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Technical Support Document for the Proposed Federal Commercial Building Energy Code

S. Somasundaram
M. A. Halverson
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D. L. Hadley

November 1995

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
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Richland, Washington 99352

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Foreword

This report is one in a series of documents describing research activities in support of the U.S. Department of Energy (DOE) Building Energy Standards Program. The Pacific Northwest Laboratory (PNL) leads the program for DOE.

The goal of the program is to develop and encourage the implementation of performance standards to achieve the maximum practicable energy efficiency in the design of new buildings. Such standards are required of DOE by Title III of the Energy Conservation and Production Act (42 USC 6831 et seq.) as amended by the Energy Policy Act of 1992 (Public Law 102-486).

The program approach to meeting the goal is to initiate and manage individual research and standards and guidelines development efforts that are planned and conducted in cooperation with representatives from throughout the buildings community. Projects under way involve practicing architects and engineers, professional societies and code organizations, industry representatives, and researchers from the private sector and national laboratories. Research results and technical justifications for standards criteria are provided to standards development and model code organizations and to federal, state, and local jurisdictions as a basis for updating their codes and standards. This approach helps to ensure that building standards incorporate the latest research results to achieve maximum energy savings in new buildings, yet remain responsive to the needs of the affected professions, organizations, and jurisdictions. This approach also assists in the implementation, deployment, and use of the codes and standards.

This report documents the technical bases for revisions and updates to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) *Energy Code*. Changes made to that document, which is the codified version of *ASHRAE/IES Standard 90.1-1989*, are reflected in the proposed new federal commercial building energy standard.

Readers with comments, questions, or suggestions about this document or the work it describes are encouraged to contact the author(s), program managers, or project managers.

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Abstract

This report presents the justification and technical documentation for all changes and updates made (since 1993) to the *Energy Code for Commercial and High-Rise Residential Buildings*, the codified version of *ASHRAE/IES Standard 90.1-1989*, "Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings." These changes and updates, which were subject to the ASHRAE addenda approval process, include Addenda b, c, d, e, g, and i. A seventh addenda, Addenda f, which has not been officially approved by ASHRAE, has been included into the proposed rule. Also included in the changes was technical work conducted to justify revisions to the 1993 DOE lighting power densities. The updated text will be reviewed by the U.S. Department of Energy (DOE) and issued as the new Federal Commercial Building Energy Code (10 CFR 434); Mandatory for New Federal Commercial and Multi-Family High Rise Residential Buildings.

Contents

Introduction

The U.S. Department of Energy (DOE) has proposed a new Federal Commercial Building Energy Code. The proposed code revises the current interim federal commercial standard (10 CFR 435, Subpart A) to generally conform with the format of various U.S. voluntary model codes. Those revisions reflect changes in the areas of electric motors, lighting, mechanical ventilation, building envelope materials and rating procedures, and heating and cooling equipment test procedures.

DOE worked with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standing Standards Project Committee (SSPC) 90.1 and the Illuminating Engineering Society of North America (IESNA) Energy Management Committee when those committees developed addenda to their commercial building energy standard for the private sector, *ASHRAE/IES Standard 90.1-1989*. Those addenda, which reflect new building technologies and materials, were not available in 1989 when DOE promulgated its interim standards. DOE is proposing to include all approved ASHRAE addenda, Addenda f, and revisions to the DOE 1993 lighting power densities in its new Federal Commercial Building Energy Code.

This report documents the technical bases underlying inclusion of those addenda in the DOE proposed code. Key interrelationships between and among the DOE interim standard, Standard 90.1, and the ASHRAE *Energy Code* are described, explaining the rationale for DOE's inclusion of certain features in its proposed code.

Documentation for the
Proposed Federal Commercial Building Energy Code

The DOE proposed federal commercial building energy code is based largely on the ASHRAE *Energy Code* (ASHRAE 1993) with some modifications. This section describes several of those modifications and the rationale for making and incorporating them into the federal code. Estimates of the cost and energy impacts of the changes are also provided.

The changes made are discussed one by one in the following pages. Each discussion begins with a two-column table in bold type. Intended as a map, each table displays the section from the *Energy Code* or *ASHRAE/IES Standard 90.1-1989*, modified by DOE, opposite the corresponding section in the proposed federal code that now reflects the modification(s).

Readers will note that the section numbers in both the *Energy Code* and the proposed federal code are closely matched at first. However, they diverge in the fifth main section of each document because the proposed federal code also includes material (Subparts E and F) extracted from the 1989 DOE interim standard (10 CFR 435).

ASHRAE *Energy Code*	**Proposed Federal Code (10 CFR 434)**
Chapter 4 Building Design Requirements	**Subpart D - Building Design Requirements**
401 Electrical Power and Lighting Systems **...** **401.2 Electric Motors** **401.2.1 Efficiency**	**434.401 Electrical Distribution Systems** **...** **434.401.2 Electric Motors** **434.401.2.1 Efficiency**

Changes

Table 401.2.1 in the ASHRAE *Energy Code* is replaced with Table 5-1 from *ASHRAE/IES Standard 90.1-1989* Addendum c (approved by the ASHRAE Board of Directors on October 28, 1993). Addendum c addresses changes to motor efficiency requirements (Table 5-1 of Addendum c and Table 401.2.1 in the ASHRAE *Energy Code*). The changes include the addition of National Electrical Manufacturers Association (NEMA) standards to the references chapter in the ASHRAE *Energy Code* (ASHRAE 1993) to reflect their in-text citations.

Rationale and Discussion

Addendum c to *ASHRAE/IES Standard 90.1-1989* was developed in response to information provided by NEMA. The rationale underlying Addendum c was to bring Standard 90.1 in line with NEMA's own more stringent requirements for motor efficiencies.

Most of the changes are simplifications of text and updates to references. In addition, the changes greatly expand Table 401.2.1, which sets minimum efficiencies for motors, in the proposed code .

Some of the efficiency values were increased (i.e., became more stringent). These changes are found also in EPAct legislation, which establishes standards for electric motors ranging from 1 to 200 horsepower. EPAct defines electric motors in terms of *NEMA Standard MG1-1987*, "Motors and Generators" (NEMA 1987).

Because the new efficiency requirements reflect the industry's own recommendations, it is anticipated that motor manufacturers will readily support their adoption.

The requirements spelled out in Addendum c were compared with those of *ASHRAE/IES Standard 90.1-1989*. The overall average increase in efficiency required by Addendum 90.1c for motors of different sizes, types, and pole numbers was found to be approximately 2%. For example, a motor required by Standard 90.1 to be 76.2% efficient would now be required to be 80% efficient.

Estimated Energy Impacts

The use of energy by motors should decrease by approximately 2% under Addendum c requirements if the motors are directly replaced. As a very rough estimate (based on fan and pump usage), motors consume approximately 12% of the total energy used by commercial buildings. This number would decrease by 2%, for a total savings of 0.24% of the total commercial building energy usage. For individual buildings, savings may range anywhere from 0% to 0.5%.

Estimated Cost Impacts

The motor efficiencies listed in Addendum c are to become mandatory manufacturing standards by October 1997, per EPAct. At that time, the cost impact will not be an issue. However, over the next several years, motors meeting these requirements may be more expensive than less energy-efficient motors. Addendum c codifies the current state of the motor industry, which is already manufacturing to *NEMA Standard MG1-1987*. The cost impact of the change, therefore, will be negligible.

ASHRAE ***Energy Code***	**Proposed Federal Code (10 CFR 434)**
Chapter 4 Building Design Requirements	**Subpart D - Building Design Requirements**
401 Electrical Power and Lighting Systems	**434.401 Electrical Distribution Systems**
...	**...**
401.3 Lighting Power Allowance	**434.401.3 Lighting Power Allowance**
...	**...**
401.3.2 Building Interiors	**434.401.3.2 Building Interiors**

Changes

The proposed rule contains unit power density (UPD) values for 106 defined space/area types. Several of the unit power density (UPD) values (lighting requirements) in Tables 401.3.2b and 401.3.2c reflect the 1993 values from the interim standard. The remaining UPD values are the same as those found in Standard 90.1.

Rationale and Discussion

The interim federal standard (10 CFR 435, Subpart A) defines two sets of UPD values for 106 space-type categories. One set became effective in 1989 when the interim standard was published. The 1989 UPD values are the same as those in *ASHRAE/IES Standard 90.1-1989* and its codified version. The second set of UPD values in the interim standard became effective in 1993. The DOE 1993 values in that set were more stringent (lower) than the 1989 values.

The values selected for the proposed rule are based on an assessment study conducted by the Pacific Northwest Laboratory for the U.S. Department of Energy during a demonstration of the applicability of the 1993 values in the interim standard. Of the 106 space-type categories, 79 will have proposed UPD values that exceed the stringency of the 1989 values (same as DOE 1993). The remaining 27 have proposed UPD values identical to those of the 1989 requirements. None of the proposed values is less stringent than the 1989 values. Therefore, it can be categorically stated that the proposed federal lighting requirements meet or exceed the requirements in *ASHRAE/IES Standard 90.1-1989* and its codified version, the ASHRAE *Energy Code* (ASHRAE 1993). For most space types, the proposed federal lighting requirements are more stringent than those mandated in EPAct for private commercial construction. Table 1 provides a comparison by standard or code of UPD values required for office buildings.

Table 1. UPD Value Comparison for Office Buildings

Standard or Code	UPD Value, W/ft^2	
	Whole Office Building	Office Space (Reading)
Standard 90.1 or DOE 1989	1.65	1.9 to 2.2
DOE 1993	1.22	1.5 to 1.7
Proposed Federal Code	Not developed	1.5 to 1.7

The updates to Tables 401.3.2b and 401.3.2c in the ASHRAE *Energy Code* are supported by the lighting analysis data in the Appendix of this technical support document. That text documents the assumptions, methodology, and final recommendations of PNL's lighting assessment completed in December 1993.

Energy Impacts

The energy consumption impacts of the updated lighting requirements may be estimated as follows. The UPD values for approximately 75% of the space-type categories will be the same as the DOE 1993 values. Consequently, we can assume as a first approximation that around 75% of the lighting energy savings noted in Hadley and Halverson (1993) would be obtained with the proposed federal code. Hadley and Halverson (1993) compared the energy savings for DOE 1989 and DOE 1993 requirements to *ANSI/ASHRAE/IES Standard 90A-1980*. Their comparison looked at ten different building types in six locations in the United States. In the study, the "average" DOE 1989 building (with DOE 1989 being essentially equivalent to *ASHRAE/IES Standard 90.1-1989*) was found to use 63.8 kBtu/ft^2/yr, while the "average" DOE 1993 building was found to use 59.7 kBtu/ft^2/yr. The entire difference of 4.1 kBtu/ft^2/yr is attributable to differences in lighting requirements. Therefore, if 75% of the DOE 1993 lighting energy savings are achieved with the proposed lighting requirements, the "average" building will save about 3 kBtu/ft^2/yr. This savings represents 4.7% of the energy consumption of the average DOE 1989 building.

Cost Impacts

In 1992, PNL conducted a case study of a 27,300-ft^2 law office building in New York. The life-cycle costs (LCCs) of different lighting design options were assessed using the National Institute of Standards and Technology (NIST) "Building Life-Cycle Cost" (BLCC) program, Version 3.1 (Petersen 1991). Energy prices and discount factors from the 1992 annual supplement to NIST Handbook 135 (Lippiatt 1991) were used. The BLCC program Version 3.1 automatically accesses these 1992 values. Table 2 specifies the economic parameters and values used in the analysis.

Although the applicable electricity price in New York was $0.12/kWh, the average commercial building electricity rate in the United States is $0.08/kWh (Energy Information Administration 1994). Lucas (1994) has noted that federal electric rates are typically 24% lower than rates levied to the private sector, indicating that the federal electric rates may be expected to be approximately $0.06/kWh.

The results of the LCC analysis for five lighting design options and for a range of electricity prices are shown in Table 3. No reduction in illumination from Standard 90.1 levels is involved in any of the options considered. Option 2, which uses three energy-saving 32-W T8 lamps with electronic ballasts and has a UPD level of 1.14 W/ft^2, has the lowest LCC, so long as the electricity rates are higher than $0.06/kWh. Option 2 exceeds the delta LCC column in Table 3 that indicates the cost advantage of Option 2 in each case. The other design options may be used in situations where the electronic ballasts or the T8 lamps are not available, even though they yield a higher UPD (consume more energy) and have a higher LCC.

More energy-efficient lighting designs (more stringent than the levels prescribed in *ASHRAE/IES Standard 90.1-1989*) can be achieved at lower LCCs primarily because of the new technologies and products on the market that were not widely available when Standard 90.1 was approved.

Table 2. Assumptions Underlying the Lighting LCC Analysis

Parameter	Value
Base date	1992
Study period	20 years
Planning/construction period	0 years
Occupancy date	1992
Discount rate	4.6%
Expected component life	20 years
Energy type	Electricity
DOE region	1 (New York)
DOE rate schedule type	Commercial
Energy price per unit	$0.12/kWh
Annual demand charge	$0.00
DOE energy price escalation rates filename	ENCOST92.RAN

Energy price escalation rates by year

1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
-0.51	-0.14	0.76	-3.15	-2.23	-1.20	-0.73	-0.63	0.69	0.02
2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
0.08	0.25	-0.08	0.72	0.47	0.78	-0.12	-1.00	1.19	0.64

Table 3. Lighting Design Option LCC Analysis Results

Design Option	UPD, W/ft²	Energy Use, kWh	Energy Cost, $	First Cost, $	Maint. Cost, $	Total LCC, $	Delta LCC, $	Comments
Electricity Cost = $0.12/kWh								
OPT2	1.14	81,246	119,765	144,779	31,073	295,617	0	Lowest LCC
OPT3A	1.42	103,452	152,499	148,651	46,246	347,396	51,769	
OPT1	1.52	108,147	159,420	189,354	58,704	407,478	111,851	
OPT3B	1.24	93,867	138,370	223,754	46,115	408,239	112,612	
OPT4	1.7[a]	79,920	117,810	339,848	55,654	513,312	217,695	Highest quality
Electricity Cost = $0.08/kWh								
OPT2	1.14	81,246	79,843	144,779	31,073	255,695	0	Lowest LCC
OPT3A	1.42	103,452	101,666	148,651	46,246	296,563	40,868	
OPT1	1.52	108,147	106,280	189,354	58,704	354,338	98,643	
OPT3B	1.24	93,867	92,247	223,754	46,115	362,116	106,421	
OPT4	1.7[a]	79,920	78,540	339,848	55,654	474,407	218,346	Highest quality
Electricity Cost = $0.06/kWh								
OPT2	1.14	81,246	59,833	144,779	31,073	235,774	0	Lowest LCC
OPT3A	1.42	103,452	76,250	148,651	46,246	271,147	35,373	
OPT1	1.52	108,147	79,710	189,354	58,704	327,768	91,914	
OPT3B	1.24	93,867	69,185	223,754	46,115	339,054	122,260	
OPT4	1.7[a]	79,920	58,905	339,848	55,654	454,407	237,613	Highest quality
Electricity Cost = $0.04/kWh								
OPT2	1.14	81,246	39,922	144,779	31,073	215,774	0	Lowest LCC
OPT3A	1.42	103,452	50,833	148,651	46,246	245,730	29,956	
OPT1	1.52	108,147	53,140	189,354	58,704	301,198	85,425	
OPT3B	1.24	93,867	46,123	223,754	46,115	315,992	100,219	
OPT4	1.7[a]	79,920	39,270	339,848	55,654	434,772	218,999	Highest quality

[a] Option 4's total 1.7 UPD value is based on 1.22 W/ft² plus allowance for additional controls.

ASHRAE *Energy Code*	Proposed Federal Code (10 CFR 434)
Chapter 4 Building Design Requirements **402 Building Envelope Assemblies and Materials** **402.1 Calculations and Supporting Information** **402.1.1 Material Properties**	**Subpart D - Building Design Requirements** **434.402 Building Envelope Assemblies & Materials** **434.402.1 Calculations and Supporting Information** **434.402.1.1 Material Properties**

Changes

The reference cited in the last sentence of the second paragraph was changed from "Table 41, Chapter 27, of RS-4" (*1985 ASHRAE Handbook Fundamentals*) to Table 31, Chapter 27, of *1989 ASHRAE Handbook Fundamentals*.

Rationale

This change was made to make the proposed federal code consistent with *ASHRAE/IES Standard 90.1-1989* by referring to the correct table in *1989 ASHRAE Handbook Fundamentals*.

ASHRAE *Energy Code*	Proposed Federal Code (10 CFR 434)
Chapter 4 Building Design Requirements **402 Building Envelope Assemblies and Materials** **402.1 Calculations and Supporting Information** **...** **402.1.2 Thermal Performance Calculations** **402.1.2.1 Envelope Assemblies Containing Metal Framing**	**Subpart D - Building Design Requirements** **434.402 Building Envelope Assemblies and Materials** **434.402.1 Calculations and Supporting Information** **...** **434.402.1.2 Thermal Performance Calculations** **434.402.1.2.1 Envelope Assemblies Containing Metal Framing**

Changes

Table 402.1.2.1b in the ASHRAE *Energy Code* (based on Table 8C-2 in *ASHRAE/IES Standard 90.1-1989*) was expanded to account for thicker wall members (2 x 8s) and a larger variety of higher-performance insulation products.

Rationale and Discussion

The expansion of Table 402.1.2.1b in the proposed rule adopts the expanded informational text contained in Addendum g to Standard 90.1 (approved by the ASHRAE Board of Directors on July 1, 1993). Addendum g addresses metal stud correction factors. These correction factors are used to account for the presence of thermally conductive metal studs in insulated walls. Both the existing and revised tables contain precalculated results of commonly used heat-transfer calculations. The new table just contains more precalculated values.

Estimated Energy Impacts

This change is estimated to result in no energy impacts because the calculations are already required by Standard 90.1. The table merely precalculates the results for defined situations.

Estimated Cost Impacts

This change is estimated to result in no cost impacts. If anything, the expanded table reduces calculation time and therefore saves money.

ASHRAE *Energy Code*	Proposed Federal Code (10 CFR 434)
Chapter 4 Building Design Requirements	**Subpart D - Building Design Requirements**
402 Building Envelope Assemblies and Materials	**434.402 Building Envelope Assemblies & Materials**
402.1 Calculations and Supporting Information **402.1.1 ...** **402.1.2 Thermal Performance Calculations** **402.1.2.1 ...** **402.1.2.2 Envelope Assemblies Containing Nonmetal Framing**	**434.402.1 Calculations and Supporting Information** **434.402.1.1 ...** **434.402.1.2 Thermal Performance Calculations** **434.402.1.2.1 ...** **434.402.1.2.2 Envelope Assemblies Containing Nonmetal Framing**

Changes

The reference cited in the last sentence in Section 402.1.2.2 of the ASHRAE *Energy Code* was changed from "page 23.2 of Chapter 23 of RS-4" (*1985 ASHRAE Handbook Fundamentals*) to page 20.8 of Chapter 20 of *1989 ASHRAE Handbook Fundamentals*.

Rationale

This change was made to make the proposed federal code consistent with *ASHRAE/IES Standard 90.1-1989* by referring to the correct page and chapter in *1989 ASHRAE Handbook Fundamentals*.

ASHRAE *Energy Code*	Proposed Federal Code (10 CFR 434)
Chapter 4 Building Design Requirements **402 Building Envelope Assemblies and Materials** **402.1 Calculations and Supporting Information** **402.1.1 ...** **402.1.2 Thermal Performance Calculations** **402.1.2.1 ...** **402.1.2.2 ...** **402.1.2.3 ...** **402.1.2.4 Fenestration Assemblies**	**Subpart D - Building Design Requirements** **434.402 Building Envelope Assemblies & Materials** **434.402.1 Calculations and Supporting Information** **434.402.1.1 ...** **434.402.1.2 Thermal Performance Calculations** **434.402.1.2.1 ...** **434.402.1.2.2 ...** **434.402.1.2.3 ...** **434.402.1.2.4 Fenestration Assemblies**

Changes

This section was replaced with new text and an updated method of calculating the thermal transmittance of fenestration assemblies based on *1989 ASHRAE Handbook Fundamentals*. This change also resulted in revisions to Tables 402.4.1.1 and 402.4.1.2 (see page 13).

Rationale and Discussion

Addendum f (being considered for approval by ASHRAE) changes the fenestration requirements section of *ASHRAE/IES Standard 90.1-1989*. The changes made to the text are fairly numerous, but they all stem from a single source. ASHRAE updated the fenestration calculation procedure in *1989 ASHRAE Handbook Fundamentals* to provide new descriptions of fenestration properties. The most significant change was to calculate the overall thermal transmittance of fenestration assemblies (basically windows and skylights) based on the thermal transmittance of the center-of-glass, edge-of-glass, and frame components. These components are defined and listed in the *1989 ASHRAE Handbook Fundamentals*, whereas the previous edition (1985) of the Handbook contained a procedure including thermal transmittance values for various fenestration components plus correction factors for sashes, frames, edges, and other features. Although both procedures have the same ultimate goal (prediction of overall thermal transmittance), the values calculated using the two methods could be different.

The issue here arises when precalculated thermal transmittance values listed in Standard 90.1 and the ASHRAE *Energy Code* (based on the 1985 procedure) are recalculated using the new 1989 method but under the same assumptions as those that went into the original value. For example, a requirement to use an overall thermal transmittance of 0.45 for cold climate skylights (section 8.4.8.1d) becomes a requirement to use 0.52 in Addendum f.

If we pick several standard fenestration constructions and calculate the overall thermal transmittance using the new and the old procedure, we get the following:

Glazing	Calculation Procedure for U-Values, Btu/h • ft^2 • °F	
	1985	1989
Single-pane	1.15	1.23
Double-pane	0.81	0.72
Enhanced double-pane (vinyl frames, low-emissivity/thermal break)	0.45	0.52

Note that some precalculated values moved up (became less stringent) while others moved down (became more stringent).

Addendum f also provides revisions to a number of testing methods and specifications for windows and doors, as well as revisions to current versions of ASHRAE-supplied compliance software. These revisions have no significant impact.

Estimated Energy Impacts

The issue here is not whether rating number scale changes, but whether the types of windows and sklylights required by the code change. As evidenced by the data in the table above, the same window requirement will simply have a different theoretical performance characteristic under the updated procedure. Therefore, the energy performance of a building will not be any different because of the provisions in Addendum f. Thus, the changes in fenestration assembly requirements will have no impact on a building's energy consumption.

Estimated Cost Impacts

Since the fenestration requirements noted in Standard 90.1 and the ASHRAE *Energy Code* and those in Addendum f call for the same underlying construction (as stated in **Estimated Energy Impacts** above), there is **no cost impact.**

ASHRAE *Energy Code*	Proposed Federal Code (10 CFR 434)
Chapter 4 Building Design Requirements **402 Building Envelope Assemblies and Materials** **402.1 ...** **402.2 ...** **402.3 ...** **402.4 Exterior Walls** **402.4.1 Prescriptive Criteria** **402.4.1.1 Opaque Walls** **402.4.1.2 Fenestration**	**Subpart D - Building Design Requirements** **434.402 Building Envelope Assemblies & Materials** **434.402.1 ...** **434.402.2 ...** **434.402.3 ...** **434.402.4 Exterior Walls** **434.402.4.1 Prescriptive Criteria** **434.402.4.1.1 Opaque Walls** **434.402.4.1.2 Fenestration**

Changes

Table 402.4.1.1 on Maximum Wall Thermal Transmittance (Uow) and Table 402.4.1.2 on Maximum Window Wall Ratio (WWR) are replaced by new tables.

Rationale and Discussion

Portions of the individual city tables were updated using the fenestration U-value calculation procedures in Chapter 27 of the *1989 ASHRAE Handbook Fundamentals*. (See the changes to Section 402.1.2.4 discussed above.)

ASHRAE *Energy Code*	Proposed Federal Code (10 CFR 434)
Chapter 4 Building Design Requirements **403 Building Mechanical Systems and Equipment**	**Subpart D - Building Design Requirements** **434.403 Building Mechanical Systems & Equipment**

Changes

Changes were made to the text in Subsection 9.5.2 and to the tables and text on HVAC equipment performance criteria in Section 10 of *ASHRAE/IES Standard 90.1-1989* (which corresponds to Section 403 of the ASHRAE *Energy Code*). The seven changes made to this section are described below.

Change 1. A term was added to Exception (a) of Subsection 9.5.2. The existing exception allows the use of variable air volume (VAV) with reheat capability if the VAV dampers are designed to reduce airflow to minimum volumes before reheat occurs. The change allows a slightly higher airflow for cases where there is a very high heat loss from the space and a relatively small airflow rate.

Change 2. Table 10-1 was modified to provide requirements for small three-phase unitary air-cooled equipment in terms of seasonal equipment efficiency ratings and heating seasonal performance factors rather than coefficients of performance (per updates in *ARI Standard 210/240-89*). The requirements for "prior to January 1, 1992" were also dropped.

Change 3. Table 10-2 was modified to update references and drop requirements labeled "prior to January 1, 1992."

Change 4. Table 10-3 was modified to update references and drop requirements labeled "prior to January 1, 1992."

Change 5. Table 10-4a was modified to update references and drop requirements labeled "prior to January 1, 1992."

Change 6. Table 10-7 was modified to update references and drop requirements labeled "prior to January 1, 1992."

Change 7. Table 10-9 was modified to clarify provisions for National Appliance Energy Conservation Act (NAECA) of 1987 products and for products not covered by NAECA. Requirements labeled "prior to January 1, 1992" were dropped.

Rationale and Discussion

ASHRAE/IES Standard 90.1-1989 Addendum i (approved by the ASHRAE Board of Directors on July 1, 1993) addresses changes needed to update references to testing and rating procedures that have been modified or revised since 1989.

Change 1 provides a technical change (related to VAV reheat). This change is only a minor part of a single exception.

Change 2 merely restates existing requirements for small air-cooled equipment in terms of currently used rating terms rather than old rating terms.

Changes 3 through 6 merely update references and eliminate old "pre-1992" requirements.

Change 7 provides guidance on equipment covered by the National Appliance Energy Conservation Act (NAECA) of 1987.

Estimated Energy Impacts

Change 1. The change addresses adding an item (4) to exception (a) of subsection 9.5.2 of the ASHRAE/IES Standard 90.1-1989 as follows: (4) 300 cfm. The subsection deals with the operational issues of a zone control for a VAV system. It is estimated that the 300 cfm requirement would be needed to meet the higher heat ing loads that may occur in certain northern zones or zones with large areas of well-shaded glass. As such, there is no energy or cost impact because of this change.

Change 2. No energy impact, because existing requirements are just being restated.

Changes 3 through 6. No energy impact, because references to test and rating procedures are just being updated.

Change 7. Changes made to comply with NAECA requirements. Energy impacts of these changes are beyond the scope of this rule.

Estimated Cost Impacts

Change 1. No cost impact on construction costs. The only cost impacts would be from increased energy usage that is caused by Addendum e requirements. This issue must be balanced against increased occupant comfort in affected zones.
Changes 2 through 6. No cost impact.

Change 7. Cost impacts of NAECA requirements are outside the scope of 10 CFR 434 documentation.

ASHRAE *Energy Code*	Proposed Federal Code (10 CFR 434)
Chapter 5 Reference Standards **501 General**	**Subpart G - Reference Standards** **434.701 General**

Changes

Existing references listed in this section were updated, and new references were added.

Rationale and Discussion

Some existing references were changed, and additional references were cited, to make the *Energy Code* document consistent with the updated requirements stemming from the ASHRAE addenda to *ASHRAE/IES Standard 90.1-1989.*

References

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Appendix

Lighting Analysis Details

Appendix

Lighting Analysis Details

When the current DOE commercial building energy standard (10 CFR 435, Subpart A) (the federal standard) was first promulgated in 1989, it contained two sets of UPD values--1989 (DOE89) and 1993 (DOE93) values. The first set of values was taken from *ASHRAE/IES Standard 90.1-1989* and became effective upon promulgation of the federal standard. The second set of values was more stringent and was due to become effective in January 1993. This second set of values was deemed inappropriately and unjustifiably stringent by a large segment of the lighting industry. Unacceptable lighting quality results if energy codes require lighting power densities that are not achievable by practitioners with currently available technology and/or are not economically reasonable. Specifically, excessively low lighting power densities are likely to result in extreme glare or inadequate illumination levels. Although energy codes and standards do not provide requirements for lighting quality, these codes and standards ensure the design of quality environments is possible and not endangered by prohibitively low lighting power density requirements.

To respond to public concerns over the DOE93 UPD values, DOE implemented a demonstration phase to evaluate the DOE93 values and make recommended changes where necessary and appropriate. As a result, the promulgation of the DOE93 values was delayed by one year to await the results of the study. The demonstration phase, called the Lighting Impact Assessment Task (Assessment), was performed by Pacific Northwest Laboratory and their subcontractors. The passage of the Energy Policy Act of 1992 (EPAct) legally prohibited the amendment of the 1989 federal standard. Therefore, the proposed federal Code will be the first opportunity to implement the results of the Assessment.

The following is a description of the results of the Assessment, which provides technical support for the recommended changes to UPD values in the federal Code. The supportive rationale behind these recommended revisions is presented and its empirical basis is summarized. The recommended revisions remove some previous inconsistencies from the DOE93 UPD values and adjust values where necessary so Table 401.3.2 reflects a common goal of progressive energy-conserving practice without prohibiting the design of quality lighting in interior environments.

Objective

A major Assessment objective was to develop a consistent, empirically supported rationale for the UPD values in the federal standard, and to use that rationale to recommend appropriate revisions to the UPD values. Revised UPD values were determined by calculating suggested revisions through a statistical procedure designed to smooth out inconsistencies in the values. The Assessment included the following complementary efforts:

- a thorough review of any evidence on the relationship between lighting quality and lighting power density

- an intensive outreach effort to locate and utilize all building case studies and post-occupancy evaluations that reported lighting power densities and occupant satisfaction with lighting in new and retrofitted installations

- an examination and comparison of variability in lighting power densities from different North American standards sources and organizations that have published UPD recommendations and proposed rationales

- a series of lighting simulations by expert lighting designers of exemplar spaces to determine obtainable lighting power density levels while ensuring high lighting quality for those environments.

Guiding Principles

The Assessment directly addressed the question of how far an energy standard can go in reducing lighting energy consumption in buildings before lighting quality is compromised. This question is currently being widely researched throughout Europe and North America. The Assessment has combined relevant results from this research with a suitable statistical procedure into a rationale that generates UPD recommendations for the federal standard. The rationale is guided by the following principles:

- Lighting power density standards should be grounded in the best available empirical evidence that shows how building occupants respond to and accept lighting designed to meet those energy usage levels.

- When consensus in professional judgments is uncertain, an analytical model may be successfully employed to make informed judgments and augment the limitations of such judgments.

- Common lighting technologies are used, and common visual tasks are performed by occupants across a variety of space types. Therefore, a relationship exists between different space types.

- Lighting power density numbers in an energy standard must be based upon assumptions; but given the societal impact of an energy standard, all assumptions underlying the resulting lighting power densities should be responsibly determined and clearly defined.

Together, these principles suggest a rationale that is data driven, consistently implemented across all space types, and open to thorough verification at each step.

Rationale

Unit power densities in a lighting energy standard that encourage energy conservation and maintain lighting quality are bounded by two levels. The upper bound is represented by current professional practice that produces both energy savings and acceptable lighting (from the occupant's point of view). The lighting energy standard should not mandate UPDs higher than this bound, which has already been achieved. The lower bound is represented by lighting mock-ups and simulations of selected space types that extend the capabilities of professional practice. These mock-ups and simulations demonstrate much more energy-conserving lighting and that high lighting quality can be maintained. The lighting energy standard should not mandate UPDs lower than this bound, which describes the best that can be done under ideal circumstances. The upper bound, referred to as ALADA (As Low as Achievable with Demonstrated Acceptability), describes the region from which lighting practice is moving, and the lower bound, referred to as ALAHSQUA (As Low as Achievable with High Simulated Quality), describes the region toward which lighting practice is moving.

Analysis Overview

The five steps taken in the Assessment were as follows:

First, an extensive technical outreach effort was conducted to identify and obtain any relevant data on UPD values.

The technical outreach effort identified current information on the quality impacts of energy-efficient lighting in nonresidential environments. This effort involved contacting individuals currently working, or who have worked, in this field to assist in obtaining unpublished and little-known reports and to find ongoing lighting evaluation efforts. Copies of research articles and case studies on energy-efficient buildings were also obtained. In addition, data on energy consumption and expenditures by building type were obtained from the Energy Information Administration (EIA).

Over 60 individuals were contacted by phone and/or in person. These individuals represent the following entities:

- organizations active in energy efficiency issues - Natural Resources Defense Council, Electric Power Research Institute, Lighting Research Institute, International Association of Lighting Designers, and the Illuminating Engineering Society

- laboratories - Lawrence Berkeley Laboratory, National Institute of Standards and Technology, Seattle City Light's Regional Lighting Design Laboratory, Lighting Research Center, Pacific Energy Center, National Research Council of Canada

- universities - University of California at Berkeley, University of Washington, University of Minnesota, University of Kansas, Cornell University, Penn State University

- states - California, New York, Minnesota, Washington, Oregon

- utilities - Pacific Gas and Electric Company, Southern California Edison, San Diego Gas and Electric, Northern States Power Company, Northeast Utilities, Bonneville Power Administration

- energy management companies - ADM Associates, Sieben Energy Associates

- lamp and luminaire manufacturers - Osram Corporation, Litecontrol

- lighting consultants - Synergy Lighting Consultants, Inc., Hayden McKay Lighting Design, Luminae Souter Lighting Design, Architectural Design Lab, Horton Lees Lighting Design, Clanton Engineering

Case studies and/or functional space lighting information were acquired for different space types from the above-listed sources. Post-occupancy evaluations done on seven Bonneville Power Administration buildings were obtained. Individuals at Lawrence Berkeley Laboratory and Pacific Gas and Electric Company, involved with post-occupancy evaluations to be done on the Advanced Customer Technology Test for Maximum Energy Efficiency (ACT^2) buildings, were contacted. Other utilities provided limited lighting information (in the form of UPDs) from some of their new commercial construction programs.

The technical outreach phase included a Lighting Quality and Efficiency Technical Exchange Symposium on July 8-9, 1993 at Seattle City Light's Regional Lighting Design Lab in Seattle, Washington. This symposium presented the Assessment and solicited commentary on the rationale for the revision of the 1993 federal standard UPD values. Lighting researchers, practitioners, and utility personnel active in lighting design, along with lighting efficiency panels and professional communities, presented their results and thoughts on issues surrounding lighting standards.

Second, a comparative analysis of UPD values was performed to determine which of the 106 space types used in the federal standard showed significant inconsistencies and would potentially require revision and case study simulations.

The comparative UPD analysis began with a comparison between the DOE89 and DOE93 UPD values in the federal standard. Of the 106 space types used in Table 3.5-1, "Base UPD for Area/Activity," in the federal standard, 21 were identified as likely to be significantly impacted by the proposed changes to the DOE93 UPD values. Specifically, a decrease in the level by 40% or more and a shift of at least 0.1 Z-score[a] unit or a change in sign from a positive to a negative Z-score in the distribution of UPD values were considered significant. These combined criteria resulted in the list of space types displayed in Table A.1.

Additionally, lighting power density values from the following sources were used in UPD comparisons:

- federal standard (1989 and 1993) values
- *ASHRAE/IES Standard 90.1-1989*
- California Code of Regulations, Title 24 (CEC 1992)
- New York State Energy Code
- Natural Resources Defense Council (NRDC)
- 1990 Northwest Energy Code as adopted by the Northwest Power Planning Council
- National Research Council (NRC) Canada.

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[a]The number of standard deviation units above or below the mean of a distribution.

Table A.1. Potentially Impacted Space Types

Space Type	Change, %	Absolute Diff., w/ft^2	Z-Score Diff.
1. Classroom	50	2.0 to 1.0 = 1.0	0.258 to -0.406
2. Leisure Dining	44	2.5 to 1.4 = 1.1	0.743 to 0.006
3. Bar, Lounge	48	2.5 to 1.3 = 1.2	0.743 to -0.097
4. Library Cardfile	50	1.6 to 0.8 = 0.8	-0.13 to -0.613
5. Library Reading Area	47	1.9 to 1.0 = 0.9	0.16 to -0.406
6. Reception & Waiting	45	1.0 to 0.55 = 0.45	-0.71 to -0.871
7. Elevator Lobbies	50	0.8 to 0.4 = 0.4	-0.906 to -1.026
8. Atrium, Floors 1-3	43	0.7 to 0.4 = 0.3	-1.003 to -1.026
9. Air/Bus/Rail Stations	50	0.9 to 0.45 = 0.45	-0.809 to -0.974
10. Ticket Counter	48	2.5 to 1.3 = 1.2	0.743 to -0.097
11. Wait/Lounge Area	50	1.2 to 0.6 = 0.6	-0.518 to -0.819
12. Church Cong. Area	43	2.3 to 1.3 = 1.0	0.549 to -0.097
13. Dormitory Bedroom	40	1.0 to 0.6 = 0.4	-0.712 to -0.812
14. Study Hall	50	1.8 to 0.9 = 0.9	0.064 to -0.510
15. Jail Cell	50	0.8 to 0.4 = 0.4	-0.906 to -1.026
16. Hotel Banquet Room	42	2.4 to 1.4 = 1.0	0.646 to 0.006
17. Hotel Rest Room	50	1.2 to 0.6 = 0.6	-0.518 to -0.819
18. Hotel Guest Room	50	1.4 to 0.7 = 0.7	-0.324 to -0.716
19. Exhibition Hall	50	2.6 to 1.3 = 1.3	0.840 to -0.097
20. Museum Inactive Stg.	58	0.6 to 0.25 = 0.35	-1.1 to -1.8
21. Mall Concourse	57	1.4 to 0.6 = 0.8	-0.32 to -0.81

This analysis focused on space types requiring further study, and created the basis for the empirical database of ALADA and ALAHSQUA UPD values. Where insufficient data existed for ALAHSQUA UPD values, the need for case study simulations was indicated. The individuals who performed the case studies under contract to PNL were JoAnne Lindsley of Synergy Consultants, Inc. and Naomi Miller of Lighting Research Center at Rensselaer Polytechnic Institute (formerly of Architectural Lighting Design, Inc.) The working model of the case studies was created by Hayden McKay of Hayden McKay Lighting Design.

Third, based on the results of the UPD comparative analysis, empirical data (ALADA and ALAHSQUA) was collected for use in establishing the statistical model. Case study simulations were performed where insufficient data existed for ALAHSQUA UPD values.

Attachments A.1 and A.2 to this Appendix list the sources of the ALADA and ALAHSQUA data points that were recovered and used as the basis for the eventual predictions in the statistical model. Based on the comparative analysis of UPD values, 26 different space types out of the 106 listed in the federal standard (Table 3.5-1, "Base UPD for Area/Activity") are represented.

Figures A.1 and A.2 plot the UPD data points on bars that reflect the federal standard's DOE89 and DOE93 UPD values. ALADA points are plotted as black circles and ALAHSQUA points as open squares. Significant mismatches are evident between data and the federal standard's values for several of the space types. For example, the DOE93 UPD value for Classrooms in the federal standard appears to be far too low to accommodate both current energy-efficient practice and energy-exemplar simulations. By contrast, the values for Offices seem to show that the DOE value (an average of the various office UPDs in the federal standard) can be further lowered to gain additional energy savings.

Figures A.1 and A.2 also show there are no corresponding ALADA and ALAHSQUA data points for all space types. For example, Leisure Dining, Conference/Meeting, and Auditorium do not have corresponding ALAHSQUA points; and Museum Storage (inactive) and Exhibits and Airport Waiting and Ticketing do not have corresponding ALADA points. In the extant building studies and simulations available on lighting, some space types are very strongly represented and others are apparently ignored. This condition in currently available research was considered in the development of the UPD assessment model.

The first step in developing revised UPDs was to predict the missing values from the basis data set. Figures A.3 and A.4 use the extant pairs of ALADA:ALAHSQUA points to derive at the linear regression estimates for those that are missing. The correlation of 0.873 between the sets of points is high enough to justify this procedure. In each of these figures, the missing points being estimated belong to those plotted on the y-axis as indicated in the regression equation.

Figures A.5 and A.6 show the means of completed data sets for the 26 space types (including both original and estimated points) plotted in increasing order of the joint means. Figure A.5 plots these means on bars that reflect the DOE89 values, while Figure A.6 places these means on bars that reflect the DOE93 values. These figures show the clearest summative comparisons between the state of building studies and simulations and the mandates of the federal standard's values. Two conditions are noticeably evident. First, there is a better overall fit between the ALADA:ALAHSQUA pairs of means and the DOE89 values than between those means and the DOE93 values. Second, the differences between ALADA:ALAHSQUA pairs of means were much lower than was expected.

The first condition appears to verify the presence of inconsistencies in the DOE93 values that motivated this research. If the federal standard more appropriately reflected the current state-of-the-art lighting practice, the tops of the bars would be near or between the ALADA:ALAHSQUA pairs of means. The second condition was surprising because a greater disparity between real-world case studies and simulations was hypothesized. Either the assessed buildings are pushing the energy performance envelope, or simulation studies are more closely attuned to real-world practice than their ideal conditions might suggest.

Fourth, the ALADA and ALAHSQUA data were used as a statistical base to describe a predicted overall relationship between ALADA:ALAHSQUA pairs and indicate where UPD values required revision. The statistical model produced a target guideline of predicted UPD values based on the principles and rationale of the UPD comparative analysis.

These pairs of means served as a statistical base to describe a predicted overall relationship between ALADA:ALAHSQUA pairs and indicate where the 80 federal standard space type values (not represented in the original 26 space types) will appear in the overall relationship.

Figures A.7 and A.8 show the correlation between the ALADA:ALAHSQUA pairs of means on the original 26 space types. These figures are different from Figures A.3 and A.4 because they include the missing values that were estimated in the previous regression equations. Note that the correlation has now moved to 0.910 from 0.873, which is to be expected with the addition of these highly correlated estimates.

It is worth noting that the decision to use the line of structural relations[b] analysis is superior to using simple linear regression analysis (i.e., correlation) because this procedure allows for an estimation of standard values from the information in both lighting distributions (lighting as practical and lighting as simulated).

Technically, the line of structural relations is the weighted mean of the two regression lines, Y on X and the reciprocal of X on Y, where the weighing is proportional to the measurement errors in observing data in the two distributions. Because of the high correlation and the similarity of ALADA:ALAHSQUA data points, made a simplifying assumption was made that the ratio of the error variances in the two distributions was 1.0. This assumption made the line of structural relations the simple mean of these two regression lines.

Figure A.9 shows the 26 pairs of points with the inscribed line of structural relations. This line shows the linear relation toward which the two distributions of points are strongly tending. The predicted DOE93 values based on the ALADA:ALAHSQUA linear relation are determined by perpendiculars to the line of structural relations drawn from each point. When the original ALADA point is higher than its corresponding ALAHSQUA, the predicted value is read off of the ordinate. If the original ALAHSQUA is higher, the value is read off of the abscissa of the graph.

Table A.2 summarizes the 26 predicted UPD values, their corresponding ALADA and ALAHSQUA means, and their differences from DOE89 and DOE93 values.

There were some peculiarities in the predicted values, which are expected when working from a global statistical model. For example, the predicted UPD value of 0.60 for Library Stacks occurred because this point is extremely off-axis, with a large difference and a position reversal between its ALADA and ALAHSQUA means. The very high predicted UPD value (with respect to DOE89 and DOE93 values) for the Fast Food category occurred because the data points supporting this category are exclusively from retail fast food establishments, while the federal standard's values inexplicably include cafeterias in the same category. This peculiarity suggests that there should be two space type categories to accommodate these very different types of eating facilities.

The final step in extrapolating to the federal standard's other space type categories is shown in Figure A.10. This figure correlates the 26 predicted UPD values from Table A.1 with their respective DOE89 values and shows the regression equation for deriving other predicted UPD values for the remaining 80 DOE89 space types. There is a moderate 0.52 R-value here, which is sufficient

[b]The straight line that has a minimum distance to all points in a cloud of points.

Table A.2. Predicted UPD Values for 26 Area/Activity Space Types for Which ALADA and ALAHSQUA Data Are Available

Area/Activity	ALADA Mean	ALAHSQUA Mean	Predicted UPD Value	DOE89 Value	DOE93 Value
Fast Food	3.61	2.27	3.50	1.30	0.8
Museum(Inspection)	2.59	2.02	2.65	3.90	3.0
Bar/Lounge	2.46	2.12	2.60	2.50	1.3
Retail D(Gen Merch)	2.42	1.78	2.40	3.00	2.3
Classroom	1.99	1.62	2.05	2.00	1.0
Airport (Ticket)	1.94	1.55	2.00	2.50	1.3
Mall Concourse	1.81	1.52	1.90	1.40	0.6
Museum (Exhibit)	1.73	1.4	1.75	1.90	1.2
Office	1.47	1.23	1.50	2.44	2.07
Dorm Bedroom	1.45	1.2	1.50	1.00	0.6
PO Sorting	1.29	1.19	1.35	2.10	2.1
Dorm Study Hall	1.18	1.01	1.20	1.80	0.9
Computer/Equipment	1.13	0.7	1.10	2.10	2.1
Auditorium	1.1	1.03	1.1	1.60	1.4
Library Reading	1.08	0.94	1.10	1.90	1.0
Warehouse Active, Fine	1.0	0.51	0.85	1.00	0.9
Museum Storage Inact.	0.97	0.86	1.00	0.60	0.25
Leisure Dining	0.85	0.89	0.90	2.50	1.4
Hotel Guest Room	0.83	0.76	0.85	1.40	0.7
Airport (Waiting)	0.8	0.74	0.80	1.20	0.6
Library Card Catalogue	0.8	0.74	0.80	1.60	0.8
Conference/Meeting	0.77	0.85	0.80	1.80	1.3
Corridors	0.73	0.88	0.80	0.80	0.8
Service Station, Repair	0.54	0.38	0.45	1.00	0.8
Airport Thruway	0.5	0.83	0.65	0.90	0.45
Library Stacks	0.22	1.13	0.60	1.50	1.50

for this purpose. Each of the remaining 80 space type predicted UPD values was determined by entering its DOE89 value in the following regression equation:

$$\text{Predicted DOE93 value} = 0.526 * (\text{DOE89 value}) + 0.465 \quad (1)$$

These UPD values can also be visually determined by entering the DOE89 UPD value on the abscissa of Figure A.10 and going vertically up to the regression line, then horizontally over to the corresponding value on the y-axis. Note that this procedure is not appropriate for the original 26 space types, whose predicted 1993 UPD values were determined from their empirical database.

Fifth, the model was used to determine which of three UPD values was most appropriate for the space type: the original DOE89 value, the DOE93 value, or the predicted number from the statistical model. Table 401.3.2 was revised accordingly as shown in the proposed federal Code.

Out of the 106 Area/Activity space types, 57 have stayed with the DOE93 UPDs, 27 have been rolled back to the DOE89 UPDs, and 22 have been given new UPDs that mostly fall between the DOE89 and DOE93 values. A new value was only recommended after substantial empirical evidence had been gathered, or when the value's prediction by the statistical regression model appeared to be the best compromise between substantially different DOE89 and DOE93 values and no other evidence was available.

The guidelines for revisions to the UPD values were as follows:

- Because EPAct mandated *ASHRAE/IES Standard 90.1-1989* as the standard to meet or exceed the federal standard, and because DOE89 UPD values are almost identical to the ASHRAE values, DOE89 values are recommended when the model predicted close to or above the DOE89 values.

- When the model predicted close to or below the DOE93 UPD values, and there was no substantial empirical evidence to justify the lower prediction of the model, the DOE93 values were recommended, which are usually lower than DOE89 values. In a couple of instances (e.g., Library Stacks) where the model predicted below the DOE93 values, and there was good evidence to support it, the new, lower UPD value was recommended.

- If the model predicted between the DOE89 and DOE93 values, and was in a range where the model can be considered most valid, the new predicted UPD value from the model was substituted for the DOE93 UPD value.

Offices have a high number of new recommended UPDs because the substantial amount of case study and simulation evidence points overwhelmingly to a current capability for further lowering office UPDs from their DOE93 values, with no danger of decreasing acceptable lighting quality. The large amount of office space in the United States means that even this small decrease will result in significant additional energy savings. In only one case have we increased a DOE93 office UPD value from 1.3 to 1.5 W/ft^2 to conform with the model's prediction.

Table A.3 shows the predicted UPD values derived from the regression model for all Area/Activity space types in Table 3.5-1 of the federal standard. The table also shows a comparison of these values with DOE89 and DOE93 UPDs, and makes a recommendation based on the observed differences and the strength of the data underlying the predicted UPD values. The original 26 space types for which ALADA:ALAHSQUA data are available are marked with an asterisk (*). All values are in watts per square foot (W/ft^2).

Table A.3. Predicted UPD Values and Recommendations for Revisions to the Federal Standard UPD Values

Area/Activity	Predicted UPD Value	DOE89 Value	DOE93 Value	Recommended UPD Value
Auditorium*	1.1	1.6	1.4	DOE93 = 1.4
Corridor*	0.8	0.8	0.8	DOE93 = 0.8
Classrooms*	2.05	2.0	1.0	DOE89 = 2.0
Elec/Mech Rm				
General	0.7	0.7	0.7	DOE93 = 0.7
Contrl Rm.	1.6	1.5	1.5	DOE93 = 1.5
Food Service				
Fast Food*	3.5	1.3	0.8	DOE89 = 1.3
Leisure Dng.*	0.9	2.5	1.4	DOE93 = 1.4
Bar/Lounge*	2.6	2.5	1.3	DOE89 = 2.5
Kitchen	1.2	1.4	1.4	DOE93 = 1.4
Recreation/Lnge.	0.7	0.7	0.5	DOE89 = 0.7
Stairs				
Active	0.8	0.6	0.6	DOE93 = 0.6
Emergency	0.7	0.4	0.4	DOE93 = 0.4
Toilet & Washroom	0.9	0.8	0.5	DOE89 = 0.8
Garage				
Auto/Ped.	0.6	0.3	0.25	DOE89 = 0.3
Parking	0.6	0.2	0.2	DOE93 = 0.2
Laboratory	1.7	2.3	2.2	DOE93 = 2.2
Library				
Aud/Vsl.	1.1	1.1	1.1	DOE93 = 1.1
Stacks*	0.6	1.5	1.5	New # = 1.1
Card file*	0.8	1.6	0.8	DOE93 = 0.8
Reading*	1.1	1.9	1.0	New # = 1.1
Lobby (general)				
Recptn.	1.0	1.0	0.55	DOE89 = 1.0
Elevator	0.9	0.8	0.4	DOE89 = 0.4
Atrium				
First 3 floors	0.8	0.7	0.4	DOE89 = 0.7
Each additional floor	0.6	0.2	0.15	DOE89 = 0.2
Locker Rm & Shower	0.9	0.8	0.6	DOE89 = 0.8
Offices* < 900 ft^2				
Reading	1.5	1.8	1.3	New # = 1.5
Drafting	1.85	2.6	2.2	New # = 1.9
Accntng.	1.6	2.1	1.8	New # = 1.6
Open Plan Offices = or > 900 ft^2 with medium-high partitions				
Reading	1.5	1.9	1.5	DOE93 = 1.5
Drafting	2.0	2.9	2.6	New # = 2.0
Accntng.	1.75	2.4	2.1	New # = 1.8

Open Plan Offices = or > 900 ft^2 with high partitions				
Reading	1.7	2.2	1.7	DOE93 = 1.7
Drafting	2.3	3.4	3.0	New # = 2.3
Accntng.	1.9	2.7	2.4	New # = 1.9
Common Activity Areas				
Conf/mtng*	0.8	1.8	1.3	DOE93 = 1.3
Computer*	1.1	2.1	2.1	New # = 1.1
Filng. Inact.	1.0	1.0	1.0	DOE93 = 1.0
Mail Room	1.4	1.8	1.8	DOE93 = 1.8
Shop (Nonindustrial)				
Machinery	1.8	2.5	2.5	DOE93 = 2.5
Electrical	1.8	2.5	2.5	DOE93 = 2.5
Painting	1.3	1.6	1.6	DOE93 = 1.6
Carpentry	1.7	2.3	2.3	DOE93 = 2.3
Welding	1.1	1.2	1.2	DOE93 = 1.2
Storage & Warehouse				
Inactive	0.6	0.3	0.2	DOE93 = 0.2
Active. Bulky.	0.6	0.3	0.3	DOE93 = 0.3
Active.Fine*	0.85	1.0	0.9	DOE93 = 0.9
Matrl. Hndl.	1.0	1.0	1.0	DOE93 = 1.0
Unlisted Space	0.6	0.2	0.2	DOE93 = 0.2
Airport, Bus & Rail Station				
Baggage	0.9	0.8	0.75	DOE89 = 0.8
Thruway*	0.65	0.9	0.45	DOE89 = 0.9
Tckt. Cntr.*	2.0	2.5	1.3	New # = 2.0
Wtng/Lnge*	0.8	1.2	0.6	New # = 0.8
Bank				
Custmr.	1.0	1.0	0.8	DOE89 = 1.0
Bnkng.Area	2.0	2.8	2.2	DOE93 = 2.2
Barber & Beauty	1.6	2.0	1.6	DOE93 = 1.6
Church, Synagogue, Chapel				
Worship	1.7	2.3	1.3	New # = 1.7
Preach/Chr.	1.9	2.7	1.8	DOE93 = 1.8
Dormitory				
Bdrm.*	1.5	1.0	0.6	DOE89 = 1.0
Bdrm/stdy	1.2	1.3	1.3	DOE93 = 1.3
Stdy Hall*	1.2	1.8	0.9	New # = 1.2
Fire & Police Dept.				
Engine Rm.	0.8	0.7	0.7	DOE93 = 0.7
Jail Cell	0.9	0.8	0.4	DOE89 = 0.8
Hospital/Nursing Home				
Corridor	1.2	1.3	0.9	DOE89 = 1.3
Dental Ste.	1.3	1.6	1.4	DOE89 = 1.6
Emergency	1.7	2.3	2.0	DOE93 = 2.0
Laboratory	1.5	1.9	1.7	DOE93 = 1.7
Lounge	0.9	0.9	0.6	DOE89 = 0.9

Med. Supls.	1.7	2.4	2.4	DOE93 = 2.4
Nursery	1.5	2.0	1.6	DOE93 = 1.6
Nurse Sta.	1.6	2.1	1.8	DOE93 = 1.8
Occ/Phys.	1.3	1.6	1.4	DOE93 = 1.4
Patient Rm	1.2	1.4	0.9	New # = 1.2
Pharmacy	1.4	1.7	1.5	DOE93 = 1.5
Radiology	1.6	2.1	1.8	DOE93 = 1.8
Surgical and OB suites				
General	1.6	2.1	1.8	DOE93 = 1.8
Operating	4.4	7.0	6.0	DOE93 = 6.0
Recovery	2.1	3.0	2.0	DOE93 = 2.0
Hotel/Conference Center				
Banquet	1.7	2.4	1.4	New # = 1.7
Bath/Pwdr.	1.1	1.2	0.6	DOE89 = 1.2
Guest Rm*	0.9	1.4	0.7	New # = 0.9
Public	1.0	1.1	0.8	New # = 1.0
Exhibition	1.8	2.6	1.3	New # = 1.8
Conf./Mtng.	1.4	1.8	1.5	DOE93 = 1.5
Lobby	1.5	1.9	1.3	New # = 1.5
Reception	1.7	2.4	2.4	DOE93 = 2.4
Laundry				
Washing	0.9	0.9	0.6	DOE89 = 0.9
Irng/Sort	1.2	1.3	1.3	DOE93 = 1.3
Museum & Gallery				
Genrl Exbt.*	1.8	1.9	1.2	DOE89 = 1.9
Inspctn.*	2.65	3.9	3.0	DOE93 = 3.0
Storage(Artifacts)Inactive*	1.0	0.6	0.25	DOE89 = 0.6
Storage(Artifacts)Active	0.8	0.7	0.5	DOE89 = 0.7
Post Office				
Lobby	1.1	1.1	0.8	DOE89 = 1.1
Sort/Mail*	1.4	2.1	2.1	DOE93 = 2.1
Srvce Sta. Repr.*	0.5	1.0	0.8	DOE93 = 0.8
Theatre				
Perf. Arts	1.3	1.5	1.1	New # = 1.3
Mot. Pict.	1.0	1.0	0.75	DOE89 = 1.0
Lobby	1.3	1.5	1.0	New # = 1.3
Retail Establishments				
Type A	3.4	5.6	6.0	DOE89 = 5.6
Type B	2.2	3.2	2.9	DOE93 = 2.9
Type C	2.2	3.3	2.7	DOE93 = 2.7
Type D*	2.4	3.0	2.5	New # = 2.3
Type E	2.0	2.8	2.4	DOE93 = 2.4
Type F	1.9	2.7	2.6	DOE93 = 2.6
Mall Concourse*	1.9	1.4	0.6	DOE89 = 1.4
Retail Support Area				
Tailoring	1.6	2.1	2.1	DOE93 = 2.1
Dressing	1.2	1.4	1.1	DOE93 = 1.1

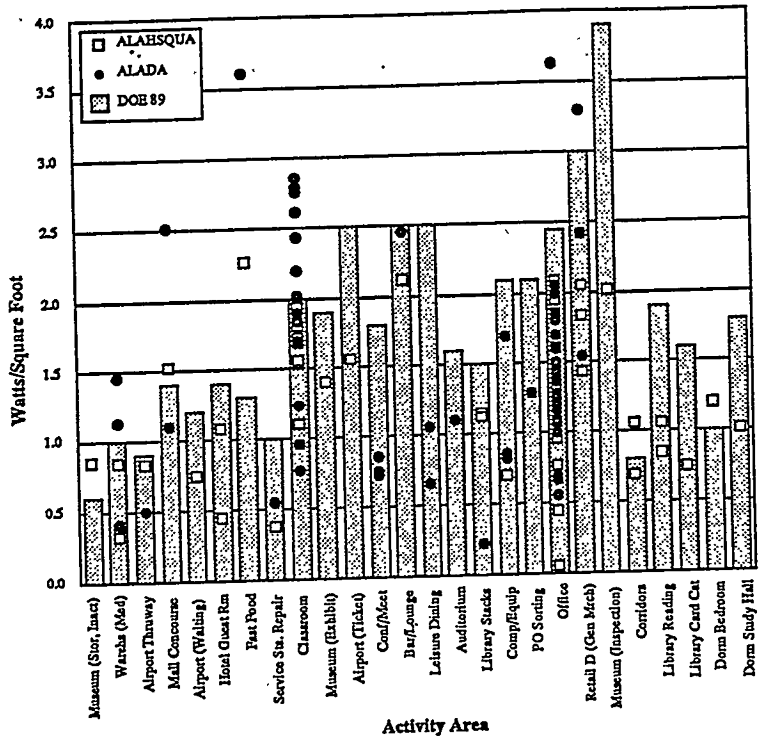

Figure A.1. DOE89 UPDs with ALADA/ALAHSQUA Points

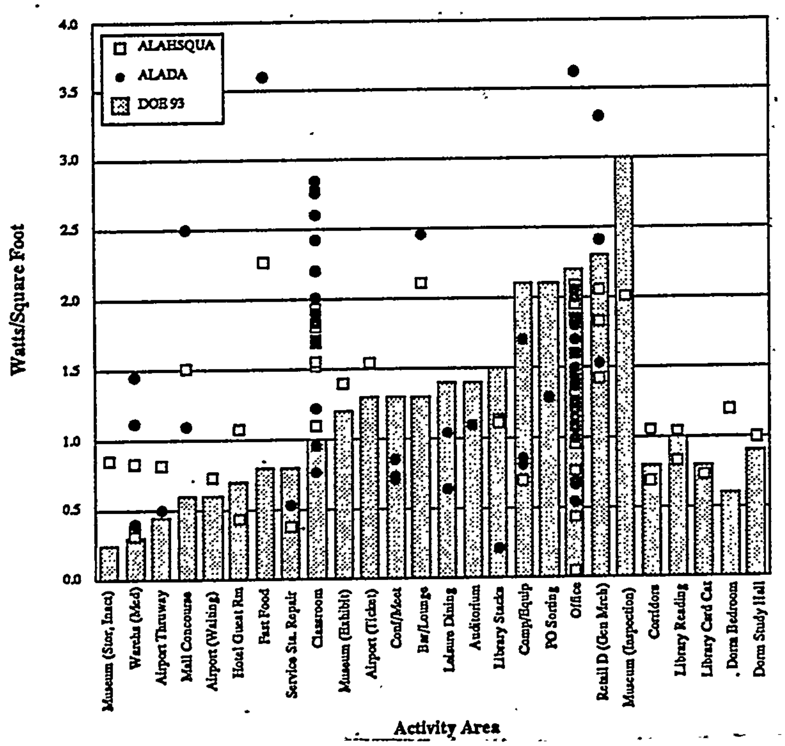

Figure A.2. DOE93 UPDs with ALADA/ALAHSQUA Points

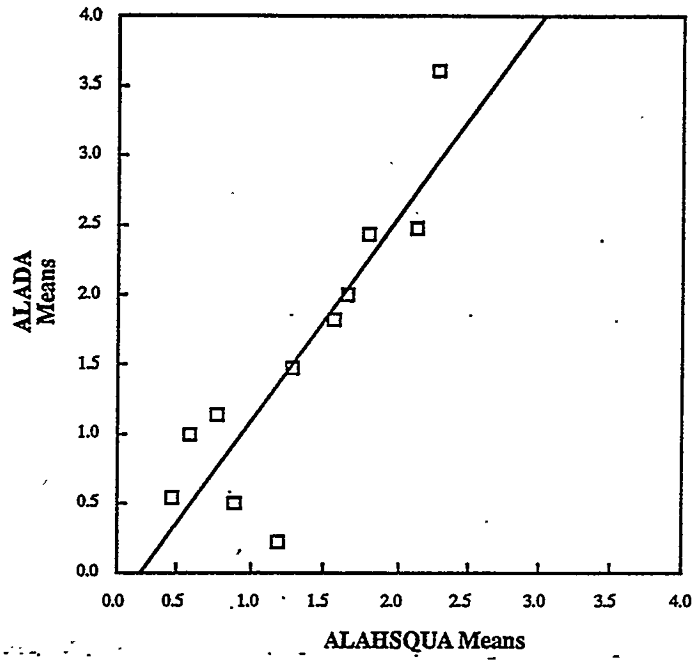

Figure A.3. Prediction Equation for Missing ALADA Points from ALAHSQUA Values: $y = 1.399x - 0.233$, $r = 0.873$

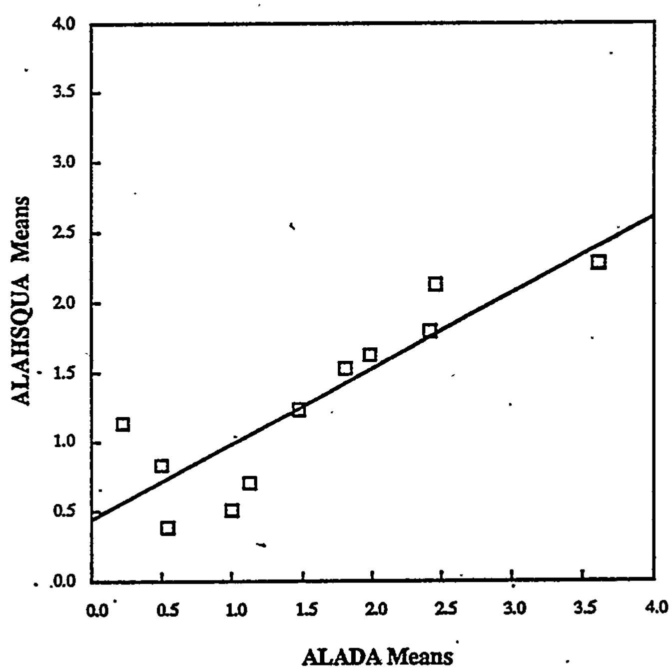

Figure A.4. Prediction Equation for Missing ALAHSQUA Points from ALADA Values: $y = 0.545x + 0.431$, $r = 0.873$

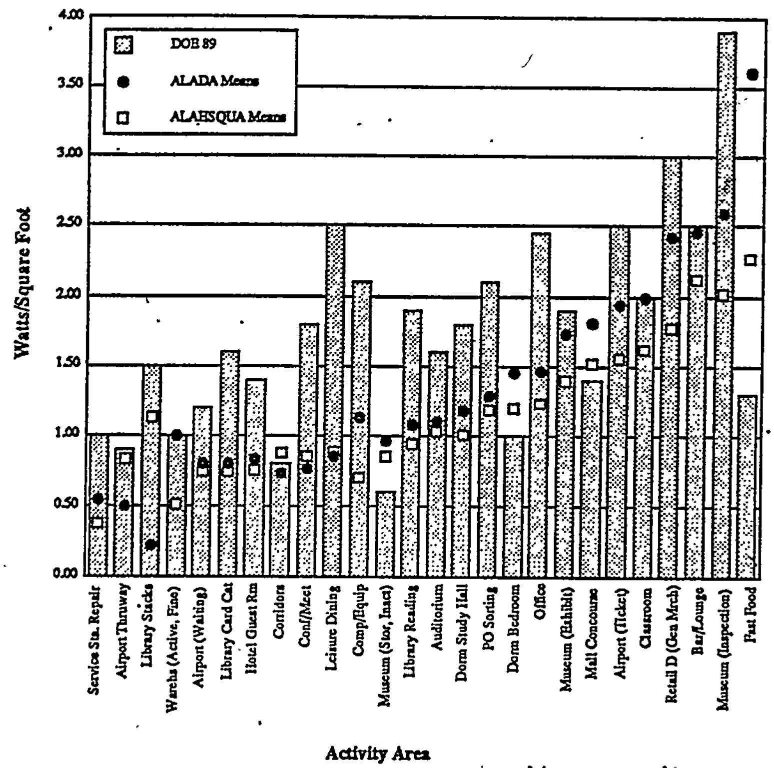

Figure A.5. Means of Completed ALADA/ALAHSQUA Data Sets Plotted on Bars Reflecting DOE89 Values

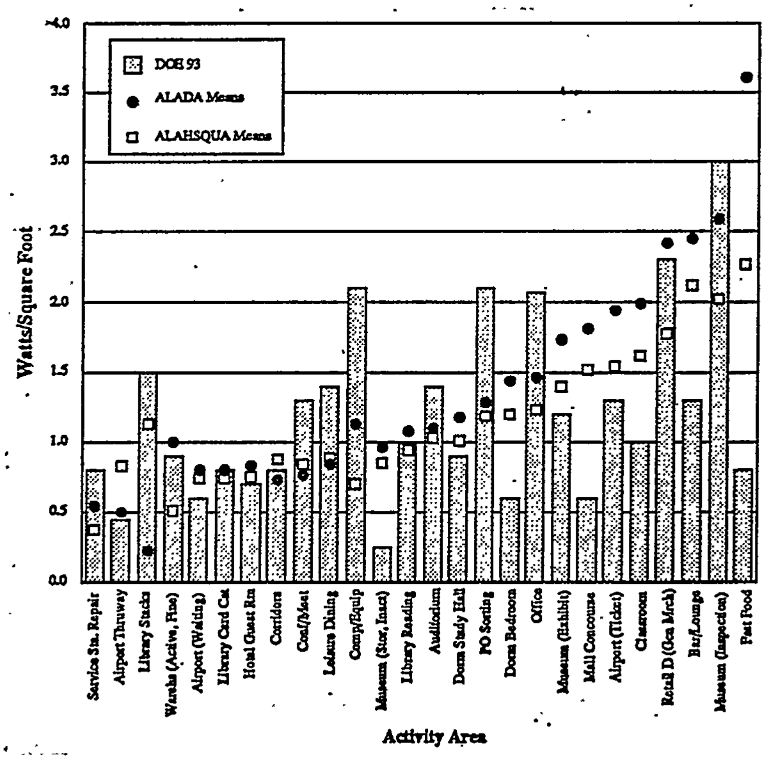

Figure A.6. Means of Completed ALADA/ALAHSQUA Data Sets Plotted on Bars Reflecting DOE93 Values

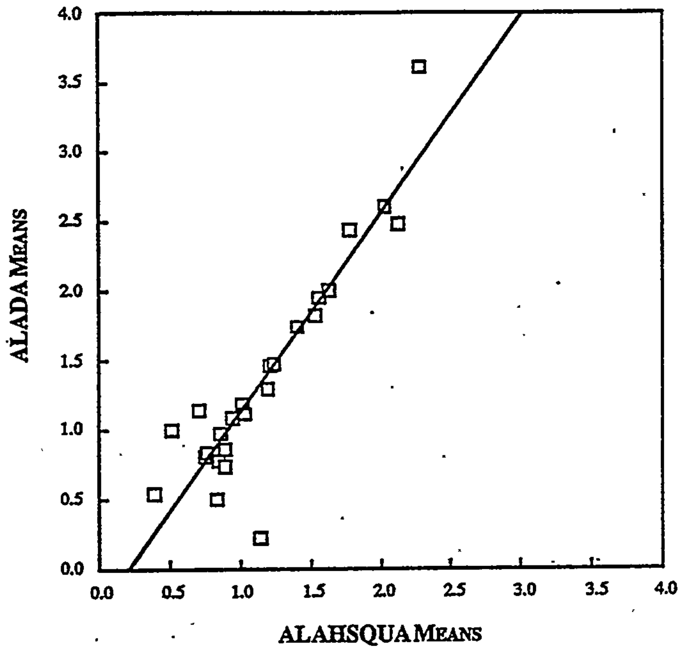

Figure A.7. Regression of ALADA on ALAHSQUA Values for the Completed 26 Pairs of Data Points: y = 1.430x - 0.302, r = 0.910

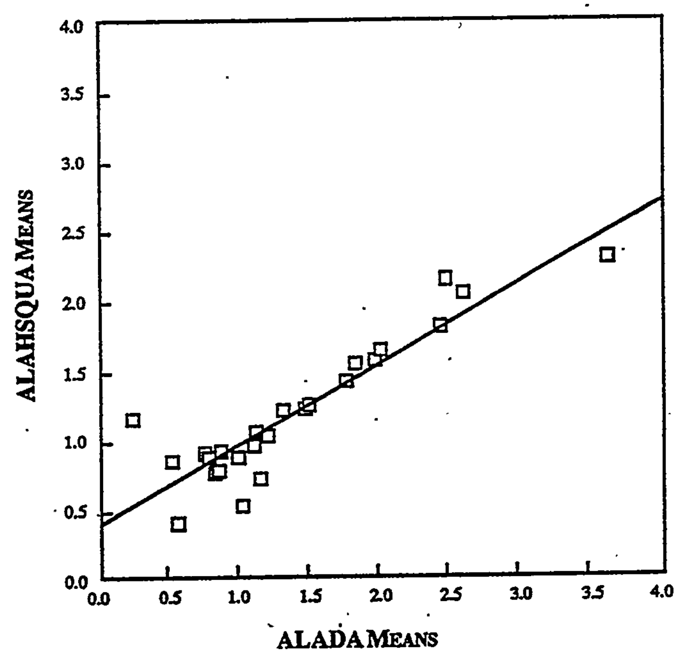

Figure A.8. Regression of ALAHSQUA on ALADA Values for the Completed 26 Pairs of Data Points: y = 0.578x - 0.375, r = 0.910

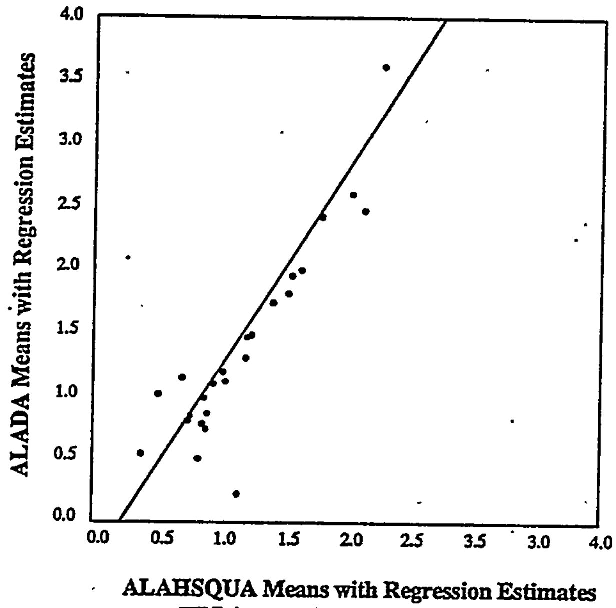

Figure A.9. The 26 Pairs of Data Points with Their Inscribed Line of Structural Relations

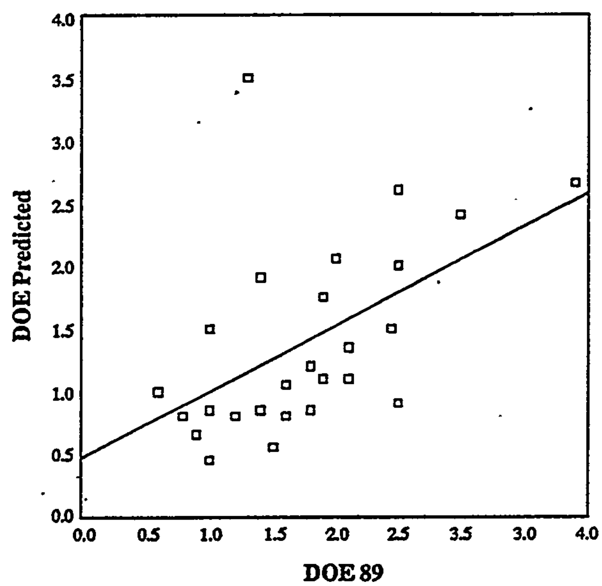

Figure A.10. The Regression Equation for Predicting UPD Revisions for the Remaining 80 DOE Space Types, Using Revised UPDs of the 26 Data Points and Their DOE89 Levels

Attachment A.1

ALADA Data Source List

Activity Area	ALADA Number	LPD Value	Source
Airport Thruway	1	0.50	Minnesota Case Studies
Auditorium	1	1.10	Minnesota Case Studies
Bar/Lounge	1	2.46	Minnesota Table 6a Existing
Classroom	1	0.77	Lighting Design Lab
Classroom	2	0.96	Lighting Design Lab
Classroom	3	1.23	Lighting Design Lab
Classroom	4	1.70	Lighting Design Lab
Classroom	5	2.85	California Energy Commission
Classroom	6	2.43	California Energy Commission
Classroom	7	2.20	California Energy Commission
Classroom	8	2.76	California Energy Commission
Classroom	9	1.84	California Energy Commission
Classroom	10	2.79	California Energy Commission
Classroom	11	1.86	California Energy Commission
Classroom	12	2.61	California Energy Commission
Classroom	13	1.90	California Energy Commission
Classroom	14	2.02	Minnesota Table 6a Existing
Computer/Equipment	1	0.82	Lighting Design Lab
Computer/Equipment	2	0.86	Lighting Design Lab
Computer/Equipment	3	1.70	Minnesota Case Studies
Conference/Meeting	1	0.86	Lighting Design Lab
Conference/Meeting	2	0.72	Lighting Design Lab
Conference/Meeting	3	0.74	Lighting Design Lab
Fast Food	1	3.61	Minnesota Table 6a Existing
Leisure Dining	1	1.05	Lighting Design Lab
Leisure Dining	2	0.65	Lighting Design Lab
Library Stacks	1	0.22	Lighting Design Lab
Mall	1	1.10	Oregon Market at Portland Industrial Airport

Mall	2	2.51	Minnesota Table 6a Existing
Post Office Sorting	1	1.29	San Diego Mail Facility
Service Sta Repair	1	0.54	Minnesota Table 6a Existing
Office	1	1.43	Lighting Design Lab
Office	2	1.20	Lighting Design Lab
Office	3	1.26	Lighting Design Lab
Office	4	1.15	Lighting Design Lab
Office	5	2.00	Belinda Collins
Office	6	1.70	Energy Edge
Office	7	1.60	Energy Edge
Office	8	1.40	Energy Edge
Office	9	1.20	Energy Edge
Office	10	1.00	Energy Edge
Office	11	1.50	R. Sullivan
Office	12	1.20	Lighting Design Lab
Office	13	0.69	RK Watson
Office	14	0.55	RK Watson
Office	15	1.08	Emerald PUD HQ Building
Office	16	1.39	Heiko Schnetz
Office	17	0.67	Minnesota Table 6a Existing
Office	18	1.85	Minnesota Table 6a Existing
Office	19	2.05	Minnesota Table 6a Existing
Office	20	2.06	Minnesota Table 6a Existing
Office	21	1.37	Minnesota Table 6a Existing
Office	22	3.63	Minnesota Table 6a Existing
Office	23	1.81	Minnesota Table 6a Existing
Retail D (General)	1	1.54	Minnesota Table 6a Existing
Retail D (General)	2	2.42	Minnesota Table 6a Existing
Retail D (General)	3	3.30	Minnesota Table 6a Existing
Warehouse (Medium)	1	1.13	Minnesota Table 6a Existing
Warehouse (Medium)	2	1.46	Minnesota Table 6a Existing
Warehouse (Medium)	3	0.41	Minnesota Table 6a Existing

Attachment A.2

ALAHSQUA Data Source List

Activity Area	ALAHSQUA Number	LPD Value	Source
Airport Ticket	1	1.55	Architectural Design Lab
Airport Thruway	1	0.83	Architectural Design Lab
Airport Waiting	1	0.74	Architectural Design Lab
Bar/Lounge	1	2.12	Minnesota Table 8a State-of-Art
Classroom	1	1.10	Lighting Design Lab
Classroom	2	1.72	California Energy Commission
Classroom	3	1.94	California Energy Commission
Classroom	4	1.56	California Energy Commission
Classroom	5	1.53	California Energy Commission
Classroom	6	1.69	Minnesota Table 8a State-of-Art
Classroom	7	1.81	Synergy
Computer/Equipment	1	0.70	Synergy
Corridor	1	0.69	Synergy
Corridor (Dorm)	2	1.06	Synergy
Dorm Bedroom	1	1.20	Synergy
Dorm Study Hall	1	1.01	Synergy
Fast Food	1	2.27	Minnesota Table 8a State-of-Art
Hotel Guest Room	1	1.08	Lighting Design Lab
Hotel Guest Room	2	0.44	Lighting Design Lab
Library Stacks	1	1.12	Synergy
Library Stacks	2	1.14	Synergy
Library Reading Area	1	0.84	Synergy
Library Reading Area	2	1.05	Synergy
Library Card Catalog	1	0.74	Synergy

Mall	1	1.52	Minnesota Table 8a State-of-Art
Museum Exhibit	1	1.40	Architectural Design Lab
Museum Inact Stor	1	0.86	Architectural Design Lab
Museum Inspection	1	2.02	Architectural Design Lab
Office	1	0.77	Kansas Electric Utilites
Office	2	1.25	R. Sullivan
Office	3	0.05	R. Sullivan
Office	4	1.61	Lighting Design Lab
Office	5	1.34	Lighting Design Lab
Office	6	1.08	Lighting Design Lab
Office	7	0.44	Minnesota Table 8a State-of-Art
Office	8	1.47	Minnesota Table 8a State-of-Art
Office	9	1.96	Minnesota Table 8a State-of-Art
Office	10	1.86	Minnesota Table 8a State-of-Art
Office	11	0.96	Minnesota Table 8a State-of-Art
Office	12	2.09	Minnesota Table 8a State-of-Art
Office	13	1.23	Minnesota Table 8a State-of-Art
Office	14	1.08	Synergy
Retail D (General)	1	1.43	Minnesota Table 8a State-of-Art
Retail D (General)	2	1.84	Minnesota Table 8a State-of-Art
Retail D (General)	3	2.06	Minnesota Table 8a State-of-Art
Service Sta Repair	1	0.38	Minnesota Table 8a State-of-Art
Warehouse (medium)	1	0.84	Minnesota Table 8a State-of-Art
Warehouse (medium)	2	0.32	Minnesota Table 8a State-of-Art
Warehouse (medium)	3	0.36	Minnesota Table 8a State-of-Art

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