# Energy-Related Commercial Building Construction Characteristics: An Assessment of National Current Practice and Energy Code Compliance

*Eric Richman, Pacific Northwest National Laboratory*
*Justin Williams, Washington State University*
*Rahul Biyani, University of Washington*
*Susanne Gaines, Pacific Northwest National Laboratory*

**ABSTRACT**

A key component in implementing effective energy standards and State adoption of energy codes to meet EPACT is to understand current building construction practice and how energy is currently used in buildings. However, baseline assessments of construction practices often rely on anecdotal observations and limited data sets and states are often faced with conflicting claims as to how energy codes impact the building community. One typical claim is that energy-related standards will impose excessive burdens on building contractors by greatly altering their practices and increasing costs. Other claims indicate that many energy-code requirements are common practice and will have little impact on the building community.

This paper summarizes the results of a recent study assessing the energy-related characteristics of over 160 buildings planned for construction in 2001 and beyond from across the United States. The data used in the assessment includes over 130 different construction characteristics (e.g., envelope R-values and construction type, room types and area, window and door types, equipment types and capacities, HVAC systems and zoning, lighting power densities and lighting technologies) from a variety of different building types. This information provides a window into current construction practice on a national basis. These data have been used to evaluate typical energy code compliance across the nation using the COM*check-EZ*™ energy standard compliance software tool. The results of the evaluation show how closely new construction across the nation is to meeting current and recently adopted energy codes such as ANSI/ASHRAE/IESNA 90.1-1999 and beyond.

## Summary

With the requirements of the Energy Policy Act (EPACT) and general interest in energy efficiency, a majority of US States have adopted some form of mandatory energy code. Along with this presence of energy codes across the nation comes increased interest in its effect on commercial building energy use. The National Commercial Construction Characteristics ($NC^3$) data set was developed to help provide answers to questions on current commercial building practice which is an important input to analysis of commercial building energy. Its inception was prompted by a need to understand the prevalence of different fluorescent lighting technologies in current construction and quickly grew to a source for all energy related building characteristics. The data set is populated with over 130 possible building characteristics for a current set of 162 buildings spread out across the nation.

The data was extracted from sets of building plans and specifications acquired from the F.W. Dodge Plans Service division of McGraw Hill. These represent real buildings that were in the bid process in the summer of 2001. The raw data extraction was completed by engineering students working under the Pacific Northwest National Laboratory (PNNL) Building Energy Codes Program (BECP) between the summer of 2001 and fall of 2002. Extensive quality and consistency checks on the data were performed in the summer of 2002 and all of the data was placed in a Microsoft Access database format.

As of the date of this report, the NC3 data set has been used to provide support to several internal and external analysis efforts. These include support for state code adoption, energy standards and codes development, and assessment of the potential cost of Federal energy tax credit legislation. An assessment of compliance with National energy codes was recently completed using this data set sample. The results of this effort provide some idea of how commercial buildings across the nation are meeting minimum energy code levels with and without state adopted code requirements. The data clearly shows that for envelope requirements, the majority of newly constructed commercial buildings in the US are already built to meet or exceed the ASHRAE/IESNA 90.1-1989 standard. At least 2/3 of these will also meet the 90.1-1999 standard as well. For lighting requirements the buildings are similarly meeting or exceeding the 90.1-1989 standard and approximately 10 to 25 percent of these will be able to meet the 90.1-1999 standard without any changes.

As the use of the data set grows it becomes increasingly important to understand the statistical significance of the data set in relation to representing the nation or a specific commercial building subset. Work is underway to place some value of significance to the data set in general and as specific analysis efforts emerge. Future efforts to increase the size of the data set will rely on this information to guide choices of additional specific building.

## Introduction

A majority of the 50 United States have adopted some version of a national or state specific commercial energy code due primarily to the requirements in EPACT. This adoption of codes, the development of the codes themselves, and the interest in national energy use creates a need for understanding how well current buildings are complying with energy codes and how code compliance affects construction. In analyzing these types of issues a lack of data on how commercial buildings are currently being constructed commonly emerges as a critical missing data element. For example, many states as they consider the adoption of a new energy code, desire to know what effect a new code will have on commercial building energy use across their state. To determine this, it is necessary to understand how buildings are currently constructed to compare this with code required construction and calculate potential energy savings.

On a national basis it can be desirable to understand what effect energy code adoption has on national energy use. Again, it can be useful to understand current practice on a national scale to be able to produce a more accurate estimate of national energy impact. Some data on building characteristics is available for small case-study type samples, covering individual states, or at an overview level. For example, the California baseline study (RLW Analytics 1999) provides detailed characteristics data from audits and modeling of a sample of commercial buildings constructed in California between 1994 through 1998. The Commercial Building Energy Conservation Survey (CBECS) data source provides less detailed building data from surveys of samples from across the country. To provide detailed characteristics on a National scale, the detailed National Commercial Construction Characteristics ($NC^3$) data set was developed under the Building Energy Codes Program (BECP) at Pacific Northwest National Laboratory (PNNL) as a data source to help answer energy and code related questions.

## Data Set Development

### Data Set Origin and Format

The National Commercial Construction Characteristics ($NC^3$) data set was originally suggested as a means of providing answers to questions on current commercial lighting technology. The benefits of collecting building characteristics beyond lighting and square footage were quickly realized and an effort to create a current practice data set of new construction was launched.

Initial work on the design of the data set and collection methodologies began in early 2001. A primary planning effort was the development of a list of the specific data characteristics to be collected. Complete facility lighting characterizations and space type square footage take-offs were the first characteristics identified. The list grew with input from staff working on various projects including code development, equipment efficiency, and code deployment. Attempts were made to include all characteristics that might be available from building plans and specifications and that would be of interest to current and future analysis and building modeling needs. Appendix A includes this list of over 130 data collection items. At the same time, a list of building types of interest was being prepared. Of prime interest were building types that were common and would represent a majority of new construction in the U.S. These same building types would also correspond to those used in ASHRAE code development work and the widely used CBECS data sources. The match with CBECS data sources would provide the ability to leverage specific CBECS data as enhancements to the $NC^3$ data set.

Previous experience in collecting space type square footage data from sets of real building plans (on micro-fiche film) from the F.W. Dodge Plans Service provided the idea for a ready source of current building information. The F.W. DODGE organization maintains sets of plans for buildings recently designed and currently in the construction bidding stage and makes those available for contractors interested in bidding. This business arrangement provides a rich source for current construction practice raw data. At the time of contact in early 2001, F. W. DODGE had developed the DodgeView software tool for conducting detailed drawing plans take-offs for dimensions, space areas, and item counts. This software allows the user to “trace” lengths and areas on the plans and to count individual items (lighting fixtures) with results automatically calculated and recorded. A contract was put in place to acquire a group of up to 200 sets of plans and specifications for commercial buildings across the nation.

The development of this data set was expected to create large amounts of data. More importantly there was a need to be able to link various tables of specific data for maximum use. This was particularly true for lighting and space-type square footage data. For example, to develop a whole building lighting power density, you need to access the detailed lighting fixture data on multiple fixture types and match this with the counts of these specific fixtures in the building and further match this with the building square footage. The flexible table array format in the Microsoft Access Database tool was chosen to allow for this type of linking and make maximum use of the varied data inputs. The development of the basic table structures, links, and field attributes was completed in early 2001.

A final step in the preparation for data collection activities was the development of sets of standardized labels for the various building characteristics that might be encountered. Lists for heating, cooling, ventilating, water heating, and lighting equipment, construction materials, and space activity types were prepared to match as closely as possible to similar label designations associated with the ASHRAE development work and standard industry terms.

**Building Characteristics Data Collection**

The downloading of building plans and specifications sets began in the spring of 2001 after the contract with F.W. DODGE was finalized. The buildings were selected with the following general guidelines in mind:

- New buildings – not just remodels
- Relatively clean examples of the building types of interest – avoid mixed use.
- Not extremely small – buildings smaller than 1,000 to 2,000 square feet may not reasonably represent "complete" buildings of a building type
- Not extremely large – buildings over a half million square feet were not expected to exhibit fundamental differences from those in the 100,000 square foot range and would require the same effort as an additional 2 or 3 smaller buildings.
- Distributed generally across the nation – as random as practical

Because the screening information for the available buildings was limited, the sets of downloaded plans were not always as clean or complete as desired. A few renovation projects were accessed, as well as some mixed-use facilities. More importantly, some of the downloaded sets of plans were not entirely complete. In some cases the bid package was not prepared for the electrical work and therefore no lighting data would be available. In other cases, there were no specifications with the drawings and therefore some specific building characteristics were unavailable. However, because a lot of the interest in this data was expected to focus on individual characteristics, the data that was available was still considered valuable.

With a few buildings downloaded, a set of test data extractions and square footage traces was completed. Based on this experience and the list of desired data items, a set of extraction procedures was created. These provided the basic instructions covering the many possible scenarios that might occur with different sets of drawings. This provided a means of ensuring reasonable consistency with the collected data between building samples.

The extraction of the raw data from the building plans and specifications was done by engineering student interns under the direction and guidance of staff at PNNL. As small groups of buildings were completed, reviews were conducted to ensure that all possible data was collected. Periodically, new or unexpected characteristics or configurations on the plans would need to be addressed. Particularly common were unusual space types or unknown lamp or lighting fixture types. This process of extraction, review, and discovery progressed with approximately 50 buildings completed by the end of the summer. The data was formatted and placed in the Microsoft Access database format. Additional building data extractions were similarly completed by students during 2002 reaching a completed total of 162.

During the summer of 2002 an extensive set of quality assurance checks and comparisons was conducted on the approximately 60,000 data points currently in the database. These checks identified outliers and inconsistencies across the various individual data points. Each of these was traced back to the original data collection and either corrected, modified, or noted as an unusual value. The completion of this quality assurance effort resulted in a data set sample of 162 commercial buildings from across the nation representing 12 general building categories.

These include assisted living, dining, dormitory, fire/police station, healthcare-clinic, hotel/motel, multi-family, office, religious, retail, school, warehouse. For some building types (office, retail) the sample sizes are large enough (approaching 30) to have some statistical validity on a national basis. For others the samples can represent an idea of current practice but need additional numbers to present statistical strength.

## Data Set Capabilities

The data set can provide a wide variety of commercial building characteristics in meaningful categorizations and comparisons on their own and as related to important external factors such as weather and code requirements. The power of the data set is this ability to present collected characteristics on a national basis in relationship to themselves and other factors. This includes simple characteristics sorts to identify common practices, trends by weather location, and lighting power density by building, space, and technology as well as potential code compliance.

The following Figures 1 through 7 provide just a few examples of the primary capabilities of the data set. They represent typical data extractions as a glimpse of the over 130 possible current commercial building practice characteristics. Some of the available characteristics such as insulation levels and construction types may not provide any specific insight. However, others such as window wall ratio, lighting densities, and comparisons among characteristics by building size and weather can provide interesting and useful information. Particularly powerful is the ability to represent specific space type lighting densities by their individual technologies. Figure 6 shows this capability for conference rooms. Figure 7 presents a sample of office buildings and their lighting power densities with horizontal lines for the current 90.1-1999 energy standard and proposed 2004 standard levels. This provides the ability to assess current standard compliance with existing and future code levels.

**Figure 1. Roof Cavity R-Value**

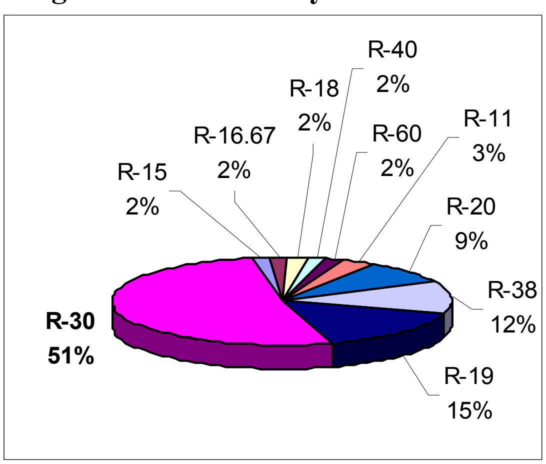



**Figure 2. Roof Continuous R-Value**

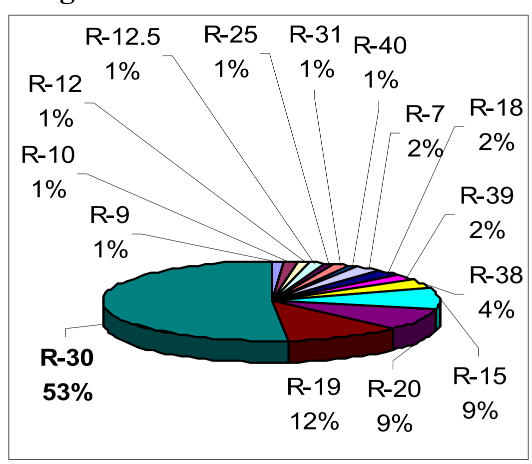


**Figure 3. HVAC Zoning Type**

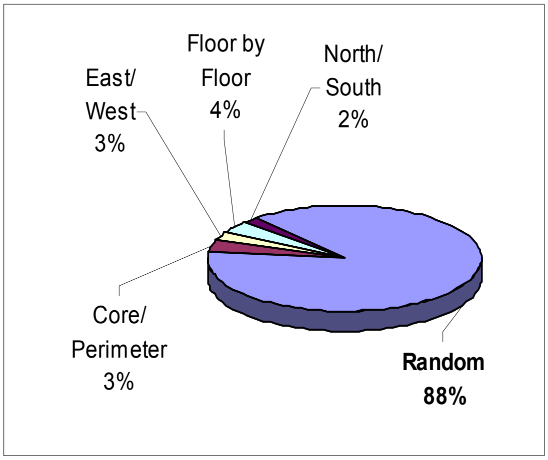



**Figure 4. Wall Cavity R-Value**

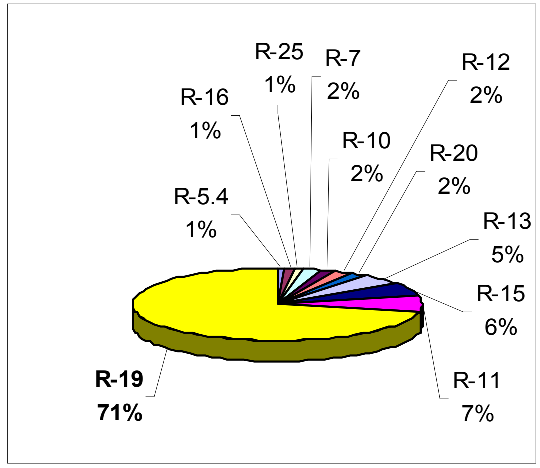



**Figure 5. Window to Wall Ratio by Building Type**

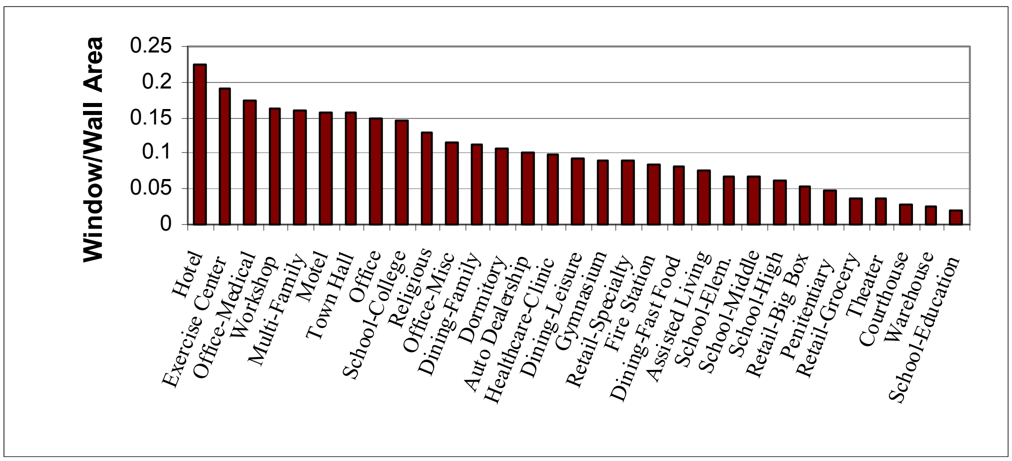



**Figure 6. Conference Room LPD by Lamp Technology Type**

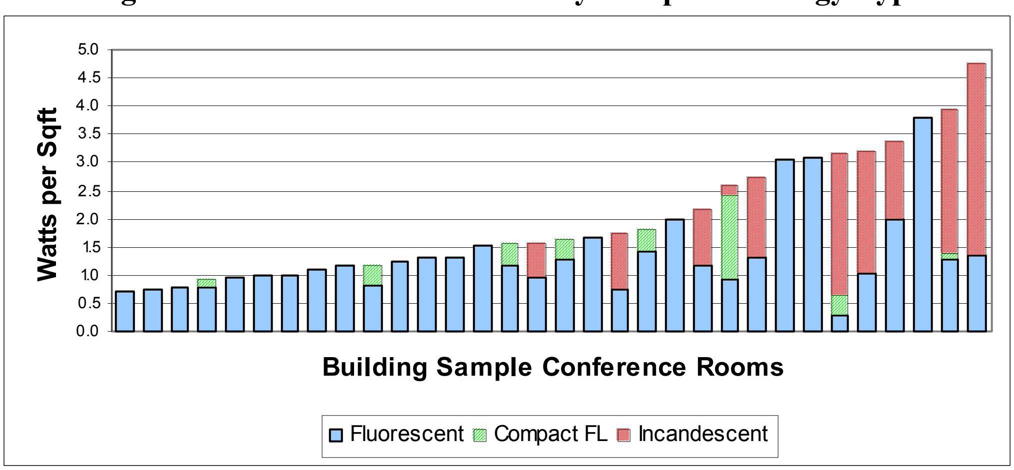
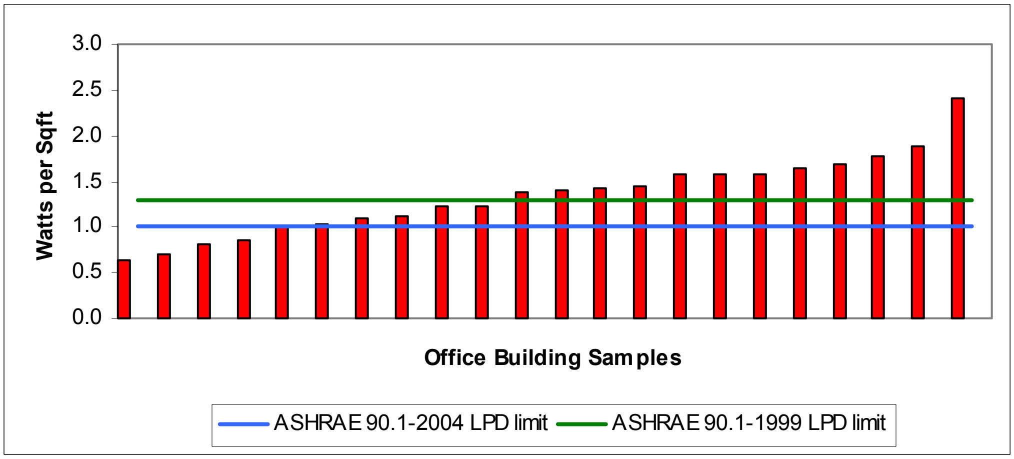


**Figure 7. Office Building Type Whole Building LPD**




## National Energy Code Compliance Comparison

One project that made use of these data was an assessment of how commercial buildings are complying with applicable energy codes. The data was used as input to the COM*check-EZ*™ energy compliance software tool developed under BECP at PNNL as a method of evaluating compliance with lighting, mechanical equipment, and envelope portions of various national energy standards and codes. Some of the data that COM*check-EZ*™ required for envelope compliance calculation was not collected in the initial development of the data set and further data collection was accomplished to provide maximum inputs. The data for each building sample was processed through COM*check-EZ*™ and percentage compliance readings obtained. These percentages indicate how close to compliance each building is as it is currently designed.

Processing was completed for both the older ANSI/ASHRAE/IESNA 90.1-1989 and 90.1-1999 standards. The 90.1-1989 standard was the current adopted standard for most of the buildings in the dataset and the 90.1-1999 standard represents an advanced standard that was not required by any of the states for the buildings in the sample. Several states were in the process of adopting this standard during the 2001 timeframe but none had completed the process.

The results of this effort for the major building types are shown in Figures 8 through 23. Throughout the figures for compliance with 90.1-1989, an indication of the code or standard in force for each building is indicated. A primary observation with the 90.1-1989 compliance data for both envelope and lighting is that the lack of a code or lesser code than 90.1-1989 appears to have little or no effect on compliance. For most building types the complying buildings are generally mixed 1989 code, state specific code, and no code. It is believed that this is primarily a result of construction practice simply overtaking the 1989 requirements due to changes in design from other forces such as buyer desires, energy costs, and technology advancement. For 90.1-1999 compliance it is interesting to note that although none of the building samples were required to design to a code more stringent that 90.1-1989 (or less), many still beat the 90.1-1999 requirements. Because the ASHRAE/IESNA standards and other national codes are "minimum standards" and not advanced design guides, it is expected that some new buildings will be naturally designed above these standards. This also reinforces the idea that buildings can and are designed above code requirements without any apparent hardship.

**Figure 8. COM*check-EZ*™ Envelope Compliance - Office Buildings – 90.1-1989**

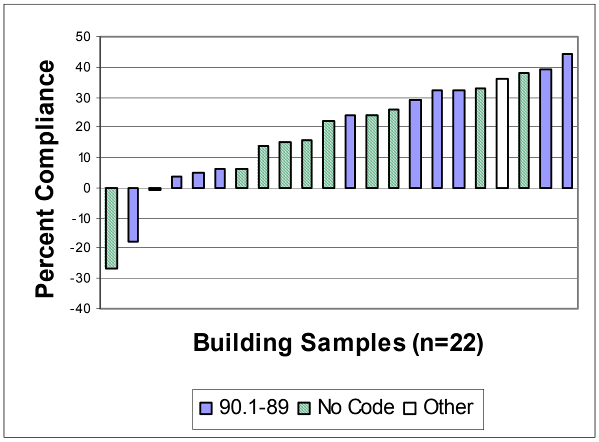



**Figure 9. COM*check-EZ*™ Envelope Compliance - Office Buildings – 90.1-1999**

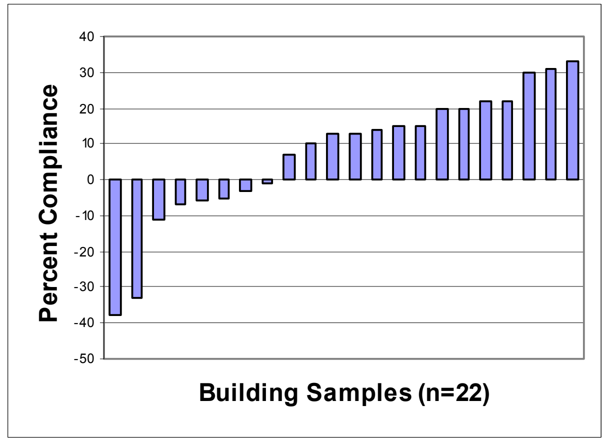



**Figure 10. COM*check-EZ*™ Envelope Compliance - Retail Buildings – 90.1-1989**

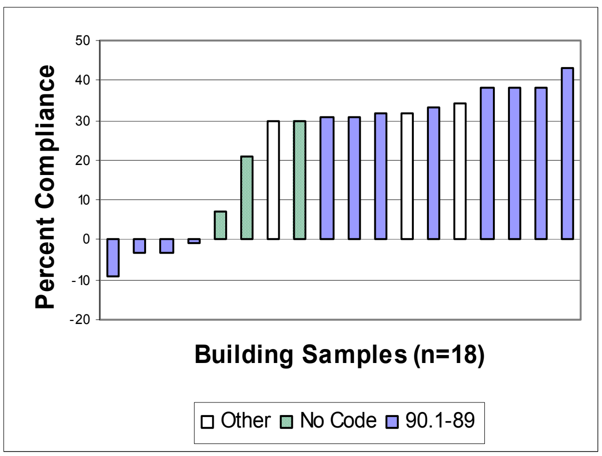



**Figure 11. COM*check-EZ*™ Envelope Compliance - Retail Buildings – 90.1-1999**

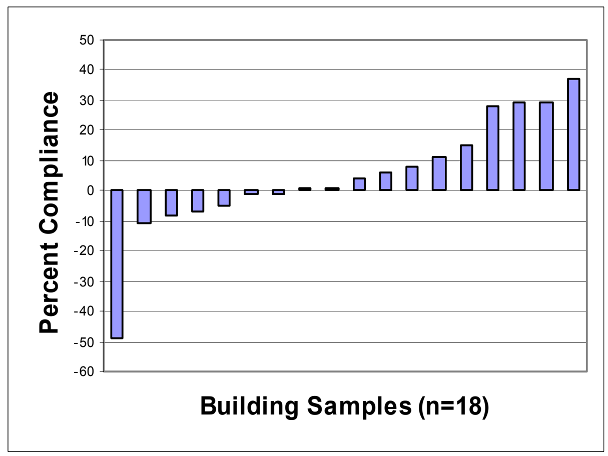



**Figure 12. COM*check-EZ*™ Envelope Compliance - Dining Buildings – 90.1-1989**

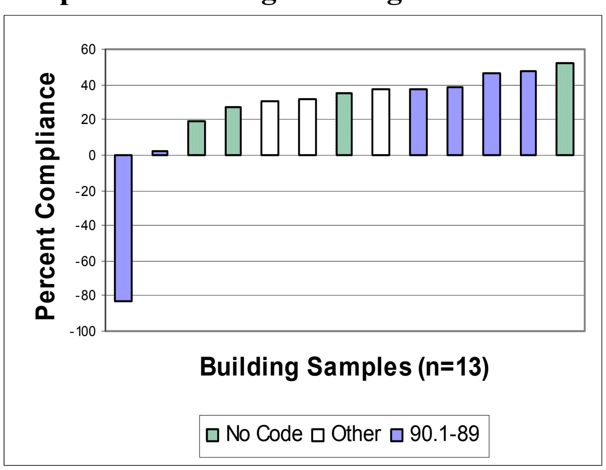



**Figure 13. COM*check-EZ*™ Envelope Compliance - Dining Buildings – 90.1-1999**

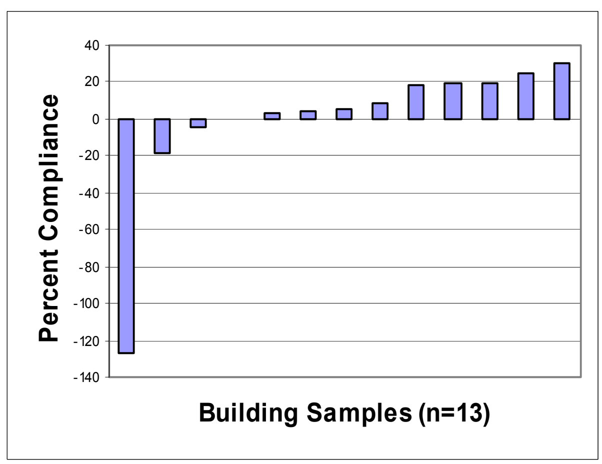


**Figure 14. COM*check-EZ*™ Envelope Compliance - Lodging Buildings – 90.1-1989**

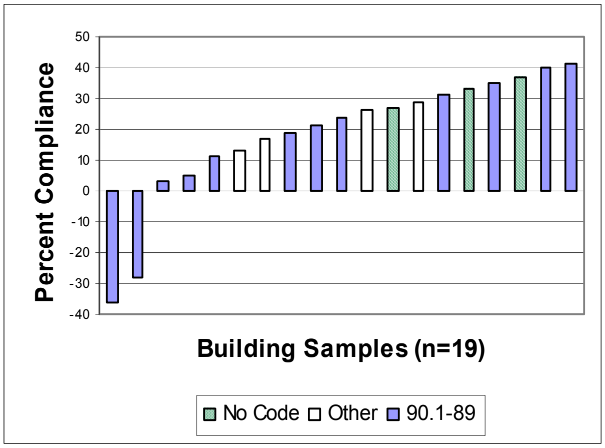



**Figure 15. COM*check-EZ*™ Envelope Compliance - Lodging Buildings – 90.1-1999**

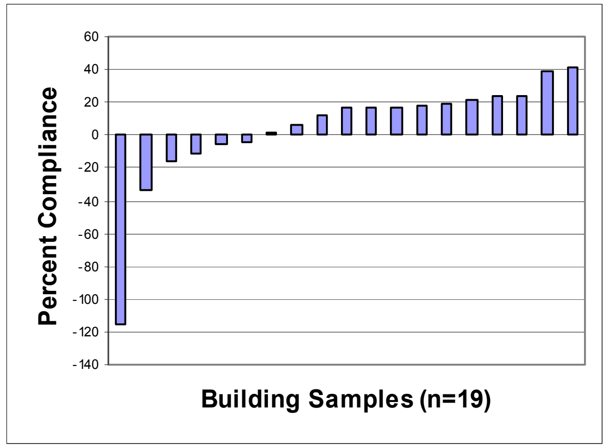



**Figure 16. COM*check-EZ*™ Lighting Compliance - Office Buildings – 90.1-1989**

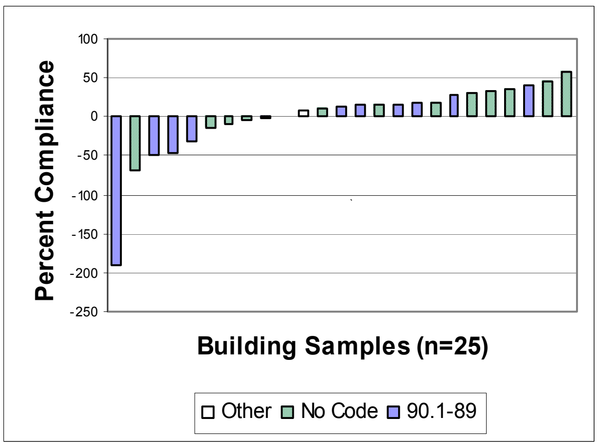



**Figure 17. COM*check-EZ*™ Lighting Compliance - Office Buildings – 90.1-1999**

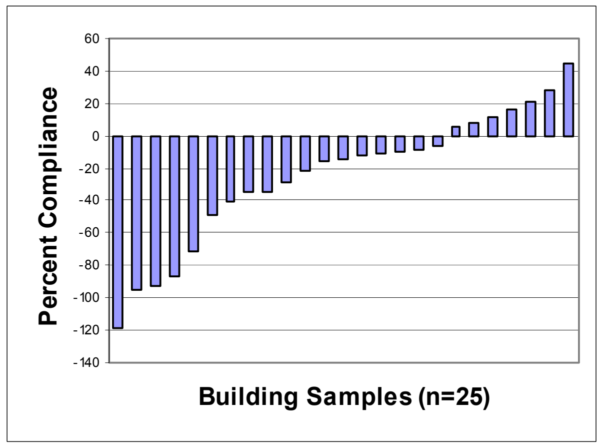



**Figure 18. COM*check-EZ*™ Lighting Compliance - Retail Buildings – 90.1-198**

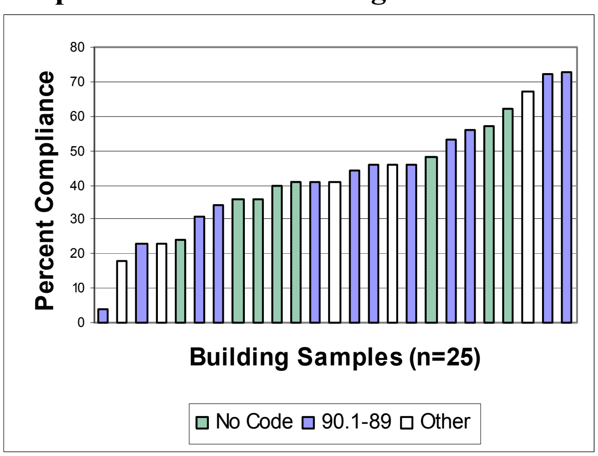



**Figure 19. COM*check-EZ*™ Lighting Compliance - Retail Buildings – 90.1-1999**

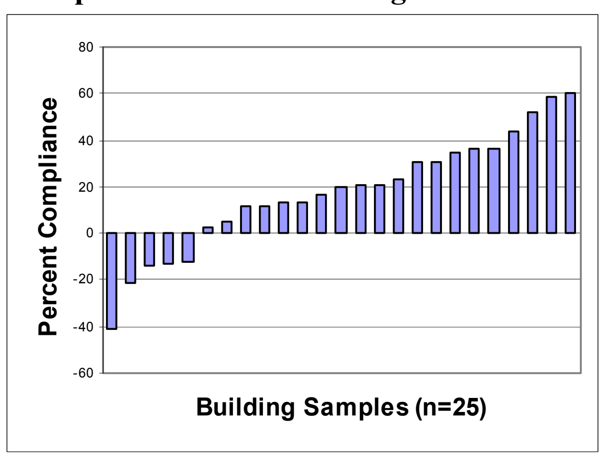


**Figure 20. COM*check-EZ*™ Lighting Compliance - School Buildings – 90.1-1989**

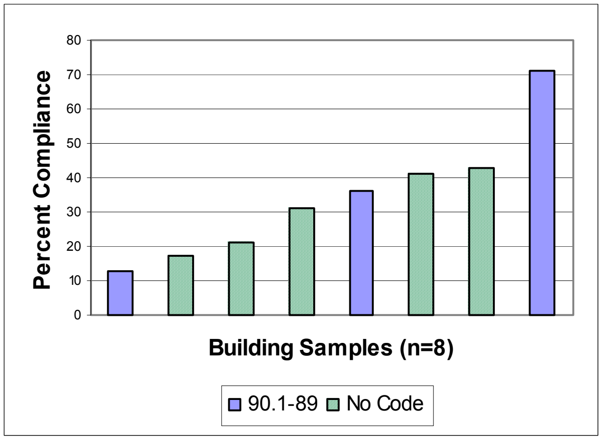



**Figure 21. COM*check-EZ*™ Lighting Compliance - School Buildings – 90.1-1999**

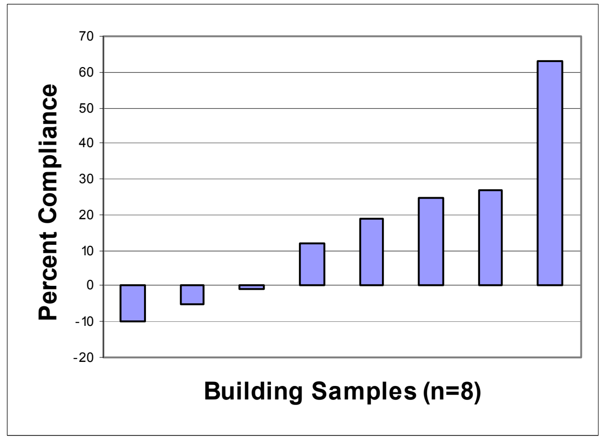



**Figure 22. COM*check-EZ*™ Lighting Compliance - Dining Buildings – 90.1-1989**

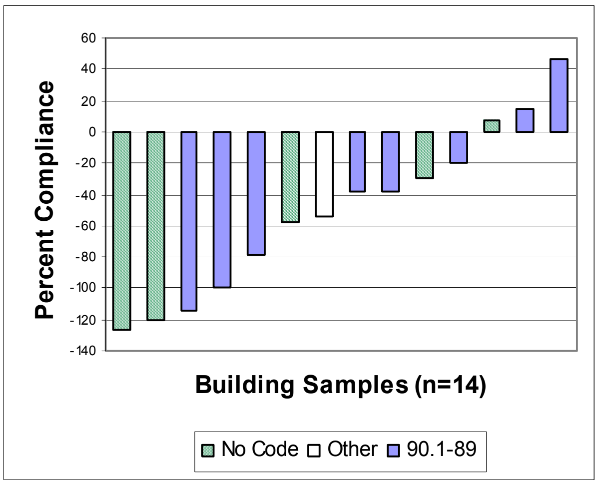
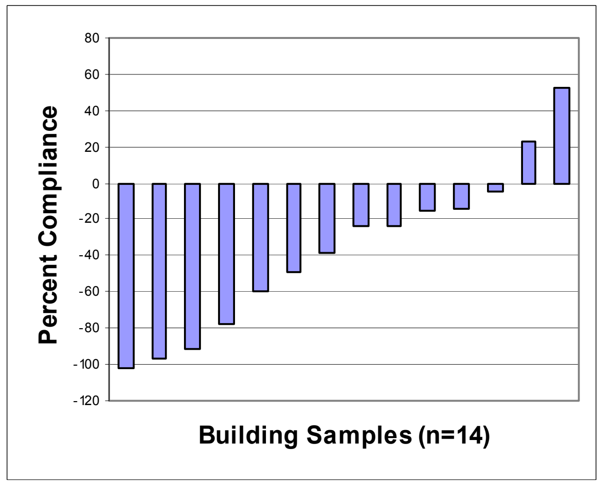



**Figure 23. COM*check-EZ*™ Lighting Compliance - Dining Buildings – 90.1-1999**




## Conclusions and Recommendations

The evaluation of code compliance for the envelope of current commercial construction shows that nearly all of the buildings are already being designed to meet the older 90.1-1989 code levels and the majority of them will also meet the newer 1999 code requirements. For most of the building types shown, the presence of a requirement to meet the older 1989 code does seem to have a slight influence on compliance with these buildings generally complying by the biggest margins. Lighting compliance is a little more mixed. Office buildings show a mixed level of compliance with more than half that fail the current 1999 standard indicating that office lighting will need to be considered more closely by designers and builders to meet current and future code levels. Retail spaces are somewhat surprisingly compliant both with the 1989 older and newer 1999 standards. This may be partially due to some display lighting not appearing on drawings for higher end sales departments and areas. However, the current 1999 standard does provide allowances for display lighting that is not included in this compliance exercise. Dining facilities appear to be in the worst position for meeting future code lighting levels. For this building type in general, redesigns may be needed to meet code requirements. A future step for this analysis is to perhaps look closer at problem building types and evaluate individual space types for potential changes that would assist in meeting code levels. The data set is structured to be able to provide space type level lighting data that could be used to support this analysis.

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# Appendix A: $NC^3$ Collected Building Characteristics

GENERAL BUILDING DATA
DodgeNumber
Building Description
Building Type
Total Size
Stories Above Ground
Stories Below Ground
Footprint Length
Footprint Width
Long Axis Orientation
Shared Walls
Daylight Sensors Specified
Occupancy Sensors Specified
City, State

SPACE TYPE AREA DATA
Square Footage by Space Type

HVAC DATA
Primary and Secondary Heat Equip Type
Primary and Secondary Heat Fuel
Primary and Secondary Heat Dist Type
Primary and Secondary Heat Percent Area Served
Primary and Secondary Total Heat BTU
Primary and Secondary Cool Equip Type
Primary and Secondary Cool Fuel
Primary and Secondary Cool Dist Type
Primary and Secondary Cool Percent Area Served
Primary and Secondary Total Cool BTU
Primary and Secondary Zoning Type
Primary and Secondary Controls Type
Primary and Secondary Zoning Percent Area Served
Secondary Heat Equip Type
Secondary Heat Fuel
Secondary Heat Dist Type
Secondary Heat Percent Area Served
Secondary Total Heat BTU
Secondary Cool Equip Type
Secondary Cool Fuel
Secondary Cool Dist Type
Secondary Cool Percent Area Served
Secondary Total Cool BTU
Secondary Zoning Type
Secondary Controls Type
Secondary Zoning Percent Area Served
Building Mgmt System
Unitary/Split (<65K) Equip Count
Unitary/Split (<65K) Total BTU
Economizer
Exhaust Air Heat Recovery
Total Fan Static Pressure (TSP)
Exterior Fan Static Pressure (ESP)
ENVELOPE SPEC DATA
Primary Window Frame Type
Number of Glazing Panes
Solar Coatings
Low-E
Operable/Non-Operable
Percent of Windows Inset/Shaded
Window SHGC
Window SC
Window-U
Door Type
Standard Door Count (double =2)
Rollup Door Count
Vestibules
Primary and Secondary Floor Type
Primary and Secondary Floor Footprint Percent
Primary and Secondary Floor Cavity-R
Primary and Secondary Floor Cont-R
Primary and Secondary Perimeter Slab-R
Primary and Secondary Below Grade Wall-R
Primary and Secondary Wall Type
Primary and Secondary Gross Wall Area Percent
Primary and Secondary Wall Cavity-R
Primary and Secondary Wall Cont-R
Primary and Secondary Roof Surface Type
Primary and Secondary Roof Structure Type
Primary and Secondary Roof Area Percent
Primary and Secondary Roof Low Albedo
Primary and Secondary Roof Cavity-R
Primary and Secondary Roof Cont-R
Window Area North, South, East, West
Window Area NE, NW, SE, SW
Wall Area North, South, East, West
Wall Area NE, NW, SE, SW

WATER HEATING DATA
Primary and Secondary Equip Type
Primary and Secondary Equip Fuel
Number of Primary and Secondary Units
Primary and Secondary Total Capacity BTU
Primary and Secondary Total GPH

LIGHTING FIXTURE DATA
Description
Lens Type
Number of Lamps per fixture
Lamp Type
Lamp technology
Lamp Wattage
Ballast Type
Fixture Counts by Space Type