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Lighting/HVAC Interactions and Their Effects on Annual and Peak HVAC Requirements in Commercial Buildings*

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Lighting measures have been identified as one of the most effective strategies for reducing energy use in commercial buildings. Reductions in lighting energy have secondary effects on the cooling and heating energy consumption and peak HVAC requirements of a building. In general, lighting energy reductions increase the heating and decrease cooling requirements of a building. The net change in a building's annual and peak energy requirements, however, is difficult to quantify and depends on the building characteristics, operating conditions, and climate.

This paper characterizes the impacts of lighting/HVAC interactions on the annual and peak heating/cooling requirements of prototypical U.S. commercial buildings through computer simulations using the DOE-2.1E building energy analysis program. Ten building types of two vintages and nine climates are chosen to represent the U.S. commercial building stock. For each combination of building type, vintage, and climate, a prototypical building is simulated with two lighting power densities, and the resultant changes in heating and cooling loads are recorded. Simple concepts of Lighting Coincidence Factors are used to describe the observed interactions between lighting and HVAC requirements. Coincidence Factor is defined as the ratio of the changes in HVAC loads to those in lighting loads, where load is either the annual or the peak load.

The paper presents tables of lighting Coincidence Factors (CF) for major building types and climates. These parameters can be used for regional or national cost/benefit analyses of lighting-related policies and utility DSM programs. Using Annual Coincidence Factors and typical efficiencies for heating and cooling systems, net changes in space conditioning energy use from a lighting measure can be calculated. Similarly, Demand Coincidence Factors can be used to estimate the changes in HVAC sizing, which can then be converted to changes in capital outlay using standard-design curves; or they can be used to estimate coincident peak reductions for the analysis of the utility's avoided costs. The results from the use of these tables are meaningful only when they involve a significantly large number of buildings.

Introduction

Utilities and energy policy analysts generally evaluate the costs and benefits of lighting-related conservation programs and standards from consumer (participant), utility, and societal points of view. Common to all these viewpoints, however, is the desire to include all of the effects of a lighting conservation measure into the specific cost/benefit analysis.

This paper presents parameters that can be used to calculate the effects of lighting measures on HVAC requirements and include these effects into the cost-benefit analysis from each perspective. Given a lighting-related conservation measure, these parameters can be used to (1) translate a reduction in Lighting Power Density (LPD) (W/ft^2) into annual lighting energy use, (2) estimate the changes in annual heating and cooling requirements, (3) estimate the changes in heating and cooling equipment sizing requirements, and (4) estimate how the modified heating and cooling demands will affect utility peaks.

Given a particular building, the parameters required for the cost benefit analysis can be generated through hourly simulations of that building using a building energy simulation program such as DOE-2. However, when a utility program affects a multitude of buildings, it is desirable to have alternative methodologies to estimate such parameters more quickly, without having to go through the costly modeling effort. This paper presents look-up tables that provide parameters facilitating the cost-benefit analysis of lighting conservation measures for an exhaustive set of commercial building types and U.S. climates. These tables should not be used for the analysis of a single building and the results from the use of these tables are meaningful only when they involve a significantly large number of buildings.

Definitions

The secondary effects of a reduction in lighting power density (LPD) are characterized by several coincidence factors. It should be noted that: (1) kWh and kW are used as the units of heating/cooling annual and peak thermal loads respectively, (2) for lighting, thermal and electrical energy are identical, and (3) the coincidence factors are non-dimensional. The terms "coincidence factor" and "conservation load factor" have been in use in the end-use forecasting and energy policy analysis community. The parameters defined below are developed from the hourly results of the building simulation runs using the DOE-2.1E building energy analysis program.

Lighting Conservation Load Factor (CLF)[1]

This parameter relates the savings in annual lighting energy use to the reduction in LPD. Given a reduction in lighting power density, the change in annual lighting-energy use can be estimated using this parameter. For a homogeneously lit building, lighting CFL is merely the product of (1) the proportion of the time the lights are on and (2) the diversity factor. The prototypes which are used for this study include spaces with different activities and lighting schedules and the calculation of annual energy from a reduction in LPD is not trivial, therefore lighting CLF is presented as a complementary parameter to the coincidence factors.

$$\textit{Lighting CLF} = \frac{\textit{Annual Lighting Energy Savings (kWh)}}{\textit{Reduction in LPD(kW)}*8760 \textit{ Hours}} \quad (1)$$

Annual Heating and Cooling Coincidence Factors

These parameters indicate the ratios of increased annual heating load and reduced annual-cooling load to the reduction in annual-lighting energy.

$$\textit{Annual-Heating CF} = \frac{\textit{Annual Heating Load Penalty (kWh)}}{\textit{Annual Lighting Energy Savings (kWh)}} \quad (2)$$

$$\textit{Annual-Cooling CF} = \frac{\textit{Annual Cooling Load Savings (kWh)}}{\textit{Annual Lighting Energy Savings (kWh)}} \quad (3)$$

Heating and Cooling Demand Coincidence Factors

These parameters indicate the increased heating and decreased cooling peak demand requirements as a ratio of the reduction in lighting power density. Changes in equipment size requirements can be estimated using these parameters.

$$\textit{Heating-Demand CF} = \frac{\textit{Peak Heating Load Penalty (kW)}}{\textit{Reduction in LPD (kW)}} \quad (4)$$

$$\textit{Cooling-Demand CF} = \frac{\textit{Peak Cooling Load Savings (kW)}}{\textit{Reduction in LPD (kW)}} \quad (5)$$

Utility Heating- and Cooling-Demand Coincidence Factors

These parameters indicate the increased heating and decreased cooling loads at the utility peak as a ratio of the reduction in lighting power density. These parameters are provided to facilitate the estimation of utility avoided costs.

$$\textit{Utility Heating-Demand CF} = \frac{\textit{Utility Peak Heating Load Penalty (kW)}}{\textit{Reduction in LPD (kW)}} \quad (6)$$

$$\textit{Utility Cooling-Demand CF} = \frac{\textit{Utility Peak Cooling Load Savings (kW)}}{\textit{Reduction in LPD (kW)}} \quad (7)$$

The utility peak heating load penalty is defined here as the building's average hourly load penalty over the peak demand period hours (8 am to 8 pm) for weekdays in January. The utility peak cooling load saving is defined as the building's average hourly load saving over the peak demand-period hours (12 pm to 6 pm) for weekdays in August (September for California).[2]

Simulations

The prototypical buildings used for this study are a modified subset of the 481 prototypical commercial buildings developed to study the market potentials of cogeneration in commercial buildings for the Gas Research Institute (Huang et al. 1991). The nine selected locations (Chicago, Lake Charles, Los Angeles, Miami, Minneapolis, New York, Phoenix, San Francisco, and Washington) represent the major climate variations within the U.S. In each location, ten different commercial building types of one or two vintages have been modeled (large and medium offices, large retail, large and medium hotels, fast-food and sit-down restaurants, hospital, secondary school, and supermarket). For the non-restaurant prototypes two building vintages are considered: (1) *Current*, representing post-1980s construction following the ASHRAE-90.75 building energy standard, and (2) *Old*, representing the average characteristics of all buildings built prior to 1980. For each of the two restaurant building types (fast-food and sit-down), a single vintage which represents the average characteristics of the stock is simulated.

Coincidence factors were defined in terms of the building loads, not that of the HVAC system or plant. System variations were not studied, but the impacts of the thermostat settings and the minimum fresh-air requirements are incorporated in calculating the building loads. Readers who wish to apply these Coincidence Factors to buildings with economizers will need to correct these factors to account for the reduced cooling requirements (see the final section for more discussion of this issue).

To estimate the impact of changes in lighting energy use on the building heating and cooling loads, we repeated the simulations for each prototype, vintage, and location, first with the lighting power density modeled at the base case level, and then reduced to 2/3 of that level. This reduction is representative of the impacts of common lighting equipment conversions. The actual lighting power densities modeled vary by building type, zone, vintage, and in some cases, location and are fully described, along with the rest of the prototype building descriptions, in Huang et al. (1991).

Coincidence Factors

The simulation results are shown in Tables 1 through 10. Each table gives the Lighting Conservation Load Factor, and three sets of Coincidence Factors for annual loads, peak demand, and utility peak demand, calculated according to the definitions given earlier in this paper.

The results for three of the building types—large office, large retail, and secondary school—are plotted in Figures 1 through 3. To illustrate the inverse relationship between heating and cooling Coincidence Factors, the first are plotted as negative, i.e., increased heating loads, while the second are plotted as positive, i.e., decreased cooling loads.

The annual coincidence factors for heating and cooling in general correlate to the duration of the heating and cooling seasons of the buildings. However, there is noticeably less coincidence for heating as compared to cooling, even when the lengths of the seasons are considered, because the lights are almost always on when cooling is required during the day, but frequently off when heating is required during the night.

For larger building types such as large office, large retail, and hospital, the sums of the heating and cooling Coincidence Factors are nearly 1.0, indicating that any changes in their lighting power density ultimately manifest themselves in modifying the buildings' heating or cooling loads. For the smaller or less energy-intensive buildings such as the medium office, motel, or secondary school, the Coincidence Factors are lower but still total nearly 0.80, due mostly to the high cooling Coincidence Factors.

The peak demand Coincidence Factors, compared to those for annual loads, show significantly large values for heating, particularly in the warmer locations. In other words, although the penalty in annual heating loads from reduced lighting might be minuscule in those locations, it may not be so in terms of the peak heating demand. This is particularly apparent in Los Angeles, where the heating Coincidence Factor in the large retail building jumps from 0.03 for annual load to 1.38 for peak. It may seem surprising at first that the heating demand CF can exceed 1.0. However, the hourly outputs reveal that this is due to the thermal lag of the building at the end of the setback period at 8 a.m. A reduced lighting level during the nighttime hours resulted in a colder building, and hence a larger heating load in that initial hour. Despite this increased coincidence, the Coincidence Factors for heating peak are still small in most locations and building types compared to those for cooling peaks, and the down sizing potential in cooling systems will outweigh the need for increased peak heating capacity by a factor of two or more.

Compared to the Coincidence Factors for building peak demand, those for the utility peak demand show some interesting differences. Since the latter are averaged over the utility peak demand hours for a month, it is unsurprising that in most cases they will be lower, and nearly always so for cooling. For heating, however, the utility peak demand Coincidence Factors are higher in the colder locations (Minneapolis, Chicago, New York, and Washington). This is because the utility peak demands are averaged only over the daytime hours, while the building peak demands for heating occur at night.

Example

Given a lighting conservation measure, the change in lighting power density for the relevant floorstock can be estimated using engineering analysis. For example, in a project involving conversion from standard fluorescent lamps with energy efficient ballasts to T8 fluorescent

Table 1. Heating and Cooling Coincidence Factors for Fast-Foods Restaurant

Location	Vintage	Light. Conservation Load Factor	Coincidence Factors: Annual Heat.	Annual Cool.	Demand Heat.	Demand Cool.	Utility Demand Heat.	Utility Demand Cool.
Chicago	Average	0.78	0.16	0.79	1.21	1.01	0.39	1.04
Los Angeles	Average	0.78	0.04	0.90	0.37	1.01	0.05	1.04
Lake Charles	Average	0.78	0.05	0.89	0.53	1.01	0.15	1.03
Miami	Average	0.78	0.00	0.95	0.41	1.00	0.00	1.03
Minneapolis	Average	0.78	0.21	0.73	1.10	1.01	0.54	1.05
New York	Average	0.78	0.16	0.78	1.18	1.01	0.38	1.03
Phoenix	Average	0.78	0.03	0.91	0.70	0.96	0.08	0.98
San Francisco	Average	0.78	0.09	0.84	0.78	1.00	0.19	1.06
Washington	Average	0.78	0.13	0.81	1.03	0.92	0.31	1.03

Table 2. Heating and Cooling Coincidence Factors for Hospital

Location	Vintage	Light. Conservation Load Factor	Coincidence Factors: Annual Heat.	Annual Cool.	Demand Heat.	Demand Cool.	Utility Demand Heat.	Utility Demand Cool.
Chicago	Current	0.71	0.06	0.94	0.13	0.95	0.13	0.92
"	Old	0.71	0.11	0.88	0.51	0.95	0.22	0.92
Los Angeles	Current	0.71	0.01	0.99	0.08	0.95	0.00	0.92
"	Old	0.71	0.01	0.99	0.07	0.95	0.01	0.92
Lake Charles	Current	0.71	0.03	0.96	0.11	0.95	0.05	0.92
"	Old	0.71	0.03	0.96	0.13	0.95	0.08	0.92
Miami	Current	0.71	0.00	0.99	0.07	0.95	0.00	0.92
"	Old	0.71	0.00	1.00	0.09	0.95	0.00	0.92
Minneapolis	Current	0.71	0.07	0.92	0.18	0.95	0.15	0.92
"	Old	0.71	0.13	0.85	0.36	0.95	0.25	0.92
New York	Current	0.71	0.06	0.92	0.09	0.95	0.13	0.92
"	Old	0.71	0.11	0.86	0.32	0.95	0.22	0.92
Phoenix	Current	0.71	0.01	0.99	0.08	0.96	0.01	0.92
"	Old	0.71	0.01	0.99	0.09	0.96	0.01	0.92
San Francisco	Current	0.71	0.03	0.96	0.08	0.95	0.05	0.93
"	Old	0.71	0.04	0.95	0.08	0.95	0.06	0.93
Washington	Current	0.71	0.03	0.96	0.11	0.95	0.08	0.92
"	Old	0.71	0.07	0.91	0.30	0.95	0.16	0.92

Table 3. Heating and Cooling Coincidence Factors for Large Hotel

Location	Vintage	Light. Conservation Load Factor	Coincidence Factors: Annual Heat.	Annual Cool.	Demand Heat.	Demand Cool.	Utility Demand Heat.	Utility Demand Cool.
Chicago	Current	0.49	0.15	0.67	0.51	0.48	0.38	0.45
"	Old	0.49	0.24	0.57	0.29	0.44	0.29	0.45
Lake Charles	Current	0.49	0.08	0.87	0.57	0.46	0.25	0.45
"	Old	0.49	0.08	0.86	0.56	0.46	0.25	0.45
Los Angeles	Current	0.49	0.02	0.96	0.44	0.61	0.09	0.46
"	Old	0.49	0.02	0.95	0.44	0.62	0.10	0.45
Miami	Current	0.49	0.00	0.99	0.55	0.66	0.02	0.45
"	Old	0.49	0.00	0.99	0.55	0.65	0.01	0.45
Minneapolis	Current	0.49	0.20	0.59	0.39	0.66	0.37	0.45
"	Old	0.49	0.28	0.50	0.29	0.58	0.27	0.45
New York	Current	0.49	0.14	0.67	0.60	0.51	0.38	0.45
"	Old	0.49	0.23	0.56	0.31	0.44	0.32	0.45
Phoenix	Current	0.49	0.02	0.96	0.61	0.47	0.11	0.45
"	Old	0.49	0.03	0.95	0.60	0.47	0.13	0.45
San Francisco	Current	0.49	0.06	0.88	0.41	0.51	0.22	0.46
"	Old	0.49	0.09	0.84	0.56	0.56	0.26	0.46
Washington	Current	0.49	0.10	0.75	0.64	0.66	0.31	0.45
"	Old	0.49	0.20	0.62	0.33	0.51	0.33	0.45

Table 4. Heating and Cooling Coincidence Factors for Large Office

Location	Vintage	Light. Conservation Load Factor	Coincidence Factors: Annual Heat.	Annual Cool.	Demand Heat.	Demand Cool.	Utility Demand Heat.	Utility Demand Cool.
Chicago	Current	0.42	0.23	0.65	0.79	1.01	0.39	0.66
"	Old	0.42	0.25	0.62	0.67	0.95	0.37	0.66
Lake Charles	Current	0.44	0.04	0.87	0.77	0.99	0.08	0.70
"	Old	0.44	0.04	0.87	0.64	0.96	0.09	0.70
Los Angeles	Current	0.40	0.03	0.87	0.32	0.97	0.03	0.61
"	Old	0.40	0.03	0.87	0.30	0.96	0.04	0.61
Miami	Current	0.44	0.00	0.92	0.21	0.89	0.01	0.69
"	Old	0.44	0.00	0.92	0.22	0.98	0.00	0.70
Minneapolis	Current	0.42	0.32	0.56	0.63	1.04	0.45	0.66
"	Old	0.42	0.33	0.54	0.61	1.02	0.44	0.66
New York	Current	0.42	0.30	0.57	0.59	1.08	0.48	0.66
"	Old	0.42	0.31	0.55	0.57	1.00	0.49	0.66
Phoenix	Current	0.40	0.03	0.88	0.27	1.19	0.06	0.66
"	Old	0.40	0.03	0.87	0.32	0.96	0.06	0.66
San Francisco	Current	0.40	0.09	0.74	0.61	0.97	0.15	0.61
"	Old	0.40	0.08	0.77	0.61	0.97	0.13	0.61
Washington	Current	0.42	0.18	0.70	0.73	1.07	0.36	0.66
"	Old	0.42	0.20	0.68	0.63	1.03	0.35	0.66

Table 5. Heating and Cooling Coincidence Factors for Large Retail

Location	Vintage	Light. Conservation Load Factor	Coincidence Factors: Annual Heat.	Annual Cool.	Demand Heat.	Demand Cool.	Utility Demand Heat.	Utility Demand Cool.
Chicago	Current	0.44	0.42	0.44	0.35	1.02	0.67	0.80
"	Old	0.44	0.43	0.42	0.32	1.01	0.64	0.79
Lake Charles	Current	0.45	0.10	0.76	0.99	1.08	0.36	0.84
"	Old	0.44	0.11	0.74	0.95	1.06	0.36	0.83
Los Angeles	Current	0.54	0.03	0.88	1.38	0.97	0.07	0.97
"	Old	0.54	0.03	0.88	1.34	0.97	0.07	0.96
Miami	Current	0.45	0.00	0.89	1.18	1.09	0.01	0.84
"	Old	0.44	0.00	0.88	1.08	1.08	0.01	0.83
Minneapolis	Current	0.44	0.49	0.38	0.24	1.08	0.61	0.81
"	Old	0.44	0.50	0.36	0.23	1.05	0.58	0.80
New York	Current	0.51	0.40	0.49	0.72	1.08	0.87	0.94
"	Old	0.50	0.39	0.49	0.51	1.06	0.86	0.93
Phoenix	Current	0.54	0.04	0.88	1.00	0.94	0.09	0.96
"	Old	0.54	0.04	0.88	1.05	0.90	0.10	0.94
San Francisco	Current	0.54	0.12	0.75	0.81	0.97	0.42	1.02
"	Old	0.54	0.19	0.64	0.74	0.95	0.53	1.01
Washington	Current	0.51	0.33	0.55	0.77	1.11	0.83	0.94
"	Old	0.50	0.34	0.54	0.63	1.09	0.83	0.93

Table 6. Heating and Cooling Coincidence Factors for Medium Office

Location	Vintage	Light. Conservation Load Factor	Coincidence Factors: Annual Heat.	Annual Cool.	Demand Heat.	Demand Cool.	Utility Demand Heat.	Utility Demand Cool.
Chicago	Current	0.42	0.34	0.54	0.60	0.89	0.49	0.66
"	Old	0.42	0.37	0.48	0.43	0.93	0.47	0.65
Lake Charles	Current	0.44	0.08	0.81	0.77	0.95	0.16	0.70
"	Old	0.44	0.08	0.80	0.69	0.92	0.16	0.69
Los Angeles	Current	0.40	0.06	0.81	0.82	0.95	0.07	0.60
"	Old	0.40	0.06	0.79	0.63	0.94	0.08	0.60
Miami	Current	0.44	0.01	0.90	0.31	0.75	0.01	0.70
"	Old	0.44	0.01	0.90	0.36	0.92	0.01	0.69
Minneapolis	Current	0.42	0.41	0.47	0.43	1.00	0.51	0.66
"	Old	0.42	0.45	0.41	0.41	0.92	0.50	0.65
New York	Current	0.42	0.35	0.50	0.52	0.96	0.51	0.66
"	Old	0.42	0.37	0.47	0.43	0.93	0.49	0.64
Phoenix	Current	0.40	0.05	0.84	0.45	0.82	0.09	0.67
"	Old	0.40	0.06	0.82	0.53	0.91	0.11	0.65
San Francisco	Current	0.40	0.16	0.65	0.68	0.98	0.23	0.64
"	Old	0.40	0.17	0.63	0.73	0.95	0.23	0.62
Washington	Current	0.42	0.28	0.59	0.65	0.95	0.46	0.66
"	Old	0.42	0.29	0.55	0.58	0.91	0.43	0.64

Table 7. Heating and Cooling Coincidence Factors for Small Hotel/Motel

Location	Vintage	Light. Conservation Load Factor	Coincidence Factors: Annual Heat.	Annual Cool.	Demand Heat.	Demand Cool.	Utility Demand Heat.	Utility Demand Cool.
Chicago	Current	0.39	0.35	0.54	0.60	0.36	0.29	0.36
"	Old	0.39	0.48	0.42	0.36	0.36	0.33	0.38
Lake Charles	Current	0.39	0.16	0.70	0.61	0.37	0.09	0.35
"	Old	0.39	0.19	0.66	0.65	0.37	0.12	0.36
Los Angeles	Current	0.39	0.16	0.63	0.59	0.40	0.01	0.45
"	Old	0.39	0.22	0.56	0.64	0.42	0.02	0.48
Miami	Current	0.39	0.02	0.93	0.43	0.37	0.00	0.36
"	Old	0.39	0.02	0.93	0.38	0.38	0.00	0.35
Minneapolis	Current	0.39	0.43	0.48	0.31	0.40	0.34	0.36
"	Old	0.39	0.54	0.37	0.40	0.36	0.34	0.38
New York	Current	0.39	0.36	0.54	0.34	0.35	0.28	0.36
"	Old	0.39	0.44	0.44	0.34	0.35	0.32	0.37
Phoenix	Current	0.39	0.12	0.78	0.58	0.38	0.01	0.35
"	Old	0.39	0.15	0.74	0.40	0.37	0.02	0.35
San Francisco	Current	0.39	0.31	0.40	0.58	0.43	0.09	0.40
"	Old	0.39	0.44	0.27	0.61	0.42	0.16	0.41
Washington	Current	0.39	0.27	0.62	0.60	0.38	0.21	0.36
"	Old	0.39	0.40	0.50	0.60	0.38	0.28	0.36

Table 8. Heating and Cooling Coincidence Factors for Sit-Down Restaurant

Location	Vintage	Light. Conservation Load Factor	Coincidence Factors: Annual Heat.	Annual Cool.	Demand Heat.	Demand Cool.	Utility Demand Heat.	Utility Demand Cool.
Chicago	Average	0.80	0.44	0.51	0.80	1.02	0.79	1.03
Los Angeles	Average	0.80	0.17	0.75	0.83	1.02	0.43	1.02
Lake Charles	Average	0.80	0.18	0.73	1.03	1.01	0.23	1.09
Miami	Average	0.80	0.02	0.93	0.96	1.02	0.04	1.02
Minneapolis	Average	0.80	0.51	0.44	0.78	1.02	0.85	1.05
New York	Average	0.80	0.42	0.52	0.80	1.01	0.78	1.03
Phoenix	Average	0.80	0.12	0.82	0.89	1.01	0.25	1.02
San Francisco	Average	0.80	0.34	0.54	0.97	1.03	0.57	1.17
Washington	Average	0.80	0.37	0.57	0.83	1.02	0.70	1.02

Table 9. Heating and Cooling Coincidence Factors for Supermarket

Location	Vintage	Light. Conservation Load Factor	Coincidence Factors: Annual Heat.	Annual Cool.	Demand Heat.	Demand Cool.	Utility Demand Heat.	Utility Demand Cool.
Chicago	Current	0.89	0.30	0.61	1.75	1.00	0.76	1.05
"	Old	0.89	0.42	0.48	0.91	1.01	0.86	1.05
Lake Charles	Current	0.89	0.07	0.85	1.69	0.99	0.23	0.98
"	Old	0.89	0.12	0.78	0.96	0.98	0.37	0.98
Los Angeles	Current	0.89	0.04	0.85	1.43	1.08	0.06	1.07
"	Old	0.89	0.08	0.77	1.22	1.07	0.13	1.09
Miami	Current	0.89	0.00	0.97	1.34	0.98	0.01	0.97
"	Old	0.89	0.01	0.96	1.23	0.98	0.01	0.97
Minneapolis	Current	0.89	0.37	0.54	1.88	1.04	0.79	1.06
"	Old	0.89	0.50	0.41	0.90	1.02	0.90	1.07
New York	Current	0.89	0.28	0.62	1.72	1.00	0.73	1.04
"	Old	0.89	0.39	0.49	0.97	0.99	0.85	1.04
Phoenix	Current	0.89	0.03	0.92	1.69	0.99	0.05	0.97
"	Old	0.89	0.08	0.83	0.94	0.98	0.16	0.97
San Francisco	Current	0.89	0.10	0.75	1.66	1.09	0.29	1.14
"	Old	0.89	0.22	0.55	0.96	1.26	0.47	1.10
Washington	Current	0.89	0.22	0.68	1.72	0.99	0.63	1.02
"	Old	0.89	0.34	0.54	1.09	0.98	0.78	1.00

Table 10. Heating and Cooling Coincidence Factors for Secondary School

Location	Vintage	Light. Conservation Load Factor	Coincidence Factors: Annual Heat.	Annual Cool.	Demand Heat.	Demand Cool.	Utility Demand Heat.	Utility Demand Cool.
Chicago	Current	0.29	0.31	0.53	0.50	1.13	0.45	0.25
"	Old	0.29	0.44	0.37	0.65	0.98	0.49	0.23
Lake Charles	Current	0.29	0.11	0.72	1.05	1.09	0.22	0.24
"	Old	0.29	0.15	0.67	1.00	1.02	0.27	0.24
Los Angeles	Current	0.29	0.08	0.75	0.91	1.03	0.09	0.45
"	Old	0.29	0.10	0.70	0.88	0.92	0.13	0.45
Miami	Current	0.29	0.01	0.83	0.47	1.06	0.01	0.24
"	Old	0.29	0.01	0.82	0.47	1.03	0.02	0.24
Minneapolis	Current	0.29	0.40	0.44	0.25	1.13	0.50	0.25
"	Old	0.29	0.51	0.30	0.28	1.00	0.50	0.23
New York	Current	0.29	0.27	0.56	0.29	1.11	0.41	0.24
"	Old	0.29	0.42	0.38	0.29	0.98	0.49	0.23
Phoenix	Current	0.29	0.05	0.79	0.52	1.11	0.09	0.24
"	Old	0.29	0.08	0.74	0.80	1.01	0.15	0.23
San Francisco	Current	0.29	0.15	0.66	0.28	1.02	0.23	0.45
"	Old	0.29	0.23	0.55	0.28	0.92	0.30	0.45
Washington	Current	0.29	0.22	0.62	0.51	1.18	0.38	0.25
"	Old	0.29	0.37	0.44	0.49	1.02	0.47	0.23

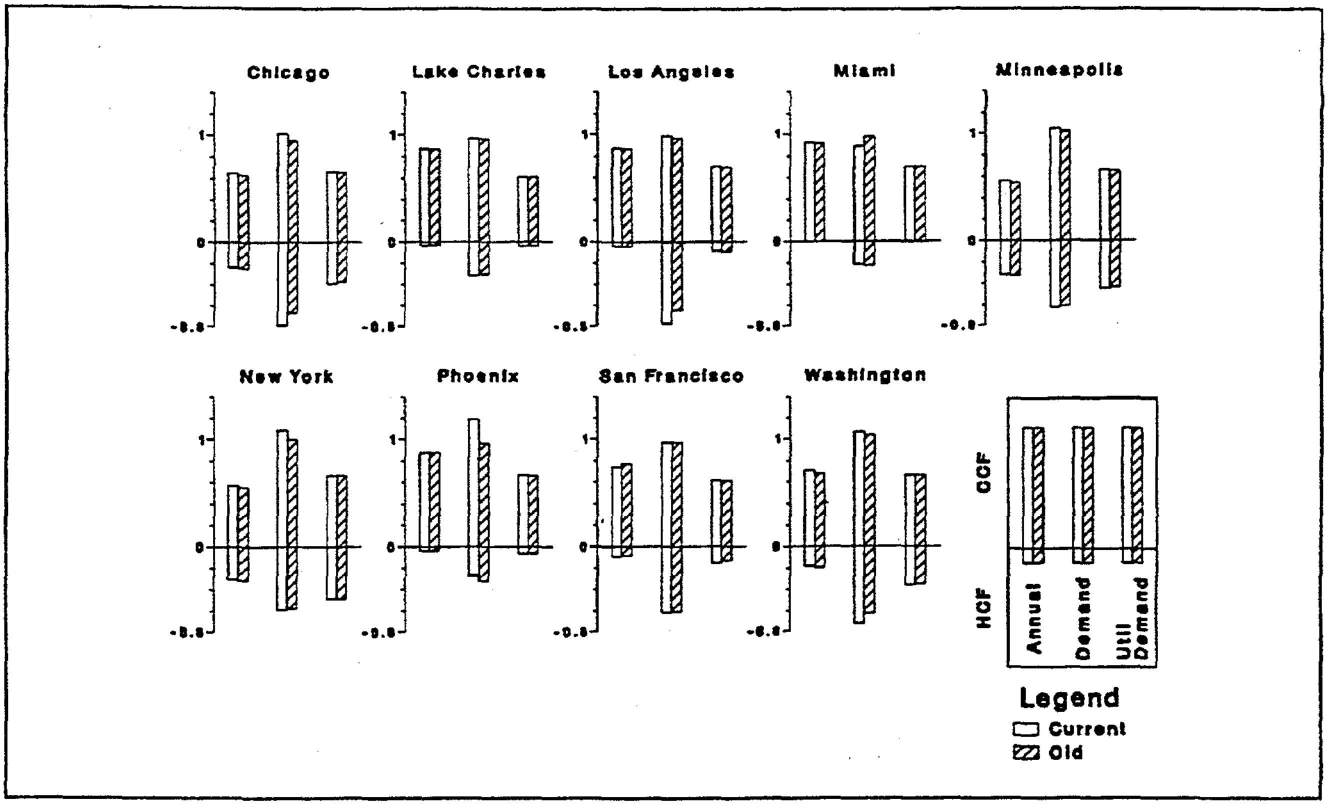

Figure 1. Heating and Cooling Coincidence Factors for Large Office

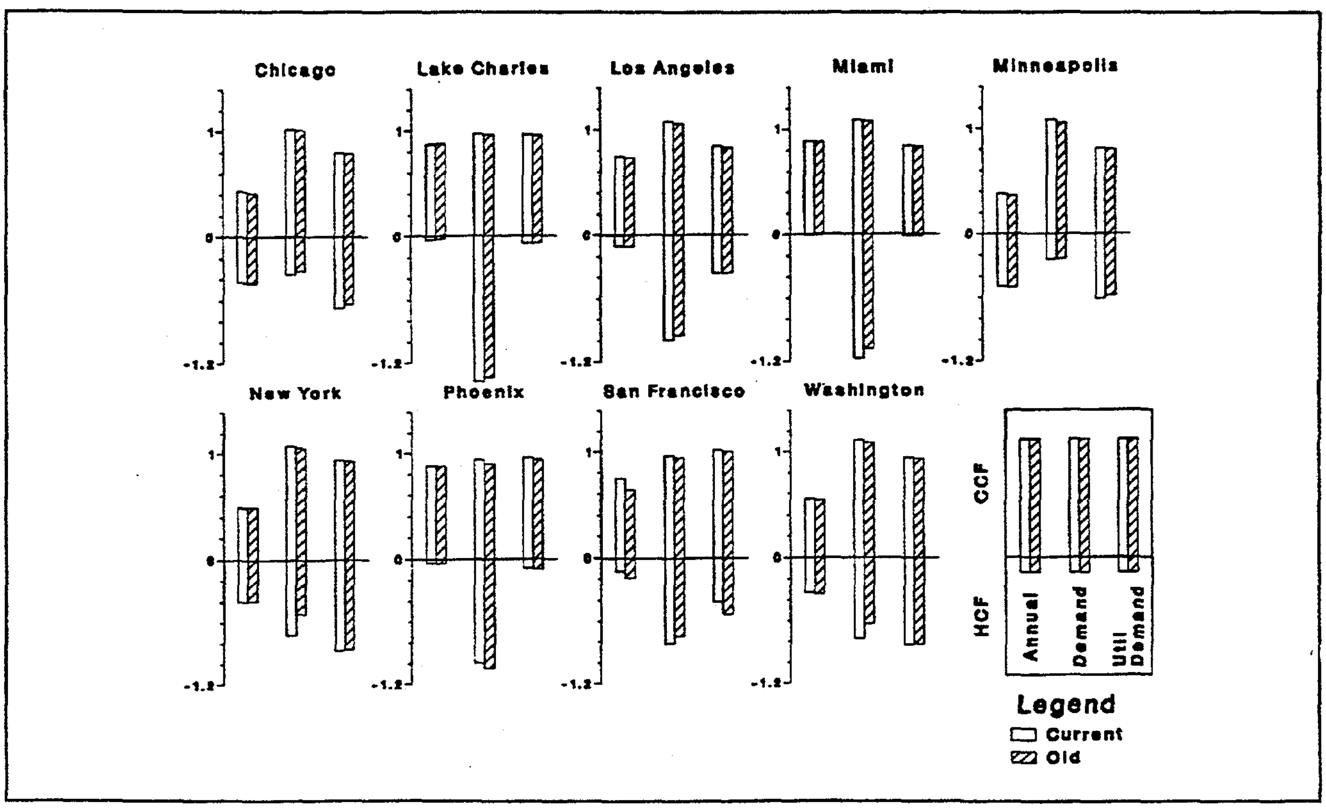

Figure 2. Heating and Cooling Coincidence Factors for Large Retail

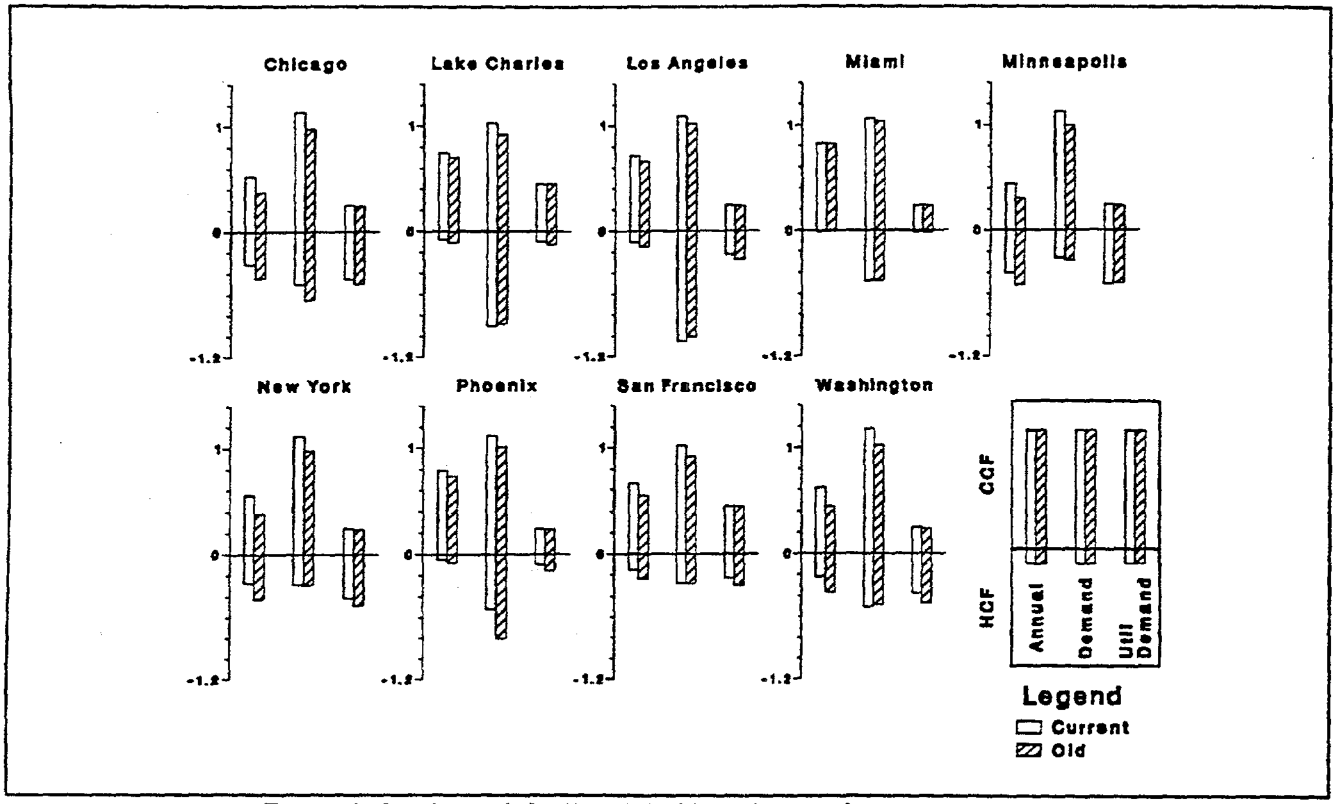

Figure 3. Heating and Cooling Coincidence Factors for Secondary School

lamps with electronic ballast, for offices where an illumination level of 50 lumens/ft^2 is required, the change in lighting power density of 0.43 W/ft^2 can be estimated.[3]

Given the reduction in lighting power density, for the population of current large offices in Chicago for example, the parameters developed in the previous section can be used to calculate the key elements for cost-benefit analysis as shown in Table 11.

Table 11 shows that the above measure will save 1.58 kWh/ft^2 of lighting energy. The annual cooling loads will be reduced by 1.03 kWh/ft^2 and the annual heating load will be increased by 0.36 kWh/ft^2. If we assume an average cooling Coefficient of Performance (COP) of 3, the cooling electricity consumption will be 0.34 kWh/ft^2. For the electrically heated segment of floorstock in the Chicago area, it is clear that the gain in cooling is almost same as the loss in heating in terms of site electricity.

Table 11 also shows that cooling equipment can be down sized by the full amount of the LPD reduction (0.43 W/ft^2), although the electric utility will see only approximately 2/3 of this reduction in terms of cooling load (0.28 W/ft^2). Using a cooling COP of 3, the coincident electricity demand reduction that the utility will see will be 0.09 W/ft^2 (0.28*1/3). The heating equipment has to be sized up by 0.34 W/ft^2 but only about half of this increase in heating load will effect the coincident utility peak if the heating is by electricity.

Related Work

For more accurate cost-benefit analyses, region specific parameters can be developed for specific utilities and rate schedules, using the hourly outputs generated by the simulation runs used for this paper.

For a more detailed analysis from the customer point of view, a more accurate estimation of the reduction in utility bills may required. The energy expenses can be estimated by binning the heating/cooling loads for the building into on-peak and off-peak periods shown in the particular rate schedule and determining the energy and demand charges using efficiencies for the heating and cooling equipment. Since the rate schedules are considerably different from region to region, this paper does not try to generalize the estimation of customer energy expenses.

Similarly, for the analysis from a utility's point of view, HVAC loads can be binned into utility on-peak and off-peak periods depending on the utility's base load generation capacity and sizes of the cycling and peaking generation units. The load reduction at the peak of the

Table 11. Calculation of Changes in Annual and Peak Air-conditioning Loads for New Large Office Buildings in Chicago for a Reduction in LPD of 0.43 W/ft^2

	Equation	Value
Lighting Energy Savings (kWh/ft^2)	ΔLPD * Lighting Conservation LF * 8760/1000	1.58
Annual Heating Load Penalty (kWh/ft^2)	Lighting Energy Savings * Annual Heating CF	0.36
Annual Cooling Load Savings (kWh/ft^2)	Lighting Energy Savings * Annual Cooling CF	1.03
Heating Capacity Penalty (W/ft^2)	ΔLPD * Heating Demand CF	0.34
Cooling Capacity Savings (W/ft^2)	ΔLPD * Cooling Demand CF	0.43
Increase in Heating Load at Utility Peak in Winter (W/ft^2)	ΔLPD * Utility Heating Demand CF	0.17
Reduction in Cooling Load at Utility Peak in Summer (W/ft^2)	ΔLPD * Utility Cooling Demand CF	0.28

particular utility can also be recorded. Utility avoided costs can then be estimated more accurately using efficiencies for the heating and cooling equipment. Again, we do not attempt to generalize the on- and off-peak hours for generation; therefore, this paper does not cover development of these parameters.

The methodology presented in this paper has to be modified for buildings which utilize economizers. Generally, it is safe to assume that the heating/cooling demand and the annual heating load will not be effected seriously because of the existence of economizers. On the other hand, the annual cooling load will change considerably, and the annual cooling coincidence factor has to be reduced to account for this change. There are several ways of estimating the correction on the annual cooling coincidence factors. The most accurate way is by modeling the building with the particular HVAC system, but this involves a large number of simulation runs and development of factors for each type of HVAC system. A simpler way is by estimating the reduction in cooling hours due to the economizer and reducing the cooling energy coincidence factor by the same ratio.

Finally, the authors have tried to develop regression equations to estimate the parameters developed in this paper from the heating and cooling degree days. It was possible to get satisfactory estimations for the heating related parameters but not for the cooling related parameters. Therefore, for regional studies, depending on the nature of the analysis, it may be advisable to run the building models with the specific weather data.

Endnotes

1. The term "conservation load factor" was introduced by Koomey et al. (1990).

2. The issue of estimation of a conservative coincidence between building loads and utility system peak is covered in detail in Nadel et al. (1993).

3. Efficacies of 65 lumens/W and 88 lumens/W are assumed for the standard fluorescent lamp with energy efficient magnetic ballast and T8 fluorescent lamp with electronic ballast respectively. A fixture efficiency of 0.7 and a room efficiency of 0.67 are assumed for both cases (Coefficient of Utilization = $0.7 \times 0.67 = 0.47$).

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