CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

2008 California Energy Commission Title 24 Building Energy Efficiency Standards
March 28, 2006

Draft Report
TDV (Time Dependent Valuation)
Lighting Controls Schedules

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Overview

Starting with the 2005 Title 24 building efficiency standards, a new basis was developed for comparing the energy impacts of various efficiency measures. This basis, called time dependent valuation or TDV, compared the costs of providing energy on an hour by hour basis. This valuation scheme recognized that electricity provided during times of peak system electrical load on hot summer days could cost as much as a 10 times more than electricity provided during times of low system loads. As a result, the energy efficiency standards provide more credit to those measures that reduce peak demand. This TDV basis is incorporated into the alternative compliance method calculations (performance approach) in that each hour of energy consumption simulated is multiplied by a TDV factor that accounts for the cost of energy for that hour.

Now that the alternative compliance method (ACM) has a method of evaluating the relative value of efficiency measures with respect to their timing of savings, we are proposing an upgrade to how the energy savings of lighting controls are calculated. As will be described below, the changes proposed here do not alter the lighting control credits given by the prescriptive method, nor do they have appreciable impact on the outcomes of the performance method compliance simulations. These changes do however; alter the fundamental method of how lighting control savings are calculated. This change in methodology may be more significant if the time dependent valuation factors change substantially or additional controls, which specifically target demand reduction, are given compliance credits.

Description

This code and standards enhancement initiative will encourage the use of the existing capabilities of the California Energy Commission approved energy simulation tools for modeling lighting controls in line with the TDV regimen.

The 2005 Title 24 standards encourage multi-level occupancy sensing and daylighting controls through lighting credits called Power Adjustment Factor or PAF. Power Adjustment Factors are a way of encouraging application of a new technology by giving compliance credit for the control. Lighting that is automatically controlled by qualifying controls is treated as if there is less installed lighting for compliance purposes. Controls that qualify for such PAFs are in Table 146-A of the 2005 Title 24 Standards. Currently, those lighting systems which have a lighting credit (PAF) associated with them are modeled in the performance approach as if the lighting system simply has a lower connected load. In other words the presence of a lighting control reduces the power draw of the controlled lighting uniformly over all hours.

In the past the timing of the power reduction from controls was not important as the value of a kWh of electricity was unvarying. With the introduction of TDV (time dependent valuation) which values electricity consumed during hot summer afternoons much more than that consumed at night or during mild weather, the timing of lighting energy consumption is more important. Thus to better evaluate the trade-off between lighting controls and other measures using the performance (computer energy simulation) approach, an improved model of lighting controls would more closely approximate the timing of power reductions. A daylighting control would reduce power draw the most when there is lots of sunlight, and an occupancy sensor would reduce power consumption most during off hours and during lunch periods when spaces are unoccupied.

For occupancy sensor based controls that receive PAFs, we propose a change in the *lighting schedule* modeled in the compliance software, where some hours would have power reduced more than others, based on the best available existing data on occupancy sensor usage. Similar time varying reductions in lighting power are proposed for daylighting controls in the "Revisions to the Treatment of Skylighting" and "Revisions to the Treatment of Sidelighting" CASE reports. In these other reports, daylight-responsive lighting controls (photocontrols) reduce power consumption in a time varying manner based on daylight availability whereas the power reductions from occupancy sensors described in this report are based on time schedules.

Energy Benefits

The proposed measures are a change to the calculation procedures in making performance calculations for existing lighting controls credits in the 2005 Title 24 standards. We are not proposing a change to the magnitude of lighting controls credit provided for each of the measures, and hence do not anticipate any additional savings due to the measures outlined in this CASE report.

Though there are no savings from this proposal as compared to the 2005 Standards, this report confirms that the actual lighting energy savings and TDV weighted energy savings are greater than the control credits given by Title 24. Thus a minimally compliant building making full use of the Power Adjustment factors and installing more connected lighting power would consume less lighting energy than a minimally compliant building without qualifying controls. This results in a net energy cost savings for the building with qualifying occupancy sensing controls. This conservativism for evaluating the impacts of automatic lighting controls is justified on several grounds: the life of the lighting controls is expected to be less than the life of the lighting systems they control and the level of confidence in the estimates of savings from occupancy sensor controls is lower than the estimate of consumption from connected lighting loads. Some of these controls savings estimates are based on a handful of manufacturer conducted studies.

Non-energy Benefits

The primary non-energy benefits resulting from lighting controls are the reduction in air emissions that results from any energy savings measure and the increase in electric system reliability that accompanies the reduction in peak electrical demand. However, since this calculation method does not change appreciably the compliance credit associated with these lighting controls there is no net environmental benefit. The benefit of this proposal is to preferentially value those controls which save primarily peak electrical demand.

Currently, single level on/off occupancy controls are used as an alternative to time sweep (time clock) automatic off controls that are a mandatory requirement in Section 131(d). Occasionally, these single level occupancy sensors can falsely detect no occupancy and turn off lights until larger movements are made in the space. This can be an annoyance and have some small effect on productivity. Most of the controls described here are either manual-on or bi-level occupancy controls. The manual-on feature does not impact the timing of occupancy sensors turning off and thus would not have any impacts associated with annoyance. Manual-on controls save energy; these controls allow occupants to consciously decide whether or not they want their lights turned on. Manual-on controls also reduce the possibility that lights are turned on by activity in nearby areas. Bi-level controls either control only half of the lights or require that a manual operation is required to turn on all the lights. When only half of the lights are controlled in areas such as library stacks and warehouses, this minimizes safety and security issues associated with all of the lights being off in these areas as they are initially entered. Thus these measures have a small positive non-energy impact relative to single level automatic on occupancy sensors. However, this calculation method does not change the compliance credit incentives that exist in the 2005 Standards.

Statewide Energy Impacts

This proposal recommends changes to the performance method calculation procedures for lighting controls credits that already exist in the 2005 Title 24 standards. We do not propose a change to the magnitude of lighting controls credit provided for each of the measures, and hence do not anticipate any additional savings due to the measures outlined in this CASE report relative to the 2005 Standards.

However, as mentioned earlier, the savings calculated in both the prescriptive PAF's in Table 146-A and the method to calculate similar levels of savings in the performance approach are less than the actual energy savings from these controls. Thus, when these controls are applied to minimally compliant buildings across the state of California, energy savings result.

If 1% of the 91 million sf of qualifying new commercial construction area makes use of the advanced controls that qualify for compliance credits, the net statewide savings would be approximately 143 MWh/yr from the first year's new construction. These results are contingent on the sustained operation of the controls. The details of this estimate are described in the Results section of this report.

Environmental Impact

This proposal if adopted would change the performance method calculations for lighting controls credits in the 2005 Title 24 standards. We do not propose a change to the magnitude of lighting controls credit provided for each of the measures, and hence do not anticipate any additional savings due to the measures outlined in this CASE report. There are no adverse environmental impacts identified.

Type of Change

Modeling The change would modify the calculation procedures or assumptions used in making performance calculations for PAFs in Table 146-A of the 2005 Title 24 Standards. This change would not add a compliance option or a new requirement, but would affect the way that tradeoffs are made in the performance method.

The Nonresidential Alternative Compliance Manual would be updated to reflect the change in calculation procedures for PAFs in Table 146-A of the 2005 Title 24 standards:

- For occupancy sensor based measures we propose additional hourly lighting schedules that incorporate Hourly Adjustment Factors (HAFs) derived from field research.

Technology Measures

The proposed measures use existing occupancy sensor based technologies that are promoted in the 2005 Title 24 standards.

Measure Availability and Cost

Some of the control technologies have been widely available for a long time while the bi-level controls are relatively new. This proposal does not introduce any new control credits or applicable technologies. The pricing of controls was not preformed for this CASE report since there is not a need to evaluate cost-effectiveness for compliance credits. Such an analysis would have been necessary if we were recommending a prescriptive or mandatory requirement.

Useful Life, Persistence and Maintenance

The changes proposed in this document are of a modeling nature, and we do not propose any change to the measure life, persistence and maintenance procedures for the occupancy based sensors currently embedded in the PAF calculations in the standards.

Performance Verification

We do not propose any additional performance verification of the measures in this document than what is currently required per the Mandatory requirements and Acceptance Testing requirements in the standards.

Cost Effectiveness

A cost-effectiveness analysis was not performed since this proposal does not include any new mandatory or prescriptive requirements.

Analysis Tools

The recommendation is to provide Hourly Adjustment Factors for the modeling of sensors eligible for PAFs in Table 146-A of the 2005 Title 24 standards. Creating these factors required no special analysis tools. The compliance calculations in the Nonresidential ACM manual would need to be updated to reflect the change in calculation procedures.

Relationship to Other Measures

The time dependent valuation of occupancy based lighting controls interacts with other forms of lighting controls. The combined occupancy and daylighting controls listed in this proposal apply a revised lighting schedule to the occupancy part of the savings while daylighting controls will be modeled using the daylighting algorithms in the reference tool (DOE-2.E). The modeling rules for daylighting controls are contained in the "Revisions to the Treatment of Skylighting" and "Revisions to the Treatment of Sidelighting" CASE reports. This proposal currently has a placeholder for an estimate of savings for manual dimming with automatic load control of dimming ballasts. This measure will be evaluated in more detail in the demand response section of the CASE report on Indoor Lighting. Depending on the outcome of that report and the timing of the demand response signal within the compliance simulation, the schedule and format for demand responsive controls may change.

Methodology

This section describes the analysis procedures used to calculate Hourly Adjustment Factors for the PAFs awarded to occupancy sensor based controls in Table 146-A of the 2005 Title 24 standards.

In the 2005 ACM rules, the TDV kBtu 2005 PAF credit is calculated by proportionally reducing the controlled wattage specified by the designer in the proposed model, while keeping the same schedule for both the proposed and base case models.

For the TDV kBtu actual savings, we propose revised schedules for lighting usage to account for the controls operation, instead of using a simple proportional wattage reduction number for all hours. The schedules that we developed are based upon a review of all available hourly lighting controls data from various monitoring projects.

Review of Available Research Data

The first step of the analysis was to review the best available data on the savings available from occupancy sensor based measures. In this section we present the nature of the data and the results derived from the data sources.

To be useful in this study, research data had to be broken down by hour of the day. Most data was not available by hour, or was only recorded for "working hours" or some other subset of the day.

Additionally, lighting energy use both with and without occupancy sensors had to be recorded. From an initial pool of twenty candidate studies, we were able to identify five research studies that fulfilled these criteria, and that were methodologically sound. The five studies are described below; three are peer-reviewed research papers, one is a report on a research study conducted by a private consultant for a utility, and one is a database of information from a reputable lighting controls manufacturer.

ADM Associates, Lighting Controls Effectiveness Assessment (2002)

This study was conducted by ADM Associates for Southern California Edison Company under the Statewide MA&E Program for Nonresidential New Construction. Data loggers that recorded occupancy and the state of the lighting were placed in 62 classrooms, 67 open offices, 88 private offices and 39 retail spaces, and were left in place for two weeks. All the spaces had only manual bi-level controls (i.e. no occupancy sensors or photocontrols) and were located in California. Data was presented for weekdays only, not for weekends. We used only the data from classrooms and private offices.

Richman, Dittmer and Keller, Field Analysis of Occupancy Sensor Operation: Parameters affecting lighting energy savings (1996)

This study was conducted by staff at the Pacific Northwest National Laboratory, on offices that were occupied by government employees. This research was described in a paper for the Illuminating Engineering Society of North America (IESNA). Data loggers that recorded occupancy and the state of the lighting were placed in many types of space, and were left in place for around two weeks; for this analysis we included data from nine private offices. All the spaces had only manual single-level or bi-level controls (i.e. no occupancy sensors or photocontrols) and were located at the DOE's Hanford Site, just north of Richland in southern Washington State. Data was only available for the "whole week", i.e. there was no distinction between weekends and weekdays. The occupancy data was logged using occupancy sensors that had a time delay of 5-8 minutes.

Jennings, Rubinstein and DiBartolomeo, Comparison of Control Options in Private Offices in an Advanced Lighting Controls Testbed (2000).

This large scale study, conducted by staff at Lawrence Berkeley Lab, analyzed the effects of several different lighting control systems in a federal office building, including occupancy sensors. Since there were overlapping controls in the study spaces, there may be a slight confound in the data because occupants' use of their manual light switches many have been influenced by the lights being dimmed or switched by other control systems. Data was recorded for 70 single-occupant offices on two floors of a government office building in San Francisco. Half the offices were on the third floor and half on the fifth floor, so we have treated these as two separate data sets. Data was logged over several months.

For this study, the data showed all the times at which the lighting was switched on (whether or not it had been dimmed). Unfortunately, the study did not collect data on the occupancy of the space so we had no way of determining manual light switch use without the occupancy sensors, and therefore did not have a baseline from which to determine the savings. Instead, we used the Title 24 baseline for "other buildings" and subtracted the actual energy use from that to arrive at the savings. The fit between these curves was remarkably good – for instance there were no times at which the actual lighting usage exceeded the Title 24 baseline, so we believe this data are good.

Data were presented for weekdays only, not for weekends. Some spaces were excluded by the original authors because they were only occasionally occupied (their requirement was a minimum of 4.5 hours occupation per day). The occupancy sensors had a 15 minute time delay, and were manual-on.

Von Neida, Maniccia and Tweed, An Analysis of the Energy and Cost Savings Potential of Occupancy Sensors For Commercial Lighting Systems (2000).

This study was conducted by the Lighting Research Center at Rensselaer Polytechnic University, for the U.S. Environmental Protection Agency's ENERGY STAR Buildings Program. Data loggers that recorded occupancy and the state of the lighting were placed in five different types of spaces (break rooms, classrooms, conference rooms, private offices, restrooms). This study analyzed lighting and occupancy patterns in 42 restrooms, 37 private offices, 35 classrooms, and 33 conference rooms. These spaces were in the north-east US, so probably did not have bi-level switching as they would be required to in California. However, this difference does not affect the savings estimate as long as on/off (rather than bi-level) occupancy controls are assumed. This is because the presence of bi-level switching makes the same proportional difference to energy consumption both with and without the occupancy sensors, so the effect cancels out and leaves the proportional savings unchanged.

In this study data was presented only for weekdays, not for weekends. All the spaces in the study had manual controls only, i.e. no occupancy sensors, but logging occupancy sensors and lighting current loggers were used to record the state the lighting was in, and to calculate potential savings from occupancy sensors.

Usefully, this paper contains calculations showing the effect on energy savings of various different occupancy sensor time delays, in different building types. These values were used to adjust the calculated savings for several other data sources (i.e. those for which the effect of occupancy sensor time delays were not included in the data, or could not be calculated from the data).

Sensorswitch Inc. Unpublished Internal Project Database (2005)

Sensorswitch Inc is a lighting controls manufacturer based in Connecticut; they maintain a set of loggers that record occupancy and lighting status, and they loan these loggers to prospective clients that wish to make accurate assessments of the energy savings achievable from occupancy sensors.

Sensorswitch maintains ownership of the logged data, and has created a database of results from thousands of spaces. Most of the spaces are offices and schools, but were able to obtain results for 18 warehouse spaces, four library spaces and one hotel hallway. Because of the large number of warehouse spaces and the very large amount of data recorded for each space, we analyzed four warehouse spaces that were representative of the broader sample both in terms of the magnitude of the savings and the hourly distribution. For reasons of confidentiality the location of the logged spaces is not known, but is probably not in California.

Match between Data Sources and Data Requirements

Our bibliographic search showed that existing research data covers only offices and schools, so we attempted to find other sources of data for the other building types. As can be seen in Figure 1, the data from Sensorswitch is the only source of data for these other building types.

Type of Control (from Title 24 2005 table 146)	Types of Space	ADM Associates	Richman, Dittmer and Keller	Jennings, Rubinstein and DiBartolomeo	Von Neida, Maniccia and Tweed	SensorswitchInc.
Occupant sensor with "manual ON" or bi-level automatic ON combined with multi-level circuitry and switching	Any space <250 sq ft enclosed by floor-to-ceiling partitions; any size classroom, corridor, conference or waiting room	2(131)	9(9)	2(46)	4(116)	
Occupant sensor controlled multi-level switching or dimming system that reduces lighting power at least 50% when no persons are present	Hallways of hotels/motels					1(1)
	Commercial and industrial storage rack areas					4(4)
	Library stacks					4(4)
Dimming system (manual)	Hotels/motels, restaurants, auditoriums, theaters					
Dimming system (multiscene programmable)	Hotels/motels, restaurants, auditoriums, theaters					
Manual dimming with automatic load control of dimmable ballasts	All building types					

Figure 1 - Number of Data Sources (Number of Studies Spaces) for Each Control/Occupancy Type

Figure 1 shows the depth of research data that was available for each of the control/occupancy types. The first number in each cell shows the number of independent data sets, while the number in parentheses shows the number of spaces that were studied. For instance in the ADM associates study, data was collected on 131 spaces but this was combined into just two data sets (one dataset contained 69 offices, the other contained 62 classrooms); in the

Richman et al. paper nine spaces were studied, and the data from each individual space was available so there are nine datasets.

We were unable to find research data for three of the control systems types listed in Table 146-A of the 2005 Title 24 Standards: manual dimming, multiscene programmable dimming, and manual dimming with automatic load control. Also we had data on only one hallway space.

Analysis

The analysis of the research data involved several distinct phases which are outlined below. Note that the calculations assume a manual ON occupancy sensor, and that in California where bi-level switching is mandatory this gives a higher estimate of savings than would be obtained from a bi-level automatic ON sensor. In the majority of spaces a manual ON occupancy sensor is the best and most common solution, but in a few spaces such as libraries or warehouse aisles a bi-level automatic ON may be a better choice.

Term	**Abbrev.**	**Explanation**
Raw hourly adjustment factor	$rHAF_{h,d}$	From the raw research data, savings as a proportion of baseline consumption for each hour and each day type (note, this value is the same whether TDV-weighted or not)
Raw daily adjustment factor	$rDAF_{TDV,d}$	From the raw research data, average savings as a proportion of baseline for each day type (Saturday, Sunday, weekday), weighted by the varying TDV value of each hour
Raw power adjustment factor (kWh)	$rPAF_{kWh}$	From the raw research data, average savings as a proportion of baseline for the whole week (note, this is not TDV-weighted)
Raw power adjustment factor (TDV-weighted kWh)	$rPAF_{TDVkWh}$	From the raw research data, average savings as a proportion of baseline for the whole week, weighted by the varying TDV value of each hour
Hourly adjustment factor	$HAF_{h,d}$	Final, smoothed and adjusted hourly adjustment factors for each hour and each day type, proposed for use in Title 24 2008
Power adjustment factor (kWh)	PAF_{kWh}	Power adjustment factor based on total energy consumption.
Power adjustment factor (TDV-weighted kWh)	PAF_{TDVkWh}	Power adjustment factor based on TDV-weighted energy consumption; can be compared with PAFs in table 146-A of Title 24 2005

Figure 2 – Glossary of Terms and Abbreviations

Adjustments for Occupancy Sensor Time Delay

The first stage in the processing of the savings data was to ensure that all the data sets were comparable in terms of occupancy sensor time delay, since longer or shorter delays would affect the amount of savings. We decided to normalize to a 10-minute time delay, since this value falls in the middle of the range of occupancy sensor time delays that were used in the research data discussed above.

Calculated adjustment factors for 10-minute delays from Von Neida, Maniccia and Tweed were applied to the data from ADM and Von Neida, Maniccia and Tweed. These factors are shown in Figure 3; they are multipliers rather than "adjustment factors", so the savings calculated using a 0-minute time delay were multiplied by the factors in Figure 3 to obtain a value for savings with a 10-minute delay. It can be seen that classrooms have the highest multiplier, and this is because classrooms tend to have the least intermittent occupancy pattern; break rooms have the lowest multiplier and the most intermittent occupancy pattern.

The data from Richman et al. and from Jennings et al. already included a time sensor delay (5-8 minutes, and 15 minutes respectively). The data from Sensorswitch was broken down by 1-minute increments so we could directly calculate the effect of a 10-minute delay from the raw data.

Area	**Adjustment factor**
Break rooms	0.40
Classrooms	0.76
Conference rooms	0.69
Private offices	0.57

Figure 3 – Adjustment Factors Applied to "Ideal" Savings to Take Account of 10-Minute Occupancy Sensor Time Delay

Raw Hourly Adjustment Factors (rHAFs)

The "raw" data is calculated directly from our data sets. Hourly adjustment factors represent the fraction of baseline lighting energy consumption that is saved by the control system at each hour of the day. HAF profiles therefore consist of 24 hourly values. HAF profiles are defined for each occupancy/control type, and for each day type (Saturday, Sunday, weekdays). For each occupancy/control type, the HAF for a particular hour and day type is denoted by $HAF_{h,d}$.

$$rHAF_{h,d} = \frac{Savings_{h,d}}{Baseline\_consumption_{h,d}}$$

Where:

Subscript h refers to a particular hour of the day

Subscript d refers to a particular day type (Saturday, Sunday, weekday).

For several of the control/occupancy types, there was more than one relevant data set, so the profiles from these data sets had to be combined. We took a simple average of the profiles to create a combined profile.

It might have been desirable to take a weighted average of the energy savings from each of the studies, since some of the studies included more spaces or more floor area than others. However, because the larger studies often included multiple spaces in the same building, we felt that the similarity between these spaces didn't make them significantly more representative than results from fewer spaces in a different building.

The raw hourly adjustment factor profiles for each occupancy/control type for weekdays are shown in Figure 4.

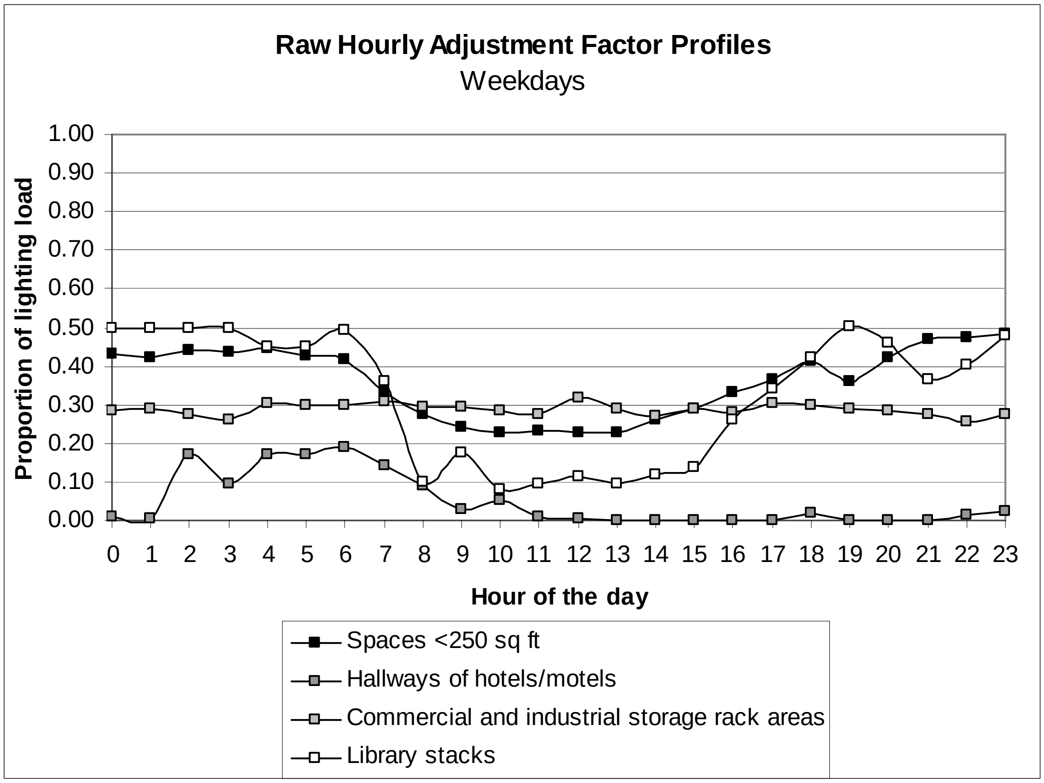

Figure 4 – Raw Hourly Adjustment Factor Profiles (Weekdays)

Raw Daily Adjustment Factors (rDAFs)

For each day type, we calculated a single TDV-weighted value for the amount of energy saved by the controls. This value is the Daily Adjustment Factor (DAF). The DAF is defined for a particular occupancy type and for a particular day type, and is denoted by DAF_d.

DAFs for each day were calculated by multiplying the HAF for each particular hour by the TDV kBtu value for the same hour on that day (see Table 1), and then dividing by the sum of those TDV kBtu values to give an average figure, as shown below.

$$rDAF_d = \frac{\sum_{h=0}^{23} rHAF_{h,d} \times TDV(kBTU)_{h,d}}{\sum_{h=0}^{23} TDV(kBTU)_{h,d}}$$

Where:

$rDAF_d$ is a single TDV-weighted figure for that day type

$TDV(kBtu)_{h,d}$ is the TDV value per kBtu for that hour and day type

Raw Power Adjustment Factors (rPAFs)

For each occupancy/controls type, and for each day type we generated two single-figure PAFs: one representing simple kWh savings and the other representing TDV-weighted kWh savings.

To calculate the simple kWh PAF we simply averaged the HAF values over the entire week, as shown below:

$$rPAF_{kWh} = \frac{\sum_{0}^{23} rHAF_{h,sat} + \sum_{0}^{23} rHAF_{h,sun} + 5\sum_{0}^{23} rHAF_{h,weekday}}{7 \times 24}$$

To calculate the TDV-weighted PAF we took a weighted average of the DAF values for each day type (weighted because there are more weekdays than weekends), as shown below:

For each control/occupancy type:

$$rPAF_{TDVkWh} = \frac{rDAF_{saturday} + rDAF_{sunday} + 5(rDAF_{weekday})}{7}$$

Final (Smoothed and Scaled) Hourly Adjustment Factors

Creating finalized curves for hourly adjustment factors involved two distinct stages. First, the HAF profiles were smoothed to remove random noise, and second the smooth curve was scaled up or down so that its total area corresponded to the required value ($PAF_{TDV\ kWh}$).

Smoothing

Most of the hourly profiles exhibited random variation from one hour to the next – a consequence of sparse data. We divided up the PAF profiles into two types: those for which we were very confident of the statistical validity of the data, and those for which we were not. For the former profiles we simply fitted a smooth curve through the data, while for the latter we simply averaged the hourly PAF values to produce a flat hourly profile. The division of the data is shown in Figure 5.

Profiles with High Confidence (smoothed profiles)	**Profiles with Low Confidence (averaged profiles)**
Spaces <250 sf, weekdays	Storage rack areas, weekdays
Library stacks, weekdays	Storage rack area, weekends
	Library stacks, weekends

Figure 5 – Division of HAF profiles into "high confidence" and "low confidence" Scaling

The final step was to scale the HAF profiles up or down so that the total value of the savings equaled the PAF value.

For each occupancy/control type:

$$HAF_{h,d} = rHAF_{h,d}\left[\frac{PAF_{TDVkWh}}{rPAF_{TDVkWh}}\right]$$

At this stage of the analysis we expanded the results to include one further control type – occupancy sensors *and manual dimming* in spaces <250 sf. From Title 24 2005, the PAF for this option is 0.25 (compared to 0.2 without manual dimming), so we simply scaled up each hourly HAF value by a factor of 1.25 (0.25/0.2). We considered whether or not to scale up the HAFs only during occupied times, on the basis that manual dimmers are more likely to be used during occupied periods, but a review of the limited research on this topic[1] showed that occupants very infrequently adjust their dimming settings, and tend to leave their dimmers set at the same level for extended periods. For this reason we assumed that dimmers would be just as likely to accrue savings during unoccupied as during occupied periods.

Analysis Results

The figures below (Figure 6 – Figure 9) show the final PAF and HAF for each occupancy/control type. We determined that there was insufficient data to calculate a figure for Hallways of Hotels and Motels, because we had only one set of data and that set appeared to show highly unusual schedules (very high occupancies in the early morning) that were not representative of hotels in general.

Furthermore, we had no data for weekend savings for spaces <250 sf; all the data sets we had did not include weekends, perhaps because most researchers don't consider weekend savings as worthwhile. They (?) conservatively assumed that weekend savings were zero, so the PAFs for spaces <250 sf should be taken as lowest possible values.

Single-Value DAFs and PAFs

		Raw Data from Research		
		kWh	**TDV-weighted kWh**	**PAFs from T24 2005**
Spaces <250 sq ft	$rDAF_{Saturday}$	no data	no data	0.20
	$rDAF_{Sunday}$	no data	no data	0.20
	$rDAF_{weekday}$	0.37	0.36	0.20
	PAF	**0.27**	**0.27**	**0.20**
Hallways of hotels/motels	$rDAF_{Saturday}$	insufficient data	insufficient data	0.25
	$rDAF_{Sunday}$	insufficient data	insufficient data	0.25
	$rDAF_{weekday}$	insufficient data	insufficient data	0.25
	PAF	**insufficient data**	**insufficient data**	**0.25**
Commercial and industrial storage rack areas	$rDAF_{Saturday}$	0.26	0.26	0.15
	$rDAF_{Sunday}$	0.27	0.27	0.15
	$rDAF_{weekday}$	0.29	0.29	0.15
	PAF	**0.28**	**0.28**	**0.15**
Library stacks	$rDAF_{Saturday}$	0.30	0.30	0.15
	$rDAF_{Sunday}$	0.24	0.24	0.15
	$rDAF_{weekday}$	0.33	0.31	0.15
	rPAF	**0.31**	**0.30**	**0.15**

Figure 6 – Data from Research: Single-Value PAFs for Each Control/Occupancy Type compared to Title 24 PAF's

[1] Moore, Carter, Slater (2003). *Long-Term Patterns of Use of Occupant Controlled Office Lighting*, Lighting Research and Technology. 35, 1 (2003) pp. 43–59. Moore et al found that "very few [occupants] use [dimmers] for anything other than to switch on upon arrival at work, with further use of systems during the day being rare."

HAF Profiles

In each of the graphs below, the HAFs are shown for each day type, for each occupancy/control type. The Title 24 2005 PAF is also shown for reference (this is of course a straight line because Title 24 2005 PAFs do not vary by hour).

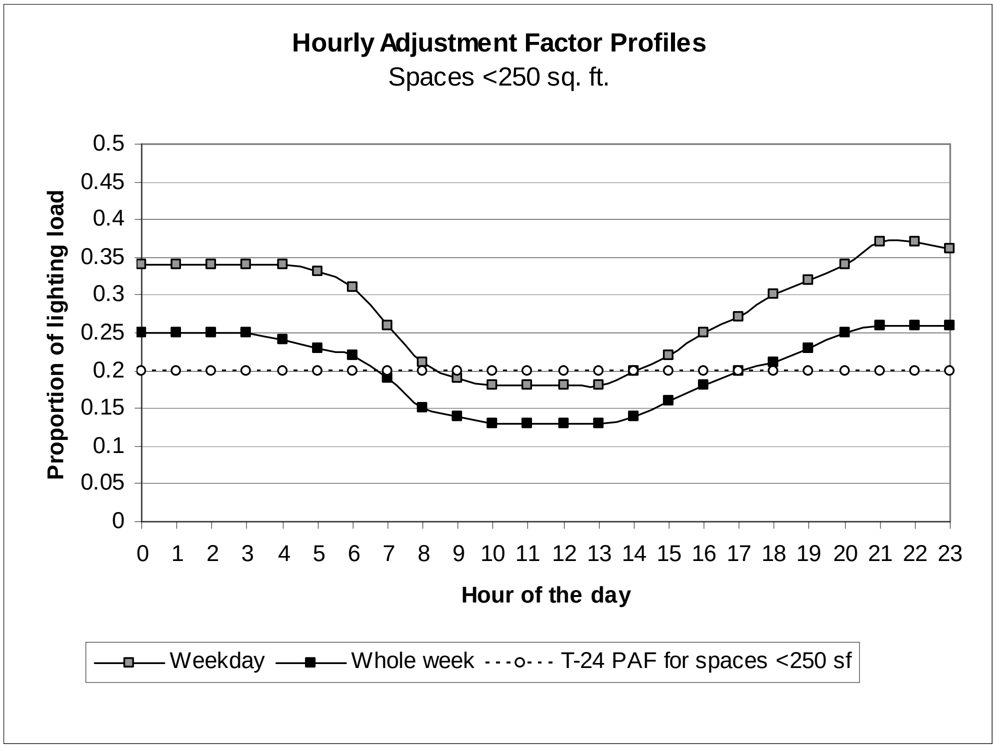

Figure 7 – Hourly Adjustment Factor Profiles (spaces <250 sf)

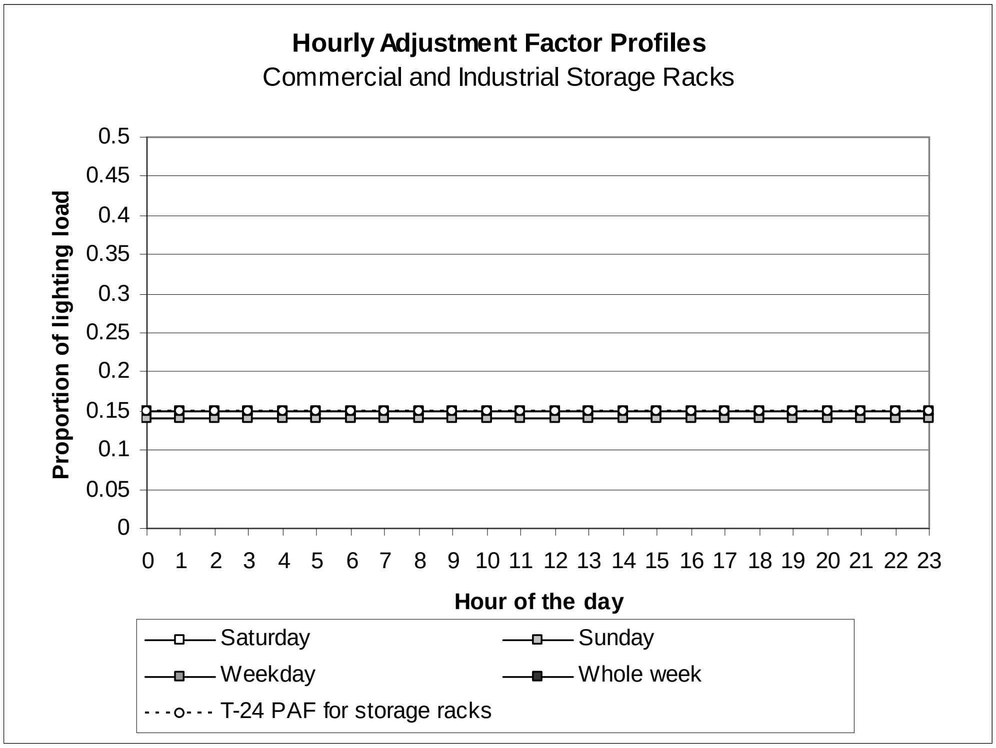

Figure 8 – Hourly Adjustment Factor Profiles (Commercial and Industrial Storage Racks)

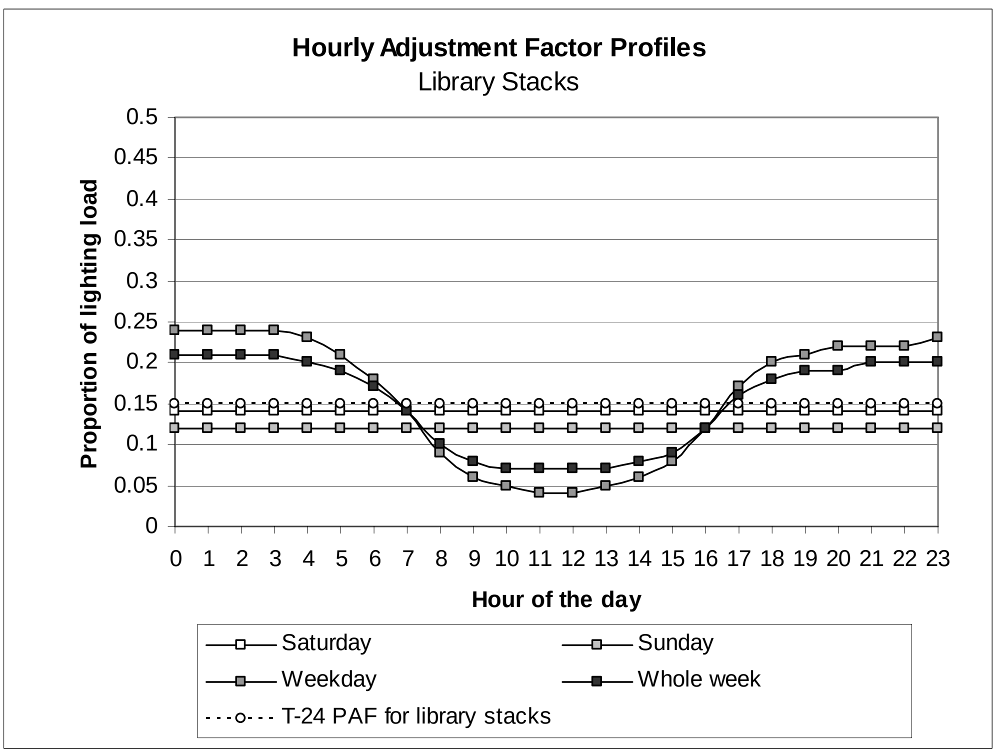

Figure 9 - Hourly Adjustment Factor Profiles (Library Stacks)

Hour	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Spaces <250 square feet, occupant sensor with manual ON or bi-level automatic ON																								
Sat	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sun	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wkdy	0.34	0.34	0.34	0.34	0.33	0.33	0.31	0.28	0.22	0.19	0.18	0.18	0.18	0.18	0.19	0.22	0.25	0.28	0.3	0.32	0.34	0.36	0.36	0.35
Whole wk	0.24	0.24	0.24	0.24	0.24	0.24	0.22	0.2	0.16	0.14	0.13	0.13	0.13	0.13	0.14	0.16	0.18	0.2	0.21	0.23	0.25	0.26	0.26	0.25
Spaces <250 square feet, occupant sensor with manual ON or bi-level automatic ON, and manual dimming																								
Sat	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sun	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wkdy	0.43	0.43	0.43	0.43	0.41	0.41	0.39	0.35	0.28	0.24	0.23	0.23	0.23	0.23	0.24	0.28	0.31	0.35	0.38	0.40	0.43	0.45	0.45	0.44
Whole wk	0.30	0.30	0.30	0.30	0.30	0.30	0.28	0.25	0.20	0.18	0.16	0.16	0.16	0.16	0.18	0.20	0.23	0.25	0.26	0.29	0.31	0.33	0.33	0.31
Commercial and Industrial storage rack areas, occupant sensors that reduce lighting power by at least 50%																								
Sat	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Sun	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Wkdy	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Whole wk	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Library stacks, occupant sensors that reduce lighting power by at least 50%																								
Sat	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Sun	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Wkdy	0.24	0.24	0.24	0.24	0.23	0.21	0.18	0.14	0.09	0.06	0.05	0.04	0.04	0.05	0.06	0.08	0.12	0.17	0.2	0.21	0.22	0.22	0.22	0.23
Whole wk	0.21	0.21	0.21	0.21	0.2	0.19	0.17	0.14	0.1	0.08	0.07	0.07	0.07	0.07	0.08	0.09	0.12	0.16	0.18	0.19	0.19	0.2	0.2	0.2

Table 1: Proposed Hourly Adjustment Factor Values

Results

The research data suggests that the current PAF values in the 2005 Title 24 standards are well chosen, i.e. they sufficiently incentivize controls without giving too much credit for those controls. Our calculations suggest that the PAF values average around 0.6 of the savings actually achieved (rPAFs) as seen in Figure 6.

More details are given below.

- The raw PAFs for spaces <250 sf are slightly higher than title 24 2005 PAFs.
- The raw TDV-weighted PAF for spaces <250 sf is 0.27 compared with the existing Title 24 PAF of 0.20. We know that the raw PAF values for this building type are higher than the calculated rPAF, because we have conservatively assumed that there are no savings at weekends (no weekend data was available for this building type).
- The raw PAFs for storage racks and library stacks are significantly higher than Title 24 PAFs.
- The raw TDV-weighted PAF for storage racks and library stacks are 0.28 and 0.30 respectively, compared with the existing Title 24 PAFs of 0.15. This finding is not statistically certain, because only four separate spaces of each type were analyzed, so we believe that this comparatively high difference between the rPAF and the PAF is appropriate given the uncertainty of the data.
- There is little difference between simple kWh PAFs and TDV-weighted PAFs.

  Figure 10 shows each of the 17 datasets plotted on a chart to show the difference between their simple PAFs and TDV-weighted PAF. It is clear that there is very little difference between the two PAFs. On average, the TDV-weighted PAFs are 2.6% lower than the simple PAFs.

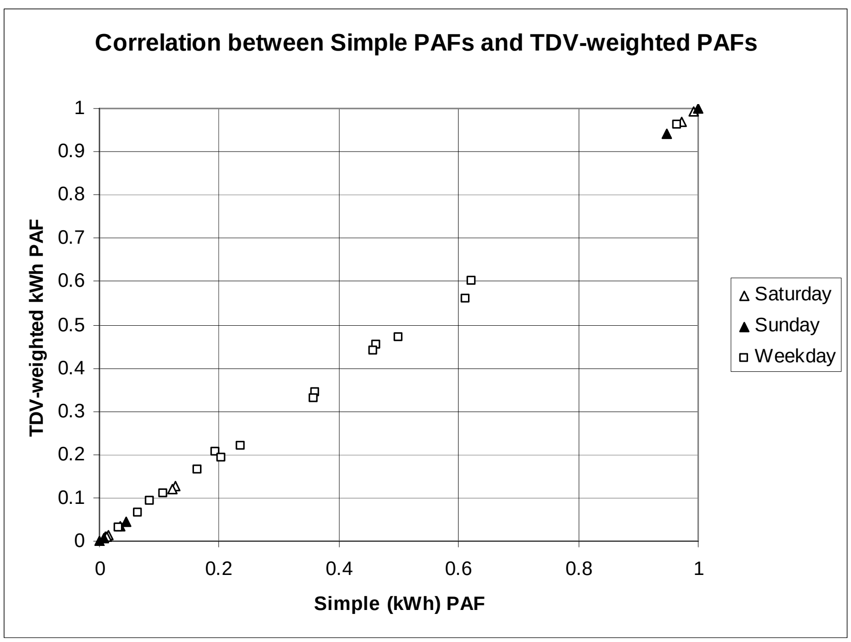

Figure 10 – Correlation Between Simple kWh PAFs and TDV-Weighted kWh PAFs

- High variability between savings in individual spaces

  Figure 10 shows that, for individual data sets, the PAFs for weekdays spread over a range from 0.03 to 0.96. The mean is 0.32 and the standard deviation is 0.25. The very high and very low values represent individual warehouse spaces. When these spaces are excluded, the standard deviation drops to only 0.17 while the mean PAF remains unchanged at 0.32.

- Note that some of the data sets contain data for many tens of spaces; these data sets have PAFs close to the average.
- More data required for many building types

    The one data set we could obtain for hotel hallways represented one single space, making the data unsuitable for analysis for this CASE report. Further, the space occupancy seemed to be unusual compared to the Title 24 assumptions on hallway occupancy.

    For storage racks and library stacks we could obtain data on only four buildings of each type. Because the data set is so small and data were received from one manufacturer, we are not inclined to change PAFs based on this data alone.

- For future analysis of PAFs and controls savings in general it seems unlikely that more research data on these building types will become available, so it may be prudent to gather data either by leveraging controls manufacturers' own data collection programs, or by commissioning research.
- Designers can use these PAF profiles with either 9-5 or 24-hour occupancy schedules

    For spaces <250 sf, all the spaces studied showed a typical daytime-only occupancy schedule, quite similar to the Title 24 daytime occupancy schedules. However, all of the warehouse spaces and half the library spaces showed 24-hour occupancy schedules. Therefore the HAF profiles and TDV PAF values are based on a mixture of daytime-only and 24-hour occupancy schedules.

    This raises the question of whether designers should calculate savings in, for instance, a 24-hour office space in a hospital or police station using the HAF profiles that were developed for daytime-only office spaces. Given the shape of the HAF profiles (i.e. that savings are greatest at night, and that savings are moderate at all hours), we consider the loss of accuracy in such a calculation to be small, especially in comparison with the high variation in real-world schedules between different spaces of the same type.

Energy and Cost Savings

The proposed measures are a change to the calculation procedures in making performance calculations for existing lighting controls credits in the 2005 Title 24 standards. We do not propose a change to the magnitude of lighting controls credit provided for each of the measures, and hence do not anticipate any additional savings due to the measures outlined in this CASE report.

Based on our calculations, the PAF's or HAF's are on average 40% lower than the actual savings from the measures. Thus, both the PAF's used for prescriptive compliance and the HAF's used for the revised performance method of compliance will result in net electricity savings as compared to a minimally compliant lighting system without controls.

Cost-effectiveness

Not Applicable

Statewide Energy Savings

There is no energy savings from this measure as compared to the 2005 standards. The proposed Power Adjustment Factors are the same as the 2005 PAF's and there is little impact of TDV on the energy savings calculated.

However, the actual savings estimate from occupancy based lighting controls are uniformly greater than the savings estimate from either the PAF's or the proposed performance approach calculation methodology. This simple estimate of the net energy savings from qualifying controls is based upon the following factors, as summarized in Table 2. :

- An evaluation of 1999 to 2003 Dodge construction database found that on average over this period, there were approximately 157 million sf of new commercial buildings or additions. Some building categories are not listed for qualifying controls, so we considered just the following occupancies: educational, government, medical, office, school, storage and 10% (excluding dwelling unit fractions) of hotel occupancies to yield a total annual new construction area of 91 million sf per year.
- An assumption that 1% of new construction in the above categories will make use of the qualifying controls.
- An assumption that approximately 1.0 W/sf of lighting will be controlled by these qualifying controls.
- Actual savings exceed calculated PAF's by approximately 10%. From Figure 6 the range of savings beyond the PAF's range between 7% to 15%.
- We calculated that the uncontrolled lighting schedule from Table N2-2 amounts to 3,146 full load hours per year.
- The tenth year of energy savings will be 10 times that of the first year's energy savings.

Description	Value
Commercial new construction (Million sf)	91.2
Fraction served by qualifying controls	0.5%
Average lighting power density (W/sf)	1.0
Net savings fraction beyond PAF	10%
Full load operating hours (h/yr)	3,146
1st year energy savings (MWh/yr)	144
10th year energy savings (MWh/yr)	1,436

Table 2: Net energy savings from qualifying controls on 1% of new commercial construction

This analysis assumes that the controls will be in place and working over the ten year span of savings.

Recommendations

Bearing in mind the limited amount of available data, we have drawn the following conclusions from this analysis:

We recommend that the PAF values used in the 2005Title 24 are of the right magnitude and should be used as the basis for the HAFs in the 2008 Title 24. The HAF savings are approximately 40% of the savings from field surveys. We think this conservative approach is appropriate because there is little independent field data for some of the controls and to account for the possibility that the controls do not last as long as the lighting system they control.

In the prescriptive method of compliance, the PAF values used in the 2005 Title 24 should remain as the basis for reducing wattage of installed lighting. In the performance method, the compliance software shall model the total installed lighting wattage as-is, and instead would use the HAF values in the lighting schedules.

Proposed Standards Language

Proposal does not require any change to standards language. All language changes are in the ACM Manual.

Alternative Calculation Manual

Section 2.4.2 of the NACM is modified to specify uncontrolled versus controlled lighting wattage of each space and how revised lighting schedules are assigned to lighting controlled by different types of controls.

A lighting schedule is created for each of the occupancy sensor based controls in Table 146-A of the 2005 Title 24 Standards. The lighting schedule for each measure is derived using the following formula:

$(\text{Controlled Lighting Schedule})_{hour} = [(\text{Uncontrolled Lighting Schedule})_{hour} \text{ x } (1\text{-HAF}_{hour})]$

The appropriate lighting schedule is to be selected for the controlled lighting wattage in each space. For control types where we did not have adequate data, such as manual dimming, we nevertheless propose using the same method of changing the controlled lighting schedule. In these cases the multiplier to the uncontrolled lighting schedule will be constant for all hours and equal to PAF currently in Table 146-A of the 2005 Title 24 standards.

For hallways of hotel/motel, we also propose the creation of a separate 24-hour ON lighting schedule for the uncontrolled lighting in the hallways and lobbies called “Hotel/Motel Hallway/Lobby Uncontrolled.” The controlled lighting schedule for hallways is a based on this 24-hour ON schedule. Other support spaces in hotel/motel would use the nonresidential uncontrolled lighting schedule.

If there are two control types (including no automatic control) in a space we recommend that the DOE-2.E keyword TASK-LIGHTING be assigned to the Wattage of the lighting on the second control type. In addition the TASK-LIGHT-SCH keyword is associated with the hourly schedule for the second control type. When there are more than two control types we propose that the entire lighting wattage be associated with the LIGHTING keyword and that the schedule associated with the LIGHTING-SCHEDULE be an average of the component schedules for each control type and weighted by the wattage of the lighting controlled by each of the control types in the space. The mechanics of this allocation and weighting of schedules is described in more detail in Appendix 1

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Douglas Mahone, Owen Howlett and Abhijeet Pande of the Heschong Mahone Group performed most of the analysis and reporting presented here. Jon McHugh was the CASE studies project manager for HMG.

Appendix 1

Alternative Compliance Manual

Section 2.4.2 Lighting Power

2.4.2.1 Outdoor Lighting

With the 2008 Standards, outdoor lighting is regulated and the requirements are contained in Section 147. Outdoor lighting shall not be considered in performance calculations. There are no tradeoffs between outdoor lighting and interior lighting, HVAC or water heating energy. ACMs shall not include outdoor lighting in the TDV energy budget or the TDV energy for the proposed design.

2.4.2.2 Interior Lighting

Description

ACMs shall model lighting for each space. Lighting loads shall be included as a component of internal heating loads. ACMs shall allocate 100% of the lighting heat to the space in which the lights occur for both controlled and uncontrolled lighting.

ACMs shall receive an input to indicate one of the following conditions for the building:

1. *Lighting compliance not performed.* When the user indicates with the required ACM input that no lighting compliance will be performed, the ACM shall require the user to select and input the occupancy type(s) of the building from Table N2-2 or Table N2-3. The ACM shall determine the lighting levels based on the selected occupancy type(s). An ACM shall not allow the user to input any lighting power densities for the building.

   NOTE: ACMs may use Table N2-2 even if the building has multiple occupancies.

2. *Lighting compliance performed.* When the user indicates with that lighting compliance will be performed and lighting plans will be submitted for the entire building (excluding the residential units of high-rise residential buildings and hotel/motel guest rooms), the ACM shall require the user to select and input the occupancy type(s) from Table N2-2 or Table N2-3and enter the proposed interior lighting equipment or interior lighting power density (LPD) for each space that is modeled. Proposed design use-it-or-lose-it lighting power shall be entered separately from the general lighting. However, if lighting plans will be submitted only for portions of the building, the ACM shall require the user to select and input the occupancy type(s) from Table N2-3and enter the actual lighting levels for portions of the building with lighting plans.

ACMs shall allow the user to input a Tailored Lighting Input, lighting control credits and the fraction of light heat rejected to indirectly conditioned spaces for each zone.

The tailored lighting method is intended to accommodate special lighting applications, Complete lighting plans and space plans shall be developed to support the special needs triggering the tailored method. Compliance forms for the tailored method shall be developed and these shall be verified by the plans examiner.

If the tailored lighting method is used, the ACM shall make an entry in the special features section on the compliance forms that the tailored lighting method has been used in compliance and that all necessary tailored lighting forms and worksheets documenting the lighting and its justification shall be provided as part of the compliance documentation and be approved independently.

With the tailored method the use-it-or-lose-it lighting power shall be entered into the ACM separately from the general lighting. No tradeoffs are allowed for the use-it-or-lose-it lighting power.

If a value is input for lighting control credits, the ACM shall output on the compliance documentation that lighting control credits have been used in compliance. When lighting control credits are used, the following lighting power must be entered for each space:

1. Uncontrolled lighting power
2. Controlled lighting power for each different control type

The default uncontrolled schedule as given in tables 2-5 through 2-9 for the space shall be assigned to the uncontrolled lighting wattage for the space.

A lighting schedule associated with the control type as given in tables 2-5 through 2-9 shall be assigned to the controlled lighting wattage for each type of control in the space. There can be more than one type of control type qualifying for credit and thus more than one controlled wattage in the space.

The current reference program DOE-2.1E has a maximum two lighting schedules per space that are allocated to separate lighting wattage amounts. These two lighting circuit are:

1) Task Lighting - the lighting power allocated to the TASK-LIGHTING keyword and associated TASK-LIGHT-SCH and

2) Ambient Lighting - the lighting power allocated to the LIGHTING keyword and associated LIGHTING-SCHEDULE. Note that in the DOE-2.1E reference program, daylighting controls through the DAYLIGHTING command can only be allocated to the lighting power described by the LIGHTING keyword and cannot be allocated to the TASK-LIGHTING keyword.

Spaces containing daylighting controls shall be specified in terms of total floor area, daylit floor area under skylights and daylit area by windows. Each of these areas shall be specified in terms of associated wall area, fenestration, and controlled vs. uncontrolled lighting power.

If all the photocontrolled lighting in a given space is on a single type of control, assign the wattage for the photocontrolled lighting wattage to the LIGHTING keyword and the associated LIGHTING-SCHEDULE.

If the photocontrolled lighting has more than one type of control eligible for power Adjustment Factors (PAFs) in Table 146-A of the Standards, then the schedule for the photocontrolled lighting shall be the wattage-weighted schedule, $WSCH_{h,d}$, of the controls schedules in Tables 2-5 through 2-9 for each hour, h and for each day type, d.

Equation 2-6 $$\mathrm{WSCH}_{h,d} = \frac{W1 \times SCH1_{h,d} + W2 \times SCH2_{h,d} + ..Wn \times SCHn_{h,d}}{W1 + W2 + ...Wn}$$

where,

Wn = wattage of lighting associated with lighting schedule SCHn, Watts

SCHn = predefined lighting schedule contained in Tables N2-5 through N2-9 that reflects the uncontrolled lighting schedule or the lighting schedule of a control that qualifies for a lighting power adjustment factor in Table 146-A of the Standards, no units

The program shall have the capability of weighting at least 3 separate pre-defined schedules for the controlled lighting. The wattage-weighted schedule and the combined wattage of the photocontrolled lighting shall be assigned to the LIGHTING keyword and the associated LIGHTING-SCHEDULE.

In spaces containing daylighting controls, the wattage of the lighting system that is not controlled by photocontrols shall be associated with the TASK-LIGHTING keyword. If the portion of the lighting system that is not controlled by photocontrols has a single type of control (including the default control not qualifying for a PAF from Table 146-A of the Standards), the TASK-LIGHT-SCH shall be associated with the appropriate Lighting Schedule from tables 2-5 through 2-9.

If the portion of the lighting system that is not controlled by photocontrols has more than one control type, then a weighted hourly schedule, $WSCH_{h,d}$, shall be created as described above (in Equation 2-6) and associated to TASK-LIGHT-SCH . The program shall have the capability of weighting at least 3 separate schedules for the non-photocontrolled lighting.

For spaces without daylighting controls, if all the controlled lighting wattage is on a single type of control, assign the wattage for the controlled lighting wattage to the LIGHTING keyword and the associated LIGHTING-SCHEDULE.

Any uncontrolled lighting wattage in the space is assigned to the TASK-LIGHTING keyword and the associated TASK-LIGHT-SCH.

If all the lighting in the space is controlled, and there are two types of controls eligible for PAFs, the lighting wattage controlled by one of the two types of controls is assigned to the LIGHTING keyword and the associated LIGHTING-SCHEDULE. The wattage controlled by the second control type is assigned to the TASK-LIGHTING keyword and the associated TASK-LIGHT-SCH.

If all the lighting in the space is controlled, and there are more than two controls eligible for PAF's, then a weighted hourly schedule, $WSCH_{h,d}$, shall be created as described above and assigned to the LIGHTING keyword and the associated LIGHTING-SCHEDULE.

If the space has a combination of uncontrolled lighting and multiple controlled lighting systems that qualify for the PAFs in Table 146-A of the Standards, assign the uncontrolled lighting wattage to the TASK-LIGHTING keyword and the appropriate default lighting schedule associated with TASK-LIGHT-SCH. The controlled wattage shall be assigned to the LIGHTING keyword and a weighted hourly schedule, $WSCH_{h,d}$, shall be created as described above and associated with the LIGHTING-SCHEDULE for that space.

The control type names are abbreviated below and refer to the appropriate controls listed in Table 146A and have the limitations as described in Standards §146(a)4.

Bi-level Osensor – Occupant sensor with "manual ON" or bi-level automatic ON combined with multi-level circuitry and switching for any space ≤ 250 square feet enclosed by floor-to-ceiling partitions; any size classroom, corridor, conference or waiting room

Hallway Osensor – Occupant sensor controlled multi-level switching or dimming system that reduces lighting power at least 50% when no persons are present for hallways of hotels/motels

Stack Osensor – Occupant sensor controlled multi-level switching or dimming system that reduces lighting power at least 50% when no persons are present for Commercial and Industrial Storage stack areas (max. 2 aisles per sensor)

Library Osensor – Occupant sensor controlled multi-level switching or dimming system that reduces lighting power at least 50% when no persons are present for Library Stacks (maximum 2 aisles per sensor)

Manual Dimming - Dimming system, Manual dimming for Hotels/motels, restaurants, auditoriums, theaters

Program Multiscene - Dimming system, Multiscene programmable for Hotels/motels, restaurants, auditoriums, theaters

Combined Daylight – Occupant sensor With "manual ON" or bi-level automatic ON combined with multi-level circuitry and switching in conjunction with daylighting controls. Note this schedule is used in conjunction with the daylight modeling capability of the reference program.

Combined Dimming – Manual Dimming with Dimmable Electronic Ballasts and Occupant sensor with "manual ON" or automatic ON to less than 50% power and switching

Note: If the standard design would otherwise be modeled with skylights and automatic lighting controls as required by Standards Section 143(c) and Section 131(a), and the user would like to apply an occupancy exception, the user shall select and input the occupancy type(s) of the building from Table N2-2. All occupancies qualifying for the exception are included in the following list: Auditorium, Commercial/Industrial Storage – Refrigerated, Exhibit Display Area and Museum, Theater (Motion Picture), and Theater (Performance).

Daylighting controls are modeled using the DOE-2 DAYLIGHTING command and methodology. If occupancy sensors are used in conjunction with daylighting controls, the revised "combined daylight" control schedule is used as described above in conjunction with the DAYLIGHTING command.

DOE-2 Command	SPACE
DOE-2 Keyword(s)	LIGHTING-SCHEDULE LIGHTING-W/SQFT TASK-LIGHT-SCH TASK-LT-W/SF LIGHT-TO-SPACE DAYLIGHTING
Input Type	Required
Tradeoffs	Yes
Modeling Rules for Proposed Design:	The proposed design lighting level is restricted based on which of the above two conditions is selected by the user for the building. The proposed design lighting level is determined as follows:

1. *Lighting compliance not performed.* The proposed design lighting level shall be the lighting level listed in Table N2-2 or Table N2-3. ACMs shall report the default lighting energy on PERF-1 and indicate that no lighting compliance was performed. ACMs shall not print any Lighting forms.

2. *Lighting compliance performed.* The proposed design lighting level for each space shall be as follows:

   a) *Nonresidential occupancies*: For each space the proposed design lighting level shall be the actual lighting level of the space as shown in the construction documents and lighting compliance documentation. For each space without specified lighting level, ACMs shall select the default lighting level from Table N2-3 according to the occupancy type of the space.

   b) *High-rise residential and hotel/motel occupancies*: User inputs for lighting (and lighting controls) for the residential units and hotel/motel guest rooms shall be ignored and the lighting levels determined from Table N2-3 shall be used.

ACMs shall print all applicable lighting forms and report the lighting energy use and the lighting level (Watts/ft^2) for the entire project. ACMs shall report "No Lighting Installed" for nonresidential spaces with no installed lighting. ACMs shall report "Default Residential Lighting" for residential units of high rise residential buildings and hotel/motel guest rooms.

If the modeled Lighting Power Density (LPD) is different than the actual LPD calculated from the fixture schedule for the building, ACMs shall model the larger of the two values for sizing the mechanical systems and for the compliance run. ACMs shall report the larger value on PERF-1. Lighting levels shall be adjusted by any lighting Control Credit Watts, if input by the user.

Table N2-5 – Nonresidential Occupancy Schedules (Other than Retail)

		Hour																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Heating (ºF)	WD	60	60	60	60	60	65	65	70	70	70	70	70	70	70	70	70	70	70	65	60	60	60	60	60
	Sat	60	60	60	60	60	65	65	65	65	65	65	65	65	65	65	65	60	60	60	60	60	60	60	60
	Sun	60	60	60	60	60	65	65	65	65	65	65	65	65	65	65	65	60	60	60	60	60	60	60	60
Cooling (ºF)	WD	77	77	77	77	77	73	73	73	73	73	73	73	73	73	73	73	73	73	77	77	77	77	77	77
	Sat	77	77	77	77	77	73	73	73	73	73	73	73	73	73	73	73	73	73	77	77	77	77	77	77
	Sun	77	77	77	77	77	73	73	73	73	73	73	73	73	73	73	73	73	73	77	77	77	77	77	77
Lights (%) Uncontrolled	WD	5	5	5	5	10	20	40	70	80	85	85	85	85	85	85	85	85	80	35	10	10	10	10	10
	Sat	5	5	5	5	5	10	15	25	25	25	25	25	25	25	20	20	20	15	10	10	10	10	10	10
	Sun	5	5	5	5	5	10	10	15	15	15	15	15	15	15	15	15	15	10	10	10	5	5	5	5
Lights (%) Hotel/Motel Hallway/Lobby Uncontrolled	WD	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	Sat	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	Sun	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	10	100	100	100	100	100	100	100	100
Lights (%) Bi-level Osensor	WD	4	4	4	4	8	15	31	56	67	73	74	74	74	74	73	71	70	64	28	8	8	7	7	8
	Sat	4	4	4	4	4	8	12	20	21	22	22	22	22	22	17	17	16	12	8	8	8	7	7	8
	Sun	4	4	4	4	4	8	8	12	13	13	13	13	13	13	13	13	12	8	8	8	4	4	4	4
Lights (%) Hallway Osensor	WD	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75
	Sat	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75
	Sun	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	8	75	75	75	75	75	75	75	75
Lights (%) Stack Osensor	WD	4	4	4	4	9	17	34	60	68	72	72	72	72	72	72	72	72	68	30	9	9	9	9	9
	Sat	4	4	4	4	4	9	13	22	22	22	22	22	22	22	17	17	17	13	9	9	9	9	9	9
	Sun	4	4	4	4	4	9	9	13	13	13	13	13	13	13	13	13	13	9	9	9	4	4	4	4
Lights (%) Library Osensor	WD	4	4	4	4	8	16	33	60	73	80	81	82	82	81	80	78	75	66	28	8	8	8	8	8
	Sat	4	4	4	4	4	9	13	22	22	22	22	22	22	22	17	17	17	13	9	9	9	9	9	9
	Sun	4	4	4	4	4	9	9	13	13	13	13	13	13	13	13	13	13	9	9	9	4	4	4	4
Lights (%) Manual Dimming	WD	5	5	5	5	9	18	36	63	72	77	77	77	77	77	77	77	77	72	32	9	9	9	9	9
	Sat	5	5	5	5	5	9	14	23	23	23	23	23	23	23	18	18	18	14	9	9	9	9	9	9
	Sun	5	5	5	5	5	9	9	14	14	14	14	14	14	14	14	14	14	9	9	9	5	5	5	5
Lights (%) Program Multiscene	WD	4	4	4	4	8	16	32	56	64	68	68	68	68	68	68	68	68	64	28	8	8	8	8	8
	Sat	4	4	4	4	4	8	12	20	20	20	20	20	20	20	16	16	16	12	8	8	8	8	8	8
	Sun	4	4	4	4	4	8	8	12	12	12	12	12	12	12	12	12	12	8	8	8	4	4	4	4
Lights (%) Combined Daylight	WD	4	4	4	4	8	15	31	56	67	73	74	74	74	74	73	71	70	64	28	8	8	7	7	8
	Sat	4	4	4	4	4	8	12	20	21	22	22	22	22	22	17	17	16	12	8	8	8	7	7	8
	Sun	4	4	4	4	4	8	8	12	13	13	13	13	13	13	13	13	12	8	8	8	4	4	4	4
Lights (%) Combined Dimming	WD	4	4	4	4	7	14	29	53	64	70	71	71	71	71	70	68	65	60	26	7	7	7	7	7
	Sat	4	4	4	4	4	7	11	19	20	21	21	21	21	21	16	16	15	11	7	7	7	7	7	7
	Sun	4	4	4	4	4	7	7	11	12	12	13	13	13	13	12	12	12	8	7	7	3	3	3	3
Equipment (%)	WD	15	15	15	15	15	20	35	60	70	70	70	70	70	70	70	70	65	45	30	20	20	15	15	15
	Sat	15	15	15	15	15	15	15	20	25	25	25	25	25	25	20	20	20	15	15	15	15	15	15	15
	Sun	15	15	15	15	15	15	15	20	20	20	20	20	20	20	20	20	20	15	15	15	15	15	15	15

		Hour																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Fans (%)	WD	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	off	off	off	off
	Sat	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	off	off	off	off	off	off	off	off	off
	Sun	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off
Infiltration (%)	WD	100	100	100	100	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	100	100	100
	Sat	100	100	100	100	100	0	0	0	0	0	0	0	0	0	0	100	100	100	100	100	100	100	100	100
	Sun	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
People (%)	WD	0	0	0	0	5	10	25	65	65	65	65	60	60	65	65	65	65	40	25	10	5	5	5	0
	Sat	0	0	0	0	0	0	5	15	15	15	15	15	15	15	15	15	15	5	5	5	0	0	0	0
	Sun	0	0	0	0	0	0	0	5	5	5	5	5	5	5	5	5	5	5	5	5	0	0	0	0
Hot Water (%)	WD	0	0	0	0	10	10	50	50	50	50	70	90	90	50	50	70	50	50	50	10	10	10	10	0
	Sat	0	0	0	0	0	0	10	20	20	20	20	20	20	20	20	20	20	10	10	10	0	0	0	0
	Sun	0	0	0	0	0	0	0	10	10	10	10	10	10	10	10	10	10	10	10	10	0	0	0	0

Table N2-6 – Hotel Function Occupancy Schedules

		Hour																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Heating (ºF)	WD	55	55	55	55	55	55	63	68	70	70	70	70	70	70	70	70	70	70	70	70	70	70	55	55
	SAT	55	55	55	55	55	55	63	68	70	70	70	70	70	70	70	70	70	70	70	70	70	70	55	55
	Sun	55	55	55	55	55	55	63	68	70	70	70	70	70	70	70	70	70	70	70	70	70	70	55	55
Cooling (ºF)	WD	95	95	95	95	95	95	95	95	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	95
	SAT	95	95	95	95	95	95	95	95	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	95
	Sun	95	95	95	95	95	95	95	95	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	95
Lights (%)	WD	5	5	5	5	5	5	5	5	25	50	90	90	90	90	90	90	75	50	50	50	50	10	5	5
	SAT	5	5	5	5	5	5	5	5	25	50	90	90	90	90	90	90	75	50	50	50	50	10	5	5
	Sun	5	5	5	5	5	5	5	5	25	50	90	90	90	90	90	90	75	50	50	50	50	10	5	5
Equipment (%)	WD	5	5	5	5	5	5	5	5	50	50	50	50	30	50	50	50	30	10	30	30	30	10	5	5
	SAT	5	5	5	5	5	5	5	5	50	50	50	50	30	50	50	50	30	10	30	30	30	10	5	5
	Sun	5	5	5	5	5	5	5	5	50	50	50	50	30	50	50	50	30	10	30	30	30	10	5	5
Fans (%)	WD	off	off	off	Off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	off
	SAT	off	off	off	Off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	off
	Sun	off	off	off	Off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	off
Infiltration (%)	WD	100	100	100	100	100	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
	SAT	100	100	100	100	100	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
	Sun	100	100	100	100	100	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
People (%)	WD	0	0	0	0	0	0	0	5	35	90	90	90	25	90	90	90	50	25	50	50	50	10	0	0
	SAT	0	0	0	0	0	0	0	5	35	90	90	90	25	90	90	90	50	25	50	50	50	10	0	0
	Sun	0	0	0	0	0	0	0	5	35	90	90	90	25	90	90	90	50	25	50	50	50	10	0	0
	WD	0	0	0	0	0	0	10	40	40	60	60	60	90	60	60	60	60	40	50	50	50	10	0	0
	SAT	0	0	0	0	0	0	10	40	40	60	60	60	90	60	60	60	60	40						