National Commercial Construction Characteristics and Compliance with Building Energy Codes: 1999-2007

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ABSTRACT

As States adopt the latest energy standards, which continue to be developed with more stringent requirements, a better understanding of actual compliance with standards and associated common construction practice can be important. Claims are often made that energy-related standards impose excessive burdens on building owners and the construction industry. Other claims indicate that many energy-code requirements are common practice and will have little impact on the building community. Information collected on current construction practice is critical in the analysis of the effect of energy code adoption and in understanding the rational possibility of specific future code development. Because an increased focus is placed on energy consumption in the building sector, the effective analysis of code impacts, as well as energy efficiency projects and programs, will become more important. Decision makers need better information on the current state of new commercial construction to accurately assess the impacts of codes, standards, incentives and policies. Regional and national studies exist that provide survey data for only selected types of buildings in specific locations. This paper presents an assessment of how current new commercial construction complies with applicable energy codes on a national basis for a range of code levels represented by buildings designed in the 1999 – 2007 timeframe. This analysis makes use of a recently updated commercial buildings database with more than 130 energy-related building characteristics from over 340 new commercial buildings across the United States. Energy code compliance for the buildings in this sample is assessed using the COM*check*™ energy standard compliance software tool to determine how closely new construction across the Nation is to meeting current and recently adopted energy codes such as ASHRAE/IESNA 90.1. The results present an interesting look at where code requirements stand with respect to current construction and provide insights into the challenges faced by the building community to meet these standards.

Summary

The National Commercial Construction Characteristics (NC^3) data set was developed to help provide answers to questions on current commercial design practices, which are important inputs to analysis of commercial building energy consumption. The data set is populated with over 130 possible building characteristics for 340 buildings from across the Nation. The building characteristics were extracted from sets of real building plans and specifications acquired from the F.W. DODGE Plans Service Division of McGraw Hill. These represent buildings that were in the bid process during the summer of 2001 through the spring of 2007. It

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is understood that changes are made to buildings during construction, but these sets of plans do provide complete designs that are representative of expected common construction practice.

As of the date of this report, the NC^3 data set has been used to support several internal and external analysis efforts including: support for state code adoption, analysis of the potential effect of Federal energy tax credit legislation, and the assessments of lighting power density (LPD) and window wall ratios to support code adoption and development of the 90.1 energy standards jointly sponsored by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the Illuminating Engineering Society of North America (IESNA). The most recent use has been assistance in the development of Department of Energy Benchmark building prototypes used in a variety of building energy analysis efforts. Another application is the assessment of current constructed building stock compliance with national energy codes to provide some idea of how commercial buildings across the Nation are meeting minimum energy code levels with and without State-adopted code requirements. The compliance results provided in this paper clearly show that, for envelope requirements, the majority of newly constructed commercial buildings in the U.S. that were built to meet the ASHRAE/IESNA 90.1-1989 standard far exceeded it. However, at least 1/4 of those built to meet the 90.1-1999 standards did not meet minimum code requirements. For lighting requirements, a majority of the buildings are also meeting or exceeding the 90.1-1989 standards, but between approximately 20% and 30% of buildings designed to meet the 90.1-1999 standard would not comply.

Introduction

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 those being constructed. In analyzing these types of issues, data on how commercial buildings are currently being constructed commonly emerges as a critical missing element. For example, as many states consider the adoption of a new energy code, they have the 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 the energy impacts of currently constructed buildings, and to compare this with the energy code implications to then calculate potential energy savings.

On a national basis it can be desirable to understand the effect energy code adoption has on national energy consumption. Again, it can be useful to understand current practice on a national scale 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 and regions, or at an overview level. One recently completed study completed for the Northwest Energy Efficiency Alliance (NEEA) and known as the 2006 non-residential baseline presents characteristics of approximately the same number of buildings as NC^3 data set but only for buildings in the Northwest. The Commercial Building Energy Conservation Survey (CBECS) data source provides less detailed building data from surveys but covers the entire country. To provide the necessary detailed characteristics on a national scale, the National Commercial Construction Characteristics (NC^3) data set was developed at the Pacific Northwest National Laboratory (PNNL) as a data source to help answer energy and code related questions.

Data Set Development

The 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 stock was launched.

Initial work on the design of the data set and collection methodologies began in early 2001 and an expansion took place throughout 2007. Appendix A includes this list of over 130 data collection items, which includes lighting characterizations and detailed square footage take-offs to include heating, ventilation and air conditioning (HVAC); water heating; and envelope characteristics. 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. At the same time, a list of building types of interest was prepared with primary focus on 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 nationally available energy codes and standards 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.

The F.W. DODGE Plans Service Division of McGraw Hill maintains sets of plans for buildings recently designed and currently in the construction bidding stage and makes those available for contractors interested in bidding. PNNL contracted with this service to obtain a total of over 340 sets of plans and specifications of various types of commercial buildings across the Nation. The buildings included in the data set were selected with the following general guidelines in mind with resulting quantities shown in Table 1.

- New buildings – not remodeled facilities or additions
- Relatively clean examples of the building types of interest – avoiding mixed use
- Not extremely small – buildings smaller than 1,000 to 2,000 square feet may not reasonably represent “complete” buildings of a particular type
- Not extremely large – buildings over one-half million square feet were not expected to exhibit fundamental differences from those of 100,000 square foot
- Distributed across the Nation – as evenly distributed as practical

Table 1. Distribution of NC^3 Sample by Building Type

Building Type	Number of Buildings
Assisted Living	14
Fast Food	12
Grocery Store	17
Hotel	24
Inpatient Health Care	23
Large Office	7
Medium Office	17
Motel	2
Outpatient Health Care	15
Primary School	26
Resturant	18
Retail	30
Secondary School	27
Small Office	25
Strip Mall	18
Warehouse	20
Other	47

A set of extraction procedures was created that 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. During the 2001/2002 efforts, 162 buildings were completed and during the 2006/2007 effort, an additional 182 new buildings were added. Extensive quality assurance checks of existing buildings and new buildings were completed by early 2008, and the data was placed in the MySQL database format.

Data Set Capabilities

The data set in its current form is able to provide important building energy related characteristics for a wide variety of commercial building attributes. These characteristics can be provided in meaningful categorizations and comparisons on their own and can be related to important external factors, such as weather and energy code requirements. A major advantage of the dataset over others is the ability to present collected characteristics on a national basis. This includes simple characteristics sorts to identify common practices, identification of trends by weather location, and lighting power density by building, space, and technology, as well as potential code compliance.

Figures 1 through 10 highlight just a few examples of the variety of capabilities of the data set. They provide a glimpse of the information available from the over 100 major commercial building practice characteristics. Some of the available characteristics, such as insulation levels, may serve to simply confirm existing understandings. However, others, such as window wall ratio and lighting technology mix, can provide interesting and useful information and may conflict with generally accepted practice.

The data set contains useful information for whole building modeling, such as shape type (Figure 1) and insulation levels shown with average as well as minimum and maximums of the dataset in Figures 2 through 4. Other useful modeling and characterization information includes building component structure and surface types. These data for wall components are shown in Figures 5 and 6. Another useful building characteristic of great interest to energy modelers is window wall ratio, which has been used as part of the development of many energy codes. Historically, they have been thought to be in the range of 20% and higher. The NC^3 data provides new information that the ratios are not that high for most building types (Figure 7). The data set's level of detail is able to provide characteristics such as window wall ratio by orientation, as illustrated by the south facing values in Figure 8. One particularly powerful capability of this data is the detail available on installed lighting technologies and power densities. Figure 9 identifies the amount of T12 fluorescent lighting still being installed in new buildings. Figure 10 provides a similar representation of the relative prevalence of incandescent technologies. Figures 11 and 12 show the designed lighting powers densities for selected building types and space types in the data set. Figure 11 shows building level power density with the average and minimum/maximum providing an assessment of the variability of densities by building type. Figure 12 provides the aggregated power density for selected space types across the data set split by its contribution by lighting technology.

These samples show the basic data set capability. Variations and other aggregations and detailed splits can be produced to provide a wide variety of information.

Figure 1. Shape Type by Building Type

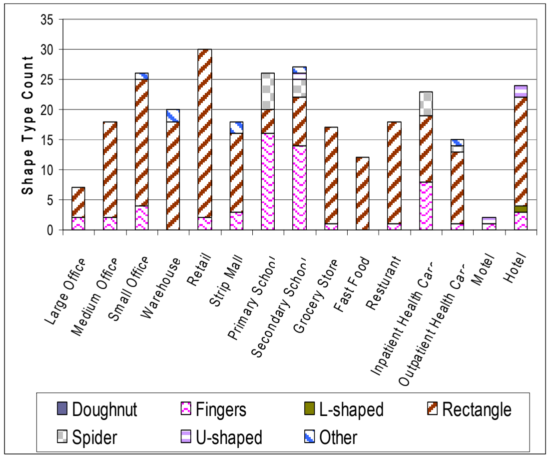


Figure 2. Slab Perimeter Insulation R-Value

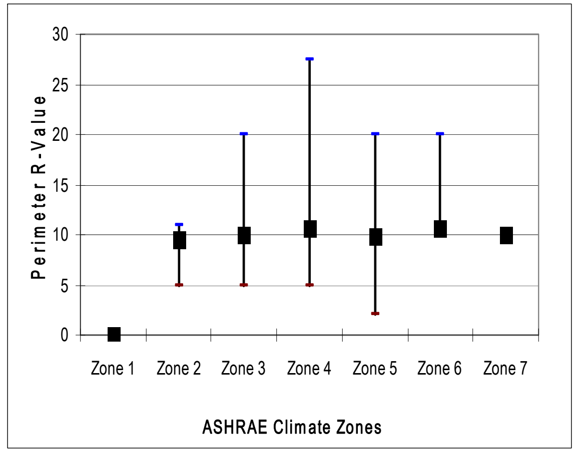


Figure 3. Cavity Wall R-Value By ASHRAE Climate Zone

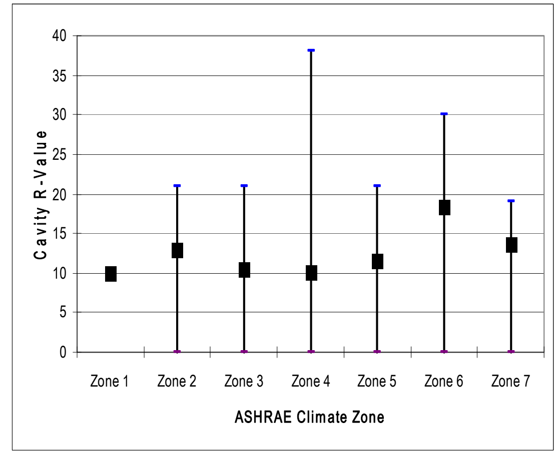


Figure 4. Continuous Wall R-Value by ASHRAE Climate Zone

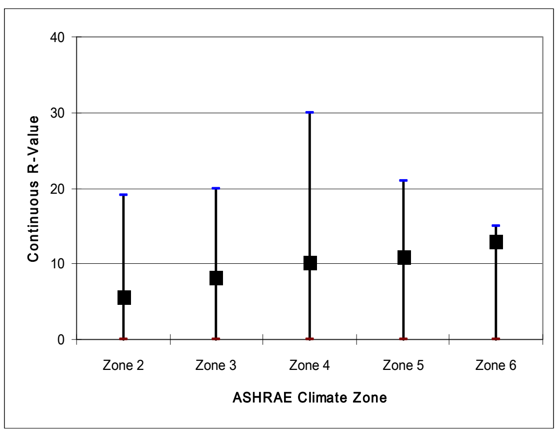


Figure 5. Wall Structure Type by Building Type

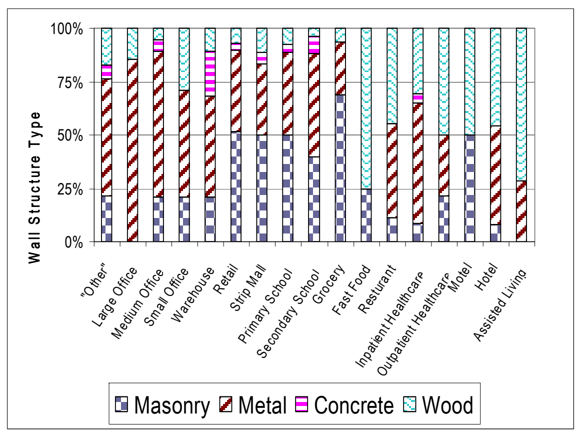


Figure 6. Wall Surface Type by Building Type

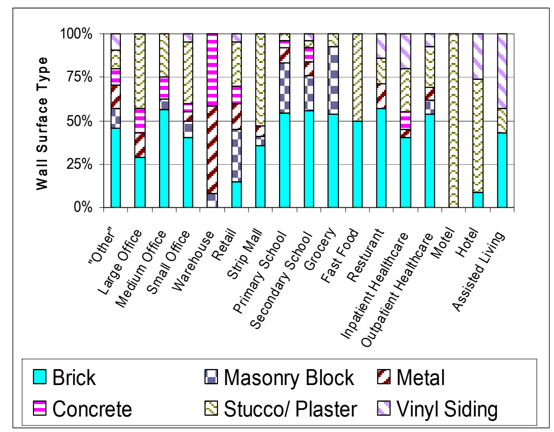


Figure 7. South Orientated Window Wall Ratio by Building Type

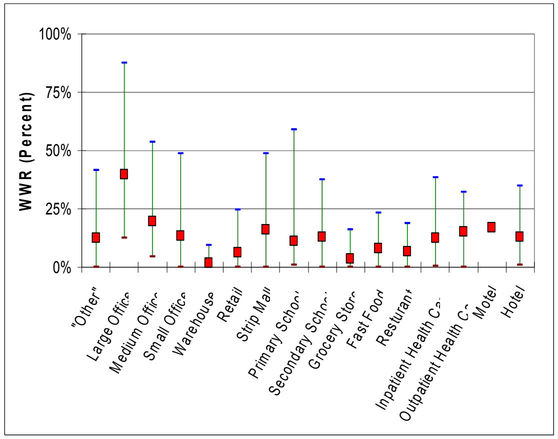


Figure 8. Total Window Wall Ratio by Building Type

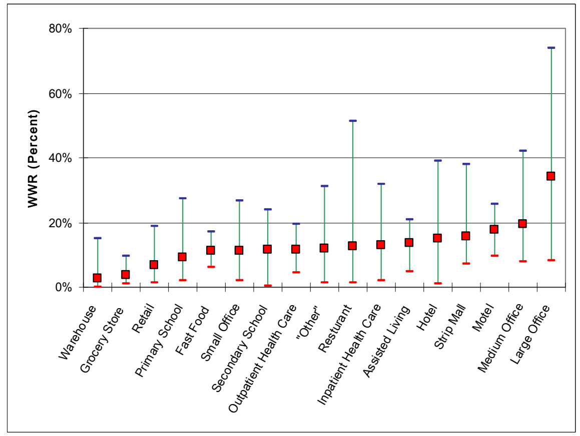


Figure 9. T12's as a Percent of Total Fluorescent Lighting

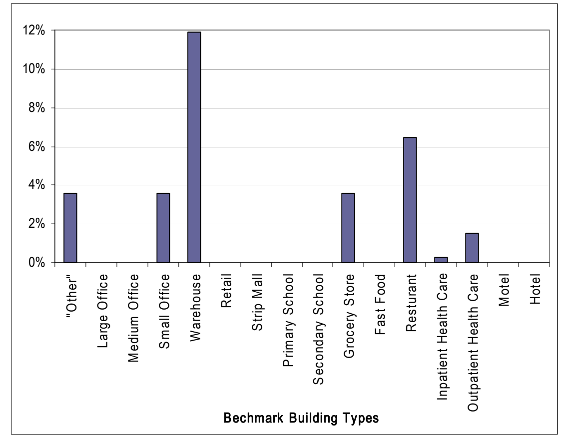


Figure 10. Incandescent Lighting as a Percentage of Total INC + CFL Lighting

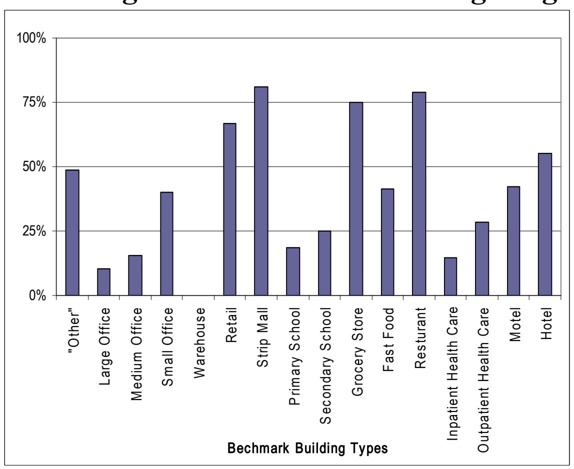


Figure 11. Lighting Power Density by Building Type – Avg, Min, Max

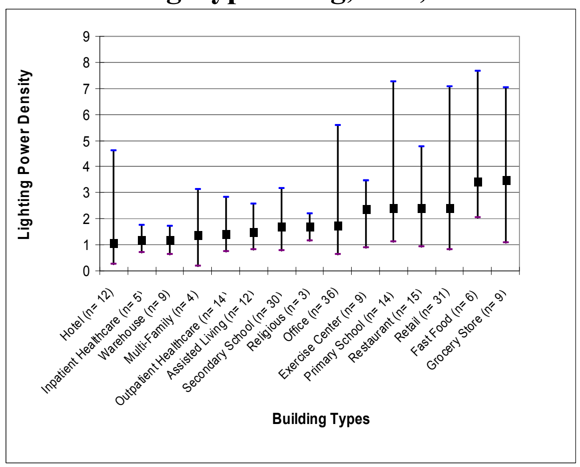
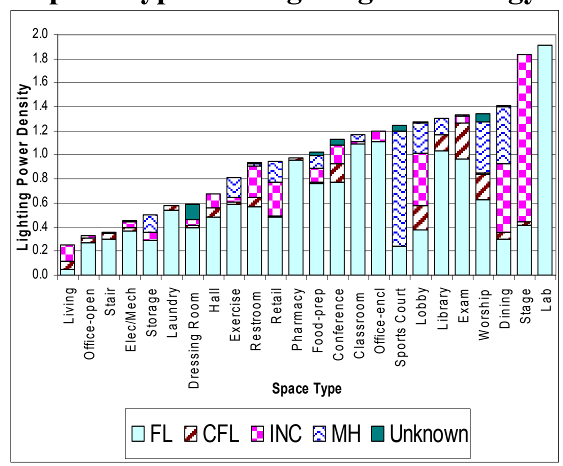


Figure 12. Lighting Power Density by Space Type and Lighting Technology

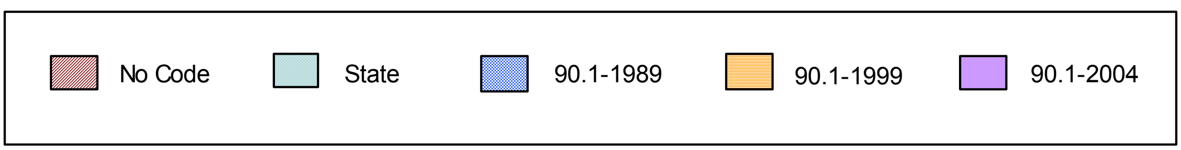


National Energy Code Compliance Comparison

One important capability of the NC[3] data is supporting the assessment of how commercial buildings are complying with applicable energy codes. The data is able to provide an unbiased basis for looking at compliance trends among new buildings. The energy code compliance software tool COM*check* 3.5.3 developed under the Building Energy Code Program (BECP) program at PNNL was used to determine the compliance of each building as a percentage above or below the compliance level for envelope and lighting requirements. These percentages indicate how close to compliance each building is as it is currently designed.

Compliance was calculated for the ANSI/ASHRAE/IESNA 90.1-1989, 90.1-1999, and 90.1-2004 standards where applicable. The 90.1-1989 and 1999 standards were the current adopted standard for many of the buildings in the data set. The remaining buildings are under state-specific codes or no code. Figures 13 and 14 show how buildings with 90.1-1989 or 90.1-1999 requirements comply with the envelope provisions of their code. Figures 15 through 18 show compliance to the older 90.1-1989 and more recent 90.1-2004 standards for buildings with no code or a state-specific code in place. Figure 13 shows that most buildings with older 90.1-1989 requirements are easily complying. Buildings with a 90.1-1999 code requirement show approximately 2/3 compliance (Figure 14). Buildings with no code or a state specific code are also easily complying with the older 90.1-1989 code level and 2/3 are also complying with the higher code level of 90.1-2004 (Figures 15 through 18). Similar lighting compliance trends are shown in Figures 19 through 24.

The remaining compliance figures show how buildings are meeting specific code levels for all buildings of a particular type, regardless of that building's code requirement. In these figures the required code for each building is identified by its bar color and pattern according to the following key:



For example Figure 25 shows that all of the primary school samples comply with the 90.1-1989 envelope requirements. This includes those with 90.1-1989 as a requirement, as well as those with 90.1-1999, no code or state-specific code requirements. The remaining primary school compliance figures (Figures 26 and 27) show compliance to higher level codes, and it is clear that a building's required code level does not always dictate its compliance or non-compliance. In all of the remaining envelope compliance figures (28 through 36), the results are similar. The final set of figures (37 through 48) present similar results for lighting power density compliance among various building types and show the same primary trends as in the envelope compliance.

Figure 13. Envelope Compliance for Buildings with 90.1-1989 Code Requirements

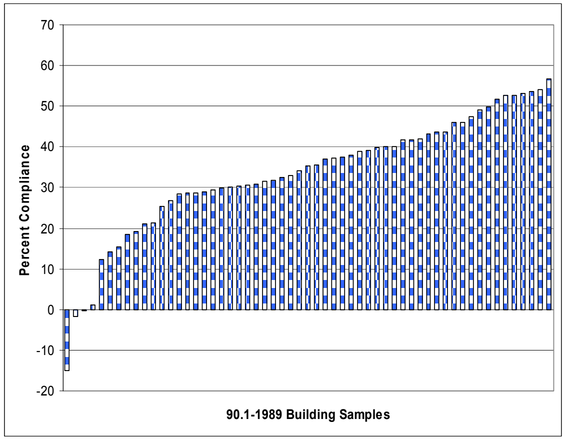


Figure14. Envelope Compliance for Buildings with 90.1-1999 Code Requirements

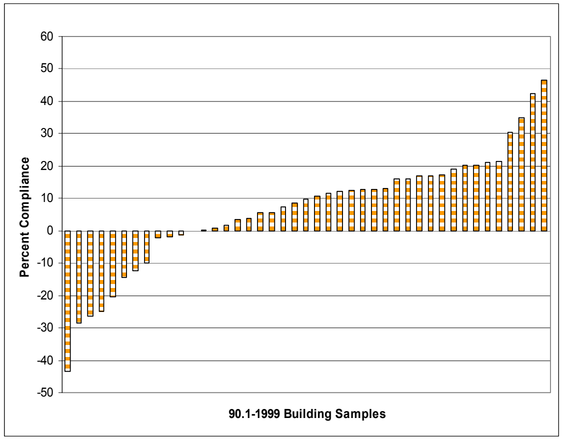


Figure 15. Envelope Compliance to 90.1-1989 for Buildings with No Code

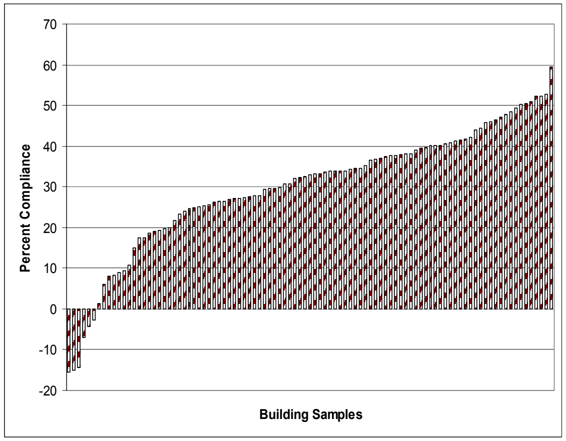


Figure 16. Envelope Compliance to 90.1-2004 for Buildings with No Code

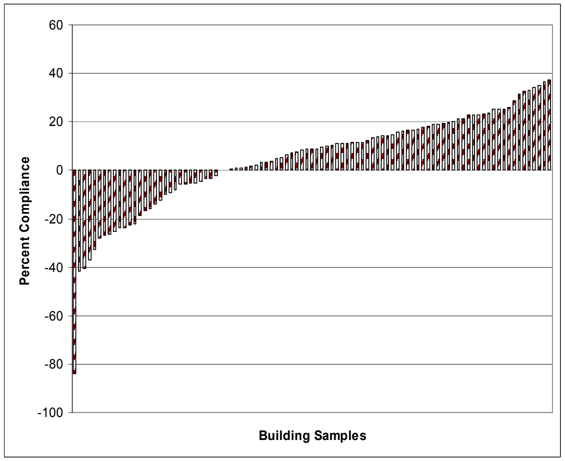


Figure 17. Envelope Compliance to 90.1-1989 for Buildings with State Specific Code

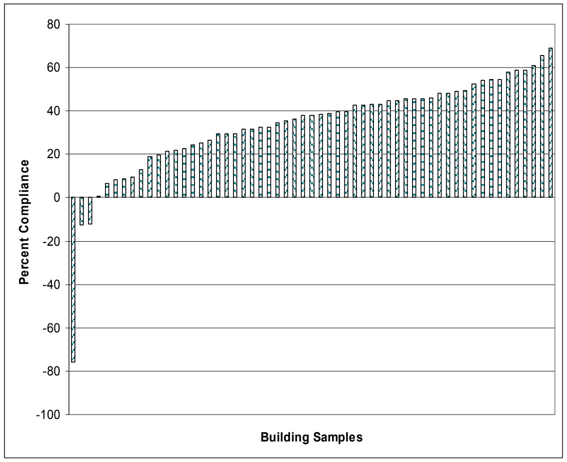


Figure 18. Envelope Compliance to 90.1-2004 for Buildings with State Specific Code

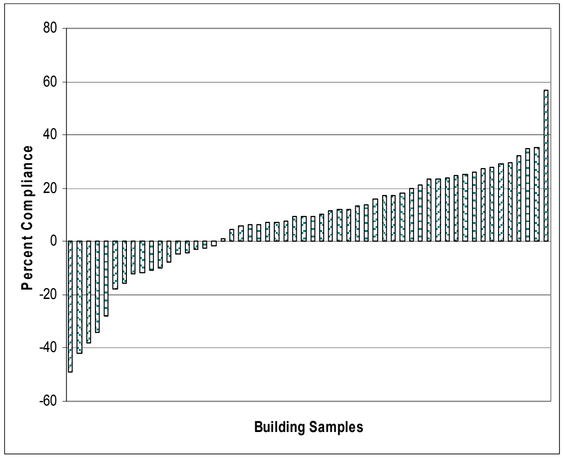


Figure 19. Lighting Compliance for Buildings with 90.1-1989 Code Requirement

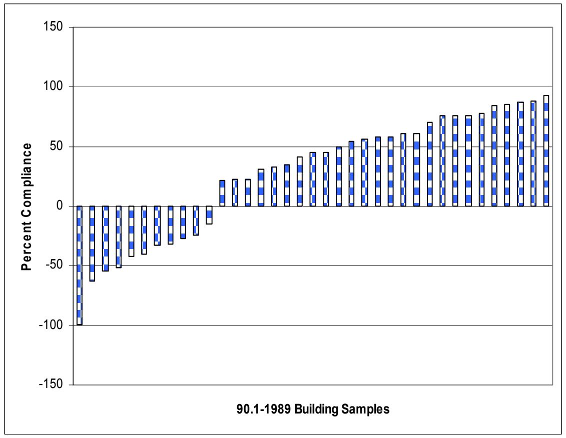


Figure 20. Lighting Compliance for Buildings with 90.1-1999 Code Requirement

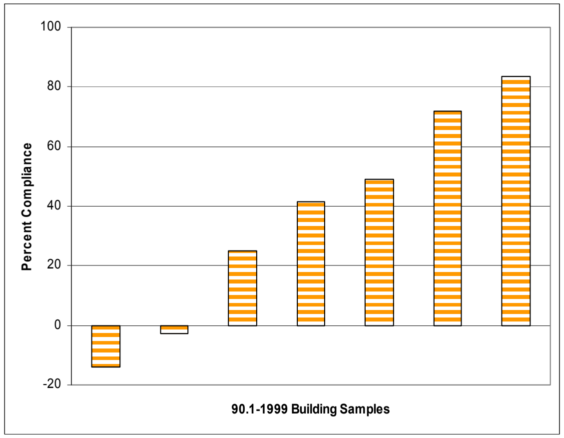


Figure 21. Lighting Compliance to 90.1-1989 for Buildings with No Code

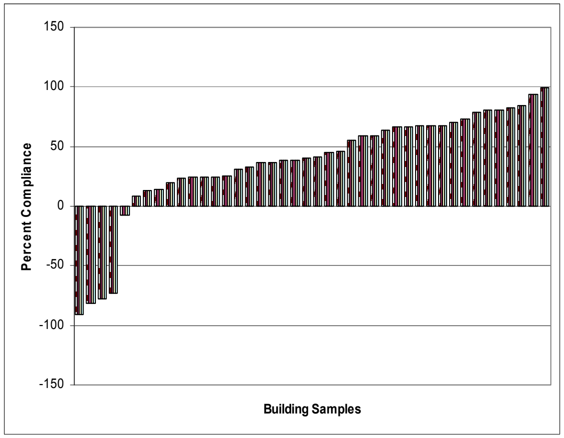


Figure 22. Lighting Compliance to 90.1-2004 for Buildings with No Code

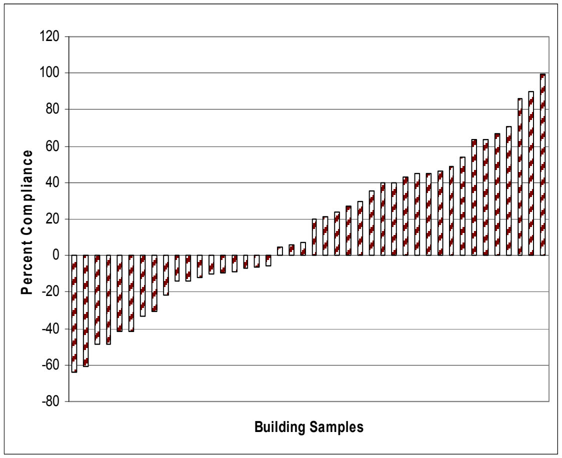


Figure 23. Lighting Compliance to 90.1-1989 for Buildings with State-Specific Code

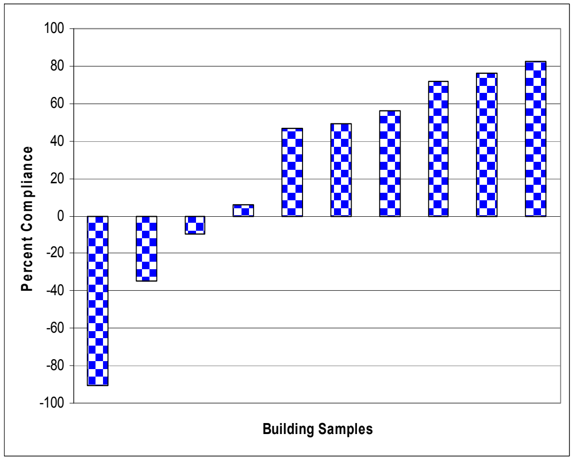


Figure 24. Lighting Compliance to 90.1-2004 for Buildings with State-Specific Code

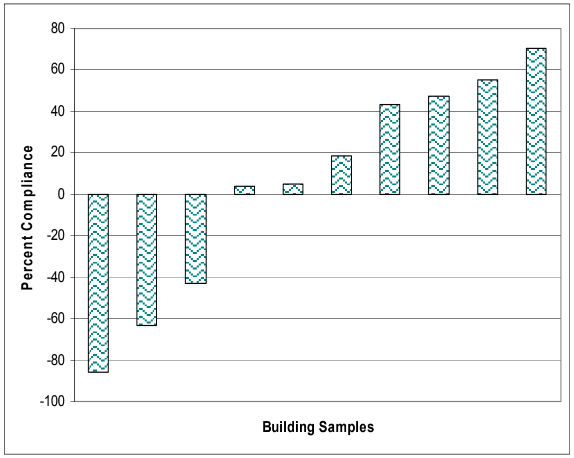


Figure 25. Envelope Compliance to 90.1-1989 Primary School Buildings

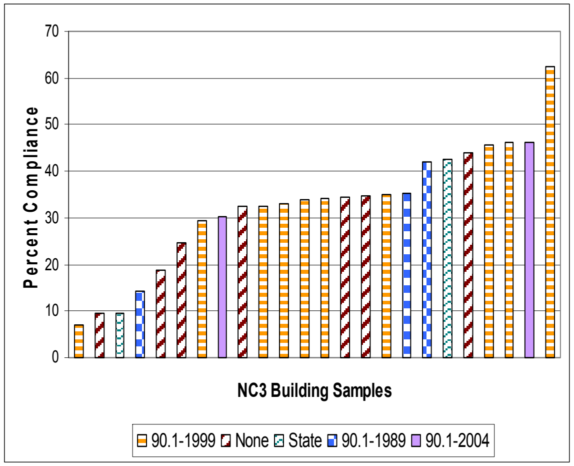


Figure 26. Envelope Compliance to 90.1-1999 Primary School Buildings

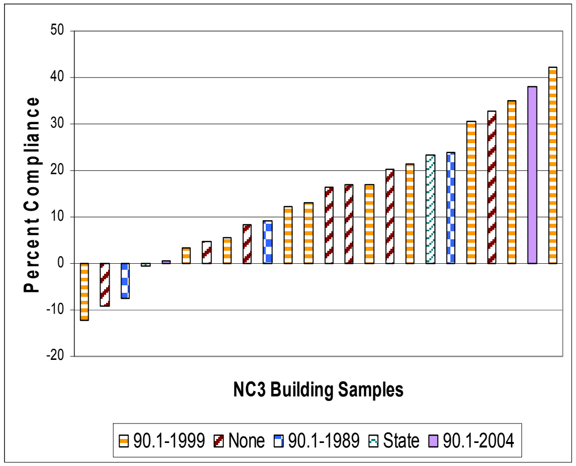


Figure 27. Envelope Compliance to 90.1-2004 Primary School Buildings

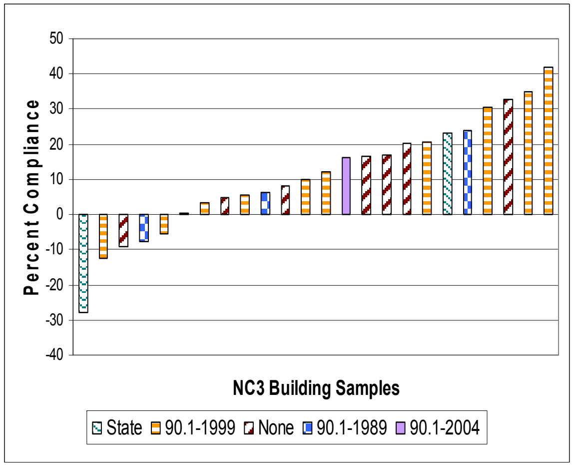


Figure 28. Envelope Compliance to 90.1-1989 Medium Office Buildings

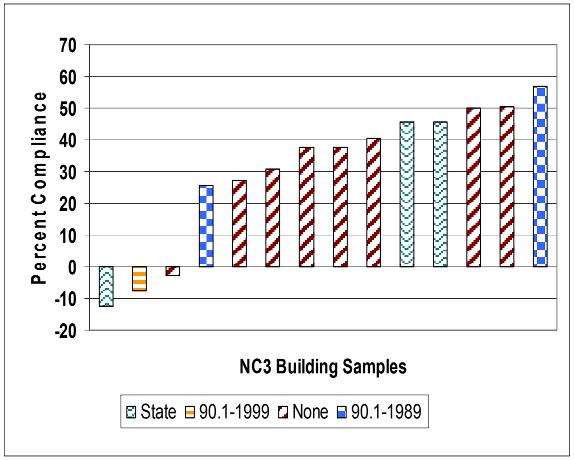


Figure 29. Envelope Compliance to 90.1-1999 Medium Office Buildings

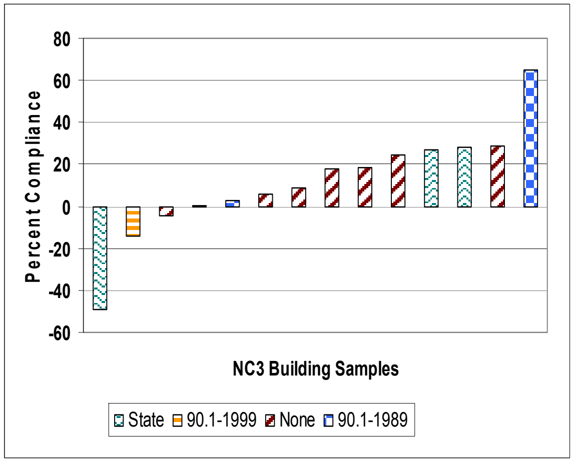


Figure 30. Envelope Compliance to 90.1-2004 Medium Office Buildings

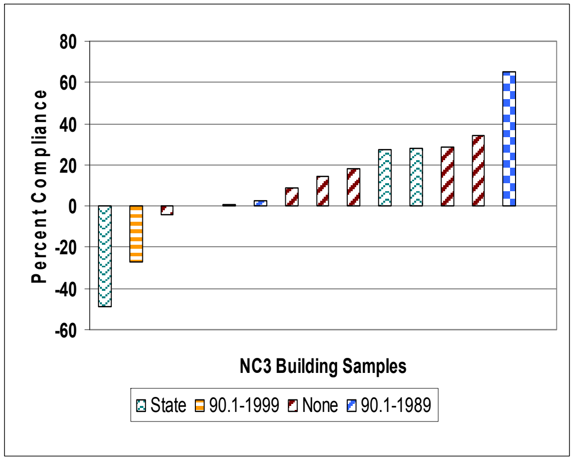


Figure 31. Envelope Compliance to 90.1-1989 Retail Buildings

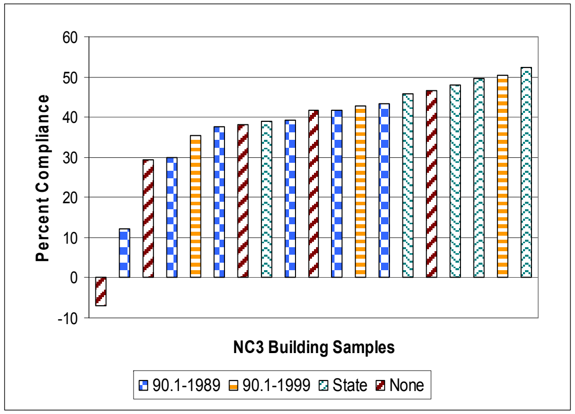


Figure 32. Envelope Compliance to 90.1-1999 Retail Buildings

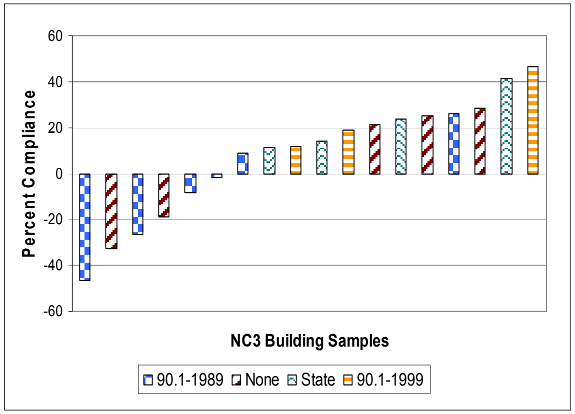


Figure 33. Envelope Compliance to 90.1-2004 Retail Buildings

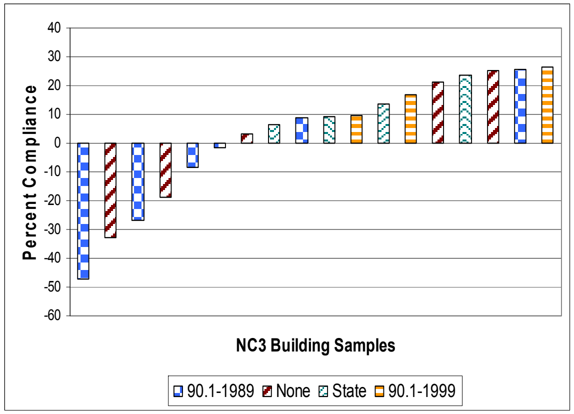


Figure 34. Envelope Compliance to 90.1-1989 Hotel Buildings

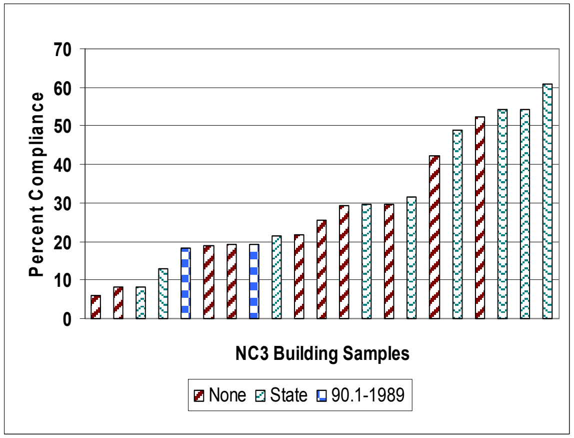


Figure 35. Envelope Compliance to 90.1-1999 Hotel Buildings

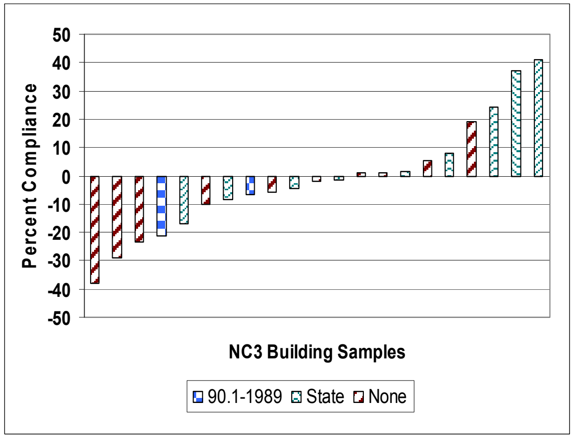


Figure 36. Envelope Compliance to 90.1-2004 Hotel Buildings

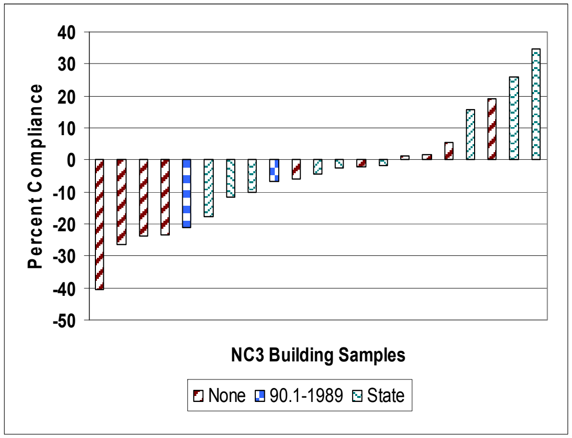


Figure 37. Lighting Compliance to 90.1-1989 Small Office Buildings

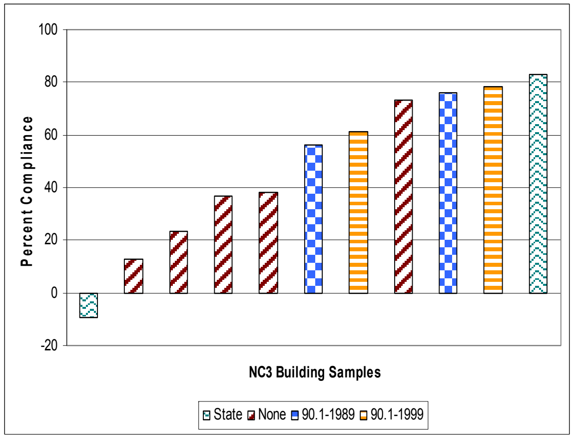


Figure 38. Lighting Compliance to 90.1-1999 Small Office Buildings

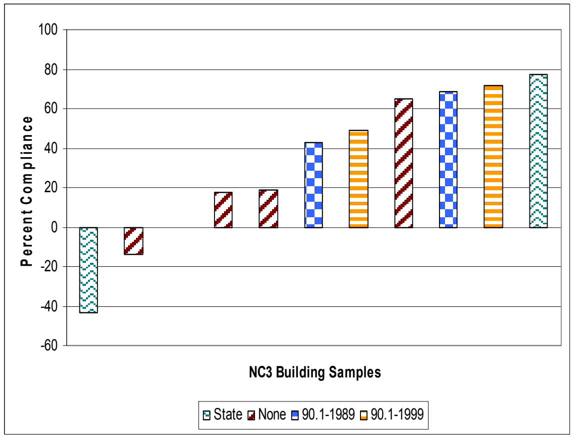


Figure 39. Lighting Compliance to 90.1-2004 Small Office Buildings

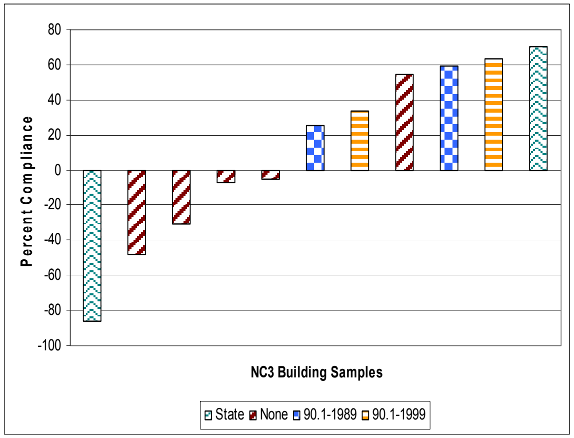


Figure 40. Lighting Compliance to 90.1-1989 Retail Buildings

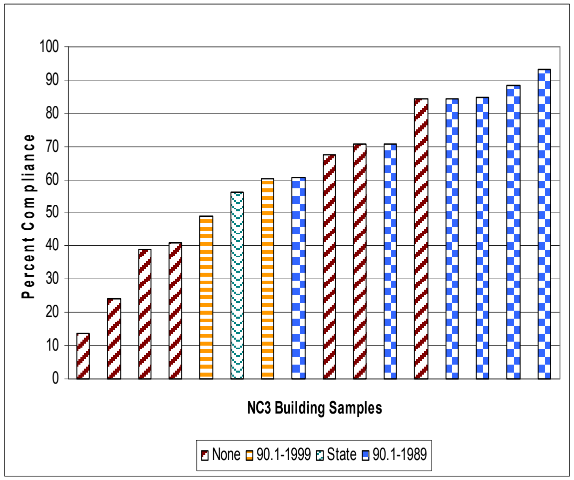


Figure 41. Lighting Compliance to 90.1-1999 Retail Buildings

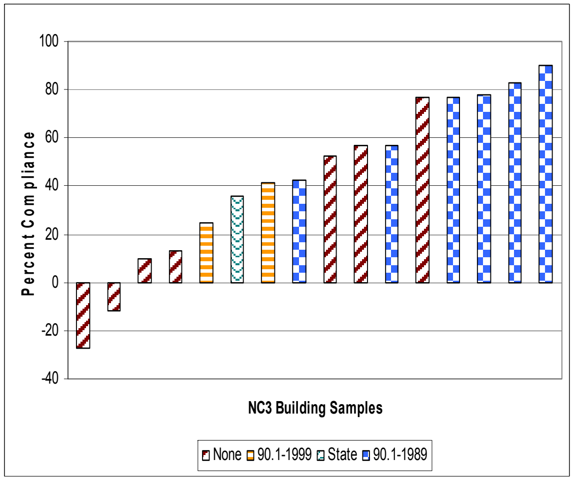


Figure 42. Lighting Compliance to 90.1-2004 Retail Buildings

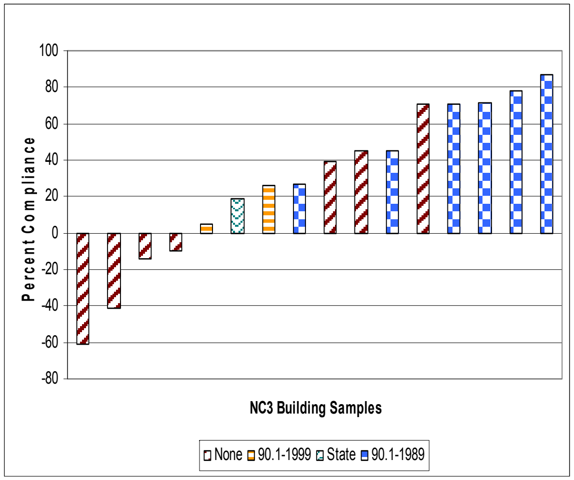


Figure 43. Lighting Compliance to 90.1-1989 Restaurant Buildings

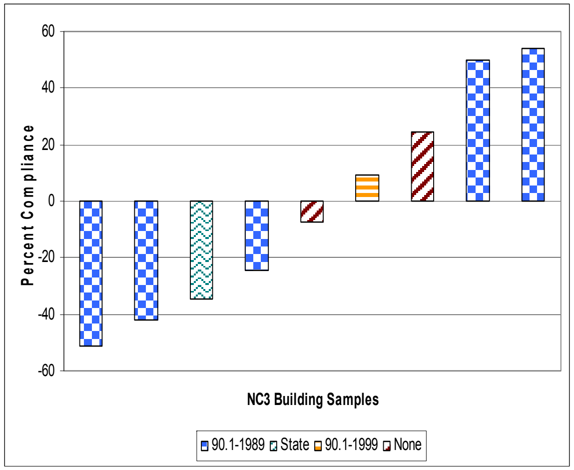


Figure 44. Lighting Compliance to 90.1-1999 Restaurant Buildings

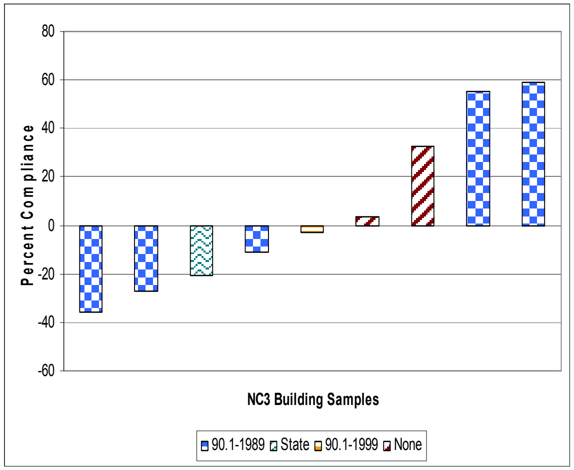


Figure 45. Lighting Compliance to 90.1-2004 Restaurant Buildings

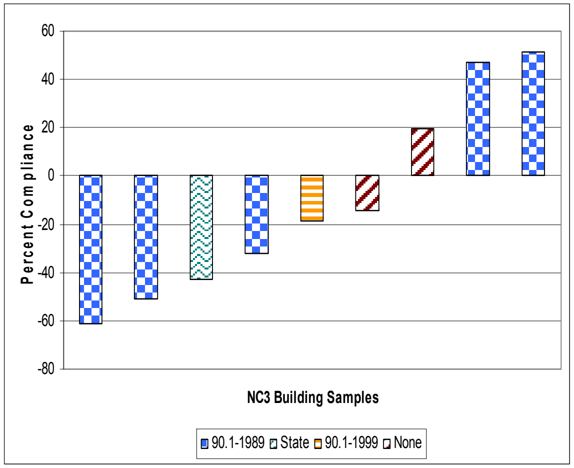


Figure 46. Lighting Compliance to 90.1-1989 Grocery

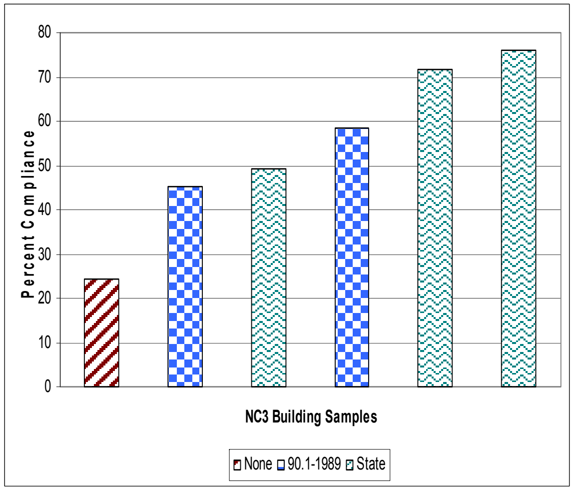


Figure 47. Lighting Compliance to 90.1-1999 Grocery

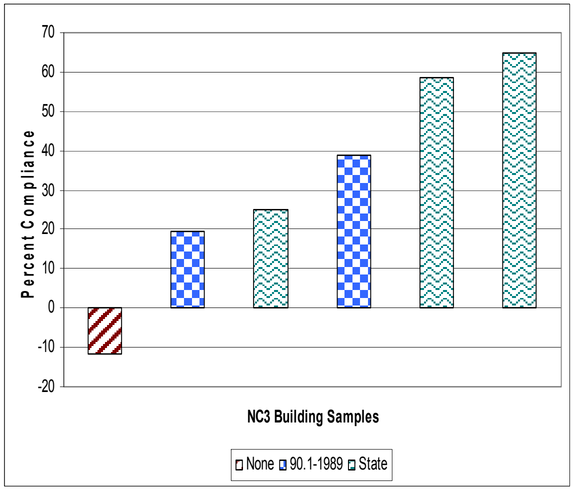
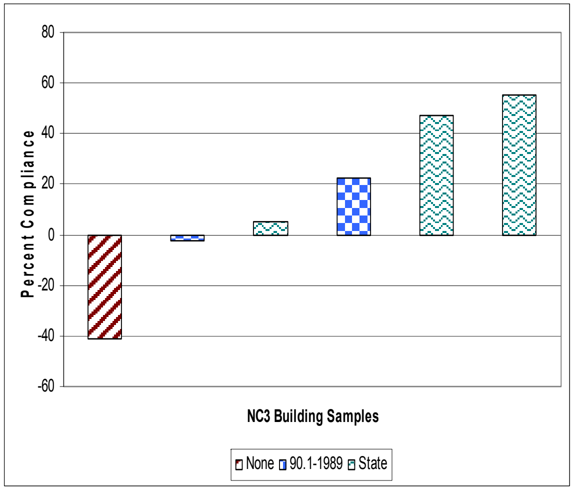


Figure 48. Lighting Compliance to 90.1-2004 Grocery



Conclusions and Recommendations

The availability of accurate new building construction data is an important part of building energy analysis and can provide critical information. This data set provides one source of this data. While the data set can be considered small compared to other collections such as CBECS, its strength lies in its detail and consistency of collection. Its sample size of approximately 340 buildings distributed across the country can not be considered statistically significant in representing the US. However, many of the building type samples and the entire set itself provide sample sizes above the generally accepted minimum threshold of 20 to 30 samples needed for some assurance or representation of a large set of data.

Window wall ratios, long thought to be relatively high, are found to be lower than expected, which can have an impact on the development of code requirements. The still relatively large presence of T12 fluorescent technology in new building construction is a surprising trend. This could indicate slowness in the market to adopt newer technologies and/or a lack of code stringency or enforcement that might force these less efficient lamps out of new construction.

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 also meet the newer 1999 code requirements regardless of actual code level requirements. The data provides two primary observations:

- The presence of building energy code requirements does not by itself produce compliance. Among buildings with a specific code level requirement, most comply but in some cases up to half do not.
- Buildings in jurisdictions with older (less stringent) codes show almost complete compliance. This is believed to be a result of the continued improvement in construction practice in part spurred by increasing code level stringency in surrounding regions.

In general, it is clear there are other factors at play in achieving energy code compliance beyond adoption of a set of code requirements. Other probable factors in producing these mixed (over- and under-compliance) results include:

- A strong consistency in construction practice that can override energy issues or requirements and reduce compliance
- Construction practice change over time that elevates energy related construction beyond code requirements (i.e., in states where older codes are in place)
- Lack of enforcement and/or education, which does not ensure that all buildings are forced to comply with adopted codes.

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. At the same time, it is clear that more is needed to ensure that code requirements that are in place are applied in building design and verified for compliance.

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Appendix A
NC^3 Collected Building Characteristics

GENERAL BUILDING DATA
Dodge Number
Plan Year
Building Description
Building Type
Summed Size
Parking Garage Summed Size
Footprint Size
Stories Above Ground
Stories Below Ground
Footprint Length
Footprint Width
Long Axis Orientation
Shape Type
Shared Walls
Daylight Sensors Specified
Occupancy Sensors Specified
City
State
County
ASHRAE Climate Zone
Benchmark ID No.
Bldg Type PBA
Bldg Type PBA Plus
Listed Size
No Elec
Partial Elec
No Spec
Partial Arch
No Mech
Partial Mech

SPACE TYPE SPECIFIC DATA
Square Footage by Space Type
Fixture Counts by Space Type

HVAC DATA
Major and Minor Heat Equip Type
Major and Minor Heat Fuel
Major and Minor Heat Dist Type
Major and Minor Heat Percent Area Served
Major and Minor Total Heat MBTU
Major and Minor Cool Equip Type
Major and Minor Cool Fuel
Major and Minor Cool Dist Type
Major and Minor Cool Percent Area Served
Major and Minor Total Cool MBTU
Major and Minor Zoning Type
Major and Minor Controls Type
Major and Minor Supply Fan CFM
Major and Minor Supply Fan Total S.P.
Major and Minor Return Fan CFM
Major and Minor Return Fan Total Static Pressure
Building Mgmt System
Unitary/Split (<65K MBTU) Equip Count (Cooling Only)
Unitary/Split (<65K MBTU) Total MBTU
Economizer
Exhaust Air Heat Recovery

ENVELOPE SPEC DATA
Major Window Frame Type
Number of Glazing Panes
Solar Coatings
Low-E
Percent of Windows Operable
Percent of Windows Inset/Shaded
Window SHGC
Window SC
Window-U
Door Type
Standard Door Count (double =2)
Rollup Door Count
Vestibules
Major and Minor Floor Type
Major and Minor Floor Footprint Percent
Major and Minor Floor Cavity-R
Major and Minor Floor Cont-R
Major and Minor Perimeter Slab-R
Major and Minor Below Grade Wall Cavity-R
Major and Minor Below Grade Wall Cont-R
Major and Minor Wall Structure Type
Major and Minor Wall Surface Type
Major and Minor Gross Wall Area Percent
Major and Minor Wall Cavity-R
Major and Minor Wall Cont-R
Major and Minor Roof Structure Type
Major and Minor Roof Surface Type
Major and Minor Roof Area Percent
Major and Minor Roof Low Albedo
Major and Minor Roof Cavity-R
Major and Minor Roof Cont-R
Window Area N,S,E,W or NE, NW, SE, SW
Wall Area N,S,E,W or NE, NW, SE, SW

WATER HEATING DATA
Major and Minor System Type
Major and Minor Equip Type
Major and Minor Equip Fuel
Number of Major and Minor Units
Major and Minor Equip Total Capacity MBTU
Major and Minor Total Recovery GPH
Major and Minor Total Tank Size (Gallons)

LIGHTING FIXTURE DATA
Fixture Code or Label
Description
Lens Type
Number of Lamps per fixture
Lamp Shape Type
Lamp Technology
Lamp Wattage
Ballast Type (For Efficiency)
Ballast Type (Other)