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Evaluating the Measured Results of Demand-Control Strategies in New and Retrofitted Commercial Buildings

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ABSTRACT

There has been little evidence that demand-control techniques have succeeded in reducing power demand, or that their implementation has been cost-effective. To fill this gap, the measured results of demand-control in new and retrofitted commercial buildings are being compiled. Various demand-control strategies and their impact on power and energy consumption, and a methodology for analyzing the measured performance of these demand-control strategies are described. Four performance indicators are developed and applied to 17 buildings that have implemented demand control. The limitations to using whole building data to evaluate peak power performance in the commercial sector are discussed.

INTRODUCTION

Demand-control strategies in commercial buildings have become more common as utility demand and time-of-use charges have increased. There appears to be great potential for reducing peak power in the commercial sector through various peak-shaving and load-spreading measures. Widespread implementation of successful demand-control strategies can reduce the need for new electric power plants.

There are few data available, however, on the actual performance of these strategies. Most studies evaluating the power-reduction potential of demand control have been based on predictions of performance, using engineering calculations or computer simulations. Measured performance data have typically come from single building analyses, where results are not readily generalizable to other commercial buildings. Our goal is to compare measured performance results across many buildings. These comparisons are designed to assist building owners, operators and designers with making decisions regarding power control techniques, and to assist utilities with evaluating the impact of demand-control strategies on utility system loads.

The Buildings Energy Data Group at the Lawrence Berkeley Laboratory is currently developing a data base of the measured performance of demand control in commercial buildings. This new compilation is an extension of the two existing "BECA"* data bases of measured performance of energy conservation strategies in commercial buildings, BECA-CR for retrofitted buildings and BECA-CN for new buildings designed to be energy efficient (Gardiner et al. 1984; Wall et al. 1984). To date, analyses of these two data bases have emphasized energy performance; analysis of power performance has been limited.

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* The Buildings Energy Use Compilation and Analysis (BECA) project is an ongoing effort at the Lawrence Berkeley Laboratory. It includes compilations on the energy performance and cost-effectiveness of low-energy new homes (BECA-A), existing "retrofitted" homes (BECA-B), energy-efficient new commercial buildings (BECA-CN), existing "retrofitted" commercial buildings (BECA-CR), appliances and equipment (BECA-D), and the validation of models (BECA-V).

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This paper describes a methodology for analyzing the measured performance of commercial buildings that use demand control. To a large extent, the rate structure applicable to a particular building will determine that building's approach to reducing its peak demand. At the same time, there is a wide variation in commercial building rate structures across utilities, because rates are determined by a utility's mix of resources and types of customers served. In this paper, however, we emphasize the technical performance of commercial buildings, and only implicitly consider the impact of rate structure. First, we describe various demand-control strategies and their expected impact on power and energy consumption. Second, we illustrate useful performance indicators for evaluating building peak power performance, using the measured results from 17 buildings that have implemented demand control as examples. Finally, we describe the limitations of using whole-building data to make performance comparisons across commercial buildings.

DEMAND-CONTROL STRATEGIES TO BE INCLUDED IN THE DATA BASE

We define a "demand-control strategy" as any control system, piece of hardware, or operational change whose primary purpose is reduction of a building's peak demand. Most of these strategies will also reduce energy consumption during the period when the peak demand would have occurred. This definition excludes strategies aimed at energy conservation, even though energy conservation strategies may result in peak demand reductions that are equal to or greater than peak demand reductions due to demand control. Energy conservation strategies do not target the peak demand. For example, installing energy-efficient fluorescent lamps will reduce peak demand if the lights are operated when the building peak occurs, but the strategy is not specifically aimed at reducing the peak demand. Similarly, we have also not considered envelope improvements to reduce building loads, such as tinted glass or improved insulation, to be demand-control strategies, although these may also reduce building peak demand.

We have divided demand-control strategies into four categories: (1) demand limiting, (2) off-peak storage, (3) daylighting, and (4) on-site electricity generation. Each of these strategies is described below.

Demand-Limiting Controls

Demand-limiting or load-shedding controls turn equipment off when the building demand reaches a pre-set level, in anticipation of the peak demand reaching an even higher point. Both peak demand and energy consumption are reduced while the demand-limit control is in effect, that is, while the affected equipment is turned off.

Off-Peak Storage

Off-peak storage methods shift space-conditioning loads from peak to off-peak periods. On-peak demand is reduced as energy consumption is shifted to off- or mid-peak periods. Total energy consumption may increase or decrease. Off-peak ice and chilled water storage for space cooling are the most common of these strategies. Cold storage in thermal mass using night ventilation, or heat storage in buildings with winter peak demands caused by heating loads have also been used. Demand control using heat storage, however, is only applicable to electrically heated buildings.

Daylighting

Many new buildings take advantage of natural light to reduce artificial lighting energy and power requirements. Often, cooling requirements are reduced as well (Usibelli et al. 1985). Dimmer or on/off controls reduce artificial lighting when daylight is available. Unlike more common methods to reduce lighting energy and power consumption, daylighting strategies target the peak demand, since maximum daylight generally coincides with a building's peak demand.

Standby Generators, Gas-Fired Equipment, Cogeneration

Replacement of utility generated electric power with another source, either on-site generation or alternate fuels, may reduce peak demand and electricity consumption during on-peak periods. Gas-fired absorption chillers, for example, can replace electric chillers, reducing cooling peak demand. The savings due to peak demand and energy consumption reductions must be traded off against the capital and operating costs of the alternative generation.

DATA COLLECTION

To evaluate the success of these strategies, we are presently compiling performance data for commercial buildings that have implemented demand control. Sources of building data presented in this paper include the existing BECA-CN and -CR data bases, as well as some additional buildings identified from journal and report articles, and industry contacts. The list below summarizes the basic set of information sought for each building.

1. Building characteristics - location, type (retail, office, etc.), floor area, operating hours, HVAC and lighting system type and controls, envelope characteristics.

2. Power and energy saving features - retrofit descriptions, demand-control strategies implemented, problems associated with features, if any.

3. Special conditions - process loads (e.g. computer loads), special humidity or temperature requirements, changes in building operations over time.

4. Energy and power consumption - annual and monthly peak demand, energy consumption, submetered data (if available), and consumption for on-, mid-, and off-peak periods (where applicable).

5. Economics - utility energy and demand charges, retrofit costs, incremental costs or savings of features on new construction, details of applicable rate schedule, costs or savings due to operations and maintenance requirements, utility incentives.

PERFORMANCE INDICATORS

We have gathered data for 17 buildings that have implemented demand-control strategies. Table 1 presents the performance results, type of demand-control strategy, gross floor area and location for each building. At this point in the development of the data base there are not enough buildings in our sample to make statistically valid conclusions about the overall or comparative performance of these buildings, or of their demand-control strategies. Instead, we use the data to illustrate the use of performance indicators that best describe the impacts of a demand-control strategy.

Eleven of the buildings in Table 1 are taken from the existing BECA-CR and -CN data bases. Sixteen of the seventeen buildings are office buildings; the other is a church. Seven of the offices are retrofit projects and nine are new buildings. Each office retrofit project and five of the new offices use demand limiting to reduce peak demand. Four of the new offices use chilled water storage, two use off-peak ice storage. One of the new offices with off-peak chilled water storage also utilizes daylighting; another uses both off-peak chilled water storage and demand-limiting. The last building in Table 1, the church, uses off-peak ice storage.

We have identified four indicators of the effectiveness of demand-control strategies. They are: (1) the annual peak demand, (2) average monthly peak demand, and (3) annual site energy consumption, each normalized to gross floor area, and (4) the load factor. We discuss each of these parameters and provide examples of their use below.

Annual Peak Demand. Annual peak demand is a crucial parameter from a utility or societal perspective. The annual peak determines the maximum power a utility must supply to a building.* For buildings that use a fuel other than electricity for heating, the annual peak will

* In general, the utility system peak demand and an individual building peak demand will not be coincident due to the contribution of demand from other sectors (industrial and residential).

occur during the cooling season (generally April through September). If the building is electrically heated, the annual peak demand may occur during the heating season (roughly October through March) or the cooling season. Building operators are most concerned with annual peak demand if they are billed on a ratchet rate schedule, where future monthly demand charges are dependent on the highest peak demand for the year. Annual peak demand may be the only peak data available for some buildings.

Average Monthly Peak Demand. The building operator is often most concerned with average monthly peak demand (the average of the 12 maximum monthly demands over a year), unless the rate schedule has a ratchet clause. Many utility demand charges are based on monthly peaks, rather than the single, annual peak. In some instances, as greater peak reductions are possible in months other than the peak month; this will show up a reduction in average monthly peak power. Annual peak demand will show a much smaller reduction. We have not calculated average monthly demands for all of the buildings, since monthly data were not consistently available.

Figure 1 shows the change in annual peak demand and average monthly peak demand for the seven office building retrofits. This figure shows the importance of examining both average monthly and annual peak data. Building R5, for example, is a 40,000 ft^2 (3,700 m^2) office building in Santa Rosa, California (Sylvester Associates 1981). This building is all-electric and has 24 heat-pump package units for heating and cooling. An energy management system was installed to duty cycle the electric-resistance heaters on the heat pumps during morning warm-up periods. For the year following the retrofit, the annual peak demand was 5.3 W/ft^2 (57 W/m^2), compared to an annual peak demand of 4.5 W/ft^2 (48 W/m^2) in an adjacent building identical to building R5, except that no demand or energy saving measures were implemented. The building's energy management system failed during November and that month registered the annual peak demand. Average monthly demand, however, was about the same as that in the adjacent building, so that the annual demand charge in both buildings was similar, in spite of the difference in annual peak demands.

In contrast to Building R5, Building R4 reduced its annual peak demand by 11% but reduced its average monthly demand by only 6%. Building R4 is a large state office building in West Virginia, and uses electricity for cooling and natural gas for heating (State of West Virginia 1980). This building installed an energy management system to load shed and duty cycle heating and cooling equipment. In this case, the demand-control strategy was able to reduce higher monthly peak demands by a greater percentage than lower monthly peak demands. There are two explanations for this result. First, the demand limiting will affect higher, cooling season monthly peak demands more than lower, heating season monthly peak demands, since heating is not supplied by electricity. Second, data processing equipment was added after the retrofit, adding to the peak demand in every month. The monetary savings in annual demand charges will depend on whether there is a ratchet clause in the building's rate structure.

In Figure 2, we have plotted summer (cooling season) peak demand, winter (heating season) peak demand, and average monthly demand for each of the new office buildings in Table 1. This figure shows a wide range in annual peak and average monthly peak across the nine new buildings. The range is explained by both building-specific characteristics and the effect of the demand-control strategy in each building. Building N2, for example, has an average monthly peak only slightly less than either its winter or its summer peak. Building N2 is a 1.4 million square foot (130,000 m^2) all-electric office building in Quebec, Canada (CRS Inc. 1983). The building uses a centralized control system that limits demand by cycling perimeter heat pumps and fans. In this building, monthly peak demands are almost equal over the year. There are two reasons for this pattern of monthly peak demands. First, a constant monthly demand may mean that the demand-limiting strategy was successful; large variations across months have been eliminated. Second, Building N2 is all-electric, resulting in both a winter heating peak and a summer cooling peak. This evens out the hills and valleys in the monthly demand profile.

In fact, four of the five all-electric buildings in Figure 2 have average monthly peaks that are only slightly lower than their annual peaks. The mixed-fuel buildings, on the other hand, show a much greater spread between annual and average monthly peak demand. Not surprisingly, the two winter-peaking buildings are all-electric.

Annual Site Energy Intensity, and Building Load Factor. Building power performance cannot be thoroughly evaluated without also considering building energy consumption. Changes in annual site energy intensity indicate whether a building reduced energy consumption as well as peak power. Further, a low peak demand may simply be the result of an energy-conservation effort as opposed to demand-control effort, even though the energy-conservation measure did not target the peak demand.

Given two buildings with the same energy intensity, the building with the lower peak demand has done a better job of "demand control." The relationship between energy intensity and power intensity can be quantified as the electric load factor. Table 1 presents this load factor for each of the 17 buildings. Electric load factor is the ratio of average demand to annual peak demand, where average demand equals annual electricity consumption divided by 8,760 hours per year. The load factor is always a ratio between zero and one. A higher load factor indicates that large peaks in daily demands have been eliminated, and that there is less variation in individual monthly peak demands. At the same time, however, buildings with long operating hours or high process loads (such as computer equipment) will have higher load factors than those without.

Peak-power level alone is not enough to judge building power performance. In fact, the combination of a low power intensity and a high load factor may be the best indicator that a building has successfully controlled power levels. The electric load factor, however, does not account for energy consumption due to other fuels that may be used in a building. It follows that mixed-fuel buildings will have lower electric load factors than all-electric buildings. In order to eliminate this bias, we have plotted annual peak electric demand against annual site energy intensity (electricity and fuel) in Figure 3. On this plot, mixed-fuel buildings shift to the right from where they would fall on a plot of peak demand against electricity consumption. Plotting electric demand against site energy assumes that mixed-fuel buildings would not become winter-peaking if they were all electric. Based on the monthly profiles for the buildings included in Figure 3, this assumption appears to be valid.

The diagonal lines in Figure 3 represent lines of constant load factors of 0.2, 0.4, and 0.6. Two buildings falling on the same line have the same load factor. This plot shows that buildings with the same peak power intensity may have significantly different load factors, and vice versa. Buildings N4 and N8, for example, have similar annual peak demands (5.3 W/ft^2 (57 W/m^2) for Building N4 and 5.5 W/ft^2 (59 W/m^2) for Building N8) but have different load factors. Based on site energy intensity, the load factors are 0.63 for Building N4 and 0.34 for Building N8. Both buildings are all-electric office buildings with off-peak cold storage for demand control. In this case, the difference in load factor is explained in part by the fact that Building N4 has a large computer center and a portion of the building operates 24 hours a day, while Building N8 operates only eight hours a day, five days per week.

On-, Mid-, and Off-Peak Indicators

In some instances, the indicators above are not sufficient to characterize the power performance of a building that has implemented a successful demand-control strategy. For buildings on time-of-use (TOU) rates, it is important to distinguish between on-, mid-, and off-peak demands and energy consumption. Although a building may have its peak during an off- or mid-peak period, this demand is often free or inexpensive, and is not coincident with the utility system peak. Therefore, on-peak demand should be used to evaluate building power performance. Energy consumption in on-, mid-, and off-peak periods shows the extent to which energy consumption has been shifted out of the on-peak period.

Table 2 illustrates the importance of on-, mid-, and off-peak indicators, with performance results from two office buildings: one with and one without demand control. Building N6 is a one million square foot (93,000 m^2) office building in southern California, and uses off-peak chilled water storage to control peak demand. Since Building N6 is a new building and not a retrofit, there is no "pre" period to show how performance would have differed if the building had not used off-peak storage. The comparison building, also in southern California, is 426,000 ft^2 (40,000 m^2), and uses a conventional chilled water system for cooling. Both buildings are served by the same utility and are on the same time-of-use rate schedule. Several building-specific characteristics besides the type of cooling system affect differences in the performance of the two buildings. Building N6, for example, operates more hours per day than the comparison building. In spite of these differences, comparing the performance indicators discussed above for the two buildings illustrates the importance of considering on-, mid-, and off-peak performance data. Annual peak, average monthly peak, and energy intensity show little to distinguish the performance of these two buildings (see Table 2); they do not distinguish between on-, mid-, and off-peak periods.

Comparing the performance of Building N6 to the performance of the comparison building shows that average monthly on-peak demand in Building N6 is 20% less than in the comparison building. Figure 4 shows monthly on-, mid-, and off-peak demands for both buildings; Figure 5 shows their monthly energy consumption in each time period. Building N6 consistently peaks in off- or mid-peak periods; in other words it has succeeded in shifting energy consumption to off- and mid-peak periods. In addition, Building N6 consumes 51% of its electricity in the off-peak period, compared to 36% for the comparison building, showing that energy as well as demand has been shifted from of the on-peak period.

COMPARISONS ACROSS BUILDINGS

Baseline Comparisons

Once performance indicators have been established, they can be used to make comparisons across buildings that use demand control, and with those buildings that have not tried to reduce peak power levels. The question that needs to be answered is, do buildings practicing demand control do better than average in terms of peak power and energy consumption? To address this question, one must know what peak power intensities are representative of the commercial building stock. For retrofitted buildings, this is less of a problem, since pre- and post-retrofit period performance can substitute for a stock baseline.

We know of no data collection based on measured performance able to answer this question. For example, the Nonresidential Building Energy Consumption Survey (NBECS), sponsored by the Department of Energy, does not publish data on peak power (EIA 1982). As a preliminary reference point, Figure 2 includes the average annual peak-power intensity for all the offices with power data in BECA-CN (4.4 W/ft^2, 47 W/m^2). (The average for all-electric offices is only slightly higher, at 4.7 W/ft^2 (51 W/m^2).) The BECA-CN data base is not, however, intended to be representative of the commercial building stock. We have also included the range of peak power intensities from simulations performed for a medium (49,500 ft^2, 4,600 m^2) and a large (600,000 ft^2, 56,000 m^2) office building to test the ASHRAE-90 new commercial building standard (Battelle 1983).

Limitations to Comparisons of Whole-Building Performance Data

The performance indicators discussed above evaluate whole-building power and energy performance based on monthly utility bills. Utility billing data are useful because they capture the interactions between end-uses that determine the aggregate energy and power consumption of all building systems. Differences in building-specific characteristics, however, make valid comparisons across buildings difficult. Some of the more important characteristics are:

1. Climate, both among climate zones and within a zone for different years,

2. HVAC system types, envelope characteristics, building types and sizes, internal loads, operating hours, and mixed fuel types, and

3. The interactive effects of energy-saving features implemented along with the demand-control strategy that make the impact of demand control alone difficult to determine.

We have three approaches for incorporating these effects into our analyses: (1) analysis of simulation results, (2) correction with additional individual building data, and (3) submetering.

Simulations. Isolating the main causes of variations in building peak-power across climate zones and building configurations can be initiated with parametric studies using building simulations. This level of analysis highlights parameters to be considered for comparisons across buildings. We have used some results from DOE-2 simulations of buildings designed to meet different versions of the ASHRAE-90 standard (Battelle 1983). These simulations were done for several building types, with several different envelope, system, and lighting characteristics, and across a wide range of climate zones. Preliminary results indicate that variations in climate and HVAC system type may not have as large an effect on peak power as do differences in envelope characteristics and lighting loads.

Correction of Performance With Building Data. In some cases, additional data we collect can be used to correct for variations in power and energy performance due to building-specific parameters. The simplest example of this is normalizing energy and power data to gross floor area. Ultimately, we hope to normalize the data for other characteristics, most importantly, connected lighting loads, process loads (particularly computer loads), and occupant densities. We are currently unable to make these corrections due to the lack of data.

Submetering. Submetered data for loads that are being demand-controlled is the most straightforward way of assessing the success of a demand-control strategy. As with simulations, extensive submetering of many buildings could also be used to illustrate variations in performance across climate and building type. In general, submetered data for commercial buildings are not currently available. A large-scale end-use monitoring project is now underway in the Pacific Northwest; we hope to incorporate results from this project into future analyses.

CONCLUSIONS AND IMPLICATIONS FOR FUTURE WORK

The goal of this compilation of measured performance is to evaluate the power and energy performance and cost effectiveness of demand-control strategies in commercial buildings. In this paper, we illustrated the use of performance indicators important to our analysis, using actual performance data for 17 buildings with demand control.

The four performance indicators are: annual peak power intensity, average monthly peak power intensity, annual site energy intensity, and load factor. Annual peak power is the highest power level reached during the year in a building, and determines the annual power bill if the building is on a ratchet rate schedule. Average monthly peak power incorporates the monthly variation in peak demands, and determines the annual power bill if the building is not on a ratchet rate schedule. Annual site energy intensity and load factor indicate the relationship between peak power levels and energy consumption, and a high load factor in combination with a low peak demand may be the best indicator of a successful demand-control strategy. All four indicators must contribute to an evaluation of the success of a demand-control strategy in any one building or across many buildings. For buildings on time-of-use rate structures, performance during on-, mid-, and off-peak periods is the best measure of the effectiveness of the demand-control strategy.

Future analyses on this data compilation will emphasize comparisons of the performance of demand control across many commercial buildings. While whole-building utility data can be used to isolate some of the impacts of demand control, there is a limit to what can be concluded from these data. Additional information about building controls and equipment is needed to help explain building performance. We are using results from building simulations to isolate the building-specific characteristics most significant in determining a building's peak power level. Ideally, demand-controlled equipment or building end-uses would be submetered.

Beyond documenting the actual performance of demand-control strategies, there is a need for a thorough economic analysis. Analysis of project cost-effectiveness will also be emphasized in future work.

Since the data compilation is a continuing effort, we welcome from the reader any comments, suggestions, or leads to additional data sources.

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TABLE 1
Data Summary of 17 Buildings with Demand Control

No.	Building Description: Floor Area (x 1000) ft^2	(m^2)	State	Demand Control Strategy	Type	Performance Results: Annual Peak W/ft^2	(W/m^2)	Avg Monthly Peak W/ft^2	(W/m^2)	Annual Site Energy $kBtu/ft^2$	(MJ/m^2)	Electric Load Factor	Comments
R1	48	4	NY	DL	PRE	7.1	77			133	1510	0.32	
					POST	6.0	65			89	1012	0.28	
R2	119	11	MD	DL	PRE	4.9	52			93	1057	0.64	All electric.
					POST	4.0	43			73	835	0.62	
R3	251	23	GA	DL	PRE	7.9	85			107	1213	0.45	All electric.
					POST	5.7	62			67	760	0.39	
R4	770	72	WV	DL	PRE	3.8	41	3.1	33	126	1426	0.38	Process loads increased after retrofit.
					POST	3.4	37	2.9	31	95	1079	0.38	
R5	40	4	CA	DL	PRE*	4.5	48	4.0	43	42	476	0.31	Controls failed during one month. All electric, winter peak.
					POST	5.3	57	4.0	43	28	315	0.17	
R6	177	16	AZ	DL	PRE	8.3	89	6.7	72	128	1451	0.49	
					POST	5.4	58	4.5	48	83	944	0.48	
R7	82	8	CA	DL	PRE	6.8	73	5.9	64	78	884	0.38	All electric.
					POST	5.4	58	5.1	55	60	685	0.38	
N1	1,948	181	DC	DL	NEW	3.9	42	3.2	34	79	895	0.37	
N2	1,394	130	Quebec	DL	NEW	3.5	38	3.4	37	52	593	0.50	All electric.
N3	760	71	GA	DL,CHW	NEW	4.4	47	3.9	42	61	694	0.46	All electric, winter peak.
N4	410	38	CA	CHW	NEW	5.3	57	4.9	42	101	1142	0.63	All electric.
N5	135	13	CA	CHW	NEW	7.0	75	6.2	67	127	1438	0.53	May have unusually high process loads.
N6	1,000	93	CA	CHW,DY	NEW	4.6	50	3.2	34	65	732	0.46	Peak figures are for on-peak demands. Off and mid-peak demands are higher.
N7	110	10	CA	ICE	NEW	4.6	50	3.9	42	76	868	0.39	Ice thickness sensors failed.
N8	68	6	IL	ICE	NEW	5.5	59	4.4	47	56	629	0.34	All electric.
N9	1,000	93	NJ	DL	NEW	9.6	103	7.5	81	143	1624	0.50	All electric, winter peak. Large computer center.
CH	18	2	MD	ICE	PRE	6.4	69	4.1	44			0.21	Church. Heating fuel consumption not available.
					POST	3.9	42	2.9	31			0.31	

Demand control strategy codes:
DL - demand limiting, duty cycling, load shedding
CHW - off-peak chilled water storage
ICE - off-peak ice storage
DY - daylighting with on/off or dimmer controls on lighting

PRE: performace before retrofit
POST: performance after retrofit

Blank spaces in table indicate no data available.

* - Pre figures are based on consumption of adjacent building, identical except that no demand or energy saving measures were implemented.

TABLE 2
Performance Characteristics of Building N6
and Comparison Building
(Same Location and Rate Schedule)

	Units	Building N6	Comparison Building
Annual building peak	W/ft^2 W/m^2	4.7 (51)	5.0 (54)
Average monthly building peak	W/ft^2 W/m^2	4.3 (46)	4.2 (45)
Annual site energy intensity	$kBtu/ft^2$-yr MJ/m^2-yr	64.5 (732)	52.9 (600)
Load Factor		0.46	0.35
Annual on-peak demand	W/ft^2 W/m^2	4.6 (50)	4.8 (52)
Average monthly on-peak demand	W/ft^2 W/m^2	3.2 (34)	3.9 (42)
Annual on-peak electricity	kWh/ft^2-yr kWh/m^2-yr % of total	3.3 (36) 17%	3.8 (41) 24%
Annual mid-peak electricity	kWh/ft^2-yr kWh/m^2-yr % of total	6.0 (65) 32%	6.2 (67) 38%
Annual off-peak electricity	kWh/ft^2-yr kWh/m^2-yr % of total	9.7 (104) 51%	6.0 (65) 38%

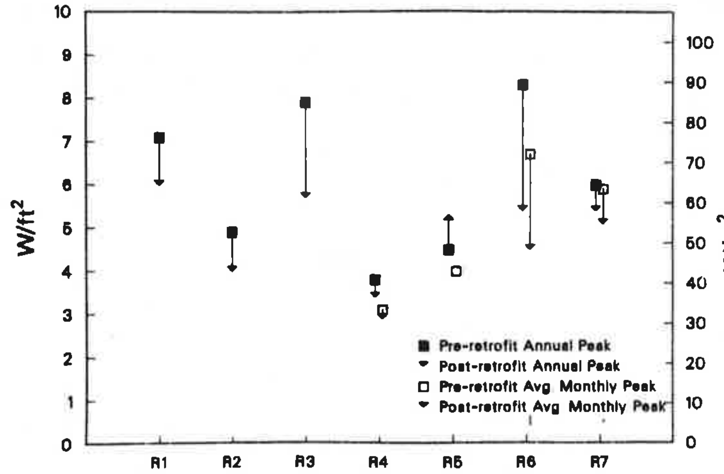

Figure 1. Annual peak and average monthly peak power intensity for seven buildings that have installed a demand-control strategy as a retrofit. In one case (R5), average monthly peak demand stayed constant, while annual peak demand increased due to a control failure in one month

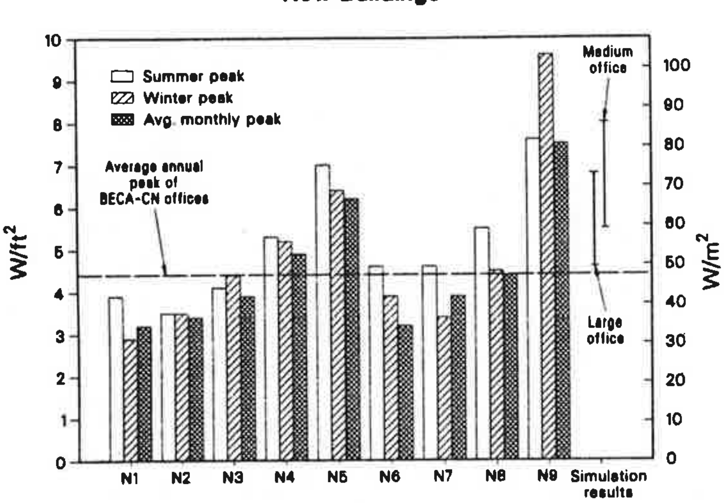

Figure 2. Summer, winter, and average monthly peak power intensity for nine new buildings that use demand-control strategies. For comparison, the dashed line represents the average annual peak power for 50 office buildings in the BECA-CN data base. Also presented are the annual peak results from a series of simulations performed to test the ASHRAE 90 standards (using DOE 2.1B) for a large and a medium office building. (The buildings modeled do not use any demand-control strategy). Both winter-peaking buildings (N3, N9) are all-electric. The building with the highest peak (N9) has a large computer center

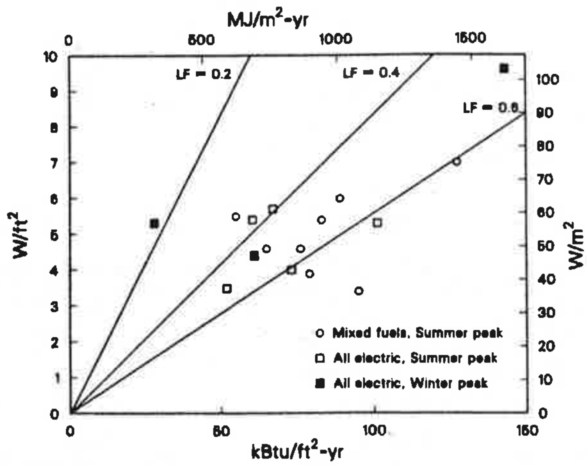

Figure 3. Annual peak power intensity versus annual energy intensity for 16 buildings that use demand-control strategies. The solid lines represent lines of constant load factor (LF), that is, the same ratio between annual peak demand and energy consumption. Buildings that fall on the same line have the same load factor. Annual energy consumption includes both electricity and fuel consumption for mixed-fuel buildings. A building with a higher load factor and a lower annual peak power intensity has come closer to achieving its full potential for demand control

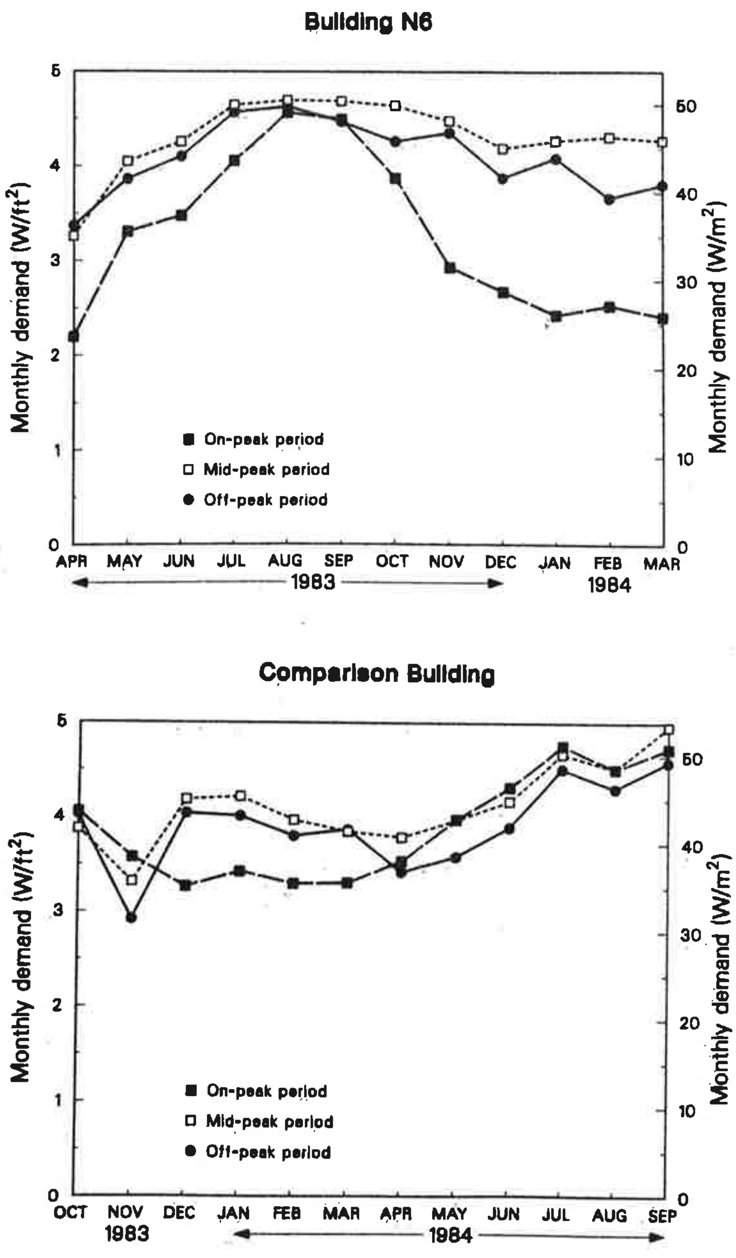

Figure 4. On-, mid-, and off-peak power intensity for building N6 (off-peak cooling) and a comparison building (conventional cooling). Building N6 has succeeded in keeping on-peak demand significantly below mid- and off-peak demand in most months, while the comparison building shows little variation in on-, mid-, and off-peak demand

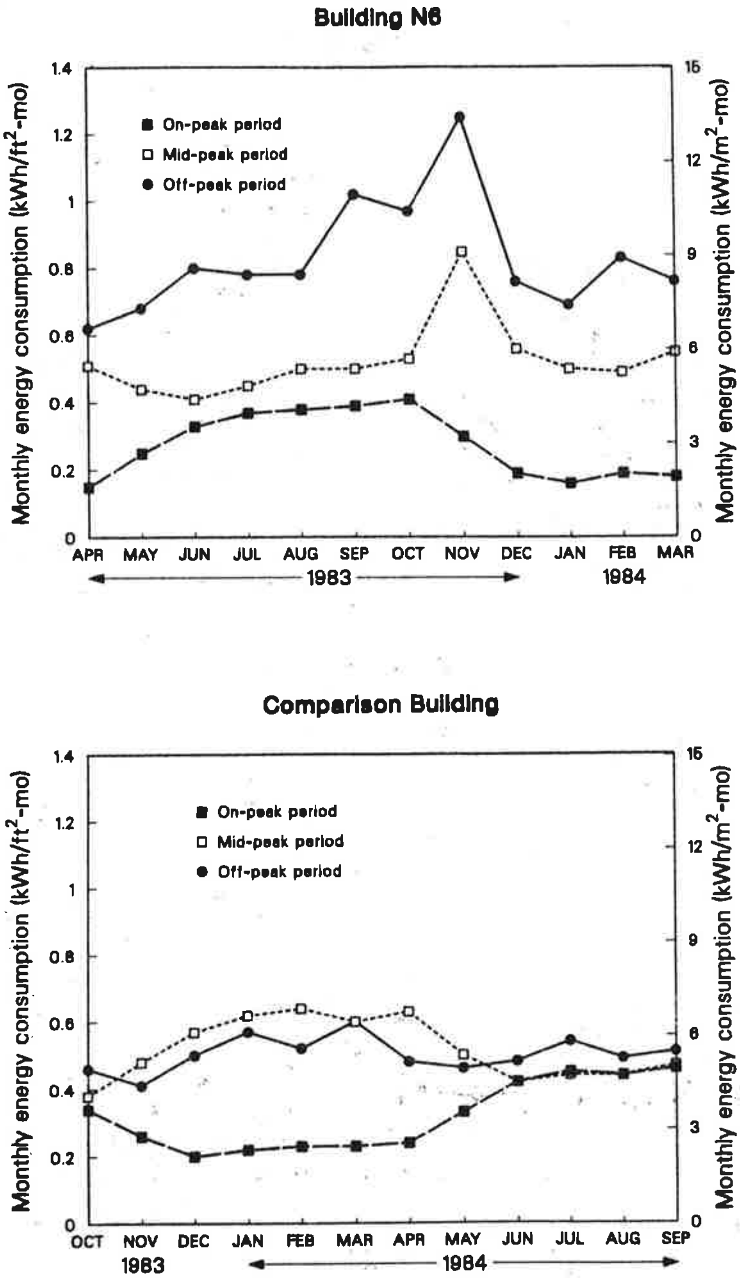

Figure 5. On-, mid-, and off-peak electricity intensity for building N6 (off-peak cooling) and a comparison building (conventional cooling). Building N6 consumes a much larger percentage (51% vs 38%) of its electricity during the off-peak period, when electricity charges are lowest

Discussion

D.L. GEISTERT, Southern California Edison Co., Rosemead, CA: What assurances do you have of the building examined that it was the demand control (i.e., demand shedding, duty cycling) and not a change in occupancy, operations, equipment that caused demand reduction?

MEAL: For each building, we gather as much information as possible about other factors that may affect building performance, including the factors you mentioned. We then identify those factors that will change the results for the performance indicators we have developed. If the impact of any of these factors cannot be isolated from the effect of the demand control strategy itself, we would not include that particular building in our study.