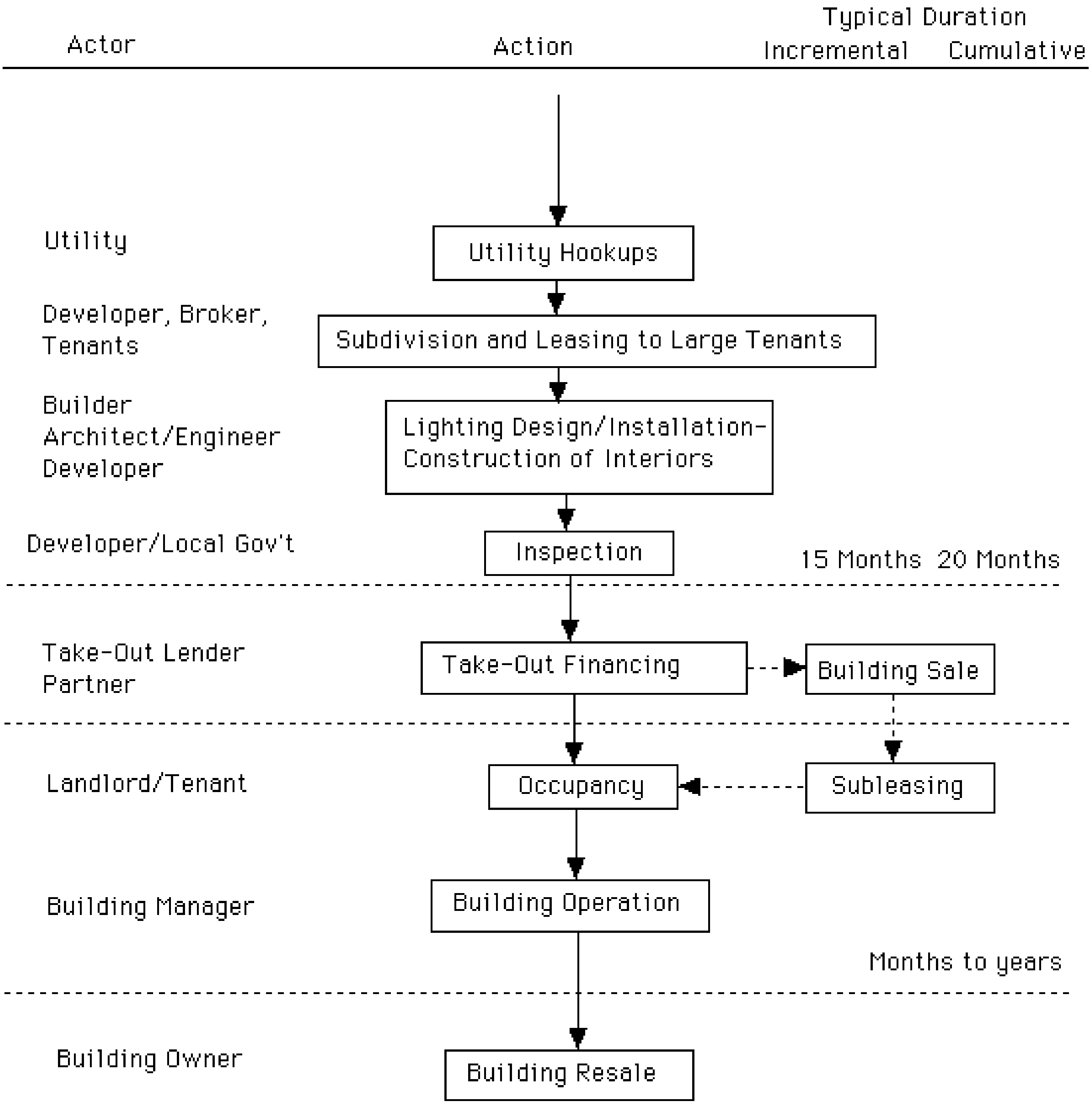
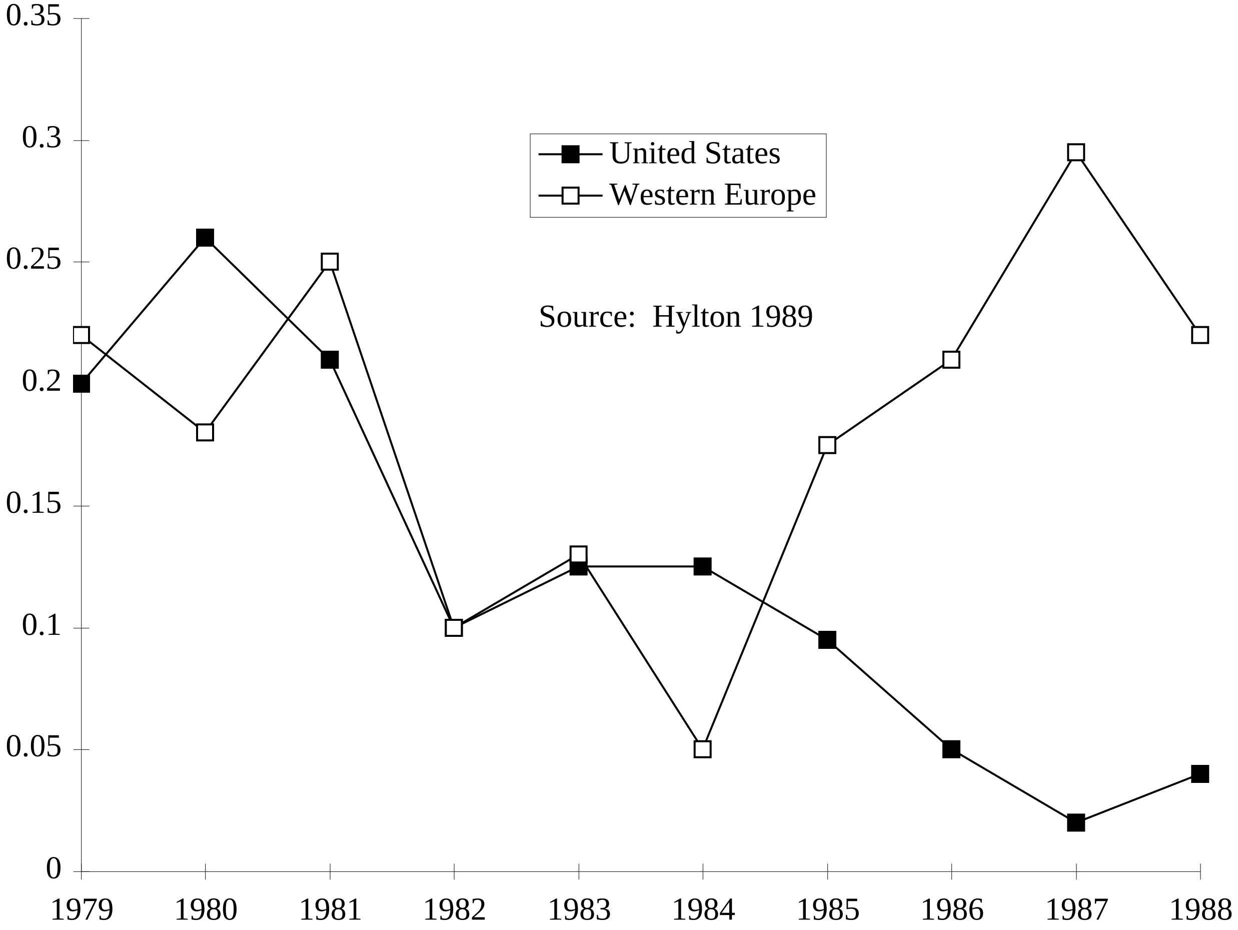


Figure IV.3: Average Annual Return on Equity for Office Buildings in the United States and Western Europe



Source: Hylton 1989

CHAPTER V: CORRECTIVE POLICIES

INTRODUCTION

This chapter explores current and proposed programs that government and utilities can use to correct market failures affecting the energy efficiency of new offices. The substantial underinvestment in energy efficiency demonstrated in Chapter III implies the existence of market failures. In particular, Chapter IV showed that information and other transaction costs, satisficing behavior, risk aversion, externalities, and regulatory distortions all impinge upon the functioning of the market for energy efficiency. Chapters II and III showed that the results of these failures can be important, both in terms of energy use and environmental insults.

These failures are susceptible in varying degrees to policies or programs affecting information costs, transactions costs, perceived cost, and perceived risk. The purpose of this Chapter is to use the analysis of market failures presented in Chapter IV to derive lessons for government and utility programs to correct these market failures.

This chapter first defines the societal perspective, from which all analysis proceeds. Next, it presents general information about the structure of incentives and the relationship of such policies to market failures. Third, it presents for each important market failure identified in Chapter IV a description of corrective policies. Finally, it briefly discusses the issue of whether utilities or government should intervene to correct market failures.

Societal Cost Perspective

The analysis proceeds from the perspective of minimizing *societal* cost for a given level of delivered service. This focus on societal cost is consistent with microeconomic theory, which shows that the outcome of perfect markets will be an efficient one from the societal perspective, under certain restrictive assumptions. The following explanation of the societal cost perspective draws more upon engineering-economics than microeconomic theory. Nevertheless, this perspective is equivalent in all respects to that assumed in neoclassical microeconomics.

The present value of social cost associated with an investment in a new building can be characterized as in Equation V.1 (for simplicity, I have chosen an all-electric building--the analysis is trivial to generalize for multiple fuels):

$$PV(SC)=C(q, other) + ((P + E^*)q + OC)\ PWF(r^*,L) + TC(q) + TC(Other) - SV(r^*,L) \qquad (V.1)$$

where $PV(SC)$ = present value of social costs (\$/sf),

$C(q, other)$ = capital costs as a function of electricity use and other factors (\$/sf),

P = price of electricity (\$/kWh), assumed to be constant,

E^* = cost of externalities (\$/kWh) ,assumed to be constant,

q = electricity use (kWh/sf/year), assumed to be constant,

OC = other operating costs (\$/sf/year).

r* = societal discount rate, which expresses society's risk preferences (usually 3-6% real)

L = life of building (years)

PWF(r*,L) = present worth factor using discount rate r* and lifetime L = $\frac{((1+r^*)^{L}-1)}{((r^*)(1+r^*)^{L-0.5})}$ for mid year assumption (see Appendix A),

TC(q) = transaction costs as a function of a given level of electricity use (q), holding non-energy related transaction costs constant ($/sf),

TC(Other) = transaction costs as a function of non-energy related parameters ($/sf), and

SV(r*) = salvage value (present valued) as a function of societal discount rate ($/sf). SV is often assumed to be equal to zero.

This analysis assumes that the level of service delivered by the building is unaffected by efficiency (i.e. that there is no change in consumer surplus from the change in efficiency). This assumption implies that the reliability and convenience of efficient devices is equivalent to that of inefficient devices. If the consumer chooses to increase the level of service after the efficient device is installed, she values the increased service more than its cost. Hence, consumer surplus has increased in this case.

From the societal perspective, transaction costs include unavoidable information costs and search costs associated with reducing electricity use beyond the level defined as "current practice". For current practice buildings, energy-related transactions costs equal zero. As described in Chapter IV, there are many varieties of information costs associated with efficiency in new offices. Those costs that can be mitigated by centralized collection and dissemination of information are discussed below.

The present value of *private* cost (PC) associated with investment in a new building can be characterized as in Equation VI.2:

$$PV(PC) = C(q, other) + (P\,q + OC)\,PWF(r',H) + TC'(q) + TC'(Other) - SV(r',H) \quad (V.2)$$

where PV(PC) = present value of private costs,

r' = the investor's discount rate, which is comprised of a risk-free portion (3-4% real), a real-estate risk portion (say 4-5% real), and an efficiency risk portion (which when added to the two previous portions will yield a discount rate that may be 30 to 100% or more (see Chapter I),

H = the holding period of the building owner (i.e., how long the owner waits before reselling the building),

TC'(q) = private transaction costs as a function of a given level of electricity use (q), holding non-energy related transaction costs constant ($/sf),

TC'(Other) = private transaction costs as a function of non-energy related parameters ($/sf), and

SV(r',H) = salvage value (present valued) as a function of private discount rate ($/sf). SV in this case equals the present value of the resale price of the building.

and the other parameters are as before.

Some of the differences between Equations V.1 and V.2 indicate where market failures and policy actions can affect the outcome. First, the cost function (C(q, other)) of investors can be affected by policy actions (e.g., utility bulk purchase of compact flourescent light bulbs that leads to lower installed cost). Second, the external cost associated with electricity consumption is not included in the private costs. Third, the investor may use a different (usually higher) discount rate (r') than that which society uses (or that which the investor uses to evaluate other aspects of real estate), which reduces the importance of operating cost savings to total life-cycle costs. This high discount rate implies that the risk the investor associates with efficiency investments is much larger than society's assessment of such risk, which may be the result of risk aversion, misinformation, or satisficing behavior (rules of thumb). Fourth, since many of the transaction costs (TC) are associated with information costs, they can often be reduced using centralized information collection and dissemination.

Krause (1989) introduces the concept of *technology cost*, which is helpful in discussing the societal cost perspective illustrated above. Technology cost ($/kwh saved) is defined as "the cost of demand-side measures as calculated in engineering economic analyses", using a societal discount rate, and "off-the-shelf" cost estimates for different devices. Technology cost plus societal transactions costs plus external costs equals total social cost per kWh saved.

The technology cost is society's estimate of the cost of the demand-side measure, including economies of scale. For example, the *technology* cost for a compact flourescent light bulb equals the wholesale cost of the bulb, annualized using the societal discount rate, and divided by the annual energy savings. The *societal* cost equals the technology cost plus the cost of distributing the bulbs per kWh saved.

INTRODUCTION TO INCENTIVES

This section describes general characteristics of incentive policies for later use in discussing application of such policies to specific market failures. Other policies are described in the context of each market failure.

Reasons for Instituting Incentives

There are four principal reasons for implementing incentive schemes to promote energy efficiency:

1) to correct for external costs,

2) to supply information (when the incentive is tied to a specific action or investment),

3) to reduce investor risk in a new technology,

4) to accelerate the pace of adoption of efficient technologies.

Reasons 1) and 3) are discussed below under the headings *Negative Externalities from Power Production* and *Risk Aversion.* The other two possibilities are discussed in this section.

The information component of incentive policies to promote specific efficiency technologies has been almost completely ignored in the literature, but can be important. Utility rebates for compact flourescent light bulbs and electronic ballasts deliver institutional credibility to claims that these devices actually save energy. If an architect sees that the utility will pay rebates for installations of ten different devices, search costs have been reduced. The designer can just focus on ways to use those ten technologies in her design, without necessarily undertaking a lengthy (and potentially intimidating) analysis of all techniques available to reduce energy consumption.

External constraints may argue for accelerated adoption of efficiency technologies, using incentives that are larger than would be justified by currently measurable environmental externalities or by the size of tax distortion effects. Large incentives can overcome institutional inertia and market barriers, and can be applied more quickly than the more complicated information delivery policies can be implemented. External constraints may be related to environmental concerns (e.g., the need to phase out greenhouse gas emissions within a certain time period to achieve climate stabilization (Krause et al. 1989)) or may be a function of system reliability constraints (e.g., the immediate need for capacity to prevent blackouts in the Long Island Lighting Company's service territory).

Structure of Incentive Policies

Direct incentives can be in the form of charges or rebates. Charges are either levied at the time of building commissioning (hookup fees) or for each kWh consumed. Rebates are either disbursed at the time of building commissioning, distributed in reduced rates (just as for per unit charges), or given out in lump sums during the life of the building (for retrofits, which we omit from consideration here).

Per unit fees (rebates) would be charged (disbursed) for all kwh consumed in the utility system at the time of electricity billing.[1] These incentives are typically of the form

$$I^* = (I)\,(q)\,(12) \qquad \text{(V.3)}$$

where

I^* = the incentive per square foot (sf) of building area per month-- can be positive or negative (\$/sf/year)

I = the per unit incentive (\$/kWh positive or negative),[2]

q = monthly electricity consumed by a utility customer per sf of building area (kWh/sf/month).

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[1] as before, I restrict the analysis to all-electric buildings for simplicity.

[2] The incentive may also be paid for a given reduction in utility peak demand. In this case, the per unit incentive would be express in \$/Watt, and the savings would be expressed in Watts/sf.

and 12 = number months per year.

Lump-sum fees (also known as "up-front" fees or hookup fees) are usually calculated as the present value of per unit fees associated with energy consumption over the life of the building. Such an incentive would have the form

$$I^* = I_1 \, PWF(r^*, L) \, q \, (12) \qquad (V.4)$$

where

I_1 = the per unit incentive (\$/kWh),

$PWF(r^*, L)$ = the present worth factor at discount rate r^* and lifetime L,

r^* = the societal discount rate,

L = device lifetime,

I_1 PWF(r*, lifetime) = the present value of incremental fees on 1 kWh of electricity consumption in each year of the building's lifetime, and

q = monthly electricity consumed by a utility customer per sf of building area (kWh/sf/month).

Lump-sum rebates are usually calculated as the present value of per unit rebates, with reference to some target consumption (T) for a building or device. Up-front fees may also be calculated with reference to a target consumption (fees would be charged when $q > T$). A lump-sum rebate incentive would have the form

$$I^* = - I_2 \, PWF(r^*, L) \, (q - T) \, (12) \qquad \text{for } q < T \qquad (V.5)$$

where

I_2 = the per unit incentive, not necessarily equal to I_1 (\$/kWh),

T = target consumption of building (kWh/sf/month)

12 = the number of months per year,

and the other quantities are as before.

Revenue-neutral incentives (e.g., sliding scale hookup fees) combine the attributes of target-based, up-front fees and rebates:

$I^*(\text{fee}) = I_1 (q - T)$ for $q > T$

$I^*(\text{rebate}) = I_2 (q - T)$ for $q < T$

subject to the constraint that

$$\text{Revenues} - \text{Expenditures} \approx 0$$

$$\left(\sum_{i=1}^{M} \sum_{q_i=T}^{\infty} I_1(q_i - T)A_i + \sum_{j=1}^{N} \sum_{q_j=0}^{T} I_2(q_j - T)A_j\right)(12) - AC \approx 0 \qquad (V.6)$$

where

$q_{i,}$ (q_j) is the monthly electricity consumption for building i (j), which is charged a fee (given a rebate).

$A_{i,}$ (A_j)= the area of building i (j), which is charged a fee (given a rebate).

M (N) = number of buildings that are charged fees (given rebates)

AC = administrative costs ($/year),

and the other quantities are as before.

Like the other forms of direct incentives, revenue-neutral programs can be applied to devices or buildings. When applied to particular devices, they convey information. Since such an incentive program would change the "standard" new building efficiency over time, the target level would have to be periodically adjusted to maintain revenue neutrality.

Lump sum fees or rebates may also be calculated as a fraction of the cost of an efficiency investment, such as for the solar energy tax credit implemented in the Carter administration. Such incentives take the form:

$$I^* = F\ C(q,\text{other}) \qquad (V.7)$$

where F is the size of the incentive (% of capital costs), and

C(q,other) = capital cost as a function of energy use and other variables.

This type of incentive may lead to perverse results, since it rewards the installation of a technology, not its performance. The incentive depends on capital costs, so that a more expensive device that delivers the same service will receive a larger absolute incentive than a less expensive device. In addition, this type of incentive further disguises the assumptions behind the choice of incentive level. For these reasons, incentives that are based on a percentage of capital costs should be avoided.

Effectiveness of Externalities Incentives

Equations V.1 and V.2 can be used to throw light on the characteristics and limitations of incentive policies. By adding the optimal per unit fee to each kWh consumed, the private cost function is transformed to:

$$PV(PC) = C(q,\text{other}) + ((P + E^*)q + OC)\ PWF(r',H) + TC'(q) + TC'(\text{Other}) - SV(r',H) \qquad (V.8)$$

The differences between Equation V.8 and the social cost function (V.1) are the discount rate (r'), the transaction costs (TC'), the holding period (H vs. L) and the salvage value (SV(r',H)). The TCs are still based on those facing the consumer, and the high discount rate reduces the effect of the externality tax. The salvage value (i.e. resale value) may also significantly affect the total return of the investment (see Chapter VI).

The up-front fee, on the other hand, changes the private cost function by present valuing the externality cost first and adding it to the total cost function.

$$PV(PC) = C(q,other) + E^* q\ PWF(r^*,L) + (Pq + OC)\ PWF(r',L) + TC' - SV(r',H) \qquad (V.9)$$

Per unit fees (Equations V.3 and V.8) may be affected by high consumer discount rates that would negate the effect of the incentive in many cases, while up-front fees (Equations V.4 and V.9) isolate the externality charge from this effect. The effectiveness of target-based fees and rebates (Equations V.5-V.6) will be less than that of up-front fees based on *total* consumption. This property of target-based incentives somewhat reduces one of the generic advantages up-front incentives have over per unit fees (see Chapter VI).

The transaction costs component remains the same as before, which indicates a weakness of both simple and front-ended fees and rebates per kWh: they tell investors to do *something*, but do not elaborate the options available. Up-front fees associated with a specific measure *do* convey information and reduce transaction costs.

Transaction costs can therefore impede the efficiency of some per unit incentive schemes. The information and search cost barriers that existed before the incentives are implemented will not disappear with the advent of the incentive, and require separate policy action. Conversely, policies that mitigate the transaction costs barrier will still not promote the societally optimal level of efficiency if externalities have not been internalized. Concurrent actions are necessary when multiple market failures are present--single policy solutions implemented in isolation will fail to achieve the efficient outcome.

Assume for a moment that the transaction costs (TC') have been reduced to levels approaching those for society as a whole (TC), and that these societal TCs are insignificant. Stoft (1989) points out that in this case, correctly determining the size of up-front incentives to evoke the efficient response requires that we know C(q,other)[3] and E*, while correctly setting per unit taxes only requires that we know E*. Thus if both C(q,other) and E* are not well known, and consumer discount rates are not substantially different than the societal rate, then per unit incentives are likely to be more accurately set and hence more efficient than up-front incentives. If C(q,other) is well known and investor discount rates are high, as is likely for new office buildings, up-front incentives are likely to be more effective and accurately determined than per unit fees.

Experience With Incentive Policies

Well-conceived financial incentives can influence commercial customer decisionmaking. Such incentives can affect the timing of investments by commercial firms and can affect the number of such investments a firm will undertake. They may also promote the development of the "energy service industry and financial infrastructure" needed for continuing success with energy efficiency programs (EPRI 1987b).

Many communities or utilities impose hookup charges or line extension fees (Ahern 1981), but no states currently link hookup fees with the efficiency of new buildings (Vine and Harris 1988a). Fees are rarely used to promote efficiency, while rebates are in wide use by electric utilities to promote efficiency of appliances, lighting, and HVAC equipment

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[3] We need to know C(q,other) to predict the incentive's effect in this case because the up-front incentive affects this variable directly (i.e., it changes the first cost of the building as a function of electricity use).

(EPRI 1987a, Nadel 1990). Fees are uncommon not because of legal constraints (Russell 1979), but because they are usually politically unpopular.

Electric utilities can establish lower rates for new buildings hooking up to the system or existing buildings undergoing substantial renovations if they meet minimum efficiency requirements. This policy is relatively simple to implement, and is likely to be popular since it is voluntary and uses only positive incentives. Duke Power Company in North Carolina combines a voluntary service standard with a lower rate for homes that meet the standard. Duke Power estimates that 73% of all new home construction now meets the standard, and the program is widely judged to be successful (Vine and Harris 1988a). This policy is similar to utility service standards that have been used extensively in the Northwest U.S. (see below).

Who Should Receive Rebates?

Rebates may be paid by a utility to builders, developers, architects, or purchasers of efficient buildings. They may be paid for installation of a specific technology or for meeting some performance standard. They may be paid at any stage in the design, construction, or purchasing process.

Nadel (1990), after reviewing dozens of utility rebate programs to promote energy efficiency in new and existing buildings, states that many utilities only pay rebates to people or institutions who install devices that currently have low market shares. In this way, "free-rider" problems can be avoided. As these technologies become part of "current practice", the rebates can be phased out, and new rebates instituted for devices that have low market shares.

Brambley et al. (1988b, p.2.11) believe that developers and designers have the greatest influence over the total life-cycle cost of new buildings, because of their involvement in the early stages of project development. Developers are most concerned with financial viability of the project, and can influence all subsequent participants to reflect such concerns. Designers are most influential in the choice of materials and building systems (BD&C 1989b).

Designers influence energy costs through their choice of building systems, but are not expressly concerned with financial viability, per se. They *are* concerned about designing buildings that can be constructed within pre-established budget constraints, that are aesthetically pleasing, and that are likely to result in receiving their fee from the developer. They are therefore largely constrained to operate within financial parameters set by the developer. For these reasons, developers are probably the most effective focus of rebate policies affecting efficiency of new buildings. Market failures affecting designers may be more effectively mitigated using information delivery, education, performance guarantees, and other risk-minimizing policies.

Utility Fees and Rebates

This Chapter does not specifically address many of the issues involved in determining the appropriate size of *utility* fees and rebates. For instance, utilities often argue that they should only pay incentives for energy efficiency up to the difference between marginal cost and the price of electricity. This position reflects a preoccupation with minimizing rates, and ignores the primacy of societal costs. Regulators have almost universally repudiated the least-rates approach, and adopted the societal least-cost test (or its equivalent) as their metric. These issues, as well as current controversies, have been addressed elsewhere (Hobbs and Nelson 1989, Krause and Eto 1988).

CORRECTING MARKET FAILURES AND REGULATORY DISTORTIONS

This section uses the analysis of the most important market failures from Chapter IV to address policy issues concerning mitigating these failures. For a general review of policies affecting energy efficiency, see Koomey and Levine (1989), Wilson et al. (1989), and Hirst et al. (1986).

Market Power

It is unclear just how widespread this market failure is. More study is needed to determine the extent to which favorable locations for buildings can allow developers to ignore energy efficiency. Building efficiency standards would prevent this failure from affecting energy efficiency, though it is not clear that this market failure alone could justify instituting such standards.

Information Costs

Such costs include those (1) of collecting information about efficiency measures, (2) of developing expertise, (3) of calculating the costs and benefits of different efficiency levels, (4) of establishing the credibility and reliability of new suppliers and subcontractors, (5) of demonstrating in a credible way that a new building will reduce prospective tenants' energy costs, (6) of disseminating information from a centralized source, and (7) of the architect/engineer incorporating new information about efficiency in her day to day work.

> (1) It is expensive, duplicative, and inefficient for each contractor, architect, engineer, developer, or building owner to collect information individually. Searches for costs and performance of efficiency technologies can be undertaken once, and the results replicated cheaply.
>
> The Lawrence Berkeley Laboratory's BECA[4] databases are a national compilation of costs and measured energy savings from appliances and buildings (see, e.g. Piette et al. (1985)). Utilities all over the U.S. distribute information on efficiency technologies (Vine and Harris 1988a), though these programs are almost never as comprehensive as they could be .
>
> (2) Developing expertise is analyzed below under Public Goods.
>
> (3) Calculating conservation benefits in particular circumstances involves costs that are not much affected by centralized information collection. Published examples of generic calculations may reduce computational errors, but computation is still necessary to verify cost-effectiveness in specific applications.
>
> Computerized building simulation models can greatly reduce the costs of calculating the cost-effectiveness of energy efficiency in particular circumstances. Such models have often been used in *Design Assistance Programs* run by electric utilities.
>
> The purpose of design assistance information is to ensure that designers of new buildings have access to the most useful computer simulation tools and the most

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[4] Building Energy Compilation and Analysis

current and credible information on commercially available efficiency technologies. Implementing this policy requires extensive contact between utility representatives and architecture and engineering firms, efforts by state governments to subsidize and otherwise encourage these contacts, and Federal government initiatives to actively disseminate the results of government-sponsored research.

There are two parts of information delivery for this policy. The first part (publicity) is to make designers aware of the information resources available to them. This task may be accomplished by radio, TV, and newspaper advertisements. The second part (assistance) is to deliver the information itself in various ways, including energy assistance hotlines, design guidebooks, summary rules of thumb, and site-specific design assessments. The information flow would be bidirectional, since the utility learns about the needs of their customers as the customers take advantage of the utility's demand-side expertise. The utility may want to explicitly combine the design assistance program with direct financial incentives to defray any additional design costs and make adoption of efficient technologies more likely.

Design assistance programs are in use throughout the U.S. Most programs focus on the commercial sector, since the use of architects is more extensive in commercial buildings than in residential. Vine and Harris (1988a) provide a brief list of representative design assistance programs for the commercial sector, including TVA's New Construction Energy Design Assistance Program, BPA's Energy Smart Design Assistance Program, Washington State's Design Assistance for New Commercial Buildings Program, Sacramento's Technical Assistance Program, and Northeast Utilities' Energy Conscious Construction Program.

4) The reliability of suppliers of energy efficient products and knowledgeable subcontractors who install them is information that is especially susceptible to centralized collection and dissemination. Utilities or a trade organization can certify the competence and reliability of suppliers of high efficiency equipment, and maintain and distribute a current list of those certified.

5) The costs of credibly determining new building energy consumption are discussed below under asymmetric information.

6) The cost of disseminating information can be reduced if the information distribution source is perceived by consumers as being more objective than suppliers, is centralized (it achieves economies of scale in replication and distribution) and it uses existing distribution channels (e.g. utility bills or customer service representatives).

One important means of disseminating information is to conduct demonstration products using the latest building and appliance efficiency technologies. These projects will demonstrate the capability and reliability of new technologies. They will also uncover unanticipated problems in installing these technologies, which can then be corrected before full-scale implementation gets underway.

Other means to distribute information include utility "bill stuffers", booklets of the most efficient devices, handbooks for building designers, developers, architects and others, computer programs and databases, and radio and television advertisements.

7) Time for professionals to digest and internalize new information can be substantial, but is not easily reducible by centralizing information sources.

> Education and training (see *Public Goods* below), combined with easy-to-use databases and computer design tools, can substantially reduce the time for professionals to internalize new information about energy efficiency and use it in their designs.

As Chapter IV showed, information costs affect developers and architect/engineers more extensively than other participants in the design, construction, and leasing process.

Burnette (1979b) summarizes seven elements of successful information delivery to architects. They are equally applicable to information programs targeting other people involved in the new building development process:

> 1) *Publication of any information sources must be continuous and up-to-date:* Since professionals will depend on the information sources continuously, they must have confidence that their need for current information will continue to be adequately supported in the future. Otherwise, they will not invest the time and expense to acquire a new source.
>
> 2) *Information must be packaged, indexed, and ready for convenient use.*
>
> 3) *Information must appear consistently in the same format:* consistency in presentation ensures quick comprehension, once the format is learned.
>
> 4) *Information must be concisely presented in discrete chunks:* graphically presented information is preferable (especially for architects) because it is "economical of means, potentially precise, clear in its scope, quickly apprehended, and easily handled".
>
> 5) *Information should be couched in operationally useful, performance-oriented description:* the information must include assessments of how a device works in practice, how it affects comfort, how it affects reliability, etc.
>
> 6) *Information must be accurate and complete, drawings precise and to an easily used scale:* innacurate information may lead to expensive lawsuits, which makes credibility of the information source essential.
>
> 7) *The information source must evolve, adapt, and respond to user's needs:* the producers and disseminators of information must ensure rapid correction of erroneous information and continual reassessment of the value of the information source to its users. Their needs will change over time, and information sources must adapt to those changes or risk becoming irrelevant.

These lessons must guide designers of information programs that correct for both information costs and asymmetric information.

Asymmetric Information

The solution for this market failure is to institute building energy rating systems, so that purchasers of new buildings and prospective tenants can have some objective way to estimate the operating costs of buildings without extensive technical knowledge. Without a building energy rating system, buyers and prospective tenants cannot easily insist on energy efficiency, developers and builders cannot market it, and lending agencies cannot account for it in their calculations. Chapter IV showed that information costs associated with determining the energy costs of a new building affect almost all of the participants in the design, construction, and leasing process. This policy would reduce therefore somewhat the cost and perceived risk of efficient buildings for the bulk of market participants.

To determine the efficiency of a new building, a builder or developer might have three options:

> (1) use one of several pre-approved building designs that reach certain consumption targets;
>
> (2) combine a "base" building with rated options that together reach the desired consumption level;
>
> (3) simulate the performance of the building using a specified methodology.

Methods similar to these have already proven successful in implementing Home Energy Rating Systems throughout the U.S. (Vine et al. 1987a, Vine et al. 1987b).

Rating systems have been less frequently used for new commercial buildings, in large part because these buildings are more complex than residences. However, the three-option approach described above is used to enforce the California commercial building standards (CEC 1992, CEC 1987). Even if the ratings are crude (e.g., dividing buildings up into four bins--state-of-the-art, efficient, average, and below average) they would be a vast improvement over the current lack of information. If implemented in conjunction with minimum building efficiency standards, the additional cost would be small.

Because the energy use of offices is so dependent on internal loads, the energy cost ratings (in $/sf/year) should be expressed as a function of internal loads, so that prospective tenants can estimate how much their own usage patterns will cost them in a given building. Companies are now becoming concerned with internal loads because many buildings (both new and existing) have inadequate wiring and HVAC capacity to meet increased electrical and space conditioning demands associated with computers and other office equipment (Valentine 1989). Internal load data is therefore likely to be available to most tenants.

The results of building simulations may not accurately predict the loads of actual buildings. In the beginning of an energy labeling experiment or program, the size of energy consumption and peak demand would be estimated using such simulations. A statistically valid sample of actual buildings would have their hourly loads monitored for a few years and then compared to the simulations. The simulation tools would then be adjusted to account for these data. While monitoring and an iterative correction process can be expensive, both the utility and the builders would benefit from them. The labeling program would still have value before the measured data were available as a *relative* indication of energy efficiency.

An issue that is indirectly related to efficiency in new offices is that of utility billing data. Utility bills of an existing building could contain estimates of the building's weather-normalized per square foot usage compared to the average building of each type (of similar vintage) in the utility service territory. These estimates would be supplied to prospective buyers or tenants when the building is sold or rented. Prospective tenants for new buildings could compare their utility bills to the estimates from the building energy rating system. Kempton and Layne have shown that there are large economies of scale if the utility does such calculations and delivers processed information on weather and average consumption to each consumer (Kempton and Layne 1988).[5]

Misinformation and Lack of Information

Misinformation and Lack of Information about energy efficiency are likely to be counteracted by policies proposed to minimize information costs.

Bounded Rationality and Satisficing

Bounded rationality and satisficing behavior are both related to human beings' inability to process all relevant information. The advent of inexpensive computing power has already altered rules of thumb in the development community, which is now using spreadsheets to calculate the financial effect of almost every one of its investments. However, in the design community, computer models that predict the energy consumption effects of different design strategies have in general not been integrated into the day-to-day work of architects.

These models have been designed by engineers, and do not mesh well with the intuitive design approach of architects. They do not allow easy testing of the energy consumption of different designs at an early stage in the design process (Brambley et al. 1988b). Federally-sponsored research and development to combine energy simulation tools with Computer Aided Design Programs has already begun, though it is years and millions of dollars away from a marketable product (Brambley et al. 1988b, Schuman 1989). A design-oriented energy simulation tool would increase the architect's ability to process large amounts of information. She could test her rules of thumb against those embodied in the computer program, and could alter them as she used it.

Another way to alter these rules of thumb is to disseminate information in tabular or handbook form, which is less flexible than the computerized approach, but is available now. An example of this approach is the guidebook developed by Northeast Utilities to demonstrate that a new office building could be designed that is substantially more efficient than current practice but that would cost no more than a conventional building to construct (see Chapter III and Northeast Utilities (1988)). This report analyzed more than forty different strategies for reducing energy costs, giving costs and expected energy savings in a prototypical office. The results cannot easily be modified to estimate energy savings in other buildings, which would require computer analysis. However, the guidebook does give a laundry list of options and extensive references in case the professional needs more information.

Risk Aversion

As Chapter I showed, many owners and tenants of commercial buildings use simple payback times of three years or less to evaluate energy efficiency investments. The high discount rates such simple payback times imply are to some degree an expression of risk aversion toward efficiency technologies. Smaller commercial customers are likely to use shorter payback times (Barker et al. 1986), be more risk averse, and be less likely to participate in conservation programs than larger customers (EPRI 1988b, p.3-4). Smaller

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[5] In existing buildings, the utility could also use this information to target the energy-intensive users for incentives or more information.

firms are also "much more likely to depend on subjective judgement when making investment decisions" (EPRI 1988b, p.2-6).[6] This result suggests that differentiation of electricity customers by demand level will yield dividends when designing policies to affect the behavior of these customers (EPRI 1987b, p.1-5).

Building owners are concerned about reliability of unfamiliar efficiency technologies, since worker productivity is so valuable compared to energy use per square foot (see Chapter IV). This concern suggests that demonstration projects and measured data on device reliability should be a major focus of policies to combat this source of risk aversion. Another (actually complementary) approach is some form of insurance or performance guarantee by the supplier of an efficiency technology or by the utility who installs it (see EPRI (1988b, p.2-17) and shared savings, below). Analysis of the loss of productivity as a function of equipment reliability is needed to quantify the expected insurance costs. A third approach, and one that is becoming more common, is leasing of the more efficient equipment, with an option to purchase when the term expires (ACHRN 1990, Smith 1989, Smithart 1989) Risk aversion will also be counteracted to some degree by supplying information.

Policies that reduce the cost of efficient devices (e.g., up-front rebates or simply giving away efficiency technologies) unquestionably reduce risks for investors, while fees can either increase or decrease risks associated with installing more efficient devices. For example, per unit fees added to the price of electricity would decrease the risk and increase the benefits of adding more efficiency, but would increase overall business risk because electricity prices have increased for all buildings, efficient or not. Chapter VI explores the extent to which a representative externality fee of 15% of energy prices might affect the rate of return for typical small, medium, and large office projects. In part because they reduce such risks, utility customers prefer rebates to most other forms of incentives (Schon et al. 1987). EPRI (1987b, p.3-3) found that commercial customers rated guaranteed savings above rebates, which in turn were rated above all other programs.

Negative Externalities of Power Production

Economists have long advocated correcting for external costs using market mechanisms such as marketable permits, per unit fees, or other incentives (Dorfman and Dorfman 1972, Fisher 1984). Incentives have recently been gaining favor among policy makers (Gilliam 1989), although they have been resisted by some environmentalists who see pollution as a moral issue, not an economic one (Passell 1989).

Chapter IV summarized estimates of external costs of power production for existing plants in the U.S., showing that \$0.01/kWh is a reasonable round-numbered estimate for these costs (they vary substantially by location and by fuel type). For the purposes of illustration, this Chapter uses an estimate of \$0.01/kWh for pollution from existing plants, which is slightly less than 15% of the 1988 U.S. commercial sector electricity price.

Correcting for externalities requires incentives of some kind or prescriptive emissions standards on power plants. Economists generally prefer incentives (e.g. taxes) to standards when monitoring costs are low, because they allow more flexibility to those

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[6] The survey upon which this generalization is based found that "of those having made investments in the year prior to the survey, nearly half used no formal economic analysis at all".

producers who are producing output valuable enough to still be profitable even after the tax is imposed.

If a per unit tax of $0.01/kWh is to be imposed to correct for externalities, it would increase the 1988 average price of U.S. commercial sector electricity by 13.5%. Such a price increase would be substantial, but its effect on electricity use would be diluted by high investor discount rates. Front-ended incentives would likely be charged (or disbursed) to specific customers for specific actions (e.g., installation of electronic ballasts). The effectiveness of such incentives would not be affected by high discount rates, but would be somewhat reduced (compared to up-front fees) because the fee is applied to the *savings* and not to *total* consumption (see the analysis of incentives above and Chapter VI).

As an illustration, we can calculate the size of the appropriate up-front rebate for electronic ballasts (see Chapter I for more details on ballasts), based on a $0.01/kWh externality incentive. The present worth factor using a 6 percent real discount rate and a 17.3 year lifetime (2600 hours per year of operation and a 45k hour lifetime) is 10.9.[7] For every 1 kWh of annual savings, the present value of the $0.01/kWh externality surcharge totals $0.109. Since the electronic ballast saves 65.8 kWh/year compared to an efficient core-coil ballast, the total rebate is $7.17/ballast ($0.109/kWh x 65.8 kWh). This incentive reduces by about forty percent the additional capital cost associated with the electronic ballast. Up-front rebates for less cost-effective devices will yield incentives that are a smaller fraction of capital costs.

There will always be some uncertainty in estimates of externalities. Given the wide range of justifiable best estimates, incentives should be set at a level within that range that will promote vigorous consumer response. The size of incentives can be adjusted as better data become available on the monetary value of externalities avoided by conservation.

Split Incentives

The landlord-tenant problem when the tenant pays the utility bill will probably be mitigated by institution of a building energy rating system and corresponding normalized energy usage information attached to utility bills, since tenants can more reliably compare operating costs of new and existing office space. However, if the landlord pays the bill, the landlord still cannot prevent the tenant from using energy wastefully, which might jeopardize the cost effectiveness of any efficiency investments. Minimum efficiency standards would force the landlord to install efficiency in any case, while incentives could reduce the risk for the landlord when she pays the utility bill.

Public Goods-R&D and Program Evaluation

This policy involves federal funding of basic and applied research and development for both energy conservation policies and technologies, and support of building industry funding for such technologies. Even increasing building R&D by a factor of 2 (to 0.8% of the cost of buildings constructed) would leave this industry substantially below the rate of total R&D expenditures for average U.S. companies (3% to 4% of net sales).

An effective R&D strategy involves research on technology, exploration of ways to commercialize that technology, coordination with the private sector (using appropriate

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[7] All present worth calculations use the middle of year assumption (see Appendix A).

cofunding arrangements), and transfer of technical knowledge to the private sector. Efficiency R&D does not have a guaranteed payoff, but past experience shows that it has yielded substantial benefits to the U.S. economy by advancing the production date of dozens of new technologies (Geller et al. 1987).

Program evaluation means researching and analyzing the effectiveness of energy efficiency programs and technology in the field, including direct metering and measurement of building and appliance efficiency, as well as analyses of program success and comparisons with previous programs. It is the next step after R&D develops and commercializes a technology. The federal government and utilities have been the principal sponsors of program evaluation in the past, compiling program experience and technology assessments in a systematic form (Krause et al. 1989, Piette and Harris 1988, Vine 1985, Vine and Harris 1988a).

Public Goods-Education

Energy education for builders, developers, and architects has much in common with design assistance. I define one type of energy education to be design assistance delivered to many professionals at once, instead of the detailed, site-specific evaluations common for design assistance for individual projects (described above). It is a more common means to reach builders of residential and small commercial structures, since these projects are often not large enough to warrant the individual attention granted to large new commercial buildings.

Vine and Harris (1988a) mention two energy education programs for residential buildings: the Alaska Craftsman Home Program and Arizona's Building Industries Short Course Program. The Alaska program is targeted principally at the new residential building industry, while the Arizona program includes seminars for people involved in all segments of new and existing residential real estate, including builders, realtors, and apartment managers. In addition, education programs have been used in states with building standards to familiarize the design and development community with the features of the new requirements (as well as to train the officials who were charged with enforcing the policy). For a description of this process in California, see Feinbaum (1981).

Peter Rojeski, a construction industry consultant (quoted in Olivieri (1989b)) states that "it takes about seven years of experience to produce a capable design engineer". He adds that with proper university training, this training time can be cut in half.

The licensing procedure for architects could more strongly emphasize knowledge of energy efficiency and integration of this knowledge with design practice. These technologies are evolving so quickly that coursework in the early years of a professional's career would be insufficient to ensure adequate knowledge. Architects and other energy professionals could be required to take annual half-day courses to keep the professional in touch with the latest developments in efficiency technology. Such requirements for continuing education are not uncommon in many professions, though changing such requirements can be difficult because of institutional constraints (Feinbaum 1981).

Regulatory Distortions-Utility Bias

One policy has been implemented and several proposed to at least make utilities indifferent between conservation and energy supply technologies, and in some cases to add incentives if the utility promotes conservation effectively. California instituted the Electric Revenue Adjustment Mechanism (ERAM) in the 1970's, which is a mechanism to keep track of the difference between forecasted and actual revenues, and to use this information to reimburse the utility for exactly the losses incurred (in the next rate case) (Marnay and Comnes 1989, NPPC 1989d). This policy eliminates the disincentive to conserve, but some critics have argued that ERAM also eliminates the utility's incentive to combat bypass by industrial customers who can cogenerate.

Other possible changes in regulation include allowing higher rates of return for capital invested in conservation, indexing the utility's total rate of return to the rate of reduction in customer bills compared to some index, or indexing the total rate of return to some other measure of a utility's dedication to pursuing demand-side programs (Krause and Eto 1988). Such policies are important to make the utilities full participants in their customers' design and construction decisions. Since utilities are obligated to serve new load, they have an interest in the efficiency of new buildings in their service territory.

Utilities have usually been allowed to charge rebates as an expense, but some PUCs have considered the option of "rate-basing" or capitalizing conservation. This choice affects the utility's profits if the rate of return granted for rate-based conservation is higher than that for competing supply technologies (Reid 1988).

Regulatory Distortions-Average Cost Pricing

Because of limitations (principally costs) of metering technology, small and medium-sized electric utility customers have traditionally been charged rates that did not vary with season or time of day, even though the utility's costs vary substantially over time. New metering technology based on microprocessors allows relatively inexpensive measurement of usage instantaneously or by time-of-day. The price of such meters is falling fast enough that widespread installation of time-of-use (TOU) and even real-time meters (in some applications) is likely in the coming decades.

Once such devices are widely used, demand-side technologies can be designed to take advantage of price differentials between peak and off-peak periods. For instance, cooling or heating storage devices can be installed in small commercial buildings to take advantage of TOU pricing. These meters have other advantages, including allowing remote meter reading, automatic payment of utility bills, automatic collection of load data (for researchers), collection of information on usage (for the customer), and integration with other electronic and communication systems.

One of the British electricity boards has tested their Credit And Load Management System (CALMS) for several years in the 1980s. ICS of Atlanta is experimenting with a similar system that would be integrated with communications, entertainment, and home energy management systems (Rosenfeld et al. 1986).

The role for policy in this case is to advocate the adoption of microprocessor-based TOU pricing in small and medium sized office buildings,[8] and to encouragestandardization of communication protocols to maximize data gathering capability, avoid wasteful duplication of effort, and allow maximum flexibility. Much of the utility industry will initially resist efforts to move to microprocessor-based meters, since their current meter design is rugged, reliable, inexpensive, and has proven itself over decades. They may need some financial or institutional encouragement to accept new metering approaches.

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[8] Most large offices already have TOU pricing available to them.

Regulatory Distortions-Building Codes

Building codes should be based on a national model code, which should vary to account for regional differences in climate (ACHRN 1989c). The model code should encourage (or at least not inhibit) innovation and the use of manufactured components. Restrictive and obsolete requirements of current codes should be eliminated. The requirements for the national codes could be stored and distributed on optical disks, just as specification guidelines for bidding on federal government contracts are now distributed (NIBS 1988).

Regulatory Distortions-Subsidies

Government subsidies should be eliminated for established resources like oil, natural gas, coal, and nuclear power, and should almost exclusively be used to promote basic research and development. Governments should resist attempts to subsidize production, except where market or regulatory failures are well documented. Such production incentives almost always become corporate welfare programs once a new technology becomes well established. Any subsidy of production should incorporate a "sunset" provision that would lead to the subsidy's gradual but virtually certain demise over a specified time period.

Regulatory Distortions-Taxes

Taxes create a financial incentive that inhibits adoption of efficiency options. This regulatory failure is an unanticipated side effect of the way income and property taxes are currently structured. It may require financial incentives of some kind to counteract its effects. In the case of income taxes, the disincentive to efficiency is relatively modest and is most important for those measures with the shortest payback times, which are already extremely cost effective. Income tax credits can be used to offset the slightly negative effect of the current income tax system in short payback time investments, though this policy option would suffer from the difficulties inherent in subsidies that reward installation and not energy saved.

Where building energy rating systems have been adopted and the assessed value of buildings more accurately reflects operating cost considerations, the property tax "surcharge" on efficiency may become a serious problem. In this case, tax reductions (or exemptions) in response to efficiency can be instituted to offset this effect, or separate financial incentives may be used.

Cash Flow Constraints

Cash flow constraints may be alleviated using low interest loans, rebates, or shared savings (see below). Another way to improve access to capital is for lending agencies to consider reduced operating costs when determining eligibility and size of the take-out loan. Changing lending procedures requires that a building energy rating program already be in place, so that can lenders can have an objective source upon which to base such determinations (Faesy 1988, Prindle and Reid 1988). More research is needed on how well commercial lenders currently account for operating costs in their proforma analysis.

POLICIES AFFECTING MORE THAN ONE FAILURE OR DISTORTION

The following policies address several market failures at once, but may not be as desirable as policies specifically targeted to each market failure.

Minimum Building and Equipment Efficiency Standards

The American Society for Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) has promoted a set of national building efficiency standards on a voluntary basis (PNL 1983). There is sufficient experience in ASHRAE and at the state level that a federal standard could be designed relatively quickly, although it might be politically difficult to pass these standards in the face of opposition from the building industry. Such a standard has already been designed for federally-owned new buildings, though it is voluntary for non-federal buildings (US DOE 1989b). Standards are also now in place banning use of inefficient core-coil ballasts (Geller and Miller 1988).

Minimum efficiency standards may apply to new buildings or to those undergoing substantial renovations that require additional electric services. Efficiency standards can take two forms: prescriptive standards, which mandate a specific technology, and performance standards, which mandate a specific level of energy consumption. A standard can also give the user a choice of prescriptive or performance approaches. The California standards specify that buildings may meet the code by installing predetermined packages of efficiency measures without deviation, by using a simplified "points" system that relies on a primitive performance analysis, or by doing a building energy analysis using one of several approved computer models. The third approach is the closest to the pure performance standard, and it is also the most complicated.

Mandatory standards are relatively predictable in effect, and combat bounded rationality, risk aversion, information cost, and transaction cost barriers. Standards are often enforced by local building officials who are often understaffed and insufficiently trained (Feinbaum 1981, Usibelli and Stevens 1988). By themselves they provide no incentive to build a more efficient building than the standard requires, and are often much less stringent than would be cost effective from society's perspective. They can, however, be combined with incentive programs that will encourage efficiency beyond the standard level.

Utility Service Standards

This policy, which is almost identical to government-instituted efficiency standards, involves electric utilities establishing minimum efficiency requirements for new buildings hooking up to the system (Bellamy and Fey 1988). Utility service standards have been used extensively in the Northwest U.S., in the form of the Model Conservation Standards (Vine 1986). They have been successful in part because they apply leverage to the builder/developer at a key point in the development process. A variation of the utility service standard has been used by Duke Power Company in North Carolina; this approach combines a voluntary service standard with a lower rate for homes that meet the standard (see above).

Incentives

Since direct incentives are usually tied to specific efficiency measures, they convey information, reduce search costs, and reduce risk. They are addressed in detail above.

Shared Savings

Shared savings schemes involve utilities installing efficiency options on customers' premises *at utility expense.* The customers agree to pay for the conserved energy as if it were energy actually supplied to the building, or they agree to lease the more efficient equipment. The utility uses these payments to cover the cost of the conservation option. Under certain conditions "shared savings may contribute as much to covering fixed costs as [kWh] sales would", thus avoiding the disincentives for utility conservation built into the current regulatory framework (Krause and Eto 1988). There can be problems, however, when savings projections are inaccurate (Lutz 1988). Shared savings has traditionallybeen used for retrofits, but it could also be used in new construction.

Shared savings schemes are being used by the Department of Defense for retrofit of nine military facilities. An earlier Federal government project used a shared savings arrangement to retrofit the San Diego Post Office (IRT 1988). More recently, the U.S. headquarters of U.S. Sprint was retrofitted with efficient lighting, using a similar shared savings arrangement (Buildings 1989).

A scheme similar to shared savings has been used by a New England Utility to promote the use of compact flourescent light bulbs in residences. In this scheme, the lightbulbs are leased to customers for $0.20 per month, and the customers get to keep the energy savings. The barrier of high apparent first cost of the lightbulbs is eliminated, as are search costs, and risk (the utility replaces the lightbulbs for free if they burn out, and guarantees $50 bill savings over the life of the bulbs) (Krause et al. 1989). The same leasing approach could be applied to equipment in new office buildings, with the incremental costs of more efficient flourescent ballasts being "leased" to the customer for a monthly fee.

Government Purchase Programs for Efficient Technologies

This policy would involve federal (and to a lesser extent state governments) creating a market for new efficiency technology through their purchasing choices. In this way the latest technology will be supported in the early stages, which would allow manufacturers to increase production of cutting-edge products and achieve economies of scale more quickly. This policy can be justified simply on the grounds of direct operating cost savings to the government, with the added benefit of encouraging more rapid adoption of efficiency technologies in the economy as a whole. Governments could simply mandate technologies for use in new government construction, or they could mandate a certain efficiency or performance level. Government purchase programs of this nature have not been tried in a systematic fashion or at a scale sufficient to assess their effectiveness.

INCENTIVES VS. MANDATES

Incentives are often preferable to mandates because they allow individual actors to choose the most cost effective path to achieve the desired level of energy efficiency or emission reductions. Incentives are also more flexible than mandates. Mandates are useful when there are relatively high monitoring costs for incentives or when the required actions are easy, non-controversial, or inexpensive. Properly enforced mandates also may have more predictable effects than incentives, although experience gained with early incentive programs can be used to great advantage when predicting the results of future programs. Mandates and incentives should work in tandem, with policymakers using standards to eliminate the least efficient buildings, and using incentives to promote improvements beyond the level of the mandated standards.

UTILITY OR GOVERNMENT INTERVENTION?

Public goods such as government purchase programs, education, or R&D are most effectively addressed at larger geographic scales, which means that state and federal governments are the most important actors for implementing these policies. Externalities taxes and changing utility regulation are also primarily the tasks of government. Other types of programs fall clearly under the purview of utilities, such as changing billing procedures to deliver information, changing rates, setting a service standard, or adopting TOU meters. Many others, including design assistance, per unit externalities taxes, hookup fees, rebates, or building energy rating systems, could be implemented by either government or utilities.

Privately-owned utilities have the advantage over government that they operate for profit, and hence can be given incentives for efficient implementation of such programs. Utilities have not been models of economic efficiency in the past, in part because "cost-plus" regulation did not encourage such efficiency. In the newly competitive utility environment, regulators are exploring means by which incentives can promote efficiency. Government would also gain less by interacting with utility customers than would the utility. In addition, many of the institutions necessary for implementing such programs already exist in many utilities, though often in skeletal form.

SUMMARY OF POLICIES

Table V.1 shows fifteen policies listed by the market failures they can effectively mitigate. Efficiency standards and many direct incentives attack many market failures at once, while government purchases, R&D, utility regulatory reforms, and various information policies are targeted at specific market failures.

A Minimum Set of Policies

The absolute minimum set of policies (i.e. those required for the market for energy efficiency in new offices to function properly) are listed below. Implementing these policies is a necessary condition for "market success". Whether their existence is a sufficient condition for such success is a question that some day may be answered empirically.

1) instituting building energy rating systems, and encouraging banks to use them in their lending calculations.

2) creating and distributing weather-normalized utility billing data

3) compiling costs and effectiveness of efficiency technologies, to reduce search costs.

4) correcting for externalities using appropriate incentives.

5) eliminating the utility's disincentive to conserve.

6) promoting the adoption of TOU meters in small and medium-sized offices.

7) eliminating production subsidies for established energy production technologies.

8) increasing funding for energy efficiency R&D, both for new technologies and programs.

9) making credible design assistance information available to architects at an early stage in the design process (especially in those regions that do not yet have active energy consulting industries).

10) developing visually-oriented, computer-based design tools for architects that allow easy and rapid testing of the energy implications of various design approaches.

No jurisdiction currently has all these policies in place. Some of the programs require Federal initiatives, some require state action, and some can most effectively be implemented at the utility level. If implemented in tandem, their effects are likely to be greater than if they are implemented piecemeal.

CONCLUSIONS

Only a coordinated set of policies that attack market failures at all stages in the development process simultaneously will succeed. Giving the developer a financial incentive to improve efficiency will only yield results if the architect/engineer knows about the latest technology and is able (and willing) to incorporate it into her designs, and the contractor knows where to purchase and how to install these technologies correctly. Policies that try to redress problems at single links in the decision process will encounter resistance and will be less effective than those implemented in concert.

Programs operated in parallel can benefit each other. For example, utilities will acquire information about utility customers when designing and operating efficiency programs, which can then be used to target incentives for greatest effectiveness (this customer information will also be useful to utilities as deregulation of generation continues and competition increases). Building energy rating systems can be implemented simultaneously with performance-oriented building efficiency standards, at low marginal cost. With such a rating system in place, banks and other lending agencies can more accurately estimate the operating costs of a new building, and a larger loan can be arranged. Rebates can be used in conjunction with design assistance or other information programs to encourage more rapid adoption of efficient technologies than information alone would induce. Through such synergisms, market barriers can be most rapidly overcome.

Table V.1. Applicability of Policies to Mitigate Particular Market Failures

Type of Failure	*Design Aid*	*Education*	*Rating System*	*Lower Rates*	*Hookup Fees*	*Utility Rebates*	*Externality Tax*
Imperfect Competition							
Natural monopoly							
Market Power				x	x	x	x
Monopoly& Oligopoly							
Information Collection							
Information Costs	x	x	x	x	x	x	x
Asymmetric Info		x	x	x	x		
Misinformation	x	x	x	x	x	x	x
Lack of Information	x	x	x	x	x	x	x
Economic Non-Rationality							
Bounded Rationality	x	x	x	x	x	x	x
Other	x	x	x	x	x	x	x
Risk Aversion	x	x	x	x	x	x	x
Side Effects							
Negative Externalities					x	x	x
Split Incentives					x	x	
Public Goods		x					
Cash Flow Constraints	x			x	x	x	
Regulatory Distortions							
Regulatory Bias							
Average Cost Pricing				x	x	x	x
Building Codes							
Income Taxes						x	
Property Taxes						x	

Design Aid = Design assistance supplied to architects, engineers, and developers;
Education = Educate architects and engineers about energy efficient design. Educate building operators about latest techniques. Educate developers about efficiency potential;
Rating System = mandate all new buildings to be rated for energy efficiency, so that purchasers can comparison shop;
Lower Rates = lower utility rates for buildings that meet minimum efficiency guidelines;
Hookup Fees = hookup fees/rebates related to efficiency of new building;
UtilityRebates = Utility rebates for specific efficiency measures installed in new buildings;
Externality Tax = Tax on all fuels in proportion to their comparative external costs;

Table V.1. Applicability of Policies to Mitigate Particular Market Failures (Continued)

Type of Failure	*TOU Pricing*	*Shared Svgs*	*ERAM +*	*Bdg Stds*	*EqpmtStds*	*Utility Svc Std*	*Govt Prchse*	*R&D*
Imperfect Competition								
Natural monopoly			x					
Market Power				x	x	x		
Monopoly& Oligopoly								
Information Collection								
Information Costs		x		x	x	x		x
Asymmetric Info				x	x	x		
Misinformation		x		x	x	x		
Lack of Information		x		x	x	x		
Economic Non-Rationality								
Bounded Rationality		x		x	x	x		
Other		x		x	x	x		
Risk Aversion		x		x	x	x		
Side Effects								
Negative Externalities		x						
Split Incentives				x	x	x		
Public Goods							x	x
Cash Flow Constraints		x		x	x	x		
Regulatory Distortions								
Regulatory Bias			x					
Average Cost Pricing	x							
Building Codes				x	x	x		
Income Taxes								
Property Taxes								

TOU Pricing = Time-of-Use pricing for utility customers;
Shared Savings = Value of savings shared between utility and participating customer;
ERAM + = mechanisms that reform current regulations to make a utility's least-cost plan the most profitable plan;
BdgStds = Minimum building efficiency standards;
EqpmtStds = Minimum efficiency standards for commercial equipment (HVAC, ballasts, etc);
Utility Svc Std = Utility Service standard--minimum efficiency required for utility hookup;
Govt Prchse = Government purchases efficient products to spur innovation and economies of scale;
R&D = government-sponsored research and development

CHAPTER VI: INCENTIVE POLICIES AND INVESTOR RESPONSE: A FINANCIAL PERSPECTIVE

This Chapter analyzes four of the incentive policies discussed in Chapter V. Criteria for designing such incentives often focus on the maximum acceptable incentive from the utility or societal perspectives, based on engineering-derived device costs, utility avoided costs, energy prices, and equally-spaced cash flows. Such criteria say little about the actual investor response to a given incentive, or about the relationship of non-energy related parameters to the investor's response.[1]

This Chapter uses a discounted cash-flow model that is representative of those used by real estate professionals, to assess an individual investor's response to different incentive policies. The first section of this Chapter presents the inputs to the model and outputs calculated by the model. The second section presents analysis of the dozens of model runs, with implications for design of incentive policies.

METHODOLOGY

Computer models are often used to assist investors in assessing the value of a proposed project, or to convince the prospective purchaser of a newly constructed building that the property will be a worthwhile investment. This chapter recreates the decision environment of the purchaser of a new office building, first developing baseline characteristics of three projects of different sizes, then incorporating these characteristics into a discounted cash flow model. The analysis assesses the relative impact of four different types of incentive policies, to determine the advantages and disadvantages of each.

The choice of parameters in this analysis is illustrative. As described in Chapters II and IV, the heterogeneity of the office building sector makes comprehensive generalizations difficult. However, such an illustrative analysis can lead to general conclusions about investor response and suggest fruitful areas for further research.

The Model

The model is a standard discounted cash flow model, which is used in finance classes at the University of California, Berkeley's Business School.[2] A printout of the model, as modified for this analysis, appears in Appendix D. Such models usually calculate Internal Rate of Return (IRR) and Net Present Value (NPV) at a given discount rate. The model has been modified to calculate additional numbers that characterize an investor's sensitivity to changes in operating costs and rental income.[3]

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[1] This Chapter does not attempt the difficult task of assessing the overall investor response to incentives applied to the nation as a whole. Such an analysis would require detailed supply curves of conserved energy for many different types of offices, as well as extensive surveys of the simple payback times used by office building investors.

[2] The model and explanation were graciously supplied by Mr. Dan Lee, who is the teaching assistant for Professor Ken Rosen's real estate finance classes.

[3] The model was originally written in Lotus 1-2-3. I converted it to Microsoft Excel for use on a Macintosh SE-30, and deleted all parts of the spreadsheet unrelated to fixed rate financing. All runs and formatting used macros custom designed for that purpose.

Operating Cost and Rental Income Tradeoff Factors

Grimm (1976) developed the concept of Operating Cost and Rental Income Tradeoff Factors (OCTFs and RITFs) in the mid-1970s. He used a discounted cash flow model and information about then-current tax rates and other parameters to calculate the number of dollars the capital cost of the building could be increased for every dollar of operating cost savings or additional rental income, holding the internal rate of return (IRR) constant. This way of characterizing the value of cost savings and rental income to the investor is similar to that of the present worth factor (see Appendix A), but it is not limited by the assumption of equal annual payments, and incorporates tax effects and other complexities. It is a more comprehensive measure of investor decisionmaking than the PWF.

Grimm defines the OCTFs to vary with holding period of the building. However, if the market is working properly, an investor should be willing to pay an amount equivalent to the total net present value of cash flows over the life of the building, independent of holding period. Assume the life of the building is twenty years, and the building purchaser expects to hold the investment for three years. A review of the tables in Appendix E shows OCTFs of about -7.5 in the twenty year case and -2 in the three year case. The investor should be willing to pay $7.5 more for the building with $1/year operating cost savings, regardless of holding period, as long as she is certain that in five years time, the second purchaser of the building will pay $7.5 - $2 = $5.5 more (in present value terms) to obtain the benefits of the remaining cash flows over the life of the building.

It is not known how well energy cost savings are capitalized into the value of new buildings. The range of possibilities is spanned in this analysis by three cases: zero assessment of efficiency's value, cost assessment, and value assessment (see below).

Grimm uses these parameters in a simple equation to assess the benefits of a proposed investment that will affect operating costs, rental income, or both. This equation is

$$\Delta BC = (RITF \times \Delta GPARI) + (OCTF \times \Delta OC) \tag{VI.1}$$

where

ΔBC = the justifiable change in building costs in response to a given change in rental income and operating costs ($/sf),

ΔGPARI = Change in first year gross possible rental income caused by a proposed design change ($/sf/yr),

ΔOC = Change in first-year annual operating cost caused by proposed design change ($/sf/yr),

RITF = Rental Income Tradeoff Factor (Years), and

OCTF = Operating Cost Tradeoff Factor (Years).

Grimm states that the RITF and OCTF are dimensionless. However, since they are analogous to the present worth factor, and since the present worth factor is equal to the Simple Payback Time (see Appendix A), RITFs and OCTFs are equivalent in function to SPTs. I therefore assign them dimensions of years, which fits nicely in Equation 1.

The spreadsheet model calculates OCTFs and RITFs by calculating the IRR for a given set of assumptions, and subtracting or adding (respectively) one dollar from annual operating costs or rental income (recall that the IRR is the discount rate that will make the Net Present Value of a given set of cash flows equal to zero). The model then recalculates the Net Present Value using the IRRs calculated in the first instance. This change in NPV for a one dollar change in operating costs or rental income is equal to the OCTF or the RITF.

Inputs

Input assumptions are summarized in **Tables VI.1** through **VI.6**.

Building Size

The building floor area definitions are taken from the PNL analysis in Chapter III (see Table III.1). The small building has about 2.1k net rentable square feet, the medium building has about 41k net rentable sf, while the large building has slightly less than 700k net rentable sf.

Building Energy Use

As shown in Chapter III, a reasonable estimate of the untapped efficiency potential in new offices would be a 30% reduction in energy costs at a three year simple payback time. The base case, or inefficient building, is assumed to correspond to current practice (ASHRAE Standard 90A-1980), while the efficient building has first year operating costs that are thirty percent lower than the base case building. The energy consumption numbers are taken from the PNL building simulations summarized in Table III.2, and the energy prices are 1988 values (adjusted to 1989$ using 5% inflation) from US DOE (1989c).

Building Capital Costs

Capital costs are based on Means Averages (Mahoney 1988, p.439) for small, medium, and large office buildings, adjusted by the factors for land cost, depreciable development cost, and non-depreciable development costs, which are taken from Grimm (1976). Parking cost is an approximation based on discussions with Professor Mary Comerio at the University of California, Berkeley School of Architecture. When incentives are applied to the first cost of the building, they are automatically included in the building "cost". Similarly, when assessed value of a more efficient building increases over that of a base case building, this incremental increase is added to building "cost".

Energy Prices

Energy Prices are 1988 values expressed in 1989 dollars.[4] Escalation rates for commercial-sector electricity and natural gas (1990 = year 1) were obtained from U.S. DOE (1989a), and are shown in **Table VI.3**. Price escalation rates for these fuels after 2000 were assumed to drop to the inflation rate by 2007.

Other Operating Costs

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[4] The energy prices should be those projected for 1990 in the Annual Energy Outlook 1989 (which is the source of the energy escalation rates).

I assumed that all non-energy related costs but property taxes (insurance, repairs, trash removal, cleaning, grounds maintenance, and miscellaneous) escalate at the rate of inflation (5%). Initial values for these and other costs, derived from Brambley (1988b) and IREM (1982), are contained in Tables VI.1 and VI.2. Property taxes, assumed to be 2% per year, are tied to the rate of capital appreciation.

Taxes

I assume a Federal income tax rate of 28%, and a State/local income tax rate of 7%, for a combined total marginal tax rate of 33%.[5] The 28% Federal tax rate is the marginal rate for most taxpayers.[6] The State/local tax number is a rough estimate based on a review of Mendoza (1989). A corporation that owned its own buildings would be more accurately represented by the Federal corporate tax rate of 34%, plus a State/local tax rate of 7%.

Real Estate Cycles

Real estate cycles are unique, and depend strongly on regional economic conditions and particular circumstances. It is therefore difficult to develop representative cycles. In lieu of realistic, general, real-estate cycles, I have chosen to use a constant vacancy rate of 7%, and capital appreciation and rent inflation rates equal to the general rate of inflation. The chosen vacancy rate is significantly lower than current U.S. average levels for offices (~20%), since the analysis is for *new* buildings, which can more easily attract tenants with their modern amenities.

Financing

The analysis assumes a fixed rate mortgage of 30 years, with a nominal interest rate of 10.625%. This interest rate corresponds to a real rate of 5.36% (assuming 5% inflation). The downpayment equals 20% of total building cost. When incentives are added to the first cost of the building (or the assessed value of the building increases because of assessment method), I assume that they do not affect the downpayment ratio (80% of the increased cost comes from a larger loan), and that they are depreciable (if fees).

The analysis of fixed-rate financing is the simplest case. Variations in the structure of commercial mortgages are almost infinite, as there are few Federal regulations to standardize them as there are for residential mortgages. For a review of historical and current trends affecting commercial mortgages, see Sternlight (1985) and Webb (1980).

Lease Terms

I have assumed a gross lease (landlord pays all operating expenses), which is the simplest situation to model. Discussions with real-estate professionals indicate that gross leases are the predominant type of leases for offices, though there are no easily available statistics summarizing lease types.

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[5] It is not correct to calculate the total marginal tax rate by simply adding federal and state tax rates, since state taxes are deductible on the federal return. The effective marginal tax rate equals 28% + 7% - 28%x7% or 33% (Rosen 1989).

[6] Single tax payers who make between $45k and $93k per year are subject to a 33% marginal Federal tax rate, while those making above or below this amount are subject to the 28% rate.

Gross Possible Income

I used the previous assumptions and chose a value for gross possible income that yielded base case IRRs of between 8% and 9% real, for holding periods of 10 to 20 years.

Assessment Method

There are three possible alternatives for an assessor confronted by a building with lower operating costs (these alternatives were presented in Chapter IV for use in calculating tax effects, and are summarized here for convenience):

1) the assessed value of the building can be unaffected by the increased efficiency, which might occur if the assessor did not have the information to evaluate the lower operating costs or did not believe the source of the available information. This is the best case for the building purchaser, because the lower operating costs could be obtained at zero additional cost. However, the purchase of a more efficient building in this case would be a chance occurrence without the existence of a building energy rating system.

2) the assessed value of the building can be based on capital cost, which is easily verifiable but does not reflect the true value. The package of efficiency options has a three year simple payback time, and saves thirty percent of first year energy expenses. The added capital cost therefore equals three years times 30% of annual first year energy expenses.

3) the building can be assigned the full *value* of the efficiency, which equals the added amount the purchaser is willing to pay to achieve one dollar of first year operating cost savings over the life of the building. This parameter is equal to the Operating Cost Tradeoff Factor (OCTF) discussed above, calculated for the building lifetime. I use an illustrative OCTF of 6 for purposes of assessing the added value of the efficiency.[7] This is the best case for the developer/seller of an efficient new building, since the price of the building is higher than in the other assessment cases. The benefits for the purchaser of the efficient new building depend on how well she negotiates with the seller.

Summary: Zero assessment means efficiency is ignored, cost assessment means it is assigned a value exactly equal to the increased first cost of the building, and value assessment means efficiency is assigned the full value, based on the net present value of cash flows over the building lifetime. These cases span the range of possibilities.

Policies

I have designed incentive policies for clarity of presentation, based on the formulas developed in Chapter V. I assume that externalities total 15% of energy prices for both electricity and direct use of natural gas. To calculate up-front incentives, I use a real discount rate of 6%, a lifetime of 20 years, and an assumption of equal annual payments occurring at midyear to calculate the Present Worth Factor or PWF.

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[7] This choice of OCTF for the building lifetime will serve to show that the effect of full value assessment can be important. A higher OCTF should probably be used in future analysis (i.e. one corresponding to 30 to 40 year lifetime).

Per Unit Fees : a 15% fee is applied to all energy use for both efficient and inefficient buildings. This policy corresponds to the incentive most commonly favored by economists to correct for externalities.

Up-Front Fees : the fees in this case are applied to all energy use, so that both efficient and inefficient buildings must pay fees. I multiplied 15% by the PWF (11.63) and then by the first year energy use to calculate the size of the fee. I assume that fees are added to the building cost and are depreciable. This policy corresponds to an consumption-based hookup fee.

Up-Front Rebates : the rebates in this case are disbursed to efficient buildings, and inefficient buildings are not directly affected by the policy. I multiplied 15% by the PWF (11.63) and then by the first year energy *savings* to calculate the size of the rebate. These rebates are comparable to the rebates disbursed by utilities to customers who adopt efficiency measures or who meet some target level of efficiency.

Revenue-Neutral Incentives : the rebates in this cases are disbursed to efficient buildings, while inefficient buildings must pay fees. I multiplied 15% by the PWF (11.63) then multiplied this product by the first year energy *savings*. I divided this product by 2 to calculate the size of the fees and rebates, assuming that the target consumption is equally spaced between the consumption of the efficient and inefficient buildings. The efficient building therefore receives rebates based on 7.5% of first year energy costs, and the inefficient buildings pay fees of the same magnitude.

The effects of the different policies and assessment methods on capital and operating costs are summarized in **Tables VI.4-VI.6**.

Outputs

Appendix E contains the runs completed using the inputs described above. All cash flows, IRRS, OCTFS, and RITFS, are in *real* terms (net of 5% inflation), and are based on the mid-year assumption for cash flows.[8] Thus they are fully comparable to the discount rates and Present Worth Factors calculated in Chapter I. Calculating IRRs based on mid-year assumptions is not trivial, since standard financial functions in commercially available spreadsheets are usually based on beginning or end of year assumptions.

Table VI.7 compares IRRs calculated using mid-year and end-of-year assumptions for the Large Office, Base Case, Value Assessment, and No Incentive Policy. The IRRs calculated using the mid-year assumption for annual cash flows are slightly higher than those calculated using end-of-year assumptions for holding periods longer than five years. This difference is not as dramatic as in the example given in Appendix A, because the IRRs are much lower and because only the annual cash flows (not building purchase and sale) are adjusted to reflect mid-year assumptions in this instance. The difference between assumptions is larger in percentage terms for the OCTFs than for the IRRs.

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[8] The initial purchase of the building occurs at the beginning of the first period, and the sale of the building occurs at the end of the last period. All annual cash flows occur in the middle of the year.

Operating Cost and Rental Income Tradeoff Factors

Operating Cost and Rental Income Tradeoff Factors are described above.

IRR Partitioning

Valachi (1978) and Zerbst (1980) present a methodology called *partitioning the IRR*, for analyzing risk from real estate investments. Any series of cash flows can be divided into the investment(s) and the return(s). The return can be further subdivided into proceeds from building sale and annual cash flow.[9] If the components of the return are discounted by the IRR, summed, and divided by this total, they yield the percentage of the total return attributable to each component.

IRR partitioning can be useful in investment analysis, since it lays bare heavy dependence on either building sale proceeds or cash flow. It is included in the summary tables since it shows how investors with short time horizons are more dependent on proceeds of sale than those with longer investment horizons. It also shows how different policies affect the balance between cash flow and proceeds of sale.

Some of the partitioned IRR numbers are negative, or are greater than 100%. These ostensibly anomalous results occur because annual cash flow is negative during the first few years in some cases. Thus, annual cash flow is a "drain" on the IRR and the total return in this case.

Change in Net Present Value/PV of Total Return

Investing in the more efficient building will yield a higher net present value than that calculated for the base case building, because an investment with a three year Simple Payback Time (SPT) yields a real return that is larger than the base case IRRs in these examples. One way to measure the significance of that change is to divide the change in NPV (calculated at an 8% real discount rate)[10] by the present value of the total base case return (net proceeds from sale plus cash flow). This indicator can be used to assess the relative and absolute size of the change in NPV when investing in a more efficient building, under a variety of different incentive policies. The larger this indicator is, the greater the incentive to reduce operating costs by 30%.

DISCUSSION OF RESULTS

Effect of Valuation Method

According to basic microeconomics, the price of a good (e.g., a new office building) should be bid up to reflect its net present value (NPV). Purchasers of that building should be willing to pay more if it is more efficient (ceterus paribus). In fact, they should be willing to pay up to OCTF(for building lifetime, L) times the expected operating

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[9] Valachi also included a component for tax savings. The 1986 Tax law eliminated many of the tax advantages of real estate (Shenkman 1987, Copley 1989), so I assume that only proceeds of sale and annual cash flow are of interest. Zerbst goes into more detail on how to partition the return even further. However, the simple two-component model will be adequate for this analysis.

[10] When appropriate, this section and the next use the convention of 8% real discount rate for real-estate investors adopted in Chapter IV.

cost savings. If the market is working properly, then the price of the building will be bid up, because every dollar spent on the building will save more than the OCTF(L), up to the last dollar spent, which will increase the NPV by the OCTF(L).

If the market is working properly, the purchaser of the building will not gain a windfall from the purchase of a more efficient building, since the price will be bid up to reflect the higher NPV. Whether the premium for the more efficient building will negate the entire benefit from the efficiency for the new owner depends on the negotiating skill of the buyer and seller. The benefit for the purchaser will not be as large as would be calculated from a simple engineering calculation. The other part of the benefit from the efficiency is captured by the developer.

If the new building purchaser is skeptical about the additional cash flows being capitalized in the resale value and will hold the building for less than five years, she will be reluctant to pay more than $2-3 for the $1/year operating cost savings. For example, Chapters IV and V described how the lack of building energy rating systems for new buildings and weather-normalized utility estimates of energy consumption for existing building make it extremely unlikely that the value of energy savings will be consistently capitalized in the value of buildings. In addition, the new building purchaser who expects a short holding period may be risk averse. Paying more than $3 for the $1/year operating cost savings entails heavy dependence on proceeds of building sale for future cash flows, and a risk averse investor may be wary of this dependence. As Table VI.12 shows, this dependence on proceeds of sale or capital appreciation declines for longer expected holding periods.

Both the 30% savings case IRRs and the total value of energy savings (as measured by change in NPV divided by total return) are highest for the case where efficiency does not increase the assessed value of the building, and lowest for the case where efficiency is assessed at full value. Value-based assessment makes efficiency less cost-effective for buyers and makes policy instruments affecting these buyers less effective.

Table VI.8 shows that 30% savings case IRRs (cost assessment) are 5-7% lower than for the zero assessment, while value assessment IRRs are 10-13% lower than in the zero assessment case.[11] These differences are insensitive to the imposition of various incentive policies.

Table VI.9 shows the change in NPV divided by total return, at an 8% real discount rate. This Table measures the financial efficacy of different policies relative to the zero assessment case. In all instances, the *No Policy* case is most affected by the valuation methodology, and the *Up-Front Fee* is least affected.

Operating Costs vs. Rental Income

Tables VI.10 and **VI.11** show the OCTFs and RITFs in a summary fashion. According to this analysis, and based on the assumptions described above, it is uniformly more valuable to decrease operating costs than to increase rental income (|OCTF|>RITF). This preference for operating cost reductions is not a strong one, since the |OCTFs| are typically no more than 15% higher than the RITFs for the small building, and no more than

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[11] Except where otherwise stated, the generalizations about ΔNPV, IRRs, OCTFs, and RITFs are based on simple averages over specified holding periods (e.g., 3 to 20 years in Table VI.8).

9% higher for the medium and large buildings. According to test runs (not shown in Appendix E) even if energy prices are expected to escalate at the same rate as rental income (the rate of inflation in this case) the |OCTFs| are higher than the RITFs. This result agrees qualitatively with the OCTFs and RITFs calculated by Grimm for a large office building, which also showed |OCTFs| as slightly larger than RITFs.

IRR Partitioning

Table VI.12 shows partitioned IRRs for the Base Case, Large Building, Value Assessment, *No Policy* applied (Appendix E contains the same parameters for all cases). This Table shows that investors who expect to hold the building for ten to twenty years are much more dependent on annual cash flows than investors with shorter time horizons. Investors who expect rapid capital appreciation over a short period, and whose total return is heavily dependent on such appreciation, are not likely to be strongly affected by incentives that affect annual cash flows, unless those investors are certain that future cash-flow benefits will be capitalized in the building sale price.

The differences in the dependence on the net proceeds of building sale have important consequences for analysis of market failures and investor response to incentives. It is perfectly rational for a short-term investor who values capital appreciation to ignore substantial operating cost savings when they will not be capitalized in the building sale price, since the bulk of the annual cash flow benefits from these savings will not accrue to the short term investor, and the building sale price will not be increased by the added efficiency.

Effectiveness of Policies

As a measure of the effectiveness of a given policy, **Table VI.13** shows the change in Net Present Value (NPV) from the base to 30% savings case divided by total return, relative to the *No Policy* Case. A larger percentage implies a larger incentive to adopt the more efficient building technology. The *Up-Front Rebate* policy creates the smallest incentive to achieve 30% savings, *Revenue-Neutral Fees and Rebates* are next, followed by *Per Unit Fees* and *Up-Front Fees*.

Table VI.14 shows the other part of the story: the fees create a larger differential in NPV by reducing the overall NPV by 5-15% of its *No Policy* case value. They reduce the IRR of the efficient building less than the IRR of the Base Case building (in percentage terms). The *Up-Front Rebate* does not affect the Base Case IRRs and improves the 30% Savings Case IRRs. The *Revenue-Neutral* policy reduces IRRs for the Base Case building and improves them for the 30% Savings Case. The *Revenue-Neutral* policy, if properly administered, should have little effect on the total return from all new offices, while the rebates will improve total returns overall, and fees will reduce the total return.

A building that is not paying the societal cost of pollution is in effect being subsidized by society. It may therefore be economically efficient to impose fees and reduce the IRRs for these buildings. However, it is much easier politically to give rebates than to impose fees.

CONCLUSIONS

Valuation method can have an important influence on the effectiveness of incentives and on the overall incentive for developers to create an efficient building and an investor to purchase one. The valuation method is likely to vary substantially between locales, depending on market conditions, the funding and staffing of the firms and government agencies creating these assessments, and the existence of objective, credible ways to measure new building consumption in terms comparable to usage in existing buildings (such as a building energy rating system). More research is needed to determine which valuation methods are prevalent and the reasons for their predominance.

Per Unit and *Up-Front Fees*, because they are based on total energy use and not on energy savings, will create a larger difference in Net Present Value between efficient and inefficient buildings than will *Up-Front Rebates* and *Revenue-Neutral Incentives*. *Fees* will, however, have a negative effect on overall returns, while *Rebates* and *Revenue-Neutral Incentives* will not. If the incentive corrects for externalities, reducing the return for new offices may be economically efficient. However, it is politically more difficult to impose fees than to give rebates.

Table VI.1. Building Size-Independent Input Assumptions

Financial Parameters		**Base Capital Costs**	
Property Tax Rate	2%	Building Cost	65.4%
Owner'sEffective Tax Rate	33%	Land Cost	10.5%
Useful/Tax Life of Bdg (yrs)	31.5	Depreciable Dev Cost	17.6%
		NonDepreciable Dev Cost	6.5%
Closing costs on Sale	1%	Total	100.0%
Mortgage Closing Costs ($)	2000		
		Ratio of Land to Bdg Cost	16%
Nominal Mortgage Interest Rate	10.625%		
Mortgage Term (years)	30	Ratio of Parking Cost to Bdg Cost	10%
Downpayment (% of Total Cost)	20%	Ratio of Depreciable Development Cost to Bdg Cost	17%
Electricity Price (1989$/kWh)	0.074		
Gas Price (1989 $/MMBtu)	4.862	Ratio of Non-Depreciable Development Cost to Bdg Cost	10%
Operating Costs	$/Nsf		
Yr 1 Repairs Expense	1.88	Ratio of Rentable to Gross Area	86%
Yr 1 Cleaning Expense	1.50		
Yr 1 Grounds Upkeep	0.43		
Yr 1 Miscellaneous Expense	1.17		

Miscellaneous expense includes trash collection. Parking cost is assumed to be depreciable. Bdg = Building. All costs are in 1989$.

Table VI.2. Building Size-Dependent Input Assumptions

	Small	*Medium*	*Large*
Area (Gross sf)	2500	48644	797124
Net rentable area (Net sf)	2150	41834	685527
Base Building Capital Costs ($/Nsf)	66.57	71.69	88.55
Land Cost	10.65	11.47	14.17
Depreciable Development Cost (Incl Parking)	17.97	19.36	23.91
Non-Depreciable Development Cost	6.66	7.17	8.85
Total	101.85	109.68	135.48
Total Energy Cost($/Nsf/yr)	1.92	1.62	1.33
Electricity Costs (% of Total)	*79.6%*	*98.5%*	*96.2%*
Gas Costs (% of Total)	*20.4%*	*1.5%*	*3.8%*
Gross Possible Income ($/Nsf/yr)	18.50	19.00	21.50
Yr 1 Insurance Expense (% of GPI)	1.5%	1.0%	0.5%
Commission paid on Sale (% of Cost)	6.0%	5.0%	3.0%

All costs are in 1989$.

Table VI.3. Nominal Annual Escalation Rates in Commercial-Sector Energy Prices

Year	*Electricity*	*Natural Gas*
1990	4.6%	7.5%
1991	4.7%	7.2%
1992	4.6%	9.2%
1993	3.6%	9.2%
1994	4.8%	9.5%
1995	4.7%	7.9%
1996	5.2%	12.6%
1997	5.5%	7.8%
1998	5.9%	7.2%
1999	5.7%	9.9%
2000	5.8%	7.1%
2001	5.5%	7.1%
2002	5.3%	6.6%
2003	5.0%	6.3%
2004	5.0%	6.1%
2005	5.0%	5.5%
2006	5.0%	5.3%
2007	5.0%	5.0%
2008	5.0%	5.0%
2009	5.0%	5.0%

Source: U.S. DOE (1989a), for 1990-2000 forecast.
Assumed Inflation Rate = 5%.

Table VI.4. Effect of Assessment Type and Incentive Policies on Building Cost and First Year Energy Costs: Small Building

Small Building (1989 $)	*Building Cost* $/Nsf	*First Yr Energy Cost* $/Nsf/yr	*Building Cost* % of Base	*First Yr Energy Cost* % of Base
Base Case				
No Incentive	101.85	1.92	100.0%	100.0%
Per Unit Fee	101.85	2.20	100.0%	115.0%
Up-Front Fee	105.10	1.92	103.2%	100.0%
Up-Front Rebate	101.85	1.92	100.0%	100.0%
Revenue-Neutral Incentives	102.34	1.92	100.5%	100.0%
30% Savings, Zero Assessment				
No Incentive	101.85	1.34	100.0%	70.0%
Per Unit Fee	101.85	1.54	100.0%	80.5%
Up-Front Fee	104.13	1.34	102.2%	70.0%
Up-Front Rebate	100.88	1.34	99.0%	70.0%
Revenue-Neutral Incentives	101.36	1.34	99.5%	70.0%
30% Savings, Cost Assessment				
No Incentive	103.58	1.34	101.7%	70.0%
Per Unit Fee	103.58	1.54	101.7%	80.5%
Up-Front Fee	105.85	1.34	103.9%	70.0%
Up-Front Rebate	102.60	1.34	100.7%	70.0%
Revenue-Neutral Incentives	103.09	1.34	101.2%	70.0%
30% Savings, Value Assessment				
No Incentive	105.30	1.34	103.4%	70.0%
Per Unit Fee	105.30	1.54	103.4%	80.5%
Up-Front Fee	107.58	1.34	105.6%	70.0%
Up-Front Rebate	104.32	1.34	102.4%	70.0%
Revenue-Neutral Incentives	104.81	1.34	102.9%	70.0%

All incentives are based on an externalities surcharge of 15% of the price of energy. This surcharge is then applied directly to the energy price for the Per Unit Fee, or is present valued (6% real, 20 years) and is added to the cost of the building based on total energy costs (for Up-Front Fees). Up-Front Rebates and Revenue-Neutral Incentives use the same present worth factor but are based on the energy *savings*. Revenue-Neutral Incentives divide the size of the Up-Front Rebate by two and apply that value as a surcharge on the inefficient building and as a rebate for the efficient building.

Table VI.5. Effect of Assessment Type and Incentive Policies on Building Cost and First Year Energy Costs: Medium Building

Medium Building (1989 $)	*Building Cost* $/Nsf	*First Yr Energy Cost* $/Nsf/yr	*Building Cost* % of Base	*First Yr Energy Cost* % of Base
Base Case				
No Incentive	109.68	1.62	100.0%	100.0%
Per Unit Fee	109.68	1.86	100.0%	115.0%
Up-Front Fee	112.43	1.62	102.5%	100.0%
Up-Front Rebate	109.68	1.62	100.0%	100.0%
Revenue-Neutral Incentives	110.09	1.62	100.4%	100.0%
30% Savings, Zero Assessment				
No Incentive	109.68	1.13	100.0%	70.0%
Per Unit Fee	109.68	1.30	100.0%	80.5%
Up-Front Fee	111.60	1.13	101.8%	70.0%
Up-Front Rebate	108.86	1.13	99.2%	70.0%
Revenue-Neutral Incentives	109.27	1.13	99.6%	70.0%
30% Savings, Cost Assessment				
No Incentive	111.14	1.13	101.3%	70.0%
Per Unit Fee	111.14	1.30	101.3%	80.5%
Up-Front Fee	113.06	1.13	103.1%	70.0%
Up-Front Rebate	110.31	1.13	100.6%	70.0%
Revenue-Neutral Incentives	110.72	1.13	101.0%	70.0%
30% Savings, Value Assessment				
No Incentive	112.59	1.13	102.7%	70.0%
Per Unit Fee	112.59	1.30	102.7%	80.5%
Up-Front Fee	114.52	1.13	104.4%	70.0%
Up-Front Rebate	111.77	1.13	101.9%	70.0%
Revenue-Neutral Incentives	112.18	1.13	102.3%	70.0%

All incentives are based on an externalities surcharge of 15% of the price of energy. This surcharge is then applied directly to the energy price for the Per Unit Fee, or is present valued (6% real, 20 years) and is added to the cost of the building based on total energy costs (for Up-Front Fees). Up-Front Rebates and Revenue-Neutral Incentives use the same present worth factor but are based on the energy *savings*. Revenue-Neutral Incentives divide the size of the Up-Front Rebate by two and apply that value as a surcharge on the inefficient building and as a rebate for the efficient building.

Table VI.6. Effect of Assessment Type and Incentive Policies on Building Cost and First Year Energy Costs: Large Building

Large Building (1989 $)	*Building Cost* $/Nsf	*First Yr Energy Cost* $/Nsf/yr	*Building Cost* % of Base	*First Yr Energy Cost* % of Base
Base Case				
No Incentive	135.48	1.33	100.0%	100.0%
Per Unit Fee	135.48	1.53	100.0%	115.0%
Up-Front Fee	137.74	1.33	101.7%	100.0%
Up-Front Rebate	135.48	1.33	100.0%	100.0%
Revenue-Neutral Incentives	135.82	1.33	100.3%	100.0%
30% Savings, Zero Assessment				
No Incentive	135.48	0.93	100.0%	70.0%
Per Unit Fee	135.48	1.07	100.0%	80.5%
Up-Front Fee	137.06	0.93	101.2%	70.0%
Up-Front Rebate	134.80	0.93	99.5%	70.0%
Revenue-Neutral Incentives	135.14	0.93	99.7%	70.0%
30% Savings, Cost Assessment				
No Incentive	136.68	0.93	100.9%	70.0%
Per Unit Fee	136.68	1.07	100.9%	80.5%
Up-Front Fee	138.26	0.93	102.1%	70.0%
Up-Front Rebate	136.00	0.93	100.4%	70.0%
Revenue-Neutral Incentives	136.34	0.93	100.6%	70.0%
30% Savings, Value Assessment				
No Incentive	137.88	0.93	101.8%	70.0%
Per Unit Fee	137.88	1.07	101.8%	80.5%
Up-Front Fee	139.46	0.93	102.9%	70.0%
Up-Front Rebate	137.20	0.93	101.3%	70.0%
Revenue-Neutral Incentives	137.54	0.93	101.5%	70.0%

All incentives are based on an externalities surcharge of 15% of the price of energy. This surcharge is then applied directly to the energy price for the Per Unit Fee, or is present valued (6% real, 20 years) and is added to the cost of the building based on total energy costs (for Up-Front Fees). Up-Front Rebates and Revenue-Neutral Incentives use the same present worth factor but are based on the energy *savings*. Revenue-Neutral Incentives divide the size of the Up-Front Rebate by two and apply that value as a surcharge on the inefficient building and as a rebate for the efficient building.

Table VI.7. Illustrative Comparison of End-of-Year to Middle-of-Year IRRs and OCTFs

Holding Period	*End-Year Real IRR*	*Mid-Year Real IRR*	*Mid/End*	*End-Year OCTFs*	*Mid-Year OCTFs*	*Mid/End*
20	8.770%	9.014%	102.8%	-7.27	-7.77	106.9%
19	8.760%	9.000%	102.7%	-7.15	-7.64	106.9%
18	8.745%	8.980%	102.7%	-7.02	-7.51	107.0%
17	8.724%	8.953%	102.6%	-6.89	-7.36	106.8%
16	8.694%	8.916%	102.6%	-6.74	-7.20	106.8%
15	8.654%	8.869%	102.5%	-6.58	-7.03	106.8%
14	8.601%	8.807%	102.4%	-6.41	-6.84	106.7%
13	8.532%	8.729%	102.3%	-6.22	-6.64	106.8%
12	8.448%	8.631%	102.2%	-5.88	-6.35	108.0%
11	8.355%	8.517%	101.9%	-5.52	-5.96	108.0%
10	8.250%	8.517%	103.2%	-5.13	-5.54	108.0%
9	8.129%	8.242%	101.4%	-4.72	-5.10	108.1%
8	7.980%	8.065%	101.1%	-4.29	-4.64	108.2%
7	7.791%	7.844%	100.7%	-3.83	-4.15	108.4%
6	7.535%	7.552%	100.2%	-3.35	-3.63	108.4%
5	7.162%	7.141%	99.7%	-2.86	-3.09	108.0%
4	6.572%	6.510%	99.1%	-2.34	-2.53	108.1%
3	5.519%	5.418%	98.2%	-1.8	-1.93	107.2%
2	3.277%	3.157%	96.3%	-1.24	-1.31	105.6%
1	-3.693%	-3.716%	100.6%	-0.66	-0.67	101.5%

Base Case, Value Assessment, No Incentive Applied, Large Building.
Mid-year assumption: Annual cash flows occur at the middle of the year, but building purchase occurs at the beginning of year 1 and building sale occurs at the end of year.
End-year assumption: All cash flows occur at the end of the year, except for building purchase, which occurs at the beginning of year 1.

Table VI.8. Effect of Valuation Methodology: Ratio of 30% Savings Case IRRs Relative to Zero Assessment

	Assessment Type	*No Policy*	*Per Unit Fee*	*Up-Front Fee*	*Up-Front Rebate*	*Fees/Rebates*
Small	Zero	100.0%	100.0%	100.0%	100.0%	100.0%
	Cost	94.1%	93.6%	93.8%	94.2%	94.1%
	Value	88.4%	87.5%	87.9%	88.6%	88.5%
Medium	Zero	100.0%	100.0%	100.0%	100.0%	100.0%
	Cost	95.1%	94.9%	95.0%	95.1%	95.1%
	Value	90.4%	90.0%	90.2%	90.5%	90.4%
Large	Zero	100.0%	100.0%	100.0%	100.0%	100.0%
	Cost	96.9%	96.9%	96.9%	96.9%	96.9%
	Value	93.9%	93.8%	93.9%	93.9%	93.9%

Numbers compare the effect of valuation methodology on the IRRs of the efficient (30% Savings Case) building. Base Case (No energy efficiency) is unaffected by valuation methodology. All numbers represent simple averages over holding periods of 3 to 20 years. Years 1 and 2 have been omitted because the IRRs are sometimes negative in these years, which could lead to anomalous results.

Table VI.9. Effect of Valuation Methodology: Ratio of ΔNPV to PV of Total Return, Relative to Zero Assessment

	Assessment Type	*No Policy*	*Per Unit Fee*	*Up-Front Fee*	*Up-Front Rebate*	*Fees/Rebates*
Small	Zero	100.0%	100.0%	100.0%	100.0%	100.0%
	Cost	71.1%	74.9%	77.4%	75.2%	75.2%
	Value	42.3%	49.8%	54.9%	50.4%	50.4%
Medium	Zero	100.0%	100.0%	100.0%	100.0%	100.0%
	Cost	69.8%	73.7%	76.7%	74.3%	74.3%
	Value	39.3%	47.3%	53.2%	48.4%	48.4%
Large	Zero	100.0%	100.0%	100.0%	100.0%	100.0%
	Cost	70.1%	74.1%	76.9%	74.5%	74.5%
	Value	40.3%	48.1%	53.7%	49.0%	49.0%

Numbers compare the effect of valuation methodology on the total incentive to buy an efficient (30% Savings Case) building instead of the Base Case building. Base Case (No energy efficiency) is unaffected by valuation methodology. Discount rate used to calculate NPV is 8% real. All numbers represent simple averages over holding periods of 3 to 20 years. Years 1 and 2 have been omitted because the IRRs are sometimes negative in these years, which could lead to anomalous results.

Table VI.10. Operating Cost Tradeoff Factors (OCTFs) with No Policies Implemented, for Different Holding Periods

OCTFs	*Building Size*	*Assessment Type*	*Holding Period*			
			3-5 Yrs	*6-10 Yrs*	*11-15 Yrs*	*16-20 Yrs*
Base Case, No Policy	Small		-2.43	-4.03	-5.43	-6.37
	Medium		-2.56	-4.66	-6.49	-7.37
	Large		-2.52	-4.61	-6.56	-7.50
30% Savings Case	Small	Zero	-2.35	-3.82	-5.07	-5.87
		Cost	-2.37	-3.88	-5.17	-6.01
		Value	-2.39	-3.94	-5.27	-6.15
	Medium	Zero	-2.52	-4.50	-5.94	-6.70
		Cost	-2.53	-4.55	-6.02	-6.82
		Value	-2.54	-4.61	-6.25	-7.08
	Large	Zero	-2.49	-4.52	-6.27	-7.08
		Cost	-2.50	-4.55	-6.33	-7.17
		Value	-2.51	-4.58	-6.39	-7.25

Indices	*Building Size*	*Assessment Type*	*Holding Period*			
			3-5 Yrs	*6-10 Yrs*	*11-15 Yrs*	*16-20 Yrs*
Base Case, No Policy	Small		100.0%	165.9%	223.6%	262.5%
	Medium		100.0%	182.1%	253.8%	288.2%
	Large		100.0%	183.2%	260.7%	297.7%
30% Savings Case	Small	Zero	100.0%	162.7%	215.7%	250.0%
		Cost	100.0%	163.7%	217.9%	253.5%
		Value	100.0%	164.6%	220.2%	257.0%
	Medium	Zero	100.0%	178.8%	235.6%	266.0%
		Cost	100.0%	179.7%	237.9%	269.3%
		Value	100.0%	181.1%	245.8%	278.2%
	Large	Zero	100.0%	181.4%	251.4%	284.3%
		Cost	100.0%	182.0%	253.1%	286.6%
		Value	100.0%	182.5%	254.6%	289.0%

Numbers compare the effect of holding period on the OCTF, which is the number of dollars that the capital cost of the building may be increased for a one dollar reduction in first year operating expenses. All numbers represent simple averages over different holding periods. Years 1 and 2 have been omitted because the IRRs are sometimes negative in these years, which could lead to anomalous results.

Table VI.11. Rental Income Tradeoff Factors (RITFs) with No Policies Implemented, for Different Holding Periods

OCTFs	*Building Size*	*Assessment Type*	*Holding Period*			
			3-5 Yrs	*6-10 Yrs*	*11-15 Yrs*	*16-20 Yrs*
Base Case, No Policy	Small		2.21	3.64	4.83	5.62
	Medium		2.37	4.33	6.02	6.82
	Large		2.34	4.30	6.09	6.94
30% Savings Case	Small	Zero	2.14	3.46	4.52	5.19
		Cost	2.16	3.51	4.61	5.31
		Value	2.18	3.56	4.69	5.43
	Medium	Zero	2.33	4.19	5.50	6.19
		Cost	2.34	4.23	5.58	6.30
		Value	2.35	4.28	5.80	6.54
	Large	Zero	2.32	4.22	5.82	6.56
		Cost	2.32	4.24	5.88	6.63
		Value	2.33	4.27	5.93	6.71

Indices	*Building Size*	*Assessment Type*	*Holding Period*			
			3-5 Yrs	*6-10 Yrs*	*11-15 Yrs*	*16-20 Yrs*
Base Case, No Policy	Small		100.0%	164.4%	218.3%	253.7%
	Medium		100.0%	183.0%	254.2%	287.8%
	Large		100.0%	183.8%	260.4%	296.3%
30% Savings Case	Small	Zero	100.0%	161.4%	210.8%	242.2%
		Cost	100.0%	162.3%	212.9%	245.4%
		Value	100.0%	163.1%	215.0%	248.6%
	Medium	Zero	100.0%	179.6%	236.0%	265.7%
		Cost	100.0%	180.5%	238.2%	268.9%
		Value	100.0%	181.9%	246.2%	277.8%
	Large	Zero	100.0%	182.0%	251.2%	283.1%
		Cost	100.0%	182.5%	252.8%	285.4%
		Value	100.0%	183.1%	254.4%	287.6%

Numbers compare the effect of holding period on the RITF, which is the number of dollars that the capital cost of the building may be increased for a one dollar increase in first year gross possible income. All numbers represent simple averages over different holding periods. Years 1 and 2 have been omitted because the IRRs are sometimes negative in these years, which could lead to anomalous results.

Table VI.12. IRR Partitioning for Large Office, Zero Assessment, 33% Tax Rate,No Policy

	Base Case			*30% Savings Case*		
Holding Period--Yrs	*Real IRR*	*Proceeds of Sale*	*Cash Flow*	*Real IRR*	*Proceeds of Sale*	*Cash Flow*
20	9.01%	44.6%	55.4%	9.80%	38.8%	61.2%
19	9.00%	47.1%	52.9%	9.79%	41.3%	58.7%
18	8.98%	49.8%	50.2%	9.79%	43.9%	56.1%
17	8.95%	52.7%	47.3%	9.77%	46.6%	53.4%
16	8.92%	55.7%	44.3%	9.75%	49.5%	50.5%
15	8.87%	58.8%	41.2%	9.72%	52.5%	47.5%
14	8.81%	62.1%	37.9%	9.67%	55.8%	44.2%
13	8.73%	65.6%	34.4%	9.61%	59.2%	40.8%
12	8.63%	69.6%	30.4%	9.53%	62.7%	37.3%
11	8.52%	74.6%	25.4%	9.43%	66.6%	33.4%
10	8.52%	70.1%	29.9%	9.43%	62.6%	37.4%
9	8.24%	84.6%	15.4%	9.16%	76.9%	23.1%
8	8.07%	89.5%	10.5%	8.99%	82.1%	17.9%
7	7.84%	94.1%	5.9%	8.78%	87.0%	13.0%
6	7.55%	98.3%	1.7%	8.49%	91.7%	8.3%
5	7.14%	101.8%	-1.8%	8.09%	96.0%	4.0%
4	6.51%	104.4%	-4.4%	7.47%	99.5%	0.5%
3	5.42%	106.0%	-6.0%	6.39%	102.0%	-2.0%
2	3.16%	106.0%	-6.0%	4.13%	103.2%	-3.2%
1	-3.7%	104.2%	-4.2%	-2.8%	102.7%	-2.7%

Table shows for different holding periods the percent of total return attributable to proceeds of sale and annual cash flow. For a sale after a short holding period, purchaser is heavily dependent on proceeds of sale, while sales after longer holding periods are more dependent on annual cash flow. 30% Savings case shows higher IRRs and more dependence in annual cash flows, as we expect. For Base Case building, the annual cash flow acts as a drain on the IRR in years 1 to 5, which explains the ostensibly anomalous IRR partitioning results in this period.

Table VI.13. Effect of Valuation Methodology: Ratio of ∆NPV to PV of Total Return, Relative to *No Policy* Case

	Assessment Type	*No Policy*	*Per Unit Fee*	*Up-Front Fee*	*Up-Front Rebate*	*Fees/Rebates*
Small	Zero	100.0%	123.2%	132.9%	116.3%	117.0%
	Cost	100.0%	129.7%	144.7%	123.0%	123.7%
	Value	100.0%	145.5%	173.5%	139.4%	140.2%
Medium	Zero	100.0%	123.5%	136.5%	117.0%	118.1%
	Cost	100.0%	130.4%	149.9%	124.5%	125.6%
	Value	100.0%	148.7%	185.2%	144.4%	145.6%
Large	Zero	100.0%	120.2%	133.0%	116.8%	117.5%
	Cost	100.0%	127.0%	145.8%	124.1%	124.7%
	Value	100.0%	143.6%	177.5%	142.1%	142.9%

Numbers compare the effect of incentive policies on the total incentive to buy an efficient (30% Savings Case) building instead of the Base Case building. Discount rate used to calculate NPV is 8% real. All numbers represent simple averages over holding periods of 3 to 20 years. Years 1 and 2 have been omitted because the IRRs are sometimes negative in these years, which could lead to anomalous results.

Table VI.14. Ratio of Policy Case IRRs to *No Policy* Case IRRs

Base Case	*Assessment Type*	*No Policy*	*Per Unit Fee*	*Up-Front Fee*	*Up-Front Rebate*	*Fees/Rebates*
Small	Zero	100.0%	85.6%	85.0%	100.0%	97.7%
	Cost	100.0%	85.6%	85.0%	100.0%	97.7%
	Value	100.0%	85.6%	85.0%	100.0%	97.7%
Medium	Zero	100.0%	90.8%	89.7%	100.0%	98.4%
	Cost	100.0%	90.8%	89.7%	100.0%	98.4%
	Value	100.0%	90.8%	89.7%	100.0%	98.4%
Large	Zero	100.0%	94.6%	93.9%	100.0%	99.1%
	Cost	100.0%	94.6%	93.9%	100.0%	99.1%
	Value	100.0%	94.6%	93.9%	100.0%	99.1%

30% Savings Case	*Assessment Type*	*No Policy*	*Per Unit Fee*	*Up-Front Fee*	*Up-Front Rebate*	*Fees/Rebates*
Small	Zero	100.0%	93.0%	94.5%	103.5%	101.7%
	Cost	100.0%	92.6%	94.3%	103.6%	101.8%
	Value	100.0%	92.0%	93.9%	103.8%	101.9%
Medium	Zero	100.0%	94.5%	95.5%	102.9%	101.4%
	Cost	100.0%	94.3%	95.4%	102.9%	101.4%
	Value	100.0%	94.1%	95.3%	103.0%	101.5%
Large	Zero	100.0%	96.5%	97.1%	101.8%	100.9%
	Cost	100.0%	96.4%	97.1%	101.8%	100.9%
	Value	100.0%	96.4%	97.1%	101.8%	100.9%

Numbers compare the effect of incentive policies on the IRR for Base Case and 30% Savings Case buildings, relative to the *No Policy* case. All numbers represent simple averages over holding periods of 3 to 20 years. Years 1 and 2 have been omitted because the IRRs are sometimes negative in these years, which could lead to anomalous results.

CHAPTER VII: SUMMARY OF CONCLUSIONS

This dissertation has investigated market failures and regulatory distortions affecting the energy efficiency of new office buildings in the United States, and prescribed policies in response to each failure or distortion. The most important conclusions of this analysis are:

(1) Simple payback times of three years or less are the rule and not the exception for most Investors deciding on energy efficiency investments in the commercial sector. Such simple payback times correspond to real discount rates of 39% or more.

(2) Inefficient core-coil ballasts would have comprised about 90% of the market for such ballasts in 1987, had minimum efficiency standards not been enacted in five populous states. The market discount rate implied for purchasers of inefficient core-coil ballasts (instead of efficient core-coil ballasts) is about 60% real, using conservative assumptions. A market discount rate that is much higher than societal discount rates (typically 3-6% real) indicates that market failures or regulatory distortions must be inhibiting the adoption of efficient core-coil ballasts. Since such ballasts are found in every office building, it is plausible to argue that market failures and regulatory distortions affecting these ballasts are also likely to affect other efficiency technologies.

(3) The electricity sector will be the dominant source of growth in major pollutants (1990-91), contributing about 74% of expected growth in CO_2 emissions, 57% of growth in NO_X, and 67% of the growth in SO_X. The commercial sector will contribute about 29% of the growth in CO_2, 20% of the growth in NO_X, and 22% of the growth in SO_X. New offices will contribute 8% of the growth in CO_2 emissions, 6.1% of the growth in NO_X emissions, and 7% of growth in SO_2 emissions.

(4) Technical evidence can be used to infer market failures. This evidence typically consists of engineering calculations of the cost-effectiveness of particular energy efficiency technologies. Users of these calculations for this purpose must ensure that the technology in question is not being adopted even though it is widely available, that it has been available for many years, that it does not involve hidden costs, and that all its parameters are correctly specified.

(5) The studies and calculations cited in Chapter III indicate that the conservation/energy cost reduction potential in new office buildings (relative to current practice) implies at least 30 percent savings in annual energy costs. These cost savings can be achieved by investing in efficiency with a simple payback time of three years or less.

(6) Designing buildings to take full advantage of lighting control strategies requires substantially more skill and effort than designing "current practice" buildings that are similar to the last building designed, since they involve complex interactions between lighting, fenestration, and HVAC systems. Many architects and engineers are not familiar with the technologies involved (even though daylighting and occupancy sensors have been available and cost effective for many years). There is risk involved in implementing an unfamiliar technology, and many architects and engineers are reluctant to specify "innovative" technologies for fear of lawsuits.

(7) Market failures and regulatory distortions likely to have important influences on new office energy efficiency include information costs, asymmetric information, bounded rationality, satisficing behavior, risk aversion, negative externalities from electric power

production, public goods (research and development, and education/training), regulatory bias against conservation, average cost pricing, obsolete building codes, subsidies for established energy sources, income taxes, and property taxes.

(8) Energy use is of secondary concern to people involved in the real estate industry. Their training and interests focus on building, buying, and selling real estate: not on operating costs but on the profits those operating costs affect. For this reason, transaction costs are likely to be a larger fraction of the potential cost savings than in the case where an institution is devoted to energy efficiency, and its employees are trained to maximize cost-effective efficiency of buildings. The point is not that developers should make efficiency their main preoccupation, only that under such circumstances, transaction costs will be relatively important.

(9) The absolute minimum set of policies (i.e. those required for the market for energy efficiency in new offices to function properly) includes:

a) instituting building energy rating systems, and encouraging banks to use them in their lending calculations.

b) creating and distributing weather-normalized utility billing data

c) compiling costs and effectiveness of efficiency technologies, to reduce search costs.

d) correcting for externalities using appropriate incentives.

e) eliminating the utility's disincentive to conserve.

f) promoting the adoption of TOU meters in small and medium-sized offices.

g) eliminating production subsidies for established energy production technologies.

h) increasing funding for energy efficiency R&D, both for new technologies and programs.

i) making credible design assistance information available to architects at an early stage in the design process (especially in those regions that do not yet have active energy consulting industries).

j) developing visually-oriented, computer-based design tools for architects that allow easy and rapid testing of the energy implications of various design approaches.

No jurisdiction currently has all these policies in place. Some of the programs require Federal initiatives, some require state action, and some can most effectively be implemented at the utility level.

(10) Only a coordinated set of policies that attack market failures at all stages in the development process simultaneously will succeed. Giving the developer a financial incentive to improve efficiency will only yield results if the architect/engineer knows about the latest technology and is able (and willing) to incorporate it into her designs, and the contractor knows where to purchase and how to install these technologies correctly. Policies that try to redress problems at single links in the decision process will encounter resistance and will be less effective than those implemented in concert.

(11) Programs operated in parallel can benefit each other. For example, utilities will acquire information about utility customers when designing and operating efficiency programs, which can then be used to target incentives for greatest effectiveness (this customer information will also be useful to utilities as deregulation of generation continues and competition increases). Building energy rating systems can be implemented simultaneously with performance-oriented building efficiency standards, at low marginal cost. With such a rating system in place, banks and other lending agencies can more accurately estimate the operating costs of a new building, and a larger loan can be arranged. Rebates can be used in conjunction with design assistance or other information programs to encourage more rapid adoption of efficient technologies than information alone would induce. Through such synergisms, market barriers can be most rapidly overcome.

(12) The assessment method used to value efficiency for building sale can have an important influence on the effectiveness of incentives and on the overall incentive for developers to create an efficient building and an investor to purchase one. The valuation method is likely to vary substantially between locales, depending on market conditions, the funding and staffing of the firms and government agencies creating these assessments, and the existence of objective, credible ways to measure new building consumption in terms comparable to usage in existing buildings (such as a building energy rating system). More research is needed to determine which valuation methods are prevalent and the reasons for their predominance.

(13) *Per Unit* and *Up-Front Fees*, because they are based on total energy use and not on energy savings, will create a larger difference in Net Present Value between efficient and inefficient buildings than will *Up-Front Rebates* and *Revenue-Neutral Incentives*. *Fees* will, however, have a negative effect on overall returns, while *Rebates* and *Revenue-Neutral Incentives* will not. If the incentive corrects for externalities, reducing the return for new offices may be economically efficient. However, it is politically more difficult to impose fees than to give rebates.

APPENDIX A: RELATIONSHIP BETWEEN SIMPLE PAYBACK TIME (SPT) AND INTERNAL RATE OF RETURN (IRR)

John Plunkett uses a discounted cash flow approach to calculate the relationship between SPT and IRR (Plunkett and Chernick 1988), but assumes that the benefits accrue at mid year, instead of the beginning or end of the year. This assumption makes a surprising difference in the calculation of the IRR (Plunkett 1989). Plunkett assumes 5% inflation in his calculation. However, I have reproduced his calculation in **Table A.1** without inflation for simplicity. The IRRs are therefore in real terms.

Table A.1 shows the cash flow of a conservation investment that lasts for 30 years, costs $1000, and saves $333.33 annually. This measure therefore has a three year simple payback. The table then calculates the present value of each year's cash flow based on mid-year, end-of-year, and beginning-of-year assumptions about the discount period, using the discount rate that equates the initial cost to the net present value of cash flows. The highest discount rate (49.9%-based on the beginning-of-year assumption) is about 50% higher than the lowest discount rate (33%-calculated based on the end-of-year assumption). The differences between these assumptions become more pronounced at shorter lifetimes and smaller SPTs.

Analytic Derivation

From the definition of net present value (NPV), we know that

$$\mathrm{NPV} = \sum_{j=1}^{L} \frac{\mathrm{dOC}}{(1+r)^{L}} - \mathrm{dCC} \qquad \text{(A.1)}$$

where

dOC = Annual Change in Operating Cost (i.e. energy savings in $)

dCC = Change in Capital Cost ($)

L = the lifetime of the conservation measure (years), and

r = the discount rate

This equation is the one commonly used for such calculations, and it assumes that the energy savings benefits are paid in one lump sum at the end of the year.

To calculate the IRR, we set the NPV equal to zero, and solve for the discount rate.

$$\mathrm{dCC} = \sum_{j=1}^{L} \frac{\mathrm{dOC}}{(1+r)^{L}} \qquad \text{(A.2)}$$

From the definition of Simple Payback Time (SPT), we know that

$$\mathrm{SPT} = \frac{\mathrm{dCC}}{\mathrm{dOC}} \qquad \text{(A.3)}$$

$$\mathrm{dCC} = (\mathrm{SPT})(\mathrm{dOC}) \qquad \text{(A.4)}$$

Substituting for dCC in the IRR equation, we get

$$(SPT)(dOC) = \sum_{j=1}^{L} \frac{dOC}{(1+r)^{L}} \tag{A.5}$$

Canceling dOC, we see that the SPT is equal to the present worth factor (PWF) .

$$SPT = \sum_{j=1}^{L} \frac{1}{(1+r)^{L}} = PWF(r, L) \tag{A.6}$$

where the PWF (derived below) is defined as

$$PWF = \frac{((1+r)^{L} - 1)}{r(1+r)^{L}} \tag{A.7}$$

We must then solve iteratively for r to get the IRR.

For the beginning-of-year assumption, the PWF must be redefined as follows:

$$PWF = \frac{((1+r)^{L} - 1)}{r(1+r)^{L-1}} \tag{A.8}$$

For the middle-of-year assumption, the PWF must be redefined as follows:

$$PWF = \frac{((1+r)^{L} - 1)}{r(1+r)^{L-0.5}} \tag{A.9}$$

This formula yields a PWF = 3 = SPT for an investment with a 39.32% IRR and a thirty year life, which is the same result shown in Table A.1. **Table A.2**, reproduced from Krause and Eto (1988) uses this formula to relate SPTs and IRRs with a variety of investment lifetimes.

The SPT is always equal to the PWF, but the correct formula for PWF must be used. I choose the mid-year assumption because it more accurately characterizes the way a rational investor would analyze the value of energy investments, which typically save money throughout the year. In specific circumstances the other assumptions may be appropriate, but in general, the mid-year assumption is most likely to be correct. The mid-year assumption almost always results in a PWF that is equal to the simple average of the PWFs calculated using the end-of-year and beginning-of-year assumptions.

One complication in this simple approach is that cash flows are not spaced equally in time, and are not all the same size. Chapter VI calculates Operating Cost Tradeoff Factors, which are identical in function to the PWF, but must be interpreted in the context of the valuation method used. OCTFs include the complications of unequal cash flows and tax effects on cash flows .

Derivation of the formula for PWF

This section contains derivations of the formulas for PWF using the end-of year, beginning of year, and middle of year assumptions. First, define D as

$$D = \frac{1}{(1+r)} \qquad (A.10)$$

where r = the discount rate

The present value of a stream of annual benefits (A) received at the end of each of the following L years is

$$PV = AD + AD^2 + AD^3 + ...+ AD^L \qquad (A.11)$$

Multiplying both sides by D, we get

$$PV\ D = AD^2 + AD^3 + ...+ AD^{L+1} \qquad (A.12)$$

Subtracting (A.12) from (A.11) we get

$$PV(1-D) = A\ (D - D^{L+1}) \qquad (A.13)$$

Rearranging and substituting for D, we find that

$$PV = (A)\frac{((1+r)^L - 1)}{r(1+r)^L} = (A)(PWF) \qquad (A.14)$$

The derivation is the same for the beginning of year assumption, but equation (A.11) must be rewritten as

$$PV = A + AD + AD^2 + AD^3 + ...+ AD^{L-1} \qquad (A.15)$$

For the middle of year assumption, equation (A.11) must be rewritten as

$$PV = AD^{0.5} + AD^{1.5} + ...+ AD^{L-0.5} \qquad (A.16)$$

Table A.1. Calculation of IRR using Discounted Cash Flows (CFs)

		Middle-of-Year		*End-of-Year*		*Start-of-Year*	
			IRR 39.32%		*IRR* 33.30%		*IRR* 49.90%
Year	*CF*						
0	-1000	*Period*	*PV CF*	*Period*	*PV CF*	*Period*	*PV CF*
1	333	*0.5*	282	*1*	250	*0*	333
2	333	*1.5*	202	*2*	187	*1*	222
3	333	*2.5*	145	*3*	141	*2*	148
4	333	*3.5*	104	*4*	105	*3*	99
5	333	*4.5*	75	*5*	79	*4*	66
6	333	*5.5*	54	*6*	59	*5*	44
7	333	*6.5*	39	*7*	45	*6*	29
8	333	*7.5*	28	*8*	33	*7*	20
9	333	*8.5*	20	*9*	25	*8*	13
10	333	*9.5*	14	*10*	19	*9*	9
11	333	*10.5*	10	*11*	14	*10*	6
12	333	*11.5*	7	*12*	11	*11*	4
13	333	*12.5*	5	*13*	8	*12*	3
14	333	*13.5*	4	*14*	6	*13*	2
15	333	*14.5*	3	*15*	4	*14*	1
16	333	*15.5*	2	*16*	3	*15*	1
17	333	*16.5*	1	*17*	3	*16*	1
18	333	*17.5*	1	*18*	2	*17*	0
19	333	*18.5*	1	*19*	1	*18*	0
20	333	*19.5*	1	*20*	1	*19*	0
21	333	*20.5*	0	*21*	1	*20*	0
22	333	*21.5*	0	*22*	1	*21*	0
23	333	*22.5*	0	*23*	0	*22*	0
24	333	*23.5*	0	*24*	0	*23*	0
25	333	*24.5*	0	*25*	0	*24*	0
26	333	*25.5*	0	*26*	0	*25*	0
27	333	*26.5*	0	*27*	0	*26*	0
28	333	*27.5*	0	*28*	0	*27*	0
29	333	*28.5*	0	*29*	0	*28*	0
30	333	*29.5*	0	*30*	0	*29*	0
SUM	9990		1000		1000		1000

Source: Plunkett (1989)

Table A.2. Implicit Real Discount Rates, Lifetimes, and Simple Payback Times

SPT	*Investment Lifetime (Years)*							
(Yrs)	*3*	*5*	*7*	*10*	*15*	*20*	*25*	*30*
1	146.5	159.8	161.5	161.8	161.8	161.8	161.8	161.8
1.5	68.4	87.3	91.2	92.3	92.5	92.5	92.5	92.5
2	33.5	55.5	61.3	63.5	64.0	64.0	64.0	64.0
2.5	13.3	37.2	44.4	47.6	48.6	48.8	48.8	48.8
3	0.0	25.1	33.4	37.5	39.0	39.3	39.3	39.3
4		9.7	19.4	24.9	27.5	28.1	28.3	28.3
5		0.0	10.7	17.2	20.7	21.6	21.9	22.0
6			4.6	11.9	16.0	17.3	17.8	18.0
7			0.0	7.9	12.6	14.2	14.8	15.1
8				4.8	9.9	11.8	12.6	12.9
9				2.2	7.8	9.9	10.8	11.2
10				0.0	6.0	8.3	9.3	9.9
12					3.1	5.8	7.1	7.7
15					0.0	3.1	4.6	5.5
20						0.0	1.9	3.0

This table assumes that energy savings benefits accrue at mid-year.

Source: Krause and Eto (1988).

APPENDIX B: RELATIONSHIP BETWEEN COST OF CONSERVED ENERGY, MARKET DISCOUNT RATES AND SIMPLE PAYBACK TIMES

Market Discount Rates

Engineering calculations of the Cost of Conserved Energy (CCE) can be used to derive estimates of *market* discount rates, which characterize the behavior of the entire market for energy efficiency. The market is acting *as if* it is using discount rates equivalent to the market discount rate. This is not to imply that the market discount rate is actually used by investors, only that the purchased efficiency is the same as would result if that discount rate were actually being used. These market discount rates include both the effects of market failures and the high investor discount rates often used by residential or commercial customers.

The cost of conserved energy (CCE) is defined as

$$\text{CCE} = \frac{\text{Annualized Capital Cost}}{\text{Annual Energy Savings}}$$

From the societal perspective, the CCE is equal to

$$\text{CCE}_{\text{societal}} = \frac{\text{dCC}}{\text{PWF}(\text{r}^*,\text{years})}\,\frac{1}{\text{dQ}} \qquad \text{(B.1)}$$

where r* is the societal discount rate, dCC is the incremental capital cost of a conservation measure ($), and dQ is the change in annual energy consumption associated with this measure. dCC/dQ is solely a function of the relationship between energy consumption and capital cost (it is independent of discount rate). If investors are not choosing the conservation measure, they are acting as if the CCE was greater than the price of electricity, as shown in Equation B.2:

$$\text{CCE}_{\text{market}} = \frac{\text{dCC}}{\text{PWF}(\text{r}'',\text{years})}\,\frac{1}{\text{dQ}} > \text{P} \qquad \text{(B.2)}$$

where r'' is the market discount rate characterizing this choice,[1] P is the electricity price, and $\text{CCE}_{\text{market}}$ is the investor's perceived cost of conserved energy.

We can calculate the relationship between $\text{CCE}_{\text{societal}}$ and P by dividing (B.1) by (B.2) to get

$$\frac{\text{CCE}_{\text{societal}}}{\text{P}} >= \frac{\text{PWF}(\text{r}'',\text{years})}{\text{PWF}(\text{r}^*,\text{years})} \qquad \text{(B.3)}$$

$$\text{PWF}(\text{r}'',\text{years}) <= \frac{\text{PWF}(\text{r}^*,\text{years})\ \text{CCE}_{\text{societal}}}{\text{P}} \qquad \text{(B.4)}$$

---

[1] Chapter V uses r' to denote the *investor* discount rate, so here I use r'' to represent the market discount rate (to avoid confusion).

We can then use equation B.4 to solve iteratively for r'' (the lower bound to the market discount rate). Table I.3 (Chapter I) shows representative discount rates calculated using this method.

The simple payback time of a given change in a investor's efficiency investments (i.e., movement along the capital cost-energy consumption curve) can be expressed as

$$\mathrm{SPT} = \frac{\mathrm{dCC}}{\mathrm{dOC}} = \frac{\mathrm{dCC}}{\mathrm{P\ dQ}} \qquad \text{(B.5)}$$

Solving for dQ in (B.5) and substituting into Equation B.1 (modified to represent the CCE from the *investor's* perspective), we get

$$\mathrm{CCE}_{\mathrm{investor}} = \frac{\mathrm{(SPT)(P)}}{\mathrm{PWF(r',\ years)}} \qquad \text{(B.6)}$$

where r' is the investor's discount rate, and the other parameters are as before. Solving Equation B.6 for SPT, we get

$$\mathrm{SPT} = \frac{\mathrm{CCE}_{\mathrm{investor}}\ \mathrm{PWF(r',\ years)}}{\mathrm{(P)}} \qquad \text{(B.7)}$$

When $\mathrm{CCE}_{\mathrm{investor}}$ = P then the NPV = 0, the investor's life-cycle cost function is minimized , and Equation B.6 reduces to SPT = PWF (Equation A.6 in Appendix A)

APPENDIX C: CALCULATIONS FOR FIGURES AND TABLES IN CHAPTER II

1988 Energy Consumption by Sector

The Energy Information Administration reports consumption by fuel type for Residential and Commercial Sectors together for 1988. OBCS (1989) separates these two sectors for the period 1960-1986. I estimated residential and commercial sector energy consumption in 1988 by calculating total residential primary energy consumption in 1986 as a fraction of total residential and commercial energy consumption in 1986, and multiplying this fraction by total residential and commercial energy consumption in 1988. For example residential energy consumption comprised 56.57% of total residential and commercial consumption in 1986. I then multiplied this ratio by the total residential and commercial consumption in 1988 (29.143 Quads) to get the residential total (16.49 Quads). All fuels were treated in this way.

Energy Intensities of 1980-86 Buildings

The sample size for buildings built between 1980 and 86 is too small in the NBECS survey to have confidence in data extracted by building type and by fuel type for these buildings. The energy intensities for the different building types (1980-86) have therefore been imputed.

Table C.1 shows floor area and energy use by fuel type and by building type for all buildings existing in 1986. This table was derived directly from the NBECS database. **Table C.2** shows the same data as imputed for 1980-86 buildings. The only row on this table taken directly from NBECS is the last row (totals). The other rows have been derived by multiplying this total by (for example) the fraction of electricity consumption attributed to Lodging buildings from Table C.1. I then divided these energy consumption numbers by the appropriate square footage to yield the energy intensity.

Floor Space Projections

Table C.3 shows the Office of Buildings and Community Systems forecast for commercial floor area 1986-2010 (OBCS 1989). This forecast has been derived assuming an average demolition rate of 0.46% of total stock existing in a given year, and a net growth rate of 1.99% per year for the 1986-2010 period.

Peak Demand

The North American Electric Reliability Council (NERC) projects electricity use and peak demand (NERC 1989). For consistency I used the U.S. DOE forecast of electricity consumption, which contains higher annual growth rates (2.7%) for electricity use than does the NERC forecast (2.0%), and calculated peak demand using the load factors implicit in the NERC forecast (NERC 1988). The number used for commercial and office sector load factors (53%) is taken from a load research study performed by Southern California Edison Company (Sorooshian-Tafti 1989). There are no studies analyzing sector by sector load factors throughout the country, but the SCE estimate should be acceptable as a rough approximation.

Office Energy Consumption

The energy consumption numbers for offices in Tables II.5 and II.6 were derived by calculating the energy intensity of offices (kBtus/sf) for each fuel as a fraction of the commercial sector average, and multiplying this relative intensity by the fraction of commercial floorspace attributable to existing (16.8%) or new (20%) offices (these calculations assume that 1980-86 offices are a reasonable representation of new offices in 1990). This product (as shown in **Table C.4**) was then multiplied by the commercial energy use of each fuel to yield office energy use. Oil, LPG, and other were multiplied by the same factor, which is the average intensity of oil plus LPG plus other fuel used in offices. Use of these fuels in offices is almost negligible, so this approximation will introduce little error. Non-fossil energy was multiplied by the same factor as other electricity.

Emissions Factors

The emissions factors for CO_2 in **Table C.5** are derived from Chernick and Caverhill (1989). These factors times the fuel use in Tables II.5 and II.6 yield the total carbon emitted.

The emissions factors in **Table C.6** for NO_x and SO_2 from gas, oil, and coal consumption by electric utilities is based on 1988 data from the U.S. DOE's *Electric Power Annual* (US DOE 1988a). The emissions factors for NO_x and SO_2 for direct fuel use were derived using emissions data from the EPA (Zimmerman et al. 1988) and energy consumption data from the U.S. DOE (1989c). The emissions data was collected in 1985 for the National Acid Precipitation Assessment Program (NAPAP), and it contains emissions estimates by fuel type broken down by end-use sector. Table C.6 divides total emissions by energy used in each sector to calculate emission factors (thousand metric tonnes per quad). These factors are then multiplied by the U.S. DOE's forecasted energy consumption by sector and fuel to calculate the total emissions in Tables II.5 and II.6.

The 1990 estimates of total emissions includes the assumption that non-energy related (industrial) sources of NO_x and SO_2 grow at 2% per year from 1986-1990. Wood and other biomass is not included in the energy consumption numbers for direct fuel use, but it is included for electricity generation (under other). I treated it separately for the purposes of deriving emissions factors from direct fuel use, and added it back to the total emissions estimates for the U.S. I assumed 2% growth in biomass emissions as well. I ignored any direct wood consumption in the commercial sector, since it is not reported or forecasted by the U.S. DOE. It is probably small, in any case, since the emission numbers for all direct U.S. wood and biomass consumption change the U.S. totals only slightly.

New growth in electricity demand is met by a combination of new plants (which are much cleaner than existing plants) and existing plants that are operated at higher capacity factors. To address this complexity, I have assumed that half of the growth in electricity consumption is met by new plants that meet the New Source Performance Standards (NSPS), and half by existing plants with emissions factors shown in Table C.6. The footnotes to this Table contain the estimated NSPS emissions factors from Koomey (1990a). The approach used here is only a crude approximation.

Table C.1. Total Energy Consumption By Fuel Type and Building Type (1986 Buildings)

Building Activity	*Floor Area M sf*	*Electricity TBtus*	*Nat. Gas TBtus*	*Oil TBtus*	*Dist. Heat TBtus*	*Propane TBtus*
Assembly	7305	164	157	42	31	7
Education	7292	179	254	103	97	3
Food Sales	712	99	45	2	2	2
Food Service	1281	121	114	6.5	6.5	12
Health Care	2107	132	205	20	80	20
Lodging	2785	120	105	20	54	12
Mercantile and Service	12781	536	332	105	12	17
Office	9532	641	258	39	71	1
Public Order and Safety	678	30	25	10.3	10.3	10.3
Warehouse	8558	252	143	48	11.5	11.5
Other	1704	83	46	13.3	13.3	13.3
Vacant	2090	35	38	6.3	6.3	6.3
Total	56825	2392	1722	415.4	394.9	115.4

Source: NBECS (US DOE 1988b, US DOE 1989d)

Table C.2. Total Energy Consumption By Fuel Type and Building Type (1980-86 Buildings)

Building Activity	*Floor Area M sf*	*Electricity TBtus*	*Nat. Gas TBtus*	*Oil TBtus*	*Dist. Heat TBtus*	*Propane TBtus*
Assembly	1246.45	32.22	18.96	2.43	2.51	1.09
Education	1244.23	35.17	30.68	5.95	7.86	0.47
Food Sales	121.49	19.45	5.44	0.12	0.16	0.31
Food Service	218.58	23.78	13.77	0.38	0.53	1.87
Health Care	359.52	25.94	24.76	1.16	6.48	3.12
Lodging	475.20	23.58	12.68	1.16	4.38	1.87
Mercantile and Service	2180.81	105.32	40.10	6.07	0.97	2.65
Office	1626.44	125.95	31.16	2.25	5.75	0.16
Public Order and Safety	115.69	5.89	3.02	0.60	0.83	1.61
Warehouse	1460.24	49.52	17.27	2.77	0.93	1.79
Other	290.75	16.31	5.56	0.77	1.08	2.07
Vacant	356.61	6.88	4.59	0.36	0.51	0.98
Total	9696.00	470.00	208.00	24.00	32.00	18.00

Source: NBECS (US DOE 1988b, US DOE 1989d)

Table C.3. Projected Commercial Floorspace 1986-2010 (Billion sf)

	Stock	*Net Growth*	*Additions*	*Demolitions*	*86 Stock Remaining*	*Cumulative Additions*
1986	58.2	0	0	0	58.2	0.00
1987	59.36	1.158	1.433	0.274	57.93	1.43
1988	60.54	1.181	1.461	0.280	57.65	2.89
1989	61.74	1.205	1.490	0.285	57.36	4.38
1990	62.97	1.229	1.520	0.291	57.07	5.90
1991	64.23	1.253	1.550	0.297	56.77	7.45
1992	65.51	1.278	1.581	0.303	56.47	9.04
1993	66.81	1.304	1.613	0.309	56.16	10.65
1994	68.14	1.330	1.645	0.315	55.85	12.29
1995	69.50	1.356	1.677	0.321	55.52	13.97
1996	70.88	1.383	1.711	0.328	55.20	15.68
1997	72.29	1.411	1.745	0.334	54.86	17.43
1998	73.73	1.439	1.780	0.341	54.52	19.21
1999	75.20	1.467	1.815	0.348	54.18	21.02
2000	76.69	1.497	1.851	0.354	53.82	22.87
2001	78.22	1.526	1.888	0.362	53.46	24.76
2002	79.78	1.557	1.926	0.369	53.09	26.69
2003	81.36	1.588	1.964	0.376	52.71	28.65
2004	82.98	1.619	2.003	0.384	52.33	30.65
2005	84.64	1.652	2.043	0.391	51.94	32.70
2006	86.32	1.685	2.084	0.399	51.54	34.78
2007	88.04	1.718	2.125	0.407	51.13	36.90
2008	89.79	1.752	2.167	0.415	50.72	39.07
2009	91.58	1.787	2.210	0.423	50.30	41.28
2010	93.40	1.823	2.254	0.432	49.86	43.54

Additions=replacements+demolitions

Source: OBCS (1989)

Table C.4. Calculating Office Building Energy Use for Tables II.5 and II.6

	% of Comml Floor Area	*Intensity as % of Average*	*Weighting Factor*
Existing Offices			
Natural Gas	16.8%	89.3%	15.0%
Oil, LPG, Other	16.8%	71.5%	12.0%
All Electricity	16.8%	159.8%	26.8%
Offices 1980-86			
Natural Gas	20%	89.3%	17.9%
Oil, LPG, Other	20%	65.8%	13.2%
All Electricity	20%	159.8%	32.0%

Weighting factors represent the fraction of total commercial energy use (or growth in such use) attributable to office buildings. Intensities for new and existing *Oil, LPG, Other* are different because they are calculated as the sum of products instead of the product of sums. The fuel mix of *Oil, LPG, Other* is different between new and existing, and the method used in calculating the office building share assumes that the amount of each fuel used as a fraction of the total is the same between new and existing. This leads to differences in the average intensity as a fraction of total for the *sum* of these fuels. If they were treated individually there would be no difference in the relative intensities as a function of total consumption.

Source: NBECS (US DOE 1988b, US DOE 1989d).

Table C.5. Carbon Emission Factors

Fuel	*Grams Carbon/kWh*	*Megatons-Carbon/Quad*
Natural Gas	46.5	15.0
Oil	68.2	22.0
Coal	88.4	28.5
Non-Fossil	0	0

The first column reports carbon emitted per kWh of fuel use (3412 Btus/kWh).

Source: Chernick and Caverhill (1989).

Table C.6. Derivation of NOx and SOx Emission Factors for Tables II.5 and II.6

	SO2	*NOx*	*1985 fuel use*	*SO2*	*NOx*
	10e3 T	10e3 T	Quads	10e3 T/Q	10e3 T/Q
*UTILITY COMBUSTION**					
Natural Gas	0.0	498.0	2.71	0.00	183.75
Oil	735.0	256.0	1.56	471.42	164.20
Coal	15853	6163	15.85	1,000.10	388.80
Hydroelectric	0	0	3.33	0.00	0.00
Nuclear	0	0	4.15	0.00	0.00
Other	21.3	8.1	0.21	100.00	38.03
Non-Fossil	21.3	8.1	7.69	2.77	1.05
Total	16178	6770	26.48	610.86	255.61
RESIDENTIAL					
Natural Gas	1.2	248.3	4.57	0.26	54.38
Oil	128.7	75.1	1.54	83.74	48.86
Coal	37.2	2.9	0.07	536.80	41.85
Total w/o Wood	167.1	326.3	6.17	27.07	52.87
COMMERCIAL					
Natural Gas	1.2	138	2.50	0.48	55.13
Oil	240.3	120.5	1.04	232.04	116.36
Coal	159.5	39.3	0.11	1490.65	367.29
Total w/o Wood	401	297.8	3.65	109.99	81.68
INDUSTRIAL					
Natural Gas	176.1	2200	7.09	24.84	310.37
Oil	709.3	275.2	7.70	92.09	35.73
Coal	1528	554.2	2.75	556.21	201.75
Total w/o Wood	2413	3030	17.54	137.60	172.74
TRANSPORT					
Oil	863.5	8834	19.56	44.15	451.70
OTHER SOURCES	2946	1140			
BIOMASS	43.7	169.6			
GRAND TOTAL	23013	20567			

*For Utility Gas, Oil, and Coal Consumption, the data are for 1988, from the *Electric Power Annual* . The emissions factors for direct fuel combustion in new devices are assumed to be the same as for existing devices, except in the case of utility power plants. The emissions factors for new power plants are derived assuming that 50% of emissions are from new plants meeting the New Source Performance Standards, and 50% are from existing power plants. NOx emissions factors for new NSPS plants are 100 kT/Quad for oil and natural gas, and 300 kT/Q for Coal. SO2 emissions factors for new plants are 0 for gas, 100 kT/Q for oil, and 300 kT/Q for Coal (see Koomey (1990a)).

Sources: *Monthly Energy Review* (US DOE 1989c), *Electric Power Annual* (US DOE 1988a), and Zimmerman et al. (1988)

APPENDIX D: FINANCIAL MODEL

This appendix presents the financial model used in the calculations in Chapter VI. It is a spreadsheet model, originally created in Lotus 1-2-3, and converted for use on a Macintosh SE-30 (4MB RAM) using Microsoft Excel. The model is a set of linked spreadsheets, some of which contain input data (presented in Chapter VI) and some of which do calculations. This Appendix contains a copy of the main spreadsheet that does financial calculations. An almost identical spreadsheet is linked to this one that adds one dollar to rental income (or subtracts it from operating costs) to calculate RITFs and OCTFs. A program written in the Excel Macro Language changes inputs, runs the model, copies the results, and automatically places them in an output file.

APPENDIX E: OUTPUT OF FINANCIAL MODEL

In the original version of the dissertation, this Appendix contained the runs from the financial model shown in Appendix D. To save paper, only an example of these runs has been included. Readers desiring the complete set can contact me at Lawrence Berkeley Laboratory Bdg 90-4000, Berkeley, CA 94720 (415/486-5974).

These runs include a variety of outputs, most of which have been summarized in Chapter VI. All IRRs, Operating Cost Tradeoff Factors (OCTFs), Rental Income Tradeoff Factors (RITFs), and calculations of Net Present Value (NPV) are in real terms. The model calculates these parameters in nominal terms then corrects for five percent inflation.

In addition to the outputs reported in Chapter VI, the summary sheets have OCTFs and RITFs calculated using an 8% real discount rate, for comparison with the same parameters calculated to keep IRR constant. Another unused parameter is the Change in Net Present Value/Total Change in First Year Operating Costs. The OCTF described in Chapter VI is the *marginal or point-value* sensitivity to operating cost savings, while this indicator is the *average* sensitivity over a large range. The numerator of this indicator is the same as for the calculation of ΔNPV/PV return in Chapter VI, while the denominator is the total change in first year operating costs ($). This indicator is an *average* OCTF for the 30% cost savings. For every dollar reduction in first year operating costs, the NPV goes up by an amount equal to this average OCTF.

The Tables in this Appendix are coded. The number following E (e.g., Table E.3.a) relates to the following table:

	Zero	*Cost*	*Value*
Small	1	2	3
Medium	4	5	6
Large	7	8	9

The letter following the number indicates the policy being analyzed:

a = no policy

b = per unit fees

c = up front fees

d = up front rebates

e = revenue neutral incentives

For example, Table E.3.a refers to the the small building, value assessment, no policy case.

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