Behavioral Characteristics of Energy Use:
Is An Office Just An Office Just An Office?

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I. Introduction

Net energy consumption in the commercial sector, a category that embraces everything from office buildings to schools to warehouses, accounted for 17.3 percent of all non-transportation energy use in the United States in 1999, up from 16.2 percent in 1986. Much, if not all of this 6.8 percent relative gain, as documented in the U. S. Energy Information Administration's (EIA) annual state energy data series (SEDS), is due to increased electricity use, whose generation is a major source of air pollution and greenhouse gas emission. Being built up from energy supplier information, SEDS data alone is not adequate to investigate the causes, or possible directions, of this trend.

Intuitively, it is easy to conclude that this dramatic increase in market share has been caused by the ever-growing adoption of electronic equipment and appliances in commercial buildings, most of which serve to either increase occupant comfort or increase human productivity. However, what if this trend has actually been caused by other factors? Many alternative explanations come to mind. What if demographic and lifestyle factors are influencing the principle types of activities in buildings, or the actual physical attributes of commercial buildings? What if population migration is causing geographic realignments of businesses, resulting in new, locally- responsive building designs, equipment choices, and fuel preferences?

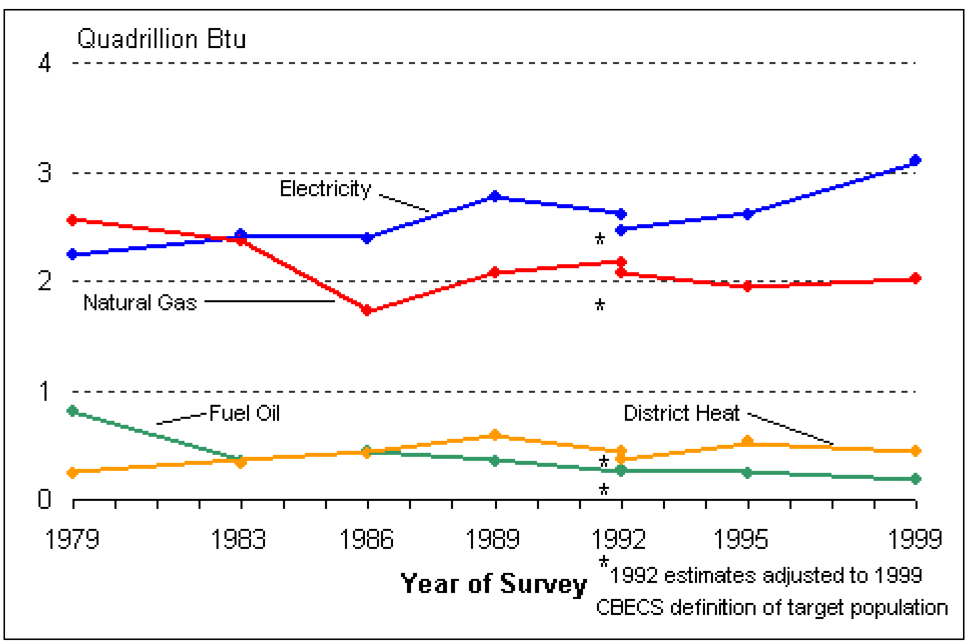
The list of intelligent conjectures can quickly grow long and complicated, even more so once technical issues of engineering systems and architecture, voluntary and involuntary efficiency standards, regulatory policy and more, enter the discussion. Of course, it is hardly the purpose of this paper to enumerate all of the possible causes of this upward trend. However, it is the purpose of this paper to address a small handful of issues, and in doing so try to illuminate some hidden aspects of this trend. In meeting this goal, the paper will focus on one particular type of commercial building, offices, and describe changes in a few key variables between 1986 and 1999.

II. Data Resources

How do we move beyond intuition and conjecture if not without national data recorded at different points in time? Fortunately, such a dataset exists in the Commercial Building Energy Consumption Survey (CBECS). This quadrennial survey (for a time triennial) is fielded by EIA, one of whose core missions is to collect and disseminate information that benefits the public and that would not otherwise be available. CBECS, which is made up of a probability sample of between four and six thousand buildings, has been conducted since 1979. One of its main uses is to supply statistical inputs -- such as square footage and fuel shares – for EIA's national energy modeling system, or NEMS. This large scale, multi-fuel, engineering-economic simulation model is mandated by Congress to produce and publish annual, long-term energy supply, demand, and price forecasts. Fortuitously, since 1986 CBECS has employed similar sampling plans and questionnaires that make complex comparisons possible between the findings of the 1986, 1992, 1995, 1999, and 2003 surveys. (As of this writing the 2003 CBECS energy consumption data files have not been issued for public use).

Despite the wealth of building energy use comparisons that are possible from the 1986 CBECS onwards, the amount of trend-related research on commercial building energy use is remarkably scant. EIA itself, primarily an information dissemination agency, produces little more CBECS-based analysis other than bivariate tabulations of the variables for the year in which a survey is conducted. The one trend-related report EIA has issued can found in an on-line report on the CBECS homepage within EIA's website. It shows key national indicators, such as the number of commercial buildings, the amount of floor space, and the level of energy use in commercial buildings, spanning all the CBECS cycles. Figure 1, taken from this on-line report, *Trends in the Commercial Buildings Sector*, compares total site energy consumption for the four main building fuels, from 1979 through the 1999 survey cycle.

Figure 1: Site Consumption by Source, 1979 to 1999



(Source: *Trends in the Commercial Buildings Sector*, EIA, January 2000)

These fuel trend lines, constructed from the CBECS microdata, lend supporting evidence to the trend in commercial sector net energy consumption derived, cited above. In particular, the fuel trend lines show that increases in electricity use are responsible for the commercial building sector's increasing share of national energy consumption. CBECS database permits further investigation into what is behind this trend and the particulars of commercial building energy consumption.

III. Efforts to Understand the Trend

We might begin exploring commercial building energy use trends by noting that Figure 1 shows levels of fuel consumption, in quadrillion Btu, but does not provide information about its relative use. Relative use, or energy intensity, often allows for more interesting comparisons over time than does comparisons of levels of fuel consumption. For example, it may not be unexpected to find that more electricity was consumed by the U.S. population in 2000 than in 1949. After all, the national population increased in this period from about 148 million to 280 million people. However, it may be surprising to discover the extent to which electricity consumption *per capita* changed. According to EIA, "From 1949 to 2000, while the population of the United States expanded 89 percent, the amount of electricity use grew 1,315 percent. Per-capita average consumption of electricity in 2000 was more than seven times as high as in 1949." In other words, the increase in population accounted for a much smaller part of the overall change in electricity consumption than did the change in the personal use of electricity.

In the commercial sector, an important indicator of energy intensity is the amount of electricity used per square foot of building space. Table 1 contains kWh per square foot for offices, which accounts for a little less than 20 percent of all commercial sector building space, as well as for all commercial buildings (Alaska and Hawaii are excluded from all analyses). Note that these statistics are population totals, not averages. For computing these population statistics, probability sampling weights are assigned to each building and multiplied by kWh and square footage. Summed-up kWh is then divided by summed-up weighted square footage to arrive at the population ratios

Table 1: Commercial Building Electricity Intensity Ratios (Population-weighted)

Year	Offices kWh/sqft	CBECS n	Sq. ft. %	All Bldgs. kWh/sqft	CBECS n	Sq. ft. %
1986	19.7	1,096	17%	12.3	5,868	100%
1989	19.2	1,126	19%	13.1	5,652	100%
1992	16.6	1,442	19%	11.5	6,548	100%
1995	18.9	1,226	18%	13.4	5,633	100%
1999	18.8	1,138	18%	13.8	5,318	100%

The statistics show that at the national level, electricity intensity for all commercial spaces combined increased between 1986 to 1999 by 1.5 kWh per square foot, or 12 percent. This may help explain the upward trend in commercial sector electricity use. However, it is important to note that intensity in the office building population appears to have declined from 1986 to 1999 by 4.8 percent. (Note that the 1992 statistics are substantially lower than in any other year – perhaps partially, at least, due to the effect of the 1991-1992 recession). Given the dramatic increase in electronic equipment and appliances in the office sector, this finding is unexpected and a curious exception to the overall trend, one that warrants further investigation.

To do so we may switch the focus of the analysis from population-expanded statistical estimates, which are derived from the national CBECS weights, to estimates of average kWh per square foot based on samples of buildings that are self-weighted, meaning that each building is treated equally in the analysis. Table 2 contains the mean intensities for all offices in total, as well as for the buildings located in each one of the five distinct climate zones (CZONE) in the United States. To ensure the quality of the data, building electricity use estimates that are suspected of being erroneously low (as indicated by an intensity of less than 5 kWh per square foot) and building square footage estimates that are suspected of being erroneously high (as indicated by an intensity of more than 45 kWh per square foot), are dropped from the analysis.

Table 2: Average Electricity Intensity of Office Buildings

Location	1986	1989	1992	1995	1999
All Offices	17.0	18.5	17.4	18.5	18.1
n	813	852	1120	996	970
CZONE 1	15.8	16.6	14.2	15.8	16.0
n	59	51	63	63	67
CZONE 2	17.1	19.0	17.4	18.5	17.3
n	197	220	250	232	227
CZONE 3	18.3	18.6	17.6	18.9	18.9
n	186	207	299	277	263
CZONE 4	16.5	17.7	17.2	17.6	17.3
n	206	220	273	260	255
CZONE 5	16.4	19.4	18.1	20.1	20.0
n	165	154	235	164	158

As shown in Table 2, *average* electricity intensity per office building offers a different perspective than the population statistics. The average office building electricity intensity increased from 17.0 to 18.1 kWh per square foot, or 6.5 percent, between 1986 and 1999. The largest gain, an increase in intensity of 22 percent, occurred in climate zone 5, the warmest area of the country, which experiences more than 2000 cooling degree days per year.

In trying to explain these changes, it is reasonable to suspect that one of the determinants of electricity intensity is the amount of square footage that is served by electricity, only. For example, all things being equal, average electricity intensity is likely to be higher if an office space is heated with electricity than if it is heated with natural gas. However, as can be seen in Table 3, the percent of office space in the population that is served by electricity, only, has declined in all but climate zone 1 (the statistic for 1992 suffers from a sample of only 3 electric, only, buildings). In fact, even in climate zone 5 in which office building electricity intensity climbed by 22 percent from 1986 to 1999, the amount of office space served by electricity, only, declined from 51 to 41 percent.

Table 3: Percent of Electricity-only Office Space (Population-weighted)

Location	1986	1989	1992	1995	1999
CZONE 1	12.8%	15.2%	1.3%	22.3%	15.7%
CZONE 2	12.7%	16.8%	10.3%	9.9%	10.2%
CZONE 3	29.4%	22.9%	13.7%	24.3%	13.9%
CZONE 4	26.2%	21.7%	15.7%	19.1%	18.9%
CZONE 5	51.3%	52.8%	42.4%	42.3%	41.4%
TOTAL	**26.4%**	**24.6%**	**17.4%**	**22.4%**	**18.3%**

Another variable that may be thought to be an important determinant of energy use trends is the age of office buildings. The time period in which a building is built could affect its fuel mix, the equipment and technologies it houses, and the number of times it has been updated or modernized, to name but a few factors. Also, geographic and climatic areas have been developed economically at different times, and tend to have differing growth rates. This could affect the rate of change in energy intensity. On the other hand, given the permanency of building structures, turnover in office stock, like commercial building stock in general, tends to be relatively low. Low turnover would suggest a slow rate of change.

Table 4 contains the mean ages of office buildings in the CBECS samples, by climate zones and survey years. Since the means are skewed towards older buildings, median age values are also reported in the table. As can be seen, climate zones 4 and 5 tend to have the youngest buildings. Yet, generally speaking, no clear pattern presents itself that would suggest that the age of the building stock is related to electricity intensity.

Even the single most obvious economic variable, electricity purchase cost, appears to have little power, in and of itself, to explain the trend in electricity intensity. As can be seen from Table 5, the average cost per kWh for office buildings, computed at the building level and then averaged across buildings, dropped an average of 26 percent, in constant 1996 dollars, from 1986 to 1999. With the exception of climate zone 1, this drop is fairly similar and does not appear to explain why average intensity per building increased dramatically in climate zone 5 while remaining relatively constant in climate zones 2, 3, and 4.

Table 4: Age of Office Buildings - in Years

Location	Statistic	1986	1989	1992	1995	1999
All Offices	Mean	25	25	24	27	28
	Median	16	18	17	19	22
	n	813	852	1120	996	970
CZONE 1	Mean	29	37	31	31	43
	Median	19	28	22	21	33
	n	59	51	63	63	67
CZONE 2	Mean	29	27	31	32	29
	Median	16	18	20	20	19
	n	197	220	250	232	227
CZONE 3	Mean	29	30	27	28	30
	Median	20	21	19	22	26
	n	186	207	299	277	263
CZONE 4	Mean	18	19	18	22	24
	Median	13	15	13	17	20
	n	206	220	273	260	255
CZONE 5	Mean	20	19	20	24	26
	Median	15	16	15	18	22
	n	165	154	235	164	158

Table 5: Average Cents per kWh Paid by Office Buildings (1996 $)

Location	1986	1989	1992	1995	1999	% Change (1986-1999)
All Offices	10.14	9.35	9.20	8.35	7.50	-26.0%
n	813	849	1114	989	967	
CZONE 1	8.75	7.30	7.79	8.02	7.64	-12.6%
n	59	50	62	63	67	
CZONE 2	10.38	9.24	9.54	8.59	7.71	-25.7%
n	197	220	249	231	226	
CZONE 3	11.10	9.94	9.39	8.38	7.49	-32.5%
n	186	206	297	274	261	
CZONE 4	10.15	9.53	9.49	8.88	7.81	-23.1%
n	206	219	272	258	255	
CZONE 5	9.26	9.14	8.66	7.24	6.69	-27.8%
n	165	154	234	163	158	

IV. Conclusion

Despite common sense and common wisdom, it is very difficult to find empirical support for many of the conjectures regarding national trends in energy use in the building sector. This paper adds an essential pieces of information to the energy efficiency literature by focusing on a small number of seemingly critical variables associated with energy use in office buildings and demonstrating that individually, none does a good job of explaining national trends. It appears that describing changes in office building electricity use, and electricity intensity in general, is a complex undertaking that defies initial expectations.