A COMPARISON OF MEASURED END-USE CONSUMPTION FOR 12 ENERGY-EFFICIENT, NEW COMMERCIAL BUILDINGS*

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ABSTRACT

Assessment of the energy efficiency of commercial buildings is greatly enhanced by using energy consumption data that is more detailed than whole-building utility bills. We have compiled and analyzed measured end-use data for 12 new, energy-efficient commercial buildings from the BECA-CN data base. Data sources include federally funded energy-efficient building research programs and utility demonstration projects. Energy use data, broken down into lighting, cooling, heating, fans and pumps, and miscellaneous, are available for eight of the buildings.

Data analysis consists of defining and comparing monthly and annual end-uses among the 12 buildings. When making comparisons among the buildings we consider differences in 1) miscellaneous equipment loads, 2) occupancy patterns, and 3) weather. Seasonal variations of end uses are discussed. Heating and cooling energy use appears to be correlated with average monthly outdoor temperature for most of the buildings. Lighting energy use tends to be higher in the winter than in the summer. We also compare the measured data to simulation data from ASHRAE Standard 90 research.

*The work described in this paper was funded by the Assistant Secretary for Conservation and Renewable Energy, Office of Building and Community Systems, Building Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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INTRODUCTION

Many commercial buildings are referred to as "energy-efficient", yet detailed performance data are not often published to back up claims. This lack of data is due in part to the difficulties associated with defining, collecting, and analyzing commercial buildings performance data. For example, to accurately address many questions about energy efficiency one needs energy consumption data more disaggregated than whole-building utility bills. This paper examines end-use* data for 12 buildings that have been designed to save energy. The buildings are a subset from a larger data base called BECA-CN (Buildings Energy-Use Compilation and Analysis: part CN) which contains data on 152 new, energy-efficient commercial buildings.

The basic goal of the BECA-CN project is to understand which energy conservation and load shaping techniques have been most successful in occupied buildings. However, compared to the residential sector where techniques for normalizing for varying building conditions, such as weather (Fels, 1985), have been developed, commercial building analysis is not well defined. Since the commercial sector is very diverse, we must be able to account for diverse conditions and their influence on energy use. We are interested in developing standardized techniques to assess commercial building energy efficiency based on the information available for particular buildings. Such a framework should include: defining which data should be collected, developing performance parameters for the available data, and comparing results to a relevant data set.

To address these needs we have been compiling data on new commercial buildings to document their performance. These buildings are not typical new buildings; most have won awards for energy conservation, were low-energy demonstration projects, or have been featured as energy-efficient buildings in journal articles. Past BECA-CN analyses have focused on comparing annual whole-building performance indicators for various groups of buildings (Piette, 1986). We have calculated energy and electric peak demand intensities after grouping buildings according to type, size, climate, and other characteristics that influence consumption. As expected, we have found that low annual intensities (kBtu/ft^2-year) do not necessarily mean a building is energy-efficient; nor do high intensities determine inefficiency. For example, the presence of a large computer center or of 24 hour/day occupancy cause high intensities. Similarly, a very temperate climate may explain a low intensity.

Factors affecting energy use in commercial buildings can be divided into four basic categories: 1) building design (configuration, operation, lighting systems, etc.), 2) miscellaneous equipment loads (computer centers, kitchens, etc.), 3) weather, and 4) occupancy conditions (schedules, number of people, etc.). Since we are concerned with assessing the energy conservation features of the building design, we must understand the influence of the latter three factors on energy use. Submetered data help us to better understand their influence. These data shed light on the assumptions and results of our past analyses by clarifying where and when energy is used. We compare, for example, the largest end uses for each building. We also address the question, "Do buildings with daylighting use less energy for lighting than those without?" We would ideally compare the lighting energy use of the daylit buildings with average

*We use the term "end-use" to mean some subset of total energy used by a particular system such as lighting, heating, etc. Exact definitions of end-use categories differ among data sources, as discussed below.

buildings, but sufficient end-use data do not exist for the buildings stock.

In the following sections, we first describe the end-use data we have collected. We then discuss the whole-building energy intensities, followed by sections on 1) lighting, 2) heating, ventilation, and air conditioning (HVAC), and 3) miscellaneous loads. In the HVAC section we describe simple techniques for examining the effects of weather on energy use. We conclude the paper with a summary of the major findings, and briefly describe future and related work.

DESCRIPTION OF DATA

Data Sources

End-use data are available for only 12 of the 152 BECA-CN buildings. A brief overview of the HVAC systems and conservation strategies employed in each, along with the building numbers, is presented in Table I. Data sources include federally funded case studies (buildings #1 through 6, 7, and 12), utility demonstration projects (#8 and 9), privately funded research (#11), and a British case study (#10). The end-use data have been studied and reported elsewhere for every building except #9 (Table II). As with BECA-CN, data are more widely available for offices than for other building types. Six of the buildings are offices, varying in size from 11 kft^2 to 1,000 kft^2. The other six are: a library, a day-use medical clinic, an air terminal, a church classroom addition, a visitors' center, and a hospital.

Monitoring techniques varied among the buildings. Metering of buildings 1 through 6 from the Passive Solar Commercial Buildings Program (PSCBP) included hourly weather data, such as horizontal solar insolation and temperatures, in addition to energy use. We use National Oceanic and Atmospheric Administration (NOAA) climatological data for the others. We do not present a detailed discussion of how the end-use data were measured, but refer the reader to the literature on each building for more detailed information (Table II). Measurement issues, missing data, and other such complications have been documented in the individual building literature.

End-Use Categorization

After collecting the data, we organized the end-uses into consistent categories. End-use descriptions are different for each building. Differences in building configurations and metering techniques have been the source of the inconsistencies. We discuss examples below.

A recent study from Pacific Northwest Laboratories (PNL), which indicated that very little end-use data has been collected for commercial buildings in the U.S., suggests that end-use energy records, at a minimum, should include the following 6 categories: lighting, heating, cooling, ventilation, water heating, and process energy use (Heidell, 1985). Only four of the 12 BECA-CN buildings satisfy this level of disaggregation because of difficulties in isolating circuits. (Table III summarizes the end-use definitions for each building.) For example, fan coil energy use in the Park Plaza building (#12) is included in the "miscellaneous power" circuit, thus complicating the calculation of both fan and miscellaneous equipment energy use. Comparing the entries in column F in Table III illustrates how the "other" category is a "catch-all". It may include wall heaters (#6), task lights (#1, 9, 10, 12), computers (#4, 6, 9, 10, 12), or kitchens (#4, 6, 10). (We use the terms "other" and "miscellaneous" interchangeably.) If a computer center is included in the "other" category, it may or may not include the extra cooling energy dedicated to the process load. Understanding the loads included in the "other" category is extremely important, as we discuss below.

Consistently defined end-use data are difficult to obtain for other reasons as well. Monitoring techniques are often designed to meet the particular needs of a data analyst, and therefore may not be useful for more general analysis. One example is the medical clinic in Seattle (#8), which has an active solar system to assist heat pump heating. In order to evaluate the solar energy collected to replace heat pump energy, the monitoring team carefully monitored heat pump heating energy and included fan energy in the "lights plus miscellaneous" category for periods where heating was needed. Unfortunately, for periods of cooling, monthly heat pump fan energy was included in the "cooling" category. Another problem is that equipment on circuits often change over the first few years of building operation. A very common change is for energy use to increase due to the addition of computer loads.

In only a few cases do we have the actual utility bills with which to compare monthly end-use totals. The differences between submetered and utility bill totals are often not well documented. Exterior lights account for the difference in at least one case, where they consume about 3% of total energy use (#3). Collecting the utility bills is important since most of the buildings are no longer being submetered, so utility bills are an important source of long-term performance data.

Very few peak electric demand data, especially peak demand end-use breakdowns, have been reported for these 12 submetered buildings. We would like to know, for example, what the end-use breakdown of peak electrical demand is on the annual and monthly peak days. BECA-CN results indicate that demand costs typically account for 30% of annual electricity costs, suggesting the importance of peak demands in determining operating costs. For these buildings, seven of the 12 buildings are all-electric, yet many are small and are not on charged for demand. Still, end-use power data should be assessed in addition to the energy data. (For more discussion of peak demand BECA data see Piette, 1986.)

COMPARATIVE ANALYSIS

Our analysis begins with a discussion of the annual whole-building data contrasted with other sources of building energy data. Next are sections describing the three major end-use categories: lighting, HVAC, and miscellaneous. We have reviewed the data three ways, by: 1) monthly end uses, 2) monthly predicted versus actual end uses, and 3) monthly end uses versus average monthly outdoor temperatures. The energy use versus temperature plots were generated to study heating and cooling consumption trends. We have examined the seasonality of a variety of end uses. Our analysis is limited to monthly instead of weekly, daily, or hourly data because monthly data have been the most readily available, and are simplest to manage. Also, we are interested in the lessons learned from monthly data since this is the frequency interval available for most buildings.

Overall Performance

The most common indicator of commercial building performance is the annual, whole-building energy intensity. We compare the intensities to each other, to predicted energy use, to national stock averages, and to simulation data depicting performance in compliance with energy conservation standards. Table IV shows the annual energy intensities and seven categories of end uses as defined in Table III. We calculate the annual energy intensity based on the total site energy use normalized by the gross floor area, excluding enclosed parking area*. The table is ordered by building type and ascending size.

Figure 1 shows the 12 BECA-CN buildings plotted from least to most intensive. Energy use is divided into "HVAC" and "lighting plus miscellaneous" as described in Table III.** As anticipated, building type is an important determinant of energy use. The church classroom building uses the least (20 kBtu/ft^2-year) and the hospital the most (142 kBtu/ft^2-year). As mentioned, it is important to consider the variations in miscellaneous equipment loads, weather, and occupancy when comparing building energy use and energy efficiency. Hospitals typically have high equipment loads and long hours of occupancy, whereas churches and classrooms have the opposite. To account for differences in operating hours a parameter such as Btu/ft^2-occupied hour is useful. Based on a reported occupancy of 53 hours/week in the church classroom, the occupant normalized intensity is 7.3 Btu/ft^2-occupied hour. This brings the value within a factor of two of the hospital's 16.2 Btu/ft^2-occupied hour (based on 24 hour/day use), whereas the annual intensities were different by a factor of seven. Obviously this is an oversimplification

*Two of the 12 buildings (#7 and 12) have enclosed garages. Developing consistent floor area data has been an area of difficulty in BECA-CN because there are no widely used definitions for reporting area (Piette, 1986).

**There are minor data problems for buildings 12, 6, 2 and 11. Small amounts of miscellaneous fan and heating energy use are not included in "HVAC". If measured, the breakdowns would change a few percent.

of the relationship between hours of operation and energy use, but it is useful for first-order comparisons.

The six offices range from the 36 to 118 kBtu/ft^2-year. We compare BECA-CN office data to two other sources of buildings data. The first is based on actual energy data from the national Nonresidential Buildings Energy Consumption Survey (NBECS) (EIA, 1983). The second is based on DOE 2.1 simulation runs designed to test ASHRAE (American Society of Heating, Refrigeration, and Air Conditioning Engineers, Inc.) Standard 90 for new commercial buildings (PNL, 1983). NBECS results show that the average U.S. office consumes 124 kBtu/ft^2-year. Each of these six submetered offices is below this value. In fact, all but two (#11 and 12) are below the average BECA-CN office intensity of 66 kBtu/ft^2-year. The end-use data for buildings 11 and 12 help explain the higher intensities; both have large computer centers.

The Standard 90 data are useful for comparison since they were developed to simulate typical U.S. commercial buildings. We chose two office configurations to utilize in comparisons. One is a medium office designed to meet Standard 90-75, which represents "good engineering practice" of the mid-70's. The second is the same office, in the same climate (Washington D.C.), redesigned for better energy efficiency, which includes daylighting. We chose the medium office over the large and small office prototypes because the intensities were mid-range values. The medium office is a 49.5 kft^2, three-story building. Heat is supplied by a gas boiler, and cooling by a reciprocating chiller. We discuss these data further below.

Predicted energy data are available for ten of the 12 buildings; eight used more than predicted, two used less. The prediction methods range from simple engineering estimates to detailed DOE-2 simulations. With end-use data, we can look closely at the individual components of energy use that varied from the predicted. Examples are presented below. Variations in weather, operating conditions, and system characteristics usually explain the difference between predicted and actual energy use. Four of the ten used within 15% of the predicted total, but each of these four predictions were based on simulation runs that was revised after the building was in operation. For the few buildings that used substantially more than predicted by factors of two or three, simulations were based on operating conditions that varied greatly from the actual conditions.

Lighting Energy Use

Lighting energy use is regarded as one of the largest end uses in commercial buildings. In terms of the extraneous factors affecting energy use discussed above, comparisons of lighting energy use should be relatively straightforward since climate has little impact on lighting energy use. Hours of operation are probably the most important factor to compare among the buildings. Unfortunately, as noted in Table III, the lighting data are the most problematic end-use category. The worst cases are when lighting energy is not measured separately from miscellaneous. Even when overhead lighting is submetered, task lighting usually is included in miscellaneous. Data descriptions for four of the 12 buildings mention that task lighting is included in the "other" category.

Figure 2 shows the eight buildings (five offices, the library, the visitors' center, and the hospital) for which the lighting data are measured separately from miscellaneous, plus the two Standard 90 office configurations. Although there are still minor problems with the end-use categorizations for these eight BECA-CN buildings, the data are adequate to show that each of these buildings has low lighting energy use. The lighting intensities vary from 1.5 to 19.8 kBtu/ft^2-year, or from four to 40 percent of total energy use.

Lighting energy is the largest end use, in terms of annual percentage, for two offices (#7 and 9). Lighting consumes 40% of building #9's annual energy use, but this includes parking lot and exterior lighting. This building is discussed further below. Building #7, the Norris Cotton Federal Office Building (NCFOB) uses 16.6 kBtu/ft^2-year for lighting, which is 31% of the annual total. The NCFOB was the subject of an energy-conservation demonstration project, so different lighting systems were installed on each floor, with an average lighting power density of 1.8 W/ft^2. The highest lighting intensity of these eight buildings is Park Plaza's 19.7 kBtu/ft^2-year, which represents only 19% of the annual total, but is 32% of the total when "other" energy use is subtracted off. Park Plaza's fluorescent lighting utilizes parabolic fixtures with a power density of 1.7 W/ft^2.

Although buildings 11 and 12 have the highest absolute lighting intensities, they are well below the Standard 90-75 medium office intensity of 23.7 kBtu/ft^2-year. Both of these BECA-CN offices are occupied about 70 hours/week, which is greater than the Standard 90 office occupancy of 53 hours/week. Both BECA-CN offices also have lighting power densities below the 90-75 office's 2.5 W/ft^2. The redesign value for the Standard 90 office with daylighting consumes 37% less energy than the 90-75 prototype (15.0 kBtu/ft^2-year), which is less than the Park Plaza and NCFOB values. The lighting power density was reduced to 1.9 W/ft^2.

Lighting energy use for building #1 is only 1.5 kBtu/ft^2-year, or 4% of the total. These values are low because only one of three zones was included on the lighting submeter, of which one is warehouse space. The remainder of lighting energy use is in "miscellaneous". The next lowest intensity (2.8 kBtu/ft^2-year) is found in the library (#3) and the bank (#4). Both of these buildings, like #1 where the results are less clear, have very low lighting energy use due in part to the daylighting techniques (Table I). Cooling intensities remain comparatively low as well. Daylighting is also used in buildings 6 and 9. Building #6 is a visitors' center with some 24 hour/day occupancy by police, which may explain the higher lighting energy use of 8.5 kBtu/ft^2-year. As mentioned, Building #9's lighting data includes exterior and parking-lot lighting. Otherwise, these daylit buildings use less energy for lighting than the other buildings.

One might expect hospitals (#10) to have high lighting energy use. A study of building #10 reports three reasons for the low lighting intensity of 8.6 kBtu/ft^2-year: 1) natural lighting is good, 2) patients are elderly and in bed early, so evening consumption is low, and 3) staff are attentive to switching off lights. The lighting power density is a low 1.5 W/ft^2. Over-bed lights are included in the "other" category; they are estimated to be another 13% of lighting energy use.

Comparing predicted and actual energy data for building #9 illustrates some of the complexities of this process. This low-energy office (44.0 kBtu/ft^2-year) is a 29.6 kft^2 building on the temperate Oregon coast. The conservation features include high thermal mass, skylighting, atriums, light shelves, and external shading. Submetering consists of four kWh meters, which supply data for heat pumps, fans, lighting, and miscellaneous. The heat pumps rarely operate in a cooling mode. Figure 3 shows how flat the monthly profiles are, which is due in part to the climate. In only one month did the average monthly outdoor temperatures reach 60°F or dip below 40°F (based on Astoria weather data). We further discuss the importance of climate in the next section.

The building was estimated to use 11.6 kBtu/ft^2-year for HVAC and lighting. This is about 1/3 of what it actually uses for heating, fans, and lighting (32.6 kBtu/ft^2-year). The estimate was developed, along with six other simulation runs, to study alternative building configurations. Lighting energy use was designed to be 5.5 kBtu/ft^2-year, but the circuit measures 17.7 kBtu/ft^2-year (which is still below lighting energy use for buildings 7 and 12). Without knowing the extent of the parking-lot lighting on the circuit, we cannot determine whether the lighting energy is low compared to the predicted energy use. The fan and heating energy were also greater than predicted by a factor of two. The building is still being "debugged" and energy use is expected to drop another 25% with better maintenance of the mechanical controls and other operational fine tuning.

One often expects heating and cooling energy use to vary seasonally, but less is known about the seasonal characteristics of lighting energy use. These buildings tend to use more energy for lighting in the winter than in the summer. One measure of "flatness" is the ratio of the maximum to the minimum monthly energy use. The ratios range from 1.2 for the NCFOB (#7), to over 5 for two buildings (#6 and 3). The NCFOB had an average monthly intensity of 1388 Btu/ft^2-month and a maximum and minimum of 1518 and 1230 Btu/ft^2-month, respectively. Four (#3, 6, 9, and 12) of the seven buildings in Figure 2 have their highest months in the winter months (between November and March). In order to compare winter average lighting energy use to summer averages we compared November through February consumption with May through August. Looking at the data in this manner shows that only one of the seven buildings used more lighting in the summer than in the winter. In fact, three of the buildings (#3, 6, and 12) used over 35% more energy in the winter than in the summer.

HVAC Energy Use

Comparing energy used for heating, cooling, and ventilating in different buildings is complicated by differences in climate and climate sensitivity among the buildings. How to account for the affects of weather on energy use is not clear for commercial buildings. A variety of research is currently underway utilizing whole-building and end-use data, based on simulated and actual buildings (Rabl, 1986; Eto, 1985; Palmiter, 1986).

Heating is the largest end use for six of the 12 buildings (#1, 3, 4, 5, 6, 10). This is probably not typical of the commercial sector, but understandable for our sample since five of the six are small buildings (all are under 18 kft^2). The hospital's high heating consumption (#10) is due to 24 hour/day heating. Also, the building has a floorwarming heating system, installed to take advantage of low off-peak electricity rates. Hot water storage tanks are charged overnight, so electric demand charges are reduced, yet heating energy use may slightly increase. This building is Britain's first all-electric hospital, which uses only 141 kBtu/ft^2-year. Typical U.S. hospitals use well above 200 kBtu/ft^2-year (Hunt, 1983). None of the 12 BECA-CN buildings are cooling dominated, yet the Standard 90-75 office consumes more energy for cooling (24.5 kBtu/ft^2-year) than any other end use, with lighting use being almost as great. One reason for low cooling consumption in the 12 buildings is that natural ventilation and cooling techniques, used in four of six PSCBP buildings, have been successful.

Figure 4 shows the relationship between average monthly outdoor temperature and HVAC energy for the library (#3). (The y-axis scale is high to be consistent with Figure 6, discussed below.) This suggests that further regression analysis for weather normalization would be appropriate (Rabl, 1986). In addition to clear heating and cooling slopes, fan energy use also shows a slight seasonal variation (greater use in cold or warm months, less in transitional months). Fan data include the air circulating fans on the heat pumps, plus two exhaust fans. Therefore, when heating or cooling is needed, heat pump fans operate. The monthly totals show the level of correlation that would be apparent if only utility bills were plotted. Monthly data must be interpreted with caution; differences in the total number of days, of working days, or of weekends in a month will affect the data. Weekly or daily data are more appropriate for many types of end-use or whole building performance analyses (Palmiter, 1986; Rabl, 1986).

For one month (May) the building was able to maintain comfortable conditions without needing to heat or cool. This achievement is a result of the high mass of the structure. Large solar apertures admit solar heat which is stored in the tiled concrete floor slab. Shading and diffusion of sunlight prevent overheating. In addition to providing end-use data, the monitoring system: 1) helped identify system malfunctions that would have gone unnoticed, 2) showed the need for frequent thermostat calibration, and 3) showed that manual lock-outs of heating and cooling systems could be used to save more energy.

Another small, heating dominated building is the Johnson Controls office building (#1) in Salt Lake City, Utah. Figure 5 shows the predicted (54.7 kBtu/ft^2-year) and actual (37.6 kBtu/ft^2-year) monthly data. Total, heating, and fan and pump energy are plotted: heating and fan energy use make up 78% of the annual total. Lighting, heating, cooling, and service hot water energy usage were all below predicted, while fan and miscellaneous use were up. The differences are a result of factors which include weather, occupancy, HVAC operation, and equipment differences. Winter weather was milder than average; summer, spring, and fall were cooler and wetter than average. The design prediction included a vapor compression cooling system, but an evaporative cooler was installed. A computerized energy management system (EMS) allowed closer control of return air for morning warm up, night flushing, and ventilation control. Heating and cooling energy was therefore reduced, but fan usage increased because of the night flushing. A number of other differences have also been documented. The prediction values, based on early planning, are not a good basis for comparison with the building "as built", yet they emphasize the success of the low energy intensity.

The next example shows energy use for a commercial building on the opposite end of the scale in terms of size, loads, and occupancy. Figure 6 is another plot of monthly energy use versus average temperature for the million ft^2 Park Plaza building (#12) in Newark, NJ. For the purposes of this plot the heating and cooling category includes energy used by the hot and cold water distribution pumps. This was done because the pump energy use tracks heating and cooling consumption, therefore allowing a clearer climate correlation. Hot water pumps consume 1.2 kBtu/ft^2-year and cold water pumps consume 2.8 kBtu/ft^2-year. Park Plaza, although it is a large building with large computer loads, shows some seasonality in energy use. Heating energy increases at temperatures below 45°F and cooling energy increases above 50°F. As mentioned above, lighting energy use also increased in the winter.

Comparing Figure 6 with Figure 4 we see: 1) the dramatic difference in the base loads, and 2) the higher cooling energy use for Park Plaza. For Park Plaza, as for the library discussed above, May's energy use was the lowest during 1982 (average temperature of 63.2°F). During 1983 the lowest month was September (66.7°F). Since both heating and cooling occurred in these low months, we cannot use the lowest month's consumption as a "base" load. Calculating base energy use is helpful in identifying non-weather sensitive energy use. We could perhaps use the end-use data to calculate a base, but it is not clear how to separate cooling energy for the 24 hour/day computer center from the weather sensitive portion of the cooling energy use. Both this building and the NCFOB (#7) cool all year.

Fan and pump energy use is the third category of HVAC energy use. Energy use in this category ranges from 3 to 29% of total energy use, or from 5.4 to 27.6 kBtu/ft^2-year, for the nine buildings with fan and pump end-use data (Table IV). It is the second largest end-use for four of these nine (#9, 7, 3, and 10). The fan energy use of the Standard 90-75 building is based on a dual-duct VAV (DD-VAV) system (9.9 kBtu/ft^2-year). One of the other HVAC configurations tested for the Standard 90 medium office included a constant-air-volume (CV) system which used about twice as much energy for fans as the VAV system. None of these 12 buildings have CV systems.

The seasonality of fan usage data depends on the type of HVAC system present. When fans are connected with heat pump operation they tend to appear to have a seasonal pattern. We showed this with Mt. Airy, discussed above (#3). The same result was found with building #9. Fan and pump energy use for the NCFOB tracks heating and cooling energy since circulation pumps are included. For Park Plaza (#12) the fan energy does not track average outdoor temperatures, but pump energy does. Buildings 1, 4, 5, also showed no seasonal variation. Fan energy consumption may vary over 12 months by 600% (#3), or as little 30% (#6).

Miscellaneous Energy Use

A final, and often underestimated category, is "miscellaneous" or "other" energy use. Figure 2 shows that if the Park Plaza building did not consume so much "miscellaneous" energy, consisting primarily of computer loads (41.5 kBtu/ft^2-year), energy use would be within a few percent of energy used in the efficient, daylit Standard 90 configuration. Miscellaneous energy use is increasingly important to consider as more buildings add large computers and copy machines. Analysis of Enerplex North (#11) also cites computer energy use as a major cause for consumption of more energy than predicted. For the hospital, 54% of the "other" energy use, or 12.2 kBtu/ft^2-year of the 22.5 kBtu/ft^2-year, is used by the kitchen.

Elevators are another significant load found in all large buildings. The Park Plaza building used 2.6 kBtu/ft^2-year for vertical transport. NCFOB used 2.1 kBtu/ft^2-year. (A similar amount is reported for the sum of the fire, EMS, and emergency systems in the NCFOB.) In the Standard 90 offices energy use for vertical transport was estimated to be 5.0 and 3.9 kBtu/ft^2-year in the medium and large offices, or twice as much as the 2 BECA-CN offices report.

Another indication of the increasing importance of "miscellaneous" energy is based on the multi-year data we have for four of the buildings (#1, 5, 6, and 12). Energy use went up in the second year of monitoring for three of these four buildings (which is the year of data we have presented). For all four buildings energy use in the "other" category increased. The impact of the increase from "other" energy use ranged from 10% to over 100% of the annual increase. In the latter case (#6), energy use decreased for lighting and fans, but increased for cooling, heating, and miscellaneous. Miscellaneous use was up 7.0 kBtu/ft^2-year, which was greater than the total change (46.8 to 51.9 kBtu/ft^2-year). As with the other end-use categories, better definition of the category, and assessment of its size, is needed.

SUMMARY

The buildings discussed above have, in general, achieved low energy intensities in various ways. The end-use data greatly increase our ability to understand why the energy intensities are low. The data have been discussed in both relative and absolute terms in order to illustrate the size and variations in end-use consumption. The most important findings are:

- Lighting data tend to be the hardest to isolate because of wiring configurations. Fan energy data are also problematic.
- The daylit buildings use less energy for lighting than the non-daylit buildings.
- Heating and cooling energy use track average monthly outdoor temperatures in many of the buildings. Lighting energy use tends to be higher in the winter. Fan energy use may also show seasonal variations.
- End-use data allow one to assess important impacts on energy use of large miscellaneous loads, such as kitchens and computer centers. Better data are needed to understand the impact of these large loads.
- Each of the eight buildings plotted in Figure 2 tends to be relatively "energy-efficient" compared to the other sources of comparison data, which include: NBECS, Standard 90 office simulation runs, and BECA-CN averages. The data are less conclusive for the other four buildings.

Further analysis of these and other end-use metered buildings is needed for more specific conclusions. A variety of research is underway which relates to our analysis. The work can be categorized into two areas. The first area is in data collection efforts such as ELCAP (End-Use and Load Conservation Assessment Program) (Heidell, 1985) in the Pacific Northwest. ELCAP will cover data collection for over 200 commercial buildings. Many utilities are also sponsoring end-use data collection efforts. EMSs are another useful source of building data currently being explored (Flora, 1986). A final source of data, and perhaps the most promising, is from future buildings built to the proposed ASHRAE Standard 90.1P. As it is now written the standard recommends that submetering be installed in all commercial buildings whose electrical service is over 150 KVA. The second area is in developing commercial data analysis techniques. Weather normalization research, for example, is showing progress towards developing methods to interpret the effects of climate. In addition to more end-use data, better economics data are needed to determine the cost effectiveness of energy saving features.

These findings are a preliminary look at the end-use data for energy-efficient, new commercial buildings. The study is an ongoing project (BECA); data contributions from readers are welcomed.

ACKNOWLEDGEMENTS

The work described in this report was funded by the Assistant Secretary for Conservation and Renewable Energy, Office of Building and Community Systems, Buildings Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098. We also thank Hashem Akbari, Joe Eto, Jeff Harris, and Rosemary Riley for their helpful advice and assistance.

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- Pacific Northwest Laboratory (PNL), *Recommendations for Energy Conservation Standards and Guidelines for New Commercial Buildings,* Volume III, (ASHRAE Special Project #41), DOE/NBB-0051/1 to 9, PNL, Richland, WA, October 1983.
- L. Palmiter, J. Hanford, "Relationship Between Electrical Loads and Ambient Temperature in Two Monitored Commercial Buildings", to be published in *ASHRAE Transactions,* presented at the June 1986 ASHRAE Conference, Portland, OR.
- M.A. Piette, R. Riley, "Energy Use and Peak Power for New Commercial Buildings from the BECA-CN Data Compilation: Key Findings and Issues", *Energy Technology XIII: Energy in Transition,* Proceedings of the Thirteenth Energy Technology Conference, Washington D.C., March 1986. Also published as LBL Report No. 20896.
- Ari Rabl, "Steady State Models For Analysis of Building Energy Data", (draft), to be presented at the ACEEE 1986 Summer Study on Energy Efficiency in Buildings, August 1986.

Table I. Selected building characteristics*.

BLDG. #	BUILDING NAME	BLDG. TYPE	CITY/STATE		FLOOR AREA (KSQFT)	YEAR BUILT	PRIMARY EQUIPMENT HEAT	COOL	SPECIAL FEATURES OR EQUIPMENT	SPECIAL CONTROLS OR OPERATIONS	DAYLIGHT CODE	OCCUPANCY DENSITY (#/KSQFT)	HOURS (#/WEEK)
4	SECUR. ST BNK, WELLS	SOFF	WELLS	MN	11.0	1981	BO	CH	MS,HW	EZ,TM,NC,LM	CL	2.3	55
1	JOHNSON CNTRL UT	SOFF	SALT LAKE	UT	16.0	1981	BO	ED&I	MS,MI,TM,EB	NC,EZ,EMS,NS	SH,CL	1.7	45
9	CENTRAL LINCOLN PUD	SOFF	NEWPORT	OR	29.6	1982	HP	HP	HR,OT,TM,HW	NS,EZ	SKY,SH,AT	3.4	
7	NORRIS COTTON FOB	LOFF	MANCHESTER	NH	104.0	1976	BO	SARC	SO,HW,HR	NS,EZ			70
11	ENERPLEX NORTH	LOFF	PRINCETON	NJ	129.0	1984	RS	CH	ST,OT	EZ	AT,SKY		
12	PARK PLAZA BLDG	LOFF	NEWARK	NJ	1000.0	1979	BO	CCDB	HR	EMS,EZ,DC,LM		3.4	53
6	RNS POLY IN VST CNTR	OTHR	TROY	NY	5.2	1981	RS	DX	TM,MI,EB,OW,MS	EZ,NC,TM	SKY,RF,SS	1.9	115
5	COMMUNITY UNIT METH.	OTHR	COLUMBIA	MO	5.5	1981	FR	DX	OW,TM,FS	NC,NS,TM	CL,SH	1.8	52
2	GUNNISON CO AIR TRM	ARPT	GUNNISON	CO	9.7	1981	BO	N	MI,TM	NS	CL,SH	4.1	84
8	ODESSA BROWN CLINIC	CLIN	SEATTLE	WA	12.4	1980	HH	HH	SO,HW,HR,HL,EB		SKY		45
3	MT. AIRY	LIBR	MOUNT AIRY	NC	13.5	1982	HP	HP	TM,FS,OT	NS,EZ,NC,TM	CL,SH,RF	1.7	65
10	FENLAND HOSPITAL	HOSP	PETERBOROUGH	UK	72.2	1981	OT	N	HR,OT,HS	LM,TM			168

*Source: BECA-CN Data base

Code Definitions

-BUILDING ID #: assigned arbitrarily .

-BUILDING NAME: name of building.

-BUILDING TYPE: based on predominant use of occupied space.

ARPT	Airport terminal	CLIN	Clinic
LIBR	Library	LOFF	Large office building, >50,000 ft^2
OTHR	Other type (ex: church and a visitors center)	SOFF	Small office building, <50,000 ft^2

-LOCATION: city and state where building is located. UK-United Kingdom.

-GROSS FLOOR AREA: total gross floor area in 1000 ft^2. This includes conditioned and non-conditioned spaces, but does not include parking.

-YEAR BUILT: year when construction was completed.

-HEATING EQUIPMENT CODE: primary type; other secondary systems may also be in use.

BO	Boiler	FR	Furnace
HH	Hydronic Heat Pump	HP	Heat Pump (air-to-air)
RS	Resistance (electric)		

-COOLING EQUIPMENT CODE: primary type; two code entries (4 letters) refer to primary and secondary equipment.

CC	Centrifugal Chiller	CH	Chiller (type unknown)
DB	Double Bundled Chiller	DX	Direct Expansion Cooler
ED&I	Direct & Indirect Evaporative Cooling	HH	Hydronic Heat Pump
HP	Heat Pump (air-to-air)	N	None
RC	Reciprocating Chiller	SA	Solar Absorption

-SPECIAL FEATURES AND EQUIPMENT: notable energy saving or load shaping features.

EB	Earth Berms	EZ	Economizer
FS	Fixed External Shading	HL	Heat Recovery Luminaires
HR	Heat Recovery	HW	Hot Water Storage
MI	Movable Insulation	MS	Movable External Shading
OT	Other	OW	Operable Windows
SH	External Shading (type unknown)	SO	Active Solar
TM	Thermal Mass (includes trombe walls, direct solar gain)		

-SPECIAL CONTROLS OR CONTROL STRATEGIES:

DC	Duty Cycling	EMS	Energy Management Control System
EZ	Economizer	LM	Load Management
NC	Natural cooling/night ventilation	NS	Night Setback
TM	Timers/clock thermostats		

-DAYLIGHT TYPE:

AT	Atrium	CL	Clerestory
RF	Reflectors for bouncing light	SH	Light shelves
SKY	Skylights for lighting (not decorative)	SS	Sunspace

-OCCUPANT DENSITY (#/KSQFT): average number of occupants per 1000 ft^2 (often estimated).

-WEEKLY HOURS OF OCCUPANCY: hours per week that the majority of the building is occupied (often estimated).

Table II. Primary references for each building.

Building 1: Energy and building data are from the Passive Solar Commercial Buildings Program (PSCBP) documentation and the building manager at the site.

- Architectural Energy Corporation, "Site Handbook: Johnson Controls Inc. Building," PSCBP, Westminster, CO, November 1984.

Building 2: Energy and building data are from the PSCBP documentation.

- Michael Miller, "Lessons Learned From Passive Solar Design," *Building Design and Construction*, February 1983.
- Dr. Jan Kreider and Leon H. Waller, "Forms 1 and 2 (One Time and Continuous/Weekly Measurements)" Gunnison County Airport Terminal, PSCBP, April 1982.

Building 3: Energy and building data are from the PSCBP documentation.

- Architectural Energy Corporation, "Site Handbook: Mount Airy Public Library," PSCBP, Westminster, CO, April 1984.

Building 4: Energy and building data are from the PSCBP documentation.

- Architectural Energy Corporation, "Site Handbook: Security State Bank," PSCBP, Westminster, CO, November 1984.

Building 5: Energy and building data are from the PSCBP documentation.

- Architectural Energy Corporation, "Site Handbook: Community United Methodist Church," PSCBP, Westminster, CO, October 1984.

Building 6: Energy and building data are from the PSCBP documentation.

- Architectural Energy Corporation, "Site Handbook: Rensselaer Polytechnic Institute Visitor Information Center," PSCBP, Westminster, CO, January 1985.
- John Tichy, "Performance of the RPI Passive Solar Visitors Information Center Building For 1982," *Solar Engineering 1984*, Proceedings of the 1984 ASME Solar Energy Division Conference.

Building 7: Energy and building data are from this reference.

- William May, Jr., "Analysis of Data from the Energy Monitoring and Control System at the Norris Cotton Federal Office Building," National Bureau of Standards, Washington, D.C., November 1981.

Building 8: Energy and building data are from this reference.

- R. Lastimosa, et. al., "Odessa Brown Children's Clinic: Solar Heating System Monitoring Report," Seattle City Light, Seattle, WA, June 1984.

Building 9: Energy and building data are from this reference and from the building manager at the site.

- Moreland/Unruh/Smith Architects and Planners, et al., "Central Lincoln People's Utility District Passive Solar Energy Study," Eugene, OR, November 1980.

Building 10: Energy and building data are from this reference.

- I. Alexander, et al., "Early Operational Experience of Britain's First All-Electric Hospital," *Building Services Engineering Research and Technology*, Vol. 5, No. 1, 1984.

Building 11: Energy and building data are from this reference and from researchers at the site.

- L. Norford, et al., "Monitoring the Energy Performance of the Enerplex Office Buildings: Results for the First Year of Occupancy", Princeton University, PU/CEES Report No. 203, 1985.
- L. Norford, et al., "Energy Use in the Enerplex Office Buildings: A Progress Report," Princeton University, draft, will be published in the Proceedings of the ACEEE 1986 Summer Study, Santa Cruz, August 1986.

Building 12: Energy and building data are from this reference.

- Tishman Research Corporation, *Design and Operational Energy Studies in a New High-Rise Office Building*, DOE/CS/20271-1 through 5, New York, NY, 1984.

Table III. End-use data descriptions for 12 BECA-CN buildings and 2 Standard 90 office configurations.

	SPECIFIC END-USES							GENERAL	
BLDG. # & TYPE	A LIGHTING	B HEATING	C COOLING	D FANS & PUMPS	E DHW	F OTHER	G SOLAR AUXIL	H HVAC	M LIGHTS & MISC.
#4 SOFF	Overhead	Gas Boiler	Chiller	Exhaust & Air Handler	Elec. Resistance	Kitchen, Misc. Power	None	B+C+D	A+E+F
#1 SOFF	*Only 1 of 3 Zones (Some in F)	Gas Boiler	Direct & Indir. Evap. Cooling	Exhaust & Air Handler, Fan Coils, Pumps	Elec. Resistance	Some Task & Overhead Lights, Misc. Power	None	B+C+D	A+E+F
#9 SOFF	Overhead, Exterior, & Parking Lot	Heat Pumps, Some Cooling	(Some in B)	Supply, Exhaust & Heat Pump Fans Solar Aux.		Misc. Power, Task Lights, Mini Cmptr.	(in D)	B+D	A+F
#7 LOFF	Overhead & Basement	Heat Pumps, Gas & Oil Boilers	Heat Pumps & Chillers	Misc. Fans & Pumps, Solar Aux.	Gas	Misc. Power,Elevators Security Systems	(in D)	B+C+D	A+E+F
#11 LOFF	**Overhead & Misc., Power, Cmptr. Center, Kitchen	Elec. Resistance	Chiller & Ice Pond	*Supply, Exhaust, VAV Fans	(in F)	*(Some in A), DHW Misc. Lights, Fans, Controls, Elevators	None	*B+C+D	*A+F
#12 LOFF	*Overhead, Small Amount of Fan Coils	*Elec. Boiler & Small Unit Heaters, Some Dock Cooling	Chillers, Cooling Tower Fans	*Supply, Exhaust, Circulation Pumps (see A,F)	Elec. Resistance	Misc. Power, Cmptrs., Fan Coils, Elevators	None	*B+C+D	*A+E+F
#6 OTHR	Overhead	*Elec. Furnace, Radiant Panels (Not Include Wood)	Direct Expansion	Air Handler	(in F)	Misc. Power, DHW, Kitchen, Small Cmptr., Wall Heaters	Fan to Cool Ventil-ation Tower	*B+C+D+G	*A+F
#5 OTHR	**Overhead & Misc. Power	Gas Furnace	Direct Expansion	Air Handler	*Estimated	Night Cooling Fan	None	B+C+D+F	A+E
#2 ARPT	**Overhead & Misc. Power & Fans	Elec. Resistance	None	(in A)	Elec. Resistance		None	*B	*A+E
#8 CLIN	**Overhead & Misc. Power	Heat Pumps	*Heat Pumps	*Heat Pump Fans	Elec. Resistance	(in A)	Solar Aux.	B+C+G	A+E+F
#3 LIBR	Overhead	Heat Pumps	Heat Pumps	Exhaust & Heat Pump Fans	Elec. Resistance	Misc. Power, Refrigerator	Solar Aux.	B+C+D	A+E+F+G
#10 HOSP	Overhead	Elec. Boiler, Floorwarming	None	Supply & Exhaust	Elec. Resistance	Misc. Power, Bed Lights, Kitchen	None	B+D	A+E+F
90-75 Med Of	Overhead	Gas Boiler	Chiller	Supply & Exhaust, Circulation Pumps	None	Misc. Power Elevators	None	B+C+D	A+F
DAYLIT Med Of	Overhead	Gas Boiler	Chiller	Supply & Exhaust, Circulation Pumps	None	Misc. Power Elevators	None	B+C+D	A+F

The 12 BECA-CN buildings are listed in the same order as in Table 1, with the same 4 letter building type code. The 90-75 and DAYLIT medium offices are from DOE 2.1 simulation runs to test Standard 90.

* - Minor problem with end-use description. ** - Major problem with end-use description.

Heating and cooling modes of heat pumps have been metered separately except as noted.

Table IV. Annual end-use data for 12 BECA-CN buildings and for 2 Standard 90 office simulations.

BLDG NO.	BUILDING TYPE & LOCATION		GROSS AREA (KSQFT)	YEAR OF DATA	T TOTAL BTU/ SQFT	A LIGHT BTU/ SQFT	B COOL BTU/ SQFT	C HEAT BTU/ SQFT	D FANS& PUMPS BTU/ SQFT	E DHW BTU/ SQFT	F OTHER BTU/ SQFT	G SOLR BTU/ SQFT	H HVAC BTU/ SQFT	M LIGHT& BTU/ SQFT	H %	M %	ACTUAL WEATHER HDD (BASE 65F)	CDD
4	SMALL OFF	MN	11.0	1984	55784	2763	4176	36452	3508	775	8110	0	44136	11648	79	21	7121	1218
1	SMALL OFF	UT	16.0	1984	36299	1537	228	19065	7173	234	8062	0	26466	9833	73	27	5731	1092
9	SMALL OFF	OR	29.6	1984	44006	17748		2112	12763		11383		14875	29131	34	66	5304	5
7	LARGE OFF	NH	104.0	1979	54285	16653	3894	10752	13055	284	9647		27701	26584	51	49	7253	459
11	LARGE OFF	NJ	129.0	1986	117500	61900	17000	12800	19900		5900		49700	67800	42	58	*4972	*1091
12	LARGE OFF	NJ	1,000.0	1983	102851	19797	21187	2421	16692	1284	41470	0	40300	62551	39	61	4405	1164
6	VSTRS CNTR	NY	5.2	1984	40619	8484	2521	15271	3841		10250	252	21885	18734	54	46	6701	1108
5	CHRCH SCHL	MO	5.5	1983	20164	1873	76	16804	437	876	98	0	17415	2749	86	14	5099	1402
2	AIR TERMNL	CO	9.7	1982	70589	40156	0	29836		597		0	29836	40753	42	58	9581	418
8	CLINC	WA	12.4	1983	73995	41383	19263	3106	6391	3797		55	28760	45235	39	61	4350	173
3	LIBRARY	NC	13.6	1983	23155	2724	4723	9827	5387	119	332	43	19980	3175	86	14	4068	1824
10	HOSPITL	UK	72.2	1983	141784	8564	0	61218	27596	21886	22520	0	88814	52970	63	37	*5945	*92
90-75	MED OFF	DC	49.5		78300	23700	24500	9000	9900	0	11200	0	43400	34900	55	45	4236	1425
DAYLT	MED OFF	DC	49.5		56700	15000	15900	6500	8100	0	11200	0	30500	26200	54	46	4236	1425

NOTES: 1. ALL ENERGY UNITS ARE IN SITE BTU/GROSS SQFT
2. H% = COLUMN H/COLUMN T
3. M% = COLUMN M/COLUMN T
4. LAST TWO ROWS OF DATA (90-75 AND DAYLT) ARE FROM DOE 2.1 RUNS 90A AND 90G, FOR HVAC ALTERNATIVE #1 [PNL, 1983].
5. WEATHER DATA ARE ACTUAL YEAR'S DATA EXCEPT AS NOTED:
* BUILDING #11'S DATA ARE BASED ON LONG TERM AVERAGE CONDITIONS FOR NEWARK, NJ.
* BUILDING #10'S DATA ARE BASED ON LONG TERM AVERAGE CONDITIONS FOR LONDON, UK.
SOURCE OF UK DATA: ENGINEERING WEATHER DATA, DEPARTMENT OF THE ARMY, JULY 1978.

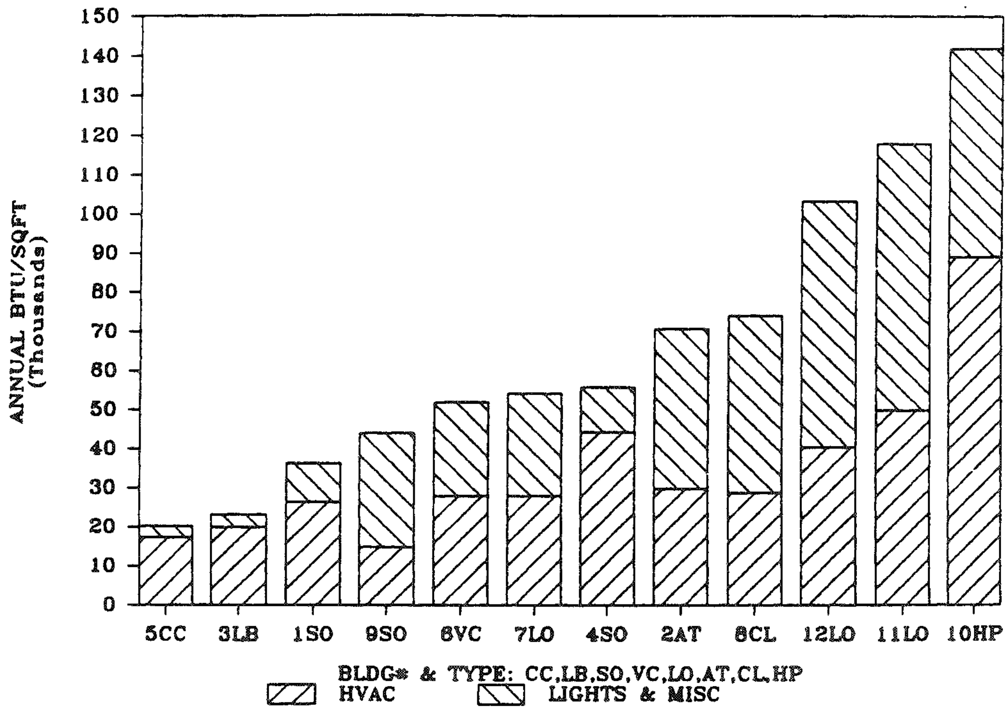

Figure 1. Annual site energy intensity for 12 BECA-CN buildings. Energy use is divided into 1) HVAC and 2) lights plus miscellaneous energy use. Six of the buildings are large (LO) and small (SO) offices (#1, 11, 9, 7, 4, and 12). Others include a church classroom (CC), a library (LB), a visitors' center (VC), an air terminal (AT), and a hospital (HP).

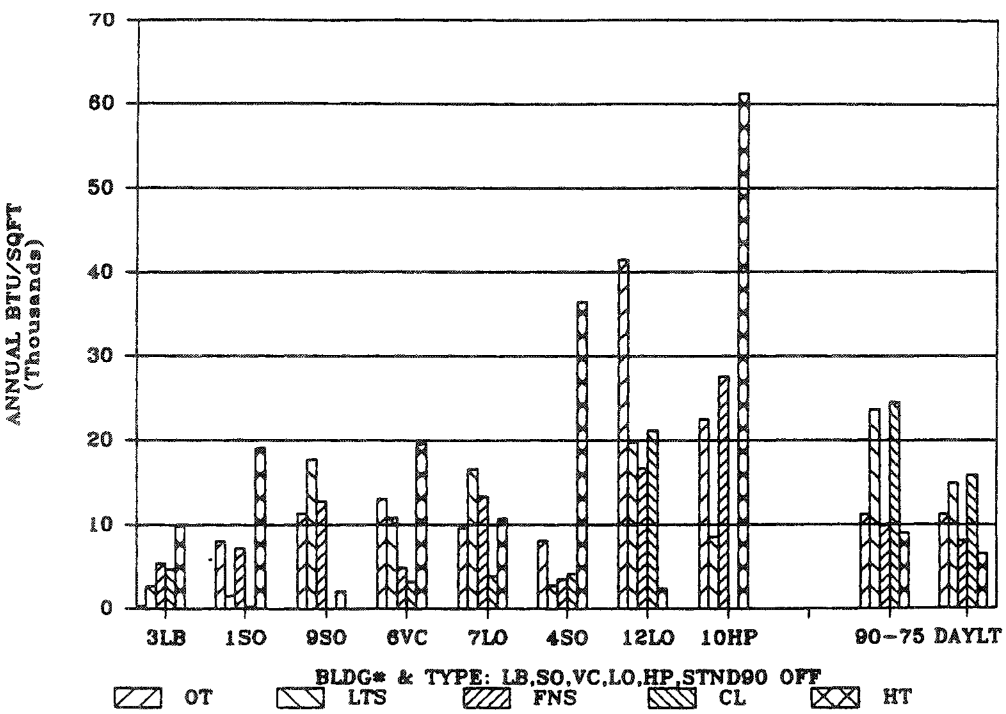

Figure 2. Annual site end-use consumption for 8 BECA-CN buildings compared to 2 ASHRAE Standard 90 configurations. Energy use divided into miscellaneous (OT), lighting (LTS), fans and pumps (FNS), cooling (CL), and heating (HT) are shown for a library (LB), 3 small offices (SO), a visitors center (VC), 2 large offices (LO), and a hospital (HP). Service hot water and and solar auxiliary are included in the "other" category for this plot. Two medium offices based on DOE-2.1 simulations represent ASHRAE Standard 90-75, and an energy-efficient redesign which includes daylighting (DAYLT).

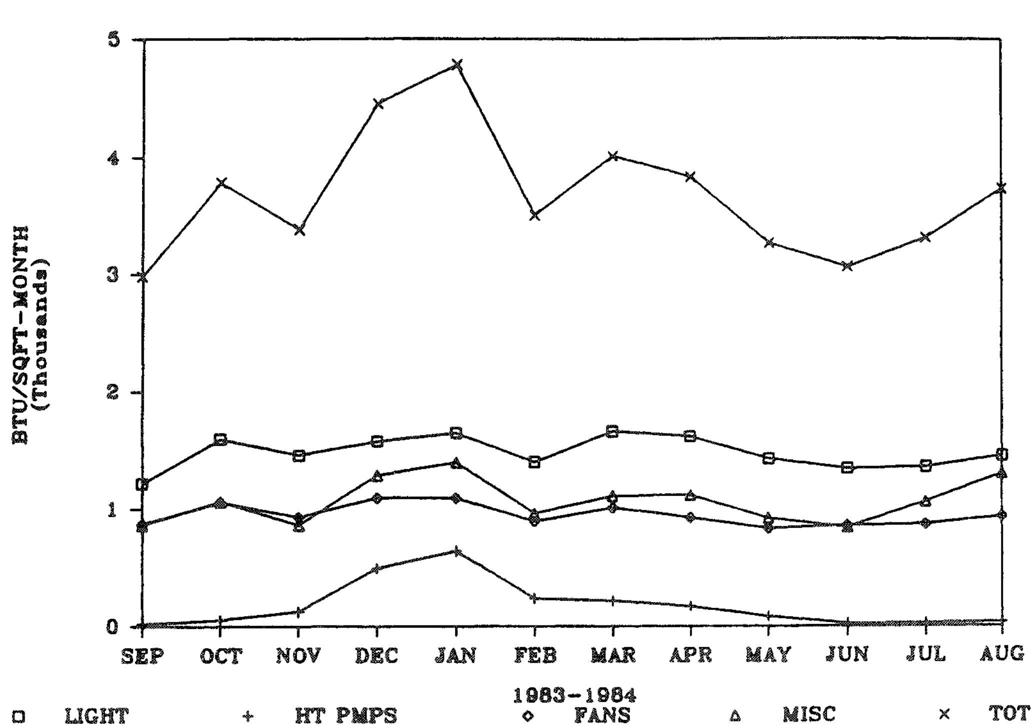

Figure 3. Monthly end-use consumption for a small office in Newport, Oregon - building #9. End uses consist of lighting, heat pumps, fans, and miscellaneous. Total is also plotted. Exterior and outdoor parking-lot lighting is included in the lighting category.

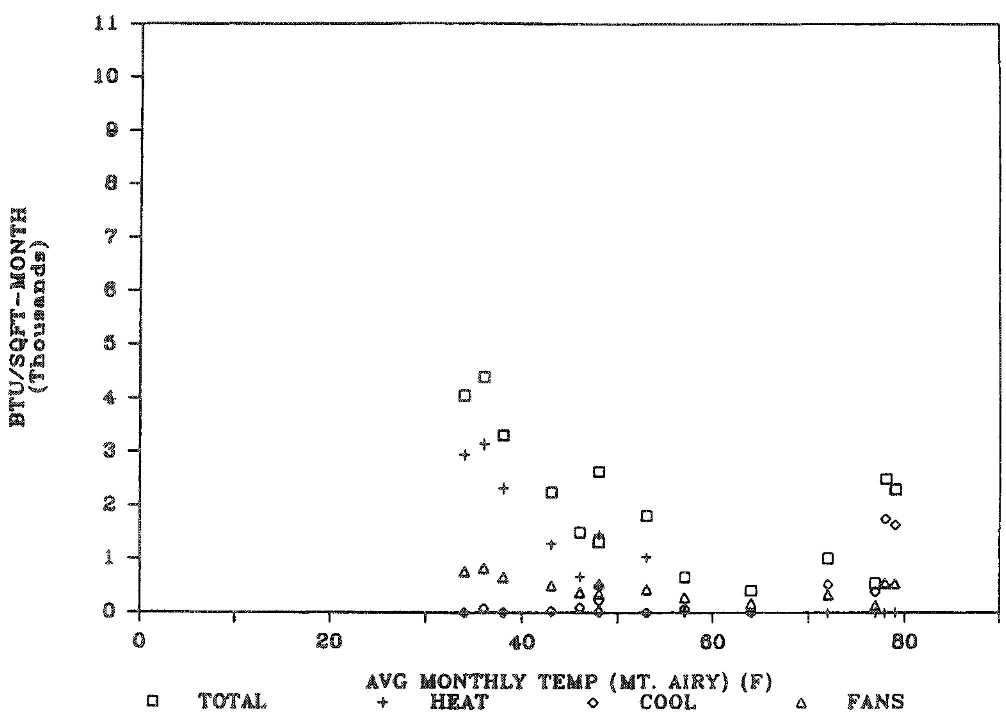

Figure 4. Monthly energy use versus average outdoor temperature for a library in Mt. Airy, North Carolina - building #3. Total, heating, cooling and fan energy use are plotted for November 1982 through December 1983. Energy use appears to be well correlated with average temperature.

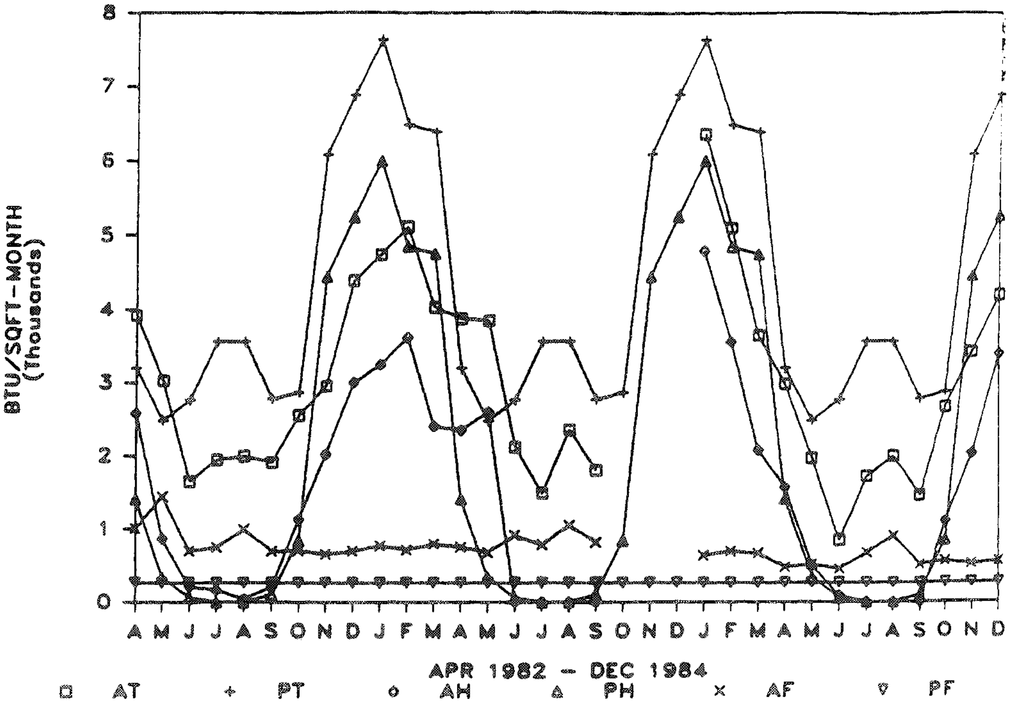

Figure 5. Predicted versus actual end-use consumption for a small office in Salt Lake City, Utah - building #1. Monthly data consisting of actual and predicted total (AT and PT), heating (AH and PH), and fans and pumps (AF and PF) are plotted. The building consumed 37.6 kBtu/ft^2-year, below the predicted 54.7 kBtu/ft^2-year. The building "as built" differed in many ways from the simulated building.

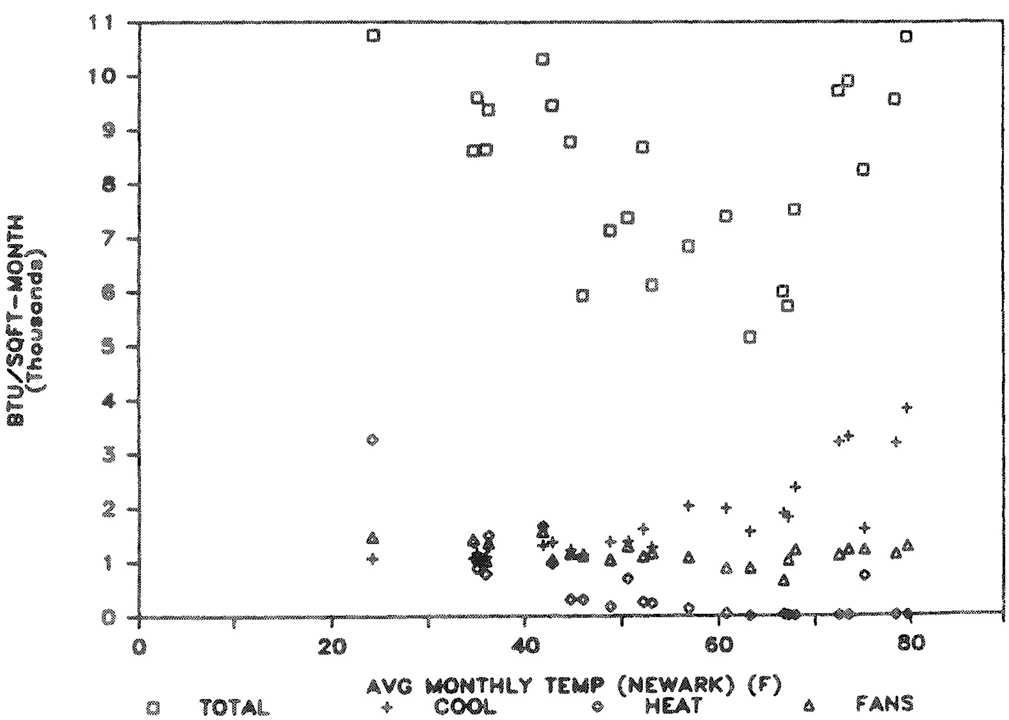

Figure 6. Monthly energy use versus average outdoor temperature for a large office in Newark, New Jersey - building #12. Total, cooling, heating, and fan energy use is plotted for the period of August 1981 to July 1983. Cooling and heating categories include energy used to pump chilled and hot water. A large 24 hour/day computer center causes the high base load.