ENERGY CONSUMPTION BY COMPUTERS AND MISCELLANEOUS EQUIPMENT IN COMMERCIAL BUILDINGS

H. Dan Nguyen, Rosy Alereza, and Ednan Hamzawi
California Energy Commission

ABSTRACT

The increasing popularity of computers and miscellaneous electrical (CME) equipment in recent years is expected to add significantly to the energy consumption of commercial buildings. Unfortunately, the data concerning the type, penetration rate, and energy characteristics of CME equipment are generally lacking. The paucity of CME equipment data has hindered efforts to produce more reliable forecasts of energy consumption and conservation by commercial buildings.

This paper presents some preliminary results of a study of CME equipment in commercial buildings. Specifically, the paper addresses three issues: (1) the kinds of CME equipment used in various types of commercial buildings, (2) energy consumption of CME equipment by equipment kind, building type, and building vintage, and (3) the impact of CME equipment heat output on the building's HVAC load requirement.

The analyses are based on recent on-site surveys of 855 buildings in the PGandE service area in California. These surveys are part of the California Energy Commission's efforts to collect building/end-use specific data to support its energy consumption and conservation forecast programs.

The major conclusions resulting from these analyses are:

1) The electrical load resulting from computer and other data processing equipment is still small relative to the overall miscellaneous equipment load for all building types.

2) The electrical load resulting from the miscellaneous equipment category, as a whole, is still small relative to the overall building load.

3) The effects of CME equipment heat output on the HVAC equipment are important and can have a significant impact on long-term forecasts of electricity demand and especially the peak forecast.

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1. INTRODUCTION

Since its introduction nearly a decade ago, the end-use approach to forecasting energy use in the commercial building sector [Jackson and Johnson, 1978] has gained wide acceptance. Variations of the original Jackson model were used by utilities and other agencies for forecasting purposes throughout the U.S., including the Department of Energy, California Energy Commission (CEC), the major utilities in California, Bonneville Power Administration, etc. One version, the COMMEND model [Lann et Al, 1985] supported by EPRI, claims more than 80 registered users. This modeling approach generally divides total energy use by commercial buildings into eight end-uses: heating, ventilation, air conditioning, water heating, cooking, refrigeration, lighting, and a catch-all category often called miscellaneous end-use. The CEC staff estimate of consumption by each end-use for the PGandE planning area in 1985 is depicted in Figure 1, which shows that the miscellaneous end-use category consumes approximately 11% of the total commercial sector electrical energy use. Furthermore, in previous electricity forecasts, the miscellaneous end-use category has been assumed to be (1) insignificant in overall connected load and energy usage (typically less than two percent of total energy use), (2) growing slowly (typically two percent annually), and (3) having no effect on the HVAC load (no heat gains from miscellaneous equipment).

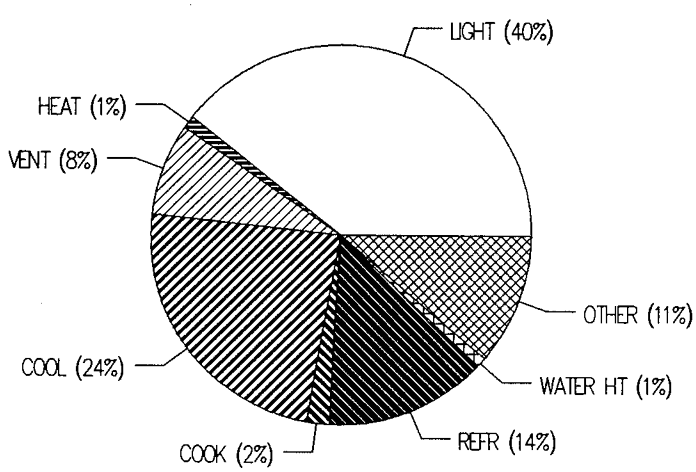

Figure 1: Shares of total electrical consumption by end-use, PGandE commercial building sector (1985).

Recent studies, however, indicate that in newer commercial buildings, CME equipment may reach as high as 20 watt/sf [Squitieri, Yu, and Roach, 1986] or 10 percent or more of total building energy use ([EPRI, 1986], [Schultz,1984], and [Xenergy, 1987]). Furthermore, increasing use of computers and miscellaneous electrical (CME) equipment in recent years is expected to raise the energy consumption of this category significantly. If this is true, then the above assumptions of low intensity, slow growth, and zero heat gains due to CME equipment are unrealistic and would lead to biased forecasts. Unfortunately, the data concerning the type, penetration rate, and energy utilization characteristics of CME equipment are generally unavailable, resulting in inconsistent treatment of this end-use between modelers. During the recent forecasts (CFM-7) of electricity demand, the major California utilities and the CEC staff treatment of CME equipment differed substantially. This was a major factor in accounting for differences between the forecasts [CEC, Aug. 1987] and led the Commission to recommend a more uniform treatment of the miscellaneous end-use category [CEC, Dec. 1987].

This paper presents some results from our analysis of data collected on site in 1985 from 855 commercial buildings in the PGandE service area. Similar surveys were also conducted in the SCE (375 buildings), SDG&E (100), LADWP (100), and SMUD (150) service areas, however the analyses in this paper are restricted to the PGandE data. These surveys are part of the California Energy Commission's on-going efforts to collect building/end-use specific data to support its energy consumption and conservation forecast programs. The on-site survey data include detailed information on the building physical characteristics, thermal properties, HVAC, and Non-HVAC equipment. CME equipment data include equipment type, connected load (nameplate), quantity, and hours of operation per standard day (by means of an interview). Preliminary results indicate that the type of CME equipment used in each building type varies greatly, as expected. Computers and related equipment are used mostly in small and large office buildings, food processing equipment in restaurants and foodstores, laboratory equipment in hospitals, and so on. Furthermore, the importance of CME equipment in terms of energy consumption varies greatly by building type, ranging from less than one percent of total electricity consumption in school buildings to 17 percent in office buildings. The energy impact of CME equipment in the future will likely be more significant as it is penetrating rapidly into the business world. Finally, simulation results indicate that heat gains due to CME equipment will have a significant impact on HVAC load requirement, especially air conditioning (AC). Thus, ignoring such heat gains would lead to serious forecasting bias.

It should be noted that the analyses of the PGandE service area carried out for this paper are applied to the raw unweighted data. Sample weights were not available in time to incorporate them into the data. Readers should, therefore, exercise caution when attempting to apply the results to the general commercial sector population or to other utilities.

2. DEFINITION OF CME EQUIPMENT CATEGORIES

Due to the diversity of commercial buildings and CME equipment, it is necessary to divide both commercial buildings and CME equipment into general but distinct subgroups. The commercial buildings are grouped into 13 general building types based on their business nature. These building type definitions are the same ones used in the CEC, as well as many other, commercial end-use models. The building types utilized are shown in Table I.

Table I. Commercial building type categories.

Small office	College
Large office	Health
Retail	Sit-down restaurant
Foodstore	Fast food restaurant
Refrigerated warehouse	Hotel/Motel
Non-refrigerated warehouse	Miscellaneous
School (K-12th)	

Similarly, the CME equipment are divided into nine categories based on their intended usage. For instance, the food processing equipment category includes scales, coffee grinders, slicers, and other relevant equipment not listed under cooking equipment. Office equipment includes non-computer related equipment such as copiers, calculators, and typewriters. The CME equipment categories utilized in this paper are shown in Table II, along with typical equipment type and utilization factors for each. A complete listing of equipment types is not included here, due to space limitations. The utilization factor, shown in Table II is defined further in this section.

Table II. CME equipment categories, typical equipment types, and utilization factors.

Category	Label	Typical Equip. and (Util. Factors)
Data processing	DTP	PC (.85), main frame (.85), printer (.85)
Food processing	FDP	toaster (.26), coffee maker (.25), Soup heater (.35), hot plate (.6)
Laboratory and medical	LAB	dental lathe (.95), vacuum (.95), analyzer (.2), exam table (.2)
Sanitation	SAN	washer (.7), dryer (.6), trash compactor (.95), dishwasher (.28)
Office	OFF	copier (.5), typewriter (.84), shredder (1.), calculator (.8)

Table II (Continued).

Category	Label	Typical Equip. and (Util. Factors)
Shop	SHP	saw (.95), compressor (.95), welder (.65), gas pump (.5)
Vertical transportation	VRT	elevator (.75), escalator (.95)
Specialty	SPE	pool pump (1.), iron (.6), cash register (.8), enlarger (1.)
Entertainment	ENT	TV/stereo (.95), projector (1.), vending machine (.5), VCR (1.)

To evaluate the electrical consumption of different CME equipment categories in various building types, we estimate annual electricity use per square foot (electrical intensity) for each building type and equipment category using the utility on-site survey data. For a particular building type and CME equipment category, electrical intensity is estimated as the sum of the product of name plate capacity, operating hours, and utilization factor divided by the sum of building area as shown in Equation 1 below. This method is used, rather than utilizing the mean of electrical intensity for individual buildings, to reduce the effect of anomalous or unusual building equipment and area configurations, since survey weights were not available. The estimation method used here differs from those in other studies such as Schultz [1985] or Jaske [1983] in which, due to the lack of data, miscellaneous electrical intensities are estimated as the residual of all other end-uses.

$$E = \sum^{N} \sum^{L} 3.413 * (C_{ij} * H_{ij} * U_{ij}) / \sum^{N} A_i \qquad (1)$$

where,

N - the number of buildings of a particular type,

L - the number of CME of a particular category,

E - electrical intensity in 1000 btu/sf of a particular CME category and building type,

C - name plate capacity in KW of a piece of CME j within building i,

H - number of hours equipment j is on during the year

U - utilization factor of equipment j. The utilization factor is defined as the ratio of estimated power consumption over name plate capacity under normal operating conditions, and

A - total enclosed area in sq. ft. of building i.

Data on capacity , C; annual hours of operation , H; and enclosed floorspace, A; come from the PGandE on-site survey. Data for the utilization factor, U, come from an earlier study [Alereza,1984] as well as our own estimates. The estimated electrical intensity of CME equipment by category and building type produced by Equation 1 are shown in Table III.

Table III. CME equipment intensity by building type and category.

Building Type	# of obs.	DTP	FDP	LAB	SAN	OFF	SHP	VRT	SPE	ENT	CME Total	Bldg. Total
		CME Equip. Category										
Sm. off.	103	17.95	1.03	0.00	0.00	0.82	1.44	0.38	0.23	0.41	22.28	132.74
Lrg. off.	76	10.26	0.07	0.00	0.01	0.37	0.04	3.63	0.06	0.82	15.24	89.40
Retail	133	0.31	0.05	0.00	0.03	0.12	0.02	3.66	0.14	0.14	4.48	94.42
Foodstore	88	0.60	2.74	0.00	0.09	0.01	1.33	0.00	0.83	0.58	6.18	159.44
Ref. ware.	14	0.08	0.03	0.00	0.02	0.01	0.76	0.00	9.51	0.00	10.42	177.50
Warehouse	22	0.75	0.10	0.00	0.01	0.03	2.51	0.00	0.02	0.08	3.50	89.99
School	53	0.33	0.19	0.00	0.01	0.20	0.13	0.00	0.03	0.05	0.94	101.29
College	1	0.00	0.11	0.00	0.00	0.00	0.00	1.49	0.00	0.00	1.60	16.68
Health	90	0.47	0.17	1.09	0.35	0.14	0.26	7.59	0.60	0.11	10.24	110.28
SD rest.	63	0.01	0.80	0.00	0.59	0.02	0.02	0.01	0.11	1.41	10.96	133.18
FF rest.	22	0.07	6.75	0.00	0.11	0.00	0.00	0.13	0.78	0.74	8.58	282.29
Hotel	34	0.02	0.12	0.00	0.35	0.00	0.40	3.50	0.87	0.48	5.74	55.19
Misc.	156	0.50	0.39	0.00	1.02	0.02	7.50	0.98	0.72	0.25	11.59	86.24
All Bldgs.	855	5.05	0.21	0.25	0.21	0.22	0.86	3.99	0.38	0.49	11.67	93.64

Three general conclusions are derived from the Table III. First, electrical intensity of computers and related equipment (DPT) is still small relative to other CME equipment as well as total building intensity, except for office buildings. In office buildings where DPT equipment are used most often, its electrical intensity accounts for between 67 (large office) and 82 percent (small office) of all CME equipment intensity; but only 11 to 14 percent of the total building intensity. These results are still low in comparison with the conclusions of Squitieri, Yu, and Roach, and the recommendation by CEC [Dec. 1987]. Future growth, however, is very likely to produce higher DPT equipment intensities for office buildings consistent with the Squitieri, et al. conclusions. Second, the estimated electrical intensity of all CME equipment is also small in all building types and ranges between 1 percent in schools to 17 percent in large offices, with an average of 13 percent for the whole sample. Third, energy intensity levels differ significantly across CME category and building type. For instance, computer related equipment are used mostly in small and large office buildings but are nearly non-existing in all others. Elevators and escalators, as expected, are dominant only in hospitals, large offices, and hotels. This fact contradicts with the common assumption made in most existing commercial end-use energy forecasting models of identical CME electrical intensity and growth rate in all building types.

Stratification of the sample by building vintage was carried out (pre and post 1979 construction), however, the post 79 sample was not large enough to show any significant variation in CME equipment intensity.

3. IMPACT OF CME EQUIPMENT HEAT OUTPUT ON HVAC LOAD REQUIREMENTS

As discussed above, the energy impact of CME equipment at the present is still small in many commercial buildings. As CME equipment penetrate the commercial sector, however, they introduce uncertainty in energy forecasting and modeling. The penetration rates and, therefore, their potential heat output impact on building HVAC load requirements are subject to speculation. As a result of this uncertainty, modeling treatment of future CME equipment load growth varies significantly. In recent preliminary forecasts of commercial electricity consumption, the major California utilities and CEC staff assumptions on future growth of CME equipment differed significantly. PGandE assumed that electrical intensity for "other" end-use (miscellaneous, refrigeration, ventilation, cooking, and ventilation) in office, restaurant, and hotel buildings grew at 5, 3, and 0.7 percent annually for the 1985-1999 period and declined for all other building types. SCE's forecast on the other hand showed increasing electrical intensity for all building types, however, the increases were fastest in the school, college, hospital, and hotel buildings. CEC forecast results also showed increasing electrical intensity, but the growth rates were usually less than half of the SCE rates. Due to this inconsistency, the CFM 7 committee directed all involved parties to adopt a common growth scenario in which electrical intensity of miscellaneous end-use was assumed to grow rapidly in the short term (mostly due to the rapid penetration of personal computer and related equipment) and return to a slower pace in the long run [CEC, Dec. 1987].

In nearly all existing commercial end-use models, the impact of CME equipment heat output is ignored. Under the assumption of faster penetration of CME equipment, ignoring this feedback would create serious forecasting bias. To estimate the potential impact of CME equipment heat output on the HVAC load, we used the DOE-2 Hourly Building Energy Simulation program to analyze three buildings: a small office (low rise), a large office (high rise), and a sit-down restaurant. These buildings were arbitrarily chosen from the PGandE on-site survey sample and may not be "representative" of the general building population. The general characteristics of each building are shown in Table IV; all buildings contain medium insulation levels. In each case, we simulated the building energy use parametrically by changing the miscellaneous equipment internal loads from 0 to 20 Watts/sf at increments of 4 Watts/sf. The upper limit of 20 Watts/sf represents the intensity level referenced by Squitieri, Yu, and Roach [1986]. The simulations were carried out for two climate zones, Fresno and San Francisco, to illustrate the effect of weather on this process. The results of these simulations are shown in Table V and Figures 2 through 7.

Table IV. General characteristics of the simulated buildings.

Building Type	Area (sf)	Zones	HVAC Distribution Sys.	Heating Equip.	Cooling Equip.
Small office	5750	5	Package single zone	Gas furnace	Direct expansion
Large office	38400	5	Package VAV system	Gas furnace	Direct expansion
Sit-down rest.	4300	5	Package single zone	Gas furnace	Direct expansion

Table V. DOE-2 building energy simulation results.

Building type: High rise office

CME equip Intensity (Wat./sf)	Fresno Peak Load (Kbtu/hr) Cool	Fresno Peak Load (Kbtu/hr) Heat	Fresno HVAC Energy Use (Kbtu/sf) Cool	Fresno HVAC Energy Use (Kbtu/sf) Heat	Fresno Total Load (Kbtu/sf)	San Francisco Peak Load (Kbtu/hr) Cool	San Francisco Peak Load (Kbtu/hr) Heat	San Francisco HVAC Energy Use (Kbtu/sf) Cool	San Francisco HVAC Energy Use (Kbtu/sf) Heat	San Francisco Total Load (Kbtu/sf)
0	946.5	516.6	37.5	17.1	57.1	743.8	449.9	11.0	9.1	29.5
4	1120.0	462.6	41.7	18.4	86.1	917.9	409.8	12.2	10.5	54.6
8	1294.5	418.6	47.3	20.0	117.1	1092.1	409.8	15.6	11.1	83.0
12	1469.5	412.1	53.2	20.9	148.7	1266.2	409.8	19.3	11.4	112.1
16	1644.5	407.1	59.0	21.4	180.2	1440.4	409.8	22.9	12.8	141.3
20	1819.5	407.1	58.4	21.1	206.3	1614.6	409.8	28.8	13.2	172.7

Building type: Low rise office

CME equip Intensity (Wat./sf)	Fresno Peak Load (Kbtu/hr) Cool	Fresno Peak Load (Kbtu/hr) Heat	Fresno HVAC Energy Use (Kbtu/sf) Cool	Fresno HVAC Energy Use (Kbtu/sf) Heat	Fresno Total Load (Kbtu/sf)	San Francisco Peak Load (Kbtu/hr) Cool	San Francisco Peak Load (Kbtu/hr) Heat	San Francisco HVAC Energy Use (Kbtu/sf) Cool	San Francisco HVAC Energy Use (Kbtu/sf) Heat	San Francisco Total Load (Kbtu/sf)
0	238.2	135.1	74.4	65.5	186.5	168.8	112.2	16.8	56.4	118.8
4	290.8	132.3	91.2	49.0	250.0	221.5	105.9	31.6	39.1	180.3
8	343.5	131.1	109.4	37.5	314.8	274.2	105.9	49.5	30.2	244.7
12	396.2	129.8	128.2	29.9	380.4	326.8	105.9	67.7	24.7	309.6
16	448.8	128.6	147.3	24.8	446.1	379.5	105.9	85.5	20.9	374.2
20	501.5	127.3	166.5	21.8	515.1	432.2	105.9	103.4	18.3	441.1

Building type: Sit-down restuarant

CME equip Intensity (Wat./sf)	Fresno Peak Load (Kbtu/hr) Cool	Fresno Peak Load (Kbtu/hr) Heat	Fresno HVAC Energy Use (Kbtu/sf) Cool	Fresno HVAC Energy Use (Kbtu/sf) Heat	Fresno Total Load (Kbtu/sf)	San Francisco Peak Load (Kbtu/hr) Cool	San Francisco Peak Load (Kbtu/hr) Heat	San Francisco HVAC Energy Use (Kbtu/sf) Cool	San Francisco HVAC Energy Use (Kbtu/sf) Heat	San Francisco Total Load (Kbtu/sf)
0	153.8	103.7	64.4	71.7	352.9	113.4	87.7	12.4	76.2	296.3
4	192.9	102.2	81.3	46.3	418.6	152.6	86.2	27.2	37.2	355.4
8	232.2	100.7	99.6	29.0	485.7	191.8	84.8	50.3	20.6	432.0
12	271.4	99.3	119.3	19.7	554.4	231.1	83.4	74.6	15.4	505.1
16	310.6	97.8	139.3	15.8	623.1	270.2	82.3	93.9	13.8	573.2
20	349.8	96.4	157.8	14.2	691.5	309.4	81.2	108.1	13.2	636.9

The Total load column in Table V represents the sum of all end-use equipment energy use. Graphical representations of Table V for the HVAC plant energy use in the different building types and climates are shown in Figures 2 through 7. For purposes of this study, and representing one possible scenario, the characteristics of the HVAC system (capacity, efficiency, cfm, fan power, etc.) were held constant for each building type despite increasing internal load configurations. Initial HVAC system information was taken from the on-site data. Examination of Table V and Figures 2 through 7 yields the following discussions.

FRESNO

SAN FRANCISCO

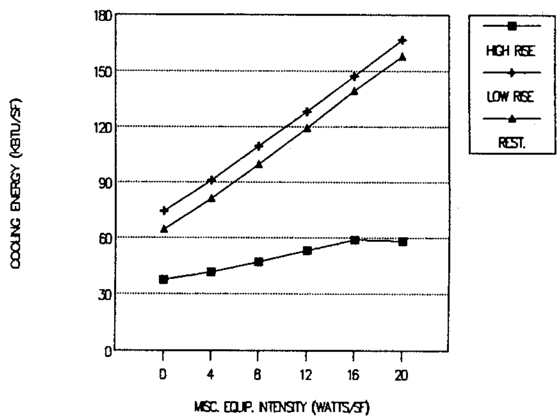

Fig. 2 Cooling energy vs. CME intensity

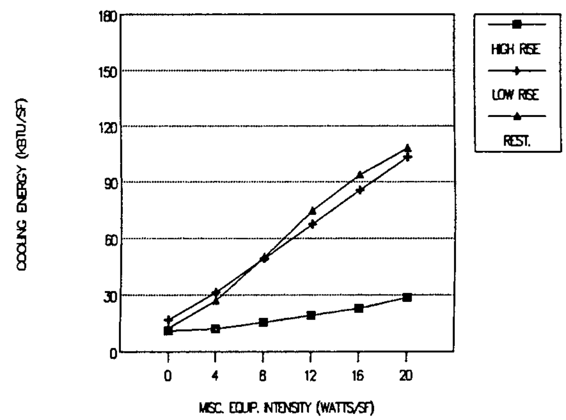

Fig. 3 Cooling energy vs. CME intensity

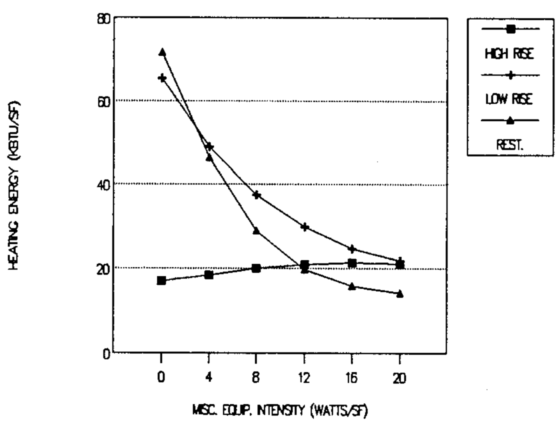

Fig. 4 Heating energy vs. CME intensity

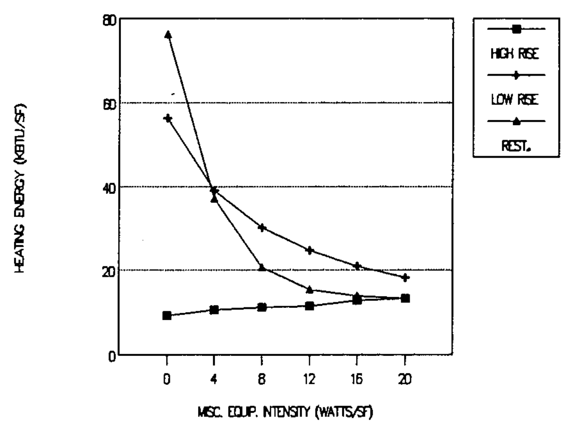

Fig. 5 Heating energy vs. CME intensity

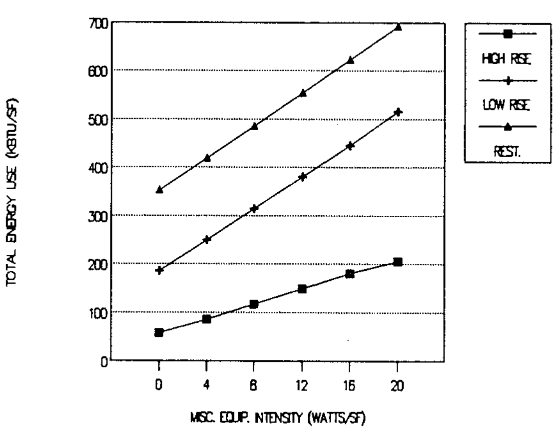

Fig. 6 Total energy vs. CME intensity

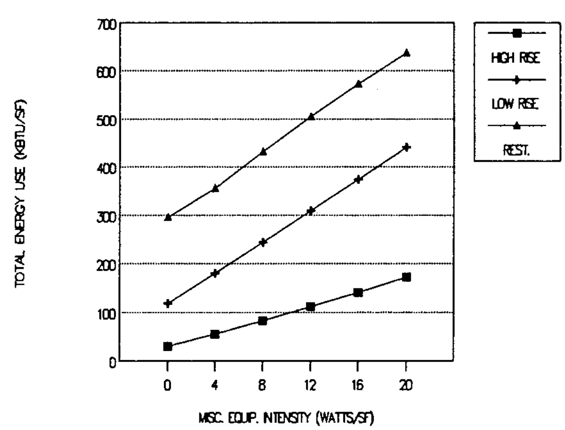

Fig. 7 Total energy vs. CME intensity

The results show that as CME equipment intensity increases, cooling load also increases and heating load decreases as expected. However, the increase in the cooling load is much larger than the decrease in heating load; as a result the total building energy use increases. This is due mostly to the fact that the heating load is relatively small to begin with. In our case, the CME equipment heat output is larger than the heating load. Therefore, additional cooling is required to remove CME equipment heat output even during the heating season.

The simulation results also show that the low rise office and restaurant buildings are more sensitive to increased CME equipment intensity than the high rise office, as indicated by the variation in slope in Figures 2 through 5. This behavior occurs despite the fact that the plant equipment are similar in all three buildings. Furthermore, the relationship between HVAC equipment energy use and CME equipment intensity is non-linear. This is not surprising, given the non-linear nature of equipment efficiency vs. heating and cooling loads for gas furnaces and direct expansion units. These results, however, differ from assumptions utilized in most end-use forecasting models (at the present), which assume no relationship between the CME equipment growth and the HVAC equipment energy use. Also interesting to note, is the slight increase in heating energy with increased CME equipment intensity for the high rise office in both climates. One possible explanation for this increase is that the heating plant is oversized and operates at the lower end of the efficiency curve for gas furnaces (where a small part load ratio produces a low operating efficiency). In terms of HVAC equipment energy use, the relative increase in cooling energy and decrease in heating energy for the low rise and restaurant buildings are very similar for both locations, despite the difference in climate. This seems to reduce the impact of weather dependency of HVAC system performance in relation to increased CME equipment load.

Another area of interest depicted in Table V is the effect of CME equipment intensity growth on the peak heating and cooling loads. Since all heating equipment specified in the three buildings modeled are gas furnaces, reduction of the heating load has no impact upon electricity demand. This is not the case, however, for the cooling load. The simulation results for the low rise office building in Fresno show that as CME equipment intensity increases from 0 to 12 watt/sf, the peak heating load decreases by 4 percent, while the peak cooling load increases by 66 percent. While actual figures are highly dependent on equipment efficiency, occupancy patterns, and equipment operating schedules, it is clear that increased CME equipment loads lead to increased electricity demand. The increased demand includes the effect of the CME equipment load itself as well as the secondary (and previously unconsidered) increase in cooling electrical demand for the removal of additional CME equipment heat outputs.

In summary, DOE-2 simulation of the three buildings reveals the following:

- The effect of CME equipment heat gain on the HVAC load is non-linear.

- The effect of CME equipment heat gain on the HVAC load varies by building type.

- The effect of CME equipment heat gain on the HVAC load does not vary significantly by climate.
- The heat gain due to CME equipment load increase will have a significant effect on the peak electricity demand.

4. CONCLUSIONS

Uncertainties regarding present commercial CME equipment intensities, future growth rates, and heat gain impact on HVAC energy requirements are key issues in commercial end-use energy forecasting. Preliminary analysis of on-site surveys of about 855 California commercial buildings indicate that: (1) electrical intensity of computer and related equipment relative to total building electrical intensity is very small in all commercial building types except offices, (2) electrical intensity of all CME equipment is also small (ranging from less than 1 to 17 percent of total electrical intensity) in all commercial building types, and (3) electrical intensities differ greatly across CME equipment categories and commercial building types. Electrical intensities of CME equipment are highest in large and small offices and miscellaneous buildings, and lowest in schools, fast-food restaurants, warehouses, and retail buildings. Data processing equipment, and vertical transportation equipment are the two dominant equipment types in terms of CME equipment intensity for the commercial sector as a whole. These results indicate that the common practice of assuming constant CME intensity across building types and years in most current commercial end-use energy forecasting models are improper.

If CME equipment penetrate commercial buildings as rapidly as expected, especially in the short run, then the heat gains would have a substantial effect on the HVAC load as demonstrated by the results of the simulations. These effects cannot be ignored as they have been in the past. Furthermore, the simulation results indicate that capturing the interactive effect between increased miscellaneous equipment and HVAC loads is not a straightforward process, but varies by building type and can be affected by climate. Results of the simulations also point to the fact that building vintage and equipment technology will also impact the interactive effects between HVAC energy use and increased miscellaneous equipment. For example addition of cooling equipment is more likely to occur than the removal or replacement of heating equipment. Newer buildings may be designed with HVAC systems sized specifically to account for a higher miscellaneous equipment load than is now the norm. More important, the simulation results indicate that increasing CME equipment loads can lead to significant increases in the peak electrical demand, mainly due to the increased cooling load. The performance of the heating and cooling equipment and the impact upon end-use forecasting model results will vary for each case.

Although this paper examined only a small part of a complex issue, the results clearly demonstrate that the miscellaneous end-use category can no longer be treated with the indifference of past end-use forecasting models.

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