
Preamble

The paper, authored in 1998 is provided to explain how the Lighting Power Density methodology was developed and used in the development of the LPDs published in the 1999 version of ANSI/ASHRAE/IESNA Standard 90.1.

Since then, the LPDs have undergone several updates resulting in the values in the 2004 version of the standard and shown here in this website tool.Changes were made in the following areas:

- the illuminance recommendations were updated to agree with the values published in the IESNA Lighting Handbook, 9th edition, 2000
- application models where new techniques or equipment suggested anddition/change
- updates to the light loss factors, lamp efficacies and luminaire efficiencies
- the LPD calculation formula.

The data in the paper, therefore, will not exactly match what you see in the Whole Building, Space Type and Calculator pages but will give you an indication of the thoroughness with which LPD documentation has been developed.

An Empirical Data Based Method for Development of Lighting Energy Standards

Paper #50

Eric E. Richman, LC - Pacific Northwest National Laboratories

Carol C. Jones - Pacific Northwest National Laboratories

JoAnne Lindsley, IALD - Lindsley Consultants Inc.

Abstract

An Empirical Data Based Method for Development of Lighting Energy Standards

The current ASHRAE voluntary lighting energy standard *Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings* (ANSI/ASHRAE/IESNA 90.1-1989) is based on the lighting power density values derived from the out-of-print IESNA publication *IES Recommended Procedure for Lighting Power Limit Determination* (LEM-1). The proposed ASHRAE/IES 90.1R developmental standard that is currently in its second public review incorporates a modified, streamlined process for determining lighting power densities for both individual spaces and whole buildings. This process combines professional consensus of quality lighting design, current efficient lighting product characteristics data and real new building construction data to develop new lighting power requirements. These new lighting power values closely match acceptable quality lighting design with current efficient lighting products and new building design. This process simplifies earlier methods while adding current building design and lighting product characteristics with accepted quality design features to ensure reasonable energy savings without detriment to the quality of the lighted environment. This report describes the methodology, its inputs, calculations, and application format as proposed for use in the new ASHRAE/IES voluntary energy standard.

Introduction

The current *Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings* (ASHRAE/IESNA 90.1-1989) standard and the *Federal Energy Standard* (10 CFR 435) are the most widely adopted and used standards for promoting energy efficient lighting of new buildings. Both of these standards have lighting requirements that are based on the lighting power density values derived from the out-of-print Illuminating Engineering Society of North America (IESNA) publication *IES Recommended Procedure for Lighting Power Limit Determination* (LEM-1). These lighting power density values are based on outdated assumptions about available lighting products and do not specifically address professional consensus concerning acceptable lighting quality or design.

The IESNA Energy Management Committee (EMC), working with the Lighting Subcommittee of the ASHRAE 90.1 Standing Standards Project Committee (SSPC) has developed an interactive methodology for determining lighting power densities for both individual spaces and whole buildings. This methodology is the basis for the lighting power density numbers found in the proposed ASHRAE/IESNA 90.1-1989R (90.1R) Standard. Support for the continued refinement and current final form of the methodology has been provided through the IES EMC, the 90.1 Lighting Subcommittee members, and the Pacific Northwest National Laboratory operated by Battelle for the U.S. Department of Energy.

The methodology combines professional consensus on quality lighting design, with empirical data such as performance data for efficient and available lighting products and new building construction data taken from recent building designs to develop lighting power density allowances. This process provides a simplified and automated method of standards development that includes more accurate modeling of the energy efficiency potential of quality lighting in spaces and whole buildings.

This methodology calculates lighting power allowances for building spaces and whole buildings. The process models lighting design assumptions from a consensus of lighting design professionals for each of the space types used in 90.1R, using currently available efficient lamp/ballast/fixture data, and illuminance values from current IESNA illuminance recommendations. In this way, the needs of the occupants are taken into account and energy-efficient design is promoted through the resulting lighting power densities.

The standard does not promote or encourage any particular type of design; it is a minimum efficiency standard, not a design guideline. The process does allow, however, quality conscious, effective design practice. The objective has been to use quality design models and efficient equipment in the development of lighting power densities, which allows the possibility that good lighting can be achieved along with energy efficiency. While a minimum efficiency standard cannot ensure that every design is high quality, it is critical that it not be so restrictive as to be detrimental to the quality of the lighted environment. The methodology described in this paper creates a platform within which applications and design issues can be addressed without being equipment or design prescriptive. The resulting allowable lighting density values incorporate current design practice for quality lighting using efficient equipment and effective distribution of light.

Methodology Concept

The general concept of this method is to develop appropriate space lighting energy limits for individual building spaces as well as whole buildings that promote lighting energy efficiency without sacrificing good design and quality lighting. To accomplish this, the methodology makes use of currently available lighting product characteristics, light loss factors, building construction data, and professional design experience. The central calculation portion of the methodology is the use of application (design) models that define typical quality design and calculate corresponding lighting power densities using a modified form of the lumen method. These models and their power densities are then applied to new construction building spaces and whole buildings to provide the lighting power requirements for the standard.

This methodology combines four basic elements in determining appropriate lighting density values. The first element is the use of representative manufacturer’s reported characteristics and performance data for currently available energy-efficient lighting products and current new building construction data. Manufacturer's data is used to determine typical coefficient of utilization (CU) values for each representative fixture type that is commonly used in current lighting design. New building construction data is used in applying the power densities determined for individual spaces to create power densities for whole buildings (see Whole Building Power Densities Format and Calculation). The second element is the use of typical light loss factors and lamp efficacies for efficient sources in each lamp type category. These first two elements combine to form the technical database which is where the foundation of energy efficiency begins– choosing the most efficient and cost effective technologies given current equipment availability.

A third element is the use of IESNA recommended light level data presented in the *Lighting Handbook*. These values provide the basis for ensuring that the standard does not promote energy efficiency at the expense of internationally accepted lighting levels. The fourth element is the application of professional lighting design consensus. This design consensus allows the lighting power density numbers to be based on real design experience, and applies energy efficient equipment in achieving lighting quality and occupant comfort. The use of these four elements allows for the development of lighting density numbers that incorporate current efficient lighting luminaire characteristics, accepted lighting technology efficiency and loss factors, IES illuminance recommendations, and practicing lighting designer experience and consensus.

Fixture Characteristics and Performance Data - Actual CU are an important part of determining achievable lighting power densities. For this methodology, fixture cut-sheet data were collected from multiple manufacturers for a variety of commonly used fixtures. Manufacturer's fixture CU data are typically presented in tabular form that allows for different room cavity ratios (RCR) as well as a choice of ceiling, wall, and occasionally floor reflectance values. Because surface reflectance values vary with building construction and over time, it was considered impractical and inappropriate to provide different CU value options based on reflectances. Instead, a typical set that represented the majority of common design and building practice was chosen. For this methodology, reflectance values of 70/50/20 for ceiling/wall/floor were selected by professional consensus as the standard for non-industrial fixture types and 50/30/20 for industrial fixtures.

The four elements are calculated together in a comprehensive Excel Workbook. This spreadsheet does allow for variations in the RCR, which is based on the room's configuration, including wall height, room width, and the distance between the work surface and the fixtures. Three different RCR ranges are considered for each space type – less than 2.5 (range 1), between 2.5 and 7 (range 2), and greater than 7 (range 3). In this case, professional judgement and experience are used to choose a typical RCR range for each different building space type (see Professional Quality Design Consensus). This chosen RCR value is calculated within the spreadsheet and used in determining the appropriate lighting power density (LPD) value for that space type and application.

Light Loss Factors and Lamp Efficacy -

The calculation of lighting power densities using the lumen method requires light loss factors and lamp efficacy values for the lighting system and proposed space type and function. There are many light loss factors that affect actual output over time. These are generally categorized as non-recoverable and recoverable. The non-recoverable factors include characteristics of the lamp or fixture, specific equipment manufacturer's choices, installation orientation, and building electrical service characteristics. Some of these factors are part of the fixture characteristics and therefore at least partially represented in a fixture CU. Others are based on building and occupation characteristics that cannot be estimated or even assured that they will exist. Therefore, the non-recoverable factors are not included in this methodology.

The recoverable factors include lamp burnouts, lumen depreciation, and lamp and room surface dirt accumulation. Lamp burnout is an occupant driven factor that is unknown and therefore not included. The remaining factors are considered to exist in all situations and can be reasonably estimated. Good data exists to estimate lumen losses and dirt accumulation losses over time for various lamp types and typical space conditions. This methodology combines room surface dirt depreciation (RSDD), luminaire dirt depreciation (LDD), and lamp lumen depreciation (LLD) factors into a total light loss factor (LLF) and is based on analysis done by H.R. Lobdell.

The luminous efficacy (LE) is a lumens per Watt value used to relate the energy efficiency of each lighting source, which affects the energy use of each fixture type and ultimately the LPD value. Values for the various lamp types used in this methodology are based on analysis by H. R. Lobdell, J. Benya and J. Howley making use of manufacturer's test data, IESNA *Lighting Handbook* information, and the *Advanced Lighting Guidelines: 1993* report data. Actual LE values change with time because of technology advances, and choosing an appropriate value for use in energy standards depends greatly on current product use and availability. Therefore, these values must be revisited periodically to ensure they are appropriate and based on current technology.

Space Type Light Levels -

The use of IESNA recommended light levels is an obvious and most defensible choice for lighting standard development. However, there are instances where a specific space type or task is not represented in the IESNA light level data. In these cases, it is left to professional consensus to determine an appropriate value that represents the space based on similar spaces and tasks.

Professional Quality Design Consensus -

Professional consensus in this system involves four separate decision points. The first is a determination of the appropriate task (if any) vs. general lighting percentages that exist in each building space. The methodology allows for the lighting level and therefore energy, to be split by percentage between task and general lighting. In some cases, the choice is obvious such as storage spaces and stairways, where there is typically no defined task. Other cases such as sales areas, service spaces, and even classrooms and offices require some professional judgement to determine the exact type of task and the area of the space this represents. In these cases, it is the professional consensus of a group of lighting designers and other lighting practitioners who determine a representative split.

A second area of professional consensus is in the determination of appropriate lighting levels for each task and general lighting space. Again, in many cases this can be taken directly from published IESNA light level data. In other cases, this requires agreement of what lighting level most closely fits the type of task in the space.

The third professional consensus area is the assignment of appropriate lighting systems and the percentage of their use that is considered to be typical for a quality and efficient lighting design for that space. The methodology allows the lighting to be supplied by up to three different lighting systems in percentages deemed appropriate for the space. This is the area of the methodology where professional design experience plays an important role in providing a large measure of real world application. As design changes over time, these decisions can be revisited to represent current practice while maintaining efficiency and quality.

The fourth professional judgement area is the assignment of typical and appropriate RCRs for each space type, which in turn determines the effective lighting power density allowed for that space (see Fixture Characteristics and Performance Data). The majority of commonly occurring space types such as enclosed offices, restrooms, hallways, conference and classrooms, lobbies, and stairways have similar geometries regardless of the building type they are in and can therefore be represented by the same RCR range.

As a part of the design consensus process, the assumptions developed for the 90.1R standard were sent to members of the various IES application committees, International Association of Lighting Designers (IALD), and other non-committee practicing lighting designers. Input from these reviewers was used to refine the analysis and resulting LPD values.

Lighting Efficiency Economics -

A potential fifth element that is present in the criteria that applies to the development of the 90.1R Standard as a whole, including the envelope and equipment related standards is cost effectiveness. Because this is not treated separately within this methodology, it bears some discussion. Lighting efficiency is based primarily on the technology of the light source, its power supply and illumination distribution, and the application or design of its use. This lighting design effect is dissimilar from the envelope and equipment sections because lighting is completely visible and provides a variety of effects on the occupants of the built environment, impacting visual performance, comfort, health, safety, mood, and satisfaction.

Lighting is also an aesthetic element that is therefore constrained by factors other than energy. Because of this, it is impractical to restrict only the lighting design as a method of energy efficiency or minimum energy standards. Rather, one should continue to utilize good lighting design solutions while substituting the most efficient and cost effective technologies available in place of outdated and inefficient equipment. Lighting efficiency is not a function of additional capability like envelope measures (insulation), and the simple reduction of function (less light) is not conducive to lighting quality or occupant comfort and safety. Repeated analysis of the cost effectiveness of lighting energy reduction projects has shown that these projects are almost always cost effective, even at low energy costs. Lighting equipment, unlike most heating, cooling, and water heating equipment does not exhibit the wide spread in cost based on efficiency.

Cost-effective improvements in lighting technology are generally quick to enter the market, and costs for these items are not large increments above standard products. For these reasons, it is difficult to effectively identify incremental cost benefits from improved lighting technology application. Therefore, this methodology approaches the cost-effectiveness issue by developing lighting power densities based on efficient product offerings. This is not a guarantee that the most efficient product is always used because the art of the lighting design can often require a different technology to achieve desired effect. However, basing a space type design on the best efficiency available will promote the use of efficient technology and discourage the overuse of the most inefficient products.

Building Space Methodology Format

The building space methodology is applied within a workbook format with multiple spreadsheets dealing with individual portions of the process. The applications spreadsheet derives the LPD values for a series of individual lighting space type models, all of which reference a common technical database. The space type models cover many different spaces and incorporate the type of lighting that is being used for each task within the space. The technical database contains information on source efficacy, fixture efficiency, and light loss factors using actual performance of lamps, ballasts, and fixtures.

The spreadsheet allows for the use of up to three different lighting systems to achieve design footcandle levels for a given space type, based on IESNA-recommended lighting levels. The spreadsheet also takes into account illumination provided by wall lighting systems and task lighting systems. The workbook includes seven distinct spreadsheets that each provide a specific function. The use of seven individual sheets instead of only one, is done to allow for easy modification or update to any portion or data point in the entire process. All of the spreadsheets are linked so that changes to user input are automatically applied throughout the workbook to update the LPD values. The following description of each of the worksheets follows the process from start to finish. This process is also presented as a flowchart in Figure 1.

The *Fixture_CU_Data* sheet includes manufacturer's model #, and CU for various manufacturer's fixtures matching a specific fixture type description. This sheet includes these CU values for many different types of fluorescent, incandescent, and high intensity discharge (HID) fixtures.

Fixture_CU_Averages takes the CU values from *Fixture_CU_Data* for similar fixture types (coded by fixture type number for the three RCR ranges) and averages them. This provides average CUs for three RCR ranges for typical fixture types across multiple (where available) manufacturers.

Fixture_Type_Data contains CU values for all of the fixture types (assigned by number in *Fixture_CU_Data*). For each fixture type, luminous efficacy values and light loss factors are assigned. From these data and the CUs, lighting power factors are calculated for each RCR range.

The *Application_Models* sheet contains the full description and derivation of the models for individual building space types. Percentages of general and task areas are assigned as well as corresponding light levels for each space. Up to three different lighting systems are chosen that represent fixture types and lighting technologies that are appropriate for that space type. For each space type model, the lighting power factors from the *Fixture_Type_Data* for each of the lighting systems are used along with assigned weightings for each of the lighting systems to calculate the LPD for the three different RCR ranges. Finally, an assignment is made of the expected RCR for each specific model depending on the most typical room geometries of that space type. This assignment sets the actual LPD value for that model.

Whole_Bld calculates a weighted whole building category LPD based on the percentage of space types found within buildings. This sheet applies the previously calculated space type LPDs to the space type usage in each building to derive a whole building value. The LPDs for multiple buildings are averaged (weighted) to arrive at a whole building number that represents a random sampling of new building construction in the US for each building type.

The *MODNUMB* sheet contains the model numbers assigned to each space and whole building type. The appropriate model choice is based on professional experience.

LPDMATRIX-IP presents the LPD values associated with the models chosen for each space type. Each cell is linked to display the LPD from *Application_Models*, which matches the corresponding model number in *MODNUMB*. These are the values used in the proposed 90.1R Standard, Table 9.3.1.2.

A Building Space Type Example

To demonstrate the way the spreadsheet is used to calculate the LPD for a given lighting space type, we will walk through the process using a typical office setting example. The space to be illuminated is classified as Office - Enclosed (a private office). First, the weighted average illuminance required to light this space appropriately must be determined. The application model for this space type assumes that 80 percent of the office is task area and should be illuminated to 50 footcandles, while the remaining 20 percent of the office is general area and should be illuminated to 30 footcandles. These assumptions yield a weighted average illuminance of 46 footcandles for the entire office. See Figure 2.

#	LPD CATEGORY	% of Area	TASK (fc)	% of Area	GEN'L (fc)	Wtd Avg (fc)
25	Office - Enclosed	80	50	20	30	46

Figure 2 - Space Illuminance Distribution

The model then assumes that for this space type, 75 percent of the illumination (percent FC) should be provided by fluorescent lamps (source) with direct/indirect fixtures (distribution). Figure 3 is a condensed version of this section of the applications spreadsheet showing this configuration as Lighting System #1. The model assumes that 15 percent of the illumination should come from fluorescent task fixtures (Lighting System #2) and ten percent from fluorescent wallwash open fixtures on two walls.

LIGHTING SYSTEM #1			LIGHTING SYSTEM #2			LIGHTING SYSTEM #3		
% FC	Source	Distribution	% FC	Source	Distribution	% FC	Source	Distribution
75	FL	Direct/Ind	15	FL	Task	10	FL	WW open - two walls

Figure 3 - Equipment

With the desired systems specified, the spreadsheet retrieves information needed to calculate the LPD (from FixtureType_Data), including average CU, LE, and LLF for each fixture type and lighting source used. With this data, a LPD number is calculated for each of the three RCR ranges as shown in Figure 4 .

LIGHTING POWER DENSITY		
RCR < 2.5	RCR > 2.5 & >7.0	RCR > 7.0

1.02	1.54	1.84

Figure 4 - LPD's in RCR ranges of Low (1), Medium (2), and High (3)

The typical RCR for an enclosed office is in the >2.5 and < 7.0 range (called range 2) yielding an LPD of 1.54. Also, an alternate office model using only two-lamp direct louvered fixtures with task lighting yields a very similar LPD of 1.60. These calculated LPDs form the lighting standard requirements.

Building Space Power Density Calculation and Technical Data

The calculation of lighting power densities applies current net lumen efficacies of lighting technologies, characteristics of the luminaires (from manufacturers' data), quality lighting design by consensus (application models), and required average weighted illuminance of the space (based on IESNA values) to determine the appropriate power limit.

The coefficient of utilization (CU), luminous efficacy (LE), room surface dirt depreciation (RSDD), luminaire dirt depreciation (LDD), lamp lumen depreciation (LLD), and total light loss factor (LLF) factors used in this methodology are shown in Table 1.

These factors are used along with quality lighting design assumptions, and the average weighted illuminance of the space to calculate the appropriate LPD for the space. The equation used is as follows:

Where:

LPD = lighting power density in Watts per square foot

Average Weighted Illuminance = an area weighted average of the illuminance (footcandles or lumens per square foot) in a space from all task and general lighting

%_1, %_2, %_3 = the percentage of the total space footcandles (percentage) supplied by each of the three lighting systems (1,2,3)

*TF_1, TF_2, TF_3 = the net lumen efficacies (lumens per Watt) of each of the three lighting systems (1,2,3) in the space that includes the effects of light source LE, fixture CU, and light loss factors (LLD, LDD, RSDD) as follows: TF = LE*CU*LLD*LDD*RSDD*

Whole Building Power Densities Format and Calculation

Whole building lighting power density values in energy standards have typically come from regional data (e.g. California, New York) or single building lighting analysis results (ASHRAE special project 41). The process presented here incorporates multiple national building space type data with space type power densities to create whole building lighting power densities that can be reasonably applied to typical national new building construction. Building space type percentages for each building type are derived entirely from multiple sets of constructed or contracted building plans from the extensive collection of full building drawing sets owned and maintained by F.W. DODGE. Typically three to four different sets of plans for each building type from across the US are used. Access to this data and the Oregon Department of Energy and the IESNA funded initial support of its analysis.

The drawings used in this analysis are chosen randomly from the F.W. DODGE collection of drawing sets from the six regions covering the entire continental US using the following criteria:

- Listed cost estimates for the chosen buildings were close to the average cost estimate for that building type as provided by F.W. DODGE. This provided a rough measure that the building size is neither excessively large nor small.
- The one-line description matches the building type as closely as possible, avoiding "mixed" occupancy buildings. Buildings that are obvious alterations or strict remodels are avoided. This provides the cleanest building type data possible.
- Most buildings are chosen with 1996 or 1997 drawing dates and none older than 1990.

Click to View Figure 5 presents a spreadsheet view of the process for calculating whole building LPD values.

For each of the drawing sets, a detailed take-off of the building square footage on a space by space basis is completed. These take-offs break the total square footage for each building into 25 or more commonly used building spaces and up to 50 or more specific building type spaces. The take-off square footage data for each building is summed by space type and building total. These space and building totals are used to calculate the percentage of each space type within the building. The space type percentages are matched to the specific application model (described previously) that fits that space type description *for that building type*. Some space types may have different models depending on building type.

For example, office-building lobbies may not have the same lighting requirements as hotel lobbies. Using these space and model matches, a weighted average LPD can be derived for that building. The building LPDs can then be weighted among themselves depending on the estimated frequency of that building design. In this analysis, because the drawings were chosen randomly, the individual building LPDs within a specific building type are given equal weight. This calculation provides a weighted building type LPD to be used for compliance in the standard

It is understood that the use of three or four sets of drawings for one building type cannot be considered a statistically valid sample. However, the wide variety of building designs makes the determination of a statistically valid sample very difficult and at best it is likely to be a very large number - much beyond the scope or practicality of the development of most energy standards. The use of a small sample of randomly chosen buildings from a well recognized and documentable source of building drawings is the best available basis for this kind of analysis. While lighting design is by nature somewhat subjective, the use of actual designed building spaces and lighting models provides the most accurate and defensible method for developing whole building energy-efficiency standards.

Results Comparison

Any presentation of a new method of deriving numbers is usually accompanied by a comparison of the results of the old method. In this case, the new lighting power density methodology is not aimed at achieving a specific change in numbers. Rather, it is aimed at providing a more consistent and defensible method of developing lighting standards that involves lighting quality design. However, for the sake of understanding the effect this can have on current standards development, comparisons of selected space type and whole building numbers are presented.

Table 2 presents a comparison of whole building LPD numbers between the current and proposed 90.1R Standard. The numbers shown here represent the most recent work of the 90.1 Lighting Subcommittee and IESNA EMC as of June 1998. They include changes made as a result of the 2^{nd} Public Review process. Several significant improvements were made in this most recent public review process, including the introduction of additional building data (space breakout information) and equipment updates to the technical database. In order to improve the usefulness of the whole building compliance path the quantity of whole building type categories has increased from 11 (90.1-1989) to 32 (June 1998).

Because of the differences between the previous and this current methodology and the current methodology's use of building and fixture data, it is not accurate to make a one-for-one comparison of whole building LPD values. However, where the old and new categories match, a comparison can be made to give a general idea of the overall shift in whole building power densities. The non-weighted averages of the nine similar categories are 1.39 for the newest version, as compared to 1.54 for the 90.1-1989 Standard. The difference in these values of -0.16 Watts per square foot or -10 percent indicates that the LPD values produced with this process are generally lower. A close estimate of the effect of the process makes use of the Commercial Buildings Energy Consumption Survey (CBECS) database that provides information on the actual distribution of building square footage by building type. This data shows that 73 percent of building square footage across the country is found in these same nine building types. Applying the appropriate CBECS weighting to these nine building LPDs indicates a difference of -0.28 Watts per square foot or 15 percent decrease in LPD with the new process. These are only rough estimates of the effect of the new process and will differ by region and as building trends change.

The individual building space type lighting power density numbers from 90.1-1989 Standard are also compared to the revised 90.1R Standard numbers that were developed using this new methodology. There are 106 individual space type LPD values in the current 90.1 Standard and over 100 in the proposed standard developed with the new methodology. Table 3 presents comparisons for the 92 space type values, where there is a one-for-one match with the same space type between both standards. As a part of the compliance process with the 90.1-1989 standard, the power density numbers are modified by an Area Factor (AF) representing the room configuration (also represented by a Room Cavity Ratio (RCR) number. The 90.1R numbers have the effect of room configuration (RCR) built into their power density numbers. Therefore in order to gat a fair comparison between the two sets of numbers, the 90.1-1989 numbers have been modified with an AF that matches the chosen 90.1R RCR for that space type. No space type weighting data has been found for use in weighting individual space types in a manner similar to the whole building numbers. Similar to the whole building numbers, a one-for-one comparison between numbers cannot be considered to be accurate given the difference in the methodologies used to create each set of numbers.

Summary

The use of this methodology provides a documentable and defensible format for developing lighting power density numbers that historically have only been based on general professional judgement, and incomplete and/or non-national data. This new method still relies on professional judgement for the incorporation of quality lighting design but includes national building characteristics data, internationally recognized illuminance recommendations, and existing technology and fixture product characteristics to provide a more consistent and demonstrable calculation of lighting densities. This method:

- Makes maximum use of current manufactured lighting product characteristics. This ensures that standards lighting power densities are based on the use of readily available efficient lighting products.
- Incorporates reasonable estimates of efficacy and light loss adjustment to model real world application and performance rather than strictly nominal values.
- Allows development of consistent power density values for any building or space type rather than only those where energy use data or other building lighting characterization data is available.
- Incorporates generally accepted quality design concepts so that energy efficiency efforts do not unduly inhibit good quality lighting design.
- Provides a coordinated methodology with maximum flexibility for potential future changes in technologies, design preferences, and product availability.

Future Work

The complexity of the new methodology, which is necessary for technical reasons, represents a potential obstacle to adoption by federal, state, or local agencies. Potential users may not readily understand the methodology because of the current multi-sheet format. This lack of understanding may create difficulties in achieving acceptance, consensus and deployment.

A project is currently underway to translate this methodology into a database format with interactive access and presentation. This project will facilitate widespread state and other agency adoption by transforming the computer models (currently in a large and cumbersome Excel spreadsheet) into user-friendly software.

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Figure 1. Lighting Power Density Calculation Process

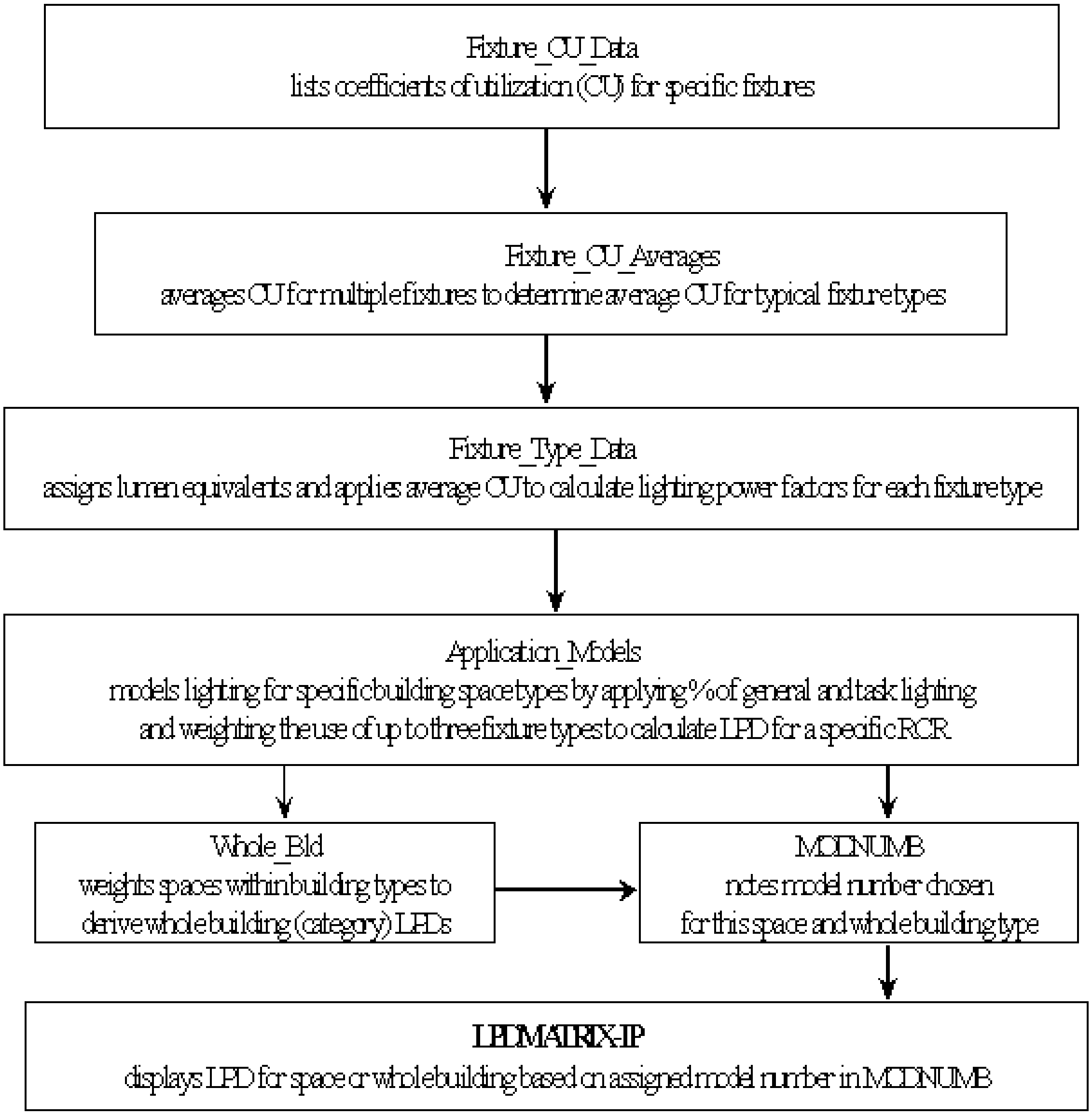


Table 1. Technical Data Used in Building Space Type Lighting Standard LPD Development

		Coefficients of Utilization							
Light Source	**Distribution Type**	**RCR=1**	**RCR=5**	**RCR=7**	**Efficacy LE**	**LLF**	**LLD**	**LDD**	**RSDD**
INC	translucent – globe	0.66	0.38	0.30	16	0.72	0.97	0.77	0.96
INC	downlight open	0.75	0.59	0.52	16	0.74	0.97	0.80	0.96
INC	indirect pendant	0.51	0.29	0.22	16	0.73	0.97	0.80	0.94
INC	dir/indir pendant	0.53	0.30	0.23	16	0.74	0.97	0.80	0.96

PAR	downlight open - flood	1.00	0.86	0.81	14	0.74	0.97	0.80	0.96
MR	task	0.80	0.80	0.80	18	0.68	0.89	0.80	0.96
CF	downlight - lensed	0.42	0.29	0.25	57	0.64	0.86	0.77	0.96
CF	downlight open	0.63	0.46	0.38	57	0.70	0.86	0.85	0.96
CF	indirect pendant	0.55	0.33	0.26	57	0.65	0.86	0.80	0.94
CF	indirect wall sconce	0.53	0.32	0.26	57	0.66	0.86	0.80	0.96
CF	task	0.60	0.60	0.60	57	0.70	0.86	0.85	0.96
FL	linear direct lensed	0.77	0.50	0.40	80	0.67	0.90	0.77	0.96
FL	linear direct w/louver	0.72	0.48	0.40	80	0.73	0.90	0.85	0.96
FL	linear dir/indir	0.82	0.51	0.41	80	0.75	0.90	0.89	0.94
FL	task	0.64	0.64	0.64	80	0.67	0.90	0.77	0.96
MH	downlight open	0.73	0.58	0.52	56	0.55	0.72	0.80	0.96
MH	translucent-globe	0.56	0.31	0.24	72	0.53	0.72	0.77	0.96
MH	downlight open	0.76	0.59	0.52	72	0.48	0.72	0.70	0.96
MH	indirect pendant	0.45	0.26	0.20	72	0.54	0.72	0.80	0.94
TH	translucent-globe	0.65	0.35	0.27	19	0.72	0.97	0.77	0.96
TH	downlight open	0.81	0.70	0.65	19	0.72	0.97	0.77	0.96
INC	WW open - 1 wall	0.48	0.44	0.42	16	0.74	0.97	0.80	0.96
INC	WW open - 2 wall	0.72	0.57	0.50	16	0.74	0.97	0.80	0.96
PAR	downlight open - spot	1.09	0.98	0.94	14	0.74	0.97	0.80	0.96
PAR	WW controlled - 1 wall	0.20	0.16	0.14	14	0.72	0.97	0.77	0.96
CF	WW open - 1 wall	0.60	0.43	0.36	57	0.66	0.86	0.80	0.96
CF	WW open	0.47	0.34	0.28	57	0.66	0.86	0.80	0.96
FL	linear indirect cove	0.55	0.35	0.28	80	0.69	0.90	0.80	0.96
FL	linear wall cove	0.26	0.19	0.16	80	0.69	0.90	0.80	0.96
FL	linear WW open - 1 wall	0.33	0.25	0.23	80	0.73	0.90	0.85	0.96
FL	linear WW open - 2 walls	0.47	0.26	0.23	80	0.73	0.90	0.85	0.96
MH	low bay lensed	0.72	0.41	0.31	72	0.55	0.72	0.80	0.96
MH	high bay (med)	0.76	0.51	0.42	72	0.55	0.72	0.80	0.96

Click to View *Figure 5. Whole Building Lighting Power Density Development Process*

Table 2. Current and Proposed (new methodology) Whole Building Lighting Power Density Comparison

	Current 90.1	Proposed 90.1R	Difference	Difference
Whole Building Type	Watts/Sq ft	Watts/Sq ft	Watts/Sq ft	Percent
Automotive Facility	---	1.5	---	---
Convention Center	---	1.4	---	---

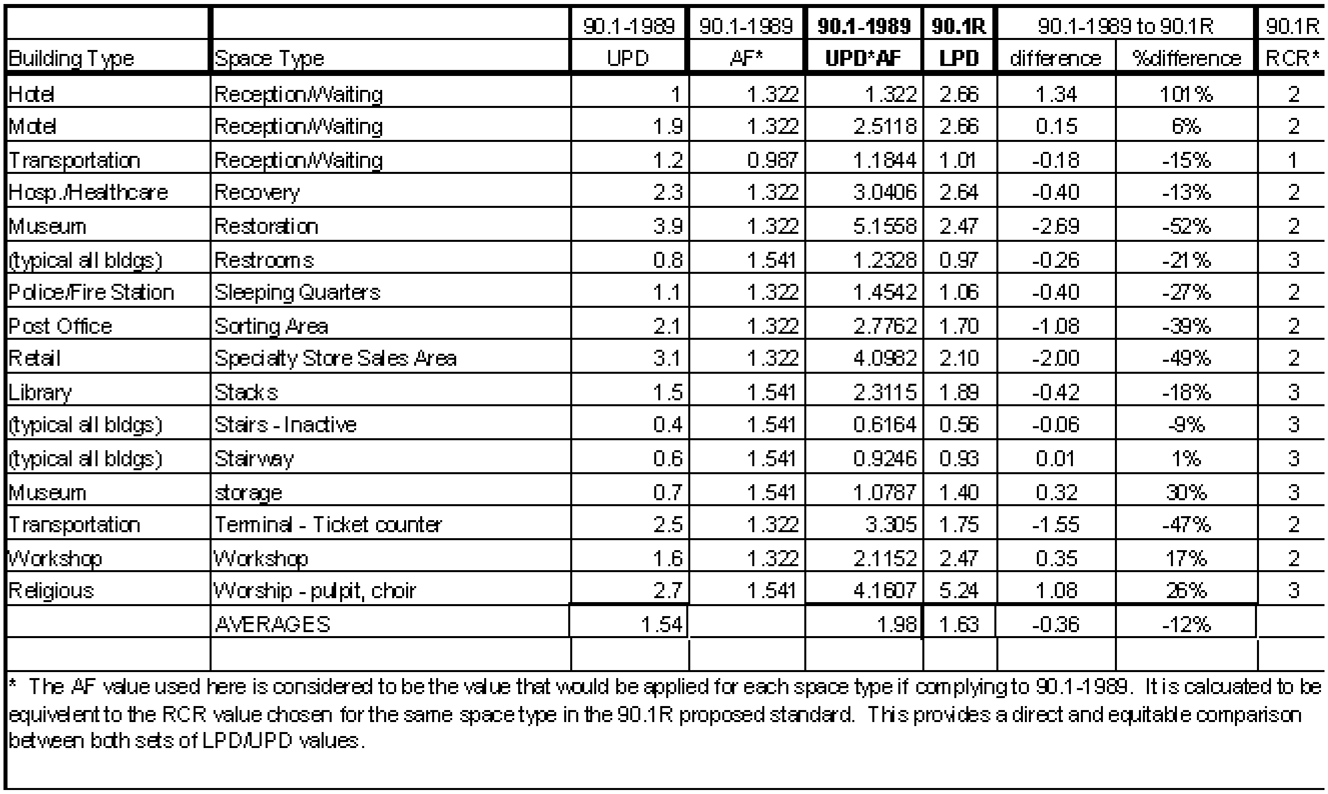
Courthouse	---	1.4	---	---
Dining: Bar Lounge/Leisure	1.7	1.5	(0.2)	-12%
Dining: Cafeteria/Fast Food	1.4	1.8	0.4	29%
Dining: Family	---	1.9	---	---
Dormitory	---	1.5	---	---
Exercise Center	---	1.4	---	---
Fire Stations	---	1.3	---	---
Gymnasium	---	1.7	---	---
Hospital/Healthcare	---	1.6	---	---
Hotel	---	1.7	---	---
Library	---	1.5	---	---
Mall Concourse	1.5	---	---	---
Manufacturing	---	2.2	---	---
Motel	---	2.0	---	---
Motion Picture Theatre	---	1.6	---	---
Multi-Family	---	1.0	---	---
Museum	---	1.6	---	---
Office	1.7	1.3	(0.4)	-24%
Parking Garage	0.2	0.3	0.1	25%
Penitentiary	---	1.2	---	---
Performing Arts Theater	---	1.5	---	---
Police Stations	---	1.3	---	---
Post Office	---	1.6	---	---
Religious Buildings	---	2.2	---	---
Retail	2.7	1.9	(0.8)	-30%
Preschool/Elementary	1.7	1.5	(0.2)	-12%
Jr. High/High School Technical Vocational	1.8	1.5	(0.3)	-17%
Technical/Vocational	2.1	1.5	(0.6)	-29%
Service Establishment	2.1	---	---	---
Sports Arena	---	1.5	---	---
Town Hall	---	1.4	---	---
Transportation	---	1.2	---	---
Warehouse	0.6	1.2	0.6	114%
Workshop	---	1.7	---	---
Average (where matched)	**1.54**	**1.39**	**-0.16**	**-10%**
Weighted Average (matched)	**1.83**	**1.55**	**-0.28**	**-15%**

		90.1-1989	90.1-1989	**90.1-1989**	**90.1R**	90.1-1989 to 90.1R		90.1R
Building Type	Space Type	UPD	AF*	**UPD*AF**	**LPD**	difference	%difference	RCR*
(typical all bldgs)	Active storage	1	1.541	1.541	1.13	-0.41	-26%	3
Hosp./Healthcare	Active storage	2.4	1.541	3.6984	2.92	-0.78	-21%	3
Transportation	Air/Train/Bus - Baggage Area	1	1.322	1.322	1.29	-0.03	-2%	2
Transportation	Airport - Concourse	0.9	1.541	1.3869	0.68	-0.71	-51%	3
(typical all bldgs)	Atrium - each additional floor	0.2	0.987	0.1974	0.20	0.00	0%	1
(typical all bldgs)	Atrium - first three floors	0.7	1.541	1.0787	1.31	0.23	22%	3
Convention Center	Audience/Seating Area	1.6	0.987	1.5792	0.45	-1.13	-71%	1
Court House	Audience/Seating Area	1.6	1.322	2.1152	1.59	-0.53	-25%	2
Exercise Center	Audience/Seating Area	0.4	0.987	0.3948	0.45	0.06	15%	1
Gymnasium	Audience/Seating Area	0.4	0.987	0.3948	0.45	0.06	15%	1
Movie Theatre	Audience/Seating Area	1	1.322	1.322	1.31	-0.01	-1%	2
Penitentiary	Audience/Seating Area	1.6	1.322	2.1152	1.85	-0.26	-13%	2
Perf. Arts theatre	Audience/Seating Area	1.5	1.322	1.983	1.76	-0.22	-11%	2
Police/Fire Station	Audience/Seating Area	2	1.322	2.644	1.59	-1.06	-40%	2
Religious	Audience/Seating Area	2.5	1.322	3.305	3.20	-0.10	-3%	2
Sports Arena	Audience/Seating Area	0.4	0.987	0.3948	0.45	0.06	15%	1
(whole bldg only)	Bank Customer Area	1.1	1.322	1.4542	1.11	-0.35	-24%	2
Office	Banking Activity Area	2.8	1.322	3.7016	2.42	-1.28	-35%	2
Library	Card File & Cataloguing	1.6	1.322	2.1152	1.40	-0.71	-34%	2
(typical all bldgs)	Classroom/Lecture/Training	2	1.322	2.644	1.59	-1.06	-40%	2
Penitentiary	Classroom/Lecture/Training	2	1.322	2.644	1.41	-1.23	-47%	2
Court House	Comfinement Cells	0.8	1.322	1.0576	1.06	0.00	0%	2
Penitentiary	Comfinement Cells	0.8	1.322	1.0576	1.06	0.00	0%	2
(typical all bldgs)	Conference Meeting/Multipurpose	1.8	1.322	2.3796	1.50	-0.88	-37%	2
(typical all bldgs)	Corridor/Transition	0.8	1.541	1.2328	0.73	-0.50	-40%	3
Manufacturing	Corridor/Transition	0.8	1.541	1.2328	0.55	-0.68	-56%	3
Hosp./Healthcare	Corridors w/patient waiting, exam	1.3	1.541	2.0033	1.62	-0.38	-19%	3
Court House	Courtroom	2	1.322	2.644	2.13	-0.51	-19%	2
Retail	Department Store Sales Area	3.1	1.322	4.0982	2.10	-2.00	-49%	2
Manufacturing	Detailed	2.5	1.322	3.305	6.22	2.91	88%	2
(typical all bldgs)	Dining Area	1.3	1.322	1.7186	1.45	-0.27	-16%	2
Civil Services	Dining Area	1.3	1.322	1.7186	0.74	-0.98	-57%	2
Family Dining	Dining Area	2.5	1.322	3.305	2.23	-1.07	-32%	2
Hotel	Dining Area	2.5	1.322	3.305	1.02	-2.29	-69%	2
Leisure Dining	Dining Area	2.5	1.322	3.305	1.24	-2.06	-62%	2
Motel	Dining Area	2.5	1.322	3.305	1.24	-2.06	-62%	2
Penitentiary	Dining Area	1.3	1.322	1.7186	1.41	-0.31	-18%	2
Transportation	Dining Area	1.3	1.322	1.7186	2.23	0.51	30%	2
(whole bldg only)	Dormitory Bedroom	1.1	1.322	1.4542	0.93	-0.52	-36%	2
(whole bldg only)	Dormitory Study Hall	1.8	1.322	2.3796	1.76	-0.62	-26%	2
Court House	Dressing/Locker/Fitting Room	0.8	1.541	1.2328	2.20	0.97	79%	3
Exercise Center	Dressing/Locker/Fitting Room	0.8	1.322	1.0576	0.81	-0.25	-24%	2
Gymnasium	Dressing/Locker/Fitting Room	0.8	1.322	1.0576	0.81	-0.25	-24%	2
(typical all bldgs)	Electrical/Mechanical	0.7	1.541	1.0787	1.29	0.21	19%	3
(whole bldg only)	Elevator Lobbies	0.8	1.541	1.2328	1.52	0.29	24%	3
Hosp./Healthcare	Emergency	2.3	1.322	3.0406	2.82	-0.22	-7%	2
Manufacturing	Equipment Room	1.5	1.322	1.983	0.76	-1.22	-62%	2
Hosp./Healthcare	Exam/Treatment	1.6	1.322	2.1152	1.61	-0.50	-24%	2
Exercise Center	Excercise Area	1	0.987	0.987	1.13	0.14	15%	1

Table 3. Current and Proposed (new methodology) Space Type Lighting Power Density Comparison

		90.1-1989	90.1-1989	**90.1-1989**	**90.1R**	90.1-1989 to 90.1R		90.1R
Building Type	Space Type	UPD	AF*	**UPD*AF**	**LPD**	difference	%difference	RCR*
Gymnasium	Excercise Area	1	0.987	0.987	1.13	0.14	15%	1
Convention Center	Exhibit space	2.6	0.987	2.5662	3.32	0.75	29%	1
Religious Buildings	Fellowship Hall	2	1.322	2.644	2.27	-0.37	-14%	2
Warehouse	Fine Material	1	1.541	1.541	1.64	0.10	7%	3
Police/Fire Station	Fire Station Engine room	0.7	1.322	0.9254	0.92	-0.01	-1%	2
(typical all bldgs)	Food Preparation	1.4	1.322	1.8508	2.18	0.33	18%	2
Automotive	Garage Service/Repair	1	1.322	1.322	1.42	0.10	8%	2
Museum	General exhibition	1.9	1.322	2.5118	1.57	-0.94	-37%	2
Manufacturing	General High Bay	2.02	1.322	2.67044	2.98	0.31	12%	2
Manufacturing	General LowBay	2.02	0.987	1.99374	2.14	0.14	7%	1
Hosp./Healthcare	Hospital - Nursery	2	0.987	1.974	1.00	-0.98	-50%	1
Hosp./Healthcare	Hospital/Medical supplies	2.4	1.322	3.1728	2.96	-0.22	-7%	2
Hosp./Healthcare	Hospital/Radiology	2.1	1.322	2.7762	0.42	-2.36	-85%	2
(whole bldg only)	Hotel/Conf. Center - Conf./Meeting	1.8	0.987	1.7766	1.47	-0.31	-17%	1
(typical all bldgs)	Inactive storage	0.3	1.541	0.4623	0.34	-0.12	-26%	3
(whole bldg only)	Inactive Storage	1	1.541	1.541	0.61	-0.93	-61%	3
Court House	Judges Chambers	1.4	1.322	1.8508	1.06	-0.79	-43%	2
Office	Laboratory	2.3	0.987	2.2701	1.84	-0.43	-19%	1
(whole bldg only)	Laundry-Ironing & Sorting	1.3	0.987	1.2831	0.70	-0.58	-45%	1
Hosp./Healthcare	Laundry-Washing	0.9	0.987	0.8883	0.73	-0.15	-17%	1
Dormitory	Living quarters	1.4	1.322	1.8508	1.94	0.09	5%	2
Hotel	Living quarters	1.4	1.322	1.8508	2.45	0.60	32%	2
Motel	Living quarters	1.4	1.322	1.8508	2.45	0.60	32%	2
(typical all bldgs)	Lobby	1	1.322	1.322	1.75	0.43	32%	2
Auditorium	Lobby	1	0.987	0.987	0.80	-0.19	-19%	1
Hotel	Lobby	1.9	0.987	1.8753	1.69	-0.18	-10%	1
Movie Theatre	Lobby	1.5	0.987	1.4805	0.80	-0.69	-46%	1
Perf. Arts theatre	Lobby	1.5	1.322	1.983	1.24	-0.74	-37%	2
Post Office	Lobby	1.1	1.322	1.4542	1.52	0.07	5%	2
Religious Buildings	Lobby	1	1.322	1.322	1.13	-0.20	-15%	2
(typical all bldgs)	Lounge/Recreation	0.7	1.322	0.9254	1.40	0.47	51%	2
Retail	Mall Concourse Sales Area	1.4	1.322	1.8508	2.10	0.25	13%	2
Retail	Mass Merchandising Sales Area	3.3	0.987	3.2571	2.10	-1.16	-36%	1
Warehouse	Medium/Bulky Material	0.3	1.541	0.4623	1.13	0.67	145%	3
Hosp./Healthcare	Nurse station	2.1	1.322	2.7762	1.78	-1.00	-36%	2
(typical all bldgs)	Office - enclosed	1.8	1.322	2.3796	1.54	-0.84	-35%	2
(typical all bldgs)	Office - open plan	1.9	1.322	2.5118	1.28	-1.23	-49%	2
Hosp./Healthcare	Operating Room	7	1.322	9.254	7.59	-1.66	-18%	2
Parking Garage	Parking Area - Attendant only	0.2	0.987	0.1974	0.12	-0.07	-38%	1
Parking Garage	Parking Area - Pedestrian	0.3	0.987	0.2961	0.23	-0.06	-21%	1
Hosp./Healthcare	Patient Room	1.4	1.322	1.8508	1.15	-0.70	-38%	2
Hosp./Healthcare	Pharmacy	1.7	1.322	2.2474	2.27	0.02	1%	2
Hosp./Healthcare	Physical therapy	1.6	1.322	2.1152	1.90	-0.22	-10%	2
Gymnasium	Playing Area	1	0.987	0.987	1.88	0.90	91%	1
Police/Fire Stations	Police Station Laboratory	2.3	0.987	2.2701	1.84	-0.43	-19%	1
Hosp./Healthcare	Public & Staff Lounge	0.9	1.322	1.1898	1.38	0.19	16%	2
Library	Reading Area	1.9	1.322	2.5118	1.77	-0.75	-30%	2

Table 3. Current and Proposed (new methodology) Space Type Lighting Power Density Comparison



		90.1-1989	90.1-1989	**90.1-1989**	**90.1R**	90.1-1989 to 90.1R		90.1R
Building Type	Space Type	UPD	AF*	**UPD*AF**	**LPD**	difference	%difference	RCR*
Hotel	Reception/Waiting	1	1.322	1.322	2.66	1.34	101%	2
Motel	Reception/Waiting	1.9	1.322	2.5118	2.66	0.15	6%	2
Transportation	Reception/Waiting	1.2	0.987	1.1844	1.01	-0.18	-15%	1
Hosp./Healthcare	Recovery	2.3	1.322	3.0406	2.64	-0.40	-13%	2
Museum	Restoration	3.9	1.322	5.1558	2.47	-2.69	-52%	2
(typical all bldgs)	Restrooms	0.8	1.541	1.2328	0.97	-0.26	-21%	3
Police/Fire Station	Sleeping Quarters	1.1	1.322	1.4542	1.06	-0.40	-27%	2
Post Office	Sorting Area	2.1	1.322	2.7762	1.70	-1.08	-39%	2
Retail	Specialty Store Sales Area	3.1	1.322	4.0982	2.10	-2.00	-49%	2
Library	Stacks	1.5	1.541	2.3115	1.89	-0.42	-18%	3
(typical all bldgs)	Stairs - Inactive	0.4	1.541	0.6164	0.56	-0.06	-9%	3
(typical all bldgs)	Stairway	0.6	1.541	0.9246	0.93	0.01	1%	3
Museum	storage	0.7	1.541	1.0787	1.40	0.32	30%	3
Transportation	Terminal - Ticket counter	2.5	1.322	3.305	1.75	-1.55	-47%	2
Workshop	Workshop	1.6	1.322	2.1152	2.47	0.35	17%	2
Religious	Worship - pulpit, choir	2.7	1.541	4.1607	5.24	1.08	26%	3
	AVERAGES	1.54		1.98	1.63	-0.36	-12%	

* The AF value used here is considered to be the value that would be applied for each space type if complying to 90.1-1989. It is calcuated to be equivelent to the RCR value chosen for the same space type in the 90.1R proposed standard. This provides a direct and equitable comparison between both sets of LPD/UPD values.

Table 3. Current and Proposed (new methodology) Space Type Lighting Power Density Comparison