Analysis of U.S. Commercial Building Energy Use Trends, 1972-1991

David B. Belzer, Thomas L. Marsh, and Ronald D. Sands, Pacific Northwest Laboratory

Over the past two decades energy consumption in commercial buildings has been the fastest growing segment among the major end-use sectors in the U.S. This paper provides a decomposition of the major factors behind the trends in commercial energy use over this period. It examines the impact on overall commercial sector energy intensity from: 1) new buildings, 2) changes in the composition of buildings by geographic region and building type, 3) the growth in office equipment and computers, and 4) the influence of several common envelope conservation measures.

A statistical decomposition of historical monthly electricity and gas consumption data is developed to separate energy use into heating, cooling, and ventilation (HVAC) and other components (non-HVAC). This data is then used in conjunction with historical commercial building floor space estimates to derive end-use intensities for these components of energy consumption.

Deterministic analyses are performed to estimate the impacts of other factors. The impact of new buildings is measured by estimating the average improvement in heating efficiencies for buildings built after 1980. The effect of building composition on aggregate commercial building energy intensity is based upon estimates of historical floor space by building type and region and building-specific intensities derived from the 1989 Commercial Building Energy Consumption Survey (CBECS). Stocks of various types of office equipment were constructed from industry statistics and independent surveys. The stocks of selected office equipment were combined with estimates of unit energy consumption to estimate the impact on total commercial electricity consumption.

For estimating changes in energy intensity due to the building retrofits, the study utilizes a new energy simulation tool developed as part of the Facility Energy Decision Screening (FEDS) system for the U.S. Department of Energy. Based upon work for the Energy Information Administration (EIA) during 1993, the FEDS Level-1 building model was linked to each of the nearly 6,000 commercial buildings in the 1989 CBECS. Energy simulation and regression analyses are used to estimate the energy savings impacts from each of the conservation retrofits.

Introduction

Over the past two decades commercial sector energy use has been the fastest growing segment among the major end-use sectors in the U.S. (i. e., residential, commercial, industrial, and transportation). From 1972 to 1991 the commercial sector increased its share of primary energy consumption from 12.970 to 16.0%. However, commercial energy use has still grown somewhat slower than an estimate of total floor space, resulting in an implied decline in overall energy intensity (consumption per square foot). This paper examines some of the factors that have been responsible for the overall trends in commercial energy use intensity. For space conditioning, we examine the role of envelope retrofits, penetration of new (more efficient) building, building composition by type and region, and the overall increase in air conditioning. For non-space conditioning, estimates of the impact of office equipment and computers are introduced.

General Methodology

In examining various factors contributing to changes in commercial energy use, we have chosen to focus on the metric of energy consumption *savings.* Savings can be defined as the amount of energy that would have been consumed assuming a constant (base year) intensity less the actual amount of energy consumed. We have chosen the year 1972 as the base year of the analysis. We define the intensity in terms of delivered energy, i.e., electricity is measured at 3,412 British thermal units per kilowatt hour (Btu/kWh).

Table 1 shows the time series of the relevant aggregate statistics of floor space, delivered energy, energy intensity, and savings (as defined above). Column one provides an estimated historical series of total floor space in commercial buildings. (A brief description of the construction of this series is given below). Column two shows the estimates of commercial sector delivered energy as provided by the EIA (1993).[1] The computed delivered energy intensity in terms of thousand Btus per square foot (kBtu/ft^2) is shown in column three. The last column shows the delivered energy savings with respect to the 1972 base year.

Table 1. Commercial Sector Energy Metrics

Year	Floor Space (bil. ft^2)	Delivered Energy (TBtu)	Energy Intensity (kBtu/ft^2)	Savings Since 1972 (TBtu)
1972	43.7	5,526.2	126.6	0.0
1973	45.0	5,657.5	125.8	36.0
1974	46.1	5,456.0	118.4	377.5
1975	46.9	5,374.6	114.7	557.6
1976	47.6	5,758.4	120.9	273.5
1977	48.6	5,711.0	117.5	440.6
1978	49.7	5,799.6	116.6	496.6
1979	51.0	5,917.5	116.1	535.3
1980	52.0	5,752.6	110.6	832.0
1981	53.1	5,609.2	105.7	1,108.3
1982	54.0	5,668.7	105.0	1,163.7
1983	55.0	5,656.2	102.9	1,305.7
1984	56.3	5,951.6	105.8	1,172.4
1985	57.8	5,798.5	100.4	1,515.2
1986	59.2	5,815.3	98.2	1,677.3
1987	60.6	6,008.8	98.2	1,660.0
1988	61.9	6,357.5	102.7	1,478.8
1989	63.2	6,432.6	101.8	1,566.0
1990	64.3	6,356.6	98.9	1,781.1
1991	65.1	6,504.6	99.9	1,734.7

As Table 1 shows, the intensity of delivered energy in the commercial sector decreased rapidly from 1973 to 1983 and, subsequently, remained relatively unchanged through 1991. As a direct result, estimated energy savings follow the same conservation trend. Energy savings have remained close to 1.7 quads from 1986 through 1991.

Overall Results

The analysis that underlies this paper (to be discussed in the subsequent section of the paper) examined nine key factors that contributed to the 1.7 quads of delivered energy savings in 1991. Figure 1 shows the contributions of each of these factors. The factors contributing to savings are shown above the horizontal axis of the graph. Other factors have consistently increased their energy intensities and, thus, have led to “negative” savings or dis-savings (shown below the horizontal axis). The algebraic sum of the these two sets of factors adds to the total savings shown in Table 1.

The key factors contributing to the 1.7 quads in energy savings are as follows:

- “Other Heating Improvements” accounted for 1.53 quads and is the largest component of commercial energy savings. This component captures changes in behavior such as turning down thermostats, installing energy management and control systems, or installing energy-efficient heating equipment.

- “Non-HVAC Gas and Oil” accounted for 0.55 quad in savings, down from a peak of 0.72 quad in 1986. The savings include the outcome of conservation programs and the installation of energy-efficient technologies that focus on water heating and cooking.

- “Geographic Shift” accounted for 0.13 quad of savings in space heating. This savings is associated with shifting trends in the geographical location and building composition of new commercial buildings. The shift in the building stock toward the South and West is accompanied by a decrease in heating consumption. In addition, this factor includes the shift in the composition of the building stock to buildings with larger internal loads (e.g., office buildings) which reduces heating consumption.

- “New Construction” accounted for 0.13 quad in savings in space heating. This component has been increasing steadily as new, more energy efficient buildings replace older buildings in the commercial building stock.

- “Shell Retrofits” accounted for 0.14 quad in savings in space heating, increasing steadily from 1972 through 1991. Improved roof insulation captures 50% of the savings, while wall insulation and storm window retrofits account for 23% and 27%, respectively.

There were also several areas that showed decreases in savings over recent years:

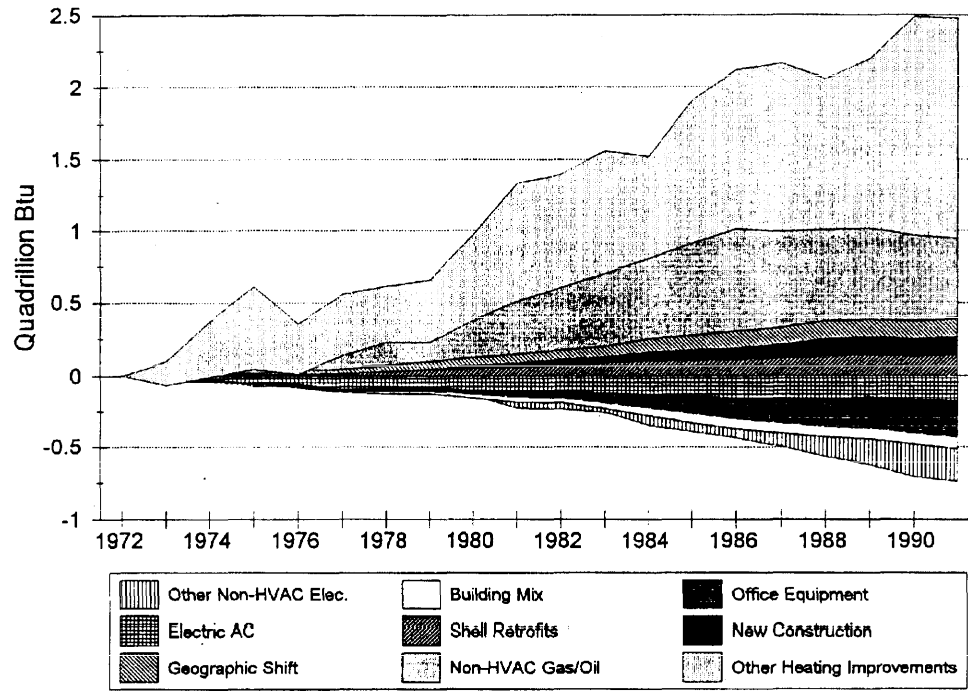

Figure 1. Components of Delivered Energy Savings - Commercial Sector

- Air conditioning ("Electric AC") accounted for a loss of 0.18 quad in savings. Electrical consumption for air conditioning has increased as more of the existing buildings and a higher proportion of the new building stock are air conditioned.

- "Office equipment" (computers, printers, and copiers) accounted for a loss of 0.25 quad in electricity savings. This trend is increasing steadily from 1981-1991 as new technologies enter the work place.

- "Building Mix" accounted for a loss of 0.08 quad in non-space conditioning electric consumption savings. This increase is associated with the construction of a large number of office buildings relative to other commercial buildings.

- Other non-space conditioning ("Other Non-HVAC Electric") accounted for a loss of 0.23 quad in electricity savings. Electricity consumption per square foot for appliances and other office equipment (e.g., fax machines) continues to increase over time.

Overall, total energy savings have leveled off in recent years. Yet, within the total savings wedge, contrasting trends exist among the individual components. That is, the space heat components display a steady trend in savings, while the growth in electric air conditioning and other uses has offset a sizable portion of these gains.

Historical Estimates of U.S. Commercial Floor Space

To support its commercial sector energy analysis activities, Pacific Northwest Laboratory (PNL) has generated historical estimates of commercial floorspace in the United States. Historical estimates of commercial building floorspace are essential to any evaluation of broad changes in commercial-sector energy efficiency.

The four surveys of commercial buildings conducted by the EIA since 1979 have provided estimates of floorspace by building type for 1979, 1983, 1986, and 1989. Differences in sampling procedures make it difficult to make comparisons over time among the surveys. Neither EIA nor any other government agency publishes time series estimates of floorspace in the commercial sector.

The floorspace estimation procedure used by PNL combines elements of several approaches. A demolition *function* was estimated from the special demolition/conversion file prepared by EIA. Additional data from the F. W. Dodge building stock database were used to interpolate over time the vintage totals from the 1989 CBECS. The F. W. Dodge data were assumed to capture the year-to-year fluctuations in construction activity much better than the annual vintage totals reported by the NBECS.

Stocks for historical years were backcast and forecast from the benchmark totals in the 1989 CBECS.

The demolition function was based on a regression analysis of the observed demolition rates by vintage between 1979 and 1983. A logistic function was fitted via a maximum likelihood method to estimate the pattern of demolitions. Unfortunately, the sample size of the demolished commercial buildings was too small to allow separate functions to be estimated by building type. Accordingly, a single function was estimated for all buildings. Given the actual pattern of demolitions between 1979 and 1983, the estimated logistic function implies a considerably longer building life than previously assumed. The half-life implied by the estimated function is a little over 90 years.

The sample sizes in the NBECS/CBECS are not large enough to accurately estimate annual additions, either by building type or all buildings together. The annual construction data, by square footage, collected by F. W. Dodge were used to allocate the 1960-1989 vintage, by building type, reported in the 1989 CBECS. The reputed underestimation of the F. W. Dodge figures is not a serious weakness in this application, as long as the bias has remained fairly constant over this period. Excluding hotels, which are not part of the F. W. Dodge commercial data, total additions reported by F. W. Dodge from 1961 to 1989 are 29.1 billion ft^2. The 1989 CBECS estimates a total of 36.1 billion ft^2 for the same period, for all building types excluding lodging.

With the estimated logistic function and recent floorspace additions, a historical floorspace series was then constructed. This is an iterative procedure, starting with the CBECS benchmark in 1989 and moving backwards to 1960 and forwards to 1991. Floorspace series were constructed for 12 building types formerly used in the PNL commercial sector model.

Energy Savings Estimation Procedures

This section describes the estimation procedures used to calculate the components whose contributions to overall savings were described above. The procedure begins with an econometric method to separate weather-sensitive from non-weather-sensitive consumption for both electricity and natural gas. Deterministic analyses and building energy simulations are used to estimate the other components.

Weather-Sensitive and Non-Weather Sensitive Consumption

Electricity and natural gas are decomposed into weather-sensitive and non-weather-sensitive consumption using monthly regression analysis. We assume weather-sensitive consumption is primarily space heating and air conditioning. Non-weather sensitive consumption is comprised of such end uses as lighting, office equipment, cooking, or water heating. These seasonal patterns of energy consumption which are evident in the monthly data series (Energy Information Administration [EIA] 1991b) provide the basis by which we decompose the weather and non-weather sensitive consumption.

Our empirical approach is to statistically fit monthly electricity and natural gas consumption using the appropriate weather data. Ideally, state or regional data would be preferable to estimate such a model, but consistent data back to 1972 is not available. Accordingly, national models were developed for both fuels. Weather is measured by heating degree days (HDD) and cooling degree days (CDD).

An important part of the analysis was the appropriate specification of temperature bases to measure national degree days. The use of a 65°F temperature base (employed in the derivation of most published degree day statistics) is generally agreed by most building energy analysts to be higher than optimal for most commercial buildings. Monthly electricity and natural gas consumption data are available by state from 1986 to the present, providing the data required to regress monthly energy consumption by state on HDD and CDD. Using monthly temperature data at the state level that could be converted to degree days for any base temperature, regression analysis was performed to choose the optimal base temperature by state for both electricity and natural gas consumption. Regression results were used to construct the HDD and CDD. The national average base temperatures (using state weights) resulting from this analysis were approximately 54°F for electricity (cooling) and 61°F for natural gas (heating).

Space conditioning consumption is correlated by increases in HDD and air conditioning consumption is correlated by increases in CDD. The electricity consumption model (Equation 1) is specified to reflect the baseload, air conditioning, and space heating. The natural gas consumption model (Equation 2) is specified to reflect baseload and space heating. In general, the baseload is represented by the intercept term, and the air conditioning and space heating the CDD and HDD coefficients, respectively.

$$ELEC_t = \alpha_0 DAY_t + \alpha_1 HDD_t + \alpha_2 CDD_t + e_t \quad (1)$$

$$NGAS_t = \alpha_0 DAY_t + \alpha_1 HDD_t + e_t \quad (2)$$

where $ELEC_t$ = monthly electricity consumption
$NGAS_t$ = monthly natural gas consumption
HDD_t = monthly heating degree days, lagged 1/2 month[2]
CDD_t = monthly cooling degree days, lagged 1/2 month
DAY_t = number of days of month in year t
e_t = residual
$\alpha_0, \alpha_1, \alpha_2$ = ordinary least squares coefficients constrained to lie along a cubic spline.

As a simple measure of goodness of fit, we examined the explained variation (R^2) for each regression. The R^2 statistics were 0.994 and 0.987 for the electricity and natural gas models, respectively. Overall, the goodness of fits results indicate Equations 1 and 2 should provide reliable predicted values for heating, cooling, and baseload consumption.

Equations 1 and 2 provide us with an approach to predict heating, air conditioning, and baseload consumption from observed patterns. These estimates, in turn, are assumed to proxy the trends in the unobservable energy consumption for these end uses.[3]

Unfortunately, fuel oil consumption is not easily decomposed into weather-sensitive and non-weather-sensitive components. Based on previous CBECS work (Belzer et al. 1993) we allocated 86% of the oil consumption to space heating and the remainder to baseload uses.

For each component—space heating, air conditioning, and baseload—annual energy consumption is summed across fuels from 1972 to 1991. Then, to estimate trended energy consumption we fix the end-use intensities at the 1972 level of energy consumption per square foot and calculate energy consumption from 1972 to 1991 at the 1972 intensity. Overall, the difference between the actual consumption and the trended consumption is the savings per year. The results of this approach are shown in Figure 1 in the space conditioning and non-space conditioning components of energy savings.

Figures 2 through 5 illustrate the basic sectoral energy intensities that stem from this decomposition process. Figure 2 shows the average end-use intensity estimates for space heating for each of three major fuels.[4] For the sum of the intensities we show both a weather-normalized

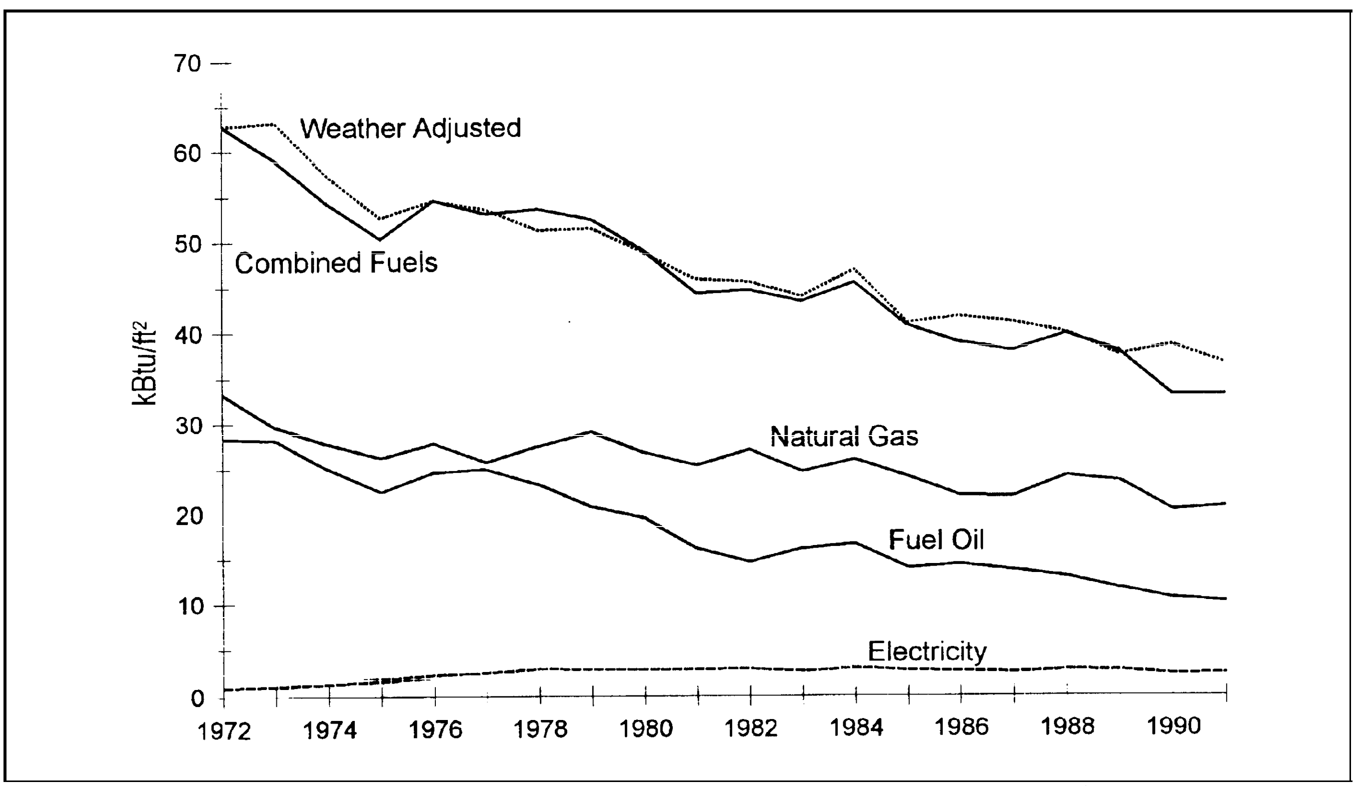

Figure 2. Average End-Use Intensity Estimates for Space Heating (kBtu/ft^2)

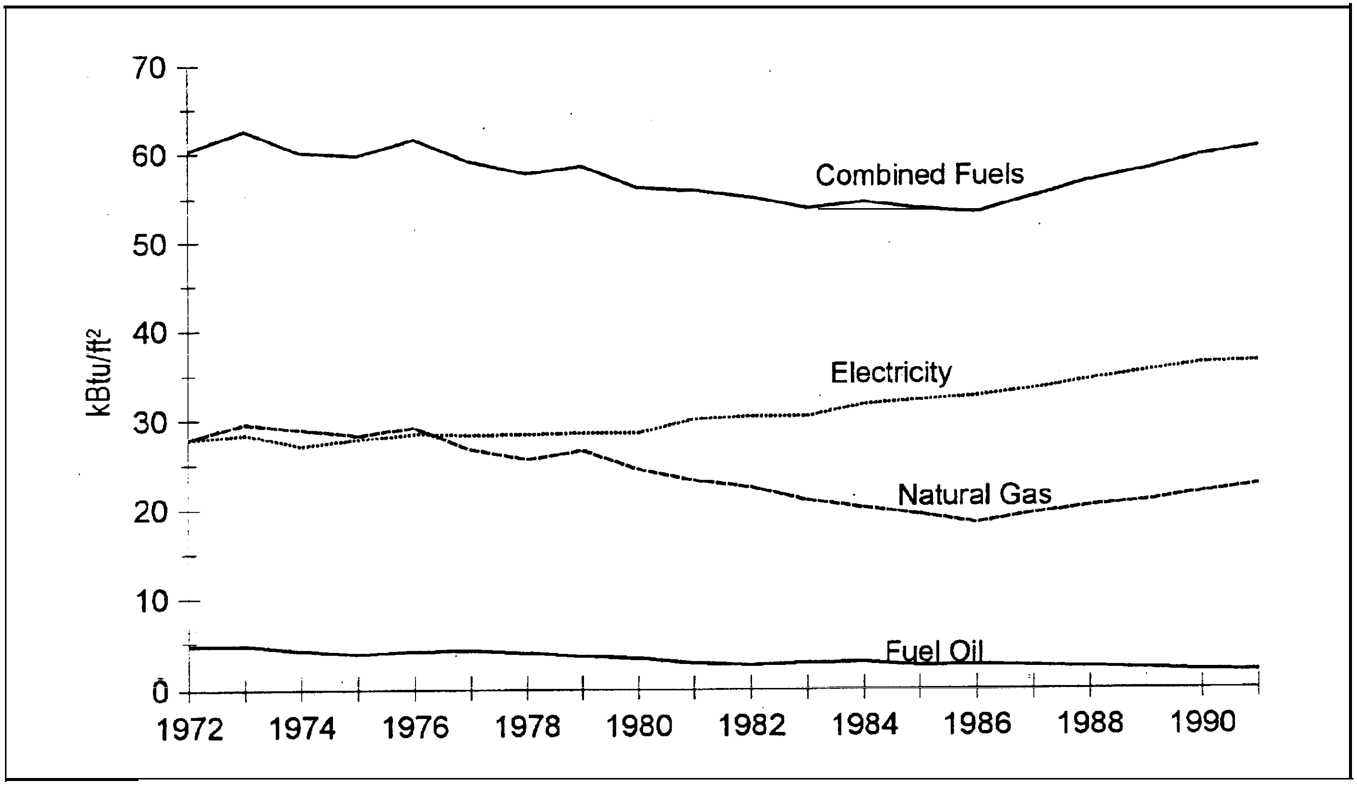

Figure 3. Average End-Use Intensity Estimates for Non-Space Conditioning ($kBtu/ft^2$)

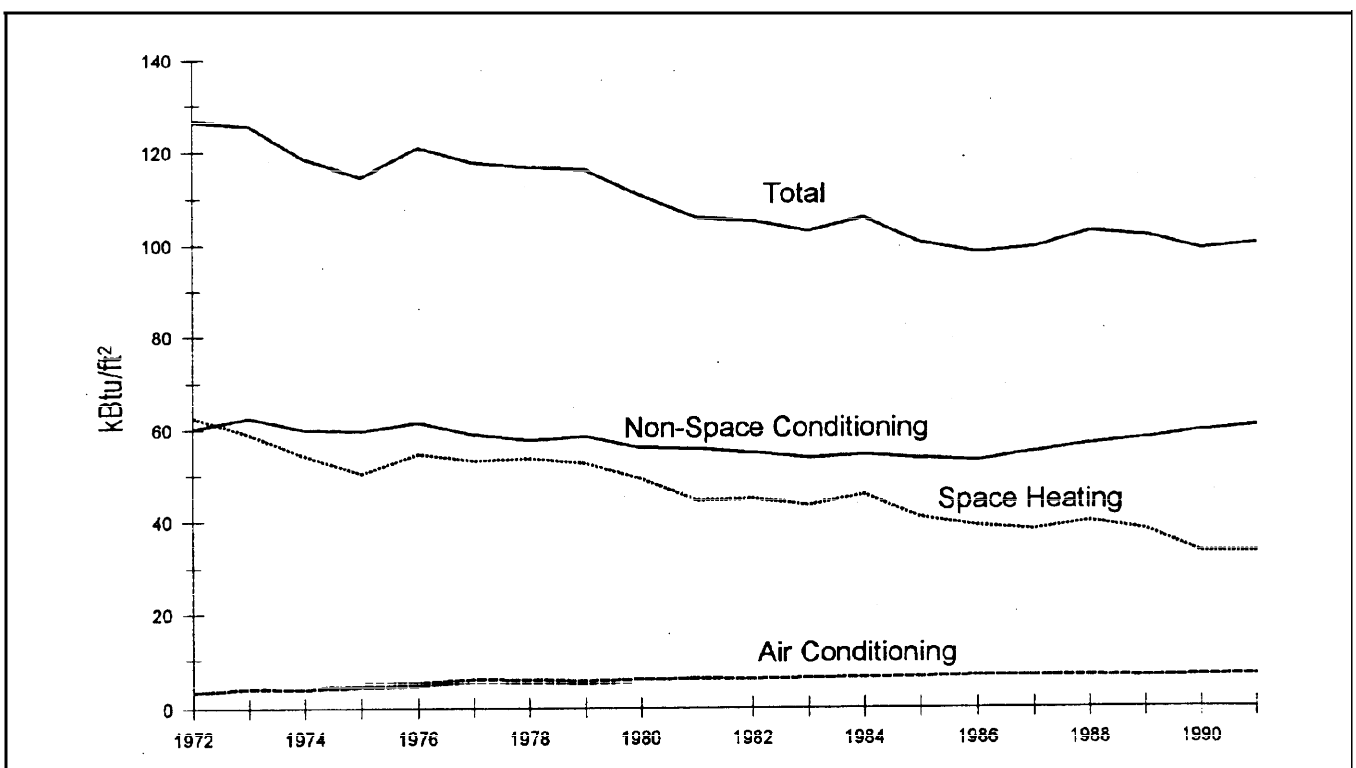

Figure 4. Average End-Use Intensity Estimates by Major End Use ($kBtu/ft^2$)

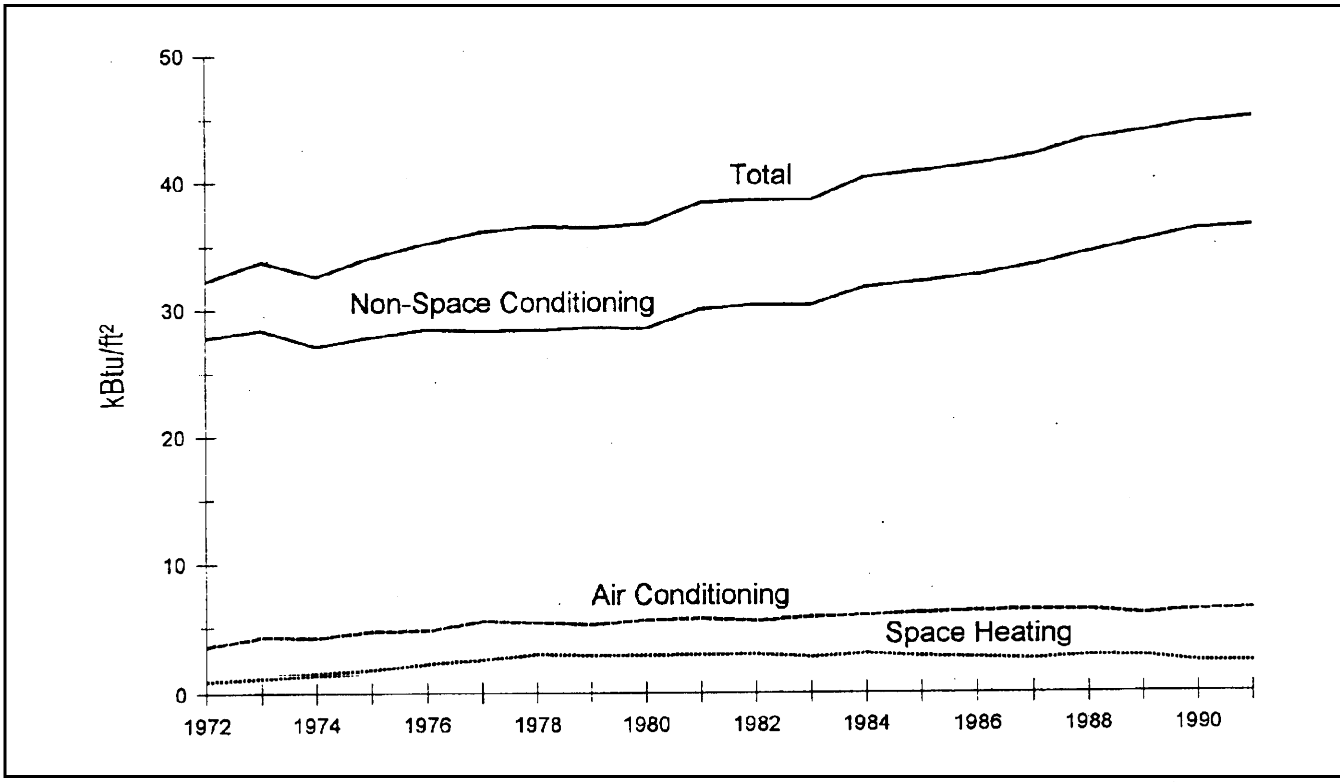

Figure 5. Average End-Use Intensity Estimates for Electricity by Major End Use (kBtu/ft^2)

intensity (assuming HDD for 1972) as well as a non-weather-normalized figure.[5] The downward trend reduction in heating intensity appears to have continued even after the fall in energy prices starting in 1985. When examining the behavior of individual fuel intensities, note that since these are compared against *total* stock, we are observing both fuel switching and conservation behavior. Generally, natural gas intensities have appeared to fall faster during the 1980s than previously. Electric space heating plays only a small role in the more recent decline in overall heating intensity.

Figure 3 shows the non-space conditioning energy intensities by fuel. Natural gas intensity for non-heating use appears to have fallen sharply over the period from 1979 to 1986. A portion of the increase in electricity intensity during the 1970s may be due to fuel switching from end uses formerly fueled by gas (cooking and water heating). The electricity intensity rises more sharply beginning around 1980, likely due to the accelerated penetration of office automation and computers.

Figure 4 contrasts the trends in intensities between non-space conditioning and space heating. Finally, Figure 5 shows a breakdown of national electricity consumption using this method. The plot clearly shows that non-space conditioning uses have risen much faster than either space heating or cooling. Non-space conditioning use of electricity clearly outweighs its use for both heating and cooling.

Space Heating in New Buildings

New, energy-efficient buildings that enter the stock require less energy. In particular, for space heating, we estimate that buildings constructed after 1979 use approximately 20% less energy than older buildings. This increase in energy efficiency was derived from an analysis of monthly billing data associated with the 1979 CBECS data. The annual contribution to the stock space heating intensity was developed by using the estimates of total additions to commercial floorspace constructed since 1980.

Envelope Retrofits

In each of the national surveys of buildings conducted by EIA, information was requested concerning some basic retrofits to the building envelope. Three such options—roof insulation, wall insulation, and double-pane windows—were analyzed in which the available building information was used to model the heating and cooling energy consumption in the building, both with and without the retrofit option in place.

Unfortunately, CBECS does not contain information on the approximate level of insulation, either before or after the conservation retrofit. As a result, we have relied upon engineering judgment to develop typical values for the changes in the building shell. The lack of specific information is similar for windows, where the CBECS asks a broad question on whether storm windows, storm doors, double pane, or triple pane glass were added. We have assumed the most prevalent option of this list is to install double-pane glass in place of single-pane glass in windows.

The engineering analysis builds upon a recent study by Belzer et. al (1993) that developed estimates of end-use consumption for the approximately *6,000* buildings in the 1989 CBECS. This study utilized the initial version (Release 1) of Pacific Northwest Laboratory's Facility Energy Decision Screening (FEDS) software. FEDS developed estimates of monthly energy consumption for eight end uses for the year 1989. A brief description of FEDS can be found in Belzer et al. (1993). The specific assumptions regarding U-values for structural components used by FEDS are given in the appendices to the same report.

With regard to insulation, the CBECS first determines whether the building contains either wall or roof insulation. This insulation is generally assumed to be a fiberglass type insulation and would augment the insulating values of the structural building materials. The CBECS also contains fairly detailed information on the roof and wall construction type (masonry, wood frame, steel, etc.). Of critical use in this study is whether the insulation was added *after* the building was built and during what timeframe the retrofit was undertaken.

For simulation purposes, we simply "remove" the retrofit option to examine its impact upon heating and cooling consumption. We do *not* use the FEDS-calculated heating loads directly. Rather, we try to use the actual consumption data in the 1989 CBECS to help calibrate the likely impact of the retrofit options. The estimated heating consumption data for natural gas in the 1989 survey is regressed against the FEDS-estimated building UA (U-value times area) and heating degree days in a cross-sectional regression. The estimated adjustment factor from this cross-sectional model is approximately 0.5. Each retrofit option is then considered individually for its impact on the average UA. Using the total floor space of all the buildings that reported retrofits in the 1989 CBECS, the weighted average reductions in UA for the three options were 1) roof insulation, -21.7%, 2) wall insulation, -23.1 %, and 3) double-pane windows, - 19.7%. Using the adjustment factor of 0.5 from the regression model provides an estimate of the percentage difference in consumption that would have been observed prior to the retrofit.

To provide a time series estimate of the effect of retrofits, we use the information supplied in the various CBECS for the amount of floor space retrofitted in different time periods. The 1979 NBECS asked for the specific year in which the retrofit was undertaken. Subsequent surveys were less precise, by asking for a particular time interval in which the conservation action was taken (e.g., 1980-1983).[6]

Building Composition

As the composition of commercial buildings changes over time, it influences aggregate energy consumption. We examined changes in the composition of buildings from the point of view of 1) the shift in the building type composition (e.g., more office buildings) and 2) the shift in the geographical composition of buildings (e.g., toward the west and south). The decomposition methodology employed the 1989 CBECS data set to identify changes in building mix and the end-use intensity results of Belzer et al. (1993) to attain average energy intensities by end use, fuel type, and census division. From our analysis, we identified space heat (electric, natural gas, and fuel oil) and non-weather-sensitive electricity consumption as the primary uses influenced by the changes in building mix. The geographic shift component reduced heating consumption in 1991 by an estimated 0.13 quad. The changing mix of buildings by building type tended to increase overall electricity intensity, contributing to a dis-savings of about 0.08 quad by 1991.

Office Equipment in the Work Place

Office equipment use in the work place and in education is thought to comprise a significant amount of the recent increase in electricity use per square foot in the commercial sector. We attempt to address this issue by examining the trends in energy use for personal computers, printers, and plain paper office copiers.

Workstations are defined as personal computers, computer terminals with cathode ray tube monitors, and/or word processors. Printers are defined as impact and nonimpact printers. Two sources of information for computers are used in this study: Future Computing/Datapro (from 1981 to 1988) and Arthur D. Little, Inc. (ADL)'s Characterization of Commercial Building Appliances (ADL 1993). The Future Computing/Datapro data set provides a time series of the quantity of personal computers and printers in use in the work place (U.S. Bureau of the Census 1991). ADL provides information on the inventory and energy use in 1990. We benchmarked the Future Computing/ Datapro time series for computers and printers to ADL's 1990 estimates and estimated energy intensity and savings. Overall, energy intensity increased from 0.1 kBtu/ft^2 in 1981 to 1.0 kBtulft^2 in 1991 for computers and from 0.02 kBtu/ft^2 in 1981 to 0.90 kBtu/ft^2 in 1991 for printers. The final result was a loss of 0.068 quad for computers and 0.055 quad for printers in 1991.

Copiers examined in this analysis are defined as plain paper copiers intended for business use. The sources of information for copiers in this study were the Computer and Business Equipment Manufacturers Association (CBEMA 1993) and ADL's Characterization of Commercial Building Appliances (1993). From the CBEMA shipment data set we estimated the inventory of copiers using a five-year life span. We benchmarked the inventory series to ADL's 1990 published estimates. To estimate trends in EUIs for copiers we used the ADL's estimated energy use, 123.4 trillion British thermal units (TBtu)/yr. EUIs increased from 0.1 thousand BTu (kBtu)/ft^2 in 1981 to 2.0 kBtu/ft^2 in 1991. Based on our assumptions the increase in consumption for copiers was 0.130 quad in 1991.

Conclusions

This paper has provided an overall look at commercial-sector energy use trends over the past two decades. Although commercial-sector energy intensities declined significantly over the first part of this period, the recent evidence is that the decline in intensities in the aggregate stock has virtually stopped over the last six years of the study period. Clearly, the casual evidence suggests that lower energy prices in the period since 1985 have deterred aggressive efforts to achieve additional energy efficiency in commercial buildings. A closer inspection suggests that heating intensities are continuing to decline from ongoing retrofit activities, better building control strategies, and the influence of efficient newly constructed buildings. However, these improvements have been offset by ever-rising electricity consumption for non-space conditioning uses.

As mentioned, the survey information collected by EIA indicate that buildings continue to upgrade their thermal integrity via improvements to the building envelope. As a whole, however, these changes over the entire timeframe appear to have played only a relatively minor role in reducing overall space heating intensity in the sector. The large unexplained residual in the reduction of heating intensities is more likely due to equipment turnover and improved maintenance and better building controls.

The long lives of buildings blunt the short-term effect of more efficient new buildings. Only about 7% of delivered energy savings in 1991, as computed from a 1972 constant-intensity base, is due to new buildings built after 1980 with significantly average lower heating requirements.

Electricity growth continues unabated in the commercial sector. Unfortunately, we have little empirical historical data to provide a clear understanding of this growth. Most observers point to the proliferation of computers and office equipment as key factors; our estimates using aggregate sales data suggest an increase of about 0.25 quads in 1991 consumption resulting from this end use.

This paper provides a useful starting point for more detailed analyses that attempt to link information in the national commercial building surveys with that in the monthly supply-side consumption data. Further work to improve the statistical decomposition of weather-sensitive and non-weather-sensitive consumption could involve available state data. In addition to the building compositional influences addressed in this study, other structural factors might also be examined, including the effect of vacancy rates, and long-term trends in building occupancy and schedules.

Endnotes

1. The statistics for delivered energy, taken from EIA's *State Energy Data Report 1991,* exclude coal and motor gasoline use in the commercial sector. Coal use is estimated to be less than 100 TBtu in 1991.

2. The half-month lag for HDD (and CDD) is intended to reflect the fact that utility-supplied consumption data generally represents time of billing rather than time of use. John Herbert provides some discussion of this issue for natural gas (Herbert 1987).

3. We are aware of the inaccuracies of this approach to generate estimates of the absolute values of the end-use consumption. Nevertheless, we believe this approach provides estimates that are sufficient to indicate the long-term trends in the behavior of these uses.

4. Note that these are average end-use intensities, rather than conditional intensities; we normalize by total floor space rather than the floor space using each fuel as a primary heating fuel. There is no consistent data that can be used to compute conditional end-use intensities over the entire time frame.

5. The weather adjustment was only applied to natural gas and electricity. Data on oil consumption reflect deliveries to storage tanks rather consumption during the period. As the annual intensity data in Figure 2 indicate, there appears to be little year-to-year variation in reported consumption that could be attributed to weather.

6. We assign equal annual amounts of floor space that are subject to the retrofit when the time frame is longer than one year.

References

Arthur D. Little, Inc. (ADL). *Characterization of Commercial Building Appliances.* 1993. Prepared for Office of Building Technologies, U.S. Department of Energy. Arthur D. Little, Inc., Cambridge, Massachusetts.

Belzer, D. B., L. R. Wrench, and T. L. Marsh. 1993. *End- Use Energy Consumption Estimates for U.S. Commercial Buildings,* 1989. PNL-8946. Pacific Northwest Laboratory, Richland, Washington.

Computer and Business Equipment Manufacturers Association. 1993. *Information Technology Industry Statistics, 1960-2003.* Washington, D.C.

Dirks, J. A., and L. R. Wrench. 1993. "Facility Energy Decision Screening (FEDS) Software System," PNL-SA-22780. Presented at the International Energy and Environmental Congress, August 4-5, 1993, Minneapolis, Minnesota. Pacific Northwest Laboratory, Richland, Washington.

Energy Information Administration. 1991 a. *Commercial Buildings Energy Consumption Survey: Commercial Buildings Characteristics 1989.* DOE/EIA-0246(89). U.S. Department of Energy, Washington, D.C.

Energy Information Administration. 199 lb. *Historical Monthly Energy Review,* 1973-1988. DOE/EIA-O035(73-88). U.S. Department of Energy, Washington, D.C.

Energy Information Administration. 1992. *Commercial Buildings Energy Consumption Survey: Commercial Buildings Energy Consumption and Expenditures 1989.* DOE/EIA-0318(89). U.S. Department of Energy, Washington, D.C.

Energy Information Administration. 1993. *State Energy Data Report 1991.* DOE/EIA-0214(91). U.S. Department of Energy, Washington, D.C.

Herbert, John H. 1987. "Data Matters—Specification and Estimation of natural gas demand per customer in the Northeastern United States," *Computational Statistics and Data Analysis,* Vol. 5, 1987, pp. 67-78, North-Holland.

U.S. Bureau of the Census. 1991. *Statistical Abstract of the United States 1990.* Table No. 1340. U.S. Department of Commerce, Washington, D.C.