C19 -COMMERCIAL & INDUSTRIAL NEW CONSTRUCTION BASELINE AND CODE COMPLIANCE STUDY

Final Report

Connecticut Energy Efficiency Board – Evaluation Committee

Date: November 6, 2015

Project name:	C19 -Commercial & Industrial New Construction Baseline and Code Compliance Study	DNV GL - Energy Policy Analysis & Research 200 Court St Middletown CT 06457 Tel: 860-346-5001
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1 EXECUTIVE SUMMARY

1.1 Background & Research Objectives

The 2014 – 2016 Evaluation Plan (the Plan) of the Connecticut (CT) Energy Efficiency Board's (EEB) Evaluation Committee for the EnergizeCT energy efficiency programs proposed a study to investigate commercial and industrial (C&I) new construction practices, specifically identifying the value of improving the accuracy of the baseline used to calculate savings estimates. Increased accuracy of baseline inputs reduces the probability of under- or over-investment in energy infrastructure, inaccurate evaluation of utility programs, and ineffective program dollars. A secondary objective of this study is to produce a rough estimate of the level of compliance with energy components of the state building code in effect at the time of construction. Inclusion of this objective in the study was based in part on the State's obligation to evaluate code compliance under the terms of a federal grant and the overlap of data requirements which permits an efficient use of evaluation dollars.

The first step in this research was to inventory energy-using systems and equipment at a statistically selected sample of 45 recently constructed commercial and industrial sites. To the extent possible without intrusive investigation methods, the baseline study collected data to support analysis of code compliance at the building level by use of COMcheck™, the US Department of Energy compliance tool. Since many of the values required by COMcheck are not observable in finished construction without intrusive investigation, the evaluation contractor[1] acquired and reviewed construction documents to supplement the onsite investigation.

1.2 Overview of Methodology

This section provides a short summary of the methodologies used in the study grouped into three phases; setup, data collection, and analysis. These phases and the activities performed therein are presented in the following image.

Figure 1: Methodology Overview

Details on the individual components of each phase are summarized and in the body of the report.

1.2.1 Setup

The project setup phase included identifying and acquiring the population data, designing the sample, developing recruiting and data collection tools, and extensive training, as summarized below:

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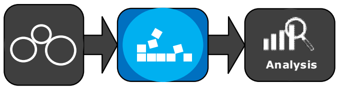
[1] DNV GL- Energy, operating as KEMA, Inc. served as the evaluation contractor for this study.

- **Population Data.** Connecticut C&I new construction data was purchased from Dodge Data and Analytics.2
- **Sample Design.** The new construction population data was extensively reviewed and cleaned to limit it to those entries reasonably expected to meet the following criteria; 1) C&I new construction during the 2010 – 2014 time frame; 2) required to meet IECC 2006 or 2009 energy code requirements; 3) containing complete data, in particular contact information and building size. The resulting sample frame of 1,014 buildings was divided into five strata defined as by the U.S. Department of Energy's Building Energy Codes Program (BECP) and randomized.
- **Recruiting Tool.** The evaluation contractor's Excel-based recruiting tool was modified for this project. It incorporated the following features: the sample frame; stratification quotas; a survey to confirm information accuracy and eligibility; and tracking capabilities.
- **Data Collection Tool.** The data requirements for the two primary objectives (baseline energy efficiency of installed measures and rating of energy code compliance) of the study were not identical. An extensive review of the data requirements of COMcheck and PSD measure inputs of interest in the baseline effort was conducted. Then the evaluation contractor's iPad based-data collection tool was adapted to meet both objectives.
- **Training.** A two-day training for field and recruiting staff addressed project objectives, customer contact protocols, safety, data collection, and exception handling.

Tools and protocols were monitored throughout project implementation by the project manager and the project sponsor and modified as necessary.

1.2.2 Data Collection



The data collection phase of the study included the recruiting of sample sites, site visits, acquisition of construction documents, data entry and quality control, and issuance of incentives.

- **Recruiting.** Trained recruiters contacted potential study participants with information about the study and the incentive, confirmed willingness to permit a site visit, asked about the availability of construction document(s), confirmed contact information, recorded the customer's preferred time for the site visit, if provided, and passed this information on to field engineers who performed final scheduling. If requested, the recruiters provided study participants with a validation letter with contact information for a representative at their utility.
- **Site Visits.** Field engineers performed a thorough walk through inventory of all energy using equipment and systems subject to energy code requirements, administered a brief survey with the site representative to collect additional information (*e.g.,* past participation in EnergizeCT programs), and attempted to acquire or review construction documents.
- **Document Acquisition.** If construction documents were not available during the site visit efforts the researchers attempted to acquire them through other channels.
- **Data Entry.** Analysts reviewed data collected in iPad forms, field engineer notes, and photographs to prepare comprehensive site-level data files, supplementing field collected data with additional research as appropriate (*e.g.,* determining equipment efficiency based on manufacturer model number).

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[2] http://construction.com/about-us/

- **Incentive Payment.** The field engineers processed incentive request forms signed by study participants and sent out incentives.

1.2.3 Analysis

The project design required two distinct analytic approaches. One approach was necessary to determine the level of code compliance among the buildings in the sample while the other was to estimate baseline energy efficiency for each building system, particularly those covered by the PSD. The analytic process followed a linear path as mapped out below:

- **Data Quality Control (QC).** Due to the extensive range of measures and systems covered by COMcheck™ and its rigorous data requirements, study analysts entering site level data into the tool also performed data quality analysis.
- **Data Revision and Finalization.** Gaps or errors discovered during QC were addressed either through follow up calls with personnel at sample sites, additional research of publically available data, direct contact with equipment manufacturers, or based on professional judgment supported by observations. The site level data files then were reviewed by a second individual and finalized.
- **Sample Code Compliance.** Code compliance was determined through the application of the USDOE's COMcheck™ (version 4.0.0.2) software. Site level data was entered into the package and the analysis run. The results of the analysis were reviewed by a second engineer for validity and completeness. In some cases data revision resulted in a second run. Once the COMcheck™ analysis was finalized, the site data file was ready for measure level analysis.
- **Population Code Compliance.** Sample level code compliance was expanded using case weights to determine overall code compliance, code compliance by strata, and code compliance by other factors where sufficient sample size existed. In addition, levels of code compliance for lighting and mechanical systems were independently determined and weighted as appropriate.
- **Sample Measure-level Analysis.** The evaluation contractor aggregated site level measure data across the sample while maintaining the ability to differentiate by sample stratification and other indices where sufficient sample existed. The sample values were weighted as appropriate and the resulting values were summarized and compared to the existing entries in the PSD.

1.3 Findings

The findings of this study are:

Compliance with energy efficiency code requirements for commercial and industrial new construction buildings permitted between 2010 and 2013 was estimated at 75% of the population when reasonable assumptions were used for missing data points and the sample was weighted by strata counts.

The average efficiency of equipment in the sample subject to PSD requirements was generally higher than the current code requirements and most often in the range of the requirements of the latest version of the most widely referenced commercial and industrial energy efficiency code (ASHRAE 90.1), specifically:

- Lighting – The energy use of for illumination was 30% below the upper limit set by code.
- Air conditioning – The average rated efficiency in all capacity bins exceeded the requirements of the PSD and were close to the requirements of ASHRAE 90.1-2013 (referenced as "ASHRAE 2013") for the majority of capacity bins.

- Air source heat pumps – The average efficiency exceeded code requirements.
- Water source heat pumps – The average efficiency exceeded current and ASHRAE 2013 requirements.
- Combustion heating equipment – The average efficiency of all types exceeded code requirements.
- Domestic hot water equipment – The average efficiency of all types exceeded current code requirements and was close to ASHRAE 2013 requirements.

1.4 Recommendations

The researchers offer the following recommendations as supported by the data and analysis:

- That utility program administrators should consider raising baselines for energy efficiency measures supported by the program based on their review of these findings and where appropriate;
- That there is substantial opportunity for light emitting diode (LED) lighting among the sample that we note are already supported by the programs;
- That there is substantial opportunity for automated lighting control measures among the sample that we note are already supported by the programs; and,
- That the application of instantaneous gas-fired boilers for dual purposes (domestic hot water and space heat) be examined and considered for inclusion in the PSD.

The researchers also offer suggestions for an anticipated 2017 study of building energy code compliance related to sample recruitment and data collection. These address the issues of:

- Identifying the population of newly constructed buildings by building a population dataset from multiple sources, potentially including direct outreach to jurisdictional code officials;
- Identifying qualified contacts at potential sample sites and increasing enrollment rate through additional outreach efforts coordinated with the utilities and modification of the incentive structure for sampled sites; and
- Acquisition of complete data either by incorporating site visits during several stages of construction or pre-screening to limit site visits to those where construction documents provide all necessary data points.

2 STUDY OBJECTIVES

The 2014 – 2016 Evaluation Plan (the Plan) proposed a study to investigate the commercial and industrial new construction practices. The Plan describes the study in the following terms:

"A study can be performed to gather data on baseline construction practices and test to see if they are lined up with the newly implemented 2012 building codes upon which PSD savings estimates are based. This effort would likely be on-site based and be comprehensive enough to assess the baseline assumptions contained in the PSD for most lost opportunity measures."

The Plan also identified the need for this study as follows:

"Industry experts have cited that the greatest source of uncertainty in our impact evaluations may be what we use for baseline. Differences between code and actual baseline practices can affect savings estimates as well as program cost effectiveness."

The baseline assumptions throughout the PSD for prescriptive measures are code-based. It presumes that since codes and standards effectively represents the lowest building practices permissible under the law, behavior will at least meet that level. Decades of research in the field of energy and countless others have proven that this is not always the case. This is challenging for all programs, but particularly for new construction where there are explicit code requirements. Research into the energy efficiency provisions has in the past shown that compliance is substantially less than perfect. Since energy efficiency programs assume and require code compliance, buildings that enter the program are more efficient than the market average even before additional efficiency measures are implemented. Thus, the true savings from these new construction programs may not be accurately estimated.

This study was primarily designed to reduce the uncertainty with regard to new construction baseline assumptions. The first step in this research was to inventory energy-using systems and equipment at a statistically selected sample of 45 commercial and industrial buildings permitted between 2010 and 2013 that were constructed and in operation. Data collection focused on measures in the PSD with the intent of increasing the accuracy of savings estimates generated by the utilities. These savings estimates are used for many purposes, the most important of which are to assist the utilities in documenting progress towards mandated savings goals and the related transfer of funds that support these efforts.

A secondary objective of this study was to produce an estimate of the level of compliance with energy components of the state building code in effect at the time of construction.[3] This objective was included in this study for the following reasons:

- The State of Connecticut is obligated to achieve a specified level of code compliance and to evaluate code compliance under the terms of an accepted federal grant.[4]
- The data collected to support the primary objective of this study constitutes a large part of the data required to establish code compliance at the building level.
- There are cost savings achieved through combining the efforts since a substantial portion of the costs of onsite investigation are incurred through drawing the sample, recruitment, and travel to the site. The

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[3] The sample included buildings subject to the 2006 and 2009 International Energy Conservation Codes.

[4] Certain funding received through the American Recovery and Reinvestment Act (ARRA) requires that states move towards and document compliance with specified energy code requirements at the rate of 90% or higher. USDOE provides methodological guidance for this effort.

incremental costs of adding an estimate of code compliance to a baseline study are orders of magnitude smaller than the costs of a standalone study.

To the extent possible without intrusive investigation methods, the evaluation contractor collected data to support analysis of code compliance at the building level by use of COMcheck™, the US Department of Energy compliance tool. Since many of the values required by COMcheck™ are not observable in finished construction without intrusive investigation, the researchers acquired and reviewed construction documents to supplement the onsite investigation.

3 METHODOLOGY

This section of the report reviews the methodology employed to achieve the study objectives discussed above. There are three high level activities undertaken that are discussed in turn. These are sample design and selection, data collection and analysis.

3.1 Sample Design and Selection

This study rested upon the performance of on-site data collection. As such, the development of a sample frame (population), sample design, sample selection and recruitment were critical initial tasks undertaken. We discuss each of these activities below.

Sample Frame/Population

Connecticut, like many other states, does not have a statewide record of new construction, despite the existence of a statewide building code. Compliance is determined and enforced at the local level (town or city). Records and access to records varies by jurisdiction, making the development of a ground up sample frame cost prohibitive. After consideration of alternative sources, DNV GL purchased a database of new construction activity from Dodge Data and Analytics (Dodge). This data set contained a total of 3,359 sites with building permits issued throughout the state from 2010-2013.

Square footage is a traditional baseline characterization stratification variable and is the key variable in the stratification approach used by the U.S. Department of Energy's Building Energy Codes Program (BECP) State Sample Generator.[5] BECP's stratification is consistent with the differentiation found in energy code requirements.[6] The strata are:

- Small – Up to 25,000 ft2
- Medium – Greater than 25,000 ft2 to 60,000 ft2
- Large - Greater than 60,000 ft2 to 250,000 ft2
- X-Large - Greater than 250,000 ft2 to 400,000 ft2
- XX – Large - Greater than 400,000 ft2

In the Dodge data acquired for this study, a total of 1,014 new construction sites, 722 (71%) had entries for the building area (ft^2). There was concern that limiting the sample to only those with the area field complete might unwittingly create bias in the final results if there was a disproportionate distribution of completed data sets across building types. To explore this, we examined the fraction of building types with and without square footage as captured in the Dodge database as well as the building types by strata (Table 1).

This table shows that the vast majority of sites without square footage also have an unknown building type (85% or 248 out of 292 sites shown as "Unk" in the table). This raised a concern that the sites missing building type data might be over-represented in one-size strata, thus potentially introducing sampling bias. The sites with unknown building types were included in the sample and thus mitigated this concern.

All building types are represented among the small, medium and large groups. In the two extra-large groups, lodging and offices are the two primary types. As one might expect, the most common newly constructed

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[5] https://energycode.pnl.gov/SampleGen/?state=Connecticut , confirmed 5/22/15

[6] U.S. Department of Energy Building Technologies Program, Measuring State Energy Code Compliance (Oak Ridge, TN, 2010). See sections 5.2.1.2 and 5.2.2.

building type is small buildings with building footprints up to 25,000 square feet. These smaller buildings represent nearly two thirds of all new construction activity among those with known square feet.

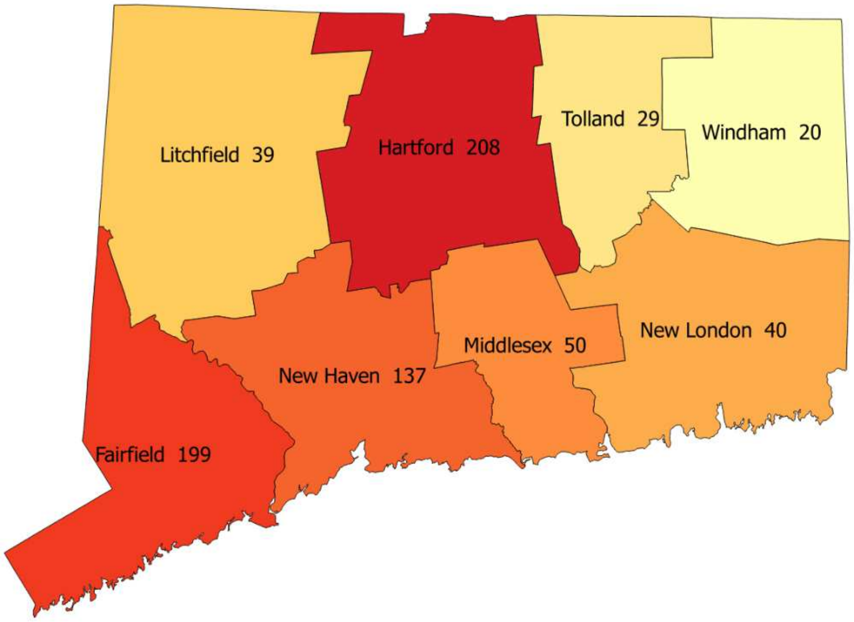
Table 1: 2010-2013 New Construction Population Stratified by Building Size and Types[7]

Square Feet	Size	Education	Food Service	Health Care	Lodging	Office	Public Assembly	Retail	C&I*	Unk	Total
Known	Small	33	75	25	43	65	67	99	60	7	474
	Medium	7	7	8	46	13	7	9	10	2	109
	Large	24	3	4	44	14	2	11	9	7	118
	X-Large	1	0	0	7	0	0	0	1	2	11
	XX-Large	0	0	1	3	3	0	0	1	2	10
	Subtotal	65	85	38	143	95	76	119	81	20	722
Unknown		12	2	1	9	4	5	7	4	248	292
Grand Total		77	87	39	152	99	81	126	85	268	1,014

*C&I includes Warehouse and Manufacturing

Figure 2 presents the new construction projects in the study population on a map of Connecticut by county. Over half of all statewide new construction activity between 2011 and 2013 occurred in the most populous counties, Hartford and Fairfield.

Figure 2: Map of 2010-2013 New Construction Activity by County



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[7] This summary table does not include 45 sites that were identified within the Connecticut Municipal Electric Energy Cooperative (CMEEC). Those municipalities removed are not in the UI or Eversource territories and include Groton, Norwich, Jewett City, South Norwalk, Norwalk, Bozrah, and Mohegan Tribe. These sites were excluded because the intent of this study was to inform baselines for participants in territories where utilities operate their programs, although we do not anticipate baseline practices to differ substantially between utility territories and CMEEC.

A sample (n) of 50 sites were targeted in the sample design to balance providing reasonable baseline and code compliance estimates and available funding for this study. This sample size is not sufficient to permit meaningful stratification by building type or county; however, it can provide meaningful results in aggregate. A stratified random sample design was used to develop targets within five strata.

Table 2: Target Sample Design

Strata	Population	Total Sq Ft	Max Sq Ft	Sample Size(n)
1	474	4,114,646	25,000	10
2	109	4,357,061	60,000	10
3	118	14,106,845	250,000	10
4	11	3,499,102	400,000	10
5	10	6,749,852	1,502,022	10
Total	722	32,827,506		50

This approach was intended to meet the requirements of the BECP sample design as well adhering to standard practice in baseline studies.

3.2 Recruiting

Once the sample design had been established, recruitment of the sample was performed. This section of the report discusses this process. The core recruitment activity was guided by a recruiting instrument and process that incorporated the following features:

- Full data on the population and the primary sample, including sample ranking and strata.
- A screening survey designed to confirm the accuracy of the sample data, identify the appropriate contact, establish the availability of construction documents, and determine the best times for a site visit.
- A means to update and log contacts made.
- A status report function that provided the distribution of recruitment activity among strata, building types, and locations.

Recruiting in accordance to the sample design was conducted by experienced evaluation staff between December 2014 and April 2015. An incentive of $250 was offered to encourage participation, either as a payment to the site representative or as a donation to a charity of their choice. Once a site had agreed to participate and confirmed the availability of construction documents, subsequent recruitment was performed to coordinate the visit and determine the means for construction document review.

The success rate for recruiting from all but the smallest strata was much lower than anticipated during study design. To improve recruitment success, email messages explaining the purpose of the study and soliciting engagement in it were sent when an address was available for the sample point. The success rate improved slightly after this process was added. However, as the samples in the larger strata neared exhaustion, the evaluation contractor attempted to achieve the design sample by three additional outreach efforts:

- A customized letter was sent to 36 targeted businesses that provided information about the study and contact information for participation or validation.
- Utility Outreach was coordinated by preparing a short list of targeted contacts for each utility for assistance in recruiting.

- The sample was opened up in the lower strata at the end of March to support the final sample size desired. We did choose to exclude sites identified by the Dodge data as "Education" or "Lodging" since these categories were already well represented at the time.

Through these efforts, the baseline study acquired the targeted sample quantity, if not the design stratification. We note, however, that 5 sites were not included in the analysis as they were determined to not be subject to commercial code due to their size. Table 3 below provides an overview of this effort. The figure of 1,445 calls made represents the vast majority of calling efforts; however, we note that not all call efforts were recorded as we began to mine contacts within each site.

Table 3: Final Sample Disposition

Strata	Population	# called	Total calls	Refused	Ineligible	Exhausted	Recruited*	Visited	Valid Ŧ
1	474	254	452	24	34	165	31	24	24
2	109	84	241	6	4	63	11	8	7
3	118	118	596	23	20	59	16	14	11
4	11	11	82	2	2	4	3	3	2
5	10	10	74	4	1	4	1	1	1
Total	722	488	1,445	59	61	295	62	50	45

Notes: * Sites recruited and passed to field staff were not always able to be scheduled.
Ŧ Five sites were excluded from the analysis that were not subject to commercial code energy efficiency requirements.

Sample Acquired

Section 3.2 on recruiting (above) describes the efforts undertaken to acquire the on-site sample, with some oversampling to allow for representative samples by building type and location. Despite these efforts, as is often the case in this type of research, the acquired sample varied from the design sample in size, building type and location distribution. This section compares the final sample acquired to the population. Overall, the sample is found to be representative of the population.

The primary stratification for code compliance per the BECP guidelines is size (square feet). Table 4 and

Table 5 compare the distribution of the sample to the distribution of the population on two indices, quantity and floor area. Overall, the sample captured 6% of the population by count and 10% by floor area. The distribution of the sample compared to the population in terms of size stratification was determined to be sufficient (given prior experience) to support the required analyses for this study.

Table 4: Sample by Counts

Strata	Number of sites		Percentages	
	Population	Sample	Population	Sample
1	474	24	66%	53%
2	109	7	15%	16%
3	118	11	16%	24%
4	11	2	2%	4%
5	10	1	1%	2%
Total	722	45	100%	6%

Table 5: Sample by Area

Square feet		Percentages	
Population	Sample	Population	Sample
4,114,646	220,053	13%	7%
4,357,061	367,700	13%	10%
14,106,845	1,679,184	43%	42%
3,499,102	964,250	11%	21%
6,749,852	650,000	21%	20%
32,827,506	3,881,187	Overall	10%

Building type and geographic distribution were not key considerations in the design of the sample. However, as shown in Table 6 and Table 7 below, the sample is generally representative of the population on these factors.

Table 6: Distribution by County

County	Population(N=722)	Sample(n=45)
Fairfield	27.6%	40.0%
Hartford	28.8%	16.0%
Litchfield	5.4%	8.0%
Middlesex	6.9%	14.0%
New Haven	19.0%	16.0%
New London	5.5%	2.0%
Tolland	4.0%	2.0%
Windham	2.8%	2.0%

Table 7: Distribution by Building Type*

Building Type	Population(N=722)	Sample(n=45)
Education	9.0%	20.0%
Food Service	11.8%	2.2%
Health Care	5.3%	2.2%
Lodging	19.8%	17.8%
Office	13.2%	17.8%
Public Assembly	10.5%	17.8%
Retail	16.5%	11.1%
C&I	11.2%	11.1%

Note: 2.6% of the Population is "unknown" and not shown.

Since all of Connecticut is in the same climate zone and the distribution of the sample is not largely disproportionate to the distribution of the population, the results of the study should accurately represent the State on this dimension. With regard to building type, the two types that are significantly under represented are food service and health care. These two categories have typically have specialized energy consuming equipment that is not subject to code requirements and in many cases outside the purview of the PSD. For these reasons, we consider the study to be largely representative across the three indices of size, location, and building type.

We do note that we were only able to acquire sample in the two largest strata from the multi-family building type. Of those building types identified in the population for those two strata, 59% were multi-family. So while we do not have other buildings types represented in these strata, the sample does provide valuable information on the majority of C&I new construction in Connecticut during the study timeframe.

<u>Weighting</u>

Samples are designed to match the characteristics of the population from which they are drawn. In the best case, they are representative with respect to all variables measured in the survey. Unfortunately, this is rarely the case. Weighting is a methodology of adjusting the sample values found during research to more appropriately represent the population based on variables known for both the population and the sample.

The population and the source for the sample were based on Dodge data, as previously described. Recruiting and data collection found inconsistencies in the key variables of size and building type. Inconsistencies between efficiency program data and survey participant self-reports excluded program participation as an adjusting variable. After thorough analysis, the only variables consistent across both the population and the sample were site count and floor area in the Dodge data. The comparison of these variables between the population as captured in the Dodge data and the sample is shown in Table 8 below.

Table 8: Population / Sample Comparison

Stratum	Population		Sample			Sample Portion of Population		
	N	Area – Dodge	n	Area -Dodge	Area - Measured	Count	Area - Dodge	Area - Measured
1	474	4,114,646	24	220,053	244,930	5.1%	5.3%	7.1%
2	109	4,357,061	7	334,700	333,078	6.4%	7.7%	9.6%
3	118	14,106,845	11	1,343,600	1,570,557	9.3%	9.5%	45.3%
4	11	3,499,102	2	667,250	668,000	18.2%	19.1%	19.3%
5	10	6,749,852	1	650,000	650,000	10.0%	9.6%	18.8%
Total	722	32,827,506	45	3,215,603	3,466,565	6.2%	9.8%	NA

Since the sample and the population were stratified, it was necessary to develop weights for the individual strata to determine the overall code compliance. Weighting stratum compliance rates by either counts or floor area as reported by Dodge are both methodologically valid. The stratum weights by site counts and by Dodge floor area are also shown in below for comparison purposes.

Table 9: Stratum Weighting Factors

Stratum	# Sites	Area
1	0.657	0.125
2	0.151	0.133
3	0.163	0.430
4	0.015	0.107
5	0.014	0.206

3.3 Data Collection

Data was collected through a series of stages for each sampled site. First, the field engineer administered a brief on-site survey with the site contact. Then they collected data on the building systems through a walk-through inventory and non-intrusive testing methods.[8] The last stage of the on-site included a review of the construction documents to verify observed data and to acquire data not observable in finished construction. Upon completion, all gathered data for each site was entered in a comprehensive database, which is discussed later in this report. Figure 3 presents an overview of this process.

Figure 3: Data Collection Overview

On-Site Survey	Walk-Through Inventory	Document Review	Data Entry
• Meet site contact • Explain process • Survey questions	• Identify and estimate spaces • Inventory wall and fenestration systems • Inventory lighting by space • Inventory mechanical equipment • Record	• Confirm floor area and volumes • Identify wall and fenestration performance characteristics • Review equipment schedules	• Complete data entry form for each building investigated • Determine gaps • Look up performance characteristics where only model number present • Enter default values if none other available

3.3.1 Site Survey

Site visits typically began with a conversation with the site contact to collect key information about the site and to establish the protocols to be followed during the site investigation. Field engineers collected the following information prior to the walk-through:

- Type of facility
- Building area types
- Approximate building square footage and building footprint
- Number of floors and conditioned floors
- Number and type of heating and cooling systems, hot water systems, and controls
- Recent participation in energy efficiency programs through the utility provider
- Recent and upcoming energy efficiency upgrades being considered
- Current energy efficiency goals and goals during construction, such as LEED certification

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[8] Equipment included hand-held electronic devices to test for low-e coatings in glazing and electronic ballasts in lighting.

- Electric and gas utility provider
- Means of access to construction documents, if not already determined.

During this initial conversation, the field engineer also arranged time to review the construction documents (if they were only available on site) and arranged an exit conversation. The exit conversation was an opportunity for the field engineer to fill any gaps in the data collected, complete the forms necessary for incentive payment, and to answer any final questions the site contact might have.

3.3.2 Walk Through Inventory[9]

Following the survey, the site contact typically escorted the field engineer to mechanical rooms and other limited access areas. After the systems in these spaces were inventoried, the field engineer was usually permitted to conduct the rest of the inventory unescorted. Every effort was made throughout the process to minimize the disruption to the facility and the inconvenience to the site contact.

Mechanical equipment, including HVAC, hot water, and auxiliary motor information was typically collected first in the presence of the site contact. The field engineer photographed and recorded the quantity and nameplate information for each piece of equipment. The nameplate information collected included size, efficiency, input capacity, and make and model number. The field engineer queried the site contact to supplement the data collected with information on the function and/or areas served by each piece of mechanical equipment.

Lighting information collected during the site visit included fixture and lamp counts, types, wattages, and controls. Ballast makes and model numbers were not collected, but a lighting ballast detector[10] was used to verify whether the ballast was electronic or magnetic. The lighting information was divided up by space type. Spaces were divided into interior and exterior spaces, conditioned and unconditioned spaces, and by each space's function.

Many building envelope and fenestration details are not observable in finished construction. Field staff recorded all of the information they could observe, including:

- Presence or absence of vestibule on entrance doors
- Presence or absence of thermal breaks, the number of glass panes on doors and windows
- Presence or absence of low-E coatings based on a representative sample of glass doors and windows using a low-e coating detector.[11]
- Visual inspection to determine thickness, material, and type of envelope systems.

In the case of larger facilities with multiple buildings, a representative sample of the facility's lighting and mechanical equipment was collected and extrapolated out by space type to represent the entire facility. This extrapolation was confirmed and/or refined through the document review process. Table 10 provides a summary of the data collected by system type.

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[9] Screen shots of the data collection instrument are attached as Appendix A.
[10] Sensor Switch BD1 Ballast Discriminator
[11] EDTM ETEKT+ Low E Coating Detector (Model #AE1601)

Table 10: Data Collection Overview

Category	Inputs	Data Collection Method
Building Type	Category	Dodge data, field observation
Building Size	Square feet floor area, floor height & count	Field observation, document review, Google Earth mapping
Wall Assemblies	Types, R-value	Field observation of external characteristic, document review, engineering estimate
Fenestration	Count, location, size, U-value, solar heat gain coefficient, transmittance	Field observation, document review, extrapolation
Lighting	Counts, types, type of ballast, location	Field observation, document review,
HVAC	Type, input/output capacity, efficiency, count	Field observation of manufacturer's nameplate, supplemental research, document review
Domestic hot water	Type, input/output capacity, efficiency, count	Field observation of manufacturer's nameplate, supplemental research, document review

3.3.3 Construction Document Review

This study relied on extensive review of construction documents to obtain data that was not directly observable in finished construction without intrusive investigation. Construction documents were also used as a quality control method to verify site-collected data. The objectives of the review were to:

- Establish inputs unavailable from site observation. As noted above, a significant portion of building envelope inputs were acquired from construction documents. In addition to fenestration details, wall assembly details such as enclosed materials and insulation type and quantity were gathered mostly from thorough review of construction documents and architectural drawings. Despite this effort, evaluators were only able to confirm fenestration performance characteristics for 16 out of 50 sites.
- Confirm or supplement the field engineer's estimates of space types and sizes.
- Validate through review of equipment schedules the types and quantity of equipment observed on site including lighting, HVAC, domestic hot water, and economizers.

3.3.4 Collected Data Summary

3.3.4.1 Physical data

While a majority of data could be gathered through either the construction documents or on-site visit, certain pieces of information were not always available through either means. Fenestration performance characteristic, such as U-Factors, solar heat gain coefficients, and visible light transmittance values were rarely obtainable. This study addressed these data gaps through various means described in the analysis section below. The energy performance characteristics of fenestration elements were only specified in construction documents for 7out of 45 sites visited (16%) and directly observed in only one, where the manufacturer's peel-off labels were still available. The research team was able to acquire the complete data set necessary for analysis of code compliance for only 1 out of 45 sites without using engineering assumptions. Each row in Table 11 below summarizes the data sources for the code compliance analysis by key systems for all 45 sites in our final sample.

Table 11: Data Completeness

Building Component	Not applicable or not acquired	Construction documents	Direct observation	Engineering assumption
Below grade wall	33	10	0	2
Floor	0	38	0	7
Exterior wall	0	39	0	6
Roof	0	39	0	6
Fenestration	0	7	1	37
Cooling system	2	6	33	4
Heating system	0	3	37	5
Lighting interior	0	19	22	4
Lighting exterior	1	23	17	4
Hot water heater	6	5	30	4

Additional detail of data completeness at the site level is provided in Appendix B.

3.3.4.2 Efficiency Program Participation Data

Determination of baseline energy efficiency, whether at the measure or site level, requires consideration of energy efficiency program impacts. Definition of "baseline" for the new construction market is not as simple as excluding some or all of the buildings that have participated in a new construction efficiency program or some other efficiency program. Ralph Prahl, an international authority in the field, in reviewing the work plan for another project commented "To simply exclude buildings that participated for a particular end-use as part of the baseline would lead to an understatement of the efficiency of baseline practices in the market, as the existence of free riding means that some participating measures are part of the baseline. To simply include such participants would lead to an overstatement of the efficiency of baseline practices, as some of the participating measures were program-induced." For this reason, the research team expended significant effort to identify energy efficiency program participation.

Utility program participation data was acquired prior to the initiation of the site visit recruiting phase. During the initial recruitment effort, potential participants were asked two questions regarding program participation:

- "SA9. During the construction or renovation of this building did your organization participate in any energy efficiency program and receive a financial incentive from your gas or electricity provider for these improvements? "
- "SA9b. (IF SA9 = NO) Has your organization participated in any energy efficiency programs available through the electric or gas utilities in the past?"

Onsite, the field investigator asked the site contact "Have you recently participated in any energy efficiency program through your utility provider?" and followed up with prompts and additional question to determine the time frame of participation as appropriate.

Extensive analysis of this data, including comparison to the Dodge data, public data sources, and cross-checks to other Connecticut program data available to the evaluation team discovered:

- Inconsistencies between the various data sources with regard to program participation, in particular participant self-report and the program data;
- Inconsistencies between identifying factors (*e.g.,* address)
- Inconsistencies between time factors (*e.g.,* dates of installation/construction)

From this analysis, the research team drew the conclusion that it was unable to definitively define participation status. In light of this conclusion, the research team with the support of the evaluation consultant determined to use the response from the on-site contact as the marker for program participation and to present the data at the measure level aggregated across the sample and differentiated by this program participation marker.

3.4 Analysis

Two levels of analysis were necessary to meet the objectives of this study. One was to estimate the level of compliance with Connecticut's commercial building energy code and the second to inform inputs for measures in the PSD. The study design specified that code compliance would be determined through USDOE's COMcheck tool and that site level compliance would be aggregated to estimate the level of compliance in the population. COMcheck's data requirements are extensive and data entry into this tool served as a quality control step. Through an iterative process of data entry, analysis, and data revision evaluators developed comprehensive and reliable data sets for each site in the sample. The following sections detail the processes used for COMcheck analysis and the measure level analysis.

3.4.1 COMcheck analysis

COMcheck compares input values for all systems to the requirements of a code specified by the user. The requirements in effect at the time of construction in Connecticut were equivalent to the International Energy Conservation Code (IECC), either 2006 (13 sites) or 2009 (37 sites) version dependent on date of permit filing. The analysis was performed using COMcheck version 4.0.0.2. Each system requires sufficient input to permit calculation of energy load (*e.g.,* lighting power density) or comparison to the applicable efficiency standard (*e.g.,* 78% AFUE for a warm air gas-fired furnace with rated input capacity of less than 225,000 Btu/hour).

COMcheck analysis requires inputs for the following main categories;

- Building characteristics such as interior and exterior size and use
- Envelope characteristics include roof, skylight, exterior wall, window, door, basement, and floor
- Interior lighting by space including fixture type, wattage per lamp, lamps per fixture, ballast type, and number of fixtures
- Exterior lighting by the same factors as interior lighting
- Mechanical systems including HVAC, water heating, and fan systems

COMcheck incorporates minimum required values, such as the 78% AFUE noted above, and will not permit input of systems that do not meet these minimums or analysis of buildings without inputs in these fields. In some cases the evaluators were not able to conclusively determine the required input values. Fenestration was the most common example of this. Windows were not typically marked with performance characteristics such as U-value, solar heat gain coefficient or model number on a visible surface. Construction documents often did not include window schedules and follow up contacts were unable to obtain them. For values such as these, the analysts either input the default value as provided by COMcheck, used an extrapolated value based on observed data, or used best engineering judgment to determine the appropriate value. Data inputs were extrapolated by a variety of methods. These included:

- Averaging of discovered values, weighted or unweighted as appropriate;
- Minimum code values or default COMcheck inputs;
- Secondary research into normal market practice; and,
- Adoption of values from comparable sites.

An apartment complex in the on-site sample made up of six apartment buildings and a leasing office offers a prime example of the application of the last approach. There were four sites in the acquired sample operated by the same management company. After completing the fourth site visit the management company decided not to provide the construction documents for this last site. It had already provided documents for the three other sites and all site visits were completed. One of the other three sites with construction documents and site visit had observable characteristics, such as design, color scheme, layout, construction practices, mechanical equipment choices similar or identical to those of the last site and follow-up conversations with site personnel confirmed that these two sites were substantially identical in most regards in terms of construction practices and materials.

As shown in Table 11 above, the researchers were not able to determine the thermal characteristics of windows at 37 sites, floors at 7 sites, roofs and exterior wall at 6 sites each, and below grade walls at 2 sites. For these sites, the average values weighted by floor area of the acquired inputs were used for the analysis of code compliance. The weighted average R-value derived from construction documents from 11 sites was 13.4 for below grade walls. Average values for the other assemblies are presented in Table 12 through Table 15.

Table 12: Window Extrapolated Inputs

Window Type	Average Assembly U-value (weighted by area) or SHGC
Wood Frame and Other	0.314
Vinyl Frame	0.300
Metal Frame	0.328
Metal Frame Curtain Wall Store Front	0.328
Solar Heat Gain Coefficient (ASHRAE 90.1)	0.440

Table 13: Floor Extrapolated Inputs

Floor Type	Average Assembly R-Value (weighted by area)
Slab-on-grade Heated	9.38
Slab-on-grade Unheated	9.94
Wood-Framed	30.00
Mass	20.00
Steel-Joist	30.00

Table 14: Roof Extrapolated Inputs

Roof Type	Average Assembly R-value (weighted by area)
Attic with Wood Joists	38.11
Metal Building Standing Seam	25.16
Insulation Entirely Above Deck	23.15

Table 15: Exterior Wall Extrapolated Inputs

Exterior Wall Type	Average Assembly R-value (weighted by area)
Wood-Framed and Other	19.98
Metal Building	22.19
Mass	11.98
Steel-Framed	20.00
Rigid Insulation R-value/inch	5.00

Overall, the average thermal values for these envelope components exceed the code requirements. These findings are not incorporated in the measure-level findings due to the small sample sizes and the fact that these values are not incorporated in PSD measures at this time.

3.4.2 Measure Level Analysis

Measure level analysis was limited to baselines for measures incorporated in the PSD. These energy performance baselines are summarized in Table 16.

Table 16: PSD Measures and their efficiency parameter

Measure	PSD Efficiency Parameter
Standard lighting by building type	Lighting Power Density
Chillers	EER or kW/ton
Unitary Air Conditioning and Heat Pumps	SEER/EER & HSPF
Water and Ground Source Heat pumps	EER & COP
Gas Boiler and Furnaces	AFUE/Thermal Efficiency
Gas Domestic Hot water heaters	EF/Thermal Efficiency

All of the data from each site was consolidated into one master file. Averages for key baseline related parameters for each measure type and category within each measure specified by the PSD (*e.g.,* cooling capacity bin for air conditioning equipment) were developed for the entire sample. The averages were derived using a weight by the floor area served by the sample point or a proxy such as percent of install capacity (*e.g.,* tons cooling, kW load). Weighted averages were also developed to differentiate the installed efficiency of equipment at program participant sites from that at non-participant sites. Salient points of the analysis for specific end-use measure categories are presented below:

- Standard lighting and controls - Efficiency requirements for lighting are expressed as lighting power density (LPD). This is equivalent to the number of Watts per square foot used to illuminate an area. The PSD differentiates by building type, as does the energy code. This study followed suit. The LPD for a specific building type was calculated by dividing the sum total of the power requirements of the installed lighting by the sum total of the area served. The data collection methodology provided additional detail on lamp technology and controls which is also presented in the Findings Section.
- Air conditioning -Cooling system data was acquired for 43 out of 50 sites. The researchers were unable to acquire cooling equipment specifications for five (5) sites and two (2) sites had no cooling equipment. The efficiency of air conditioning equipment is reported as one of three dimensionless units, seasonal energy efficiency ratio (SEER), energy efficiency ratio (EER) or integrated energy efficiency ratio (IEER) dependent on equipment category.
- For chillers, the PSD provides two paths for determining efficiency requirements. Path A is specified for process cooling and for applications where significant operating time is expected at full load. Path B is specified for "Chillers that provide comfort cooling" and for "applications where significant operating time is expected at part load". The vast majority of chiller capacity found in this study was for comfort cooling. Therefore, Path B parameters were used consistently for analysis in this study.
- Heat pumps - The PSD and the recent ASHRAE 90.1 standards differentiate the following types of heat pumps and specify capacity categories within them:
  - Air-source heat pumps -The heat pump absorbs heat from the outside air and transfers the heat to the space to be heated in the heating mode. In the cooling mode, the heat pump absorbs heat from the space to be cooled and rejects the heat to the outside air.

  - Water source heat pumps -A water source heat pump operates much like a traditional air source heat pump except that it extracts and dissipates heat through the use of water (surface water). (PSD describes a closed loop within a building, served by boiler and cooling tower)
  - Ground water heat pumps -A type of heat pump that uses a well (ground water) as heat source, as the geothermal water has more stable seasonal temperature than air making for a more efficient heat source. (PSD notes that the water used by the heat pump is in contact with the ground.)
  - Ground loop heat pumps –A type of heat pump that uses a water loop laid underground and the circulating water exchanges heat with ground water. (PSD states that this type of heat pump is defined by the fact that the water used by the heat pump is isolated from contact with the ground.)

The data collected on heat pumps inventoried during the research was separated to PSD specifications and compared to the appropriate efficiency requirements.

- Combustion heating equipment - The data collected on furnaces and boilers was sorted into the categories as defined in the PSD and compared to the baseline appropriate categories.
- Domestic hot water equipment – The analysis of the baseline efficiency of domestic hot water equipment faced two complicating factors. These factors and the approach taken are summarized as follows:
  - The building inventory found that instantaneous hot water heaters were being used to provide primary space heat in 943 out of 947 applications (99.6%). Since this equipment is marketed, labelled, and rated as DHW equipment, the researcher determined to present it in this category.
  - The PSD and ASHRAE 2013 requirements for higher capacity storage water heaters require a factor for stand-by losses in the estimation of efficiency rather than providing a single dimensionless efficiency rating as is the case for smaller equipment. Researchers were not able to obtain stand-by losses for any of the units in the sample from the equipment labels, research on manufacturers' website, or other sources. However, for a sample of these units manufacturer specifications verified conformance with the standby loss requirements of the U. S. Department of Energy and current edition of ASHRAE/IESNA 90.1. Based on this assurance, for the 16 gas storage water heaters with input capacities greater than 75 kBtu per hour and with a volume of over 20 gallons the average efficiency was estimated at 95%.

The research discovered a few examples of other end-use equipment types addressed in the PSD, but the sample size (one unit for most) was too small to serve as a basis for any finding or recommendation.

4 FINDINGS & RECOMMENDATIONS

4.1 Code compliance

The USDOE identifies 13 compliance paths for C&I buildings under ASHRAE Standard 90.1-2007.[12] These paths may include meeting prescriptive or mandatory requirements, trade-offs where greater efficiency in one component compensates for lower efficiency in another, and modelling or performance approaches where an overall energy usage threshold is not exceeded. A final path is through use of an approved analysis package, which includes COMcheck. COMcheck is the path chosen for this study and analyzes compliance for major systems on a pass/fail basis and for some systems calculates the difference between the system energy use and the maximum allowed by code. It does not permit trade-offs between systems,

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[12] U.S. Department of Energy, Energy Efficiency and Renewable Energy, Building Technologies Program. *Choosing an Energy Code Compliance Path TOPIC BRIEF.* April 2012, PNNL-89866, Table 4.

so in order to achieve compliance each analyzed system must meet code requirements. Due to the lack of trade-offs, this approach is likely to understate actual code compliance.

Table 17 below shows the compliance rates for the five major energy using systems. There are two columns for the envelope noted as "no EA" and "w/ EA." The values in these columns are driven by the presence or absence of fenestration input. The column "no EA" shows the percent of building in the stratum that met code requirements when the COMcheck default values were used in the absence of site-specific data. The column "w/ EA" shows the percentage that passed when values for missing data based on engineering assumptions were input to the tool. The "Total" column represents the portion of buildings within each stratum that passed COMcheck including those where engineering assumptions were used in the place of missing values.

Table 17: Strata Code Compliance

Strata	n	Envelope no EA	Envelope w/ EA	Lighting	DHW	Cooling	Heating	Total
1	24	54%	92%	96%	83%	100%	100%	79%
2	7	57%	100%	86%	86%	86%	100%	71%
3	11	27%	100%	100%	82%	91%	91%	64%
4	2	0%	100%	50%	100%	100%	100%	50%
5	1	0%	100%	100%	100%	100%	100%	100%

The stratum level code compliance were aggregated up to produce an estimate of state wide code compliance with stratum weights by count, and by floor area. Table 18 below shows an estimate of the compliance by major systems and overall.

Table 18: Estimate of State-wide Code Compliance

	Envelope no EA	Envelope w/ EA	Lighting	DHW	Cooling	Heating	Total
Unweighted	44%	96%	93%	84%	96%	98%	73%
Weighted by Count	49%	95%	94%	84%	96%	99%	75%
Weighted by Area	26%	99%	92%	88%	94%	96%	73%

A recent code compliance study in Massachusetts investigated a sample of building completed in the 2009 to 2011 time frame. The sample size, data collection methodology and the analysis methodology were significantly different in Massachusetts. The data collection included an extensive series of interviews with code compliance officials, architects and engineers, and other market actors preceded by a marketing effort to promote participation. It was directly supported by the program administrators. The sample size was large enough to permit exclusion of sites without complete data sets from the analysis. Finally, the analysis included other factors, such as presence of required documentation, and used a propriety Excel-based tool to calculate compliance levels. Nonetheless, the findings in Massachusetts provide some context for the findings of this study. Levels of compliance for selected systems found by the study were as follows:

- Envelope – 81%
- HVAC systems – 79%
- Lighting – 74%
- Overall – 80%

Many factors in addition to the research design differences are likely to account for the variation between studies, but overall the comparison to Massachusetts validates this study's results.

4.2 Measure baselines

This section presents the measure or equipment specific findings of the research with regard to the baseline efficiency of installed equipment. Within each equipment category, the findings are first presented in a format comparable to the presentation within in the PSD. The findings are presented for the entire sample and disaggregated by participation in any energy efficiency program, based on self-reports during the onsite survey. In addition to this basic presentation of findings, when the data set is sufficiently populated additional analyses are presented for some measures. The findings tables also include the values in the PSD (shown in the figures and tables as "PSD") which are typically equivalent to the recommendations of ASHRAE 90.1 2007 and recommendations incorporated in ASHRAE 90.1 2013 ("ASHRAE 2013") are also presented to provide an additional more recent comparison.

Overall, the research discovered that the level of efficiency for equipment installed at new C&I sites in Connecticut during the study horizon was more efficient than the minimum requirements set by the code in affect at the time of construction. The magnitude of this difference varies by equipment and within equipment categories. For some measures, the sample size was too small to support a finding that the difference was statistically significant. However, for all measures where there was sufficient sample size, this research clearly supports the conclusion that use of the current code as an assumption of market baseline overstates the actual savings by an amount that would be measurable with additional, targeted research.[13] From the perspective of program design, this finding is sufficient grounds for adjusting the baseline efficiency upwards, reducing incentive payments for lower efficiency equipment, or adopting higher efficiency thresholds for eligible equipment. As appropriate, recommendations are offered after the findings for consideration by program administrators.

4.2.1 Lighting

The LPD installed in new C&I buildings in the sample was substantially lower than that required by the relevant code and the baseline specified in the PSD, as shown in Table 19 below.[14]

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[13] To use a net-to-gross factor developed within the framework of the prior code baseline with an update to market baseline would likely double discount (erroneously reduce) the net savings estimate.

[14] The study confirmed that magnetic ballasts were not present, as was expected in light of the standards and standard practice during the construction period.

Table 19: LPD by Building Type

Building Type (N=50)	n	PSD	Avg Site LPD	Compared to PSD	ASHRAE 2013	Compared to ASHRAE 2013
Automotive Facility	1	0.9	1.0	6%	0.8	19%
Dining: Bar Lounge/Leisure	1	1.3	0.7	-43%	1.01	-27%
Dormitory	2	1	0.5	-52%	0.57	-15%
Gymnasium	2	1.1	0.9	-17%	0.94	-3%
Healthcare-Clinic	1	0.7	0.2	-66%	0.9	-74%
Hotel	1	1	0.1	-86%	0.87	-84%
Manufacturing Facility'	2	1.3	0.9	-30%	1.17	-22%
Multifamily	6	0.7	0.6	-9%	0.51	26%
Office	8	1	0.7	-32%	0.82	-17%
Parking Garage	1	0.3	0.2	-47%	0.21	-24%
Religious Building	2	1.3	0.8	-36%	1	-17%
Retail	6	1.5	0.5	-70%	1.26	-64%
School/University	6	1.2	0.5	-54%	0.87	-37%
Sports Arena	2	1.1	0.9	-17%	0.91	0%
Transportation	1	1	0.9	-14%	0.7	23%
Warehouse	3	0.8	0.6	-25%	0.66	-9%

Note: For comparison columns the percentage represents the usage above (positive) or below (negative) respective code requirements.

The building level breakout shows that within the sample most buildings are more efficient than the baselines incorporated in the PSD. But, given our uncertainty around the distribution of building types in the population (since observed building types are not consistent with those recorded in the Dodge data), and without larger sample sizes in some if not all of the building types, we aggregated sites by LPD bins according to the PSD to provide a sense of the magnitude of the difference in LPD between the PSD baseline assumption and the observations from this study. From this perspective, the total installed demand can be compared to the total permitted demand for the equivalent floor area, as shown in Table 20. Examining the difference at this level offers a more reliable representation of overall difference, which is 30% less (energy use) than what the PSD would have allowed.

Table 20: LPD by PSD Bin

PSD LPD	#	Observed Watts	Observed Area (s.f.)	Observed LPD	Allowed Watts	% Difference
0.3	1	1,152	7,200	0.2	2,160	-47%
0.7	7	1,346,259	2,118,212	0.6	1,482,748	-9%
0.8	3	34,706	76,980	0.6	61,584	-44%
0.9	1	47,748	50,000	1.0	45,000	6%
1	12	127,594	211,938	0.6	211,938	-40%
1.1	4	72,650	82,738	0.9	91,012	-20%
1.2	6	251,215	406,473	0.5	487,768	-48%
1.3	5	197,822	231,896	0.8	301,464	-34%
1.5	6	104,805	281,129	0.5	421,693	-75%
Total	45	2,183,951	3,466,565	N/A	3,105,367	-30%

Note: For comparison columns the percentage represents the usage above (positive) or below (negative) PSD requirements.

The penetration of LED technology in the market arose as a topic of interest amongst evaluators during the data collection phase of this research. Since this technology is expected to be an important near-term driver of energy use, the data collection instrument was designed to capture this information. In aggregate, LED technology accounted for lighting of 5.8% of the total area surveyed, incandescent (including halogen and related technologies) accounted for 10.0% and fluorescent lit 84.3%. Table 21 shows the share of each of three types of technology by building type for interior areas, where LED lighting accounts for 2.9% of all floor area.

Table 21: Interior Lamp Technology by Building Type for New C&I Buildings in 2010-2013

Building Type	n	Lamp Technology (% of area)		
		Fluorescent	Incandescent & Halogen	LED
Automotive	1	100.00%	0.00%	0.00%
Dining: Bar Lounge/Leisure	1	96.05%	0.00%	3.95%
Dormitory	2	90.40%	0.00%	9.60%
Gymnasium	2	98.81%	0.00%	1.19%
Healthcare-Clinic	1	100.00%	0.00%	0.00%
Hotel	1	27.58%	72.42%	0.00%
Manufacturing Facility'	2	100.00%	0.00%	0.00%
Multifamily	6	72.92%	27.08%	0.00%
Office	8	65.38%	2.22%	32.40%
Parking Garage	1	100.00%	0.00%	0.00%
Religious Building	2	79.86%	1.26%	18.88%
Retail	6	99.94%	0.00%	0.06%
School/University	6	92.50%	0.00%	7.50%
Sports Arena	2	49.12%	0.00%	50.88%
Transportation	1	95.93%	0.00%	4.07%
Warehouse	3	100.00%	0.00%	0.00%
Total	45	84.52%	12.59%	2.89%

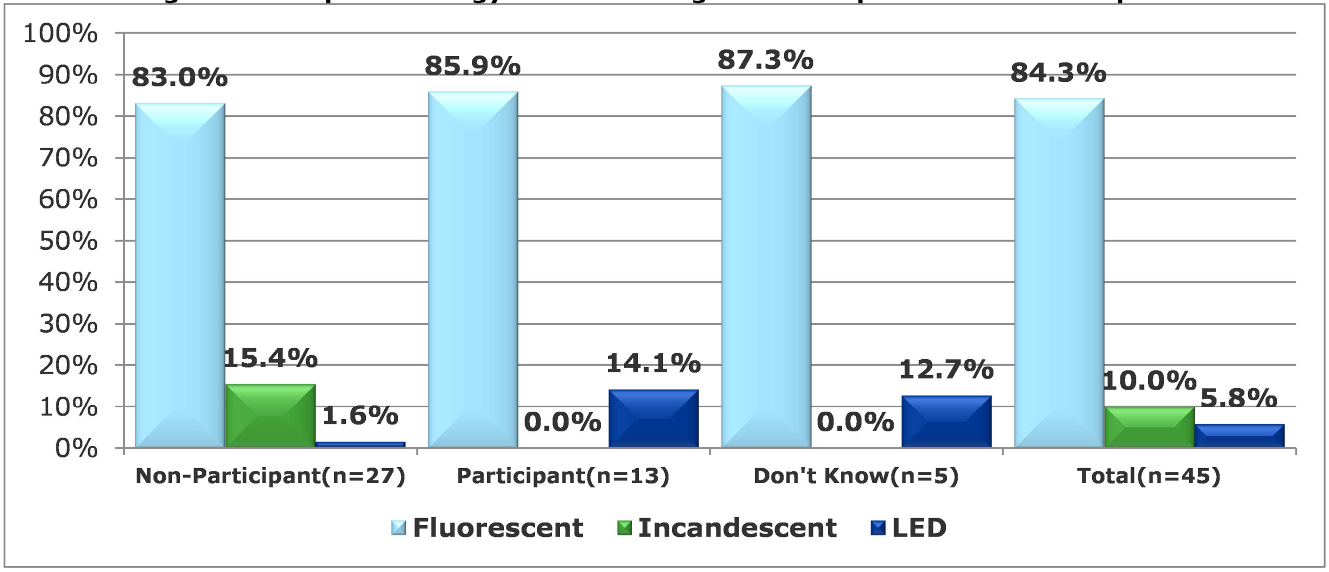
LEDs have a greater penetration in exterior use, illuminating 16.7% of all space in the sample. Their durability, length of service, and quality of light in the earlier versions are particularly well suited to these applications and may explain the faster uptake.

Table 22: Exterior Lamp Technology by Building Type for New C&I Buildings in 2010-2013

Building Type	n	Lamp Technology (% of area)		
		Fluorescent	Incandescent & Halogen	LED
Automotive	1	100.00%	0.00%	0.00%
Dining: Bar Lounge/Leisure	1	0.00%	48.00%	52.00%
Gymnasium	2	0.84%	0.00%	99.16%
Healthcare-Clinic	1	100.00%	0.00%	0.00%
Hotel	1	0.00%	100.00%	0.00%
Manufacturing Facility'	2	91.30%	0.00%	8.70%
Multifamily	2	80.99%	19.01%	0.00%
Office	7	41.86%	0.01%	58.12%
Parking Garage	1	100.00%	0.00%	0.00%
Religious Building	2	98.10%	0.00%	1.90%
Retail	5	100.00%	0.00%	0.00%
School/University	2	3.86%	0.00%	96.14%
Sports Arena	1	100.00%	0.00%	0.00%
Warehouse	2	0.00%	0.00%	100.00%
Total	30	83.04%	0.22%	16.74%

The research also found a strong correlation between program participation and increased LED penetration, as shown in aggregate below.

Figure 4: Lamp Technology Share for Program Participants v Non-Participants



The technology distribution at the sites of the 11% of respondents who did not know whether their company had participated in any energy efficiency program closely parallels the participant population. Since research has consistently shown that after a few years the institutional memory of program participation fades, it is likely that a portion of this population was affected by program efforts. The distribution of technology by interior and exterior space and by participation is shown in Table 23 and Table 24 below.

Table 23: Interior Lamp Technology Share for Program Participants versus Non-Participants (2010-2013 new buildings)

Participation Category	N	Lamp Technology (% of area)		
		Fluorescent	Incandescent & Halogen	LED
Non-Participant	27	78.66%	20.99%	0.35%
Participant	13	91.42%	0.00%	8.58%
Don't Know	5	95.73%	0.00%	4.27%
Total	45	84.58%	12.53%	2.90%

Table 24: Exterior Lamp Technology Share for Program Participants versus Non-Participants (2010-2013 new buildings)

Participation Category	N	Lamp Technology (% of area)		
		Fluorescent	Incandescent & Halogen	LED
Non-Participant	20	94.85%	0.26%	4.89%
Participant	5	22.58%	0.00%	77.42%
Don't Know	5	5.19%	0.00%	94.81%
Total	30	83.04%	0.22%	16.74%

Considering that the design and equipment specification phases for the projects surveyed probably ranged from 2009 to 2013 for the majority of the sites and that the price for LED technology is substantially lower than what it was a few years ago, it is probable that the current penetration in new construction and retrofit markets is much higher than discovered during this project. This measurement may serve as an early market measurement and indicator of program influence on LED acceptance.

Some form of automated lighting control system was in place for 23% of the total installed lighting capacity. These controls included occupancy and motion sensors, time clock, Energy Management Systems (EMS) and day-lighting control systems while 7% of the installed wattage was in continuous operation and 4% was controlled by manually operated dimmers. The control categories by building type are shown in Table 25.

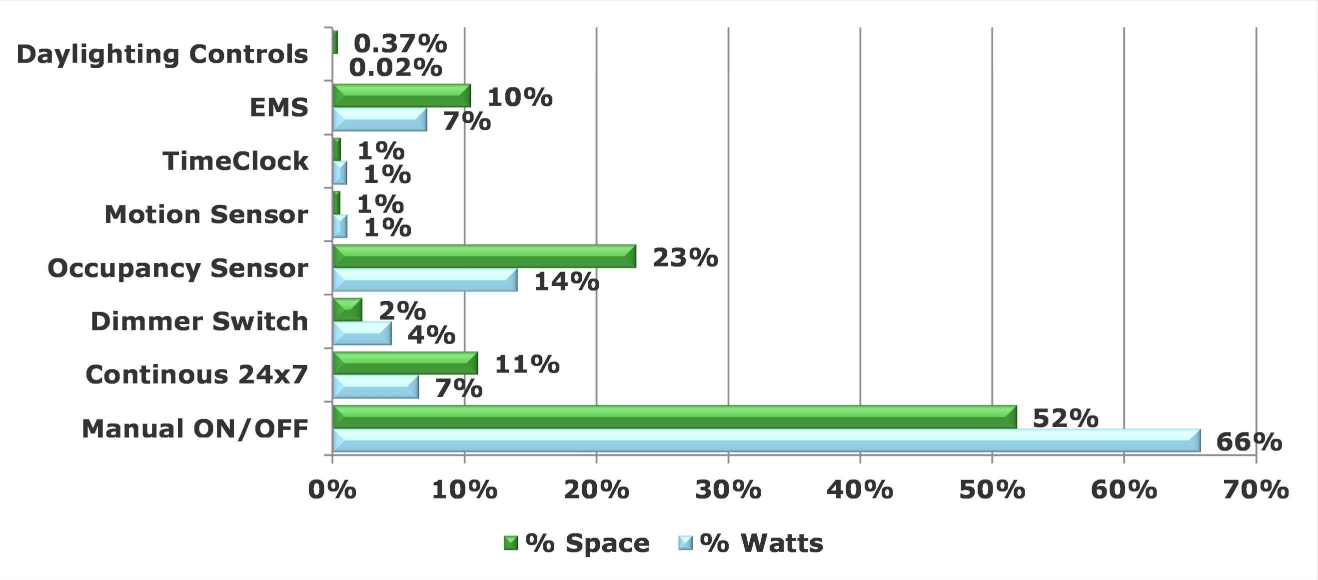
Table 25: Lighting Controls by Building type (percent of total installed watts)

Building Type	Manual ON/OFF	Continuous 24X7	Manual Dimmer	Automated*
Multifamily	80%	12%	7%	1%
Retail	49%	0%	0%	51%
Dormitory	44%	15%	0%	42%
Warehouse	94%	0%	0%	6%
Gymnasium	71%	0%	0%	29%
Office	45%	1%	0%	55%
Religious Building	50%	0%	34%	16%
Dining	100%	0%	0%	0%
Pharmacy	100%	0%	0%	0%
Manufacturing Facility	26%	0%	0%	74%
School/University	36%	1%	1%	63%
Parking Garage	100%	0%	0%	0%
Hotel	100%	0%	0%	0%
Transportation	0%	0%	0%	100%
Sports Arena	67%	0%	0%	33%
Healthcare-Clinic	97%	3%	0%	0%
All Building Types	66%	7%	4%	23%

Note: * - Includes occupancy sensors, motion sensors, time clock, EMS, daylighting controls, and other non-manual systems.

Figure 5 below shows the distribution of various control types and the percent of area served. The majority of both square feet and installed watts are controlled with manual on/off switches, with occupancy sensors the second highest means of lighting control observed.

Figure 5: Lighting Controls distribution by Watts and Space Areas



4.2.2 Space Conditioning

The research acquired data points on cooling systems for 39 sites and for heating systems for 40 sites. This section presents an overview of the systems in use followed by individual sections reporting on the efficiency of each type of equipment.

Cooling

The majority (53%) of the cooling capacity was served by direct expansion (DX) systems, commonly known as air-conditioning (AC) units. Chillers accounted for 33% of the installed cooling capacity and heat pumps made up the balance, 14% as shown in Table 26 below.

Table 26: Cooling Technology Distribution

Technology Type	System Type	% of Installed Capacity
Chiller	Water Cooled Centrifugal	1.7%
	Water Cooled Positive Displacement	22.9%
	Air Cooled Chiller	8.7%
Direct Expansion	Packaged DX Unit	14.8%
	Split System	37.9%
Heat Pump	Ground Source Heat Pump	0.1%
	Water Source Heat Pump	0.6%
	Air Source Heat Pump	13.3%

The technology distribution by stratum is presented in Table 27. Strata 1 and 2 are primarily served by DX units and heat pumps, as is typically seen in smaller buildings. In stratum 3, chillers serve 64% of the cooling load. All of the sites in stratum 4 and 5 of the sample are multifamily buildings with cooling loads primarily served by DX units, frequently a dedicated unit for each residence with the exception of common spaces.

As noted in the acquired sample section, the sample in the largest strata was limited to multifamily buildings. Other commercial and industrial end-uses typically have a significant penetration of chiller technology. For this reason we conclude that the distribution of cooling technology discovered in the new construction sample is most likely not fully representative of the distribution likely to be discovered among the population of existing C&I buildings nor the population of C&I new construction that excludes multi-family buildings.

Table 27: Cooling technology distribution in Strata (% capacity, columns total 100%)

	Stratum 1	Stratum 2	Stratum 3	Stratum 4	Stratum 5
DX Units	78%	69%	33%	96%	93%
Heat Pumps	22%	0%	3%	4%	7%
Chillers	0%	31%	64%	0%	0%

Heating

Natural gas accounted for 97% of the space heating capacity, electric was 2%, and propane held 1% in the sample. The research found a wide range of heating system types as shown, disaggregated by energy source in Table 28.

Table 28: Heating technology distribution based on the energy source

Technology	#Units	% kBtuh	Energy Source		
			Nat Gas	Electric	Propane
Central Furnace	93	43.9%	93.4%	0.0%	6.6%
Condensing Boiler	11	36.6%	100.0%	0.0%	0.0%
Duct Furnace	43	9.2%	89.3%	0.0%	10.7%
Unit Heater	92	4.4%	68.8%	25.8%	5.4%
Air Source Heat Pump	112	5.0%	0.0%	100.0%	0.0%
Water Source Heat Pump	6	0.4%	0.0%	100.0%	0.0%
Ground Water Source Heat Pump	2	0.3%	0.0%	100.0%	0.0%
Radiant Heater	2	0.1%	0.0%	100.0%	0.0%
Ground Loop Source Heat Pump	6	0.1%	0.0%	100.0%	0.0%

The sample included 367 heating units. Multiple technologies were found at 16 sites; five sites had three technologies and 11 sites had two technologies in service. The distribution of technologies by strata is presented in Table 29 below.

Table 29: Heating Technology Distribution by Strata (% Capacity, columns total 100%)

Technology Type	Stratum 1	Stratum 2	Stratum 3	Stratum 4	Stratum 5
Central Furnace	70.2%	53.6%	35.0%	0.0%	0.0%
Condensing Boiler	0.0%	24.5%	55.6%	0.0%	0.0%
Duct Furnace	12.9%	21.4%	0.0%	63.2%	0.0%
Unit Heater	4.9%	0.2%	6.2%	8.0%	0.0%
Air Source Heat Pump	9.6%	0.2%	2.3%	28.8%	100.0%
Water Source Heat Pump	0.0%	0.0%	0.7%	0.0%	0.0%
Ground Water Source Heat Pump	2.1%	0.0%	0.0%	0.0%	0.0%
Radiant Heater	0.4%	0.0%	0.0%	0.0%	0.0%
Ground Loop Source Heat Pump	0.0%	0.0%	0.2%	0.0%	0.0%

The next sections present the discovered efficiency levels by equipment type.

4.2.2.1 Air Conditioning Efficiency

The sample buildings had units with a wide range of capacity. Within each size category, the average efficiency exceeded that referenced in the PSD and in some cases was close to or exceeded that referenced in the ASHRAE 2013. The average efficiency of units under 65,000 Btu/hour capacity, the most common size found, was all but equivalent to that in the latest version of ASHRAE 90.1 2013. Table 30, below shows the observed average efficiency by size.

Table 30: Air Conditioning Efficiency

Size	Units	PSD	ASHRAE 2013	All Units		Non-Participant Units		Participant Units	
				n	Average	N	Average	n	Average
<65,000	SEER	13.0	14.0	1147	13.8	873	13.6	274	14.4
≥65,000 and <135,000	EER/IEER	11.0	12.7	24	12.3	18	12.1	6	12.7
≥135,000 and <240,000	EER/IEER	10.8	12.2	16	11.3	11	11.5	5	10.9
≥240,000 and <375,000	EER/IEER	9.8	11.4	31	12.1	18	10.6	13	14.3
≥375,000 and <760,000	EER/IEER	9.8	11.1	3	10.0	0	-	3	10.0

4.2.2.2 Air Source Heat Pump Efficiency

The PSD and ASHRAE 2013 cover six size ranges for air source heat pumps. The research discovered representatives in only two bins, the smallest with capacity of under 65,000 Btu/hour and an intermediate bin. There was no change between the PSD and ASHRAE 2013 requirements in the heating or cooling efficiency requirements for air source heat pumps, so the code requirements are not presented separately, they are shown together in Table 31 below.

Table 31: Air Source Heat Pump Efficiency

Size		PSD/ASHRAE 2013	All Units		Non-Participant Units		Participant Units	
			n	Average	n	Average	n	Average
<65,000	Cooling	13.0 SEER	110	14.7 SEER	82	14.6 SEER	28	15.0SEER
	Heating	7.7 HSPF	110	8.92 HSPF	82	8.99 HSPF	28	8.50 HSPF
≥135,000 and <240,000	Cooling	11.0 SEER	2	12.6 EER	2	12.63 EER	-	-
	Heating	3.3 COP	2	3.73 COP	2	3.73 COP	-	-

The average air source heat pump heating and cooling efficiencies from the sample were more efficient than each respective code.

4.2.2.3 Water Source Heat Pumps

The PSD and ASHRAE 2013 cover one size range for water source heat pumps (WSHPs). As Table 32 shows, the average system found in the sample, which included only participant facilities, was more efficient for heating and cooling than required by the PSD and ASHRAE 2013 for both heating and cooling.

Table 32: Water Source Heat Pump Efficiency

Size	PSD	ASHRAE 2013	Participant Units		PSD	ASHRAE 2013	Participant Units	
	Cooling				Heating			
	EER	EER	n	Average EER	COP	COP	n	Average COP
≥ 17,000 and < 135,000	12.0	13.0	5	14.9	4.2	4.3	5	4.4

4.2.2.4 Ground Water Heat Pumps

Table 33 provides the ground water heat pump results. Only one size bin is present in the PSD and ASHRAE 2013 and it is smaller than the size of the units used by the participants in the sample. Typically in the PSD and ASHRAE 2013, larger systems have lower efficiency requirements than smaller systems. The units in the study sample were all participating units with an average heating and cooling efficiency more efficient than the PSD and ASHRAE 2013 requirements for a smaller system.

Table 33: Ground Water Heat Pump Efficiency

Size	PSD	ASHRAE 2013	Participant Units		PSD	ASHRAE 2013	Participant Units	
	Cooling				**Heating**			
	EER	EER	n	Average EER	COP	COP	n	Average COP
< 135,000	16.2	16.3	0	-	3.6	3.1	0	-
≥ 135,000	N/A	N/A	2	24	N/A	N/A	2	5

4.2.2.5 Ground Loop Heat Pumps

Table 34 shows the ground loop heat pump results. Only one size bin is present in the PSD and ASHRAE 2013 and the average efficiency of the systems in the sample (which included only participant facilities) were more efficient than each respective code for both heating and cooling.

Table 34: Ground Loop Heat Pump Efficiency

Size	PSD	ASHRAE 2013	Participant Units		PSD	ASHRAE 2013	Participant Units	
	Cooling				**Heating**			
	EER	EER	n	Average EER	COP	COP	n	Average COP
< 135,000	13.4	12.1	6	14.3	3.1	2.5	6	4.9

4.2.2.6 Chillers

Table 35 shows the chiller results. Only the chiller type and size combinations found in the sample are presented in the table. Only two water-cooled positive displacement chillers were found in the sample and they were less efficient than the PSD and ASHRAE 2013 efficiency requirements. One water-cooled centrifugal chiller was found in the sample and it is more efficient than the PSD and ASHRAE 2013 requirements.

Table 35: Chiller Efficiency

		PSD	ASHRAE 2013	All Units		Non-Participant Units		Participant Units	
Size (tons)	Path	Full Load Efficiency	Full Load Efficiency	n	Weighted Average Efficiency	n	Weighted Average Efficiency	n	Weighted Average Efficiency
Air Cooled Chiller									
<150	B	≥9.562 EER	NA[15]	1	9.2	-	-	1	9.2
≥150	B	≥9.562 EER	NA[15]	2	10.3	-	-	2	10.3
Water Cooled Positive Displacement									
≥300	B	≤0.639 kW/ton	≤0.625 kW/ton	2	0.647 kW/ton	2	0.647 kW/ton	-	-
Water Cooled Centrifugal									
<150	B	≤0.639 kW/ton	≤0.695 kW/ton	1	0.63 kW/ton	0	-	1	0.630 kW/ton

4.2.2.7 Furnaces

Table 36 compares the average furnace efficiencies found in the sample to the minimum standards from the PSD and ASHRAE 2013. Both the PSD and ASHRAE 2013 contain the same values for the furnace type and size combination found in the sample. For each unit type in the sample, results exceeded the PSD and ASHRAE 2013 standards.

Table 36: Furnace Efficiency at Maximum Capacity

		PSD/ASHRAE 2013	All Units		Non-Participant Units		Participant Units	
Furnace Type	**Size (Btuh)**	**Efficiency**	**n**	**Average Efficiency**	**N**	**Average Efficiency**	**n**	**Average Efficiency**
Warm Air, Gas-Fired	<225,000	78% AFUE or 80% Thermal Efficiency	53	82.9%	42	82.7%	11	83.3%
	≥225,000	80% Thermal Efficiency	40	81.8%	25	81.2%	15	82.3%
Warm air duct furnaces, gas-fired	All capacities	80% Thermal Efficiency	43	88.6%	110	86.6%	11	94.2%
Warm air unit heaters*	All capacities	80% Thermal Efficiency	20	89.4%	19	89.1%	1	93.0%
Note: * Electric unit heaters are not subject to code requirements and not shown.								

4.2.2.8 Condensing Boilers

While only a few condensing natural gas-fired boilers from one size bin were found in the sample, the input capacity of this equipment makes up a significant portion of the total capacity in the sample. Table 37 shows the average efficiency of these units.

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[15] NA means that this requirement is not applicable and cannot be used for compliance.

Table 37: Condensing Boiler Efficiency at Maximum Capacity

Size (kBtuh)	PSD	ASHRAE 2013	All Units		Non-participant Units		Participant Units	
	Average Efficiency	Average Efficiency	N	Average Efficiency	n	Average Efficiency	n	Average Efficiency
≥300,000 and ≤2,500,000	80% Et	80% Et	11	91%	10	92%	1	92%

4.2.2.9 Domestic Hot Water

Domestic hot water (DHW) was provided to the sample buildings by three basic technology types, storage water heaters (standard), instantaneous (tank-less) and central plants. Equipment in the DHW category may also provide heat for space heating needs. For example, 943 out of 947 (99.6%) of instantaneous heaters were used as the energy source for space heat. The research also found that 9 of the 11 condensing boilers provided DHW through heat exchange/storage tank mechanisms and that one site used 93 storage water heaters to provide heat as well as hot water to dwelling units.

Table 38 below shows the distribution of energy source for DHW-specific equipment, regardless of use. Condensing boilers are addressed in Section 4.2.2.8 and excluded from further discussion in this section.

Table 38: DHW Technology Distribution Based on Energy Source (% Capacity)

DHW Technology Type	#Units	Energy Source		
		Natural Gas	Propane	Electric
Central plant, shared service	9	100.00%	0.00%	0.00%
Standard (Storage) Water Heater	640	49.33%	5.14%	45.53%
Instantaneous (Tank-less)	947	99.76%	0.23%	0.01%
Total Capacity (kBtuh)		213,961	1,463	9,193
Percent of load overall		95.26%	0.65%	4.09%

Table 39 presents the average DHW system energy factors (EF) for the sample as compared to the minimum requirements from the PSD and ASHRAE 2013. The table contains this comparison only for the smallest rating condition bin for each system type.

Table 39: DHW Efficiency

	PSD	ASHRAE 2013	All Units		Non-Participant Units		Participant Units	
Rating Condition (Input, Volume)	Performance Requirement based on unit-specific volume	Performance Requirement based on unit-specific volume	n	Average Efficiency	n	Average Efficiency	n	Average Efficiency
Electric								
≤12 kW, ≥20 gal	0.85 EF	0.95 EF	506	0.91EF	498	0.92 EF	8	0.92 EF
Gas Storage								
≤75 kBtuh, ≥20 gal	0.53 EF	0.65 EF	96	0.64 EF	96	0.64 EF	-	-
Gas Instantaneous*								
>50 kBtuh and <200 kBtuh	0.62 EF	0.62 EF	946	0.93EF	705	0.93 EF	241	0.94 EF

Note: * - Gas includes both natural gas and propane. There is no standard specified for electric.

The PSD and ASHRAE 2013 requirements for the larger bins are based on stand-by losses, which could not be obtained for the units in the sample. Researchers did verify from manufacturer's specifications that this equipment met standby loss requirements of the U. S. Department of Energy and the current edition of ASHRAE/IESNA 90.1. There are 16 gas storage water heaters in this category, with input capacities greater than 75 kBtu/hour and storage capacity in excess of 20 gallons, excluded from Table 39. There was also one electric storage water heater with input capacity in excess of 12 kW for which the critical factor of stand-by loss was not obtained and it also is not shown in the table.

5 CONCLUSIONS & RECOMMENDATIONS

The research was designed primarily to inform program baseline with a secondary objective of producing an interim estimate of compliance with energy efficiency requirements of commercial building code. Since the state has an obligation (under the requirements of an ARRA grant previously mentioned) to estimate the level of energy code compliance in 2017, this research also can and should inform the design of that effort. For this reason, the researchers determined to present two categories of recommendations, one with regard to program design (baseline) and one with regard to the 2017 code compliance study.

5.1 Baseline

The evaluation team offers recommendations with regard to the baseline for new construction measures incorporated in the PSD and, to the extent that this baseline study can act as indicator of program opportunities, specific measures to consider.

5.1.1 Conclusion

Connecticut incorporated the energy efficiency requirements of IECC 2009 (equivalent to ASHRAE 90.1-2007) in its building code in September 2011 (effective October 6). The current PSD also rests its baseline on the same code requirements. According to a state web-site[16] it appears that adoption of a new code including energy efficiency requirements equivalent to ASHRAE 90.1-2010 is scheduled for the fall of 2015. As of July 1, 2015[17], 19 states including neighboring New York, Massachusetts, and Rhode Island have adopted this code and two states in the region (Vermont and Maryland) have adopted ASHRAE 90.1-2013 (see Figure 6 below).

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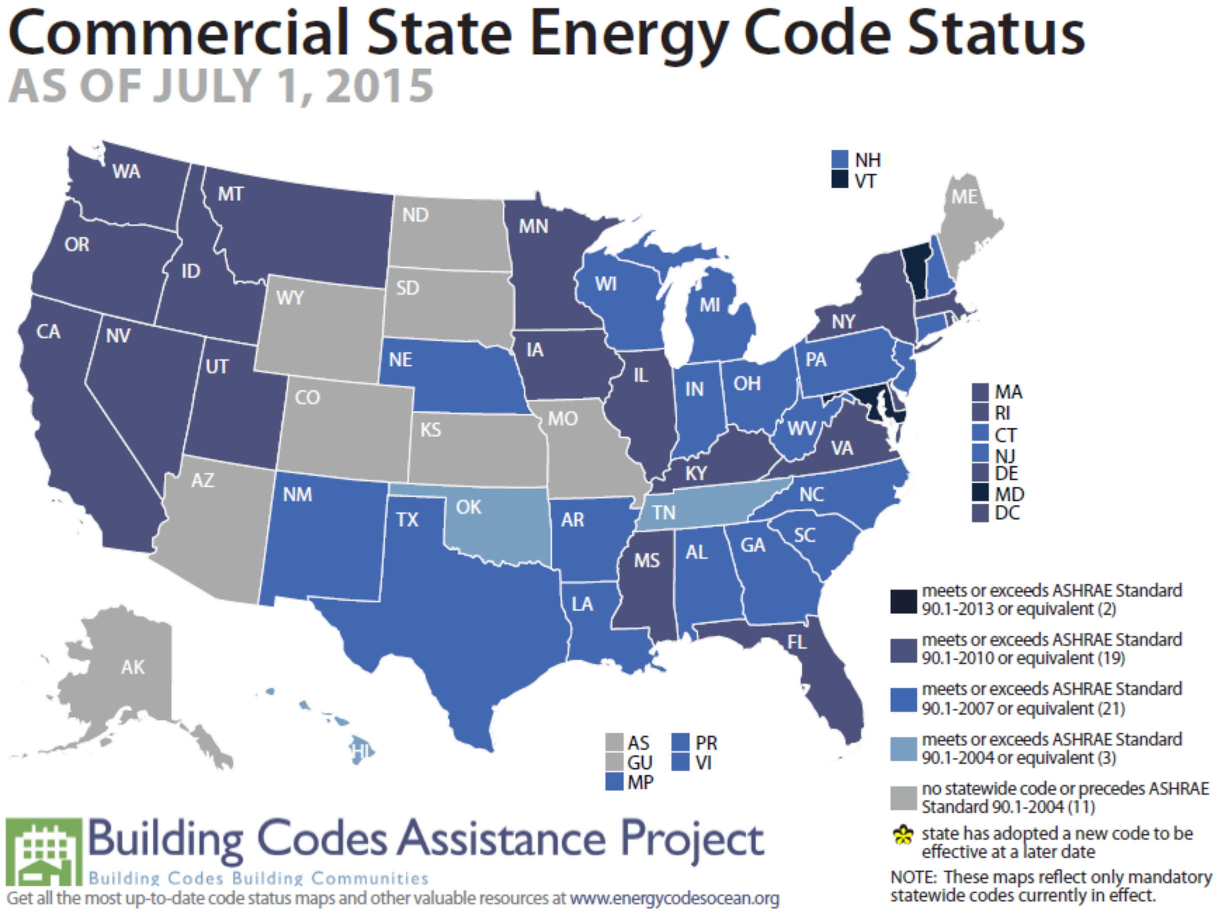
[16] http://www.ct.gov/dcs/cwp/view.asp?a=4447&q=523368&dcsNav=|, accessed 7/20/15

[17] http://energycodesocean.org/code-status-commercial, accessed 7/15/15

Figure 6: Code Status by State



The findings of this study in terms of equipment efficiency have been presented relative to the existing code and relative to the 2013 version of ASHRAE 90.1.

The findings are summarized in reference to ASHRAE 90.1-2013 in Table 40 below.

Table 40: Consolidated Efficiency Summary

Equipment Category	Current Efficiency
Lighting	More efficient than ASHRAE 90.1-2013 for 13 out of 16 building types and 30% more efficient than current code requirements overall
Air Conditioning	Average across all size bins significantly exceeds PSD and almost as efficient as ASHRAE 90.1-2013 except for one that was more efficient (n=31)
Air Source Heat Pumps	Average efficiency better than ASHRAE 90.1-2013 (no change between PSD and ASHRAE 90.1-2013)
Water source Heat Pumps	Average efficiency better than ASHRAE 90.1-2013
Ground Loop Heat Pumps	Average efficiency better than ASHRAE 90.1-2013
Ground Water Source Heat Pumps	No requirements on the sizes found, but they were more efficient that the requirement for smaller units
Chillers	Small sample, two below and one better than ASHRAE 90.1-2103
Furnaces	Average efficiency better than ASHRAE 90.1-2013 (no change between PSD and ASHRAE 90.1-2013)
Boilers	Average efficiency better than ASHRAE 90.1-2013
DHW – Storage	Average efficiency slightly below ASHRAE 90.1-2013
DHW – Instantaneous	Average efficiency better than ASHRAE 90.1-2013

This study developed compelling evidence that the energy efficiency characteristics of C&I new construction in Connecticut during the study horizon were substantially better than the code in force at the time of facility permitting. We further found it to be better than the requirements of the current PSD and relatively close to the requirements specified by the 2013 version of ASHRAE 90.1.

5.1.2 Recommendations

In this section, we provide three recommendations based on the findings of this study.

- In light of the conclusion above, the evaluation team recommends that the Energy Efficiency Board, program administrators, and other stakeholders consider increasing the baseline assumptions in the PSD for the commercial and industrial new construction market segment based on additional analysis and where appropriate. Although the sample included facilities that self-reported as program participants and non-participants, for the vast majority of equipment types there was not a substantial difference in efficiency along this index. The fact the average efficiency installed in buildings permitted in the 2010 – 2013 period was close to the requirements of ASHRAE 90.1-2013 suggests that the utilities and EEB might consider identifying areas where these efficiency requirements might serve as a baseline for program savings estimates. In cases where the requirements of ASHRAE 90.1-2013 are no more stringent than the current PSD requirements, going beyond that standard might be appropriate if utility experience or additional research further supports those adjustments.

- To the extent that this baseline study can act as indicator of program opportunities, our findings suggest LED and hot water heaters might be large reservoirs of savings in the new construction market. The buildings examined in this study were designed and permitted from 2010-2013, when LED lighting technology and advanced lighting controls were still relatively new to the market. Researchers observed that 3% of interior floor area lit by LED lighting and 23% of wattage controlled by some level of automation. We note the utility program currently offers these two technologies, which makes it well positioned to take advantage of both LED and controlled lighting systems (e.g., energy management systems and sensors) opportunities.
- Instantaneous hot water heaters were used to provide both domestic hot water and space heat at 5 out of the 9 sites where they were present. All five of these sites were large multi-family buildings or complexes. Out of 947 instantaneous hot water heaters in the sample, all but 4 were being used this way. While the sample size is not sufficient to make a definitive finding, it is sufficient to recommend additional investigation into the prevalence of this use in the market. If this research finds that this is a common measure, it may be appropriate to consider program design modifications to address it.

5.2 Code Compliance Evaluation

Since this study was undertaken partially as an interim step towards meeting the State's obligation to document code compliance in 2017, DNV GL offers the following to inform that effort.

5.2.1 Conclusions

The researchers faced challenges on several fronts during the execution of this study, including:

- Complete and accurate population data – The State of Connecticut does not maintain a building inventory, nor do most states. Buildings are permitted and inspected at the local level. The typical approach for this type of study is to purchase a database primarily targeted to those who wish to sell goods or services to support new construction, such as the Dodge database used in this study. These sources attempt to capture data early in the design phase, strive to be current and accurate through the bidding phase, and understandably have little focus on the construction and later phases. Consequently, these sources do not always capture the constructed building and accurate contact information, especially for post-construction owners and operators.
- Identification of qualified site contacts – The design of this study required access to both the building and to construction documents. The recruiting team expended considerable effort to reach an individual with authority to grant the site visit and confirmed with this individual that construction documents would be made available. In all but a few instances, construction documents were obtained, sometimes with significant additional effort, and in many cases, these were incomplete, in particular with regard to fenestration specifications.
- Enrollment rate – The attrition rate once the appropriate contact was reached was higher than anticipated, especially in the larger size strata that had smaller populations. The incentive of $250, which was relatively rich compared to recent experience, did not appear sufficient for many of the individuals contacted. While the research design did not incorporate sequences to establish the optimal incentive level, the recruiters suspected that even doubled it would not have made a substantial difference based on the responses they received.

- Missing/unobtainable data – Fenestration labelling is usually removed at the end of construction or shortly after the building's first use. The construction documents acquired frequently did not contain window specifications or schedules. Most frequently only the sizes and locations of fenestration were shown.

The USDOE recommends a methodology for measuring code compliance[18] that contemplates either visiting the same building during different stages of construction ("*e.g.,* plan review, foundation, structural, mechanical, plumbing, electrical, and final inspection") or visiting different but similar buildings at these stages. This is an expensive and time-consuming approach. The research design for this study, incorporating one post-construction site visit and document review, was deemed sufficient in light of financial limitations and the time available to complete this effort. Furthermore, since this study is only an interim step towards determining code compliance for the 2017 new construction population, a more comprehensive evaluation was not deemed necessary at this point in time.

5.2.2 Recommendations

The evaluation team offers the following recommendations for future efforts:

- Population data – This study used one purchased dataset. Options to improve the accuracy of the population data include purchase and consolidation of multiple datasets and supplemental research at jurisdictional code enforcement offices (either a sample or the population), and/or extensive analysis of utility customer information records for new accounts. Each of these has its costs and drawbacks, but until a statewide new construction database is created, they are likely the best options available.
- Identifying qualified contacts and increasing enrolment – The evaluation team recommends that future research designs consider the following features:
  - Close coordination with utility staff to identify key contacts at potential sample sites
  - Broadcast distribution to potential sample sites by surface and electronic mail notifying them of the study, perhaps included with utility bills or other communication
  - Targeted communication to primary sample sites and back-up sample sites
  - Coordination with code officials to identify potential new construction sites
  - Modifying the incentive structure, e.g.*,* a drawing for a larger prize or donation to a charity of choice with defined odds of winning. One successful incentive used in a past study by this team was $5,000 with the odds of winning being one-in-fifty.
- Data availability - The limitations on data availability this study faced largely could be overcome by adoption of the USDOE recommended methodology of incorporating periodic visits to one site or visits to comparable buildings at different stages of construction. This decision will be informed by the study sponsors' tolerance for uncertainty, funding availability, and any final guidance offered by the USDOE. As an alternative, acquisition and review of construction documents for completeness could be used to screen sample sites, but the attrition rate based on this study's experience would likely be high.

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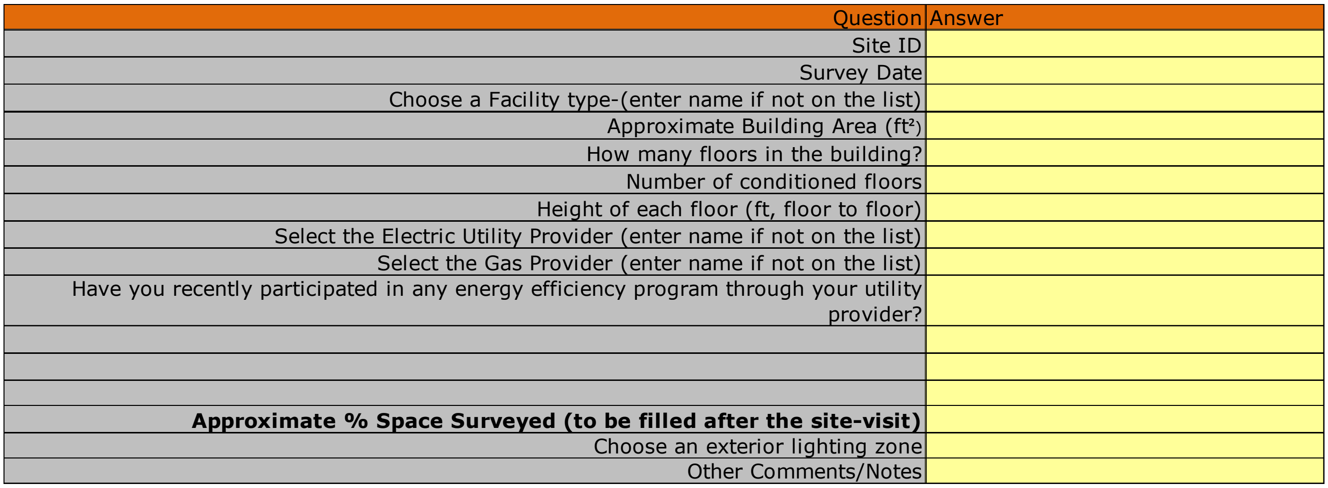
[18] https://www.energycodes.gov/sites/default/files/documents/MeasuringStateCompliance.pdf, See section 5.3.1.3 Addressing Evaluation Logistics

6 APPENDICES

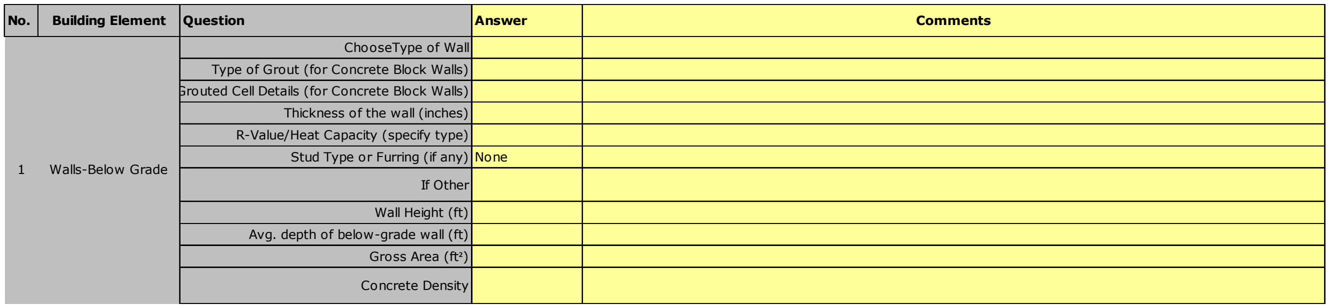
6.1 Appendix A – Data Collection Tool – Form Examples

Figure 7: General Site Information



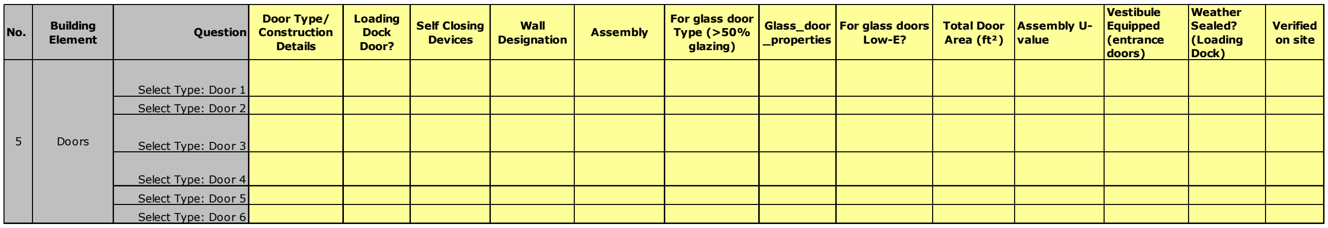
Question	Answer
Site ID	
Survey Date	
Choose a Facility type-(enter name if not on the list)	
Approximate Building Area (ft^2)	
How many floors in the building?	
Number of conditioned floors	
Height of each floor (ft, floor to floor)	
Select the Electric Utility Provider (enter name if not on the list)	
Select the Gas Provider (enter name if not on the list)	
Have you recently participated in any energy efficiency program through your utility provider?	
Approximate % Space Surveyed (to be filled after the site-visit)	
Choose an exterior lighting zone	
Other Comments/Notes	

Figure 8: Envelope – Below Grade Walls



No.	Building Element	Question	Answer	Comments
1	Walls-Below Grade	ChooseType of Wall		
		Type of Grout (for Concrete Block Walls)		
		Grouted Cell Details (for Concrete Block Walls)		
		Thickness of the wall (inches)		
		R-Value/Heat Capacity (specify type)		
		Stud Type or Furring (if any)	None	
		If Other		
		Wall Height (ft)		
		Avg. depth of below-grade wall (ft)		
		Gross Area (ft^2)		
		Concrete Density		

Figure 9: Envelope - Doors



No.	Building Element	Question	Door Type/ Construction Details	Loading Dock Door?	Self Closing Devices	Wall Designation	Assembly	For glass door Type (>50% glazing)	Glass_door _properties	For glass doors Low-E?	Total Door Area (ft^2)	Assembly U-value	Vestibule Equipped (entrance doors)	Weather Sealed? (Loading Dock)	Verified on site
5	Doors	Select Type: Door 1													
		Select Type: Door 2													
		Select Type: Door 3													
		Select Type: Door 4													
		Select Type: Door 5													
		Select Type: Door 6													

6.2 Appendix B - Data Source Summary

BECP Strata	Site ID	Below Grade Wall	Floor	Exterior Wall	Roof	Window & Door	Cooling System	Heating System	Lighting Interior	Lighting Exterior	Hot water heater
1	89	N/A	CD	CD	CD	EA	DO	DO	DO	CD	DO
1	92	N/A	CD	CD	CD	EA	DO	DO	DO	CD	DO
1	98	N/A	CD	CD	CD	EA	DO	DO	CD	CD	DO
1	115	CD	CD	CD	CD	EA	DO	DO	EA	CD	DO
1	124	N/A	CD	CD	CD	EA	DO	DO	DO	CD	DO
1	133	N/A	CD	CD	CD	EA	DO	DO	DO	CD	DO
1	181	N/A	CD	CD	CD	EA	DO	DO	CD	CD	CD
1	190	N/A	EA	EA	EA	EA	DO	DO	CD	DO	DO
1	355	N/A	CD	CD	CD	CD	DO	DO	CD	CD	N/A
1	362	N/A	CD	CD	CD	EA	DO	DO	DO	CD	DO
1	373	N/A	CD	CD	CD	CD	DO	DO	DO	DO	CD
1	415	N/A	CD	CD	EA	EA	DO	DO	EA	EA	EA
1	426	N/A	EA	CD	CD	EA	DO	EA	DO	DO	N/A
1	434	N/A	CD	CD	CD	CD	DO	DO	DO	DO	N/A
1	439	N/A	CD	CD	CD	CD	DO	DO	CD	DO	EA
1	443	CD	CD	CD	CD	CD	N/A	DO	EA	DO	DO
1	446	N/A	EA	CD	EA	EA	DO	DO	DO	DO	DO
1	464	N/A	CD	CD	CD	EA	CD	DO	CD	DO	DO
1	468	CD	CD	CD	CD	CD	DO	DO	DO	DO	EA
1	470	N/A	CD	CD	CD	EA	N/A	DO	DO	DO	DO
1	471	CD	CD	CD	CD	EA	DO	DO	DO	N/A	EA
1	517	N/A	EA	CD	CD	CD	DO	DO	CD	CD	N/A(4)
1	536	CD	CD	EA	CD	EA	DO	DO	DO	DO	DO
1	647	N/A	CD	CD	CD	EA	DO	DO	CD	CD	DO
2	48	N/A	CD	CD	EA	EA	EA	EA	CD	DO	DO
2	55	N/A	CD	CD	CD	EA	DO	DO	DO	CD	DO
2	74	CD	EA	EA	EA	EA	DO	DO	DO	CD	N/A(4)
2	510	N/A	CD	CD	CD	DO	CD	DO	CD	DO	DO
2	511	N/A	CD	CD	CD	EA	DO	DO	CD	DO	DO
2	708	EA	CD	CD	CD	EA	DO	DO	CD	CD	DO
2	721	N/A	CD	CD	CD	EA	DO	DO	CD	CD	DO
3	7	N/A	EA	EA	CD	EA	EA(3)	CD(3)	DO	EA	DO
3	24	CD	CD	CD	CD	EA	DO	EA	CD	CD	CD
3	31	N/A	EA	CD	EA	EA	EA	EA	DO	EA	DO
3	42	N/A	CD	EA	CD	EA	DO	DO	DO	DO	DO
3	207	N/A	CD (1)	CD (1)	CD (1)	EA	DO	DO	DO	CD	DO
3	213	CD	CD	CD	CD	EA	CD	DO	CD	DO	CD
3	232	EA	CD	CD	CD	EA	CD	CD	CD	CD	DO
3	482	N/A	CD	CD	CD	EA	CD	CD	CD	EA	DO
3	487	N/A	CD	CD	CD	EA	CD	DO	DO	DO	N/A
3	489	CD	CD	CD	CD	EA	EA	EA	CD	CD	DO
3	696	N/A	CD	CD	CD	EA	DO	CD	CD	CD	CD
4	192	N/A	CD	CD	CD	EA	DO	DO	DO	CD	DO
4	194	N/A	CD	CD	CD	EA	DO	DO	DO	CD	DO
5	199	CD	CD	EA	CD	EA	DO	DO	EA	CD	DO
Data Source Codes		DO = direct observation				Notes		1) - based on same owner for site 24			
		CD = construction documents						2) - based on same owner for site 42			
		EA = engineering assumptions						3) - based on same owner for site 192			
		N/A = not applicable						4) No data available; DHW not observable			

About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.