GROUP #3: COMMERCIAL BUILDINGS

SUMMARY:

OPPORTUNITIES FOR SAVING ENERGY IN COMMERCIAL BUILDINGS*

J. Deringer (Group Leader), H. Ross (Co-leader), J. Harris

INTRODUCTION AND SUMMARY

This paper addresses the technical potential for saving energy in non-residential buildings over the next twenty years, based on an assessment of recent trends in energy use and prices, consideration of the cost-justified technologies available today, and a review of the limited evidence currently available on the impact of conservation measures undertaken in new and existing commercial buildings. Also included are a brief discussion of some factors that are slowing the market's progress toward a "lowest life-cycle cost" investment criterion for commercial buildings, and an outline of future needs for research and data-collection.

Anecdotal evidence over the past few years points to a significant growth of interest and activity in energy conservation in commercial buildings--but hard empirical data are more difficult to find. Architecture and engineering journals include many articles discussing successful cases of energy savings achieved in existing buildings, and low-energy designs for new buildings. For example, Energy Users News has reported on over 80 cases of successful commercial building retrofits in the last five years. There are also examples of new commercial buildings designed to use 40,000-50,000 Btu/sq.ft./year, rather than the range of 70,000-80,000 Btu/sq.ft./year that has been common in recent

*This paper, in addition to summarizing technical presentations and discussions of the Commercial Buildings group at the 1980 Santa Cruz Summer Study, draws heavily on material presented in Part 1 [Buildings] of the SERI study: "A New Prosperity: Building a Sustainable Energy Future" (Brick House Publishing Co., Andover, Mass., 1981). J. Deringer was the principal author of the section of that study dealing with commercial building conservation potentials. Early drafts of the SERI study were made available as background material to members of the Santa Cruz Commercial Buildings group.

commercial construction.

However, given the billions of square feet of commercial buildings now in use, there is very little well-documented information on the full range of energy savings realized, and the costs of achieving them. Nor is there much detail on which of the physical changes, or operational and maintenance practices, are contributing what fraction of energy savings and costs. A significant fraction of the well-documented data on energy-saving commercial building retrofits has been compiled in a paper by H. Ross and S. Whalen, now in draft form (Ross and Whalen, 1981).

Perhaps the two most important conclusions to be drawn from the available evidence are, first, that there is a remarkably wide range of results, in terms of both energy savings achieved and dollar costs per Btu saved. We need to examine more closely the factors that separate the most successful efforts from the least successful ones (and the outright failures). Second, it is probable that few retrofit projects or new energy-saving buildings represent a truly optimal mix of conservation (and renewable energy) measures--or reflect investments in energy efficiency up to the full level that is cost-justified.

The rest of this section summarizes our estimates of the sector's conservation potentials and offers some caveats in interpreting these results.

Other papers included in this section of the Proceedings discuss a few end-use-specific technologies in more detail (windows and daylighting, efficient lighting systems, and HVAC control systems). Recent progress and potentials for improved efficiency in Canada's commercial building stock are also reviewed.

Summary of Results

Tables 1 and 2 summarize the technical potential for saving energy in existing and new commercial buildings. In arriving at these estimates, we considered the maximum potential for saving energy through improved efficiency and use of on-site solar technologies, assuming that all buildings and equipment were retrofitted or designed initially to minimize life-cycle energy costs. While assuming full market saturation of each measure, we took into account only those technologies that are now commercially available, or likely to become available in the near future. Finally, each energy-saving improvement had to be economically justified, over its useful life, at today's average energy prices.

Table 1. Comparison of Annual Energy Use in Commercial Buildings: 1980, 2000 Baseline, and 2000 Technical Potential

	Estimated 1980 Energy Use[a] (Resource Quads)			Projected Energy Use in 2000 (Resource Quads)					
				EIA Baseline Forecast[b]			Technical Potential[c]		
	Fuel	Elec	Total[d]	Fuel	Elec	Total	Fuel	Elec	Total
Exist. Bldg. (1980)	4.4	5.6	10.4	3.2	4.9	8.1	1.6	2.4	4.0
New Bldg. (1981-2000)	--	--	--	0.4	4.4	4.8	0.1	2.7	2.8
Total	4.4	5.6	10.4	3.6	9.3	12.9	1.7	5.1	6.8

(a) Oak Ridge, 1980.
(b) Energy Information Agency, 1977.
(c) Estimated SERI/LBL consumption target, assuming implementation of all feasible conservation and solar measures that are cost-effective at current U.S. average prices for oil and electricity.
(d) Includes 0.4 Q other sources.

Source: SERI/LBL (1981), as revised for 2nd Edition

For retrofits of existing buildings, the potential savings and the cost of achieving them were based on a survey of actual experience, using actual pre- and post-retrofit energy use measurements, wherever possible (see below). Estimates of savings possible in new buildings were derived from a few case studies, combined with parametric analyses (using the DOE-2 simulation model) prepared in support of the proposed Federal Building Energy Performance Standards (BEPS). A more detailed discussion of the methodology and results is included below.

Economic assumptions included: use of today's average energy prices (not escalated beyond general inflation) to determine the value of saved energy, a 10% real-dollar interest rate, and 20-30 year lifetimes for amortizing most energy-saving investments. While these assumptions might be considered realistic or even conservative, our estimates of conservation potential also assume 100% penetration of all technically feasible, cost-justified measures. It is this last assumption that distinguishes our estimate of energy-saving potential from a forecast of the energy savings that might be realistic to count on, under a given set of policies and market conditions.

The major differences between a recent DOE energy demand forecast and our estimate of the conservation potential in commercial buildings are illustrated in Table 1. In 1980, the commercial sector used about 10.4 quads of fuel and electricity (with electricity counted as primary resource energy, at 11,500 Btu/kWh). The recent mid-range projection by DOE's Energy Information Administration (EIA) shows this consumption growing over the next twenty years to a total of 12.9 quads/year by the year 2000. This growth is largely the result of the assumed addition of new commercial floorspace--largely all-electric. Only moderate gains in energy efficiency are assumed by EIA for either new or existing buildings.

In contrast, the technical potential estimate envisions an absolute reduction in commercial buildings' energy use to about 6.8 quads/year by 2000--or roughly a 35 percent drop in twenty years. This estimate is based on the same net floorspace additions as the EIA forecast and assumes equivalent levels of occupant comfort and amenity, but much

Table 2. Potential Energy Savings In Commercial Buildings and the Cost of Achieving These Savings, Year 2000.

	Potential Annual Energy Savings Year 2000, in Resource Quads[a]			Cumulative Cost 1980-2000, in \$1980 x 10^9 (undiscounted)	Average Cost of Conserved Energy[b] (\$1980/MBtu)
	Electricity	Fuel	Total		
1. Improved design of new buildings[c]	1.4	0.2	1.6	\$38	\$2.50
2. Existing Building retrofits[d]	2.4	1.6	4.0	71	1.90
a. Phase 1 (1980-1990)	(1.2)	(0.8)	(2.0)	(23.7)	1.30
b. Phase 2 (1991-2000)	(1.2)	(0.8)	(2.0)	(47.4)	2.50
3. Solar Measures (new + existing buildings)	0.4-0.6	--	0.4-0.6	19-26	4.60-5.00
a. Daylighting	(0.2-0.3)	--	(0.2-0.3)	(9)	3.20-4.80
b. Photovoltaics	(0.1-0.3)	--	(0.1-0.3)	(8-14)	4.90-8.50
c. Hot Water	(0.21)	--	(0.1)	(2-3)	2.10-3.20
4. Total Savings Potential	4.2-4.4	1.8	6.0-6.2	\$128-135	2.30

(a) Electricity is converted to resource quads (1 quad = 10^{15} Btu) at 11,500 Btu/kWh.

(b) The cost calculation assumes an annual fixed charge rate of 0.106, corresponding to a 10% real rate of return (above general inflation) amortized over a thirty-year period.

(c) 27.3 billion square feet of new commercial floorspace are expected to be added between 1980 and 2000 (Oak Ridge, 1980).

(d) 23.7 billion square feet of existing commercial buildings will still be in use in the year 2000 (Oak Ridge, 1980); existing buildings that do not survive in 2000 are not counted in the calculation of year 2000 savings from conservation retrofits.

Source: SERI/LBL (1981), as revised for 2nd Edition greater improvements in levels of energy efficiency.

Table 2 lists the major components of the potential savings in commercial sector energy use. Despite significant efficiency gains in new construction (40 to 50 percent reductions are technically possible and cost-effective, compared to current building practice) it is apparent from Table 2 that retrofits of existing buildings account for two-thirds of the total annual savings potential by the year 2000. Solar contributions are significant in absolute terms, but represent only about 10 percent of the total energy-saving potential.

The cumulative investment required to improve commercial building shells, lighting, and HVAC systems is well over $100 billion in today's dollars. This sum would be spread out over a twenty-year period, and represents an average investment of about $6 billion per year. This is equal to only about one-eighth of each year's energy costs to operate today's relatively inefficient stock of commercial buildings.

When translated into an equivalent cost per unit of energy saved, Table 2 shows that, on the average, it would cost only about $2.30/MBtu (or about $13/barrel-of-oil-equivalent) to purchase a "supply" of conserved energy equal to over half of the total U.S. crude oil imports (for all sectors) in 1980.

Limitations of the Analysis

Several limitations of this analysis of commercial sector conservation potentials need to be kept in mind. First, there is very little documented information on conservation results in actual new or retrofitted buildings, to use as a basis for estimating future technical potentials and cost-effectiveness. Although our analysis tried to draw on most of the empirical data available (as described below, and detailed in SERI/LBL, 1980), estimating conservation potential for commercial buildings still requires far more aggregate calculations, and more extrapolation from engineering assumptions, than does a similar estimate for residences.

Not only are commercial buildings, because of their size and complexity, generally more difficult to analyze than houses, but additional variations in energy use result from differences in design, type of construction, mix of functions, and patterns of ownership.

In the residential sector, most of the analysis of conservation technical potential has focused on single-family detached houses, and extrapolations have then been made for other types of structures. To derive similar estimates of commercial building conservation potential, about 15 separate analyses would be needed just to account for the major combinations of building type and usage (hospitals, schools, large vs. small office buildings, hotels, etc.). Within each category, there would have to be separate assessments of opportunities in new construction and in retrofits.

Another limitation of the analysis is that conservation potentials were examined for single buildings only, not for larger-scale projects involving clusters of buildings or entire communities (e.g., community-scale power generation or the recovery of waste heat for use in a nearby facility).

Finally, the estimated conservation potential is based primarily on hardware changes, with less emphasis on analyzing the effects of operation and maintenance improvements. This is particularly true for new commercial buildings, where the calculations are based on improved design practices, equipment, and control systems. Some operation and maintenance savings have, however, been incorporated in the savings estimated for existing buildings, since these "O & M" measures were often part of the case studies covered in our survey.

THE COMMERCIAL BUILDINGS SECTOR - PAST AND PRESENT

Trends in Energy Use and Prices

One reason why there is such a large potential for saving energy in commercial buildings is that, up until a few years ago, both fuel and electricity were viewed as readily available and energy prices (in constant dollars) were low and falling predictably from one year to the next. The design of new buildings and the operation of existing buildings and equipment reflected the economics of cheap energy--relatively little attention was paid to engineering for improved efficiency or investing in conservation measures with seemingly unattractive paybacks.

Other factors also affected the growth and composition of commercial sector energy use. Examples include the increasing standards of occupant comfort (made possible by modern mechanical cooling systems), sealed buildings with controlled humidity and mechanical ventilation, increased levels of illumination, and a trend towards all-electric rather than oil-fired heating and cooling systems in newer buildings. These trends are illustrated in Table 3 and Figure 1.

Both energy use and price trends over the last two decades can best be characterized as pre-1973 and post-1973. The years preceding the 1973 Oil Embargo saw rapid rates of increase in the use of electricity, natural gas, and (to a lesser extent) fuel oil in commercial buildings. Nationally, annual average growth rates for these three fuel types were 8.1, 7.5, and 2.8 percent respectively. The use of other fuels (i.e., coal and liquified gasses) declined over this period at an annual rate of about 6.2 percent.

Fuel prices declined significantly over the 1960-1973 period, as shown in Table 3 and Figure 1. Electricity prices showed the largest decline, averaging 3.6% per year. This factor, along with the shifts toward all-electric HVAC systems, increased levels of illumination, and a growing saturation of elevators, office machines, and computers, contributed to growth in electricity demand at nearly twice the rate of additions to commercial floorspace (8.1 percent vs. 4.2 percent per year). The decline in the real price of natural gas to the commercial sector was less dramatic (about one percent per year), while the real price of fuel oil actually rose slightly, at a rate of 0.3 percent during the same period.

The increase in commercial building energy consumption accompanying a decline in real energy prices prior to 1973 contrasts markedly with the post-1973 trends (see Figure 1). Between 1973 and 1978, the annual rates of price increase for electricity, natural gas, and oil to the commercial sector were 4.0, 10.2, and 10.5 percent, respectively. Note that while prices of natural gas and oil had far surpassed their 1960 levels as of 1978, constant-dollar electricity prices paid by commercial customers, on the average, were still no higher than they had been in 1966, and still substantially below their 1960 levels.

The consequences for commercial sector energy consumption are not surprising. Figure 1 illustrates the abrupt leveling-off in demand for gas and oil after 1973. For electricity, while the change in historical use and price trends was less dramatic, the annual growth rate in electricity demand was still reduced by more than half after 1973, from 8.1 percent to 3.7 percent.

Table 3 also identifies the shifts in market shares for the various fuels serving commercial buildings. Electricity's share of the market rose from 39 percent in 1960 to 57 percent by 1978 (measured in resource, not site, energy). Over the same time frame, natural gas retained essentially the same market share (about 20 percent), while the fraction accounted for by oil shrunk noticeably, from one-third in 1960 to about one-fifth in 1978.

Combining the trends in the three different fuel types, we see in Table 3 and Figure 1 that the relationship between growth in floorspace and energy consumption in commercial buildings changed abruptly about the time of the 1973 Oil Embargo. Before 1973, energy use increased 38% faster than floorspace; after 1973 the situation was reversed, with commercial building energy use growing at a rate one-third lower than annual additions to floorspace. The effect emerges clearly in the column of Table 3 labeled "Average Energy Intensity," which shows that overall energy intensity throughout the sector not only leveled off

Table 3. Trends in U.S. Commercial Building Floorspace, Energy Use, and Energy Prices, 1960-1978

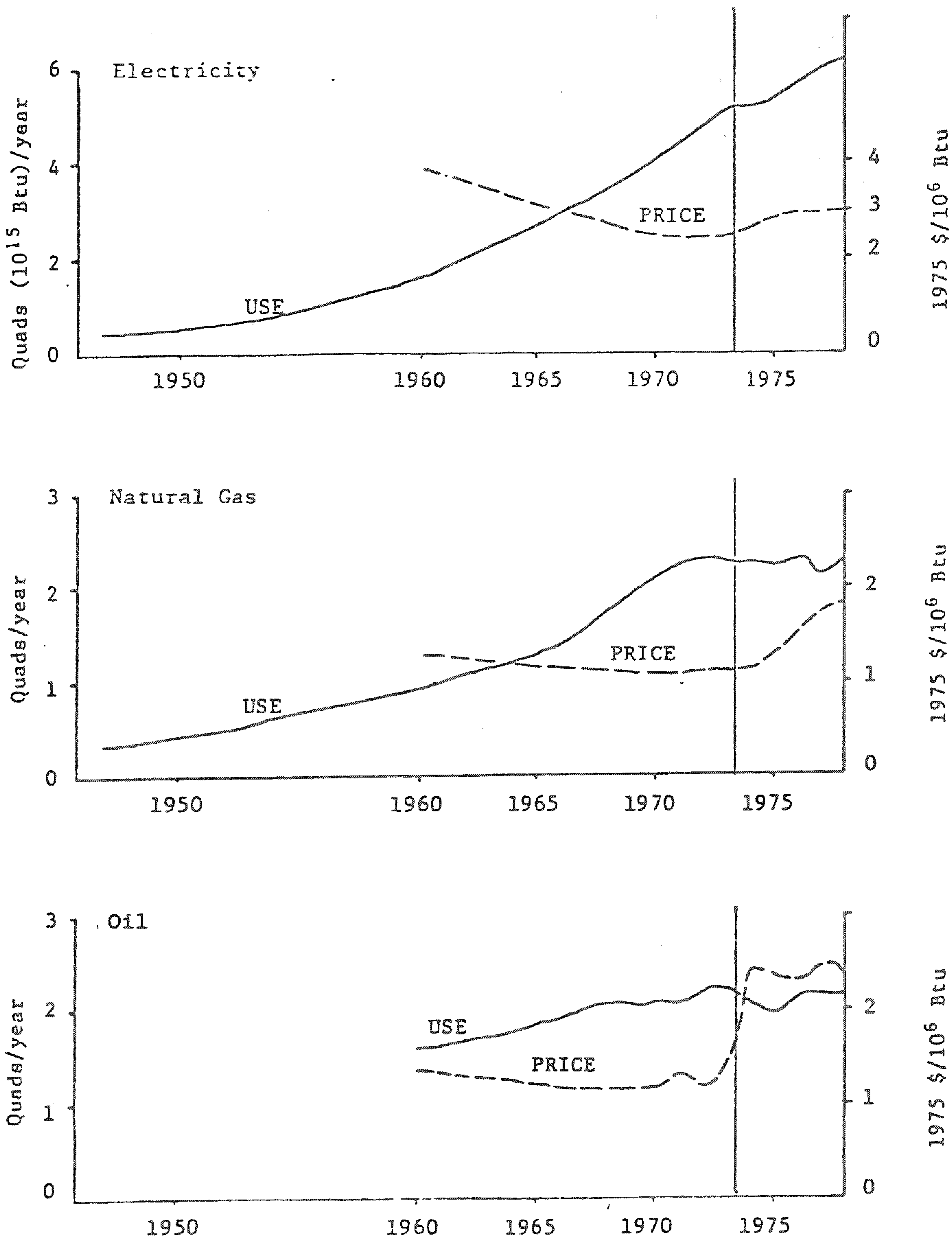
Year	Est. Floorspace (10^6 sq. ft.)	Energy Use (10^{12} Btu)					Avg. Energy Intensity (10^3 Btu/sq.ft./yr)	Prices (1975 $/$10^6$ Btu)		
		Electricity[a]	Natural Gas	Oil	Other[b]	Total		Electricity	Natural Gas	Oil
1960	15,801	1866.06	895.9	1566.32	406.1	4730.38	299	3.87	1.26	1.37
1965	20,269	2704.78	1274.66	1810.86	281.65	6071.95	300	3.14	1.22	1.22
1966	21,023	2942.45	1432.69	1886.77	289.27	6551.18	312	2.95	1.18	1.20
1967	21,777	3164.85	1716.26	1983.96	258.52	7123.59	327	2.82	1.17	1.21
1968	22,602	3465.65	1819.95	2075.69	244.36	7604.65	336	2.66	1.11	1.22
1969	23,506	3780.18	1984.02	2014.70	244.22	8023.12	341	2.50	1.07	1.15
1970	24,252	4093.91	2149.20	2085.48	217.59	8546.18	352	2.40	1.03	1.16
1971	25,061	4387.74	2226.90	2075.43	211.49	8901.56	355	2.42	1.06	1.32
1972	25,934	4783.57	2306.42	2206.44	186.65	9483.08	366	2.45	1.11	1.18
1973	26,883	5149.64	2284.81	2231.65	177.82	9843.92	366	2.41	1.10	1.43
1974	27,745	5188.42	2263.20	2028.35	174.43	9654.40	348	2.68	1.14	2.44
1975	28,328	5417.04	2220.91	1907.36	150.07	9695.38	342	2.79	1.32	2.35
1976	29,090	5691.51	2341.50	2200.12	147.82	10380.95	357	2.82	1.51	2.29
1977	29,910	5939.97	2186.61	2157.59	150.41	10434.58	349	2.94	1.79	2.46
1978	30,740	6187.68	2263.49	2151.53	157.43	10760.13	350	2.93	1.79	2.35
Average Annual Growth Rates (%)										
1960-1973	4.17	8.12	7.47	2.76	-6.15	5.80	1.57	-3.58	-1.04	0.33
1973-1978	2.72	3.74	-0.19	-0.73	-0.93	1.80	-0.89	3.98	10.22	10.45

[a]Electricity is reported in terms of primary energy; that is, losses in generation, transmission and distribution are included. The conversion factor is 11,500 Btu/kWhr. For conversion to SI units, 1 Btu = 1055 joules.

[b] Includes Coal and Liquid natural gases.

Source: J.R. Jackson (1978), as updated for 1976-78.

Estimated Commercial Energy Use and Fuel Prices, 1947-1978



Sources Pre-1960: EIA 1977 Annual Report to Congress
Post-1960: J. Jackson, in press

after 1973, but actually declined. (Note that the estimated numbers count electricity in resource energy, not site energy. To the extent that there was a simultaneous shift toward all-electric buildings, this has the effect of masking some of the reductions in on-site energy intensity that actually occurred.)

This reversal in average commercial building energy intensity is the result of several factors. Pre-1973 buildings (especially the relatively recent ones) tended to be over-lighted, over-ventilated, and heated or cooled during times when they were entirely unoccupied. Correcting some of these wasteful practices has already contributed to significant reductions in energy use, but additional savings remain to be achieved. Changes in building and lighting system design techniques and in the configuration of HVAC systems offer additional opportunities. As discussed below, the analysis conducted in support of the Building Energy Performance Standards (BEPS) points to potential energy savings of up to 60% in new buildings, with only moderate net increases in construction costs.

A number of factors other than price changes will affect future market shares for fuel and electricity in commercial building, making predictions difficult. But the electrification trend is likely to persist, for reasons related not only to the relative cost increases for electricity and fuel, but also to the trend towards larger structures (dominated by internal cooling loads) and the effects of conservation and waste heat recovery on reducing fuel requirements for space heating and water heating.

The preceding discussion has dealt only with nationwide averages. This perspective tends to mask important differences, both among regions and at the sub-regional level. Differences in both energy intensities and fuel mix arise from regional variations in the relative prices of electricity and fuels, climate differences that affect heating and cooling loads, and the age and structural characteristics of the commercial building stock. While these differences are important in analyzing conservation potentials on a regional or local basis, they are beyond the scope of this paper. Until better data on the size, composition, and energy-using characteristics of the commercial building stock become available (from EIA's recent commercial buildings survey, for example) these issues are also largely beyond the scope of the available data.

Diversity within the Commercial Sector

As previously noted, an important characteristic of commercial buildings is the wide variety of activities that they shelter. This diversity of function, combined with structural diversity, constitutes one major distinction between patterns of energy use in commercial and residential buildings. Residences, of course, also vary in size, construction type, and occupant behavior, but at least the household functions that require energy services are reasonably common to all U.S. households. In contrast, commercial buildings containing different uses can require quite different levels of energy services.

The diversity in commercial building energy use results from factors related to the specific use of the space, the duration of use (hours/day or days/week), and the intensity of use (e.g., number of occupants per 1000 square feet). For example, the energy per square foot needed to support a fast-food restaurant kitchen, a hospital operating room, or a large computer installation all differ from the energy intensities required for routine office tasks, a high school auditorium, or a warehouse. (On the other hand, due to internal loads the space heating requirements of commercial buildings tend to vary less from one climate zone to another than do heating needs of residences.)

Most commercial building classification schemes reflect only a few of the factors contributing to this diversity. This is illustrated in Figure 2, which shows the estimated average electricity and fuel use intensities for nine major categories of commercial buildings (plus the weighted average for all residences, for comparison). As the Figure shows, even among these nine broad categories average fuel use intensity varies by a factor of four, and average electricity intensity by a factor of nearly five.

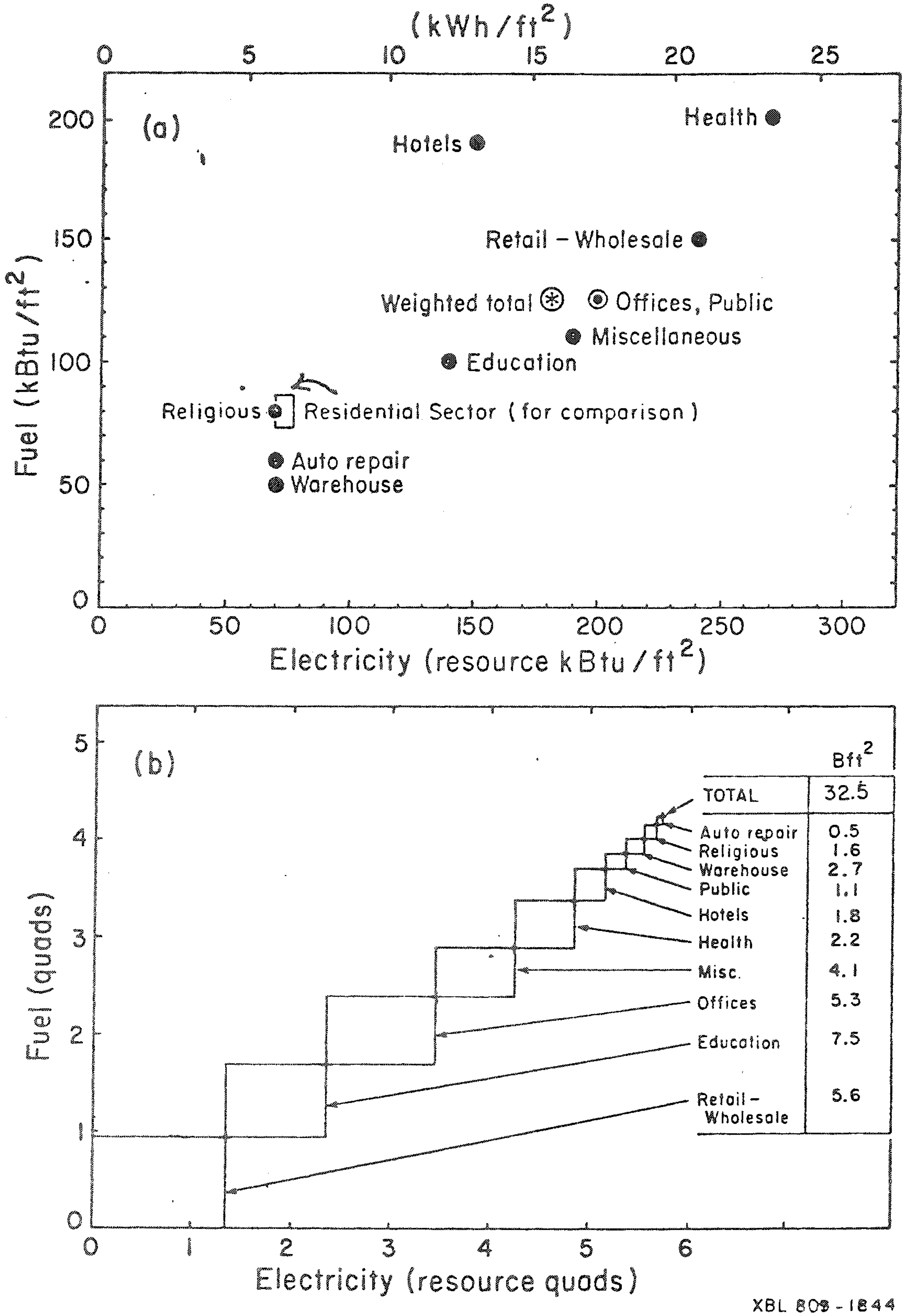


Fig. 2 (a,b). Estimated average fuel and electricity intensities for major categories of existing (ca. 1980) commercial buildings, based on the ORNL (Jackson) commercial building model. The upper figure (2.a) shows average electricity and fuel use per square foot, by building type; the lower figure (2.b) converts this to aggregate energy use for the entire stock. In the upper figure, the average energy intensity for existing residences is plotted, for comparison (using an assumed average floor space per unit of 1,350 ft^2).

Source: SERI/LBL (1981)

But these groupings are so aggregated that they disguise additional diversity. For example, the "Retail-Wholesale" category includes a wide range of users. Just one of these, "food sales and service" facilities, in turn incorporates full-service restaurants, fast-food outlets, and a variety of retail food stores, from small grocery or specialty shops to large supermarkets. While markets require little energy for food processing, they often have substantial refrigeration and lighting requirements. Fast-food restaurants, on the other hand, may use as much as 600 kBtu/square foot/year (site energy), mainly for food preparation rather than lighting or space conditioning. This is more than twice the average energy intensity (combining fuel and electricity) for the overall grouping of retail and wholesale establishments.

Contributing further to the energy use diversity of the sector are multi-function buildings, changes in occupancy over time, and variations in the needs of tenants of the same general type. Consider the following hypothetical but familiar building types:

- A small office building in which 50% is used for office space, 20% for a stationery store, and 30% devoted to a pizza parlor.
- A single space in a shopping center that houses, over a period of years, a dentist's office, a coffee shop, a liquor store, and a coin-operated laundromat.
- A 100,000 square foot suburban office building that contains thirty separate small business tenants.

Even within a single-tenant building, the mix of activities can affect energy requirements. For example, a typical warehouse might include 10 percent office space and 90 percent storage space. Generally, the office space will require much more energy for lighting and space conditioning.

All these sources of diversity complicate both energy analyses of commercial buildings and the design of policies to encourage energy conservation. The following paragraphs provide some quantitative illustrations.

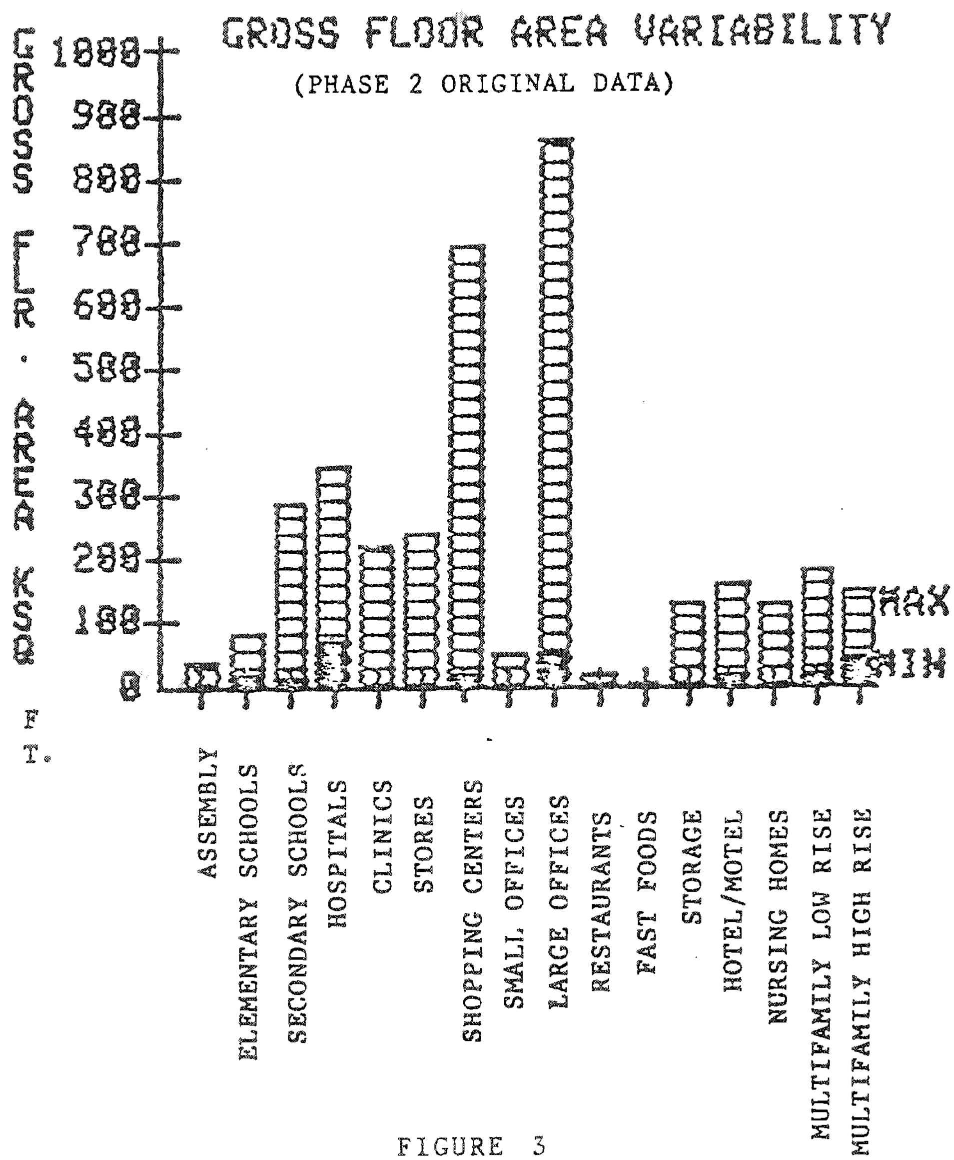


FIGURE 3

SOURCE: AIA/RC "ANALYSIS OF DATA ANOMALIES, FURTHER ANALYSIS OF PHASE II BLDGS, MARCH, 1980

Size Range. Floor area is probably the single factor showing the largest variance in commercial buildings. For instance, "an office building" can vary from a 1000 square foot real estate office to a 40-story, one million square foot office tower. Figure 3 illustrates, using data and estimates prepared for the Building Energy Performances Standards (BEPS) analysis, the range of size for major categories of commercial buildings. Variations among the categories are readily apparent; some indication of the variance within each group is given by the difference between the "typical" minimum and maximum size (solid bar vs. open bar, in each column). As the Figure illustrates, differences of a factor of ten or more, within a single building category, are not uncommon.

Glass Area. The amount of glazing (as well as the type of glass, its orientation, shading co-efficient, and the proximity of interior spaces to windows) can greatly influence both the building's heating and cooling requirements, and the feasibility of using daylighting to substitute for some interior electrical lighting during daytime hours. As illustrated in Figure 4 (drawn from the same data base as Figure 3), warehouses and stores as a group tend to have the lowest ratio of glazing to wall area, while large high-rise office buildings, not surprisingly, have the highest ratios--a factor of five greater.

Building Lifetime. Building life expectancy varies among building types. For example, many owner-occupied or speculatively-built office buildings constructed in recent years can expect to be used for 40 to 50 years. Public buildings are often constructed under the assumption that they will be used even longer than 50 years. Fast-food restaurant buildings, on the other hand, may be in use for only 15 years or less--in part because of the rapid changes in local markets, the development of new marketing strategies, and the continuing technical evolution of the fast-food industry. Buildings with longer expected lifetimes can be assumed to receive several major renovations before they are replaced, raising the possibility that major improvements in lighting, HVAC, and shell efficiency may be made periodically. Clearly, this range in expected lifetimes--and thus in the economics of investing in improved energy efficiency--calls for different initial design approaches and different retrofit strategies for sub-markets within the commercial sector.

Occupant Density. Figure 5 illustrates once again the differences both across and within major categories of commercial buildings. In this case, the Figure shows the range of average occupant densities, from a low of about 360 square feet per occupant in hotels and motels, to a high of about 20 square feet per person in elementary schools. (Note that the scale is inverted: the highest bars in the graph represent the lowest densities.)

Lighting Requirements. Illumination levels for different spaces are (or should be) related to the visual difficulty of the tasks involved. For example, guidelines set by the Illuminating Engineers Society for illumination levels at the task surface typically call for 30 footcandles (FC) for office conference areas, 70-100 FC for general office work, 50 FC for vocational cooking areas, and so forth. Such variations in recommended levels of illumination, combined with differences in interior space layout, reflectance of interior surfaces and furnishings, the availability of usable daylight, the choice and placement of lighting fixtures, and other factors, translate into even greater variance in the average number of watts/square foot that need to be designed into a lighting system.

The average watts/square foot of installed lighting in several major classes of commercial building (based on analyses for the BEPS program) are illustrated in Figure 6. Variations from minimum to maximum levels within a category range up to a factor of ten (for assembly buildings and nursing homes). The differences across building categories are also substantial, as shown in the Figure.

Average lighting levels in new commercial buildings have also tended to vary depending on the year of construction. In the late 1960's and early 1970's, installed lighting levels in new office buildings were often as high as 4 watts/square foot or more. By the mid-1970's, with an emerging awareness of higher energy prices and the need to conserve, the average for new office buildings had dropped to about 2.8 watts/square foot. As of 1980, with energy prices climbing, good office

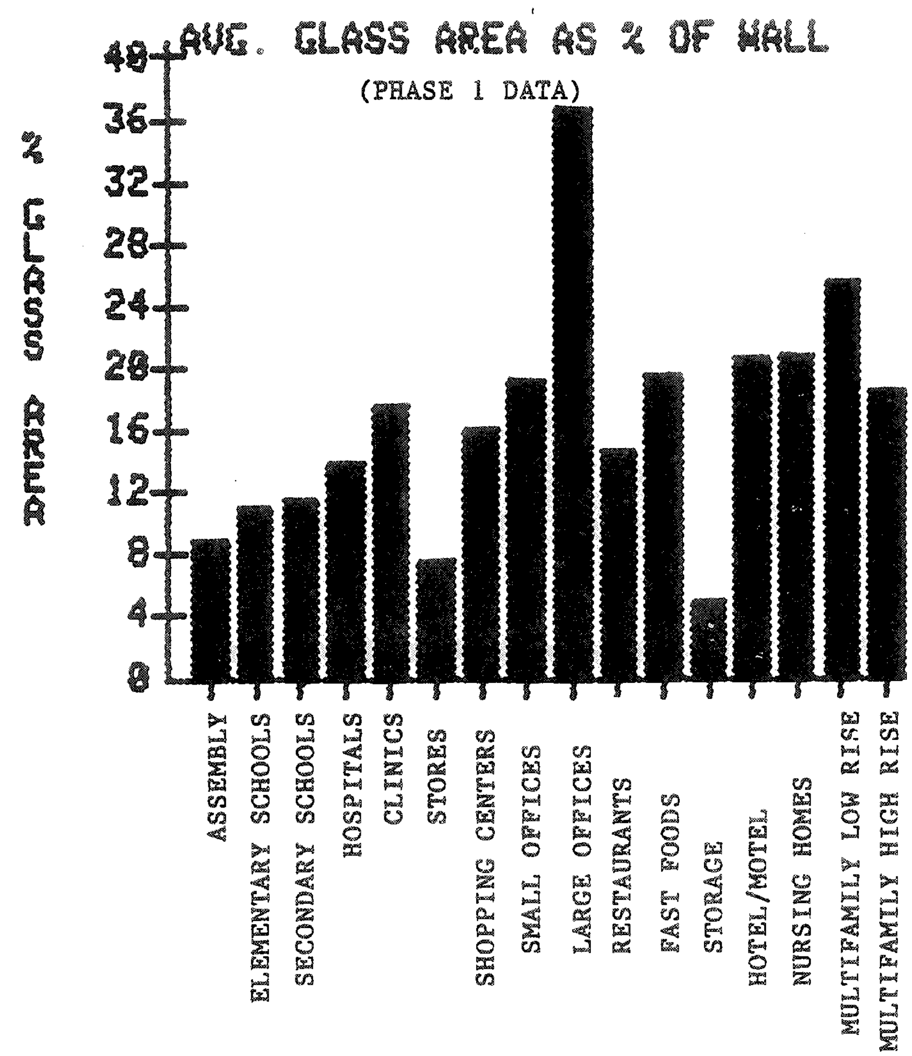


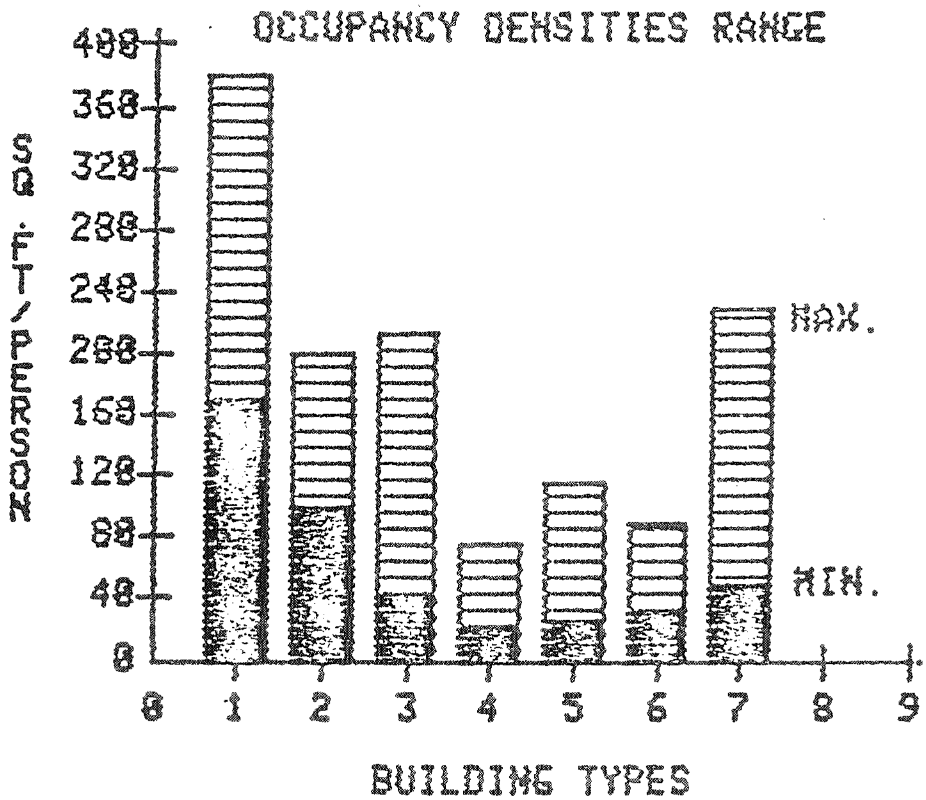
FIGURE 4

SOURCE: AIA/RC "ANALYSIS OF DATA ANOMALIES, FURTHER ANALYSIS OF PHASE II BLDGS, MARCH, 1980 design practice often achieved adequate illumination levels with installed capacities of 2 watts/square foot or less.

Over the next decade or so, it should be possible to reduce lighting energy use to about 1 watt/square foot, supplemented by effective use of daylighting, in well-designed new office buildings and possibly in renovations of existing structures. We estimate that the combination of improvements in lighting system efficiencies, building designs that use daylighting, and advanced lighting controls can cut national energy requirements for commercial building lighting roughly in half by the mid-1990's. (This is discussed further in the paper on lighting by S. Berman.)

Ventilation. Many new commercial buildings have sealed windows. Their mechanical ventilation requirements can vary considerably, depending on the level of occupancy and type of activity that may create odor, pollutants, and humidity. Minimum ventilation levels range from about 7 cubic feet/minute (CFM) for warehouses to as much as 30 CFM for commercial kitchens and dining areas. The data presented in Figure 7 show the average minimum and maximum levels of ventilation for several of the commercial building categories analyzed for the BEPS studies. (Ventilation levels are expressed in terms of the fraction of air provided to the HVAC system from outside the building).

Process Loads. Although the BEPS data on energy use for process loads (i.e., those not related to lighting or space conditioning) are very limited, there is some information on the maximum peak load requirements for individual buildings. The range is quite wide, from less than 0.5 watts/square foot for a small office to 56.5 watts/square foot for the average fast-food restaurant. Even among buildings of the same general type, peak requirements for process loads vary considerably: from about 10 watts to over 100 watts/square foot for fast-food restaurants, and from under 2 watts to more than 12 watts/square foot for hospitals. (The latter is probably due to the presence of laundry and other service facilities on-site.)



1. HOTEL/MOTEL
2. LARGE BUILDINGS
3. SMALL OFFICES
4. ELEMENTARY SCHOOLS
5. SECONDARY SCHOOLS
6. SHOPPING CENTERS
7. STORES

FIGURE 5

SOURCE: U.S. DEPARTMENT OF ENERGY, "STANDARD BUILDING OPERATING CONDITIONS, TECHNICAL SUPPORT DOCUMENT FOR NOPR ON ENERGY PERFORMANCE STANDARDS FOR NEW BUILDINGS,' NOVEMBER, 1979

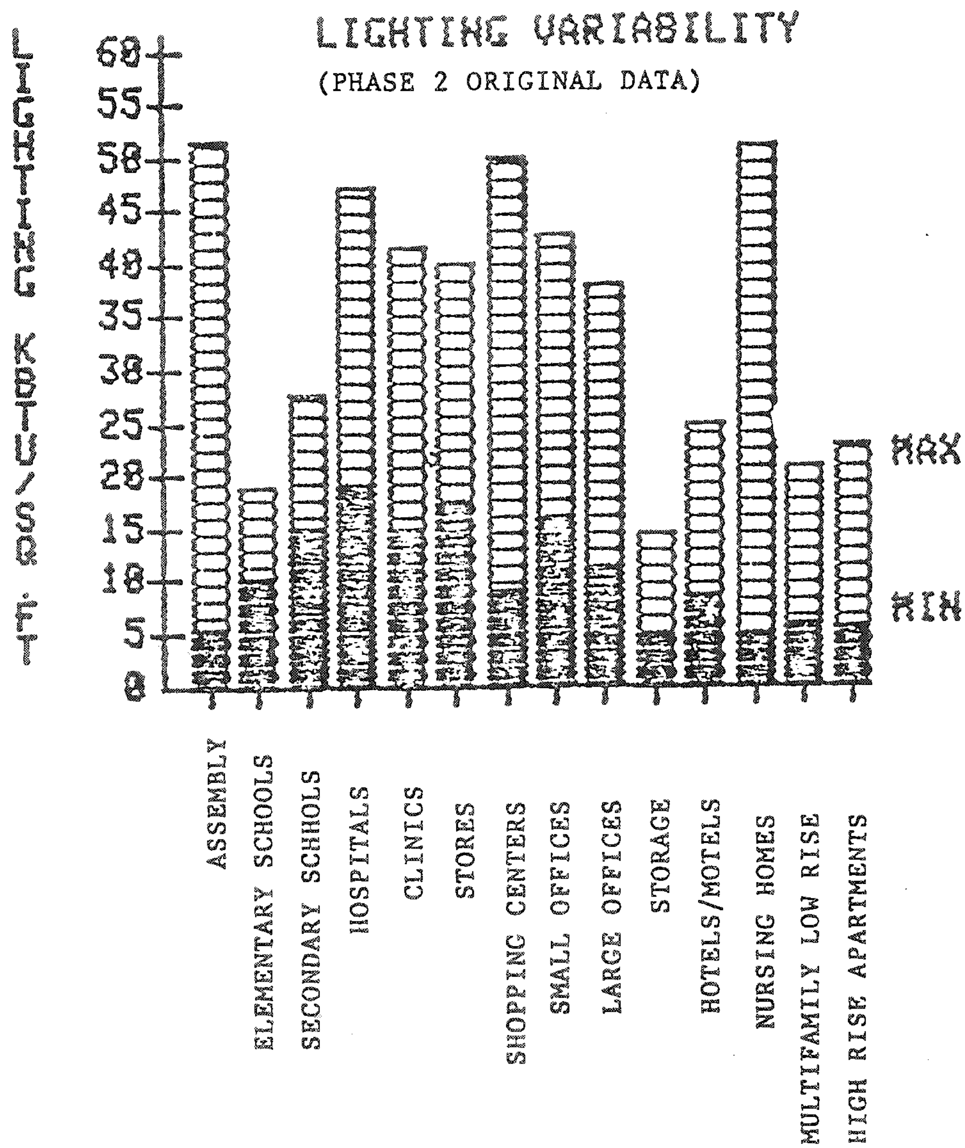


FIGURE 6

SOURCE: AIA/RC, "ANALYSIS OF DATA ANOMALIES, FURTHER ANALYSIS OF PHASE II BLDGS", MARCH, 1980

VENTILATION VARIABILITY

(PHASE 2 ORIGINAL DATA)

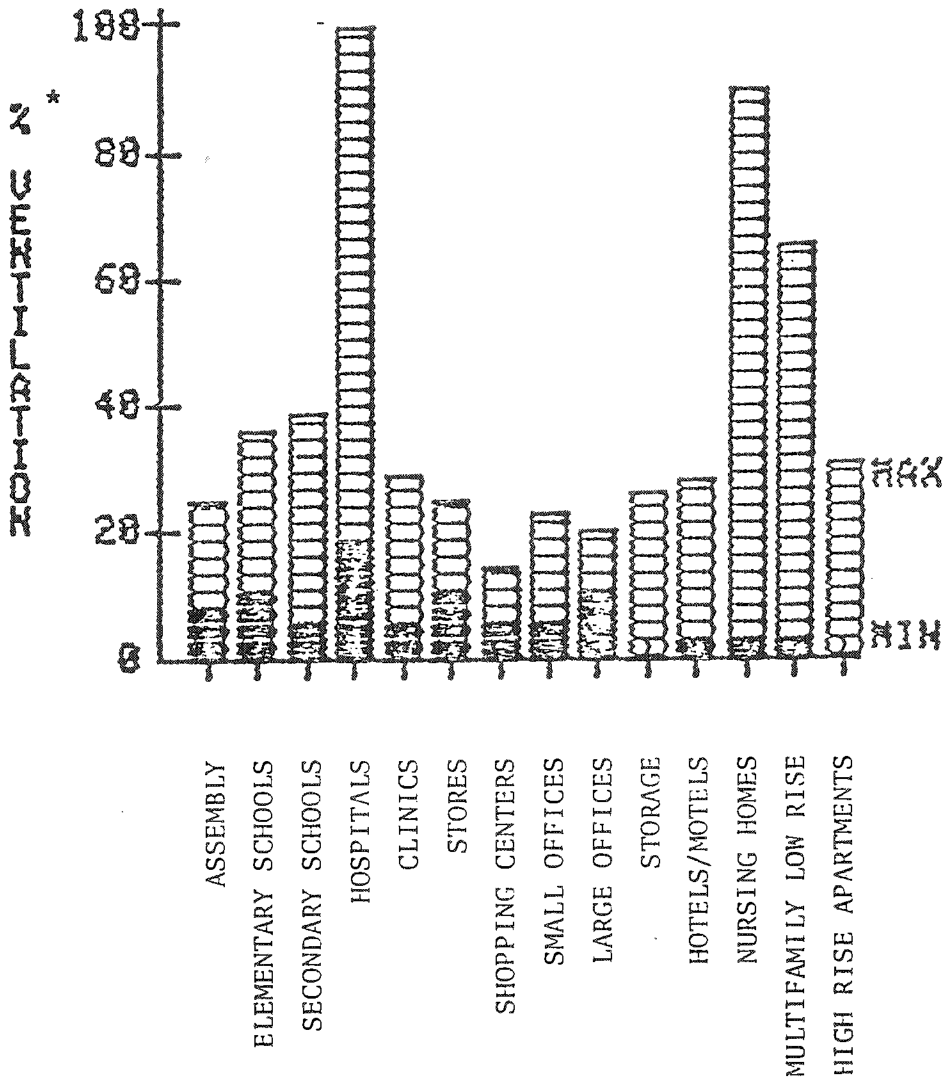


FIGURE 7

SOURCE: AIA/RC, "ANALYSIS OF DATA ANOMALIES, FURTHER ANALYSIS OF PHASE II BLDGS", MARCH, 1980

* Data expressed as a percent of daytime outside air

Having acknowledged the many sources of diversity in energy use in the commercial sector, and the shortcomings of available data, we attempt, in the following sections, to estimate the technical potential for saving energy in new and existing commercial buildings.

CONSERVATION POTENTIAL IN NEW COMMERCIAL BUILDINGS

Conservation opportunities in newly constructed (post-1980) commercial buildings are of particular interest because of the projected rapid growth in new floorspace. EIA projections using the Oak Ridge commercial sector energy demand model indicate that, by the year 2000, over half of the commercial floorspace in use will have been constructed after 1980. Even with a slower-than-expected rate of growth in the commercial sector, it is reasonable to expect that more than a third of the year 2000 commercial stock will be of post-1980 vintage. Thus, there is a major opportunity to improve the energy efficiency of 15 to 20 billion square feet of new construction over the next two decades, and in the process, significantly affect commercial sector energy and electrical peak load requirements in the year 2000.

As noted earlier, Table 2 shows a potential for about 1.6 quads of annual energy savings in new commercial buildings between now and the year 2000--roughly one-fourth of the total conservation potential in this sector.

The rest of this section presents results of the analyses prepared for the Carter administration's proposed Building Energy Performance Standards (BEPS). While the prognosis for a mandatory federal BEPS program is now doubtful, the technical analyses developed over a four-year period still provide valuable insights into cost-effective conservation opportunities in new commercial buildings.

Overall results of the BEPS research can be summarized using office buildings as an example (see Figure 8). For typical new office buildings, reductions in energy intensities of up to 60-65 percent are possible (compared with recent design practice), using only currently available technology that is life-cycle cost justified. Choosing an energy

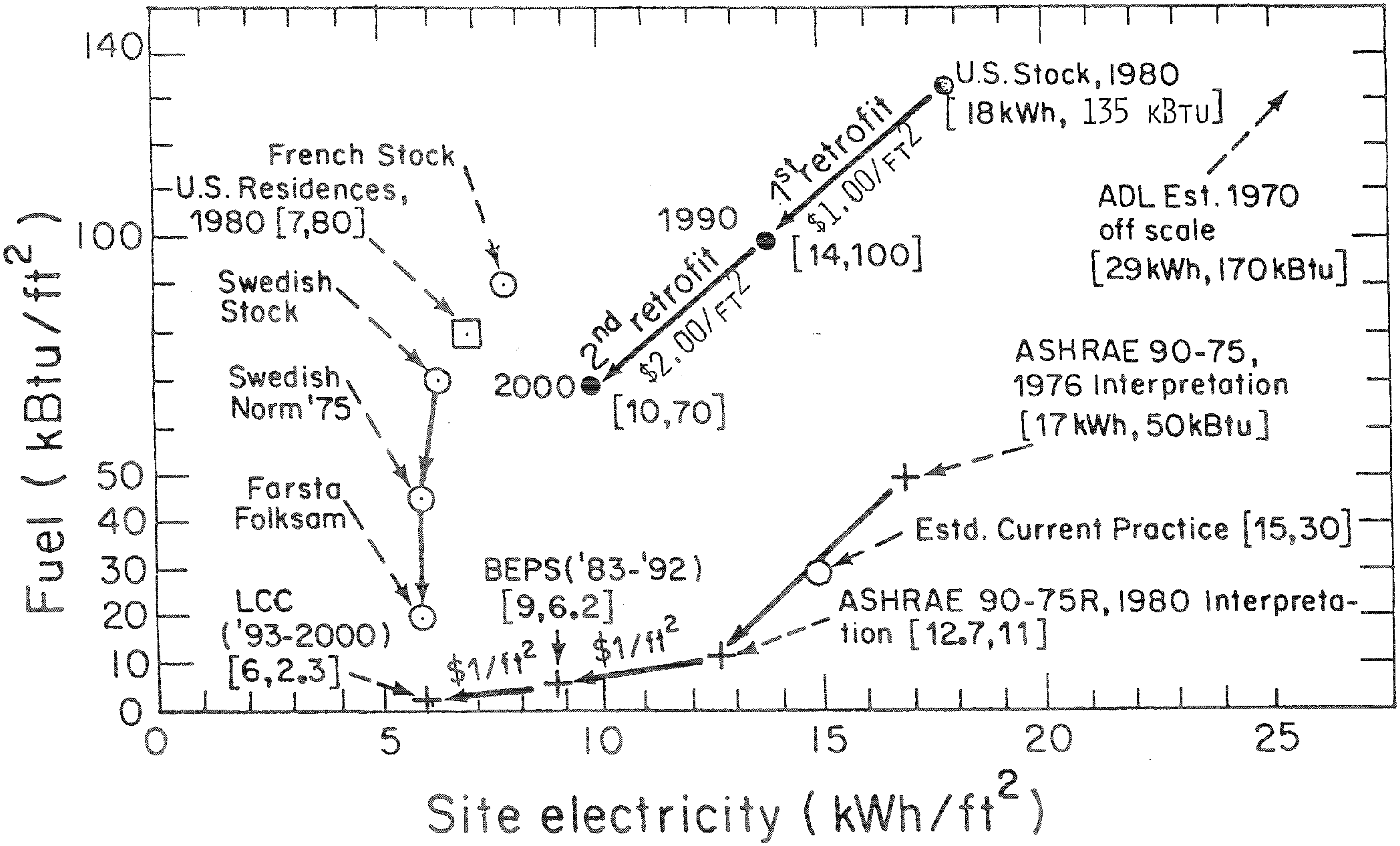


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Fig. 8. Energy use of existing U.S. office buildings and new fuel-heated office buildings. Progress in Swedish building efficiency is shown for comparison. Swedish buildings already use considerable daylighting and electricity is not decreasing, but space heat has dropped from 70 kBtu/ft^2 average for the stock to 50 kBtu for new Stockholm buildings conforming to the 1975 "Swedish Building Norm," and to 20 kBtu/ft^2 for the Farsta Folksam building which uses thermal storage over nights and weekends. The "U.S. Stock" point comes from the 1980 entries on Table III, DOE/EIA 1979 Report to Congress, divided by 32.5 Bft^2 of commercial space (from the ORNL model), with electricity scaled up by 10% to convert from "commercial sector" to "offices only." Source: SERI/LBL (1981).

consumption level that minimizes expected life-cycle costs (rather than minimizing energy use) would still come close to achieving these maximum energy savings, resulting in an expected reduction in energy intensity of 50 percent or more.

As Figure 8 indicates, the point identified as "LCC" (life-cycle cost minimum) represents about the same electricity usage per square foot, as a potential for 1993, as has already been achieved in a number of new Swedish office buildings. (Fuel use for these U.S. buildings would be lower, on average, than in Sweden, due to our more moderate climate). Finally, in some cases, it appears possible to obtain energy savings of 20-30 percent while at the same time lowering the initial costs of new commercial buildings (due to elimination of excessive lighting, the resultant down-sizing of cooling equipment, etc.).

In the rest of this section the assessments of conservation potentials for new buildings are based on four separate levels of predicted energy performance:

- Estimates for "typical" recent construction;
- Efficiency improvements based on applying current "component-based" voluntary design standards (ASHRAE 90-75R);
- The results of a redesign exercise done in 1978, which re-examined the options for improved energy efficiency in a sample of 168 actual buildings originally designed and built in the mid-1970's; and
- A life-cycle cost (LCC) analysis of further conservation options, for office buildings only, prepared in 1979.

Note that all four levels of energy performance are based on predictions of how the sample buildings will perform once constructed and occupied. They are not based on measured performance, or actual electricity and fuel consumption metering, but on the results of computer simulation models. Additional research data are needed to provide a more reliable link between such computer predictions and actual energy consumption and efficiency in real buildings.

Current Practice

The starting-point for the assessment of commercial building energy performance was to estimate the average energy intensity of typical recent buildings. Two sets of energy estimates were made using a sample of buildings from the 1975-76 period. First, energy intensity estimates were calculated for 1,661 buildings using a simplified version of an hour-by-hour energy analysis computer program called AXCESS, but with relatively little detail on each building (about 100 data points per building). Next, a subset of 168 of these buildings were evaluated in much greater detail, by asking the same design firms that had originally volunteered the data to provide, on a paid basis, more detailed information on the characteristics of their buildings.

A summary of the results for the 168 buildings is shown in Figure 9. Each arrow represents the average change in fuel and electricity intensity (on the vertical and horizontal axes, respectively) for a group of buildings in the sample. Thus, the "tail" of each arrow represents the average level of fuel and (site) electricity use per square foot for the "current practice" buildings. The head of each arrow shows estimated energy use after the "redesign" exercise (discussed below).

Effect of Component Standards (ASHRAE 90-75R)

The second level of analysis considered the likely effects of component design standards on energy use in new commercial buildings. Several years ago, when the buildings included in the sample were originally designed, few states had adopted energy conservation requirements, and the degree of voluntary compliance with voluntary standards like the ASHRAE guidelines varied among states--and among designers within a state. By now, some form of building code, most often based on the ASHRAE recommendations, is in place in some 45 states.

A subsample of 125 buildings were evaluated, using the February 1978 version of the ASHRAE 90-75R standards. The original design specifications for each building were modified to conform to all of the "mandatory" elements in the ASHRAE guidelines, except where a requirement clearly did not apply. The resulting reductions in energy intensity averaged 22 percent, but the impact of the ASHRAE standards varied widely by building type. The maximum percentage savings was 41 percent for warehouses. At the other end of the spectrum, the average net effect for hospitals resulted in an <u>increase</u> of 3 percent.

These results provide a theoretical measure of the impact of ASHRAE 90-75R requirements on mid-1970's buildings. However, the study did not address results that might actually be obtained from implementing such standards. In interpreting and applying the requirements across a range of buildings there would be not only instances of non-compliance, but also some designers who would specify equipment and components with performance somewhat better than that required by the code. Also, a number of the ASHRAE component requirements can be interpreted in different ways, especially in the section on lighting.

Information from the states' experiences with enforcement of energy codes provides further insight into the impact of requirements based on ASHRAE Standard 90-75. For example, the Massachusetts Building Code Commission (MBCC) recently examined a number of buildings for compliance with the Massachusetts energy code, which is similar to Standard 90-75. Enforcement authority in Massachusetts resides with local code officials, but the MBCC has the technical capability to do detailed compliance checks and provide feedback on code violations to both local code officials and designers. This review experience led to the following observations:

- Envelope Requirements - On average, the commercial buildings examined had envelopes some 20% better than the code required. This suggests that current envelope requirements in the 90-75 type code may be lenient, at least for the Massachusetts region, and have no substantial impact except for the least efficient buildings.

- HVAC systems and equipment requirements - 90% of the plans submitted were reported to have failed to comply with these code requirements, but the potential energy impact of the non-complying elements was not determined.

Starting with 1975-1976 practice, the energy measures required by ASHRAE's Standard 90-75 lead to about one-half the energy savings called for in the preliminary BEPS regulations (November, 1979). As part of the BEPS research, computer sensitivity analyses were conducted in 1978 and 1979 on office buildings and warehouses, to examine possible ways to increase the stringency of several of the Standard 90-75 component requirements. The results indicated that, for a typical building of the two very different types examined, the proposed BEPS energy budget levels could be attained by modifying the ASHRAE-90-75 component standards.

Thus, a more stringent set of component requirements for commercial buildings represents one possible means of achieving, in practice, the energy budget levels indicated by the BEPS proposal for commercial buildings. This assumes reasonably effective compliance with and enforcement of the requirements at local and State levels, even though to date, this degree of compliance has not been consistently demonstrated.

Redesigns: A Limited Assessment Of Energy Conservation Potential

The third energy performance level considered how much energy might be saved if designers--relying mainly on their existing knowledge, but also given some added information, feedback and incentive to conserve energy in the design process--were to redesign the original buildings to emphasize energy conservation.

The original design teams for the 168 sample buildings were hired by the AIA/Research Corporation, under contract to HUD, to redesign the buildings constructed in 1975 and 1976. Guidelines for the redesigns included:

- Designs were to stay within the same general cost range as the design for original buildings (e.g., a speculative office building should not become an expensive corporate office showpiece).

- The redesigns had to be responsive to the original requirements set by the owners.

- Designers were instructed to use off-the-shelf technology.

- Designers were, however, free to change the location of the building on the original site, its orientation, configuration, number of floors, construction material, lighting, heating and cooling systems, etc.

The designers were provided with some training and assistance: (1) a three-day workshop to review current energy-conserving design practices; (2) a workbook containing summaries of energy-efficient designs; (3) two peer-group reviews while their redesigns were being developed. The reviews included consultations with energy specialists.

The redesigns resulted in an average 40% reduction in estimated energy use, compared to the original buildings.

Figure 9 indicates, by building type, the average reduction in site electricity and fuel use after redesign. The average results for most building types tend to cluster around energy intensities of 25-40 kBtu/ft^2/year of site electricity and 10-25 kBtu/ft^2/year of fuel. The exceptions are shopping centers and hotels/motels at the high end and storage (warehouses) at the low end. Further the relative reductions in fuel and electricity use are similar for those building types which cluster in the middle of the Figure.

These average results from the sample buildings of each type help to show aggregate trends, but they could mislead a reader into thinking that all buildings within each category achieved similar energy savings. In fact, there was considerable variability in the results by building type.

The redesign exercise provided only a partial assessment of technical potential for conservation in new commercial buildings, primarily because most of the designers had only limited knowledge of the most cost-effective measures for a given situation.

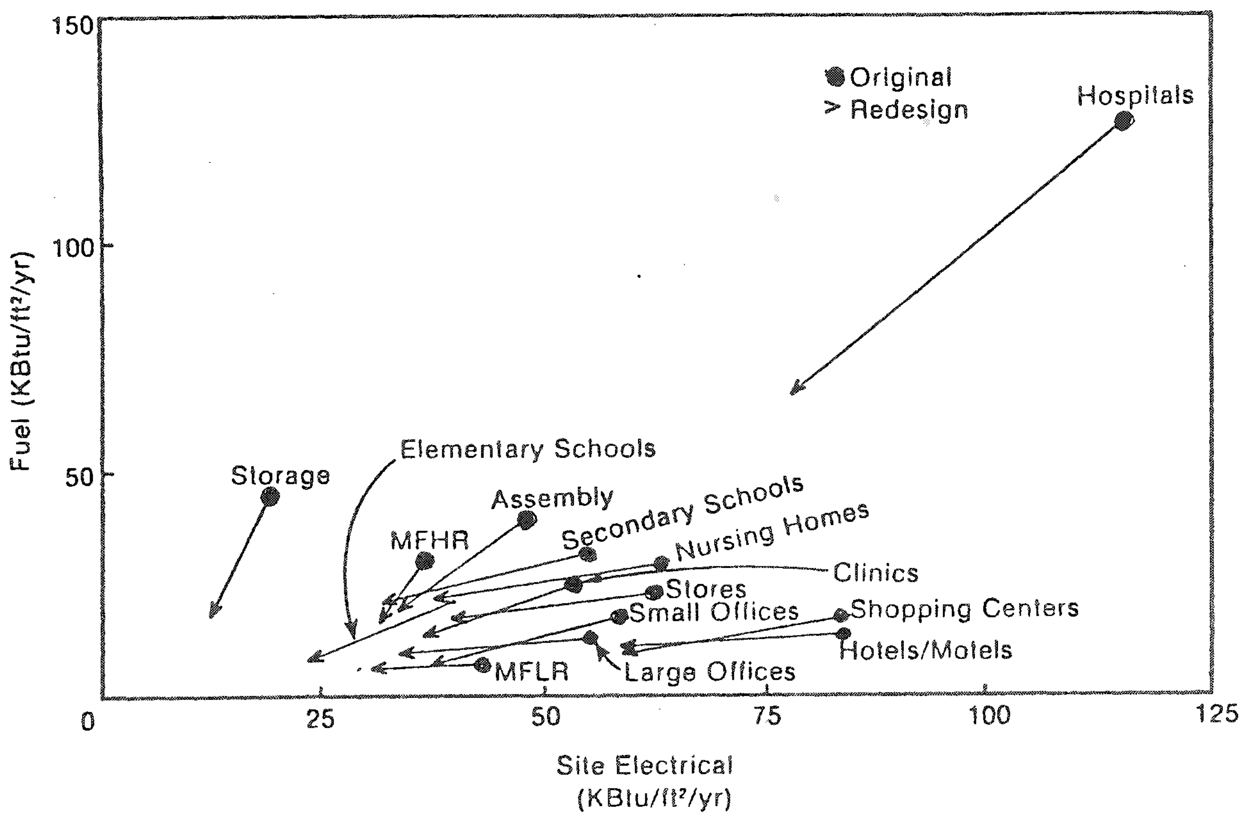

Fig. 9. Average site energy intensities before and after redesign, for a sample of 168 new commercial buildings, estimated using the AXCESS computer program as part of the development of Building Energy Performance Standards. Average energy intensity for each group of buildings is estimated under two conditions: as they were actually built during 1975-76 and as redesigned for improved energy efficiency.

In fact, the redesign exercise was as much an assessment of the current state of knowledge of energy conservation as it was an assessment of technical potential. The buildings used in the sample were selected at random in order to be representative of current design practice. The energy conservation skills and experience of these buildings' designers ranged from extensive to little or none. In fact, in 7% of the cases the redesigned buildings were calculated to use <u>more</u> energy than the original buildings. Thus, designer endeavors were not always successful, even though on the average, energy savings for all 168 buildings were about 40%.

Also, the computer tools used to estimate building energy use could not account for all significant energy-conserving features in the redesigns, especially deadband thermostat controls and daylighting strategies. Both types of measures can result in major energy savings, and few of the original 1975-1976 designs contained these features. The AXCESS computer program's capabilities were later enhanced (in 1979) to include both features. The improved version of the model was used to derive the findings concerning Standard 90, discussed in the previous section, and the life-cycle cost results summarized in the section to follow.

One can conclude from all this that the technically achievable energy intensities may be considerably lower than the averages produced by the redesigns. This expectation is supported by the results of a subsequent life-cycle cost analysis of three typical office buildings, described below. Lack of widespread information and expertise within the design professions about conservation opportunities and cost-effectiveness, as well as a lack of reasonably accurate yet cheap and easy to use energy analysis design tools, are strong impediments to achieving economically optimal levels of energy efficiency.

The following section on life-cycle cost analysis provides some further indication of the least-cost technical potential, at least for office buildings.

Life-Cycle Cost Analysis

The fourth energy performance level examined in the BEPS commercial buildings research was based on a life-cycle cost (LCC) analysis. To date, this analysis includes only office buildings.

The LCC analysis of office buildings was aimed at identifying the range of features and the resultant energy usage associated with minimum life-cycle costs. Office buildings were selected for a pilot study because of their large expected construction volume in the 1980's. The building design and energy use data from the redesign exercise provided the starting point. Three prototype buildings were selected as typical within three different climates:

- a 100,000 sq. ft., six-story speculative building in Denver, Colorado
- A 29,000 sq. ft., four-story owner-occupied building in Minneapolis, Minnesota
- A 92,000 sq. ft., four-story owner-occupied building in Raleigh, North Carolina

Additional energy-saving measures were identified and, in various combinations, systematically evaluated by the original architect/engineer design teams, assisted by energy consultants. Since the three buildings were originally all-electric, the design alternatives analyzed in greatest detail were for all-electric buildings. Comparable solutions for gas heating systems required about 2 to 10 kBtu/sq. ft./year more, depending upon the building, HVAC system, and climate.

Detailed first-costs were prepared for each design option, as well as equipment lifetimes and replacement costs. Local energy prices and regional fuel escalation rates were used, and the assumed financing methods and interest rates were varied to test the sensitivity of estimated life-cycle costs. Several important factors <u>not</u> examined in the analysis were:

- Sensitivity analyses of other economic parameters, including: construction costs, fuel prices and escalation rates, and required rate-of-return after taxes.

- Sensitivity analyses of key technical parameters including: building size, mix of functions, and climates other than those evaluated.

- Impacts of time-of-day utility rates.

- Changes in amenity levels for building occupants (these were examined on a qualitative basis only).

- Resale value of building, as it might affect payback to speculative builders or the first buyer.

Table 4 indicates the range of results for the three office buildings analyzed. In addition to changes in energy use, the Table indicates percent changes in initial construction costs. The life-cycle costs for all the alternate solutions shown are lower than life-cycle costs for the original 1975-1976 design.

Analyses of the three prototype buildings suggested that the minimum energy intensity that was life-cycle cost-justified ranged from 20-25 kBtu/sq.ft./year. Energy use would have been somewhat higher, from 25-35 kBtu/sq.ft./year, if the objective were to minimize life-cycle costs, rather than minimize energy use.

As can be seen from the "technical potential" case at the bottom of Table 4, total energy use reductions (compared to the original 1975-76 designs) ranged from 59 to 65 percent. Reductions for heating and cooling systems combined were from 70 to 87 percent. Lighting system reductions were from 32 to 57 percent. First-costs increased from 9 to 16 percent.

Conservation measures which contributed substantially to the energy savings included HVAC systems and control improvements (including thermal storage and "deadband" thermostat controls), more efficient lighting systems, and daylighting. Appendices A to C in Lenz (1976) describe in

Table 4. SELECTED RESULTS OF LIFE-CYCLE COST ANALYSIS FOR THREE PROTOTYPE OFFICE BUILDINGS

Different Design Solutions to Same Building Design Problem	Buildings: Denver A*	B*	C*	D*	Minneapolis A	B	C	D	Raleigh A	B	C	D
Original 1976-1976 Design												
Heating and Cooling	20.2	(41)			40.6	(59)			41.3	(58)		
Lighting	25.9	(52)			18.7	(27)			18.8	(27)		
Total	49.4	(100)			70.1	(100)			70.7	(100)		
ASHRAE 90-75R Exact Applicable Requirements												
Heating and Cooling	12.6	(39)	(38)		31.4	(53)	(22)		26.1	(42)	(37)	
Lighting	16.1	(50)	(38)		20.5	(34)	(0)		13.1	(26)	(30)	
Total	31.9	(100)	(35)	(-1)	59.8	(100)	(15)	(0)	50.2	(100)	(29)	(-1)
ASHRAE 90-75R Requirements Per Component, or 1975-1976 Value, whichever is Better												
Heating and Cooling	8.4	(30)	(58)		28.5	(55)	(30)		9.5	(29)	(77)	
Lighting	16.1	(58)	(38)		15.8	(30)	(16)		13.1	(40)	(30)	
Total	27.7	(100)	(43)	(-1)	51.9	(100)	(26)	(-1)	32.6	(100)	(46)	(-1)
Redesign Exercise Results												
Heating and Cooling	8.0	(30)	(61)		18.1	(45)	(55)		8.5	(28)	(79)	
Lighting	14.8	(56)	(42)		14.1	(35)	(25)		15.4	(51)	(18)	
Total	26.5	(100)	(46)	(11)	40.1	(100)	(43)	(7)	30.0	(100)	(58)	(7)
"Technical Potential"												
Heating and Cooling	6.0	(29)	(70)		5.2	(21)	(87)		9.8	(40)	(76)	
Lighting	11.2	(55)	(57)		12.7	(50)	(32)		9.2	(37)	(51)	
Total	20.4	(100)	(59)	(16)	25.3	(100)	(64)	(11)	24.6	(100)	(65)	(9)

*A = Energy in kBtu/Sq. ft./year.

*B = Percent of total building energy.

*C = Percent reduction in energy use from original design.

*D = Percent change in first-cost.

NOTES:

1. Energy results for HVAC fans, domestic hot water, elevators, escalators, and general exhaust fans not listed here.
2. "Process" energy is not included in this analysis.

detail the costs and energy savings from each of the conservation strategies.

The analysis was not sufficiently complete to derive a single LCC-minimum point for any of the three buildings; it is more appropriate to think of a range of practices (and energy use levels) that correspond to the LCC-minimum. This is particularly true given the complex interactions, tradeoffs, and alternatives possible in the design of commercial buildings, the influence of building operators and occupants after construction, and the uncertainties of economic forecasting.

It is worth noting that in this analysis first-costs did not necessarily increase as energy use was reduced. For all three buildings, alternate designs were identified which--although stopping short of the LCC-minimum--both lowered first-cost and decreased energy use by 20 to 30 percent, compared to the original building. Cost savings were primarily due to reductions in lighting levels and associated savings from reduced capacity required for cooling equipment.

Aggregating the Conservation Potential for New Commercial Buildings

The estimates presented in Tables 1 and 2, above, were derived from the technical potentials developed as part of the office building life-cycle cost analyses, scaled to reflect commercial buildings other than offices. These potential targets for energy intensity were then multiplied by the anticipated net additions to commercial sector floorspace between now and the year 2000, based on the EIA's mid-range energy demand forecasts for that year.

CONSERVATION POTENTIALS FOR EXISTING COMMERCIAL BUILDINGS

Compared with energy conservation in residences, there is relatively little reliable information about the results of retrofitting commercial buildings, even through tens of thousands (or perhaps hundreds of thousands) of buildings have now been audited nationwide--and a significant fraction of these have undergone at least operation-and-maintenance improvements.

As a general rule, the available data take the form of case studies, mostly of government offices and educational buildings. Data content is often descriptive rather than quantitative, and completeness, detail, and presentation format tend to vary considerably from case to case. For most retrofitted buildings, there is not sufficient cost data to do even a cursory cost-benefit analysis.

However, several projects now underway should provide valuable information about the energy use of commercial buildings by building category, size, age, and region. For the projects cited below, substantial work has been accomplished and draft reports are either in preparation or under internal review.

Commercial Building Data Compilations

First, H. Ross and S. Whalen, of the Department of Energy's Conservation and Renewable Energy Program, Buildings Division, are compiling data on nearly 200 existing commercial buildings that have been retrofitted, focusing on cases where there are reliable data on both energy savings and the associated costs. This study will be published by Lawrence Berkeley Laboratory, as Part C of a series titled "Buildings Energy Use Compilation and Analysis" (Parts A and B will deal with new and existing residences).

Preliminary results from the Ross and Whalen study are summarized in Tables 5 and 6 and Figures 10 through 12. Table 5 reviews the key findings from initial analysis of the data, while Table 6 provides a breakdown of sample size and average percentage energy savings for each of ten building categories. Note that although there are variations in the average percentage savings among groups, these variations are smaller for the categories with larger sample sizes (schools, hospitals, and offices).

The range of energy savings, both as a percentage of pre-retrofit usage and in total energy saved per square foot, is illustrated even more graphically in Figures 10 and 11, again based on the draft report by Ross and Whalen. In Figure 10, the three lines drawn from the origin represent boundaries of cost-effectiveness for savings of electricity,

Table 5

Key Findings

1. Average Cost of Retrofit (1980$)	$\frac{\$0.65 \pm 0.52}{\text{Sq Ft}}$	N = 77
2. Average Savings (Source)	22% $\pm$ 15%	N = 173
Average Savings of Electricity	8%	N = 156**
Average Savings of Fossil Fuel	28%	N = 151**
3. Average Savings Including Failed Retrofits — (Source)	19% $\pm$ 17.5%	N = 195***
4. Portion of Sample Which Had Failed Retrofit	10% (23 of 223)	
5. Portion of Sample with Less Than 3 Year Simple Payback	89%	N = 65
6. Average Cost of Saved Site Energy		
CRR = 0.25	$3.25 $\pm$ 3.15	N = 55*
CRR = 0.16	$2.08 $\pm$ 2.02	N = 55
CRR = 1.0	$13.00 $\pm$ 12.62	N = 55

*Excludes: (1) 5 European Buildings; (2) 3 "Failed" Retrofits; (3) 2 Buildings Where Cost of Saved Energy Was Over $100 per Million BTU, More Than Twice the Highest Cost of the Rest of the Sample

**Some Buildings All-Electric, or Only Fossil Fuel Data Available

***Less Than 222 (Entire Sample), Because Only Site Figures Available.

Source: Ross and Whalen, 1981.

Table 6

Percent Savings by Building Type

(Only Includes Buildings Which Attained Energy Savings >0.)

Building Category	Site		Source	
	Ave % Savings	Sample Size	Ave % Savings	Sample Size
Elementary	24%	72	21%	72
Secondary	30%	38	28%	37
Large Office	23%	37	21%	24
Hospital	21%	13	17%	10
Community Center	56%	3	23%	18
Hotel	25%	4	24%	4
Corrections	7%	4	5%	4
Small Office	33%	1	30%	1
Shopping Center	11%	1	11%	1
Multi Family Apartment	44%	1	43%	1

Source: Ross and Whalen, 1981.

oil, and gas (many of the buildings used more than one fuel), based on average 1980 prices of these fuels to commercial customers, and an assumed capital recovery rate of .106/year (10% real interest rate, 30-year amortization). A large fraction of the data points lie above these lines (i.e., are cost-justified at 1980 energy prices).

In practice, most commercial building owners today would demand a much higher capital recovery rate on an investment in improved energy efficiency--but would also take into account future increases in the (real) cost per unit of energy. For comparison, we have also drawn a boundary line on Figure 10 corresponding to a two-year capital recovery period (again at 10 percent real interest), using 1980 prices for all forms of energy, weighted by their fractions of commercial sector usage.

Figure 11 shows these same data replotted with percentage savings on the vertical axis. The line drawn from the origin represents, in this case, the assumptions used in developing our technical potentials estimates for commercial sector retrofits achieved by the year 2000. (These assumptions were that on the average 25% of current use could be saved with an investment of $1.00/sq.ft., and that a second round of retrofits, including some new technical innovations, could save another 25% for an additional $2.00/sq.ft.) The large majority of buildings in the sample saved at least this amount per dollar invested, by 1980 rather than 2000.

Another set of data from Ross and Whalen suggests less optimism, however. Figure 12 compares actual energy savings with the predictions made during the pre-retrofit energy audit (both in percentage terms). As the Figure shows, there is virtually no correlation between predicted and actual energy savings (a perfect correlation would have points clustered closely around the 45° line from the origin). Nor is it clear as yet why some retrofit projects performed much worse than predicted, and others much better. Clearly, though, the ability to accurately predict energy savings (and thus cost-effectiveness and paybacks) is crucial to the acceptance of energy efficiency as a management strategy and an investment opportunity for building owners. From these admittedly limited data there is a need for considerable improvement in the state of the art.

As part of a separate energy consumption survey of nonresidential buildings, the Energy Information Administration (EIA) within DOE has recently completed interviewing over 6000 building owners or managers on the energy-related characteristics of their buildings. The survey is based on a statistically representative sample of the existing building stock. EIA is now developing a series of reports describing the survey results, including building characteristics and energy consumption.

Another effort is the General Electric (GE) sponsored project on energy use of office buildings. This work is being conducted on a cost-sharing basis with DOE, and includes analyses of the 1977 Building Owners and Managers Association (BOMA) Experience Exchange Report data base for large office buildings. The analysis includes both private sector and government office buildings. It examines the relationships between energy consumption and such factors as downtown vs. suburban location, building height, building age, conditioned space for computers, and air conditioning equipment. The analysis also examines changes in energy consumption trends from the 1975 to the 1977 BOMA data base. While the BOMA data base is considered fairly comprehensive, it is limited to larger, professionally managed office buildings and relies on voluntary means for collecting data.

GE is also conducting another cost-shared project with DOE to define a more representative survey of office buildings. This study will analyze a random sample of office buildings over 40,000 sq. ft. located in twenty cities, and will include buildings not owned or operated by BOMA members. Results of this work are expected to add substantially to the data on energy use and conservation in representative office buildings.

Other studies of office buildings have focused on specific cities, including New York (Tishman/Syska & Hennessy), Baltimore (Hittman), and Philadelphia (Hittman). Hittman is now preparing a computerized data bank of over 2,000 buildings. The data were collected through on-site surveys conducted from 1970-1978, in locations including Baltimore, Minneapolis, Philadelphia, and the states of California, Illinois,

k BTU/Sq. Ft. Saved (Source) VS 1980 Cost/Sq. Ft.

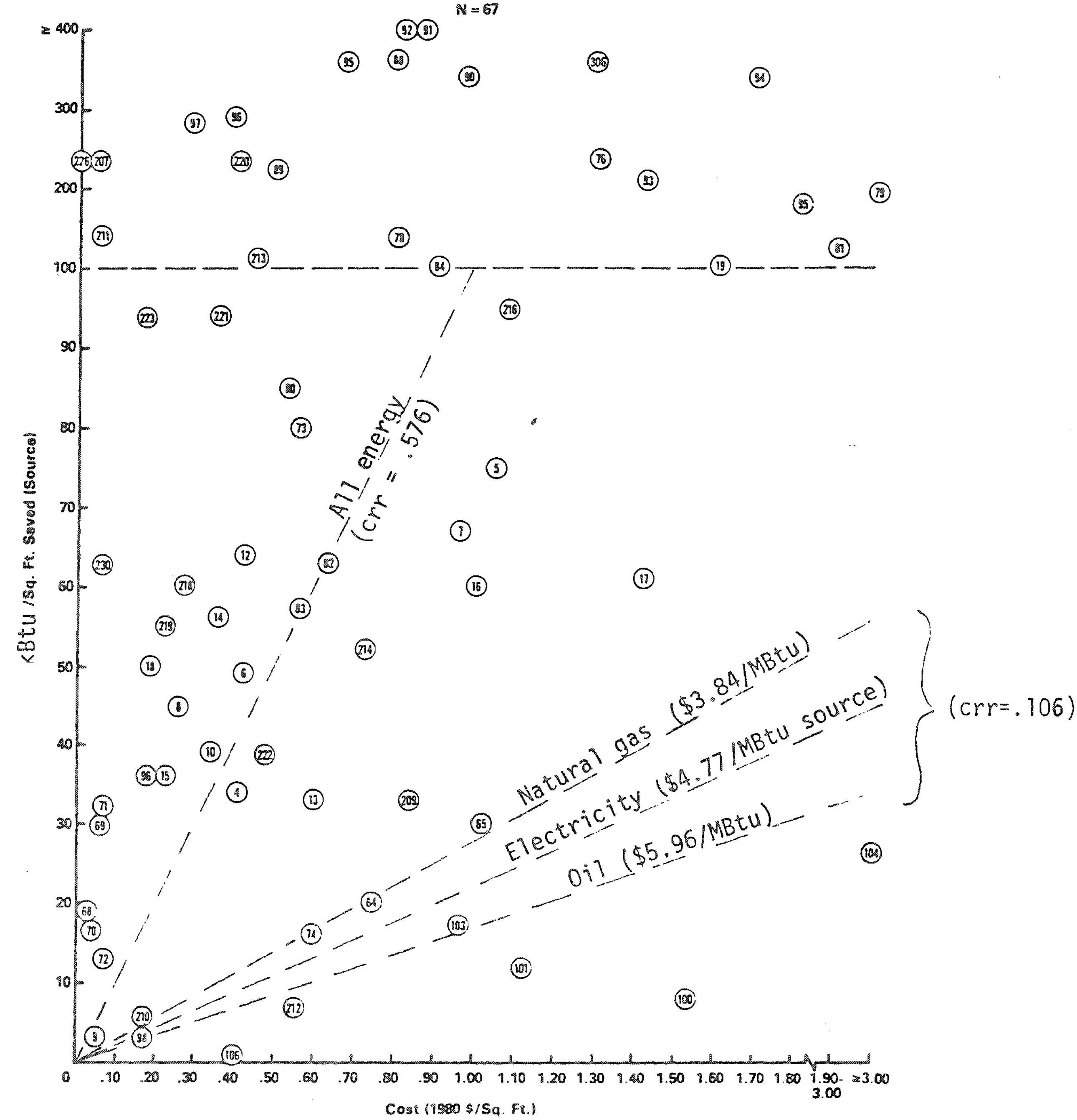

Figure 10. Annual energy savings (source kBtu/sq/ft.) vs. retrofit cost ($/sq.ft.). Note the scale changes on both vertical and horizontal axes; one indication of the degree of scatter in the data. Lines drawn from the origin indicate boundaries for cost-effectiveness in saving electricity, oil, and gas (assuming 1980 average commercial sector prices, 10% real interest, and 30-year amortization [c.r.r.= .106]). The fourth line shows the cost-effectiveness boundary for a two-year capital recovery period, 10% real interest (c.r.r.=.576), using 1980 weighted average prices for all energy used in commercial buildings.

Source: Ross and Whalen, 1981

Percent Saved VS 1980 Cost Per Square Foot

N = 66

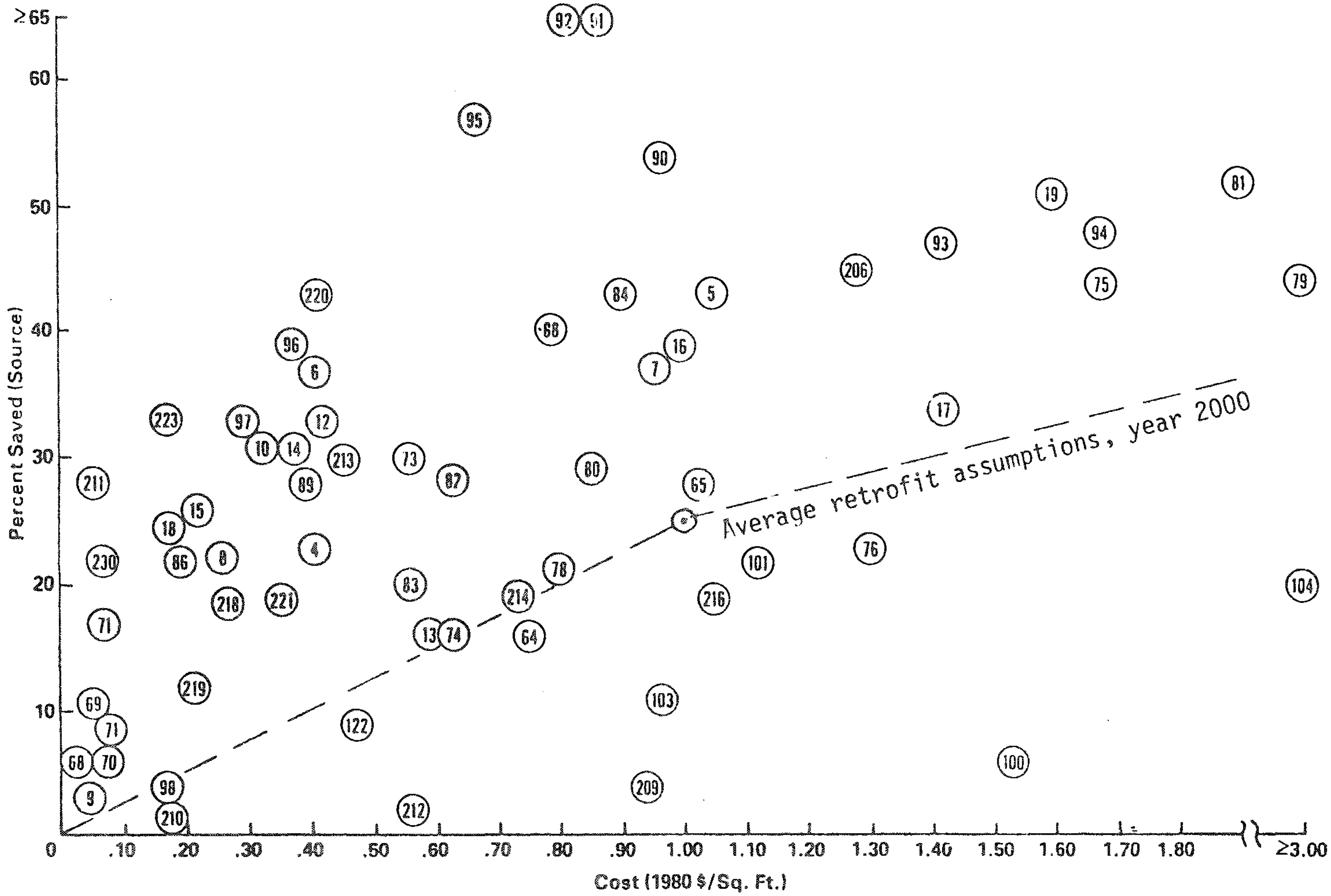

Figure 11. Percentage energy savings vs. retrofit cost ($/sq.ft.). As in Figure 10, there is a fair amount of scatter in the data on energy savings, but the majority of points lie above (i.e.-greater savings per dollar invested) the boundary line representing average assumptions for the U.S. stock of existing commercial buildings, used to estimate technical potentials for retrofitting by the year 2000.

Source: Ross and Whalen, 1981,

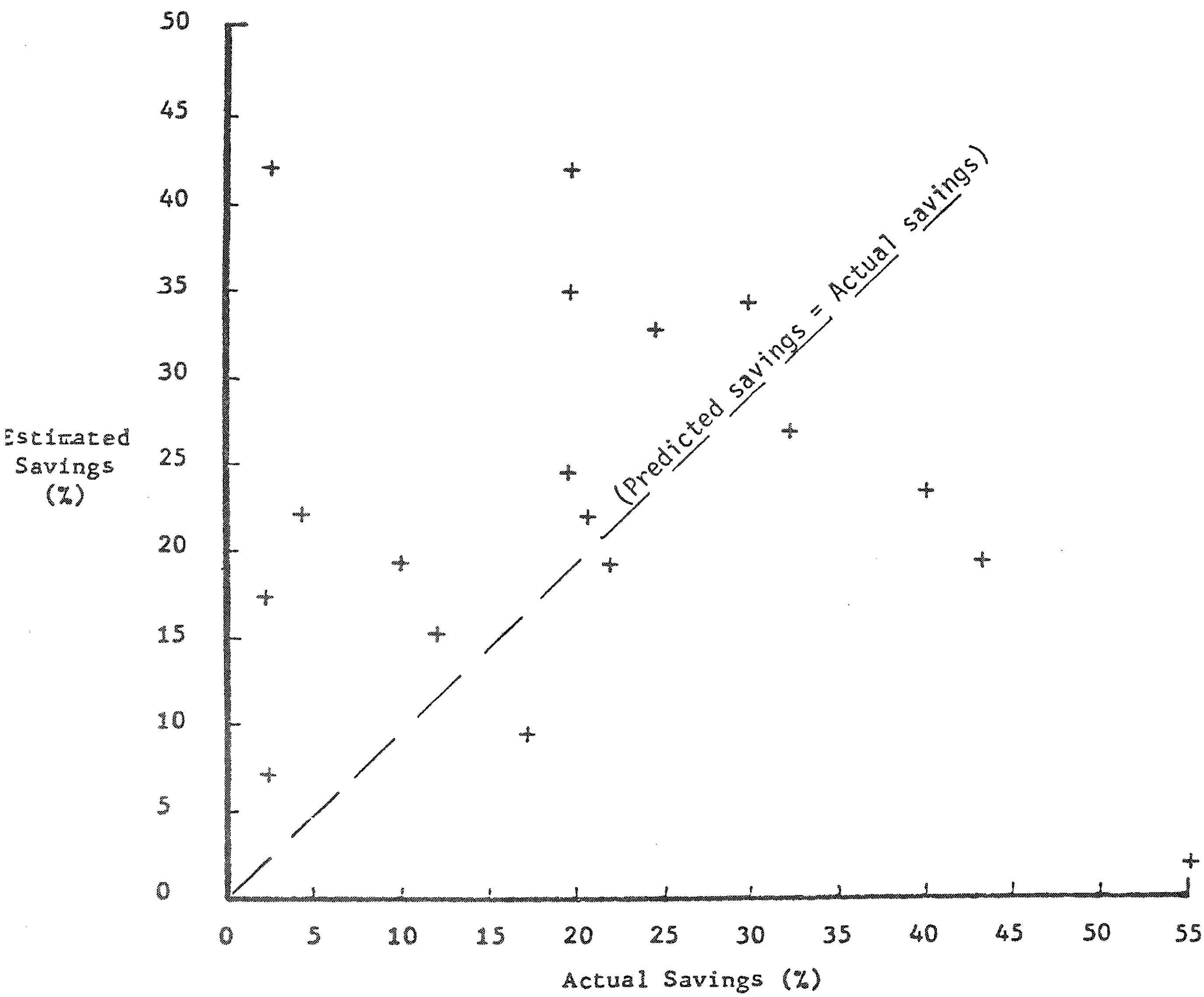

Figure 12. Estimated vs. actual energy savings (as a percentage of initial consumption) from retrofitting 18 commercial buildings. The data show no apparent correlation between pre-retrofit predictions and actual results.

Source: Ross and Whalen, 1981.

Michigan, and Wisconsin. Analysis of these data to identify potential conservation opportunities is just beginning. For some 100 buildings within this data base, data are available on how the retrofits have affected energy use.

Another effort is being undertaken for DOE as part of the BEPS research, to tabulate current data bases on energy consumption of existing buildings, including commercial buildings. This work is being done by the National Institute of Building Sciences (NIBS) and a firm called Energy, Inc. The overwhelming proportion of the sources identified to date involve state agencies, and buildings audited as part of the Schools and Hospitals program. A few other sources among Federal agencies, utilities, energy consultants, private companies, and trade organizations were identified for specific building types.

In preparing this paper two additional informal surveys were conducted. In the first, LBL asked fourteen experienced architects or engineers to provide their subjective estimates of least-cost potentials for retrofitting commercial buildings. In the second, energy-related publications were reviewed for sources of retrofit case study data. Some data were obtained for 82 commercial buildings, but for our purposes these were very incomplete. Subsequently, owners or operators of the buildings were contacted and asked to provide additional details on retrofit measures, costs, and related energy savings.

The following subsections describe each of these efforts in more detail, along with brief descriptions of four of the more complete case studies we uncovered.

Professional Judgment Survey

In this survey, a set of fourteen experienced architects/engineers were asked for their judgmental estimates of least-cost potentials for retrofitting existing commercial buildings by 1990 and by 2000. They were asked to value the energy savings at "marginal" (replacement) cost prices: \$1.50/gal. of oil, \$1/therm of gas and \$0.10/kWh of electricity.

Averaging the replies yielded a potential savings of 25% in both fuel and electricity in 1990, and an additional 25% that could be achieved technically by 2000. As noted earlier, this is reasonably consistent--or perhaps conservative, as a target technical potential--with the findings of the Ross/Whalen analysis. Thus, assuming that the 1980 stock of office buildings consumes 18 kWh/sq. ft. of electricity and 135 kBtu/sq. ft. of fuel, (18,135) the targeted consumption levels for 1990 and 2000 drop to (14,100) and (10,70) respectively, as plotted in Figure 8, above.

Note from Figure 8 that the general magnitude of these estimated potential savings from commercial retrofits is similar to the improvements called for in new construction, under the proposed BEPS standards. As shown in the Figure, electricity consumption in the average existing office building, after installing all cost-effective retrofits, would come down to about the BEPS (1983) level. However, fuel use in existing buildings remains much higher, primarily because the initial fuel use estimates for the existing stock were much higher than estimated use in new, post-1973 buildings (that provided the starting point for the BEPS analysis). This is reasonable if we assume that commercial building retrofits would often involve modifications, but not replacement, of entire HVAC systems (the major use of fuel), however inefficient they are.

Retrofit Data From Publications

To complement the professional judgment survey, we attempted to obtain additional commercial building retrofit results from case studies published in trade and technical publications. The focus was on identifying retrofit measures and collecting well-documented data on both pre- and post-energy use data and costs, by fuel type when possible. This was a small-scale effort undertaken by W.S. Fleming Associates.

First, a literature search was made of energy publications to determine the availability of retrofit data. Of particular value were articles in Energy Users News spanning a five-year period. Overall, articles reporting on 190 retrofits were identified. Of these, 82 cases were commercial buildings; the remainder were industrial facilities.

However, a careful reading of these articles showed that the existing published information is at best piecemeal, and does not lend itself to a comparative analysis across buildings or building types since owners/operators reported results using different formats and in varying levels of detail. There are often data on dollars invested and estimated percentages of energy saving, but virtually none on building size or pre- vs. post-retrofit energy consumption by fuel type (the latter is especially important where fuel-switching may have occurred).

Since very few of the published cases included even the minimal data for a consistent assessment of energy savings and cost-effectiveness, we made an effort to collect some of the missing information. Owners or operators of the commercial buildings identified from the publications were contacted, and asked to furnish additional data on building size, types of retrofit measures installed, pre- and post-retrofit energy usage by fuel type, pay-back period, etc.

Unfortunately, this effort yielded only limited additional data. For example, of the 82 retrofits identified, only 40 contained sufficient data to estimate the percent of total energy saved. Only 15 cases provided sufficient data to estimate percentage savings by fuel type. We were able to estimate retrofit costs per square foot in only 20 instances. Further, the documentation provided generally did not permit us to isolate savings due to operation and maintenance changes from those due to hardware retrofits. Finally, the cost per unit of energy saved could be derived in only 8 cases. Thus, the results presented below are extremely limited, but the whole exercise underscored the importance of a more comprehensive effort to gather and analyze data on retrofit results.

The estimated energy savings were substantial for the 40 cases where it was possible to derive such estimates (see Figures 13 and 14):

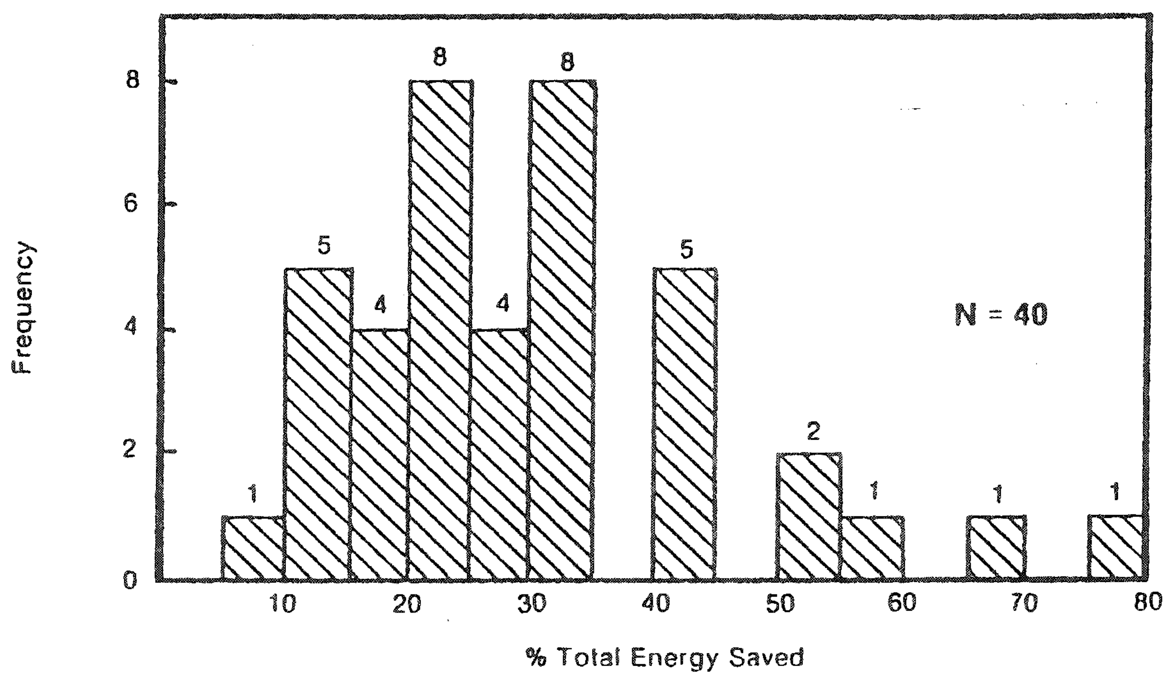

Fig. 13. Percentage energy savings after retrofitting, for a subsample of 40 commercial building case studies drawn from published sources.

Source: W.S. Fleming and Associates

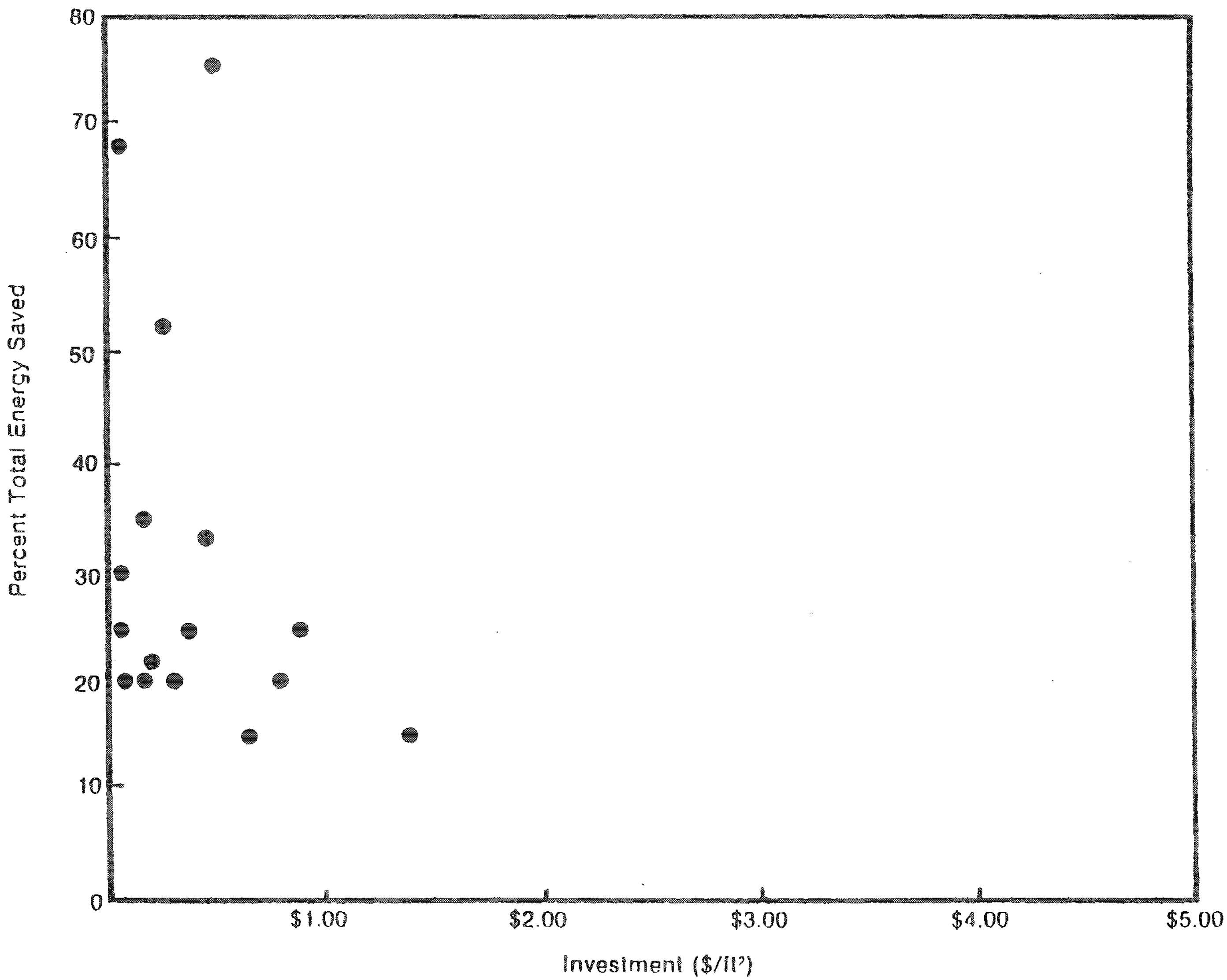

Fig. 14. Percent of pre-retrofit energy saved, vs. dollars/ft^2 invested in retrofits, for a sub-sample of 16 commercial building case studies, drawn from published sources.

Source: W.S. Fleming and Associates

- For 22 cases (55%), estimated savings exceeded 25% of total energy use.

- For 30 cases (75%), estimated savings exceeded 20% of total energy use.

These levels of savings seem to indicate sizable potential savings from commercial building retrofits and to reinforce the estimates of large potential savings from the professional judgment survey. However, there is no way to know if the buildings reported in the publications are representative of the population of all existing buildings. For example, one might suspect some selection bias, since the most successful retrofits would be better-documented and would tend to be reported in the literature, whereas less successful retrofits, or failures, might not be reported. It would be useful, although perhaps difficult, for a more comprehensive data-gathering effort in the future to try to include well-documented failures, as well as notable successes.

Case Studies

The following descriptions of several case studies offer additional examples of current retrofit activity in non-residential buildings. Fuel and electricity intensities before vs. after retrofits are plotted in Figure 15. The relative cost-effectiveness of retrofits is expressed in terms of average cost per unit of conserved energy ($/MBtu). To compare it with annual energy savings, the initial dollar investment is converted to annual costs using a uniform capital recovery factor, at a real discount rate of 10% and a loan period of 30 years (c.r.r = .106).

- Ohio State University (Columbus)

  Ohio State University's Columbus campus invested four million dollars in conservation retrofits between 1974 and 1978, reducing fuel and electricity use by 40% and 50% respectively. This has saved, to date, the equivalent of twelve million dollars in cumulative utility bills. However, as can be seen in Figure 15, the original buildings were very inefficient compared to the national average, and were apparently operated 24 hours a day for most of the year. The average cost of the retrofits was $0.60/sq. ft., savings in (resource) energy averaged 300 kBtu/sq. ft./yr., and the cost of conserved (resource) energy was about $0.20/MBtu (i.e., $0.025/gallon, or $1.16/bbl).

- State of Minnesota

  E. Hirst and several associates analyzed the results of detailed engineering audits performed at 41 institutions (including seven office buildings) owned by the State of Minnesota. (Part of these results were published in the June 1980 ASHRAE Journal, page 47). The published results--based on projected savings, not actual pre- and post-retrofit energy use--for the seven office buildings were combined, so only the average is plotted in Figure 15.

  These seven buildings started with energy intensities well below the U.S. average, yet even so, the audits identified cost-effective retrofits for about $1/sq. ft. Once the recommended measures are implemented, it is projected that fuel use will be halved and electric use reduced from 12.6 to 9.2 kWh/sq. ft., resulting in a cost-of-conserved-energy of about $1.22/MBtu.

- Ebasco

  Ebasco is a large engineering company (6,700 engineers) principally involved in power plant design and construction. It has participated in the design of 900 power plants world-wide, but recently decided to diversify into end-use efficiency. The firm has been offering audits and "guaranteed savings" for commercial office buildings, campuses, hospitals, etc. Data on seven of their current projects are shown in Figure 12. The average retrofit investment recommended was $1.19/ft., for a (guaranteed) savings of 20 percent in electricity and 45 percent in fuel. The average cost-of-conserved (resource) energy was $1/MBtu.

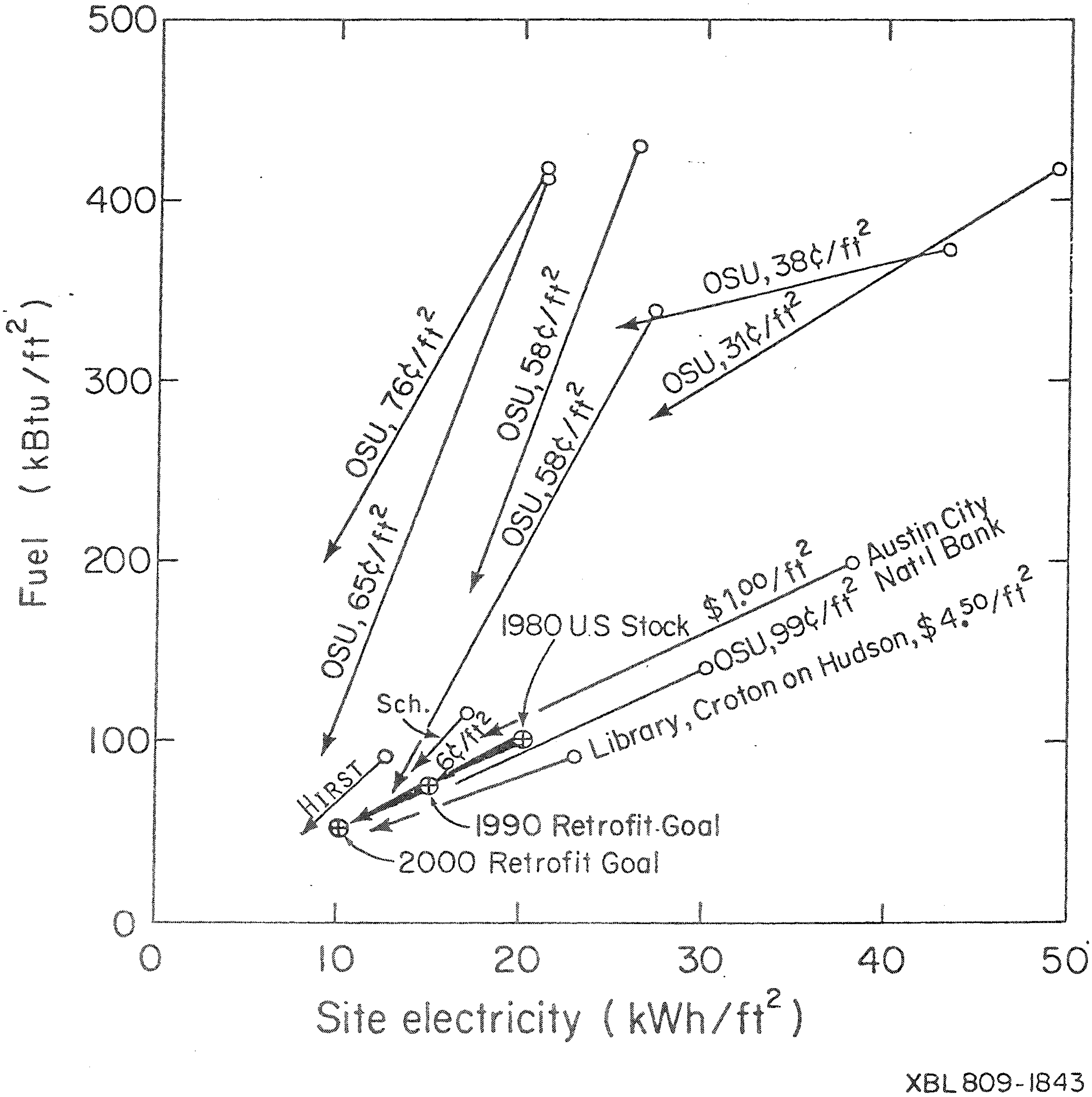

Fig. 15. Fuel and electricity savings (and cost-of-conserved-energy) for several retrofitted buildings on the Ohio State University (Columbus) campus, for seven state office buildings in Minnesota, and for seven retrofit projects with savings "guaranteed" by a private energy management firm (Ebasco). Proposed technical potentials from retrofitting the entire U.S. stock are shown (bold arrows) for comparison. Note that these University buildings were initially far more energy-intensive than the average for the entire stock.

- Elementary Schools

  For completeness, we quote one discouraging retrofit project involving ten elementary schools. The American Association of School Administrators, supported by DOE and assisted technically by LBL, undertook the retrofit of 10 elementary schools around the United States. The experiment started in 1975, when admittedly there was less interest in and experience with retrofits. Over the three years of the project, there were indeed energy savings of about 20 percent realized, but both the controls and the retrofitted schools achieved about the same results (Rudy and Rosenfeld, 1979).

We should add that the above-mentioned case study data should not be considered an indicator of least-cost technical potentials for commercial building retrofits, since they reflect the current willingness of building owners to invest in conservation. On the whole, it seems that owners are correcting gross problems and are concentrating on a relatively few, familiar items with quick paybacks (often limited to one or two years). Commercial building retrofits are now concentrated mostly on easy-to-use, off-the-shelf measures such as time clocks, demand controllers, night set-back controls, increased equipment maintenance, reduced lighting levels through simple delamping, and in some instances installation of computer-controlled energy management systems.

Summary of Retrofit Potentials

The preceding section has provided a brief overview of the existing data in order to arrive at some assessment--although admittedly a rough one--of least-cost potentials for retrofitting existing commercial buildings. Our observations can be summarized as follows:

- Retrofit data are just beginning to be accumulated in a consistent, publically available manner; the sources are numerous and reporting formats vary.

- At this time, there is no detailed, consistent, and well-documented retrofit data base in the public domain. This is a high priority for future work.

- State energy offices and utilities are potentially good sources of retrofit data; however, the best-quality quantitative data appears to be in the hands of private energy management consulting firms.

- Most of the available data cover schools, colleges/universities, offices (both public and private), and hospitals. Good documentation for retrofits of other building types has not yet been located, even though a number of restaurant and retail store chains have active retrofit programs.

- Current retrofit projects cover, for the most part, off-the-shelf measures yielding very high rates of return and very quick paybacks.

- The cases analyzed to date suggest the potential for considerably higher (but still cost-effective) levels of retrofit investment than are now occurring. The existing gap between the cost-of-conserved energy from retrofits and today's energy prices paid by commercial customers suggest that a "least-cost" investment strategy is a long way beyond current practice.

One indicator of how far the present levels of conservation lag behind the economic and technical potentials is that nearly 40% of commercial retrofits yield less than a one year pay-back, and 70% fall in the two- to three-year range.

Combining the available case study data, most notably the Ross and Whalen compilation, with the findings from our professional judgment survey, we based our aggregate estimates of conservation retrofit potentials on sector-wide average savings of 25% by 1990 (at an average investment of $1/sq.ft.), and an additional 25% by 2000 (for an additional $2/sq.ft. investment). These average savings figures were then multiplied by the EIA projections of existing stock that will still be in place by the year 2000. This is the source of the aggregate savings potentials identified in Tables 1 and 2.

There are, however, built-in market and institutional constraints that will make it difficult to achieve this technical goal over the next twenty years. Energy costs still represent a relatively small portion of a business firm's total operating expenditures. Building owners can relatively easily transfer higher energy costs to their tenants, rather than invest in improved efficiency. This process is not limited to non-owner-occupied commercial buildings; for example, hospitals bill their operating costs (including energy) to their patients or to insurance companies according to pre-set formulas. Also, the corporate tax structure now acts as a conservation disincentive, since the higher the tax rate, the higher the income tax benefits from deductions for operating expenses (including energy) and the lower the incentive to invest in conservation. These and other issues will be briefly examined in the following section.

ACHIEVING THE POTENTIAL - WHAT IS HOLDING US BACK?

The preceding sections first identified some of the analytical difficulties in assessing conservation opportunities in a sector as diverse as commercial buildings, and then estimated, based on the best available data, the technical opportunities for cost-effective conservation within new and existing commercial buildings. In this section we address a few of the practical difficulties involved in actually achieving this technical potential. We begin by discussing several of the important constraints to a least-cost conservation strategy, offer possible means of dealing with each type of constraint, and conclude with a brief summary of other policy options that could contribute to achieving the full conservation technical potential in commercial buildings.

Some Deterrents to Conservation in Commercial Buildings

In recent years it has been widely assumed that the existing investment tax credits, along with special tax credits and accelerated depreciation provisions for energy conservation and solar measures, would be sufficient to encourage energy-saving investments and improved operating practices--particularly once fuel price deregulation takes full effect. It is becoming clear, however, that there are substantial delays and gaps in the "price elasticity" response predicted by economic theory.

There are many ways of categorizing the constraints affecting energy conservation in the commercial sector (see Blumstein, 1980, and California Energy Commission, 1981). For the purposes of this paper, we will summarize them in terms of:

- problems of capital availability;
- the low credibility of engineers' recommendations and product performance data;
- misplaced incentives associated with leased space;
- delaying investment in anticipation of bigger conservation subsidies to come; and
- energy pricing that understates the actual (replacement cost) "value" of saved energy.

Of course, many of these same issues apply to residences, as well, but our discussion will focus on the aspects that are most significant for conservation in the commercial sector.

Capital availability. Capital formation has become a generic problem in the commercial sector--not only for energy efficiency improvements but for capacity expansion and normal business operations--due to general inflation and high interest rates, lagging productivity, and the disincentives to save and invest built into the present structure of both corporate and personal income taxes. Energy-saving investments are in constant competition with other investments for the limited capital available to each firm. This competition can become particularly acute in the small-business sector. Many owners of leased buildings, or owner-occupant businesses, may prefer to invest their capital in areas that improve productivity or reduce labor costs, such as word processors or self-service elevators.

One way for firms to resolve these competing capital requirements is to compare internal rates of return for the various investments. In effect, this means that energy-saving investments must demonstrate a rate of return equivalent to very short payback periods--in almost all cases well under five years and sometimes no more than one year. The result is a "cap" on energy-saving investments that stops well short of the level of efficiency corresponding to minimum life-cycle costs (using a rate of return in the range of 10 percent--the average performance of investment capital--rather than 20 to 100 percent).

Other project financing difficulties face non-profit organizations and public agencies that own their facilities, since these organizations are, of course, deprived of the benefits of investment tax credits, energy tax credits, and accelerated depreciation (although, conversely, some public agencies can reduce their cost of borrowing by issuing tax-free bonds). The Federal Institutional Buildings Grants Program (also referred to as the "Schools and Hospitals" program) was designed in part to compensate for this unavailability of tax incentives, but in addition to limited funding and the requirement for a non-Federal matching share, the program provides no capital funds for improving local government facilities, nor any assistance for non-profit groups other than health and "public care" organizations. Moreover, the program does not help overcome short-term cash flow problems, since it reimburses a portion of the capital investments rather than providing funds up-front.

In the case of new construction, there are slightly different capital constraints affecting energy-saving features. Since many construction projects are subject to the constant threat of cost overruns, energy-saving features that initially may have been designed into the building become an obvious source of first-cost savings, without sacrificing square footage or other obvious amenities.

<u>Credibility of technical information</u>. The energy conservation recommendations made by consulting engineers often suffer from credibility problems, based on a sense (unfortunately often accurate) that the projected energy savings will not be realized, or that the initial or upkeep costs of energy-conserving features will be higher than expected.

Other than shortcomings in the engineers' own training or experience, one source of this difficulty has been inaccurate or misleading performance claims made by manufacturers of equipment and shell components. The various energy-saving claims made by advertisers in just a single issue of a trade or technical journal, if one believed them all, could easily exceed the total energy use in a building. The absence of well-specified performance tests or standards for most individual pieces of equipment (or whole systems) used in commercial buildings adds to the problem.

An additional factor that has contributed to poor energy-saving performance, and thus harmed professional credibility, is inadequate supervision during the construction stage to assure that design concepts and equipment specifications were in fact followed by the numerous contractors and tradespeople involved in any large commercial building project. Finally, failure to enlist the active cooperation of building managers and tenants in operating the energy saving systems--or in some cases neglecting to even explain how these systems should be operated--has eroded some expected savings.

Leased commercial space. In virtually all leased commercial buildings, even rapidly rising energy prices create little or no incentive to conserve, because both the tenant-occupant and the building owner are partly or totally isolated from the economic consequences of their energy use decisions. Tenants in master-metered buildings will see no direct benefit from efforts to save energy, nor pay any direct penalty for wasting it. And, just as in rented residential buildings, even where the leased space is sub-metered, commercial tenants have little ability to make permanent capital improvements in the property to save energy. Conversely, even in master-metered structures, many owners express reluctance to invest in energy-saving hardware out of a concern that their anticipated savings will be reduced or eliminated by wasteful behavior on the part of tenants.

There are other special problems created by the provisions written into many long-term commercial building leases, concerning energy cost pass-throughs. During the 1960's and 1970's many long-term (25-30 year) leases were signed, providing that increased energy costs could be directly passed through to tenants, but making no equivalent provision for passing through the costs of energy-saving improvements made by the owner--even though this might be a much more attractive option for both owner and tenant.

Furthermore, some building owners are reluctant to approach the tenant to re-open this one provision in the lease, for fear that the tenant may insist on other changes at the same time. In recent years, lease arrangements for commercial space have changed in several respects, including much shorter lease periods (typically five years) and, in at least some cases, parallel provisions for passing-through the costs of energy-saving improvements as well as utility-rate increases. Modifying those long-term leases that are still outstanding, and encouraging widespread use of a "conservation cost pass-through" clause in new leases both offer considerable promise as energy conservation strategies.

Waiting for a better subsidy. Although this phenomenon may prove short-lived, for the past two or three years there have been repeated instances of commercial building owners explaining their reluctance to undertake conservation improvements on the grounds that some new, larger Federal or state government incentive has just been proposed, and may be approved if the owner waits for just a few months.

This view, that it may be better to wait before investing in conservation, has another interesting variant. It arises out of a concern that forced curtailments may be imposed in the event of a fuel or electricity shortage, based on a percentage reduction from historical usage levels. In other words, when the emergency curtailment arrives the building owner who has not already reduced consumption levels will then be able to cut back consumption by the required 10 or 20 percent with relative ease, by reducing waste rather than limiting the hours of building operation or otherwise inconveniencing tenants. From a societal point of view, of course, this inclination to continue wasteful practices so that they can be a private "reserve" of easy energy savings in the event of a shortage is not only inefficient, but may actually contribute to the circumstances under which a shortage, and curtailments, become more likely.

Under-pricing of energy. The pricing of utility-supplied electricity and natural gas based on historical average costs, rather than replacement ("marginal") costs, is often mentioned as a principal constraint to achieving potential efficiency gains. While this may be true today, it is worth remembering that until relatively recently the cost of energy from new sources was typically lower, not higher, than historical average costs. Even under average-cost pricing, the effects of natural gas deregulation on retail gas rates, and the consequences for electricity rates of rising fuel generation and capacity costs, will eventually begin to deliver strong price signals to consumers as a group.

Perhaps a more difficult problem exists in reforming the structure of utility rates, as opposed to their general levels. By now, more than one generation of consumers has been conditioned to believe that they have an "entitlement" to low-cost energy. This is true not only for residential customers, but for rural agricultural users and large commercial and industrial customers, who in many states persist in the outmoded argument that higher consumption can reduce unit costs, and thus should be rewarded with declining-block rate structures.

On the other hand, some state legislatures or regulating agencies have adopted a policy that residential gas and electricity rates are to be kept well below the "cost-of-service," with the lost revenue made up by charging higher rates to large commercial and industrial users. To the extent that these non-residential rates approximate marginal costs of energy, they create a price incentive for some customers to use energy efficiently--but may have the opposite effect for residential customers. (Nor are the ultimate equity effects of charging higher rates to businesses than to residential customers entirely obvious. Much depends on how these higher non-residential energy costs are passed through in the cost of goods and services purchased by each income group.)

As utilities and their regulators seek acceptable means of spreading the rising cost of energy across various customer classes, there is the further question of whether today's customers are able to correctly anticipate the energy cost increases (and changes in rate structure) that they will face in the future. Even aside from the forecasting uncertainties, no utility or regulatory agency is very anxious to be the bearer of bad news about future long-term energy price increases, but unless consumers can take these increases (in addition to general inflation) into account in making decisions about energy conservation investments today, they are likely to seriously underestimate the actual payback.

Possible Solutions

There are several possible ways to counteract each of the constraints mentioned above. We will summarize them briefly, continuing in the same order as before.

Capital availability. At least two innovative solutions to the capital availability problem have emerged from the private sector, and new approaches will certainly follow. The Scallop Thermal Management Corporation operates in both the U.S. and Europe, providing a range of "energy services" through a contract with the owner or manager of a commercial building. For example, Scallop might contract to provide an agreed-upon level of heating comfort in the building for a specified number of years, and then use the building owner's payments to both repay its own investments in energy-saving capital improvements and to pay the (reduced) utility or heating oil costs. If the energy-saving improvements were well-selected and well-installed, there should also be a profit margin left over; its size would depend on the cost-effectiveness of the conservation measures in that particular building. A special clause in the agreement between Scallop and the building owner provides for adjustments as unit energy costs increase.

Scallop's program offers the twin advantages of not only providing a source of outside capital, but removing from the building owner most of the risk that conservation measures might not pay off as expected. On the other hand, it also takes away from the building owner many of the financial benefits associated with conservation. Moreover, the nature of Scallop's with a building owner may preclude conservation measures that do not have a comfortable margin of cost-effectiveness--leading to the familiar "cream-skimming" problem. Finally, just as master-metering insulates the ultimate consumer from the direct consequences of wasteful energy-using practices, the Scallop plan may reduce a customer's continuing incentive to operate the building carefully, since the client's cost is adjusted only for changes in unit energy costs, rather than usage patterns.

Another private corporation, Ebasco Services, Inc., has developed a similar energy services package for large commercial customers, including engineering-type energy audits, an "energy savings guarantee," and a source of third-party capital financing through equipment leasebacks. The Ebasco program is designed to assure recovery of the customer's (or third party's) capital investment within five years. Once again, this helps to reduce the perceived risk but may also result in limiting the recommended measures to those with very high paybacks (rather than including all conservation measures that are cost-justified on a life-cycle basis). In fact, Ebasco's experience to date suggests that payback periods of no more than one-half the guarantee period (i.e., 30 months) are necessary to assure that the guaranteed savings program is commercially viable.

The Ebasco loan assistance program is structured around a financial consulting and "brokerage" service that brings together potential third-party investors into a tax-sheltered arrangement to lease energy-conserving equipment to the building owners. While there are some legal restrictions, this arrangement is nearly as attractive for local government and non-profit facilities as for privately owned buildings, since the investors in the limited partnership can capture the tax credits and accelerated depreciation benefits that would otherwise be unavailable to the government or non-profit building owners.

Ebasco also offers a monitoring service to help clients follow up on the success of conservation measures, and to assure Ebasco that the terms of the agreement are being followed. This entails a quarterly visit by a consultant to check on operation and maintenance procedures and to tally and validate energy usage and billing records.

Information credibility. One solution to the credibility problem facing professional energy analyses and recommendations is for an energy services firm like Scallop or Ebasco to guarantee the predicted savings and to put their own (or a third party's) capital at risk, based on their recommendations. On the other hand, a savings guarantee may not be appropriate in all cases (many commercial buildings may prove too small to interest an energy services firm), and as noted earlier, the guaranteed savings approach may lead to implementing only the most conservative conservation recommendations.

Moreover, only part of the credibility problem involves sound recommendations that are not adequately trusted by clients--the other side of the problem is that some energy analyses and other professional services are not technically solid to begin with, and should not be trusted (see Fig. 12 above). The issue of technical competence within the energy-related professions is one that must ultimately be dealt with, in order to make lasting headway with the credibility problem.

In general, the solution will involve not only setting high professional standards for energy management analysis, but providing engineers and other energy professionals with adequate technical data and analytical methodologies to draw upon.

A first step would be to accumulate a more extensive, detailed, and better-validated empirical data base on the actual performance and cost-effectiveness of conservation measures installed in new and existing buildings. This means that increased support for demonstration programs will be needed from the federal and state governments, utilities, and industry sources. It also requires that a serious instrumentation and monitoring program be developed and undertaken in the commercial sector, again probably involving joint efforts by several public and private sponsors. The data obtained from both demonstration projects and performance monitoring of a sample of "routine" commercial building conservation projects should then be compiled, critically reviewed, and made available in a concise and usable form to practitioners, policymakers, and researchers alike.

The selective monitoring of actual buildings' energy performance is also essential to provide energy management and design professionals with direct feedback on the accuracy and completeness of their recommendations. At present, there are few if any opportunities for the practicing energy professional to get such feedback, and therefore improve the quality of his or her energy audits.

A second step in improving the quality of conservation technical information and services involves the refinement of analytical and design tools. These include not only the elaborate computer simulation models, but simplified microprocessor and hand-calculator programs, and the even more specific calculation aids (nomographs, etc.) that are used to evaluate a single end-use or building component. While such analytical tools have been evolving for several years, considerable work still needs to be done to extend their capabilities, simplify input and output formats, improve the fit between model size/sophistication and the nature of the analytical task (to save time and reduce costs), and above all to extensively validate the models' predictions against empirical measurements.

Steps like those listed above can help to assure that energy professionals have access to valid technical data and analytical tools. Beyond this there is a need to assure that training and accreditation in energy analysis become an integral part of the professional education (and re-education) of engineers, architects, contractors, and construction tradespeople. Several national professional organizations have established energy-related training programs and seminars, but to date these programs have reached only a fraction of all practitioners in energy-related fields. The State of California has begun a process of incorporating energy-related skills and knowledge requirements in its testing and certification procedures for several energy-related trades and professions, but the program needs to be expanded as well as adopted by other states.

Finally, an important link in the efforts to improve professional credibility involves protection for clients, to reduce their reluctance to invest in conservation equipment and services. One area of need is for a system of independent testing and certification for energy-conserving products and equipment (beyond those items already tested and labeled under the FTC's residential appliance testing program). Second, there need to be effective procedures for a customer to obtain independent technical review and recourse if he or she suspects that the professional engineering or installation services provided were not of high quality.

Leased commercial space. In the case of existing, master-metered buildings, there is some potential for encouraging energy conservation retrofits through the existing tax credits and depreciation incentives, especially if energy service companies are able to offer a complete package of retrofit, monitoring, and financial services, in addition to the energy audit itself. Existing leased buildings with separate meters (where utility bills are paid by each tenant) create a more difficult situation. Realistically, retrofitting of these buildings may be limited to services provided in common to the entire facility (exterior lighting, for example) or to special circumstances such as a major building renovation or conversion to office condominiums.

In the case of leased commercial buildings, it may prove difficult to rewrite the energy payment terms of existing leases, but it may be possible to establish some form of arbitrated process for renegotiating these provisions, where energy-saving retrofits that would benefit both owner and tenant are effectively precluded only because of the lease. To address the opportunities present in new leases there should be a continuing education effort by groups such as the Building Owners and Managers Association (BOMA) to draft and disseminate to its members model lease provisions allowing pass-throughs for energy efficiency costs comparable to those for increased utility rates.

Awaiting better subsidies. This is a problem that may have all but disappeared, thanks to the market-oriented policies of the incoming Administration, but the related issue (delaying conservation investments as a "hedge" against future forced curtailments) may still be of concern. Clearly, one approach is for any Federal or state contingency plans that establish rules for forced curtailments in the event of a shortage to explicitly include a system of "credits" for conservation steps already taken. And, of course, to have the intended impact these rules need to be clearly stated, widely disseminated, and credible (in the sense that they are viewed as unlikely to shift in response to political pressures, once an energy shortage situation occurs).

Energy pricing. Full marginal cost pricing of all utility gas and electricity provided to the commercial sector is unlikely in the near future, because of both excess revenue collections and political resistance to the concept by business interests. But these two difficulties do not necessarily preclude more modest changes in existing rate structures that would seek to price "marginal consumption" at marginal-cost levels.

In many states, increasing-block rate structures have already moved in this direction, but one difficulty with these rate structures is that they only charge the higher, tail-block rates for higher levels of energy use by a given customer, not for more wasteful use. They also encounter difficulties with "horizontal equity." Given the range of energy usage levels per customer within even rather homogeneous customer classes, a multi-tier rate structure will almost inevitably result in some users avoiding the highest tier altogether (even if they are not particularly efficient users), while other large (but efficient) users may have to purchase a large fraction of their energy at the highest-tier rate.

Clearly, one approach would be to design rates so that the usage level at which higher (marginal cost) rates would be imposed would have some relation to the customer's efficiency of energy use, rather than to size alone. For example, a building energy performance index, similar to the energy budget levels developed for the proposed BEPS standards, could be used to establish cut-off points (in annual Btu's per square foot) for the rate levels applied to each commercial customer. Such a pricing structure would avoid the political and revenue problems of pricing all utility energy at marginal cost, but still provide an incentive equal to marginal cost for the least efficient users to reduce their consumption.

One key to this approach is the development of a valid, readily available performance rating system for commercial buildings, a topic that we return to in the final section. A second important element is to make sure that the multi-tiered pricing system, and its link to the efficiency index, are well understood by commercial customers. The whole point of pricing tail-block energy at the utility's marginal cost is to create a correct price signal for the customer. But this can only occur if customers are made at least as aware of the marginal rate at which conservation can save them money as they are of their total monthly bill.

Other Policy Options - Financial Incentives for Commercial Building Efficiency

At the present time there are two problems with using the federal Energy Tax Credit and the Investment Tax Credit for improvements in commercial buildings: the restrictive list of technical measures which have been designated as automatically eligible, and the pall of uncertainty cast by the Internal Revenue Service's reluctance to adopt clear generic guidelines for determining eligibility of additional measures through an energy audit. For these tax incentives to be as effective as Congress intended, both the restrictions and the uncertainties need to be addressed promptly, at the level of regulation-writing and interpretation. Finally, there is no obvious reason why federal policy should provide larger subsidies for one category of energy-saving technologies (active solar) than for others. The two sets of incentives now authorized by law should be equalized and (as discussed below) based strictly on energy-saving performance.

However, it is also true that federal tax incentives are not a complete solution to the need for conservation incentives to accelerate market penetration of measures that are cost-effective but not well-known, and to offset the historical subsidies to traditional sources of energy supply. Local government and non-profit organizations cannot benefit directly from these credits--and additional changes in the tax code (and IRS interpretations of the code) may be necessary to allow third-party investors to reap enough benefits to attract them to conservation investments.

In many parts of the country, utilities with a special interest in reducing their peak loads or energy demand growth (to avoid the need to finance new plant capacity) may want to offer their own additional incentives geared to the commercial building stock, climate, and load patterns in their service area. One possibility is for utilities to provide (or guarantee) short-term financing to help businesses with cash-flow problems until they can recover their investment through energy bill savings, depreciation, and energy tax credits.

A second option is for utilities to design their own incentive payments to apply to "incremental" conservation measures only. For example, the incentives might be provided for measures that have a payback of three or more years (up to a limit of cost-effectiveness set by the utility) but only on the condition that the customer agree to implement all measures with a payback of two years or less. The Southern California Edison Company has initiated a demonstration incentive project, designed along these lines. Third, utilities might target their commercial sector conservation incentives to new construction--which in many utility service areas not only has the fastest growth rate of any sector, but is entirely left out of the structure of federal tax incentives for conservation.

Perhaps the most important objective, over the long run, should be to entirely restructure the logic of conservation incentives at all levels (Federal, state, and utility), from a concept of reimbursing some fraction of the <u>cost</u> of energy-saving measures to a performance-based system that ties the amount of reimbursement to the actual energy savings. Such a performance-based incentive could be genuinely neutral to the mix of (solar and conservation) technologies used. Even more important, it would help to eliminate any built-in incentives for project "gold-plating," and would in fact re-establish a strong incentive for the customer to aggressively seek ways of achieving the same conservation result at the lowest possible cost (including non-hardware options, like improvements in operation and maintenance practices).

Of course, unlike an incentive that simply shares the cost of a hardware investment, a performance-based incentive requires a reliable index of energy performance, and much better methods of "keeping score" on changes in energy efficiency within a building (as distinct from weather, occupancy changes, and other factors that can affect overall energy usage). Such a performance rating system, and better methods of tracking energy consumption, are also needed for other purposes, and represent two of the items on the research agenda discussed in the section to follow.

FUTURE RESEARCH NEEDS

It should be clear from the preceding discussion that there is a great deal of data-gathering and analytical work remaining to be done, to improve our present understanding of how commercial buildings use energy, what technical opportunities exist (in what fraction of the stock) for improving energy efficiencies, and what policies or programs can most effectively complement market forces in helping to achieve various fractions of this conservation potential. A few of the most significant examples, drawn from the previous sections, are listed below:

- More detailed, empirical data on those characteristics of the existing commercial building stock, and new additions, that most affect energy use intensity and efficiency.

- An expanded data base, along the lines of the Ross and Whalen study, on the actual results (measured energy savings and cost-effectiveness) of energy efficiency features and devices installed in new or existing commercial buildings, including information on actual vs. predicted energy savings, persistence of savings, and the "non-energy consequences" (favorable or unfavorable) of the conservation measures.

- Increased attention in demonstrations and data-collection to measuring the effects of non-hardware "operation and maintenance" practices in commercial buildings.

- Continued improvements in the tools of building energy analysis, including both the large, complex computer codes designed primarily for research or analysis of large, complicated structures, and smaller, simplified models developed for design guidance on smaller-scale buildings or for use by energy auditors in the field.

- Detailed data on physical and operating characteristics of a variety of actual buildings, in enough depth to validate the accuracy of large- as well as small-scale building simulation models.

- Opinion survey results and indirect, empirical observations of the decision-making processes affecting both energy use and conservation investment decisions in commercial buildings of various structural, occupancy, and ownership types.

- A more systematic compilation of the impacts of conservation policies, programs, standards, and tax incentives in the commercial sector, including some efforts to understand what has not worked (and why not), as well as what has.

- An increase in the level of government or utility sponsorship of energy-efficiency demonstration projects (retrofits and new construction), coupled with efforts to coordinate such demonstrations to assure that they cover a broad range of construction types, climates, and design options--and also that the results are systematically compared and effectively disseminated to the engineering and design community.

- Continued experimentation with innovative rate designs that can encourage energy efficiency in the commercial sector without generating excess utility revenues, substantial cross-subsidies or other new, undesirable market distortions.

- Development, testing, and validation of an energy performance rating system for various types of commercial buildings, to be used for energy labeling, performance-based incentives, establishing compliance with performance-budget type energy standards, and other purposes.

Results from these and other research and data collection activities will begin to provide a much firmer basis for the analysis of conservation potentials and the tracking of progress toward those potentials. Also, if widely and effectively disseminated, these data will be of great value in convincing the building industry, financial community, and their clients of the concrete prospects for saving money and improving building amenities through efficient use of energy.

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