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Analysis of energy use in building services of the industrial sector in California: two case studies

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Abstract

In this paper, we address the energy use in the building services of the industrial sector by closely examining and analyzing energy use in two industrial facilities in California. Based on the information obtained for the selected case studies, we discuss the design consideration for these industrial buildings, characterize their energy use, and review their conservation and peak-demand reduction potentials. The study concludes that the lighting and the HVAC energy-use characteristics of high-tech industries (as represented by our case-study buildings) and their conservation potentials are very much comparable to those of office buildings. Simulating the impact of conservation measures commonly recommended for office buildings, we estimate that more than 50% of electricity and gas use for the building services in the two case-study facilities can be cost-effectively saved.

Introduction

California has a large number of small- and medium-sized industrial plants. These industries have a major impact on the growth rate of the electric utilities*. Energy use for building services (lighting, HVAC, office equipment, computers, etc.) constitutes an important fraction of the total site energy use. This fraction is determined by the industrial activity, the size, and the climatological location of the facility. Also, energy use in building services is more responsive to weather and occupant schedules than the traditional *base-load* industrial process energy.

Presently, the energy use for building services in the industrial sector is not often distinguished from process load by utility companies. Data on non-process energy use are not readily available in the literature. Process energy use is considered a *base load* by utility companies because it tends to increase the utilities' load factor. To increase their load factor further, utilities sometimes market energy at lower rates to industrial facilities. In those cases where energy is used primarily for building services, which have daily (and seasonal) load profiles that tend to peak at the same time as the system, the utility may be selling peak power below cost.

The industrial sector consumes approximately one-third of the energy use in California. Compared to the building services (non-process) loads, energy consumption for industrial processes has been far better researched and documented [1–10]. Moreover, the availability of measured data on energy-use applications within industrial buildings is limited. Furthermore, the limited data that are available to estimate energy use for building services in industrial facilities are conflicting.

In an earlier report, we presented the results of a limited initial literature review on energy-use characteristics of the building services in the industrial sector in California [11]. Our data sources were limited to a computer literature survey, an initial review of the 1979 Non-Residential Building Energy Consumption Survey [12], reports from Energy Analysis and Diagnostic Centers [13], and reports prepared for utilities, DOE, and other state and federal governmental institutions. In addition to the general literature, there were few other sources of data specific to California.

The Pacific Gas and Electric Company (PG&E) has conducted industrial audits under its energy

*In Northern and Central California, Pacific Gas and Electric Company identified Food and Related Products (SIC 20) and Computing Equipment and Electronics (SIC 35, 36) having significant growth in the next 20 years. Together these industries represented about 40% of the region's industrial electricity sales in 1984 [15].

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conservation program. The audits included detailed information on the process and non-process electrical loads of these facilities. An initial review of a few of these audits provided us with some useful information on the non-process energy use of these facilities [11]. The California Energy Commission (CEC) has also funded a study to review the energy-use characteristics of California manufacturing industries [8]. Our analysis of these data reveals that further clarification and characterization of energy end use is necessary to determine conservation potentials of the building service category.

Akbari *et al.* [11] focused on five growing industries in northern and central California: Instruments within (SIC 38–39), Electronics within (SIC 367–368), Motor Vehicles within (SIC 3700–3730), Frozen Fruits within (SIC 2037-2038), and Meat Packing within (SIC 2000-2016). For the five selected industries, the contribution of the total electricity consumption for lighting ranged from 9.5% in Frozen Fruits to 29.1% in Instruments; the air-conditioning energy use ranged from non-existent in Frozen Fruits to 35% in Instruments. None of the five industries had significant electrical space heating. Gas space heating, as a fraction of total gas consumption, ranged from 5% in Motor Vehicles to more than 58% in Instruments.

Akbari *et al.* [11] also conclude that industrial buildings are not necessarily as distinct from other types of non-residential buildings as is commonly thought. For practical reasons, many light industrial buildings are often physically similar to retail or office structures (see the case studies). Where occupants are in an enclosed space, they need to be provided comfort conditioning and lighting levels comparable to commercial buildings. California industrial buildings almost always contain some office workers; and the same structure, over its lifetime, may shift between industrial and non-industrial uses. Compared to other non-residential buildings, industrial buildings may have higher thermal loads, air-change rates, longer operating hours, and greater pollution-control or other environmental-conditioning requirements.

In this paper, we analyze building energy use in two selected facilities as case studies. The selected facilities, to the extent possible, were chosen from those that already have been audited by the local utility company. The specific goals of this study were to determine: (a) how are industrial buildings and systems designed, (b) what are their energy-use characteristics, and (c) what are their conservation and peak-demand reduction potentials? Our methodology consisted of collecting historical data on buildings characteristics, on-site visits and interviews with building operators and managers, and follow-up analysis of collected data using the DOE-2 building energy simulation model.

In the following Sections, we discuss the methodology in further detail, provide a summary of case-study facilities, analyze building and equipment design methodology, analyze energy-use patterns and characteristics, and review potentials in conservation and load-shaping opportunities. We conclude the report by discussing future research needs in this area.

Methodology

For case-study development, we contacted several industrial building owners, utilities, and municipal offices in an effort to identify facilities that might be studied. Once a facility was identified, we

- interviewed the owners to ascertain the design procedure for building the facilities and installing the equipment;
- acquired the as-built drawings of the building and systems;
- obtained the owners' help in contacting the tenants who were occupying the building;
- contacted the tenants and convinced them to participate in the study;
- interviewed the tenants to find out about the details of their operations and their schedules;
- acquired their utility bills for one year;
- obtained information on how the facility and the associated HVAC equipment had to be modified or extended to suit their operation; and
- performed an on-site survey of the building and equipment in the facility.

In the analysis of conservation and demand reduction potentials, we relied on computer simulation, using the DOE-2 building energy analysis program.

Case-study descriptions

Both case-study facilities are housed in similar buildings that are typical of industrial-park buildings in California. These facilities are used both for office and industrial activities with significant process loads. The two cases represent both ends of this spectrum. Case Study 1 (Case I in all Tables) is a manufacturer of small instruments whose schedules and space-use characteristics are very similar to those of an office building. In this facility, most process equipment was used intermittently. The equipment that was used continuously (e.g., microscopes and electronic test equipment) had similar energy-use characteristics as office equipment (personal computers, etc.). On the other hand, Case Study 2 (Case II in all Tables), a printed circuit board manufacturer, used process equipment that was operated continuously. The facility occupied four buildings, two of which were used for manufacturing. The two buildings were similar in nature and operated independently of each other; therefore, only one of them was studied in detail.

The summary of the on-site survey information of these facilities is presented in Table 1. Envelope characteristics were obtained from as-built drawings and verified and updated by observations. Information on lighting characteristics was gathered by counting fixtures. Data on HVAC equipment were collected by reading the nameplate information on the equipment. Information on HVAC equipment control and schedules was obtained from the facilities' managers. During our visits to the facilities and through the interviews, we also obtained fairly accurate data on occupancy, lighting equipment, kitchen equipment, and operating schedules.

There were two sources of complication in quantifying internal heat gains to the conditioned space by the process equipment. First, the operational schedules related to the equipment were very complex. It was difficult to determine what percentage of the rated power was being consumed at a given time. Second, energy used by the equipment was often removed from the system by either exhaust fans or dedicated chilled water loops before it could affect the building's space-conditioning load. In such a situation, we relied on our own surface temperature measurements to estimate internal heat gains for each piece of equipment. Common examples of such equipment were ovens with exhaust fans and hot processes with a local chilled water loop.

Analysis

Design of building and equipment

Two different approaches were taken when the two buildings were being designed. The building in Case Study 1 was built speculatively. Equipment installation and most of the interior of the building had been finished before the building was leased. In Case Study 2, however, the building service equipment was designed with input from the tenant. Table 2 gives the details of the design process for each case, and the following discussion examines the design process in greater detail.

The Case Study 1 building was built as a non-specified (general) leasable building. It was partitioned, and the HVAC equipment was specified to cope with loads of an office-type environment. The developer targeted the building for use as an office or a small-scale manufacturing facility (producing instrumentation, automotive parts, small assemblies, electronics-related components, equipment services, etc.). These buildings can be used by a very wide range of users. Some of the other companies occupying the same industrial complex were involved in small-scale industrial activities such as computer mother-board manufacturing, gas pump servicing, electronic-navigation instrument servicing, machine shop manufacturing, electronic chip manufacturing, and printing. The design procedure followed by the owner company, who manages several such industrial parks, was to install standard HVAC equipment without accurate consideration of how the building would be used. The interior and lighting systems were built as the space was leased. If the HVAC equipment was not sufficient for a particular activity, tenants bought equipment to satisfy their own needs.

The Case Study 2 building was built in 1981 as a non-specified leasable building. The interiors, the lighting equipment, and the HVAC equipment were specified and built by tenants because their processes required special ventilation and HVAC designs. The experience of this company provided clues on how a building modified to suit such specialized equipment is transferred from one tenant to the next. This company occupied another building before moving into the existing complex. Another, smaller company working in the same field bought the HVAC and some of the specialized equipment in the old building. A company official described the reselling of the HVAC equipment as a very common practice in that field.

In both case studies, lighting systems were built after the buildings were leased. Hence, they matched the needs for the activities. Also, visits to the buildings indicated that the designers had taken advantage of some of the energy-efficient technologies in designing the lighting systems.

A review of these case studies suggests the following overall process for the design of industrial buildings and equipment. The developers of industrial parks decide, based on current market conditions, either to subdivide the building or to market it as a whole. If they subdivide, they typically have the HVAC system designed and installed. In such cases, they size the equipment for office-type use. On the other hand, if they decide to lease the building as a whole, they defer the design and installation of the interior lighting and the HVAC equipment until after the space is leased. At that point, they negotiate the lighting and HVAC systems costs together with the rent: either the owner has these systems built or the tenant assumes the responsibility and the ownership of the lighting and HVAC equipment.

TABLE 1. Building and system characteristics for case-study facilities

Characteristic	Case I	Case II
Function	Manufacturing of microwave component.	Manufacturing of printed circuit boards.
Size & Layout	⅓ of a 1,300 m² single story building.	2,414 m² building, single story.
ENVELOPE		
Walls	6" concrete tilt-up walls, no wall insulation.	Same as Case I.
Interior Walls	3⅝" metal studs & ½" gypboard both sides.	Same as Case I.
Roof	Built-up roofing over 1/2" plywood deck. Roof height 16'.	Same as Case I. Roof height 13'.
Ceilings	Acoustic tiles & insulation. Ceiling height 9'.	Same as Case I.
Floor	4" concrete slab on gravel.	Same as Case I.
Glazing	Mostly on front side of building, tinted.	Same as Case I.
EQUIPMENT		
Lighting	4-lamp fluorescent light fixtures. Standard lamps and ballasts.	Same as Case I.
HVAC	4 packaged roof top units which are also equipped for gas heating: 2 four-ton and 2 six-ton units.	Unit heater for plating room, no central plant. 18 roof-top cooling units with gas furnaces (mostly 5-6 tons).
DHW	Directly purchased.	2 x 4500 watt commercial tank type, 450 liter.
Process	Microcomputers & electronic testing equipment, small ovens, laminate-flow units, small hot plates next to microscopes, freezer for epoxies, spot welders, air compressors, and vacuum pump.	Transformers, laser-plotter, vacuum port, several mini & micro computers, CAD systems, drilling equipment, lamination equipment (vacuum press, hot & cold presses), several big ovens, dry film processing equipment, exposure testing equipment, fully equipped plating shop.
Kitchen	1 refrigerator, 1 soda machine.	2 cold, 1 hot vending machines. Refrigerator. Coffee machine. Hot and cold water dispenser.
Office Equipment	8 personal computers (run overnight), telephone system, copy machine, fax.	Most of the offices located in another building.
SCHEDULES		
Occupancy	8 a.m. to 5 p.m., weekdays, maximum occupancy of 17 people (80% of these are in the building all the time). Custodial service 7 p.m.-9 p.m. two days during the week.	24 hours a day, Sunday 10 p.m. - Saturday 5 p.m. 50 people/shift, 3 shifts/day. Custodial services on Sat-Sun
Lights	Manual control, they have on/off switching strategy. Timer for outdoor lights.	On all the time.
HVAC	Zone reset thermostats. Heating 20°C-22°C, set back to 13°C. Cooling 25°C, set up to 30°C. Outdoor air dampers partially open.	Zone reset thermostats. Heating 20°C. Cooling 22°C. Outdoor air dampers not used because of pollution problems.
Process	Microcomputers are on all the time. Electronic testing equipment and microscopes operated during work hours. Laminar flow device is on all the time. Spot welders, ovens are used for short periods.	Most of the process equipment operated continuously between Sunday 10 p.m - Saturday 5 p.m.
ENERGY PURCHASES	Gas/Electricity/Hot Water	Gas/Electricity

A fundamental barrier impedes improvements in energy efficiency in building services. Neither the owner nor the user thinks that much would be saved by implementing energy-saving measures or by better design. The owners do not consider energy efficiency since they do not pay the energy bills. For tenants, energy costs are a small fraction of the total operating costs of such businesses. As a result, the building, the lighting system, and the HVAC system are built without considering energy efficiency. Facility operators of the case-study buildings were much more sensitive to issues like environmental regulations and to how changes would affect their operations in the future. In interviews,

TABLE 2. Case-study buildings and system design process

Characteristic	Case I	Case II
Potential Occupant	Leasing for office or light industrial use.	Leasing to whoever is interested including industrial use.
Interior Designs	Partially completed before leasing. Completed after leasing.	Not built before leasing.
Lighting System Designs	Specified and completed after leasing. Most of the areas have 15 W/m² lighting. Some areas have 22 W/m² lighting.	Specified and built after leasing. Lighting level is ~ 14 W/m².
HVAC System Design	Sized speculatively, designed and built before leasing.	The tenant took over the responsibility of having the HVAC system designed and built.
Related to energy use	Roof top units of standard size are used (typically 4-5 tons). Zones are assigned to these units. The units are grossly oversized.	There has been a genuine attempt to size the equipment to match internal load generated. In the cases where the equipment manufacturer supplied good documentation, the HVAC equipment was sized correctly. In some areas there is oversizing.
Related to Comfort	The zones served by the same unit are used for different purposes, some zones are over cooled.	The zones served by the same unit are used for different purposes, some zones are over-cooled. One thermostat not in the proper zone.
Ownership of HVAC Equipment	Building owner	Building tenant
Conditions on Lease Termination	There are no complications.	The tenant has to market and sell the customized HVAC system to the next tenant.

they stated they were willing to invest significantly more funding to ensure that they would be able to adjust to future regulatory requirements.

In Case 1 where the HVAC equipment was built for standard office use, we found that the equipment was oversized. Typically, cooling units of standard size were used, and zones were connected to a unit based on floor area with minimal attention paid to the function and internal loads of the zone. Where the HVAC system was custom-built, we observed some significant design flaws resulting in either energy inefficiencies or substandard comfort conditions. These flaws included:

(1) Using an HVAC unit of standard size and connecting zones of different functions to the same unit. If two zones are connected to the same unit and one requires more cooling than the other, one of the zones will not meet specified comfort criteria. This problem arises because typical systems do not include zone reheat equipment.

(2) Placing the thermostat of a certain zone in another closeby zone, resulting in inadequate control of the HVAC equipment.

(3) Not being able to size equipment for cooling zones with certain processes. Manufacturers' catalogues and drawings are usually not adequate for estimating process heat generation. HVAC engineers are not well equipped to tackle the air-conditioning problems of buildings housing industrial processes. Attempts to customize the HVAC equipment to the process involved have occurred, but generally the equipment was oversized. (For one zone, in the Case Study 2 building, there existed very detailed manufacturer's data for the process equipment including the heat generation, and the HVAC equipment is sized very accurately to meet the zone load. The process equipment happened to be used full load all the time.) Another related issue is that the rated performance of a process may be substantially different than its actual heat generation. This means that even if there exists proper manufacturer's data on the heat generation, an analysis of the operating hours and part-load heat generation is necessary to estimate the contribution of the particular process to the zone load.

Energy-use patterns and characteristics

To compare the energy-use patterns of these two buildings, we examined the details of the processes housed in them and simulated the energy use of the buildings using DOE-2. We compared the simulation results with the utility billing data. Although utility bills did not show energy use by end use, they were useful for calibrating our models. A detailed analysis of all of the processes was essential so that we could accurately estimate internal heat gains from process loads.

Table 3 shows the utility bill data for both facilities. Gas consumption (mainly for space heating) was low in both buildings because these facilities are located in a mild climate. In Case Study 2, the heating requirement was even lower because of the higher internal heat gains from the processes equip-

TABLE 3. Monthly electricity and gas consumptions data for case-study facilities. The data, in kWh/m², W/m², MJ/m², are estimated from monthly electricity use, peak demand, and gas consumption data, respectively

MONTH	CASE I (Oct 89-Sept 90) 429 m²			CASE II (Feb 89-Jan 90) 2414 m²		
	ELEC USE [kWh/m²]	ELEC PEAK DEMAND [W/m²]	GAS USE [MJ/m²]	ELEC USE [kWh/m²]	ELEC PEAK DEMAND [W/m²]	GAS USE [MJ/m²]
Jan	9.5	32	59	81	172	14
Feb	8.9	32	51	79	151	37
Mar	9.7[1]	N/A	51	64	151	6
Apr	10.8	65	17	79	151	0
May	9.5	65	8	83	151	0
Jun	13.6	75	6	73	161	0
Jul	15.6	75	2	74	172	0
Aug	15.5	75	2	76	172	0
Sep	14.5	75	2	75	172	0
Oct	9.8	54	3	75[1]	N/A	0
Nov	9.4	43	7	75[1]	N/A	1
Dec	8.2	32	25	76	172	15
Total	135.2	75	235	910	172	74

[1]Data missing: interpolated.
N/A = not available.

ment. For Case Study 1, the pattern of monthly electricity use reflected the climatic seasonality of air-conditioning use. For Case Study 2 the monthly electricity-use pattern was more affected by the seasonality of production than air-conditioning requirements. The production level in Case Study 2 was not always predictable, and there were times when the company had more orders than usual.

For data on processes, we relied on audits and site measurements or published materials. For a majority of the heat-generating equipment (such as ovens and hot presses), we performed surface temperature measurements and collected information on the usage schedule of the process equipment ·o estimate the internal heat gains in the buildings.

Having determined the contribution of the process equipment to the internal heat gains and the sizes of the HVAC equipment as accurately as possible, we simulated building energy use with DOE-2. Since we did not have detailed measured data on process loads, our calibrations of DOE-2 simulations were fairly limited; we assumed that the energy used over and above the levels calculated by DOE-2 were for the processes. Table 4 shows the simulated energy-use by end use and Table 5 compares the electricity-use intensities for the two cases with the results obtained by the analysis of the audit data obtained from the local utility [11] and with typical energy-use intensities for California office, retail, and warehouse buildings [14].

Table 5 shows that electricity use for both lighting and HVAC for both case-study buildings are very close to those intensities found in offices (perhaps also retail). The lighting electricity use in Case Study 1 was low because a large percentage of the floor space benefited from daylighting, and some sections of the building were not lighted most of the time. Also, the characteristics of the equipment in Case Study 1 were about the same as offices with almost the same characteristic internal heat gains. Similarities between the case-study buildings and office buildings suggest that a considerable amount of industrial floorspace could benefit from the same conservation measures that are applicable to office buildings. We will discuss these measures and their impact on energy use and peak power in the following Sections.

As indicated earlier, gas in these facilities was used mainly for space heating. The annual gas consumption for Case Study 1 and Case Study 2 was 250 MJ/m^2 (22 kBtu/ft^2) and 80 MJ/m^2 (7 kBtu/ft^2), respectively. The corresponding average gas-use intensities estimated from the PG&E audit data are 250 MJ/m^2 (22 kBtu/ft^2) for instruments and 260 MJ/m^2 (23 kBtu/ft^2) for electronics. The gas-use intensity in Case Study 2, because of high internal gains from process loads, was low.

TABLE 4. Simulated annual electricity and gas consumption and comparison with metered annual energy data. Note that the difference between the simulated energy use and the utility data, assumed in this analysis as the process load, is fairly small in Case Study 1 and very large in Case Study 2. This observation is confirmed by the process loads in these facilities

	Case I 429 m^2		Case II 2414 m^2	
	ELEC [kWh/m^2]	GAS [MJ/m^2]	ELEC [kWh/m^2]	GAS [MJ/m^2]
HVAC(1)				
Cooling	11	N/A	128	N/A
Heating	N/A	158	N/A	61
Fan	77	N/A	62	N/A
Total	88	158	190	61
Lighting(1)	18	N/A	117	N/A
Total Services(1)	106	158	307	61
Total Building Meter(2)	135	235	910	74

[1]Simulated values, weather data for San Jose was used.
[2]Measured data obtained from utility bills (including processes).
N/A = not applicable.

TABLE 5. Comparison of electricity use intensities (kWh/m^2) of the case-study buildings with PG&E Industrial Data. The intensities for office, retail and warehouse buildings are typical ranges reported in Akbari *et al.* [14]

	Lighting	HVAC	Equipment
Instruments (within SIC 38 - 39)			
Case Study 1	18	88	29
PG&E Audit	76	89	90
Electronics (within SIC 36)			
Case Study 2	117	190	603
PG&E Audit	108	186	292
Office	50 - 80	50 - 90	10 - 25
Retail	50 - 80	30 - 50	10 - 20
Warehouse	30 - 40	10 - 20	2.5 - 7.5

Energy conservation potentials

We simulated the effectiveness of some energy conservation measures that typically apply to commercial buildings. Measures studied included wall insulation, wall and roof color, HVAC system modifications, and lighting systems improvement. (Both buildings already had insulation above the acoustic ceiling tiles; therefore, roof insulation was not included in our analysis.) The findings are summarized in Table 6. The envelope measures resulted in little savings, due to the mild climate of the San Jose–Santa Clara area. These measures saved some heating energy, but this gain typically did not compensate for the increase in air-conditioning electricity use.

We found the conservation measures involving the HVAC and the lighting systems to be more effective than the envelope measures. The use of economizers had a large impact on compressor energy use. However, economizers are not always feasible because of the possibility of recirculating

TABLE 6. Impacts of conservation measures on HVAC annual energy use. Row 1 is base-case energy use in absolute values. All other rows show % savings with respect to base case (Row 1). Numbers in parenthesis are energy penalties rather than savings

	Case I 429 m²			Case II 2414 m²		
	Heating Gas [MJ/m²]	Cooling Elec. [kWh/m²]	Fan Elec. [kWh/m²]	Heating Gas [MJ/m²]	Cooling Elec. [kWh/m²]	Fan Elec. [kWh/m²]
BASE CASE[1]	158	11	77	61	128	62
MEASURE	% Savings	% Savings	% Savings	% Savings	% Savings	% Savings
ENVELOPE						
Wall Insulation R0→R5	25	(10)	0	44	(3)	0
R0→R11	28	(14)	0	48	(4)	0
Wall Color Normal→Light	(6)	7	0	(9)	1	0
Roof Color Normal→Light	(3)	2	0	(2)	0	0
HVAC SYSTEM						
Roof Top Unit COP 2.5→2.8	0	10	0	0	10	0
COP 2.5→3.0	0	16	0	0	16	0
Economizer	0	9	0	0	57	0
Fan Schedule	(13)	8	74	N/A	N/A	N/A
ASD on Fans	0	5	88	0	6	62
Equipment Sized to the Existing Load[2]	(31)[3]	17	75	(5)[3]	10	14
Central System; Cooling Tower	N/A	N/A	N/A	(345)[4]	34[5]	(37)
LIGHTING						
T8 Lamps with Electronic Ballasts	(10)	9	0	(39)	3	0

[1]Base case: wall insulation, R0; wall color, normal; roof color, normal; roof-top unit with compressor COP of 2.5; no economizer; no fan schedule; no ASDs; standard 4 ft. fluorescent lamps and fixtures.
[2]No provisions for future expansion.
[3]Caused by reduction in fan energy.
[4]Very small in absolute terms.
[6]Figure includes zone reheat electricity.
N/A = not applicable.

undesirable gases from nearby exhausts. In Case Study 2, for example, the building operators had to keep most of the dampers closed to prohibit the exhaust gases from the plating shop being recirculated in the building. This issue should be considered during the design stage so that exhausts and intakes can be separated by a safe distance based on the air movement studies around the building.

Supply fan scheduling also has a large impact on the fan motor energy use if the facility is used one or two shifts a day. For facilities operating three shifts, fan scheduling clearly does not yield significant energy savings.

Adjustable speed drives (ASDs) on the fan motors are effective means of closely matching the energy used by the motors to the fan loads. Use of ASDs also results in a small reduction in the compressor energy use because less heat is added to the system by the fan motors. As mentioned, in growth industries (like electronics and instruments), HVAC systems are generally oversized to accommodate the rapid growth of the companies which typically means more usage of the existing facilities and higher intensities of energy-using equipment. This oversizing may result in HVAC equipment being operated at part-load conditions. Adjustable speed drives facilitate energy conservation while guaranteeing the future availability of HVAC capacity.

Having observed that the HVAC equipment was usually oversized, we sized the equipment to meet the actual loads. The results showed savings both in fan and compressor electricity use. As mentioned before, there had been an attempt in Case Study 2 to size the HVAC equipment to match the internal loads. In Case Study 1, on the other hand, the oversized equipment was installed speculatively. In any case, it is difficult to argue for the proper sizing of equipment because the tenants of these buildings are very dynamic; businesses sometimes grow very fast, and in a short time the facility may require much greater HVAC services.

One way of improving HVAC energy performances is the use of central cooling systems. Central HVAC systems usually have better cooling performance at the expense of additional air or water circulation costs. In Case Study 1, using a central HVAC system could reduce electricity consumption considerably, but the savings might not justify the extra capital investment. In Case Study 2, although compressor energy was reduced, fan energy use increased because of duct losses. Overall, for Case Study 2, a central system did not look particularly attractive.

Delamping was not necessary in these buildings since the lighting levels were already low. Multi-switching and occupancy sensors were already being used when suitable. An applicable conservation measure is the use of more efficient lighting components which typically result in about 10% savings in lighting electricity use. In Case Study 1, the positive impact of lighting efficiency measures on cooling electricity use was about the same as its negative impact on heating energy use. In Case Study 2, the increase in heating requirement outweighted the cooling savings.

The combined impact of several of the measures given in Table 6 is shown in Table 7. The measures included in this Table are fan scheduling, economizers, efficient compressors, and efficient lighting components for Case Study 1; ASDs, economizers, efficient compressors, and efficient lighting components for Case Study 2. It is clear that the savings potential in electricity use in both cases is higher than 50%. Note that we have not addressed potentials for increasing energy efficiency in process loads. It is harder to quantify the saving potential in gas use because these buildings are located in a mild climate and heating requirements are very low.

We have not explicitly addressed the cost of conserved energy and power in the facilities we studied. Since the non-process energy-saving measures in these facilities are very much comparable to those generally recommended for office buildings, we expect corresponding conservation measures to have similar costs. Many studies of commercial buildings, particularly offices, have concluded that typically about one-third of the energy in buildings can be saved by conservation measures with less than two years payback.

TABLE 7. Potential for conservation in energy used for building services. All energy consumption figures are presented in source energy (1 kWh = 11.02 MJ)

	Case I[1]	Case II[2]
Electricity		
Base Use [MJ/m^2]	1169	3382
Practical Conservation Potential(%)	61	52
Gas		
Base Use [MJ/m^2]	158	61
Practical Conservation Potential(%)	19	46

[1]Fan scheduling, economizers, efficient compressors, and efficient lighting components.
[2]Adjustable speed drives, economizers, efficient compressors, and efficient lighting components.

Peak-demand reduction potentials

Conservation measures discussed in the previous Section would usually reduce the peak electricity demand. Table 8 shows how these measures affect the peak electricity demand. In Case Study 1, since the HVAC system is oversized, the use of ASDs and proper sizing of HVAC equipment would result in substantial peak reductions. In Case Study 2, where the HVAC equipment was designed to match the loads, the reductions caused by ASDs and proper sizing were not as high. Fan scheduling was not effective for peak reduction because the benefits of this measure usually occurred at off-peak hours. The use of efficient compressors and efficient lighting equipment, however, would result in peak reduction.

Economizers and ASDs do not usually reduce on-peak demand. (If fan and compressor motors are significantly oversized, ASDs will save on-peak de-

TABLE 8. Impact of conservation measures on peak electricity demand. Row 1 is base-case peak demand in absolute values. All other rows show % savings with respect to base case (Row 1). Number in parenthesis is an energy penalty rather than a savings

	Case I 429 m^2	Case II 2414 m^2
BASE CASE[1], Peak Use [W/m^2]	31.5	63
MEASURE	% Reduction	% Reduction
ENVELOPE		
Wall Insulation		
R0→R5	7	4
R0→R11	4	4
Wall Color Normal→Light	4	2
Roof Color Normal→Light	0	2
SYSTEM		
Roof Top Unit		
COP 2.5→2.8	8	7
COP 2.5→3.0	13	11
Economizer	0	(3)
Fan Schedule	2	N/A
ASD on Fans	39	7
Equipment Sized to the Existing Load[2]	39	10
Central System; Cooling Tower	41	7
LIGHTING		
T8 Lamps with Electronic Ballasts	9	11

[1]Base Case: wall insulation, R0; wall color, normal; roof color, normal; roof-top unit with compressor COP of 2.5; no economizer; no fan schedule; no ASDs; standard 4 ft. fluorescent lamps and fixtures.
[2]No provisions for future expansion.
N/A = not applicable.

mand.) Since HVAC systems are usually sized for design-day conditions, the peak reduction would not be significant on very warm days, but there are savings for days with less than design-day loads. Better control of lighting is also an important measure for on-peak demand reduction: daylighting techniques can and are being employed to some extent in the suitable sections of the case-study buildings. Also, motion sensors can be used in spaces that are not occupied continually.

In Case Study 2, chillers were used to provide process cooling and package systems were used for environmental cooling. A thermal energy storage (TES) system can shift both process and environmental cooling loads to off-peak hours and, thereby, save significant peak demand charges.

Conclusions

In this paper, we documented the results of our analysis for two case studies in California. Based on the information obtained for the selected case studies, we discussed design considerations for industrial buildings, characterized their energy use, and reviewed their conservation and load-shaping potentials.

The selected case studies have provided valuable information on two growing industries in California. One major finding of this study is that the lighting and HVAC energy-use characteristics of high-tech industries and their conservation potentials are very much comparable to those of office buildings. By simulating the impact of conservation measures commonly recommended for office buildings in our two case studies, we estimated that more than 50% of electricity and gas use for the building services could be saved.

There is a need for further characterization of these energy uses and patterns. This study has enabled us to understand the energy-use patterns in some industrial facilities in California. Studies of this nature need to be extended to cover other industries as well as to cover other important and populated regions of the country. Such efforts will determine the total energy use, conservation, and peak-demand reduction potentials for building services by industry.

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