Baseline Characteristics of the 2002-2004 Nonresidential Sector: Idaho, Montana, Oregon and Washington

Progress Report

PREPARED BY

Ecotope

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www.nwalliance.org

529 SW Third Avenue, Suite 600
Portland, Oregon 97204
(tel) 503-827-8416 (fax) 503-827-8437

BASELINE CHARACTERISTICS
OF THE 2002-2004 NONRESIDENTIAL SECTOR:
IDAHO, MONTANA, OREGON, AND WASHINGTON

For the
Northwest Energy Efficiency Alliance

ECOTOPE
CONSULTING
RESEARCH
DESIGN

David Baylon
Mike Kennedy

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Executive Summary

This report describes the results of a two-year, Northwest Energy Efficiency Alliance (NEEA) study intended to improve understanding of the new commercial building stock in the Pacific Northwest region. The study provides a new regional baseline for current practices in commercial buildings constructed between 2002 and 2004 and compares those practices with previous baseline and code compliance studies conducted from 1996 to 1998. The study also looks at changes in design professionals' attitudes toward energy efficiency across the same periods.

The main research activities for the study included field visits (conducted between mid-2006 and late 2007) and interviews with design professionals and building operators. Analyses included physical and operational building characteristics, code compliance, and energy use. By understanding the commercial sector's building characteristics and energy savings potential, regional planning will be improved and utilities and other energy providers will be able to design more effective energy efficiency programs.

The current study is more ambitious than similar previous studies in that both the number of buildings and the sampling goals were expanded. A total of 350 buildings received site visits, the energy audit protocol was enhanced, the amount of on-site information collected relating to ownership, operations, and maintenance was expanded, and billing releases were secured to obtain energy use information. Statistically reliable information was collected for the region, for each of the four Northwest states, for five specific building types and for several utility service territories.

Key Findings

- **Lighting.** Overall, basic lighting technologies found in this study were fairly similar to previous studies though in some cases the market share of technologies changed substantially. Notable examples and exceptions include a dramatic reduction in T12 fixtures; energy-efficient, pulse start, metal halide ballasts representing 18% of all HID wattage (up from zero in previous studies); 25% of low and high bay lighting being T8 or T5 linear fluorescent—a two-fold increase from previous surveys; 12% of all linear florescent being T5, whereas no T5 lighting was observed in the 1996-98 audits.

  The biggest changes were observed in lighting control technologies and implementation. The use of central controls for lighting, which had been an integral part of larger buildings previously, has now become almost universal for both large and middle-sized buildings. Occupancy sensor control has nearly quadrupled since the 1996-1998 study.

  The use of security lighting has nearly doubled since the previous study.
- **Heating, Ventilation, and Air Conditioning Systems.** Mechanical systems remain very similar to previous studies. The biggest changes occurred with the advent of more centralized controls, the increased use of CO_2 and OS controls to manage ventilation air, and the notable use of more complex system designs. However, there are also central control systems that have been ignored, are too complex to operate, or have been abandoned due to occupant complaints.

- **Envelope.** Over the course of the last decade, the use of low-e coatings in window glazing for both heat loss and solar heat gain control has become nearly universal throughout the region. Another positive trend is in window performance where there has been an increase in use of wood and vinyl frames (as opposed to metal) from 11% to 20% of windows. However, the increase in window performance has been accompanied by a consistent increase in overall glazing area, especially in building types where smaller amounts of glazing were observed in the past.
- **Refrigeration Systems.** Refrigeration systems have improved incrementally since the previous study. Over the last two decades, the use of heat recovery for building service hot water has become universal. However, refrigeration systems generate far more waste heat than most service water systems require, especially in grocery stores. Very few stores recover heat for space heating.
- **Energy Efficiency and Energy Codes.** There has been a dramatic increase in energy efficiency as a design consideration noted by building designers and engineers. There is an ever-increasing interest in energy efficiency in Washington and Oregon, and the interest is now reasonably comparable in Idaho and Montana.
- **Building Operations.** Building operator training was observed in only about 15% of conventional buildings overall, but in about 75% of chains where central control might be present. Some very sophisticated engineering designs were used for several buildings in this study. Engineers are being encouraged to develop alternative design approaches to improve HVAC efficiency, and this trend has introduced more careful ventilation control. However, the implementation of ASHRAE Standard 62 has increased the amount of outside air required in many building types. Even with more sophisticated controls this change has the potential to increase energy requirements.
- **Code Compliance.** There was a striking increase in energy code compliance. In the 1996-1998 study, code compliance topped out around 70% in lighting and a comparable number in other end uses. In this study, code compliance with the lighting standards is about 80% with reasonably consistent efforts to get higher efficiency lighting into many buildings. Other parts of the codes, such as building shell, had nominal compliance rates that approached 90%. Further, architects and engineers interviewed regarded compliance with energy codes as part of the design process. In the previous baseline studies architects and engineers were struggling to ensure code compliance.

Overall Observations

While the use of technologies as the major focus of utility programs and recommendations has resulted in significant improvements in the efficiency of building components, this study shows that trade-offs used by architects and designers may negate these improvements — most notably in regards to glazing area and display lighting. Overall, the results of this study point to three main opportunities for utilities to fine tune implementation of regional energy efficiency initiatives: controls, glazing, and operator training. To significantly improve the overall performance of commercial buildings, trends for better control and scheduling must be matched by trends for more integrated design and direct understanding of how high-performance buildings must be constructed.

1. Introduction

1.1. Project Goals and Objectives

This report describes the results of a two-year, Northwest Energy Efficiency Alliance (NEEA) study intended to improve understanding of the new commercial building stock in the Pacific Northwest region. Over the past 20 years, numerous energy metering and auditing studies have been performed throughout the region. These studies have sought to understand and characterize the commercial sector's energy use components, to establish baselines of building characteristics, to learn design professionals' attitudes toward energy efficiency, and to track changes in the commercial sector resulting from the adoption of more stringent energy codes and utility incentive programs. Overall, this study provides an opportunity to compare current building practices with previous baseline and code compliance studies and provides a new regional baseline for current practices in commercial buildings.

The current study had four specific goals:

1. Design a statistically representative sample of commercial buildings for:
    - The region as a whole.
    - Each of the four Northwest states.
    - Four specific building types—grocery stores, hospitals, retail establishments, and schools—that are of particular interest to NEEA and its commercial building initiatives.
    - Utilities that invested in augmented samples for their service territories.

2. Generate a summary of characteristics associated with the major energy-using components (HVAC, lighting, envelope, and refrigeration) of commercial buildings. This information includes identification of building components, equipment, and controls used in each building.

3. Assess energy code compliance for HVAC equipment, lighting, and applicable envelope components. Provide insights into the attitudes among design professionals active in the commercial sector toward energy conservation, sustainable design, and related practices in order to develop a comparison between field practices and energy codes as related to both individual states with varying energy codes and individual building compliance.

4. Perform a regional assessment of energy use and estimate Energy Use Intensities (EUIs) by building type within each sample. Activities related to this goal will be reported in a separate, future report.

1.2. Previous Studies

Beginning in 1991, a series of baseline studies were conducted to document the impacts of changes to energy codes in the commercial sector and to evaluate the market baseline for utility program planning. Over the next 10 years, about 500 separate energy audits were conducted in buildings that were largely characterized as new construction at the time of the studies. The last region-wide research was conducted in two separate studies. A sample of Washington state buildings from the 1995 construction year was studied in work done in 1997 (Baylon et al. 1997), and a sample of Oregon, Idaho, and Montana buildings from the 1997-1998 construction years were audited and studied in 2000 (Baylon et al. 2001). Throughout the current study these two previous reviews are referred to as the "1996-1998" sample even though these samples were conducted at different times and with somewhat different goals.

In 2001 and 2002, the commercial sector audits conducted in these studies were combined with the audits done in the early 1990s and the 1980s. The combined audits were assembled into a single database allowing comparisons across almost two decades of commercial building efficiency initiatives (Kema-Xenergy 2004). This study included development of a sample frame and weighting scheme that would facilitate comparisons with previous studies and allow the integration of future studies into an overall regional framework.

1.3. Current Study

The current work's goal is to understand and characterize new commercial construction during the period 2002-2004 in the Pacific Northwest. By understanding the commercial sector's energy savings potential and its building characteristics, utilities and other stakeholders will be able to design better energy efficiency programs that increase the commercial sector's overall energy efficiency. The main research activities for the study included field visits to all buildings and interviews with design professionals.

The current study is more ambitious than similar previous studies in that both the number of buildings and the sampling goals were expanded. There were a total of 346 sample points (representing 350 buildings) drawn in this sample to meet the various elements stated above in Goal 1. The energy audit protocol was enhanced to review some building components in more detail, and the amount of on-site information collected that related to ownership, operations, and maintenance was expanded. Finally, billing releases were secured to obtain energy use information.

The inclusion of billing data required a departure from previous new construction studies in that buildings included in the sample had to have been occupied for at least a year. The sample was therefore drawn from buildings with construction start dates between 2002 and 2004, with the buildings completed and occupied by 2005 or early 2006. The benefit of auditing completed buildings, beyond having access to billing records, was that more detail was available on tenant improvements and building operations. However, less information was available on component selection (especially in the building shell), and people interviewed had less detailed memories of the specific decisions that influenced the building design and code compliance.

2. Methodologies

As in previous studies, this study's sample frame was drawn from the Dodge® database. The development of the sample frame and the Dodge® database are both described in detail in Section 3. Once the sample was drawn, building owners and operators were contacted by phone to secure permission to conduct an on-site review of the individual buildings. Usually this process required an assurance of confidentiality or a "non-disclosure agreement." About 65% of the buildings contacted were recruited.

2.1. Audit Process

Once buildings were successfully recruited, energy audit teams examined the building plans ("as-built" plans when available) and reviewed specifications, operating manuals, and related documents for each building. These documents were typically available through either architects or engineers, or on-site from building operators or owners. In some cases, these documents were reviewed at the local municipality's building department.

On-site visits were scheduled to verify the information in these documents and to collect detailed information on lighting, HVAC systems, building envelope, and other aspects of building operation. Auditors recorded the square footage associated with particular building areas that had separate lighting requirements, HVAC systems, and/or functions. Information was developed about details in building schedules, operation, controls as set up and used, and building commissioning. When details from the plan reviews and site visits were insufficient to complete the protocol, suppliers and installers were consulted for information about specific components, particularly windows.

Appendix A details the field protocol used by the auditors to develop the datasets for each building. The protocol focused both on the overall specifications of the buildings as operated and the specific technologies implemented (especially in lighting and HVAC systems). It built on protocols from several previous baseline studies, with an effort to ensure that compatible databases could be developed that described changes in commercial building types across the region over time.

2.2. Data Entry and Cleaning

On-site and document reviews were assembled into a database. This process was supplemented by review of manufacturers' literature, phone conversations with installers or specifiers, and review of supplemental documentation (such as commissioning reports and sequence-of-operations specifications). This information was transferred from the auditor forms and notes and then supplemented in the resulting database to fill in missing information using the secondary sources. The database was then cleaned and reviewed to make building records as complete as possible. Due to the time lag between the construction phase and the audits of these buildings, information was sometimes unavailable for various components. In these cases, the database contains missing values or estimates of the component specifics.

To develop statistics on subspaces and detailed component descriptions across building types and other sampling units, the entire database was compiled into a series of analytical databases. These databases were separated by building type and by major building components (lighting, HVAC, envelope, refrigeration).

2.3. Data Analysis

Sections 4 through 8 summarize the characteristics of various components of the buildings. These data summaries were assembled using a weighting procedure that reflects the sampling probability for each building within the various subsamples. Most summaries were constructed and weighted using building-level information. In cases where the characteristics were summarized for specific technologies (e.g., fixture types, HVAC types) summaries and weighting were based on subspaces within the buildings. The data summaries include information taken from drawings and specifications, on-site data, and post-site visit research from installers and contractors. Where possible, this information was summarized for each subsample. In some cases, the data was normalized across the state and utility samples to provide information on the distribution of characteristics. The data was assembled into a database for future documentation of building characteristics as determined by this snapshot of commercial construction.

Note that the report contains only a small fraction of all the data that was collected. Additional data is available from either Ecotope, Inc., the author of the report, or the Northwest Energy Efficiency Alliance. The development of a public, searchable, web-based database is being considered that would be available in late 2009.

2.4. Energy Code Assessment and Compliance

In all buildings, energy code requirements and compliance were assessed. This effort was complicated by the fact that multiple energy code changes occurred during the study period, and this information was rarely well documented in the building plans or remembered by the interviewees. In most cases, it was difficult to determine which code year buildings were permitted under or which code compliance path was used. This fact coupled with the codes associated with individual tenant improvements made it necessary to select a single code to compare code compliance across all buildings.

The period from 2001-2003 was assumed to be the design window for projects reviewed in this study. Some projects were in process far longer; one building was permitted in Washington under the 1994 energy code, and some initial tenant improvements in larger projects were covered under codes enforced during late 2005.

The code that was used for analysis in each state is described in the following sections:

- **Idaho.** The International Energy Conservation Code (IECC) 2000 was implemented midway through the design/permit window for the projects in this study (June 2002 for state buildings, January 2003 for all buildings). Prior to its adoption, no commercial energy code was enforced in most of Idaho. The IECC 2003 took effect in January 2005 and made major changes to the lighting requirements. While this is after the design window it was found to be the applied code in some tenant improvements in slow-to-develop buildings.
- **Montana.** ASHRAE 90.1-1989 was in effect for the entire design window, although enforcement was quite inconsistent based upon reports.
- **Oregon.** The 1998 state code was prevalent for most of the design window. The Oregon code was updated in early 2002 to include the ASHRAE 2001 equipment efficiency requirements. The Oregon 2004 energy code, which included major changes, was enforced starting in October 2004.
- **Washington.** The 2001 state code was very similar to the previous code and enforced starting in July 2002. An enhanced code was enforced beginning in 2003, and another enhancement was enforced beginning in 2005.

This study therefore reports code compliance based upon energy codes prevalent in each state during the design window rather than the specific code used for the building in question. In Idaho, the 2000 IECC was used, in Montana ASHRAE 90.1-1989 was used, in Oregon the 1998 state energy code was used (with 2001 ASHRAE equipment efficiencies), and in Washington the 2001 state energy code was used. Additionally, the City of Seattle enforces a separate code that is somewhat more stringent than the Washington code, especially in lighting. Thus, for the 2001 period, applicable Seattle code was used to describe compliance in the Seattle market.

In the analysis of the individual buildings, the observed characteristics were compared to the code requirements listed above for the applicable jurisdiction to determine compliance with the code provisions. This process focused on the building components that could be directly observed such as the lighting power, the equipment efficiency, and the building envelope and glazing characteristics.

2.5. Interview Process

Appendix B includes the interview instrument used to discuss energy efficiency, sustainability, and energy code attitudes with engineers, architects, and owners. These interviews were conducted with slightly less than half of the overall sample.

The interviews focused on the decision-making process in the individual building projects. Because of the time between the planning phases of these projects and the actual interviews (typically at least five years or longer) the interviews tended to focus more on current attitudes toward energy efficiency and energy codes and less on the decisions made specifically for buildings in this study. These interviews were compared to observations in the particular buildings as well as to interviews conducted in the 1999 regional sample.

Auditors also performed on-site interviews with building operators and site managers. These interviews sometimes supplemented, or were comparable to, the interviews with designers but the time span between the design phase of these projects and the designer interviews limited the utility of such comparisons.

2.6. Status of Buildings During the Research Period

This study focused on buildings as occupied and operated. This strategy differed significantly from previous new construction baseline studies where each building was reviewed during the construction process. Construction documents and individuals' memories were therefore much more current in previous studies. On the other hand, this strategy did not allow review of details of the building as operated, including information on final lighting plans, decorative and display lighting, and variations in control and commissioning plans.

Because of the focus on occupied buildings, certain building features that were easily observed in previous studies were more difficult to discern in this study. For example, in all cases the building envelope components were covered by finish material. However, previous studies indicated that building components that were not visible after occupancy (such as insulation levels) did not differ significantly from plans and specifications. A more significant issue was the obsolescence of some of the manufacturers' documentation due to the time lag between the completion of construction and the audit. The building equipment sometimes included models that have since become obsolete, thus hindering documentation of model capacities and efficiencies. Window specifications from installer archives were problematic to review or even find. In general, these data points were addressed using construction documentation or specifications but in some cases, it was not possible to verify these data sources.

2.7. Comparisons to Previous Studies

Comparing random samples across two study periods will deliver varying levels of precision depending on the primary goals of the studies. For example, the primary goal of the current study was to characterize the building stock in each individual state to the maximum precision feasible. This strategy resulted in a high level of precision when reviewing individual building types or when reviewing overall state samples. However, comparisons with previous studies on the regional level are less precise. This is mainly due to differences in the building stock itself. We acknowledge that case weights could be altered to make regional comparisons between the two sample groups more precise, but this would reduce the precision of the overall building characteristics of the sample as drawn.

3. Sample Techniques and Sample Design

Broadly speaking, the commercial sector is defined by what it is not: building types that are not described by industrial processes or categorized as residential buildings. The nature of commercial sector end uses, building systems, HVAC systems, lighting systems, and occupancy vary dramatically from building to building. To develop a sample for this study, new commercial construction project data were acquired from F.W. Dodge®, a commercially available private sector data source that tracks commercial new construction and has been used for previous baseline studies in the Pacific Northwest, in California, and in other regions. The buildings categorized as commercial within the Dodge® database effectively define the commercial sector for purposes of this study.

The sample was designed to be representative of new commercial construction in the four states that make up NEEA's service territory—Idaho, Montana, Oregon, and Washington.

Sample development included the following steps:

- Utilize the Dodge® database to determine the state, building type, and utility service territory associated with each building.
- Screen the data to ensure the relevance of all buildings included in the sample frame.
- Determine the building sizes and assign them to size strata for each sample segment.
- Develop a target sample size based on the agreed-upon statistical criteria for use in the stratification and sample size.
- Randomly select sample points from each sample, including backup points to substitute for buildings that did not participate.
- Recruit qualified buildings into the study.

The study was restricted to buildings with construction start dates between 2002 and 2004. This time period was selected for two reasons:

- It provides a large enough window to smooth out variations in building types constructed in any one year.
- Most buildings would be occupied and operating with at least one year of energy use available for tracking. This also allowed auditors to review the building after sufficient occupancy period to assess lighting installation, lighting and mechanical controls, and occupancy patterns.

3.1. The Dodge® Database

The Dodge® database is constructed from detailed information about building permit and construction data. As buildings move from the permit phase through completion, the Dodge® data are augmented by further survey information to determine construction completion, building size, value, and other details. The Dodge® database is reasonably accurate with respect to building size and building type; however, the definition of area for purposes of a construction tracking system sometimes conflicts with the definition necessary to understand building energy use. The field study provided the basis for area corrections within the sample.

For certain buildings, data collection and energy analysis was complicated by the fact that pre-existing and added areas are not separately metered or contain shared systems (particularly HVAC systems). Other complications included differing definitions regarding outdoor retail areas, unconditioned parking garages, unconditioned storage areas, etc. Even with these complications, the Dodge® dataset represents the most complete database of new building construction available in the country. It also identifies building vintage more completely and accurately than even permit records, since it reflects actual construction dates that often differ substantially from permit dates.

3.2. Data Screening

The initial Dodge® dataset contained 19,990 records. Prior to working with the data, non-building records were removed, including parking garages, unheated and unenclosed storage areas or other sheds for a variety of uses, water and sewer treatment facilities, and highway and other civil infrastructure projects.

The initial screening of the Dodge® dataset combined or dropped entries that had duplicate entries. This usually was the result of later entries that reflected a later start date or a later bid phase. In some cases, there was a renovation attached to a new addition and both projects had the same Dodge® reference number. In all these cases, the first screening resolved the dataset to a single entry for each building. When this step was complete about 7300 separate building projects remained.

The next step was to remove projects that were alterations only and involved no new square footage. In this step, projects that were non-building or any low-rise residential buildings were also removed. A total of about 900 entries were screened in this step.

With the resulting database, buildings that were constructed outside of the designated timeframe for the study were identified and removed. This was mostly the result of project delays that caused building to start construction in 2005 or 2006 even though their nominal Dodge® start date was in 2004 or earlier. Similarly, some buildings entered the database from 2001 for the same reason. A net of about 100 buildings were removed in this process.

The next step removed "addition" projects with valuation less than $200,000 and a few anomalous entries (such as the clean-up of the Hanford Nuclear Reservation) which had been missed in the previous screening. This step removed about 200 building projects resulting in a final database of about 6100 buildings.

The final screening removed approximately 21 entries with insufficient data to identify the building or even the building type. Upon completion of the data cleaning steps, 6,079 projects were identified in the four-state region.

The definitions of building types used for this study included 14 categories. In some cases, the categories used by Dodge® were redefined to conform to the forecasting categories used for the Northwest Power Plan and for regional employment and space forecasts used in utility program planning. Table 3.1 and Table 3.2 summarize the final Dodge® characterization of the region's new commercial building stock by number of buildings and square footage respectively.

Table 3.1: Population (Number of projects 2002-2004)

Building Type	State				Region
	ID	MT	OR	WA	
Assembly	122	34	195	315	**666**
College	24	5	44	66	**139**
Grocery	16	5	33	54	**108**
Health	107	14	141	168	**430**
Hi-Rise Res	2	0	14	56	**72**
Hospital	18	5	30	62	**115**
Institution	43	12	84	117	**256**
Lodging	14	6	17	33	**70**
Office	340	56	364	582	**1,342**
Other	84	33	139	236	**492**
Restaurant	56	14	107	143	**320**
Retail	137	33	210	369	**749**
Schools	106	12	193	245	**556**
Warehouse	127	28	209	400	**764**
Total	**1,196**	**257**	**1,780**	**2,846**	**6,079**

Table 3.2: Aggregate Building Area in 1000 sq. ft., for buildings shown in Table 3.1

Building Type	State				Region
	ID	MT	OR	WA	
Assembly	1,627	435	2,668	5,990	**10,720**
College	852	102	1,182	2,163	**4,300**
Grocery	373	110	978	2,561	**4,022**
Health	1,396	435	3,284	5,842	**10,957**
Hi-Rise Res	330	0	2,330	6,464	**9,125**
Hospital	217	62	815	2,771	**3,865**
Institution	496	169	1,295	2,814	**4,775**
Lodging	875	205	672	1,945	**3,696**
Office	4,357	1,082	6,104	13,054	**24,597**
Other	945	308	1,527	3,616	**6,397**
Restaurant	237	85	728	763	**1,814**
Retail	3,539	1,476	6,060	10,489	**21,563**
Schools	3,333	263	5,962	9,816	**19,374**
Warehouse	1,946	411	5,568	13,013	**20,938**
Total	**20,522**	**5,144**	**39,173**	**81,303**	**146,142**

Two building types, "assembly" and "other," were removed from the population prior to sampling. These building types were treated separately and were surveyed by phone interviews to provide insights into the particular types of buildings and square footage estimates that make up these categories.

Table 3.3 and Table 3.4 show the regional sample frame with “assembly” and “other” building types removed. This reduced the overall population by about 1,200 buildings and reduced the total square footage represented by approximately 12%.

During recruitment and site visits, auditors occasionally determined that a building type was different from the original Dodge® classification. In some cases, this resulted in buildings being retroactively categorized as “assembly” or “other.” This explains why tables later in this report show entries in these building types even though they were screened out of the original data.

Table 3.3: Sample Frame Excluding "Assembly" and "Other"

Building Type	State				Region
	ID	MT	OR	WA	
College	24	5	44	66	**139**
Grocery	16	5	33	54	**108**
Health	107	14	141	168	**430**
Hi-Rise Res	2	0	14	56	**72**
Hospital	18	5	30	62	**115**
Institution	43	12	84	119	**258**
Lodging	14	6	17	33	**70**
Office	340	56	364	583	**1,343**
Restaurant	56	14	107	143	**320**
Retail	137	33	210	369	**749**
Schools	106	12	193	245	**556**
Warehouse	127	28	209	400	**764**
Total	**990**	**190**	**1,446**	**2,298**	**4,924**

Table 3.4: Aggregate Building Area in 1000 sq. ft., for Buildings Shown in Table 3.3

Building Type	State				Region
	ID	MT	OR	WA	
College	852	102	1,182	2,163	**4,300**
Grocery	373	110	978	2,561	**4,022**
Health	1,396	435	3,284	5,842	**10,957**
Hi-Rise Res	330	0	2,330	6,464	**9,125**
Hospital	217	62	815	2,771	**3,865**
Institution	496	169	1,295	3,364	**5,325**
Lodging	875	205	672	1,945	**3,696**
Office	4,357	1,082	6,104	13,254	**24,797**
Restaurant	237	85	728	763	**1,814**
Retail	3,539	1,476	6,060	10,489	**21,563**
Schools	3,333	263	5,962	9,816	**19,374**
Warehouse	1,946	411	5,568	13,013	**20,938**
Total	**17,950**	**4,401**	**34,977**	**72,447**	**129,775**

3.3. Sample Designs

Stratified random samples were developed for the region by state for four individual building types, and for several participating utilities following guidelines developed for previous baseline studies using the Dalenius-Hodges procedure (Cochran 1977).

Three strata were created based on building square footage. Stratum boundaries were constructed to minimize the variance in building area in any one stratum, which allowed the sample size to be minimized. The sample was then allocated so that each stratum represented roughly a third of the total sample. Each sample was assembled based on a 90% confidence interval, with significance criteria of 10%. This meant that there was a 90% chance that the mean of the sample would not be statistically different from the mean of the entire population.

Prior to developing the final sample, the 72 "Hi-Rise Res" buildings were derated by reducing the building areas by a factor of four, thereby relocating them into the lowest stratum. These buildings were derated on the assumption that they were mostly mixed-use buildings with 20 to 30% of their area devoted to retail or other commercial activities. While these buildings often appeared in the final sample, only those with this mixed-use characteristic were subsequently recruited. Other buildings with essentially residential characteristics such as college dormitories and assisted living facilities were not adjusted, so substantial residential uses were included in the final sample.

The sample design uses the three strata to minimize the number of buildings needed to represent a population that is naturally highly skewed—in the commercial sector, half of the buildings are quite small (less than 10,000 sq. ft.) but the sum of the area of that half only represents 11% of the commercial construction square footage. Conversely, the largest 20% of the buildings represent about 70% of the overall square footage. Both of these size ranges must be considered in characterizing this sector, but the variance in the size of buildings suggests that a simple random sample (in which all buildings would have an equal chance of selection) would have to be very large in order to represent the entire sector. Using standard sampling techniques, a sample size of about 1,200 buildings would be suggested for a population of about 5,000 buildings. This is well beyond the capacity and resources of this or any similar project. However, the use of stratification and weighting, as explained below, allowed a statistically significant sample for the entire region to be represented by a much smaller number—a reduction of over 80% compared with standard simple random sampling technique.

Literature on sampling suggests that the optimum sample balances the resources available with the precision required. To achieve this balance, the sample was divided into strata, which were selected to construct a more reasonable variance for that section of the population. In doing this the great bulk of the individual buildings were gathered as the smallest buildings and sampled with a rigorous random sample. The largest buildings still have a very large variance but since they represent less than 10% of the population they can be sampled with a very high rate (60% in this case) and relieve the rest of the sampling of the need to represent these large buildings.

The three strata design that minimized the internal variance in the smaller buildings was repeated for each state. This allowed the state sample to represent the characteristics of the buildings in individual states without concern for the dominance of both the building types and populations of the larger states (Washington and Oregon). This same process was used for the building type and utility samples.

The sampling process resulted in a different stratification design for each state population. In the case of the utilities, however, the stratification of the states in which the utility service territory was located was used. This was a suboptimum design that resulted in slightly larger samples but also resulted in a maximum overlap between the state samples and the utility samples so both could benefit from the extra sampling points.

Once the sample design was finalized, a random sample was then drawn within each stratum in each state. This procedure provides a representative sample by state but does not necessarily provide a representative sample by building type or any sub-areas such as utility service territory. To meet the goals of NEEA and of various utilities, an additional set of overlapping random samples were therefore drawn to represent four particular building types, and four different utility service territories.

3.3.1. State Sample

Table 3.5 shows the distribution of the final state sample using the original building type classifications developed from the screening. This is the primary sample used to represent and compare each state. While this sample provides a minimum number of cases, supplemental samples were drawn to allow reliable statistical analysis at the building type and utility service territory level. The values in Table 3.5 do not include the supplemental samples drawn to represent specific building types or utilities.

Table 3.5: State Sample with Original Dodge® Building Type Classification (N)

Building Type	State				Total
	ID	MT	OR	WA	
College	5	1	2	3	**11**
Grocery	3	0	1	3	**7**
Health	4	2	3	6	**15**
Hi-Rise Res	1	0	2	2	**5**
Hospital	3	1	2	3	**9**
Institution	1	2	6	5	**14**
Lodging	0	1	1	2	**4**
Office	10	5	9	10	**34**
Restaurant	1	1	2	1	**5**
Retail	6	5	12	16	**39**
Schools	9	2	13	18	**42**
Warehouse	5	8	6	8	**27**
Total	**48**	**28**	**59**	**77**	**212**

As noted above, auditors occasionally determined that the building type was different from the original Dodge® classification. Therefore, the final state sample ended up with four "assembly" and five "other" buildings. Table 3.6 shows the resulting state sample with the final classifications. In all cases in this summary, buildings that were listed as "Hi-Rise Res" were audited only as the nonresidential spaces in the building. If there were no nonresidential spaces, the building was not included in the final sample.

Table 3.6: State Sample, Final Building Type Distribution (N)

Building Type	State				Region
	ID	MT	OR	WA	
Assembly*	1	0	1	2	**4**
College	3	1	2	1	**7**
Schools	9	2	12	19	**42**
Grocery	1	0	2	3	**6**
Health Services	5	2	2	3	**12**
Hospital	1	0	2	3	**6**
Institution	2	1	6	5	**14**
Office	7	3	7	5	**22**
Other*	2	2	0	1	**5**
Residential/Lodging	0	1	2	6	**9**
Restaurant / Bar	1	0	2	1	**4**
Retail	11	8	14	20	**53**
Warehouse	5	8	7	8	**28**
Total	**48**	**28**	**59**	**77**	**212**

* "Assembly" and "other" were not the original Dodge® classifications (see paragraph above).

3.3.2. Building Type Sample

Following discussions with project sponsors, additional buildings were sampled to represent four building types—grocery stores, hospitals, retail establishments, and schools—of particular interest to current regional efforts in a statistically significant manner relative to the region as a whole (i.e., without regard to state or utility boundaries). These samples were drawn to allow the maximum amount of overlap with the regional sample. Since these building types were sampled with a different design than the state samples, not all the building type samples could be used to enhance the state sample. Table 3.7 summarizes the final regional sample for the building types.

Table 3.7: Regional Sample of Targeted Building Types (N)

Building Type Sample Groups	State				Total
	ID	MT	OR	WA	
Grocery	4	0	4	11	**19**
Hospital	7	2	7	14	**30**
Retail	9	5	22	27	**63**
Schools	13	2	24	29	**68**
Total	**33**	**9**	**57**	**81**	**180**

3.3.3. Utility Samples

Individual utilities also requested enhancements to the regional sample that would allow their particular service territories to be characterized independently. Four such enhancements were made. These samples were designed with the same stratification boundaries used to develop the state samples. This allowed the maximum overlap between the enhanced sample and the state samples and thereby allowed the maximum coverage for the particular utility service territories. Idaho Power added ten buildings to the sample to increase the statistical reliability in its service territory. The Energy Trust of Oregon (ETO), which represents all of the investor-owned utilities in the state of Oregon, requested the Oregon sample be enhanced to allow most building types to be summarized for that state with similar precision to the regional sample. Therefore, approximately 40 buildings were added to the Oregon sample, which increased the confidence interval for that state to 95%.

In the Puget Sound region, four utilities paid for audits of additional buildings. Puget Sound Energy (PSE), Snohomish County Public Utility District (SnoPUD), and Tacoma Public Utilities (TPU) added to the sample so that representation of the entire Puget Sound region could be enhanced. These three utilities are referred to as “Puget Sound Not Seattle” (PSNS). Separately, Seattle City Light (SCL) requested additional buildings to ensure a statistically representative sample for its service territory and allow more robust comparisons between its population and others in the study. In addition, a few buildings were added within SCL’s sample to allow a partial characterization of buildings certified by the U.S. Green Building Council’s (USGBC) Leadership in Energy and Environmental Design (LEED®) program. There were several buildings in the original sample that were LEED certified. The utility asked for three buildings to be added to complete a contemporary picture of this program in the Seattle area.

Table 3.8 shows the final sample drawn for each utility including both the overlap with the state samples and the utility enhanced samples. This table does not include sample points that were only part of the building type sample nor those added for the SCL LEED enhancement that were drawn from buildings built outside this study’s overall sample frame.

Table 3.8: Regional Sample of Targeted Utilities (N)

Building Type	Utility Group				Region
	ETO	IPCO	PSNS	SCL	
Assembly	2	2	1	2	**7**
College	3	0	1	1	**5**
Schools	22	8	14	6	**50**
Grocery	3	1	4	0	**8**
Health Services	3	5	3	2	**13**
Hospital	4	1	1	3	**9**
Institution	9	3	6	3	**21**
Office	9	7	4	1	**21**
Other	2	2	1	0	**5**
Residential/Lodging	6	0	6	4	**16**
Restaurant / Bar	4	2	1	0	**7**
Retail	23	11	13	5	**52**
Warehouse	10	3	11	1	**25**
Total	**100**	**45**	**66**	**28**	**239**

Table 3.9 presents the final sample. Not included are two LEED buildings, seven multi-family residential buildings, and one chain retail store that were not built within the time frame of this sample. In the latter case, the store was added to get participation from a large retail chain.

Table 3.9: Final Sample of all Audited Buildings (N)

Building Type	Utility Group				Region
	ID	MT	OR	WA	
Assembly	2	0	2	4	**8**
College	3	1	3	2	**9**
Schools	11	2	24	30	**67**
Grocery	2	0	6	10	**18**
Health Services	5	2	3	6	**16**
Hospital	4	1	7	13	**25**
Institution	3	1	9	10	**23**
Office	7	3	9	8	**27**
Other	3	2	2	2	**9**
Residential/Lodging	0	1	6	11	**18**
Restaurant / Bar	3	0	4	1	**8**
Retail	15	8	23	32	**78**
Warehouse	6	8	9	17	**40**
Total	**64**	**29**	**107**	**146**	**346**

Recruiting results varied dramatically by building type and size. Non-response rates in previous studies have been at least 50%. In this study, recruiting was more successful and showed a non-response rate of about 38%. This level of success minimized the non-response bias that is inevitable in this type of study. For the most part no changes were made in the analysis or sampling strategy because of failures in recruiting. The samples presented here are based on the recruited and audited sample. In one case, PSNS, the sample size was reduced when all the buildings in Stratum 3 (large buildings) were either participating or had declined participation.

3.4. Work Type (Addition, Remodel, New Construction)

The Dodge® data, as constructed for the development of the sample frame, included major remodels and additions. These distinctions were difficult to distinguish within the designation categories of Dodge® and therefore the auditors were asked to keep track of the type of construction work that occurred. Table 3.10 shows the distribution of additions, remodels, and new construction by percent of projects.

Table 3.10: Work Type Classification of Regional Sample (% of projects)

State	New	Addition	Remodel	Total
ID	97	3	0	**100**
MT	94	6	0	**100**
OR	74	25	1	**100**
WA	76	23	1	**100**
Regional Average	**80**	**19**	**1**	**100**

Approximately 80% of the floor area of buildings reviewed was considered new construction. This classification was used when an entire building was new and was not connected to any adjacent building. The “addition” category refers to a building addition that was built with all the components of a new building except that it was attached to another building or complex. Note that while a new HVAC distribution system was always added, the main system is served by existing equipment. Additions were ubiquitous in hospitals and frequent in existing retail chain and franchise operations. Often additions also included significant remodels of other areas. A few cases were classified as remodels. In general, the remodel designation was used for buildings where the use of the building changed, it was completely gutted, and/or significant portions of at least two building systems had been modified. In these cases, such significant building alterations were made that for purposes of building codes or energy use these projects were submitted as new construction (and thus energy codes would be applicable to the remodeled portion of the building). In addition, the original Dodge® designation implied new added floor space that was not apparent when the building was audited.

3.5. Weighting Strategies

Weighting strategies are employed to ensure an unbiased estimate is produced from the data gathered at the individual buildings. To address this potential problem, a set of corrective weights was calculated from the inverse of the sampling probability in each stratum. For example, if there are 3,000 buildings in Stratum 1 and 30 of them are sampled, the sampling probability is 1% and the weight is 100 for each case. If in the same sample, Stratum 3 included 200 buildings with a sample of 30, the sampling probability is 15% and each case has a weight of 6.6. For purposes of the developing a population summary from these two strata, each building in Stratum 1 represents 100 buildings and each building in Stratum 3 represents 6.6 buildings. When combined, the analysis would use these weights to calculate means and probabilities of any characteristics surveyed. Note that generally the area of the individual building as well as the sampling weight is used so that the relative importance of the large buildings remains dominant in most summaries.

Since this study used several overlapping samples, some of the summaries used hybrid weights that reflected the sampling probabilities of each building type and each state. This resulted in a matrix of 144 cells (twelve building types, three strata, four states) each of which had a population and a sample, thus a sampling probability. When summaries of the entire sample were constructed this was the weighting used. In individual samples (by state, building type, and participating utility) a unique set of weights was developed representing only those subsets. When samples by state or utility were constructed, separate weights were calculated for those samples and used in the summaries.

The weights used for each sample are summarized in Appendix C. Table 3.11 summarizes the weights used when all the samples were combined. The weights shown here are averages of the sampling probabilities of the various subsamples. Each of the 12 cells represented in the table have in turn up to 12 other cells that are combined. Each of those cells has a unique weight based on sampling probability. The tables in Appendix C represent most of the alternative cell values as they were constructed from each successive sample.

Table 3.11: Case Weights and Sample (N) by State for Each Stratum

State	Strata Population and Weight (in parenthesis)			Total
	1	2	3	
ID	24 (29.9)	24 (8.7)	16 (3.4)	**64**
MT	9 (11.9)	10 (3.9)	10 (1.5)	**29**
OR	32 (33.0)	38 (8.2)	37 (2.0)	**107**
WA	36 (49.3)	61 (7.2)	48 (1.5)	**145**
Total N	**101**	**133**	**111**	**345**

Appendix C includes a detailed description of the samples and weightings used in this study. Even with this level of detail, there are summaries that use these weights that are not represented. Also in this appendix are the building area boundaries that appeared as a result of variations in building and project area when the audit was conducted. It is important to note that even when a building is larger than the initial sample design it is carried with the weights assigned to the stratum to which it was originally assigned. This is because these are sampling probabilities which are constant in any particular stratum but differ across strata in the sample design.

4. Basic Building Characteristics

Auditors asked building representatives a series of questions to discern building ownership, operation, operator training, and the use of any state, utility, or other programs that influenced the design and/or building operation. In some cases, the building representative was not familiar with, or immediately aware of, the decisions made during the construction phase of the project. Nevertheless, these inquiries provided an overview of the operational characteristics, especially as they relate to the particular operating conditions under which the building is managed. The utility conservation program data are not described here because they were insufficient to assess impacts of utility incentives and rebates. The auditors also asked about commissioning, and testing and balancing. When provided, reports on these activities were reviewed.

4.1. Building Ownership and Management

Table 4.1 shows the distribution of ownership types. As the table illustrates, the majority of private ownership is in the hands of corporations. In general, this designation included any kind of corporate structure that ended up owning the real estate, including a corporation that built the building for its own uses, or a developer or development company that developed a series of buildings for operation or resale.

Table 4.1: Building Ownership Designation of Audited Buildings by State (% Floor Area)

Ownership Type	ID	MT	OR	WA	Region
Corporation/REIT	62	56	41	50	**50**
Association	2	9	0	1	**1**
Education	22	5	22	18	**19**
Federal Gov.	1	11	1	1	**1**
Individual	1	5	7	5	**5**
Local/State Gov.	10	9	17	14	**14**
Nonprofit Institution	0	0	8	5	**5**
Partnership	2	1	2	2	**2**
Religious	0	3	2	1	**1**
Tribal	0	0	0	4	**2**
Total	**100**	**100**	**100**	**100**	**100**

* Table cells may not agree with totals due to rounding.

The precise corporate structure associated with real estate ownership was not always clear to either the auditors or the interviewed building operators. Thus, the use of investment trusts or other investment and ownership mechanisms was not well discerned. Nevertheless, a small percentage of the overall ownership was classified as real estate investment trusts (REIT) and was included with "corporation" in Table 4.1. The "association" category refers mostly to condo associations either in quasi-residential applications or in cooperatively-owned, nonresidential spaces. The "schools" category refers to school districts, as well as private educational institutions that operate a school facility as their primary focus. Other types of nonprofit institutions such as museums, certain types of retirement homes, and hospitals are listed as nonprofit institutions. Private for-profit ownership represents almost 60% of the floor area surveyed in this study.

Table 4.2 shows the distribution of building management. Mostly owners and their employees manage buildings in all ownership categories in the study. Property managers are typically assigned to larger facilities and are often used to operate shopping centers, office complexes, and hospital campuses. In general, these managers are under contract to the owners and their management is largely seamless with respect to the building's ownership. In a few smaller buildings, a tenant acts as the manager and is responsible for the building's operations.

Table 4.2: Building Management of Audited Buildings by Building Type (% Floor Area)

Building Type	Owner	Prop. Mgr	Tenant	Total
Assembly	100	0	0	**100**
College	88	12	0	**100**
Schools	100	0	0	**100**
Grocery	88	11	1	**100**
Health Services	68	32	0	**100**
Hospital	92	8	0	**100**
Institution	95	0	5	**100**
Office	70	28	1	**100**
Other	100	0	0	**100**
Residential / Lodging	90	0	10	**100**
Restaurant / Bar	77	0	23	**100**
Retail	84	12	3	**100**
Warehouse	90	7	3	**100**
Weighted Average	**89**	**8**	**3**	**100**

4.2. Building Commissioning and Test and Balance

During the review, auditors examined plans for indication of commissioning, asked on-site staff whether commissioning was completed, and looked for commissioning documents on-site. Table 4.3 summarizes the observed commissioning as gathered from available documentation or from direct conversations with the building operators. Commissioning included comprehensive commissioning with reports and deficiency lists, sites with plan notes requiring witnessed operational testing, and cases where the building representative stated commissioning had been done. In many cases, the building representatives participating in the audit process were not involved in construction of the project and so may not have been aware of commissioning activities. As a result, levels of commissioning were likely higher than this study shows.

Table 4.3: Reported Commissioning by State

State	% of Buildings Reporting Commissioning	% of Floor Area Commissioned
ID	8	28
MT	7	26
OR	22	35
WA	27	43
Weighted Average	**21**	**38**

There is a distinct difference between the states. Only a small number of buildings reported commissioning in Idaho and Montana, and most of these reported cases were relatively large public buildings. In Washington and Oregon, about 25% of all buildings were commissioned. As other baseline/characteristics studies have demonstrated, Washington and Oregon often lead the region in adopting certain measures. In this study, Washington required commissioning in buildings with complex mechanical systems, while Oregon's code did not contain similar language. Nevertheless, it appears that the use of commissioning was almost as significant in Oregon as in Washington.

Table 4.4 shows the distribution of commissioning by building type. This information demonstrates the relative importance of size and building type on building commissioning (at least as reported in this study). The building types reporting more than 50% of weighted square footage commissioned include colleges, schools, hospitals, and institutions.

Table 4.4: Reported Commissioning by Building Type

Building Type	% of Buildings Reporting Commissioning	% of Floor Area Commissioned
Assembly	0	0
College	52	56
Schools	52	66
Grocery	12	12
Health Services	3	36
Hospital	40	51
Institution	58	83
Office	5	29
Other	1	3
Residential / Lodging	11	24
Restaurant / Bar	0	0
Retail	16	38
Warehouse	5	3
Weighted Average	**21**	**37**

Surprisingly, over half of the commissioned buildings used a third-party commissioning agent. One possible caveat to this is that documentation at installer- and owner-commissioned projects was sparse. It is possible that this study under reports commissioning, with most commissioning being installer- or owner-based.

The auditors also tried to determine whether the building had undergone testing and balancing (TAB) by asking staff members or locating a TAB report. These reports were quite common whether the buildings were commissioned and were often referred to by commissioning agents where commissioning was apparent. Table 4.5 shows the percent of TAB reported by building type.

Table 4.5: Air Test and Balance Reports Found During Audits (by % Floor Area)

Building Type	No	Yes	NA	Unknown	Total
Assembly	0	67	0	33	**100**
College	22	78	0	0	**100**
Schools	4	83	1	12	**100**
Grocery	0	89	2	9	**100**
Health Services	9	69	3	19	**100**
Hospital	0	98	0	2	**100**
Institution	4	72	3	22	**100**
Office	12	86	2	0	**100**
Other	0	65	0	35	**100**
Residential / Lodging	19	75	0	6	**100**
Restaurant / Bar	0	74	0	26	**100**
Retail	12	56	2	29	**100**
Warehouse	25	31	25	19	**100**
Weighted Average	**12**	**65**	**6**	**17**	**100**

Sixty-five percent of the reviewed square footage indicated TAB had been completed. Larger projects provided a report and had substantial evidence that TAB was completed by the end of the construction phase. Interviewees whose building represented approximately 23% of the building floor area either could not respond to this question or did not have systems that required a TAB review. Only about 12% of the building floor area reviewed had no TAB reports but had systems that should have required such attention. When TAB is compared to commissioning, buildings that were commissioned had TAB reports in 98% of the cases; indeed, when TAB were implemented, 50% of those buildings actually received further commissioning in conjunction with the testing and balancing report.

4.3. Operations / Training

The commissioning requirements under the Washington code and the ASHRAE code require commissioners to provide a level of documentation and training to the building owner or operator. Table 4.6 shows the percent of operators interviewed that received some degree of direct operator training either in the specifics of their particular building or as part of professionally sponsored training for building operators. As Table 4.6 shows, approximately 30% of the building operators had completed building operator training.

Table 4.6: Operator Training as Reported by Building Operators (% of Buildings)

State	Type of Training Reported				Total
	BOC[†]	Other	None	Unknown	
ID	12	9	73	5	**100**
MT	14	34	49	3	**100**
OR	13	36	42	8	**100**
WA	11	8	69	12	**100**
Region	**12**	**19**	**60**	**9**	**100**

[†] BOC = Building Operator Certification

Auditors also asked building operators about the extent of operator training they received and whether they thought it was adequate to operate the building confidently. Table 4.7 shows the results of this question. The question focused mainly on building mechanical systems and controls and the training appears to have been adequate in about two thirds of the cases.

Table 4.7: Sufficient Operator Training of Building Operators (% of Buildings)

State	Was Training Sufficient?			Total
	No	Unknown	Yes	
ID	9	14	78	**100**
MT	3	3	94	**100**
OR	16	26	59	**100**
WA	21	12	67	**100**
Regional Average	**16**	**17**	**67**	**100**

4.4. LEED Buildings

Auditors questioned building contacts to determine if buildings participated in various utility programs, state programs, or other energy-related programs. Many of these contacts were uncertain about the status of LEED applications, so the USGBC was consulted to get the most current data. The most significant of these was the LEED program, which has become part of public policy in several places. Architects and engineers throughout the region have also shown an increased interest in this program. Section 8 presents more detailed information about architects' and engineers' interest. LEED has become the centerpiece of the City of Portland and the City of Seattle's civic policies. Both of these cities mandate LEED certification for public buildings and support certification with various development credits and utility incentives. The 2002-2004 study period corresponds to a relatively early stage in the LEED certification process and consequently a small fraction of the total buildings reviewed were LEED certified. Table 4.8 shows the distribution of LEED buildings in the four states. As the table shows, the LEED certification process is just beginning in Idaho and Montana; in Oregon and Washington, 10 and 12 buildings, respectively, were certified. All LEED certified or better buildings had one or more energy credits.

Table 4.8: LEED Certified Buildings Observed (N)

State	LEED Certification			
	Certified	Gold	Silver	Total
ID	0	1	0	**1**
MT	0	0	0	**0**
OR	0	5	5	**10**
WA	3	4	5	**12**
Total	**3**	**10**	**10**	**23**

Table 4.9 shows the number of energy credits achieved for energy efficiency, energy improvements, or energy-related operations credits. It is important to note that as of 2007, two energy points are a required as part of the Energy and Atmosphere portion of certification; this was not the case for the vintage of certifications observed in this study.

Table 4.9: LEED Energy Points Achieved (N)

Credits	Certified	Gold	Silver	Yes	Total
1-3	2	0	4	1	7
6-9	1	6	5	0	12
10-13	0	3	0	1	4
Total	3	9	9	2	23

4.5. Additional Programs

Auditors also asked questions to determine whether other building design programs were used in addition to LEED; for the most part the response was "no" or "unknown." One interesting question was whether benchmarking or energy tracking was used as part of either the building design or building operation. Table 4.10 shows the distribution of answers to that question. While the great bulk of the buildings reviewed did not use a benchmarking or tracking system, about 10% did.

Table 4.10: Method and Extent of Benchmarking Strategies Reported (N)

State	Energy Star	Internal	No	Unknown	Total
ID	0	5	56	3	**64**
MT	0	1	27	1	**29**
OR	0	9	65	33	**107**
WA	5	16	103	20	**144**
Total	**5**	**31**	**251**	**57**	**344**

The Energy Star system was reported exclusively by hospitals that were presumably recruited into the Energy Star benchmarking program through NEEA program offerings. Internal benchmarking was reported almost exclusively by retail chains and/or franchises. These building operators provide an energy tracking service that also enables comparison between individual stores.

4.6. Reported Problems

Auditors asked the building contacts whether there were problems beyond normal start-up issues. These questions yielded a variety of responses; however, the data must be carefully interpreted because one building's normal start-up issue may have been viewed as a major issue in another building. In general, the more complex the building, the more significant the problems were. To handle this, a severity level was created for each reported problem.

Problem severity was assigned during data analysis and is therefore rather arbitrary. Both the perceived effort to fix the problem(s) and the consequences of the problem(s) were utilized to determine severity. Problems assigned "Severe" involved issues that required, or appeared to require, additional engineering work to remedy. These severe issues include: critical zone issues in multi-zone systems which drive large amounts of reheat; 24/7 operation; severe pressure control issues, which in one case inflated the membrane roofing; and major equipment selection errors. Problems assigned "moderate" generally involved design issues that lead to intermediate discomfort. Many of these were control problems that may or may not have been fixable. All other problems were assigned to "minor" or "unknown." Minor problems were often little more than control issues that led to minor discomfort, or that were imminently fixable. Many buildings reported batches of bad ballasts and these were assigned "minor" status. Anything where the problem was indefinitely described was assigned to the "unknown" category. These most likely were "minor" problems, as anything more significant would have been reported in more detail.

In all, 198 projects representing 57% of the floor area reported problems. Many buildings reported multiple problems, although a majority of these were inconsequential. Table 4.11 summarizes all reported problems by severity and the system(s) affected.

Table 4.11: Problems Reported (N)

Severity	System Impacted by Problem					Total
	Energy	HVAC	Lighting	Refriger-ation	Windows	
Unknown	0	13	23	3	24	**63**
Minor	1	83	75	7	8	**174**
Moderate	7	43	16	3	3	**72**
Severe	2	20	0	0	0	**22**
Total	**10**	**159**	**114**	**13**	**35**	**331**

The buildings that reported at least one moderate or severe problem represented 19% of floor area. Buildings that reported at least one severe problem represented 6% of floor area.

By the time the audits were conducted, roughly 25% of the reported problems were resolved. When examined by problem severity, it is clear that minor problems are much more likely to be resolved. Likewise, ongoing problems seem to correlate with impacts on the building system. HVAC problems accounted for half of all problems and 20 of the 22 severe problems. Table 4.12 shows the HVAC problems categorized by critical zone issues, design problems, equipment issues, or install/start-up issues. The Critical Zone problems were also design related and involved zones that forced the system to run 24/7 and/or without reset so that the critical zone was conditioned. Half of the HVAC problems were categorized as design related problems. These problems included under-sized equipment, absence of control inputs, pressurization problems, and sub-zone control issues that test and balance and normal start-up procedures failed to resolve. Equipment issues were related to early failure of equipment. Install/start-up problems were hard to distinguish from design problems. Based upon the problem description it was decided that these problems would have been solved during a thorough start-up process.

Table 4.12: Reported HVAC Problems (N)

Problem Category	Unknown	Minor	Moderate	Severe	Total
Unknown	10	0	0	0	**10**
Critical Zone	0	0	0	5	**5**
Design Problems	0	31	28	9	**68**
Equipment Issues	1	16	6	3	**26**
Install / Start-up	2	36	9	3	**50**
Total	**13**	**83**	**43**	**20**	**159**

Lighting control and design problems were common but were typically minor; although occupants noticed the problems, there was no apparent effort to remedy them. Table 4.13 distinguishes the reported lighting problems by appropriate categories. Control problems were typically broken/disabled daylighting, confusing controls, and sites that wanted more control. These problems could also be considered design or install/start-up problems. Poor zoning of controls and under lit areas were the primary design problems. Equipment issues were typically reported as bad ballasts. Install/start-up problems were observed or reported, including scheduling problems and occupancy sensor control problems.

Table 4.13: Reported Lighting Problems (N)

Problem Category	Unknown	Minor	Moderate	Total
Unknown	3	1	7	**11**
Control Issues	3	21	0	**24**
Design Problems	0	17	4	**21**
Dislike	1	2	3	**6**
Equipment Issues	16	11	1	**28**
Install / Start-up	0	23	1	**24**
Total	**23**	**75**	**16**	**114**

Table 4.14 categorizes the 35 reported window problems. Most reported window problems were related to water leakage around the windows. Air leakage and blown glazing unit seals were less common but have been included in the leakage category. The “equipment issues” category is primarily problems with operable windows, although one building reported imploded windows. The install problems included a complaint that the initial cleaning left scratches on all the glass, and another where automatic shade controls were never set up properly. The two design problems were cases where large glass areas caused glare and heat issues that the shading and HVAC systems were not designed to handle.

Table 4.14: Reported Window Problems (N)

Problem Category	Unknown	Minor	Moderate	Total
Air/Water Leakage	23	2	0	**25**
Design Problems	1	0	1	**2**
Equipment Issues	0	5	1	**7**
Install / Start-up	0	1	1	**1**
Total	**24**	**8**	**3**	**35**

Table 4.15 classifies reported energy problems. Problems were categorized by billing issues, equipment issues, or high energy use. Of only 10 reported energy problems, two were severe

and six of the seven moderate energy problems were due to unexpectedly high energy usage. The perceived high energy use sometimes resulted from expectations that a new facility would perform better than a previously-occupied facility (such as schools or government buildings). While new buildings did in fact perform better than their predecessors did overly complex systems and poorly programmed controls occasionally led to higher than expected energy bills. Retail establishments that had good benchmarking of existing building consumption also reported energy problems. Typically, these high bill complaints did not have an identifiable cause. The one equipment issue was a leaking propane tank that caused extremely high bills.

Table 4.15: Reported Energy Problems (N)

Problem Category	Minor	Moderate	Severe	Total
Billing Issues	1	0	0	**1**
High Energy Use	0	7	2	**9**
Total	**1**	**7**	**2**	**10**

5. Lighting

The observed lighting systems continue a trend towards higher efficacy lighting systems and reduced lighting power densities in the region. Idaho and Montana have made incremental reductions in overall lighting wattage. To establish and examine these trends, lighting reviews were completed for each building.

The goals of the lighting reviews were to:

- Collect details on the technologies used.
- Categorize various control strategies implemented.
- Establish current lighting power densities (LPD).
- Determine code compliance with relevant state energy codes.
- Identify problems with lamps, ballasts, and controls.

5.1. Identification of Lighting Technologies and Control Strategies

Individual fixtures and lamps were assessed using a combination of sources. Where possible, lighting plans and schedules included in the building plans were used as the primary information source. In most cases, building owners or architects provided plans that included fixture layouts and schedules with fixture type, lamp type, lamp watts, and switching and control details. These documents were used to develop the initial assessment of the lighting plans and fixture types, but occasionally changes had been made to either fixture layout or fixture selection during the construction process. The auditors reviewed lamps and fixtures on-site. This involved spot checks of major fixtures, fixture information research using O&M manuals, and discussions with the building's maintenance staff. The combination of documentation and on-site sources provided a reasonably successful estimate of both lighting watts and fixture technologies used.

Control strategies and technologies were determined using a combination of plan review and field audit. Plan notes often indicated control strategies and occasionally delineated daylighting zones. In some cases, wiring diagrams were used to quantify lighting controls by fixture type. During building walk-throughs auditors verified existence of controls and recorded control capabilities.

5.2. Lighting Power

In the current study, the lighting audit procedures largely mirrored the previous baseline study, which used a broad space-by-space model. The auditor conducted fixture counts by major functional space types. The square footage of each of the space types (e.g., retail display, general illumination) that are regulated by at least some regional lighting codes were calculated for each building. Individual subspaces were tracked and fixture identifications were assigned to each subspace. For example, in the case of a school, the auditor defined subspaces such as classroom, corridor, gymnasium, and kitchen and recorded the floor areas, fixture counts, and fixture descriptions for each subspace.

Fixture lighting power was assigned based upon the best available data. Fixture watts from the plans or submittals were used when available. If unavailable, fixture watts were assigned default watts based upon lamp and ballast type and configuration. Fixtures were characterized by the lamps installed. This approach was used to provide the best possible data to explain the actual building energy consumption. Although both incandescent fixtures and many compact fluorescent (CFL) fixtures allowed lamps with wattages other than those observed. All of the standard 4' T8 fixtures observed used 32W lamps. However, some buildings indicated they were switching to high performance T8 lamps using 30W, or in one case 25W. This flexibility caused some deviation from strict code accounting because codes require incandescent fixtures to be counted with the maximum allowable lamp wattage. In the codes used, fluorescent fixtures were not subject to this same requirement; however, current codes implemented after the study period require all ballasted fixtures to use the maximum wattage in the lighting power allowance (LPA) calculation. As ballasts gain more capabilities in the future, ballasted fixture wattage will be challenging to determine.

It is important to note that this study audited occupied buildings while previous new construction baseline studies audited buildings under construction or very recently occupied. This difference could affect the comparison of LPDs between the two studies because buildings in the current baseline study had been occupied for at least a year, and up to three years longer than buildings in previous studies. In some cases, lighting systems had already been retrofit to fix design issues, accommodate a new marketing look and feel, or to convert incandescent to CFL fixtures. Furthermore, information about equipment, which was easily accessed during construction in previous studies, was much more difficult to track down in this study because records were not always available. To the extent possible, audits reflected the buildings' lighting at the time of the audit.

5.3. Lighting Technologies

Lighting technologies (including lamp and fixture types and controls) were determined by direct observation during the field audit and/or from lighting specifications in the plans or O&M manuals.

5.3.1. Lamps

Lamps were divided into five classes: compact fluorescent (CFL), linear fluorescent (LF), high intensity discharge (HID), incandescent, and other. Table 5.1 shows the distribution of lighting wattage by these classes and compares them to the distribution observed in 1998. In general, the lighting wattages and technologies observed here are comparable to the previous survey. HID lighting decreased significantly from the previous study.

The overall efficacy of the lighting systems has not changed dramatically. Since the 1998 study improvements from the reduction in T12 technology, increases in T5 technology, the conversion of standard HID lighting to fluorescent, and pulse start technology have been largely offset by an increase in incandescent lighting. Increased incandescent levels are due to the relatively large amount of lodging, assisted living, college dormitories, and other residential space in the sample that have high levels of incandescent lighting. The previous study did not include dormitory or assisted living buildings. In the current study, college dormitories were a large fraction of the college sector, and assisted living facilities made up 60% of "Lodging." Removing dormitories and assisted living facilities would lower the incandescent fraction to 11% thus levels of incandescent lighting would be comparable between the studies.

Primary applications of incandescent lights found in this study include residential-style wall and ceiling surface mounted fixtures, retail display lighting, decorative chandelier and pendant lighting, and MR16 lighting. Retail display accounted for 20% of incandescent watts, and various decorative fixtures (including MR16) amounted to another 20%. Residential-style fixtures, mostly in residential applications and bathrooms, dominate the remaining incandescent lamps. Several buildings constructed with incandescent lamps had already been retrofit with screw-in CFL lamps mostly to reduce bulb-changing frequency; in these cases, fixtures with CFL lamps were recorded as CFL.

Table 5.1: Distribution of Lamp Type (% of Total Lighting Watts)

Building Type	CFL	LF	HID	INC	Other	Total
Assembly	12.5	60.0	15.5	12.0	0.0	**100**
College	17.3	52.0	0.5	30.3	0.0	**100**
Schools	12.4	72.1	11.5	4.0	0.0	**100**
Grocery	1.3	69.2	17.1	12.0	0.5	**100**
Health Services	11.8	69.8	5.4	13.0	0.0	**100**
Hospital	16.7	69.7	1.2	11.7	0.8	**100**
Institution	14.2	65.5	2.4	17.6	0.4	**100**
Office	9.8	78.1	2.6	9.5	0.0	**100**
Other	5.0	73.1	17.2	4.7	0.0	**100**
Residential / Lodging	14.9	22.4	0.6	55.4	6.8	**100**
Restaurant / Bar	14.8	56.0	1.0	28.2	0.0	**100**
Retail	5.3	55.4	24.4	14.5	0.4	**100**
Warehouse	0.8	34.9	60.6	3.8	0.0	**100**
Avg. of All Bldg. Types	9.1	57.8	17.3	15.1	0.8	**100**
1998 Average	**4.5**	**57.9**	**27.9**	**9.5**	**0.2**	**100**

LF technologies dominate lighting systems in virtually all building types. At the time these buildings were designed, higher efficiency T5 LF technologies were well established but high performance T8 technology was still very new. These technologies represent a 15% reduction in lighting power for the same lumens. Table 5.2 shows the distribution of LF lamps representing approximately 60% of the lighting power in the nonresidential sector. The higher performance options are increasingly more common in at least some applications within the commercial sector. T12 lamps have been greatly reduced since previous studies. The change was primarily in Idaho and Montana where previously T12 lamps were about 20% of LF wattage.

Table 5.2: Distribution of Linear Fluorescent Lamps (% of Total LF Watts)

State	Linear Florescent					Total
	T12	T5/T5HO	T8	T8HP	Other	
ID	6.8	7.7	76.0	9.5	0.1	**100**
MT	2.0	13.7	83.8	0.3	0.2	**100**
OR	0.6	19.1	78.7	1.5	0.1	**100**
WA	1.6	9.4	88.2	0.7	0.1	**100**
Region	2.1	12.1	83.5	2.2	0.1	**100**
Region 1998	10.2	0.0	87.6	0.0	2.20	**100**

HID lighting declined noticeably since the previous study. This may be because 25% of the high bay fixture wattage uses fluorescents. Countering this trend is the use of smaller HID fixtures for interior lighting, both architectural and for display illumination in retail. The advent of the ceramic metal halide (CMH) lamp, which has applications for display and accent lighting in the retail sector, had a noticeable impact on the lighting designs observed. Although the CMH technology has only recently been introduced, CMH lamps account for 1% of all lighting watts and 6% of all HID watts. Up-and-down accent lighting, display lighting, and track heads all have a number of CMH installations. Approximately 40% of the CMH wattage is associated with fixed downlights, 40% with various architectural accent lights, and 20% is found in track heads. HID sources account for 8% of all track light wattage, with CMH accounting for two-thirds of that. Table 5.3shows the distribution of HID lamps; these are still dominated by metal halide (MH) and high-pressure sodium (HPS), which are mainly used in the warehouse and manufacturing sectors. A small amount of CMH lamps were observed in this study but this technology was relatively new in the market when these lighting systems were designed.

Table 5.3: Distribution of HID Lamps (% of Total HID Watts)

HID Lamp Type	ID	MT	OR	WA	Total
HID	0.0	0.0	0.0	2.4	**1.6**
HID-CMH	1.7	0.0	2.8	7.1	**5.6**
HID-HPS	0.2	6.2	1.5	23.0	**16.2**
HID-MH	98.1	93.8	95.7	67.5	**76.6**
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

5.3.2. Ballasts

Table 5.4 shows the distribution of fluorescent ballasts. Electronic ballasts have displaced virtually all other types of ballasts in the region. A significant fraction of ballasts, especially in Washington, is based on dimmable technologies often associated with daylighting control, but in some cases local manual lighting control. Most of this group was associated with large buildings using utility incentives and/or seeking LEED certifications. High performance electronic ballasts are uncommon, barely surpassing magnetic ballasts. This seems attributable to the fact that high performance T8 technology was not well established during the design window for these buildings (2001-2003). Several of the retail chains, one very large warehouse developer, and several hospitals indicated high performance T8 systems are being used in new designs.

Table 5.4: Distribution of Fluorescent Ballast Types (% of Total Fluorescent Watts)

Ballast Type	ID	MT	OR	WA	Total
Dimmable Electronic	0.5	2.3	3.5	10.9	**6.7**
Efficient Magnetic	0.7	0.7	0.5	1.2	**0.9**
Electronic	98.8	96.8	95.6	86.0	**91.3**
High Performance Electronic	0.0	0.3	0.5	1.9	**1.1**
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

* Table cells may not agree with totals due to rounding.

Auditors did not indicate ballast type for a large number of HID fixtures. As Table 5.5 shows, for the portion with known ballast determinations, pulse start made up 50% of the watts, electronic 7%, and magnetic 43%.

Table 5.5: Distribution of HID Ballast Types (% of Total HID Watts)

Ballast Type	ID	MT	OR	WA	Total
Electronic	8.3	0.1	1.7	1.8	**2.5**
Magnetic	6.3	5.5	32.4	13.5	**15.8**
Pulse Start	21.1	0.0	23.2	17.0	**18.2**
Unknown	64.3	94.4	42.8	67.7	**63.5**
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

5.3.3. Exit Lights

Exit lights were accounted for separately. These are normally exempt from LPD calculations. To reduce audit time, exit lights were categorized on a building basis, but not counted. Table 5.6 shows the distribution of exit lights. This table shows the regional dominance of LED exit lights to the exclusion of virtually every other technology. Only electroluminescent fixtures that do not draw any power showed any other significant saturation. A single chain that has chosen this exit sign technology is responsible for most of this later group. The previous study saw much greater use of CFL and incandescent technology. These have almost completely vanished in this sample.

Table 5.6: Distribution of Lamp Types Observed in Exit Lights (% of floor area)

Exit Lamp Type	ID	MT	OR	WA	Total	1998
CFL	0.0	0.0	0.0	1.9	**1.3**	**6.3**
ELECTRO LUM	0.0	0.0	37.0	26.6	**27.6**	**4.5**
Non-Specific Fixture	0.0	0.0	3.7	0.0	**1.1**	**--**
INC	0.0	0.0	0.0	1.4	**0.9**	**9.4**
LED	100.0	100.0	59.3	70.0	**69.2**	**79.7**
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

5.4. Lighting Controls

Lighting controls have advanced considerably in their saturation since the last study. Table 5.7 shows the distribution of lighting controls by class.

Where the controls could be directly compared to previous studies' findings, the application of controls seems to have increased by a factor of four across the board. Furthermore, when the entire sample is reviewed, approximately 70% of the floor area of the buildings is controlled by some sort of automated lighting control strategy including daylighting, occupancy sensors, sweep controls, or other kind of EMS controls. This represents a considerable increase over what was observed in the last baseline study.

Table 5.7: Distribution of Lighting Controls (% of Floor Area Controlled by Particular Strategy)

Control Type	State				Region	
	ID	MT	OR	WA	2002-2004	1996-1998
Sweep	39.6	24.8	34.0	39.1	**37.4**	**8.9**
Lighting EMS	16.7	19.8	31.5	40.8	**33.6**	**--**
Daylighting	0.8	0.0	17.5	24.6	**17.9**	**4.1**
Occupancy	43.4	31.1	53.2	45.6	**46.8**	**5.3**
Multi-Level Switching	53.8	51.6	38.3	34.4	**39.2**	**--**

In both studies, many lighting controls were improperly set up, poorly scheduled, or disabled because of occupant interactions or dissatisfaction. Approximately 25% of the reported lighting problems were due to lighting control issues. Despite these complaints, from the point of view of energy efficiency, controls offer the best opportunity for energy savings in lighting systems. Their ever-increasing saturation suggests that a program to design, commission, and operate lighting systems could be extremely effective in many building types.

Occupancy sensor (OS) controls in classrooms, enclosed offices, and other enclosed spaces, are common. Much less common are OS controls in large spaces such as gyms, school corridors, and warehouses even when fluorescent fixtures are installed. However, there are examples of buildings successfully deploying OS controls in these latter spaces. Extending OS use into school gyms and corridors has significant potential energy savings because these spaces are often on extended schedules with long periods of non-use. Warehouse and storage areas are often partially used and may have certain areas that are frequently used while another area is totally vacant. In this case, OS and multi-level switching could be combined to greatly reduce the energy use.

Multi-level switching is common and was observed in a variety of applications in schools and offices. Manual switch-controlled, continuous dimming systems were included in this designation. Based upon teacher feedback and direct observations, dual level switching is much more likely to be utilized than “day light control zone” switches which are now required in Washington.

Automatic sweep controls were observed in many offices and retail buildings. Schools and other buildings with regular custodial staff often employed manual sweep control (in some cases this was true even when automatic sweep controls were installed).

Despite time clocks, OS, and sweep controls, significant amounts of lighting are left on at night and off hours. While this is often related to low level use such as product stocking of retail spaces, there is a strong trend toward leaving the emergency lighting circuits on around the clock. These circuits often have significant lighting watts associated with them. In one high school visited during the summer, the hallways were found to have 17 to 30 foot candles of light in the "off" mode. Classrooms often have 10% of the lighting load on the emergency circuit. This was primarily found in buildings with diverse schedules such as schools, colleges and hospitals but also in other buildings. In all, 70% of buildings were found to have lighting on at night that was not related to code requirements for egress.

5.4.1. Daylighting

Daylighting controls appeared in about 10% of the buildings audited representing 18% of total floor area.

Table 5.8 shows the distribution of daylighting by building type.

Table 5.8: Distribution of Daylighting

Building Type	% Buildings with Daylighting	% Floor area in Buildings with Daylighting
Assembly	42.	53
College	17.	21
Schools	31.	27
Grocery	2.	11
Health Services	1.	13
Hospital	16.	22
Institution	6.	34
Office	11.	10
Other	0.	0
Residential / Lodging	2.	5
Restaurant / Bar	0.	0
Retail	5.	27
Warehouse	0.	0
Total	10.	18

Table 5.9 summarizes daylighting control based on the daylight source:

- **Side daylight**. Refers to lighting control that responds to daylight from windows that light some part of the space. These are typically more complicated and involve daylight sub-zones in the control.
- **Top daylighting.** Usually uses skylights to control overhead lighting fixtures. These are common in big box retail designs and in some warehouse applications. The control addresses some fraction of the overhead lighting with step dimming or dimming ballasts.
- **Mixed control.** Refers to buildings with both an overhead lighting resource (such as skylights or clerestory) and side daylight from windows.

Table 5.9: Location of Daylight Source

Daylight Source	Number of Projects	Project Floor Area (%)	% of Floor Area Controlled	Percent Disabled
Side	27	5.2	30.5	15.3
Top	13	5.4	73.9	4.3
Mixed	14	7.2	28.5	3.6
Total	**54**	**17.8**	**43.0**	**6.7**

Daylighting control is surprisingly common. Fifty-four projects with 18% of floor area reported some sort of daylighting control in the design. Daylighting systems generated a significant number of complaints and eight of these projects had disabled or non-functioning systems. Notably, these were mostly side daylight configurations. The dimming configurations varied. A number of very successful top daylight projects utilized step dimming.

5.5. Lighting Power

The overall picture of lighting fixture and lamp technologies suggests progress, but overall lighting power shows very little change between the previous baseline study and this study. Because of the timing of this study there was minimal change in lighting code requirements from the previous study. That coupled with differences in the sample (especially in Idaho) introduce uncertainty into the lighting comparison with the previous studies.

The lighting for each building was divided into several categories. These included fixed or ambient lighting that provide the bulk of connected watts; display lighting as defined in the Washington code; display rack-mounted lighting; and exempt lighting including stage, sign, and display case lighting. Track lighting was identified and included as a separate item to be evaluated, usually with display lighting.

The LPD values reported in Table 5.10 include general and display lighting for both the current and the previous study. Typically code-exempt lighting such as case and rack-mounted lights and lighting for sale are not included in the LPDs reported here. LPD improved significantly in Idaho and Montana but is unchanged in Oregon and Washington. Some of the change in Idaho and Montana is due to improved lighting technology, particularly the reduction in T12 lighting; however, differences in building type distribution in the sample for each state can affect this significantly. The low lighting power in Idaho is partially explained by the larger proportion of warehouses relative to the entire sample and the lower lighting power in Idaho warehouses compared to other states' warehouses. This tends to reduce the overall LPD of the Idaho sample.

Table 5.10: State Average LPD from Current Study and Previous Baseline Studies (Watts/Sq. Ft.)

State	2002-04			1995 WA, 97/98 ID, MT, OR		
	LPD	Std. Dev.	N	LPD	Std. Dev.	N
ID	0.90	0.50	64	1.24	0.33	48
MT	1.13	0.47	29	1.25	0.32	32
OR	1.09	0.44	107	1.11	0.43	63
WA	1.15	0.45	146	1.15	0.59	88
Region	**1.08**	**0.46**	**346**	**1.16**	**0.45**	**231**

Table 5.11 shows the average code lighting power allowance (LPA) from the application of appropriate energy codes to both the present and previous baseline sample buildings. ASHRAE 90.1-1989 was used for Idaho and Montana in the previous study. In this study the Idaho buildings were largely permitted under IECC 2000. The average LPDs in Table 5.10 compare to the code LPA requirements in each state with a similar ratio of 15%.

Table 5.11: Code LPA Requirements During 2 Sampling Periods (Watts/ Sq. Ft.)

State	2002-04			1996-98		
	LPD	Std. Dev.	N	LPD	Std. Dev.	N
ID	1.21	0.46	64	1.58	0.55	48
MT	1.80	0.72	29	1.42	0.42	32
OR	1.36	0.37	107	1.30	0.28	63
WA	1.26	0.38	146	1.28	0.38	88
Region	**1.31**	**0.45**	**346**	**1.36**	**0.40**	**231**

When building type is reviewed, the features of this sample across states continue to suggest that the distinctions between the states and state codes have become much less significant than in previous studies. Table 5.12 summarizes the total LPD by building type. The results of the previous baseline are also shown. No consistent pattern of change in LPD is observable although important categories such as Office and Schools do show a substantial decrease.

Table 5.12: LPD by Building Type and State (Watts/ Sq. Ft.)

Building Type	ID	MT	OR	WA	Total	1996-98
Assembly	0.94		1.15	1.04	1.05	**1.25**
College	0.98	0.88	1.13	1.01	1.03	
Schools	1.25	0.85	0.97	1.12	1.09	**1.20**
Grocery	1.40		1.52	1.59	1.57	**1.70**
Health Services	1.37	1.81	1.62	1.33	1.38	**1.25**
Hospital	1.21	1.91	1.44	1.17	1.25	
Institution	1.05	1.21	1.31	0.95	1.10	**1.13**
Office	1.08	1.09	1.01	1.02	1.03	**1.18**
Other	0.73	1.38	1.05	0.81	0.85	**1.18**
Residential/Lodging		0.66	0.94	1.35	1.23	**0.76**
Restaurant / Bar	1.24	--	1.54	1.77	1.45	**0.94**
Retail	1.27	1.43	1.38	1.48	1.42	**1.30**
Warehouse	0.30	0.81	0.57	0.72	0.59	**0.92**
Total	0.90	1.13	1.09	1.16	1.09	**1.17**

5.5.1. Exterior Lights

Exterior lighting was assessed and usually observed in unheated parking garages, parking lots, and a variety of building decorative lighting and signage. In some cases, especially in large retail, this also included outdoor sales areas for garden supply and similar retail uses. Table 5.13 shows the distribution of exterior light technologies by state. This summary includes exterior lighting technologies in all applications including exterior grounds, parking, building, covered garage, and exterior sales lighting. HID lighting is dominant.

Table 5.13: Exterior Light Technology (% of Exterior Watts)

Exterior Lamp Type	ID	MT	OR	WA	Total
CFL	0.5	0.5	6.4	2.4	**3.9**
LF	0.7	4.5	3.8	10.1	**6.7**
HID-CMH	0.0	0.0	0.1	2.8	**1.4**
HID-HPS	0.0	0.0	13.8	13.0	**12.2**
HID-MH	98.2	94.3	73.8	69.2	**73.6**
INCANDESCENT	0.6	0.8	1.6	1.4	**1.4**
LED,INDUCTION,UNK	0.0	0.0	0.5	1.2	**0.8**
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Saturation and LPDs were calculated separately for exterior covered parking garages, exterior retail lighting, and the remainder of exterior lighting. These data are presented in Table 5.14.

Table 5.14: Exterior Lighting Ratios

Building Type	ID	MT	OR	WA	Total
Garage Per Sq. Ft. (sq. ft./sq. ft.)	0.014	0.000	0.038	0.076	**0.053**
Garage LPD (w/sq. ft.)	0.35	-----	0.26	0.15	**0.18**
Exterior Sales Per Sq. Ft. (sq. ft./sq. ft.)	0.014	0.043	0.005	0.005	**0.008**
Exterior Sales LPD (w/sq. ft.)	0.91	0.93	0.82	1.05	**0.88**
Remaining Exterior LPD (w/sq. ft.)	0.18	0.19	0.23	0.23	**0.22**

"Garage Per Sq. Ft." is the parking garage area per square foot of total project area. This includes buildings without garages. Exterior covered parking garages were found in three states and have specific lighting power allowance in each of the region codes. Idaho and Montana reported very little covered garage area. However, there are some semi-heated interior garages that are included with the interior lighting. Oregon and Washington have much higher ratios of garage floor. This is attributable to density and perhaps zoning codes.

The treatment of these garage spaces in the sample frame in uneven due to irregularities in the F.W. Dodge® data. Generally, garages have not been included in the sector areas. As such, an additional 5% over the total population area occurs in the form of parking garages.

"Garage LPD" shows the average LPD of the garages found. Included in this number are incidental storage and mechanical areas within the garage.

Exterior sales areas are outdoor retail sales areas inside the building's security perimeter. They can have hard opaque or translucent canopies, or open roofs. Exterior Sales Per Sq. Ft. is the amount of exterior sales area per square foot of all interior buildings. The Exterior Sales LPD is the average LPD of the exterior sales area. The Exterior Sales LPDs are often similar to interior spaces. Areas occupied by moveable carts under entrance canopies were not included.

The remaining exterior lighting is presented as the "Remaining Exterior LPD". The LPD is a function of the enclosed project area (the area used to calculate interior LPDs). The exterior watts do not include garage or exterior sales lighting. The project floor area only includes enclosed floor space.

Table 5.15 presents the amount and LPD of the parking garages by building type. Included in this number are incidental storage and mechanical areas within the garage. Residential/lodging structures had the largest garage area. The LPDs in Table 5.15 are calculated based on the garage floor area. The "garage sq. ft." is the total garage area divided by the total enclosed area.

Table 5.15: Ratio of Parking Garage Floor Area to Enclosed Project Area

Building Type	Gar Sq. Ft./Sq. Ft.	LPD	Std. Dev.
College	0.057	0.09	0.01
Health Services	0.026	0.32	0.02
Hospital	0.076	0.28	0.10
Institution	0.069	0.28	0.10
Office	0.159	0.17	0.03
Residential / Lodging	0.324	0.15	0.09
Retail	0.029	0.20	0.03
Average	**0.053***	**0.18**	**0.04**

*Includes all building types

Table 5.16 presents the amount and LPD of exterior sales areas by building type. Exterior sales areas were limited to grocery and retail building types. Table 5.16 also summarizes the occurrence of exterior retail space in the region. The reported values are the total exterior sales area normalized by the sector total enclosed project area. The total column is the ratio to all buildings, not just retail and grocery.

Table 5.16: Ratio of Exterior Sales Floor Area to Project Area

Building Type	Total	LPD
Grocery	0.013	0.94
Retail	0.034	0.95
Average*	**0.008**	**0.88**

*Includes all building types

Table 5.17 presents the remaining exterior lighting LPD by building type. The LPD is a function of the project area (the area used to calculate all other LPDs and project weights). This LPD does not include garage or exterior sales lighting. The project floor area only includes enclosed floor space. The restaurant building type has a significantly higher exterior light LPD. It is important to remember that these are buildings that are classified as restaurants and do not include restaurants that are part of other larger facilities such as strip malls. "Schools" is also relatively high due to the inclusion of sports field lighting.

While the survey did not explicitly break out parking area lighting, it was noted that a majority of exterior lighting is associated with parking lots. Sector parking lot area is reported and normalized by building area in Table 5.17.

Table 5.17: Exterior Lighting Power Density (Watts/Enclosed Sq. Ft.)

Building Type	Non-attributed Exterior Lighting LPD	Parking Lot Area per Total Sector Area
Assembly	0.19	0.43
College	0.19	0.70
Schools	0.35	0.42
Grocery	0.28	1.38
Health Services	0.25	0.60
Hospital	0.07	0.07
Institution	0.13	0.27
Office	0.15	0.68
Other	0.23	0.60
Residential / Lodging	0.06	0.16
Restaurant / Bar	1.04	1.34
Retail	0.32	0.96
Warehouse	0.10	0.27
Average	**0.22**	**0.53**

5.5.2. Aggregate Lighting Power

Since the various codes exempt or include different lighting categories Table 5.18 presents lighting classification independent of code status:

- **Display lighting** is generally part of the code LPD (especially in Washington) but here is defined separately using the code definition from the Washington energy code. This lighting is generally part of the permanent lighting in the building and usually regulated as part of tenant improvements in individual buildings.
- **Exempt lighting**, by definition, is not included in lighting code compliance. Exempt categories included: medical/dental lighting, theatrical lighting, display case lighting, lighting for sale, and certain dedicated security lighting. Medical/dental lighting and theatrical/stage lighting were not generally included in the lighting reviews. Refrigerated display cases were not included.
- **Rack lighting** is generally exempt under the lighting code but was found to be an important sub-category of light in retail. Linear fluorescent lighting mounted to display racks and gondola shelving was included in this category. Refrigeration display lighting is not included. There are clear indications that the use of rack-mounted lighting has expanded since the buildings in this study were designed.
- **Exterior lighting** is included as lighting regulated in a different part of the code. This transfers from Table 5.17.

- **Parking and exterior sales lighting** is used in only some building types. These are regulated separately so they are included here only to show the relative size of these uses in buildings that have parking and/or exterior sales. Because of this accounting, these values do not add to the remaining categories.

  In Table 5.18 the categories listed above have been combined and appear as mean LPDs using weighted areas for each building type. The total interior column includes all lighting observed, excluding lighting in refrigerated display cases in grocery stores (which added 0.19 watts/sq. ft. to the exempt category) and in retail (which added 0.034 watts/sq. ft).

Table 5.18: Aggregate LPD by Building Type (Watts/Sq. Ft.)

	Interior					**Exterior**			
Building Type	**General**	**Display**	**Rack / Exempt**	**Total**	**Std. Dev.**	**Building/ Parking Lot**	**Garage/ Sales**	**Total**	**Std. Dev.**
Assembly	1.03	0.03	----	1.05	0.11	0.19	----	0.19	0.18
College	1.03	----	----	1.03	0.13	0.19	0.01	0.19	0.08
Schools	1.08	0.01	0.02	1.11	0.26	0.35	----	0.35	1.35
Grocery	1.46	0.10	0.22	1.60	0.31	0.28	0.01	0.29	0.36
Health Services	1.36	0.03	0.02	1.40	0.33	0.25	0.01	0.26	0.20
Hospital	1.25	0.01	0.02	1.27	0.23	0.07	0.02	0.09	0.10
Institution	1.03	0.08	0.03	1.13	0.40	0.13	0.02	0.15	0.15
Office	1.02	0.01	----	1.03	0.20	0.15	0.03	0.17	0.15
Other	0.83	0.02	0.13	0.98	0.29	0.23	----	0.23	0.11
Residential/Lodging	1.22	0.01	0.07	1.30	0.48	0.06	0.04	0.10	0.10
Restaurant / Bar	1.19	0.26	0.03	1.48	0.43	1.04	----	1.04	0.79
Retail	1.27	0.15	0.10	1.48	0.53	0.32	0.04	0.36	0.24
Warehouse	0.59	----	----	0.59	0.40	0.10	----	0.10	0.14
Wtd. Avg. by Bldg. Type Sq. Ft.	1.05	0.05	0.03	1.12	0.49	0.22	0.02	0.23	0.59

5.5.3. Lighting: Energy Code Compliance

Approximately eight energy codes were enforced throughout the Pacific Northwest during the study's period. As discussed in Section 1.2 the code review shown here is based on the dominant code "enforced" in the 2001-2002 time period when most of these buildings were permitted. In all of the region's energy codes, lighting is regulated by a lighting power requirement.

Using these codes, a code lighting power allowance (LPA) was constructed for each building. For buildings in Washington and Oregon, this LPA was taken from the individual code tables with ceiling height adjustments. In Washington, display lighting adjustments were also made. Each building was treated separately, and the data aggregated by building type. There are some differences in both the amount of lighting allowed for certain occupancies, and the treatment of various auxiliary fixtures such as display fixtures and other fixtures that might be exempt under one or another of the energy codes.

Table 5.19 shows state compliance, which exceeds 80% for all the buildings reviewed. Compliance factors were determined on a per building basis and weighted by case weights for the buildings (i.e., not area weighted). The table includes both prescriptive and performance compliance. Prescriptive compliance considers only the LPD requirements from the relevant energy code. The performance compliance assumes an allowable trade-off under a performance path code submittal. Table 5.19 also shows a review of the compliance levels observed in the last baseline study using the then-current codes. For Washington and Oregon these codes have been revised somewhat and are slightly more stringent than in that period. Considerable changes in lighting codes in Idaho were made between those two periods. In Montana, the exact same code was used in both periods.

Table 5.19: Lighting Code Compliance Results by Building and by State for Two Study Periods

State	2002-04		1996-98	
	Compliance (%)*	N	Compliance (%)	N
ID	80	64	0.77	48
MT	78	29	0.58	32
OR	80	107	0.72	63
WA	78	146	0.67	88
Region	**79**	**346**	**0.69**	**231**

For the most part, compliance by building type followed the same pattern in all states. In Montana, code enforcement is relatively new and in many jurisdictions is not actually being practiced. In Idaho, enforcement is also new and in many cases buildings were developed before any code was in effect. While this seems to have relatively little effect on the overall compliance it does have some affect on buildings that have other design issues with lighting systems, notably restaurants/bars and health services buildings (typically nursing homes and assisted-living centers). These two building types have somewhat lower compliance rates throughout the sample than the rest of the sector. While compliance with the lighting code has improved significantly, especially in Idaho and Montana, the overall regional impact of this improvement on LPDs has been minimal. Although compliance has also improved in Oregon and Washington, the standards of lighting designs observed in the 1996-1998 study have remained essentially constant over the last decade. Due to the significance of LFs in this calculation, replacing as many LF applications as possible with high performance T8's, either inside of code measures or in lighting designs, would improve efficiency.

6. Heating, Ventilation, and Air Conditioning Systems

Auditors collected HVAC system characterization information and detailed specifications for heating, ventilation, and cooling equipment. Information was collected on space conditioning, heating fuel, cooling type, distribution system types, and basic control information. Additionally, major fans and pumps were categorized and documented. The systems were described in some detail, especially packaged or built-up, multi-zone systems. Controls and control strategies were documented when available. The auditors relied heavily on observed nameplates, O&M manuals, and as-built equipment schedules. These formed the basis for the equipment review; efficiency information was gathered from secondary sources and manufacturer literature. Each system was described as it related to the buildings as a whole. This allowed buildings with multiple systems of different types to be categorized and weighted based on all systems present rather than just the primary system.

To summarize the presence and type of space conditioning, a standard area weighting was used between projects and within a project. The amount of floor area at each conditioning level (heated, semi-heated, unheated) was combined with the building weight.

Weighting of HVAC characteristics was complicated by the fact that most of the buildings have several systems and square footage was not available for each system. Data that was available was equipment air flow, reported in cubic feet per minute (CFM), heating capacity, and cooling capacity. Based upon this data, each system was assigned a portion of the overall building weight. This was a necessary compromise in the data collection process. Previous regional characterization used a system weight developed from this information as well. While different than a true area weight this approach should result in a better gauge of system energy use.

6.1. Space Conditioning

The following subsections and tables summarize the penetration of space conditioning. Auditors separated major areas of each project and specified the presence and amount of heating and cooling. These tables use weighting based on area of the individual spaces. If an area of a building was partially unheated, the area of that space was weighted into that category while the rest of the building fell into the heated category. In all cases, population case weights were applied.

6.1.1. Heating

Semi-heated space was determined by the auditor based upon the space operation rather than specific energy code criteria. Unheated space is comprised of enclosed storage areas and also self-heating spaces with large equipment loads that are often cooling-only spaces. Table 6.1 shows the heat conditioning designations for each building type.

Table 6.1: Heat Conditioning Classification by Building Type (% Area)

Building Type	Heated	Semi-heated	Unheated	Total
Assembly	100	0	0	**100**
College	99	1	0	**100**
Schools	99	0	0	**100**
Grocery	99	0	1	**100**
Health Services	100	0	0	**100**
Hospital	100	0	0	**100**
Institution	86	10	4	**100**
Office	99	0	1	**100**
Other	93	7	0	**100**
Residential / Lodging	100	0	0	**100**
Restaurant / Bar	99	0	1	**100**
Retail	94	1	5	**100**
Warehouse	31	28	41	**100**
Building Average	83	7	10	**100**

Table 6.2 shows the distribution on heat conditioning designations for each state. The variation in unheated space between states is explained partly by the building type mix variation between the states. Idaho and Montana have roughly twice as much warehouse space (as a proportion of their samples) as Oregon and Washington, which partially explains the large unheated fraction. It also was found that warehouse space in Idaho and Montana is more likely to be unheated. This is likely due to severe weather and the need to enclose materials and equipment without the need to heat the space. In a milder climate, an open yard (which would not be defined as a building) might be sufficient.

Table 6.2: Heat Conditioning Classification by State (% Area)

State code	Heated	Semi-heat	Unheated
ID	73	0	27
MT	88	2	11
OR	86	7	8
WA	85	10	5
Region	**83**	**7**	**9**

6.1.2. Cooling

More than a quarter of the spaces are not cooled by mechanical equipment. Many of these spaces use outside air for “free cooling” (economizer cooling) or ground water cooling without mechanical cooling when possible. There is even a variable air volume (VAV) system with no cooling source other than economizer cooling.

These systems cannot provide cooling during the peak of the cooling season, thus the tendency to go without cooling is particularly marked in milder climates such as Montana. This was true in the previous baseline as well. This trend has increased within other geographic areas as interest in green construction increases. Table 6.3 summarizes the area served by mechanical cooling as distributed by building types. Table 6.4 shows this distribution by state, including results from the previous baseline study. Systems using ground water for cooling have been included in the “Cooled” category. Systems with only economizer cooling have been classified as “Uncooled” since cooling is not being delivered during the heart of the cooling season. Cold storage areas are included under "Refrig/Freeze." These spaces are generally major individual spaces in larger buildings, and do not include typical walk-in units (see Section 7). While there has been a noticeable trend toward non-mechanical cooling in some building types, this effort is being inversely matched by increased cooling in other building types, as demonstrated by the inconsequential change in overall cooling since the last study.

Table 6.3: Cool Conditioning Classification by Building Type (% Floor Area)

Building type	Cooled	Refrig. / Freeze	Uncooled	Unknown	Total
Assembly	79	0	21	0	**100**
College	71	0	29	0	**100**
Schools	78	0	22	0	**100**
Grocery	93	1	7	0	**100**
Health Services	100	0	0	0	**100**
Hospital	99	0	0	1	**100**
Institution	75	0	25	0	**100**
Office	98	0	2	0	**100**
Other	70	0	30	0	**100**
Residential/Lodging	82	0	18	0	**100**
Restaurant / Bar	99	1	0	0	**100**
Retail	94	0	6	0	**100**
Warehouse	11	4	84	0	**100**
Total	**71**	**1**	**28**	**0**	**100**

Table 6.4: Cool Conditioning Classification by State (% Floor Area)

State code	Cooled	Refrig./Freeze	Uncooled
ID	64	0	36
MT	59	0	41
OR	78	0	22
WA	70	1	28
Regional Total	71	1	28
1997-98	**73**	**-**	**27**

6.2. HVAC Characteristics

The HVAC summaries use the system as the descriptive unit. As a result, all systems in buildings with multiple systems are included in the summaries. Each system is weighted by its fraction of the building's total system weight combined with the building weight and total area. Thus, all systems in the building area were included no matter how small they were. This is consistent with previous baseline studies.

6.2.1. Heating Fuel Type

Table 6.5 and Table 6.6 summarize the primary heating fuel by building type and state. As with previous studies, multi-zone reheat systems with different primary coil fuel and reheat fuel are categorized by the reheat fuel type. Heat pump fuel includes air source and water source heat pumps. Previous studies categorized water source heat pumps by the loop heat source. "Plant" includes a small number of cases with remote plants that were not part of the audited project and whose boiler characteristics were not determined. In a few cases, these plants are operated by a different entity and steam is purchased by the building; in most cases however, the plant is operated by the same organization as the building. Most central plants have the ability to use natural gas or oil. Due to current fuel rates, natural gas is the dominant fuel. Undefined boilers are included in the plant category. Not all heat sources that might be described as plants are in the plant category. When the fuel type for building plants was recorded, it was included in the appropriate fuel category rather than plant. "Other" heat sources included geothermal, heat recovery, and wood waste.

Table 6.5: Heat Source Type by Building Type (% Floor Area)

Building Type	Electric	Heat Pump	Natural Gas	Propane	Oil	Plant	Other	None	Total
Assembly	10.3	13.8	75.9	0.0	0.0	0.0	0.0	0.0	100
College	18.9	4.1	48.5	0.0	0.0	0.0	28.5	0.0	100
Schools	4.7	10.9	75.2	5.2	0.0	3.6	0.3	0.0	100
Grocery	0.8	0.2	98.3	0.7	0.0	0.0	0.0	0.0	100
Health Services	27.9	5.6	40.9	25.5	0.0	0.0	0.0	0.0	100
Hospital	8.5	0.1	82.8	0.0	0.8	6.9	0.7	0.3	100
Institution	24.3	1.7	56.0	2.7	2.3	4.3	8.8	0.0	100
Office	33.8	23.7	35.8	0.0	0.0	0.0	4.4	2.3	100
Other	2.6	0.0	97.5	0.0	0.0	0.0	0.0	0.0	100
Residential / Lodging	27.7	27.9	44.4	0.0	0.0	0.0	0.0	0.0	100
Restaurant / Bar	0.0	7.4	92.6	0.0	0.0	0.0	0.0	0.0	100
Retail	3.8	6.6	87.5	2.1	0.0	0.0	0.0	0.0	100
Warehouse	6.8	3.7	87.6	1.9	0.0	0.0	0.0	0.0	100
Average	**12.4**	**8.7**	**71.8**	**3.2**	**0.3**	**1.3**	**2.2**	**0.2**	**100**
1996-98	**16.1**	**3.8**	**74.1**	**3.8**	**2.1**				**100**

Table 6.6: Heat Source Type by State (% Floor Area)

State	Electric	Heat Pump	Natural Gas	Propane	Oil	Plant	Other	None	Total
ID	1.9	8.2	72.0	5.2	0.1	0.0	12.7	0.0	**100**
MT	2.3	0.0	95.6	0.0	0.0	0.0	2.1	0.0	**100**
OR	13.4	7.3	74.4	1.1	0.0	2.9	0.7	0.1	**100**
WA	15.4	10.1	69.1	3.9	0.4	0.8	0.0	0.3	**100**
Average	**12.4**	**8.7**	**71.8**	**3.2**	**0.3**	**1.3**	**2.2**	**0.2**	**100**

Table 6.7 shows the distribution of electric heat by area and building type. Electric heat serves 12% of the floor area. Reheat in VAV and constant volume (CV) multi-zone systems accounts for 58% of the electric heat. Electric heat in package terminal AC (PTAC) units account for 10%, with electric furnaces accounting for 7%. The remaining 25% of electric heat IS in small secondary systems used to heat mechanical rooms, vestibules, or other auxiliary spaces.

Table 6.7: Electric Equipment Type (% Floor Area)

Building Type	Reheat	PTAC	Elec. Furnace	Unit Heat	Misc. Zonal	Total
Assembly	1.6	0.0	0.0	0.4	0.2	**2.1**
College	1.4	0.0	0.0	0.0	3.2	**4.7**
Schools	6.0	0.0	0.0	0.1	0.5	**6.6**
Grocery	0.0	0.0	0.2	0.0	0.1	**0.2**
Health Services	10.8	0.0	0.0	0.1	0.0	**10.9**
Hospital	0.5	0.0	1.4	0.1	0.0	**2.0**
Institution	14.4	0.0	2.9	0.3	2.9	**20.5**
Office	19.2	0.0	0.7	0.5	0.3	**20.7**
Other	0.0	0.0	0.1	0.0	0.1	**0.3**
Residential / Lodging	0.1	10.0	0.3	1.9	3.8	**16.1**
Retail	3.5	0.0	0.4	1.0	1.3	**6.2**
Warehouse	0.5	0.0	1.4	0.9	7.3	**10.0**

In contrast, the previous baseline study included more electric resistance heating. This was the result of an increase in hot water as a reheat fuel and the increased use of heat pumps, especially in smaller buildings.

6.2.2. Cooling Type

Table 6.8 and Table 6.9 summarize the primary cooling type by building type and state:

- **Direct expansion (DX) cooling** dominates the cooling sources that described here. These systems are typically associated with packaged single-zone, constant volume equipment though roughly 40% of all VAV systems also utilize DX cooling.
- **Chillers** make up the next most common cooling type. These chillers typically provide chilled water to fan coils or other air handlers throughout the building. Air-cooled units represent a total of 60% of all chiller capacity installed. However, there are several cases with central plant chillers where chiller details were not gathered. These are for the most part confined to hospitals, offices, and colleges and almost exclusively revolve around some kind of campus arrangement.
- **"WSHP"** refers to water source heat pumps on a distributed water loop. These systems typically utilize a cooling tower to dump loop heat, though five buildings representing 22% of all water source heat pump capacity utilize ground water source loops.
- **Evaporative cooling** is used very sparingly. Most of the evaporative cooling reported results from a single home improvement chain.
- **Cold ground water** is utilized directly by a few buildings to provide cooling. This is mostly limited to Montana buildings.
- **Economizer-only cooling** is utilized in all states. In this case, an air handler has a full economizer setting that is activated by a cooling thermostat. No additional mechanical cooling is provided in these systems. This is common in schools and is utilized in a few "sustainable" design projects. Three projects built with economizer-only cooling had been retrofit with mechanical cooling by the time of the audits. These were recorded as cooled spaces with the cooling source as the retrofit source.

- **No cooling** at all makes up a large fraction of building floor area. These areas are dominated by warehouse type activities. In Montana's cooler climate a large number of buildings have no cooling in any form. In other parts of the region, cooling is considered optional for certain buildings and building types.

Table 6.9 summarizes the distribution of cooling sources but consolidates the categories and summarizes the results by state. This allows direct comparability with the 1996-1998 study. As Table 6.9 shows, and as observed in heating, the distribution of sources is reasonably consistent between the two studies. There has been a slight shift from DX cooling to chillers. This is likely caused by building type variation rather than a change in designs. To make these summaries consistent with the previous study certain categories were consolidated. This was especially true of cooling tower-based systems such as water source heat pumps in heat pump loops. In the previous study, central plants were not differentiated and were generally part of the chiller designation.

Table 6.8: Cooling Source by Building Type (% Floor Area)

Building Type	DX	WSHP	Evap.	Chiller	Plant	Ground	Econo.	None
Assembly	74.4	0.0	4.5	7.8	0.0	0.0	3.4	9.9
College	25.3	0.0	0.3	22.5	28.5	0.0	0.0	23.4
Schools	25.2	8.2	0.5	38.6	3.2	0.2	15.2	9.0
Grocery	81.7	0.0	2.9	0.0	0.0	0.0	0.0	15.3
Health Services	51.0	4.2	0.0	42.7	0.0	0.0	0.0	2.2
Hospital	6.8	0.0	0.0	73.7	18.1	0.0	0.0	1.3
Institution	49.4	0.9	3.1	25.5	0.0	0.0	5.3	15.9
Office	74.1	6.5	0.0	11.0	5.7	0.0	0.1	2.6
Other	80.9	0.0	0.0	0.0	0.0	1.9	0.8	16.4
Residential / Lodging	59.2	15.4	0.3	4.2	0.0	0.9	8.7	11.3
Restaurant / Bar	83.5	0.0	5.6	0.0	0.0	0.0	0.0	10.9
Retail	83.4	1.3	2.6	1.8	0.0	0.0	0.0	10.9
Warehouse	34.3	0.0	0.0	3.4	0.0	0.0	0.0	62.3
Average	**52.7**	**3.6**	**1.3**	**16.6**	**2.4**	**0.1**	**3.9**	**19.5**

Table 6.9: Cooling Source by State (% Floor Area)

State	DX	WSHP	Evap	Chiller	Plant	Ground	Econo	None	Total
ID	59.0	6.2	1.1	14.0	5.9	0.0	3.5	10.3	100.0
MT	41.9	0.0	0.4	11.8	0.0	3.3	3.7	39.0	100.0
OR	58.1	1.7	1.1	18.2	2.4	0.0	2.8	15.7	100.0
WA	48.7	4.1	1.4	16.7	1.6	0.1	4.6	22.9	100.0
Regional Average	**52.7**	**3.6**	**1.3**	**16.6**	**2.4**	**0.1**	**3.9**	**19.5**	**100.0**
1996-98	**60.4**	**2.4**	**1.4**	**11.1**		**0.1**	**4.7**	**19.9**	**100.0**

6.3. Systems

Table 6.10 summarizes the main HVAC systems and their delivery systems. HVAC systems were categorized by system type and whether water was used to deliver space conditioning (either heating or cooling or both). DX cooling units and gas furnaces are included as hydronic if they used water as the main working fluid.

- **The zone/unit heater (Z/UH)** category includes all single-zone, ductless, direct heating and/or cooling equipment as well as passive radiation baseboard and heated floors that utilize hot water.
- **The single-zone (SZ)** category includes all CV, single-zone, ducted systems. This type of system is the most common type of system and is generally associated with rooftop package systems.
- **Single zone VAV (SZ-VAV)** systems have a single-zone air handler with variable flow. Flow in heating mode is at a minimum and then flow is ramped to meet cooling or ventilation needs. Fan flow is varied using a VFD drive on the fan. This system was common in school gyms and common area space with widely varied occupancy.
- **Multi-zone systems (MZ)** have CV operation and reheat to condition spaces with varying requirements. Most, but not all, of these systems are located in health care situations where designers chose not to vary zone air flow. Typically, these systems have variable frequency drives (VFD) on the central fans and many have VAV terminal boxes primarily to help with balancing the system. The systems may have a few zones with variable flow operation but overall the systems do not come close to meeting code requirements for a variable flow system. These systems also can have scheduled times of reduced flows but the flow doesn't change in response to cooling needs. These systems typically have very large heating requirements to reheat cooled primary air. All of these systems utilize hot water reheat from a boiler.
- **VAV systems** include all versions of VAV systems, fanless, series, and parallel fan-powered. Reheat is typically needed and generally adds a significant additional heating load. Sixty-six percent of the floor area served by systems with reheat utilizes hot water from a central boiler, while 34% are served by electric reheat. Generally, hot water reheat systems dominate hospital, college, lodging, and educational buildings. Electric reheat dominates office areas. Institutions and health services utilize an equivalent amount of hot water reheat and electric reheat. There was one VAV system and a few multi-zone systems that use a central economizer to maintain a supply cold deck without any mechanical cooling. During most of the year, the supply terminals reheat the economized supply air. A small number of VAV systems do not use reheat. This was observed in a few spaces with high internal loads that do not require space heating capacity.
- **Heat pump loops (HPLP**) are systems that use small heat pumps to supply zone-level conditioning. The heat pumps are connected together with a water loop that is conditioned in part by the diversity of the loads on the heat pump loop and in part by a boiler and cooling tower that ensures that the loop temperature is maintained within prescribed limits. Some heat pump loops in this study use ground water wells to provide this temperature stability.

- **2 pipe/4 pipe fan coil system (2/4-P)** is a variation on water loop conditioning. This system uses a chilled water and/or a hot water loop to feed fan coils in all zones. This system is common in hospital and school settings and favored because it affords a variety of control strategies to adjacent zones.
- **Underfloor air distribution (UFAD)** relies on the supply air to be delivered through an underfloor plenum. This can be more efficient since the conditioning air is delivered at the occupant level and thus reduced fan energy is expected. The system relies on the assumption that the dominant conditioning requirement is space cooling and reheat is limited to perimeter zones that are treated separately. In effect, this is a VAV system with reduced fan pressure and reduced airflow. Very few of these systems were observed and in two major projects severe ventilation or comfort issues were noted.

Table 6.10: HVAC System Type (% of Modified Floor Area Weight)

Delivery System	DX/Furnace	Hydronic Heat and/or Cool	Total
Zone/Unit Heater (Z/UH)	14.1	1.5	**15.6**
Single Zone (SZ)	48.3	5.3	**53.6**
Single Zone VAV (SZ-VAV)	0.2	1.4	**1.6**
Multi-zone w/reheat (MZ)	0.1	4.0	**4.2**
VAV w/reheat (VAV)	6.1	9.3	**15.4**
VAV no reheat (VAV)	0.2	0.4	**0.6**
Heat Pump Loop (HPLP)	0.0	3.6	**3.6**
2 pipe/4pipe (2/4-P)	0.0	4.2	**4.2**
Underfloor Air Distribution (UFAD)	0.0	1.3	**1.3**

Table 6.11 presents system types by building, and Table 6.12 summarizes system types by state. For these tables, the system types are simplified with VAV reheat and non-reheat systems combined. As Table 6.12 shows, the VAV systems have become dominant in building types that typically have multiple stories. Simple, single-zone equipment is nearly universal in single-story buildings. Trends in system type by state are primarily a function of building type distribution and the number of floors.

Table 6.11: HVAC Systems by Building Type (% Floor Area)

Building Type	Z/UH	SZ	SZ VAV	MZ	VAV	HPLP	2/4 P	Total
Assembly	8.0	74.0	9.7	0.0	8.3	0.0	0.0	**100**
College	15.2	27.7	0.0	0.0	31.0	0.0	26.2	**100**
Schools	4.8	34.8	6.2	4.5	27.9	8.2	13.7	**100**
Grocery	11.2	88.2	0.0	0.0	0.6	0.0	0.0	**100**
Health Services	1.9	28.7	0.0	23.5	38.2	4.2	3.5	**100**
Hospital	1.2	5.0	0.0	43.7	49.3	0.0	0.8	**100**
Institution	12.0	32.0	2.3	5.4	44.9	0.9	2.5	**100**
Office	2.1	48.3	0.0	0.0	41.1	6.6	2.0	**100**
Other	11.2	85.8	0.0	0.0	3.0	0.0	0.0	**100**
Residential / Lodging	8.3	63.2	0.6	6.4	0.9	15.9	4.7	**100**
Restaurant / Bar	0.0	100.0	0.0	0.0	0.0	0.0	0.0	**100**
Retail	11.6	84.7	0.0	0.1	1.3	1.5	0.7	**100**
Warehouse	53.4	46.2	0.0	0.0	0.4	0.0	0.0	**100**
Average	**15.9**	**52.0**	**1.6**	**4.4**	**18.0**	**3.8**	**4.4**	**100**

Table 6.12: HVAC System Type by State (% Floor Area)

Building Type	Z/UH	SZ	SZ VAV	MZ	VAV	HPLP	2/4 P	Total
ID	10.28	62.96	0.00	0.29	11.38	6.29	8.80	**100**
MT	34.91	42.47	0.00	0.52	15.14	0.00	6.96	**100**
OR	14.34	47.09	3.73	4.39	27.98	1.73	0.74	**100**
WA	17.24	51.89	1.11	5.69	14.93	4.28	4.87	**100**
Average	**15.87**	**52.00**	**1.63**	**4.36**	**17.98**	**3.76**	**4.40**	**100**

6.3.1. System Observations

The extensive amount of data collected in the process of reviewing buildings made a substantial number of characterizations and summary tables possible. Several interesting items are summarized here, although numerous additional summaries are possible. In general, the systems that were observed were simple, single-zone systems typically associated with large single-story buildings. However, a great many of the high-rise and more complex buildings offered insights into other variations of system designs.

VAV Systems

VAV systems are the dominant multi-zone system. Systems are categorized by type of terminal in Table 6.13. A system with a mix of series and fanless (squeeze) boxes is classified as a series system. The two columns to the right show the average maximum CFM delivered by fan-powered versus fanless boxes. In fan-powered systems, approximately one-third of the CFM is delivered through fanless boxes. As a side note, 12% of the series VAV systems are low-temperature systems that deliver all air with fan-powered boxes and mix primary and plenum air at all operating points to warm or to cool primary air. These systems reduce duct sizes, save fan power, and increase cooling and reheat.

Table 6.13: Multi-Zone VAV System Types

System Type	Percent of Systems	Box Type Within System	
		Fanless	Fan-Powered
VAV - Fanless	32	100	0
VAV - Parallel	21	32	68
VAV - Series	47	31	69
Average		**53**	**47**

Fan-powered terminal motors were recorded when available and are summarized in Table 6.14. Where fan motor type was determined, half of all series fan-powered boxes utilized electronically commutated motors (ECM). In many cases, the motors remain unknown and these cases might reasonably be assumed to be more likely standard than ECM as ECM motors would likely be noted in the documentation. Auditors were asked to try to determine if series terminal fans were operating in a constant or variable speed fashion but they had difficulty doing this.

Table 6.14: Motor Type: Fan-Powered VAV Terminals (%)

Terminal Fan Type	Missing	ECM	STD	Total
Parallel	12	1	18	**31**
Series	19	26	24	**69**
Total	**31**	**27**	**42**	**100**

Fan Control

Central fan controls were reported in most cases. Table 6.15 presents the findings summarized by the same system types in Table 6.10. VFD motor control is rather common and is even installed in single-zone VAV systems as well as constant volume multi-zone systems. Only a few, very small systems (5 HP or less) utilize bypass dampers or inlet vanes.

Table 6.15: Fan Motor Drive by System Type (% of CFM)

System Type	BYPASS	CV	IV	UNK	VFD	Total
Zone/Unit Heater	0.0	15.6	0.0	0.0	0.0	15.6
SZ	0.0	52.5	0.0	0.0	1.2	53.6
SZ VAV	0.0	0.1	0.0	0.0	1.5	1.6
MZ/CV	0.0	2.7	0.0	0.0	1.5	4.2
VAV	0.4	0.0	0.3	1.5	13.8	16.0
HPLP	0.0	3.4	0.0	0.0	0.2	3.6
2 pipe/4 pipe	0.0	4.1	0.0	0.0	0.2	4.2
UFAD	0.0	0.2	0.0	0.0	1.1	1.3
Total	0.4	78.4	0.3	1.5	19.4	100.0

Economizers

Economizers are common in all building types. As noted earlier, a few buildings even use economizers as the sole source of cooling. Table 6.16 includes economizers with and without mechanical cooling. Much of the equipment without economizers has cooling capacities less than four tons, or it serves spaces such as equipment rooms, backup equipment rooms, grocery stores, or swimming pools.

Table 6.16: Economizer Summary (% Floor Area)

System Type	% of Total	Economizer Type				
		Air	Water	None	NA	Total
Zone/Unit Heater	0.2	0.0	0.0	100.0	0.0	**100**
SZ	61.2	72.0	0.2	23.1	4.8	**100**
SZ VAV	2.1	97.7	0.0	0.0	2.3	**100**
MZ/CV	5.5	75.9	1.0	0.3	22.8	**100**
VAV	22.7	93.6	2.8	0.6	3.0	**100**
HPLP	2.9	89.0	0.0	11.0	0.0	**100**
2 pipe/4 pipe	5.5	76.7	1.7	18.6	3.1	**100**
Average		**78.2**	**0.9**	**15.8**	**5.1**	**100**

Energy codes require economizers in cooling equipment with capacities over certain minimum thresholds. Looking at areas without economizers, 78% are served by equipment smaller than the relevant code thresholds. An additional 10% typically serve exempt grocery areas or pass for other reasons, and 8% of areas are served by systems where the economizer description was deemed inadequate to draw conclusions. Only 4% of the floor area served by systems without economizer was deemed to not comply with code.

Heat Recovery

Table 6.17 presents the floor area in projects reporting heat recovery from the listed heat sources. Table 6.18 presents the destinations by building type. Heat recovery is common in grocery, schools, hospitals, and laboratories. The two most common heat recovery applications are grocery refrigeration condenser heat to hot water, and exhaust air to supply air recovery using heat wheels or plate exchangers.

Grocery heat recovery to hot water is common in larger grocery stores where hot water use is a concern. Only one chain (four stores in the study) and one independent grocery utilize heat recovery for space heat. In general, sites are happy with this technology for domestic hot water, though several chains (those without HR to space heat) expressed little enthusiasm for adopting heat recovery for space heating.

Common barriers/issues to heat recovery adoption cited include:

- How to configure heat recovery when the heat is provided by a fleet of roof top packages with no duct work.
- Concern about refrigerant costs.

- Skepticism about savings, particularly in the face of perceived very large water loads.

School heat recovery is limited to 100% outside air systems serving locker room areas and some science rooms. Hospital and lab heat recovery is mostly on very large 100% outside air systems serving either specialty areas or, in some cases, the whole building. One chain retailer uses a small energy recovery wheel to provide dedicated outside air to office areas.

Table 6.17: Heat Recovery Source (% Floor Area)

Source End Use	Freq.	Percent
No Heat Recovery	277	81
Data room Condensers	3	1
Exhaust Air	45	10
Refrigeration Condensers	24	8
Total	**349**	**100**

Table 6.18: Heat Recovery Destination by Building Type (% Floor Area)

Building Type	No Heat Recovery	Space Heat	Space & Water Heat	Outside Air Preheat	Water Heat	Total
Assembly	100	0	0	0	0	**100**
College	69	0	0	31	0	**100**
Schools	83	0	0	17	0	**100**
Grocery	12	10	25	0	52	**100**
Health Services	79	0	0	21	0	**100**
Hospital	41	0	0	53	6	**100**
Institution	86	0	0	14	0	**100**
Office	94	0	0	6	0	**100**
Other	97	0	0	3	0	**100**
Residential/Lodging	74	0	0	14	12	**100**
Restaurant / Bar	100	0	0	0	0	**100**
Retail	71	0	0	7	23	**100**
Warehouse	100	0	0	0	0	**100**
Average	**81**	**0**	**1**	**10**	**7**	**100**

Of the buildings reporting exhaust air to supply air heat recovery, the portion of the building impacted was typically limited. Table 6.19 shows that on average 22% of the systems in buildings with OSA/SA heat recovery utilizes heat recovery to warm incoming supply air. In buildings with refrigeration to space heat recovery, 60% of the systems (CFM and building area weighted) are supplied with heat.

Table 6.19: System CFM with HR in Projects with OSA/SA HR (% of CFM)

Building Type	Mean (%)	N
College	13	2
Schools	12	13
Health Services	10	4
Hospital	65	8
Institution	16	5
Office	9	1
Other	89	1
Residential/Lodging	45	3
Retail	1	5
Total	22	42

Comparison to Previous Baseline

The comparison to the previous baseline provides an indication of the changes or lack of changes in HVAC design strategies. Table 6.20 re-categorizes systems summarized in Table 6.10 into the categories used in the previous baseline. The blue cells show the same distribution from the previous baseline study. The distribution of single-zone and multi-zone complex systems has changed from almost 70% in the previous study to slightly over 60% in this study. This decrease is likely due to the differences in the two samples more than to differences in any particular practice at this point. The distribution of complex systems is somewhat similar; however, the number of VAV systems has remained fairly constant between the two samples while other systems, especially underfloor distribution and certain kinds of multi-zone constant volume systems, are somewhat more significant. This difference is a result of the fact that the buildings in this sample have substantially more healthcare and hospital facilities than previous samples. Only the underfloor air distribution system type, which has become a minor but noticeable trend in this sample, was not represented in any way in the 1996-1998 study.

Table 6.20: System Type Observed in This Study (% Floor Area using 1996-1998 Classification)

System Type	ID	MT	OR	WA	Total	1996-98
Simple Single Zone Equipment						
FRN-Furnace/AC	29.9	20.0	32.7	34.1	**32.6**	**41.8**
Other Furnace	32.8	19.3	7.4	8.0	**12.0**	**8.6**
PTAC/HP	0.0	0.0	3.3	2.4	**2.2**	**5.0**
Radiant Heaters	0.7	12.1	1.8	4.1	**3.2**	**4.8**
Zone/Unit Heater	7.7	23.6	12.7	10.9	**11.3**	**9.4**
Sub-total Simple	**71.1**	**75.0**	**57.8**	**59.4**	**61.3**	
1996-98	**75.5**	**43.4**	**73.5**			**69.7**
Complex Hydronic and Multi-zone Systems						
SZ VAV	0.0	0.0	4.5	1.1	**1.8**	
HPLP	6.0	0.0	1.7	4.2	**3.7**	**2.6**
MZ/CV	0.3	0.5	4.3	5.6	**4.3**	**6.1**
Misc. Comp	1.6	0.1	2.8	8.1	**5.4**	**1.8**
2 pipe/4 pipe	10.2	10.1	1.5	6.7	**5.9**	**3.0**
VAV	9.0	14.4	24.5	14.4	**16.3**	**16.7**
UFAD	1.9	0.0	2.8	0.5	**1.3**	
Sub-total Multi-zone	**28.9**	**25.0**	**42.2**	**40.6**	**38.7**	
1996-98	**24.4**	**56.6**	**26.5**			**30.3**

Innovative Systems

Several systems in the current study utilize novel methods to generate and/or deliver space conditioning. As with all innovative systems, these systems have had difficulties with some part of their operations and, in some cases, the occupants demanded (and received) changes in the system that have compromised energy efficiency.

- Three buildings utilize hot ground water directly for heating.
- Two buildings utilize cold ground water directly for cooling.
- Three buildings with water source heat pump loops utilize ground heat sinks. These systems received mostly good reviews except one instance where one of the ground source heat pump loops had cool temperature issues and needed to have a boiler added for backup heat.
- Six underfloor air delivery systems. Generally, building operators were happy with the flexibility of these systems, but most had some occupant comfort issues and there was evidence of some major configuration issues.
- Several schools are attempting to "naturally" cool the class and student areas of their buildings with operable windows and economizer. Two of these had retrofit cooling after the first year, and one indicated a retrofit cooling system is being considered.
- One assisted living facility with "natural" cooling which seems to function well. The system has mechanical venting, operable windows, and interior and exterior venetian blinds. In this case, the hot temperatures in summer are mostly welcomed.

6.4. HVAC Controls

Mechanical system controls were surveyed at the building level, and at the system level in multi-use buildings. Data were gathered from sequence-of-operation documents, site observations, and discussions with staff. Energy management systems (EMS) are common in all big projects and less common in smaller ones. In spaces without EMS control, manual and programmable thermostats, and often a mix of the two, are used. Setbacks are common everywhere. EMS also generally implement outside air damper closure for night cycling and morning warm-up. Previous studies did not gather this level of control information so no comparison is possible.

Table 6.21 summarizes the percent of floor area represented by buildings with specific control by state:

- EMS control was reported in buildings containing 55% of total floor area. This control system implies a centralized control that addresses the main components of the building HVAC systems and has a centralized time and off-hours settings that are set by the control system itself. In many cases (especially the retail chains), the EMS is controlled off-site in the corporate offices, or with a centralized property manager. Much of the state-to-state differences are likely due to the correlation of EMS with building size, and building type differences.
- Occupied period continuous fan operation was reported in buildings with 84% of the floor area. In this strategy the central fan runs constantly (sometimes at a reduced speed) to bring in ventilation air and to provide continuous mixing in the conditioned zones.
- Outside air controlled by CO_2 sensors is very common in high occupancy spaces; 33% of the buildings that reported one or more systems utilized CO_2 control. These systems control outside air dampers and are very common in buildings receiving program incentives. In some cases, auditors observed problems with the set-up of these controls that resulted in ineffective outside air control.
- Occupancy sensor control of outside air is common in classrooms and, to a more limited extent, conference rooms. A dual relay occupancy sensor is used to control lights and the local HVAC zone. Typically, the outside air or primary air damper is closed and the zone fan is turned off unless conditioning is needed to meet setpoint. For occupancy sensor control, on average, 70% of HVAC CFM is controlled in buildings reporting the control.
- Warm-up lockout of outside air during night mode and morning warm-up was typically specified in sequence-of-operation documents. In cases with simple thermostats, the control was presumed to not exist unless plans or operation documents specified it. This strategy usually closes the outside air damper (and thus the ventilation air) when the building is not occupied.

Table 6.21: HVAC Control by State (% Floor Area of Buildings with Selected Control)

State	EMS	Continuous Fan	Outside Air Control		
			CO_2	Occ. Sensor	Warm-up Lockout
ID	40	80	11	3	17
MT	44	82	15	6	10
OR	57	85	35	2	75
WA	60	84	40	9	55
Average	**55**	**84**	**33**	**6**	**51**

6.4.1. CO_2 Control

The purpose of installing CO_2 sensors is to decrease the minimum outside air requirements, thereby saving on heating, cooling, and fan energy (provided that the space CO_2 concentration is less than a predetermined maximum). Table 6.22 presents the percent of floor area represented in buildings reporting CO_2 control by building type. It is important to note, however, that within the 33% of floor area in which CO_2 sensors exist, they are only functional in half that area. Furthermore, the controls observed are not always optimally programmed to achieve potential savings.

Table 6.22: Prevalence of CO_2 Control in Buildings Reporting CO_2 Control

Building Type	% of Floor Area Represented by Buildings Reporting Control
Assembly	67
College	28
Schools	65
Grocery	19
Health Services	8
Hospital	8
Institution	57
Office	12
Residential / Lodging	40
Retail	43
Warehouse	2
Average	**33**

Two significant issues with CO_2 based ventilation control were found. First, minimum air requirement specifications often did not account for the presence of CO_2 sensors. In some cases, this was likely due to utility incentives bringing CO_2 sensors into the project after much of the engineering was finished. It was then the responsibility of the test and balance contractor or the building operator to adjust the minimum air setting. In a few cases, the CO_2 sensor was installed but minimum air was set just as the engineer specified. This study did not examine controls in most cases, so the extent of this issues in uncertain. The second issue is that a building's exhaust air requirements can require so much ventilation to keep the building pressurized that CO_2 control is rendered moot. In several cases, the exhaust air requirements for hoods and bathrooms are significantly larger than any possible ventilation requirement. One grocery chain reported they had never seen the CO_2 readings anywhere near setpoint due to high flows of make-up air necessary to compensate for high exhaust flows. Most cases were not this extreme but there were many cases where the minimum air setting with CO_2 control was actually greater than the ASHRAE 62 required minimum.

6.4.2. Thermostats

The buildings without EMS (and zones not under EMS control) use thermostats for control. These thermostats are generally programmable but in some cases they are simple, single-pole, single-throw (SPST) thermostats without any timer or automatic set back function. Table 6.23 shows the distribution of these thermostats in buildings with no EMS control. The table presents the percentage of floor area in buildings reporting a given type of simple controls.

Programmable thermostats exclusively control 59% of the floor area and share control with manual thermostats in 22% of floor area. Manual controls are used exclusively in 17% of the floor area. A small fraction reports no manual or programmable thermostats. These are unknown controls rather than anything in particular.

Table 6.23: Non-EMS Thermostat Types (% Floor Area)

Thermostat Type	Not Programmable	Programmable	Total
Non-Manual	1	59	**61**
Manual	17	22	**40**
Total	**18**	**82**	**100**

6.5. Equipment Efficiency

Where possible, auditors collected detailed capacity and efficiency information on the HVAC equipment found in the buildings. These data often came from plans, equipment nameplates, O&M manuals, and occasionally manufacturers' websites. In many cases, because of the age of the systems, much of the current manufacturer literature refers to equipment that superseded the equipment observed in the field. In these cases, it was often difficult to determine the details of efficiency or performance even from manufacturers' designations.

Each piece of equipment was assigned an energy code minimum efficiency based upon the equipment tables adopted by the applicable code. For Idaho and Montana the codes utilized the ASHRAE 90.1-1999 base values throughout the design window so those were chosen as the applicable code values. Washington and Oregon adopted the ASHRAE 90.1-1999 October 29, 2001 efficiency values in early 2002, so those values were used for buildings there. Note that ASHRAE Standard 90.1 has become a *de facto* manufacturing standard, so newly made equipment generally complies with the current standard. The problem is that there are several effective dates for enforcing this standard and it does not apply to equipment already manufactured.

Energy codes are installation standards. However, the ASHRAE equipment standards have become a quasi- manufacturing standard. Energy code installation standards are enforced at the permit or inspection phase and are independent of equipment manufacturing vintage. Thus, it is possible that equipment could be installed that did not meet code requirements, but it is unlikely. Documentation errors by the auditors and by the design team are likely sources of most of the apparent non-compliance. In two spot-checks of water source heat pumps that auditors designated as not passing code, both were found to pass code. Auditors had recorded efficiency values from the plans correctly and had also noted the equipment models in the field. A review of the model numbers, however, revealed that the engineer had entered incorrect values (water source and ground water source ratings are different and most equipment has both ratings). With the correct values, the units passed code. The numbers as entered should have raised flags at the building department.

6.5.1. Boilers

Boilers provide heated water (or steam) to built-up HVAC equipment and serve service hot water and process loads. Most boilers are gas-fired with several also having the ability to run as oil-fired boilers. Table 6.24 summarizes gas boiler size as observed in this study. Anomalies not included in this table include one single electric boiler, two 160-ton air-to-water heat pumps to generate hot water, and two oil-only boilers.

Table 6.24: Distribution of Boiler Sizes

Size Range (kBtu)	% of Boilers	% of Capacity
70-300	20	3
300-600	8	3
600-1000	48	38
1000-4000	19	31
4000-10000	4	20
10000.	1	5
Total	100	100

Boiler efficiency falls into the following categories:

- **Standard.** This refers to boilers that have combustion efficiencies between 80 and 83%. These boilers are designed to operate at the ASHRAE minimum combustion efficiency.
- **Near condensing.** This designation refers to boilers that are somewhat better than standard efficiency but do not extract heat by condensing the boiler exhaust. These boilers generally have efficiencies between 84% and 87%.
- **Condensing.** Boilers with combustion efficiencies above 87% condense liquid from the flue gas at the last stage of heat exchange. While this meets the study criteria for condensing boilers, numerous utility programs use 90% as the required minimum efficiency for incentivized condensing boilers. Most condensing hot water boilers are rated at 0.9 or better and only a few units where found between these two levels.

The boiler population is surprisingly efficient. Only one boiler failed ASHRAE 90.1-1999 October 29, 2001 standards. Twenty-six percent of boiler capacity is condensing and 43% near condensing. Table 6.25 summarizes the boiler efficiency observed by size and output type.

Table 6.25: Distribution of Gas Boiler Efficiency

Efficiency Range	Hot Water			Steam	Total
	<300 kBtu	300-2500 kBtu	>2500 kBtu	>2500 kBtu	
Standard	44.3	23.9	37.6	100.0	**30.4**
Near Condensing	25.7	35.5	62.4	0.0	**43.4**
Condensing	30.0	40.6	0.0	0.0	**26.3**
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Table 6.26 compares the boiler efficiency observed in this study with the boiler efficiency in the previous baseline. Average efficiency for the "<300 kBtu" boilers is very similar in both studies—although the sample size for the 1996-98 study was very small (n=6). However, the average efficiency for large boilers has increased dramatically. This is explained by the movement to condensing boilers in the larger sizes. Overall, there has been a significant improvement in boiler combustion efficiency since the last study.

Table 6.26: Average Boiler Efficiency

Boiler Category	2002-2004		1996-1998	
	N	Efficiency	N	Efficiency
Hot Water Gas-fired <300kBtu	15	85.0	6	85.7
Hot Water Gas-fired 300-2500kBtu	72	86.9	27	82.3
Hot Water Gas-fired >2500kBtu	15	83.4	---	---
Steam Gas-fired >25000kBtu	3	80.0	---	---
All Systems	**105**	**85.6**	**33**	**82.8**

6.5.2. Chillers

Chillers provide cold water to the coils and equipment in a majority of complex systems. Table 6.27 summarizes the chillers observed in this study. Air-cooled units represent 60% of all chiller capacity installed. Air-cooled chillers rely on outside air to cool the condenser and typically are rated (using coefficient of performance, COP) as a compressor/condenser unit. The larger sized cooling equipment is usually water cooled and uses a cooling tower to evaporatively cool condenser water. There were 16 chillers where chiller details were not gathered. These were mostly in central plant situations that presumably have water-cooled chillers. Including these would make the air and water split roughly 50/50. Table 6.27 also presents efficiency information, which found on only half the units. The code efficiency noted here is the capacity weighted average of the chillers in each state. Since Idaho and Montana had different code requirements than Washington and Oregon, the average code numbers are a little different from either the base requirements or the requirements of ASHRAE 90.1-1999 October 29, 2001.

Chiller efficiency cannot be reliably compared to the previous baseline because of the very small number of chillers reported in that work. Fully 80% of the water-cooled chiller capacity utilizes VFDs, and 28% of the air-cooled chillers also utilize VFDs.

Table 6.27: Distribution of Chiller Efficiency

Chiller Category	N	Percent Total Cap	Chiller Efficiency				
			N	COP	Std. Dev	Code	% fail
Air Cooled							
<150 Tons	36	32.2	19	2.9	0.2	2.8	13.7
>=150 Tons	22	30.0	14	3.2	0.5	2.8	17.0
Water Cooled							
Centrifugal > 300 Tons	11	20.9	10	7.4	1.4	6.1	0.0
Screw/Scroll < 150 Tons	3	2.9	1	6.1	0.0	4.4	0.0
Screw/Scroll 150-300 Tons	5	11.3	3	6.6	0.7	4.9	0.0
Screw/Scroll > 300 Tons	1	2.7	0	---	---	5.5	7.1
Absorption-single effect	1	0.1	0	---	---	--	--
Total	84	100.0	48	3.8	1.7	--	--

Table 6.28 and Table 6.29 show the detailed distribution of chiller efficiency. The vast majority of these pieces of equipment exceeded code requirements, especially the water-cooled chillers.

Table 6.28: Efficiency Distribution of Air-Cooled Chillers (% of Capacity)

COP	N	Air Cooled <150 Tons	Air Cooled >300 tons	Total
<2.7	2	6.6	4.9	5.7
2.7 -2.9	14	43.0	29.5	36.0
2.9 -3.1	11	45.7	20.4	32.5
3.1 -4.1	7	4.7	25.9	15.8
4.1 -6.0	1	0.0	19.4	10.1
Total	**36**	**100.0**	**100.0**	**100.0**

Table 6.29: Efficiency Distribution of Water-Cooled Chillers (% of Capacity)

COP	N	Screw Chiller		Centrifugal	Total
		<150 Tons	150-300 Tons	>300 tons	
4.1 -6.0	2	----	11	11	**11**
6.0 -6.5	3	100.0	----	19	**15**
6.5 -7.0	4	----	77	37	**49**
>7.0	5	----	12	33	**25**
Total	**14**	**100**	**100**	**100**	**100**

6.5.3. Package Heating Equipment

Table 6.30 presents the average heating equipment efficiency found by class of package equipment. ASHRAE 90.1-1999 efficiency values were compared to the reported efficiency as was done with the previous equipment categories. The equipment summarized in this table is generally single-zone equipment that is sometimes linked with a complex system and sometimes installed as independent conditioning for that zone.

- **Combustion** means gas or oil-fired equipment with a single-zone air delivery. This includes furnaces used in small buildings or remote zones as well as gas-fired rooftop package units conditioning a large area with several separate package installations.

- **Heat pump** typically refers to a split system with condenser and air handler with DX coils. In smaller sizes (less than six tons) the rating used is the Heating Season Performance Factor (HSPF) which is a weighted average of seasonal performance with units of Btu/watt. For larger sizes the COP is the primary rating measure at 47°F outside temperature.
- **Package terminal air conditioners/heat pumps (PTAC/HP)** are generally small, through-the-wall, single-zone units with local control of temperature and air flow. These are very common in lodging and other residential applications.
- **Water source heat pumps (WSHP)** are associated with a water loop that has conditioning supplied by other equipment or as part of a geothermal or other ground water heat source. In most cases, these function as single-zone units, though in one instance the unit supplies air to VAV systems.
- **Electric resistance single-zone equipment** is typically electric unit heaters. These are often used to condition remote spaces or semi-conditioned spaces such as storage rooms and equipment rooms. Since this is electric resistance heating the efficiency is always listed as 1.0.

Table 6.30: Average Heating Equipment Efficiency

Heating Equipment	N	Percent Total Cap.	Heating Equipment Efficiency				
			Freq.	Average Heating Eff.	Average Code Eff.	Percent Failing Code	Average 1996-98 Eff.
Combustion (efficiency)	1,043	80.3	718	81.7	78.5	1.5	**81.5**
Heat Pump (HSPF)	74	2.6	23	7.1	6.8	7.1	**6.8**
Heat Pump (COP)	26	3.2	10	3.3	3.2	0.0	**----**
PTHP (COP)	14	1.3	11	3.1	2.9	0.0	**3.2**
WSHP (COP)	127	4.9	77	4.1	3.7	5.8	**----**
Electric Resistance	184	7.7	132	1.00	1.00	0.0	**----**

The distribution of package equipment combustion efficiency is heavily weighted to the standard combustion efficiency range of 78 to 82%. Only 10% of capacity is in the condensing range. This percentage is heavily influenced by the complete lack of condensing equipment choices in popular equipment groups such as rooftop packages. From previous work, the lack of condensing unit heaters is surprising. Table 6.31 summarizes the efficiency of combustion equipment observed in these types of systems.

Table 6.31: Distribution of Combustion Furnace and Unit Heater Efficiency (% of Capacity)

Efficiency Range	N	Furnace	Unit heater	Total
Standard	702	88.4	99.2	**89.9**
Near Condensing	4	0.2	0.0	**0.2**
Condensing	86	11.4	0.8	**9.9**
Total	**792**	**100.0**	**100.0**	**100.0**

6.5.4. Package Cooling Equipment

Table 6.32 presents the average equipment cooling efficiency found by class of DX equipment. Code efficiency values were compared to the reported efficiency as was done with the previous equipment categories. The equipment reported here is generally, but not always, linked to the package heating equipment summarized above. The table covers all of the rated equipment found in this study including units that are part of built-up systems, such as a DX-cooled air handler with hot water heat hooked to a VAV system. The "2002-2004 Code Fail" column contains the percent of installed equipment that is below the required code value.

- **Air conditioning (AC) equipment** is the most common type of package cooling equipment. In fact, this feature is the most common type of HVAC equipment in commercial buildings. The compressor is usually installed with a gas burner or furnace for heating in either a package or as a split system. This category also includes split system AC and large AC equipment in built up systems.
- **Heat pumps** include any and all air conditioning equipment with a reversing valve and compressor drive heating mode. In smaller sizes (less than six tons) the rating used is a SEER; for larger sizes the EER is the primary rating measure.
- **PTAC/HP** are generally small, through-the-wall, single-zone units with local control of temperature and air flow. These are very common in lodging and other residential applications.
- **WSHP** are associated with a water loop that has conditioning supplied by cooling tower or as part of a ground water loop. In most cases, these function as single-zone units, though in one instance the unit supplies air to VAV systems.

Table 6.32: Average Cooling Equipment Efficiency

Cooling Equip.	N	Percent Total Cap	N for EER	SEER/EER Efficiency			2002-04 Code
				Install	Code	1996-98	Fail (%)
AC	986	84.9	749	10.5	9.8	9.9	14.5
HP	100	7.2	76	10.4	10.0	9.9	30.7
PTAC/PTHP	14	1.6	13	10.5	9.8	11.0	0.5
WSHP	130	6.3	85	14.3	11.4	--	0.4
Total	1,230	**100**	923	**10.7**	**9.9**	**--**	**14.8**

6.6. Service Hot Water Heating

Dedicated hot water heaters generate most service hot water. Typically, these water heaters are either small, electric tanks or large, gas-fired units. The electric tanks are used for smaller hot water loads, or in isolated locations where circulation loops would not be practical.

Table 6.33 and Table 6.34 summarize the service water systems by configuration and primary fuel. These summaries are weighted by building area and case weight. There is a tendency for central water heating in a few building types but for the most part the use of individual tanks accounts for 85% of the building surveyed.

Table 6.33: System Configuration for Service Hot Water by Building Type (%)

Building Type	From Space Heat Boiler	Central DHW Boiler	Tank
Assembly	0.0	7.6	92.4
College	0.0	35.4	64.6
Schools	9.3	16.3	74.1
Grocery	0.0	0.0	100.0
Health Services	0.0	0.0	100.0
Hospital	65.8	0.0	34.2
Institution	12.2	2.2	85.7
Office	7.8	0.0	92.3
Other	0.0	0.0	100.0
Residential / Lodging	3.5	49.7	46.7
Restaurant / Bar	0.0	8.5	91.5
Retail	0.0	0.0	100.0
Warehouse	1.7	0.0	97.7
Average	**5.9**	**7.3**	**86.6**

Table 6.34: Primary Fuel Type of Service Hot Water by Building Type (%)

Building Type	Elec.	Nat. Gas	Prop.	Heat Recovery	Other
Assembly	31.1	68.9	0.0	0.0	0.0
College	26.3	45.2	0.0	0.0	28.5
Schools	11.7	81.5	5.5	0.0	1.4
Grocery	4.0	7.8	0.8	87.4	0.0
Health Services	34.6	39.0	26.4	0.0	0.0
Hospital	0.0	98.2	0.0	0.0	1.8
Institution	15.6	76.6	3.6	0.0	4.2
Office	54.5	40.2	0.0	0.0	5.3
Other	56.0	44.0	0.0	0.0	0.0
Residential / Lodging	0.0	91.6	8.4	0.0	0.0
Restaurant / Bar	0.0	100.0	0.0	0.0	0.0
Retail	38.6	35.9	0.0	25.5	0.0
Warehouse	75.9	24.1	0.0	0.0	0.0
Average	**34.3**	**52.5**	**3.2**	**7.8**	**2.1**

The primary hot water fuel is similar from state to state, but has significant variation between building types. Higher water use buildings tend to use non-electric water heating. About 20% of the floor space reports two or more fuels for the same building. Assignment of primary versus secondary is based upon fuel type since other capacity measures are often missing. Twenty percent of the floor space with primary gas, propane, or oil fuel has electricity as a secondary fuel. Eighty percent of the sites with heat recovery have a second and sometimes a third fuel. Half of this was electric and half natural gas.

7. Envelope

Construction techniques and insulation strategies vary dramatically within the commercial sector. The techniques used are determined largely by building type and to a lesser degree location. Insulation levels are driven by code requirements that do not distinguish between individual building types. One exception to this is the use of semi-heated spaces in the Washington and Oregon codes and the use of unheated spaces in all regional codes. Semi-conditioned spaces are allowed to have less insulation if the heating equipment meets certain capacity thresholds. Unheated space has a very low maximum capacity threshold and generally allows a building to have no insulation.

The goals of the envelope review were to:

- Collect information about building envelope components.
- Calculate overall building heat loss rates.
- Identify trends in glazing components.
- Compare code compliance between the previous baseline study and the current study.

Building components have not changed drastically since the last study. However, glazing performance has increased to the point that low-ε coatings are nearly ubiquitous and solar heat gain coefficients (SHGC) have been reduced. These performance improvements are partially negated by the design trend of increased glazing areas. Code compliance has increased noticeably despite the fact that some codes have become stricter since the last study.

7.1. Overall Building Heat Loss

In this study, the auditors were asked to review the buildings' thermal components. Because the audits were completed well after the buildings had been built and occupied, these reviews were conducted using the drawing specifications, as-built plans, etc. Relatively few components could be identified directly on-site. Only in the case of windows were secondary efforts made to contact original installers, designers, or others involved in the window specifications to establish more detailed as-built conditions.

Nevertheless, many commercial buildings had detailed drawings and specifications for insulation levels and building components, and data collected in this way are closely representative of the actual construction details used to construct the building. Table 7.1 and Table 7.2 summarize the heat loss rate of all the buildings by building type and by state. This table corresponds to the same level of information collected in the previous baseline and includes a comparison to that information. However, in this case the audits in the previous studies were conducted during, or immediately after, construction and the level of detail available for insulation specifications and component construction details was somewhat higher than was available in this study.

Where auditors were unable to establish insulation values, building components, or other useful details that could be used to establish heat loss rates, the evaluation assumed that the envelope components met the requirements of the code applicable to that building. While this method was used in all previous studies, its importance here was somewhat higher because of the timing and protocol of the audit itself. A second caveat about Table 7.2 is that this table represents approximately 50 separate categories of building and state. Table 7.2 shows a remarkable homogeneity among buildings types. Only warehouses exhibit a pattern of somewhat higher heat loss rate and this is largely due to the code treatment of semi-heated or unheated spaces in the individual states. When these data are compared to the previous baseline it is clear the net impact of any changes in construction and thermal practices has not changed overall building heat loss rates appreciably.

Table 7.1: Building Heat Loss Rate by State (UA/Sq. Ft.)

Building Type	ID	MT	OR	WA	Total	N
2002-2004: mean	0.21	0.16	0.16	0.18	0.18	346
2002-2004: std. Dev.	0.12	0.15	0.09	0.12	0.12	346
1996-98	0.17	0.12	0.20	0.17	0.17	228

Table 7.2: Building Heat Loss Rate by Building Type (UA/Sq. Ft.)

Building Type	Total	Std. Dev.	N
Assembly	0.19	0.07	8
College	0.11	0.02	9
Schools	0.14	0.05	67
Grocery	0.15	0.06	18
Health Services	0.13	0.04	16
Hospital	0.10	0.06	25
Institution	0.15	0.06	24
Office	0.16	0.06	26
Other	0.20	0.12	9
Residential / Lodging	0.12	0.05	18
Restaurant / Bar	0.20	0.06	8
Retail	0.21	0.13	78
Warehouse	0.26	0.18	40
Total	0.18	0.12	346
1996-98	0.17		228

7.2. Windows

Because of regional interest on window performance, this study placed a special emphasis on window details and window area. This emphasis allowed a considerable level of detail to be ascertained about basic window characteristics, SHGC, and U-value performance.

Commercial buildings generally do not use National Fenestration Ratings Council-tested windows. Only the City of Seattle seems to have enforced NFRC requirements for windows installed in that jurisdiction. In addition, where manufactured window products were installed, NFRC test data were available and used. In all other cases, overall window performance had to be assumed based upon the center of glass (COG) performance and the frame characteristics. In many cases, specific COG performance was unknown as well and a value had to be estimated from basic glass characteristics.

As a result, the data collection effort tried to gather all available information on the windows. Window component details such as the low-ε coatings, numbers of layers, the tints, and the gas fills tended to be fairly well documented in the sources that were accessed and observation directly. COG rated values were less reliably found and often the installer or manufacturer was contacted to try to obtain this information. Details about thermal break performance in aluminum frames and related issues that could alter overall performance were much more difficult to determine even from the installers and documentation. In other cases, individual architects were asked directly (although this provided relatively little desired information).

Auditors used a multi-step process to establish window performance from information available at the particular sites:

- Determined window specifications from several sources, including architectural specifications and schedules available in the as-built plans.
- Inspected O&M manuals for installer, manufacturer and glass and frame information; unfortunately glass details or even glass type were rarely available in the O&M manuals and submittals were usually filed away and unavailable.
- Inspected windows on-site and recorded spacer information, number of layers, coloration, and frame material.
- Talked with installers and manufacturers to determine from their records what particular glazing and/or window frames were used.

Window areas were calculated from building plans and checked on-site.

7.2.1. Window areas

In virtually all the codes, window area is regulated as a fraction of gross wall area. Table 7.3 shows the averages of the window areas observed in this study.

Table 7.3: Window Area by State (% of Gross Wall)

State	Mean	Std. Dev.	1996-98
ID	12.3	14.2	9.6
MT	8.3	8.9	12.6
OR	16.4	11.4	15.3
WA	15.0	12.7	12.0
Average	**14.7**	**12.6**	**13.5**

Unlike the actual window specifications, window areas could be derived from as-built plans and direct observations and thus the estimates of absolute window area are relatively robust. In virtually all cases, the codes enforced in these jurisdictions relate window area to actual window performance; thus, as window areas exceed 15 to 20%, higher performing windows are expected. Table 7.4 summarizes observations of window area as a fraction of gross wall area weighted by building area and case weight.

Table 7.4: Window Area by Building Type (% of Gross Wall)

Building Type	Total	Std. Dev.	1996-1998
Assembly	**15.8**	10.3	**9.4**
College	**19.6**	5.8	**10.7**
Schools	**13.9**	7.8	**3.4**
Grocery	**9.1**	8.0	**19.8**
Health Services	**25.6**	11.6	**7.9**
Hospital	**21.0**	10.6	**---**
Institution	**17.5**	12.2	**7.8**
Office	**28.9**	15.1	**27.0**
Other	**9.7**	7.6	**14.4**
Residential/Lodging	**24.5**	12.6	**20.0**
Restaurant / Bar	**15.8**	7.0	**14.3**
Retail	**11.2**	12.2	**11.2**
Warehouse	**4.0**	4.7	**5.3**
Average	**14.7**	12.6	**13.5**

Table 7.4 also compares these results to the 1996-1998 baseline study. When comparing across states, a consistent pattern of increased glazing area can be observed from the previous study to the current one, with the exception of Montana where buildings such as warehouses are heavily weighted and generate a low overall glazing fraction. When compared across building types, institutions, health services, educational facilities, and college buildings demonstrated a distinctive trend toward larger amounts of glazing. Conversely, groceries exhibited a marked decrease in glazing fraction since the last study. The decrease is due to the variance between the grocery samples in the two studies. In the previous study, the grocery sample included smaller buildings where glazing represented a larger fraction of the wall area whereas the grocery sample in the current study included a few very large box stores in which the glazing is almost inconsequential.

The overall samples suggest an 8% increase in glazing area. While building type distributions between the samples make interpreting this value problematic, looking at individual building types provides clear evidence that glazing levels have increased across most building types. Given this increase in glazing area, a corresponding increase in building UA would be expected but as discussed in the previous section, that did not occur. The implication is that window characteristics and window U-value have improved enough to offset the increased window areas observed in these buildings. Table 7.5 describes skylight area as a percent of gross roof for all buildings. The overall number is small, but this includes all buildings without skylights. Twenty-five percent of the sampled buildings with 32% of the floor area have skylights. Limited to these buildings the average skylight area as a percent of roof area is 1.4%.

Table 7.5: Skylight Area by State (% of Gross Roof)

State	All Buildings (% of roof)		Pct Floor Area with skylights	Buildings w/ skylights (% of roof)	
	Mean	Std. Dev.		Mean	Std. Dev.
ID	0.1	0.5	12	1.0	0.5
MT	0.5	1.0	23	2.0	1.0
OR	0.5	1.2	34	1.4	1.2
WA*	0.6	1.1	38	1.5	1.4
Average	**0.8**	**4.4**	**32**	**1.4**	**1.4**

* Single project with 70% skylight removed. If included, WA all building mean is 1.1 and building with skylight mean is 2.8. The total includes this building in the regional average.

Table 7.6 describes window and skylight areas as a percent of the gross floor area of the project. This is a value that is useful in calibrating window areas across the commercial sector when relatively little information on building size, besides floor area, is available.

Table 7.6: Window and Skylight Area by State (% of Gross Floor)

State	Window Area		Skylight Area	
	Mean	Std. Dev.	Mean	Std. Dev.
ID	6.4	7.6	0.1	0.5
MT	3.5	3.5	0.4	0.9
OR	8.8	7.1	0.4	0.9
WA	7.4	7.1	0.6*	1.3*
Total	7.4	7.2	0.4*	1.2*

* Single project with 70% skylight removed. If included, WA skylight mean is 0.7 and region mean is 0.5.

7.2.2. Window characteristics

Table 7.7 summarizes the major glazing characteristics observed in this study. For the most part, the details of coatings and fill were available in general terms and in some cases in quite good detail. The characteristics summarized here serve as the basis for virtually all the performance estimates that were made for windows.

Table 7.7: Prevalence of Major Glazing Characteristics (% of Gross Floor)

State	Low-ε	Tint	Argon
ID	81.5	61.8	1.8
MT	86.5	38.6	36.6
OR	95.8	43.6	11.9
WA	79.5	32.4	22.5
Average	**85.3**	**40.5**	**16.2**
1996-1998	**64.7**	**73.8**	**8.6**

Low-ε coatings were prevalent in commercial windows by the end of the 2004 building year. This represents a continuation of the trend observed in the last baseline study where the presence of low-ε coatings increased from a third of the windows in buildings in the early 1990s to about two thirds by the late 1990s. Low-ε coatings have become the major tool used to achieve solar control, shading control, and glare control in glazing systems throughout the sector and are utilized in virtually all states and building types in the region.

Conversely, the use of glazing tints, which change the color of the window and not the heat loss performance, has dropped by almost half. The decrease is likely because low-ε coatings are providing virtually all of the solar control currently used in the commercial sector. The use of argon increased by about a factor of two since the 1996-1998 study. This is largely the result of the need for ever-increasing window performance to compensate for higher glazing areas. This performance trade-off strategy is particularly apparent in offices and schools where the architecture and design standards seem to demand more glass. Overall, this combination of low-ε coatings and argon fill seems to compensate for the increased glazing area according to the calculated overall heat loss rate relative to the 1996-1998 building stock.

7.2.3. Window and Frame Type

The windows observed in this study are dominated by metal frame windows usually with a nominal thermal break (TB). The auditors were not generally able to discern the details of the thermal break so most often the specifications or the window installer provided this information. Table 7.8 shows the distribution of frame type by major component. In these cases, the windows with wood or vinyl frames were manufactured and had good information while information on the remaining window frames was more uncertain. Where thermal breaks could be identified 88% of the aluminum frame windows were listed as thermally broken. All of the vinyl and wood windows were manufactured and generally included an NFRC test and rating. Less than 1% of the aluminum windows were manufactured as opposed to assembled and glazed on-site.

Table 7.8: Distribution of Frame Type by State (%)

State	Aluminum (TB)	Aluminum	Vinyl	Wood
ID	60.3	14.2	23.5	2.0
MT	40.5	3.8	30.5	25.3
OR	57.5	22.9	17.9	1.7
WA	43.0	32.1	18.8	6.1
Average	50.5	25.8	19.4	4.3

Table 7.9 shows the distribution of manufactured and site-built windows. In all cases, “curtain wall” windows are in fact site-built and site-glazed. The site-built category includes site-built “store front” and punched opening windows. Overall, 75% of all windows observed were “site-built” with very problematic documentation as to the performance of the frames.

Table 7.9: Window Type Distribution by State (%)

State	Manufactured	Curtain Wall	Site-Built
ID	26.9	15.9	57.2
MT	54.1	12.3	33.6
OR	20.0	26.2	53.7
WA	24.7	18.4	56.9
Average	**23.9**	**20.5**	**55.6**

7.2.4. Overall Window Performance

Overall window performance is only partially dependent on the glazing components. The thermal properties of the frame and thermal breaks within the frame are also important to overall window performance. Frequently, auditors were unable to determine these details or find test values for the overall performance of the window sections. As a result, auditors made assumptions based on observations of the frames and details associated with curtain wall and other site glazing.

In this process, auditors used the fenestration U-value tables from ASHRAE, 2005. This source allows estimates based on various frame types and COG U-values. In most cases, auditors were able to get documentation on frame types so that values could be interpreted from these tables and interpolated for specific COG values. Auditors reviewed a series of characteristics, including the frame types (e.g., curtain walls, punched openings, storefronts), thermal breaks on the frames (where the frames were metal), glazing types and coatings, etc. These characteristics were supplemented by performance tests or direct values submitted by the installer. When the installer-provided information was not available the ASHRAE reference tables were used.

U-factor

Table 7.10 and Table 7.11 show the distribution of window U-factor by state and by building type, respectively.

Table 7.10: Window U-Factor by State (% of Glazing Area)

State	U-Factor Class (100 x U-factor)			
	30-40	**41-50**	**51-60**	**>60**
ID	1.1	56.2	4.0	18.7
MT	54.8	37.3	6.9	0.9
OR	56.4	32.7	9.4	1.5
WA	38.5	32.5	15.5	13.4
Average	42.1	36.2	11.7	10.1
1996-98	**8.1**	**32.5**	**30.6**	**28.7**

Table 7.11: Window U-Factor by Building Type (% of Glazing Area)

Building Type	U-Factor Class (100 x U-factor)			
	30-40	41-50	51-60	>60
Assembly	17.8	79.5	2.8	0.0
College	99.3	0.7	0.0	0.0
Schools	45.3	27.1	17.4	10.2
Grocery	11.1	74.6	8.1	6.1
Health Services	23.5	44.0	24.6	7.9
Hospital	72.2	26.1	1.7	0.0
Institution	62.2	37.9	0.0	0.0
Office	43.5	40.9	5.5	10.1
Other	31.3	68.7	0.0	0.0
Residential / Lodging	50.9	20.5	22.4	6.2
Restaurant / Bar	23.0	68.4	0.0	8.6
Retail	18.7	39.1	14.6	27.6
Warehouse	17.3	39.4	21.8	21.4
Average	**42.1**	**36.2**	**11.7**	**10.1**

The window U-factors were binned into major categories based on the observed glazing components and frames. These categories (U-factor "class") are bins that refer to 100 x U-factor, thus the "30 – 40" bin includes windows with U-factors between 0.3 and 0.4. The most striking detail about Table 7.10 is the comparison between the distribution of windows by class in the current study and the 1996-1998 study. High-performance windows in the "30 – 40" class have five times the saturation of that same class of windows in the 1996-1998 study. Additionally, only rare cases of class ">60" windows were observed in this study. Class "30 – 40" windows now dominate hospitals, institutions, offices, and schools/college. The class ">60" is dominated by clear, single-glazed display windows in the retail sector and small punched openings in the warehouse sector where the heat loss rate of the windows is relatively insignificant.

Solar Heat Gain Coefficient

SHGC is largely a function of the glazing properties rather than the frame properties. SHGC varies substantially with the types of low-ε coating and types of glass substrate to which they are applied. The auditors attempted to retrieve SHGC information directly from the building, the window specifications, the window installer specifications, or the architect. Shading components were then combined with frame information to estimate SHGC, organized into bins as shown in Table 7.12.

Table 7.12: Window SHGC Category by State (% of Window Area)

	SHGC Class (100 x U-factor)		
State	17-35	35-54	55-90
ID	52.4	20.8	26.8
MT	46.2	38.1	15.7
OR	41.8	46.5	11.7
WA	41.5	34.6	23.9
Average	**43.3**	**36.6**	**20.1**
1996-98	**12.9**	**62.8**	**24.3**

The categories in Table 7.12 are based on whole numbers that are 100 x SHGC. Thus, the bin "17–35" represents an SHGC of 0.17 to 0.35. With the advent of low-ε coatings, high-performance windows throughout the sector have considerably less solar transfer than was typical in windows observed in the 1996-1998 study. The last category, glazing, was included in the "55–90" category. This category generally is associated with display windows and represents about 7% of the glazing in this category. In the 1996-98 study, clear glazing represented more than 80% of the "55-90" category.

7.3. Roof, Wall, and Floor Characteristics

Opaque component characteristics were much more limited. Generally, insulation levels were difficult to determine given the timing and documentation available to the auditor. Often specifications and plans stated "insulate to code" and various sources were not internally consistent. Where auditors did not have insulation data, it was assumed that the unknown insulation level met code. The general structure categories were much more reliable. These structural characteristics are weighted by the buildings case weight and the component area. Thus, these tables show the fraction of component area in each category.

Table 7.13 shows the distribution of wall construction types observed by the auditors. In general, the frame characterization was used in describing walls that included framing as the means of insulating the wall even if the framing was backed by a concrete or concrete masonry unit (CMU) wall. The "CMU inserts" designation refers to walls with insulated inserts that slide into the voids in the CMU to create a somewhat improved thermal performance. Similarly, "concrete" walls designate walls that are not furred out with framing. About 20% of the concrete and CMU wall categories have some amount of rigid insulation applied directly to the wall surface with mastic or fasteners. The occurrence of "unknown" illustrates the difficulty of getting this information well after the building was occupied.

Table 7.13: Wall Structure Type (%)

Wall Type	CMU	CMU inserts	Concrete	Frame-metal	Frame-wood	Other/ Unknown	Total
ID	34	13	2	18	27	7	**100**
MT	15	5	5	36	16	23	**100**
OR	10	14	6	35	27	9	**100**
WA	8	19	8	25	30	11	**100**
Average	**13**	**16**	**6**	**27**	**29**	**10**	**100**

Table 7.14 shows the distribution of roof and ceiling types. The dominant roof type is a roof deck. Generally, this category includes roof details that could have cavity insulation, but also includes cases with roof deck insulation above the roof sheathing. Roofs that are uninsulated appear in the "other" category. About half of this category includes uninsulated roofs. A small fraction of the "other" group includes dropped ceilings that are insulated as the ceiling insulation. This strategy is not allowed under the Washington or Oregon codes, although the only incidence of this occurred in those states. "cavity" refers to a framing cavity that is insulated. "Blanket" refers to the roof of metal buildings that are insulated by stretching the insulation blanket over the roof perlins prior to placing the roof sheathing. "Cavity" and

"attic" insulation are used more sparingly in this sector and are usually associated with smaller buildings with residential-type construction detailing.

Table 7.14: Roof Insulation Location/ Type (%)

Roof/Ceiling Type	Attic	Blanket	Cavity	Other/ Unknown	Roof Deck	Total
ID	6	3	5	44	43	**100**
MT	11	2	3	32	53	**100**
OR	6	5	2	31	57	**100**
WA	5	5	7	19	65	**100**
Average	**6**	**4**	**5**	**27**	**58**	**100**

Table 7.15 shows the distribution of floor structure characteristics. This category is dominated by slabs, usually in ground contact. Except in very high-density areas, the vast majority of nonresidential buildings are constructed on slabs either at grade or below grade. The majority of these cases have detailing or specifications that claim some level of slab insulation. Auditors were not able to confirm this detail. The "slab above grade" category and the "frame over other" category refer to floors above unconditioned space, usually parking garages. Note that this summary is weighted by component area and case weight. In large multi-story buildings, the case weight and the floor component (compared to the total building area) are small so the relative importance of this construction type in all floor construction is significantly reduced.

Table 7.15: Floor Structure Type (%)

Floor Type	Frame Over Crawl	Frame Over Other	Slab Above Grade	Slab Below Grade	Slab on Grade	Unknown	Total
ID	0	0	0	2	90	8	**100**
MT	0	0	0	3	93	4	**100**
OR	0	0	7	2	91	0	**100**
WA	2	3	3	6	86	0	**100**
Average	**1**	**1**	**4**	**3**	**89**	**2**	**100**

7.4. Energy Code Compliance

Envelope code requirements differ in both style and substance across the various state codes. As with other components in this study, the code review was based on the code enforced in each jurisdiction in 2001. In Table 7.16, code compliance was calculated for both the 2001 code and the "2005" code, which represents the code that would have been in place in all of the jurisdictions in 2005, including IECC 2003 and the 2004 or 2005 versions of the Washington, Oregon, and Seattle codes. The Montana buildings were reviewed under the ASHRAE 90.1-1989 code. Montana has adopted the IECC 2003 code in 2004. The difference between 2001 and 2005 for this state is an artifact of changes between these two codes.

Table 7.16: Envelope Code Compliance by State and Code (% and N)

State	State Code Year			Old Baseline	
	2001	2005	N	1996-98	N
ID	88.8	88.8	64	42.1	48
MT	47.0	77.1	29	76.3	32
OR	92.7	91.6	108	55.7	64
WA	93.6	75.6	148	86.0	84
Average	91.2	82.2	**349**	**66.9**	**228**

In Idaho, and to a lesser extent Montana, the COMCHECK program was used extensively to provide trade-offs among building and envelope components. Frequently, the compliance demonstrated by COMCHECK was not discernible in the field audits either because the components had changed or because the particular trade-off was not apparent to the auditor or reviewer. This has a potentially large effect on buildings built with concrete masonry walls. The trade-off allowed in this case seems to be more generous than is apparent in the code language.

Table 7.16 also shows the results from the similar compliance review conducted for the 1996-1998 baseline study. The overall level of compliance has improved dramatically from that period. In the 1996-1998 study, the applicable codes were fairly new and only Washington had spent substantial effort to ensure compliance. In the case of Idaho and Montana, the levels of noncompliance, while high, largely reflect the fact that these codes were not enforced in most jurisdictions throughout the states. By any count, however, the levels of compliance are considerably better in this sample than in the 1996-1998 study. While these levels of compliance have improved dramatically, the average building's heat loss rate has not improved. This suggests that the code has come to reflect the design standards of modern commercial buildings.

While levels of compliance have improved dramatically, Table 7.17 shows the nature of code failures as observed in the field. The failures are unweighted and expressed as a percent of non-complying buildings, so each individual building, independent of its position in the sample, is represented as a single point. The reasons for failure for the most part were not glazing requirements or glazing performance, but rather underperforming components, especially concrete masonry walls and related components. The semi-heated failures, which in previous codes provided a large fraction of all the envelope code failures, have been reduced to a relatively small fraction of the total. Overall, the impact of the code changes over the last seven years has had a relatively minor effect on the overall UAs and heat loss rates of the buildings, but has had in combination a fairly large effect on the levels of compliance and apparent enforcement in buildings across the region.

Table 7.17: Code Failure Categories and Occurrence

Code Fail Category	%
ASHRAE 90.1 Doors Treated as Wall	9.0
High Glazing Fraction	6.7
OR RES: High Glazing Fraction	5.5
WA/OR Semi-heat Failure (too much heat)	15.4
Questionable Component	23.5
Underinsulated Component	6.5
Uninsulated CMU (probably used COMCHECK)	11.1
Uninsulated component	22.3
Total	**100.0**

8. Refrigeration Systems

The audit protocol for refrigeration was somewhat general with auditors asked to review only significant refrigeration systems, defined as those with remote compressors. As a result, this review captured central refrigeration systems mainly associated with grocery and retail settings and walk-in refrigeration systems in other building types. Cold storage areas that were typically part of larger warehouse developments were also reviewed. Only one of these was of sufficient size to be characterized as a cold storage system. Self-contained refrigerators and freezers in restaurant kitchens and other settings were generally not surveyed.

The goals of the refrigeration review were to:

- Describe the amount of horsepower and related aspects of the refrigeration systems.
- Describe the amount and type of refrigerated display cases and walk-in coolers.
- Identify refrigeration racks that utilized heat recovery systems.
- Document the use of various sub-cooling and other control mechanisms used to improve the efficiency of refrigeration racks and characterize their installation.

Previous studies did not describe refrigeration systems; consequently, these systems cannot be compared the current characteristics to the previous data sets in regards to compressor power or casework associated with refrigeration systems.

Building refrigeration systems have been classified as food service, grocery, or warehouse. These classifications cut across building type boundaries and are defined below.

- **Food service refrigeration** is characterized by small packaged refrigeration units that include both the compressor and condenser and are usually located on the roof, or in some other protected area. There typically is no or a limited amount of retail display case. These systems were audited and categorized in all building types. In most cases, additional refrigeration was associated with stand-alone cases with integrated compressors. This part of the food service refrigeration was not a part of the building specifications and was generally not audited or characterized.
- **Grocery refrigeration** is characterized by central compressor rack refrigeration systems and numerous retail display cases as is typically found in grocery and retail stores. Buildings with grocery refrigeration often include a few areas with food service-style refrigeration as well but the whole building is assigned to the grocery type. Grocery stores undoubtedly have the largest amount of refrigeration per square foot of building. It is important to note that the retail sector here is dominated by big-box chain stores, many of which have grocery stores embedded in a larger dry goods retail operation. In almost all cases, the racks observed in the retail stores were of comparable size to those in grocery stores, although the buildings themselves were two to four times as large as a typical grocery store.

- **Refrigerated warehouse systems** characterize larger refrigerated warehouse facilities where refrigerated areas are more likely “drive in” than “walk in.” Refrigerated warehouses are strictly confined to the warehouse sector and represent a relatively small fraction of that sector’s total. Three buildings had refrigerated areas included in this group. The refrigerated areas included a very small holding area (~4000 sq. ft.), a medium sized beverage distributor (~40,000 sq. ft.), and one large grocery distribution warehouse (500,000 sq. ft.).

Table 8.1 shows the building floor area reporting the presence of refrigeration systems by type observed throughout the sample. Food-service refrigeration systems are pervasive and appear in some form in almost every building type.

Table 8.1: Distribution of Refrigeration Observed (% Floor Area)

Building Type	Refrigeration Style			
	Food Service	Grocery	None	Ref Warehouse
Assembly	26.1	0.0	73.8	0.0
College	22.6	0.0	77.4	0.0
Schools	29.0	0.0	71.0	0.0
Grocery	0.0	100.0	0.0	0.0
Health Services	0.9	0.0	99.0	0.0
Hospital	19.6	0.0	80.3	0.0
Institution	6.5	0.0	93.5	0.0
Office	1.6	0.0	98.4	0.0
Other	1.5	0.0	98.5	0.0
Residential / Lodging	39.9	0.0	60.1	0.0
Restaurant / Bar	100.0	0.0	0.0	0.0
Retail	35.1	14.6	50.3	0.0
Warehouse	2.2	0.0	96.7	1.1
Average	**22.5**	**5.6**	**71.7**	**0.1**

8.1. Refrigeration Compressor Systems

To characterize these systems the auditors collected detailed horsepower information from racks, equipment nameplates, and refrigeration schedules. Table 8.2 shows the amount of compressor horsepower found in buildings with refrigeration by building type. Compressor horsepower results have been normalized by project area and only those buildings with refrigeration present are summarized. The grocery sector has far more refrigeration than the other sectors. Buildings in the retail sector with refrigeration have about a third the density of refrigeration as the grocery sector, largely because the grocery refrigeration is in a store that is only about 30% grocery. Since the retail and grocery sectors were oversampled, estimates can be considered representative. In other sectors, the nature of the refrigeration systems was quite variable and the results more uncertain.

Table 8.2: Distribution of Compressor Horsepower Observed by Building Type

Building Type	HP/1000 Sq. Ft.	Std. Dev.	N
Assembly	0.19	0.27	2
College	0.07	0.02	2
Schools	0.04	0.03	31
Grocery	3.04	1.43	18
Health Services	0.01	0.01	2
Hospital	0.05	0.05	6
Institution	0.05	0.06	4
Office	0.03	0.02	4
Other	0.05	.	1
Residential / Lodging	0.03	0.02	13
Restaurant / Bar	1.02	0.55	8
Retail	0.98	0.88	35
Warehouse	1.44	1.05	5
All Building Types	**0.66**	**1.09**	**131**

8.1.1. Refrigerant Types

Table 8.3 shows the variety and usage of refrigerant types observed. Forty percent of the compressor horsepower utilize R22. Approximately 50% of R22 is utilized in reused or existing units in refurbished systems within the grocery sector. The remaining R22 was found in food service, and small, refrigerated warehouses. R404a and R507 are more modern refrigerants designed to meet the requirements of the Montreal Protocols for 2012 (ASHRAE 2005). They represent more than half of the refrigerant used in this sample. The only ammonia (R717) based system was the single, large refrigerated warehouse.

Table 8.3: Refrigerant by System Type (% of Compressor HP)

Refrigerant	Refrigeration Type			
	Food Service	Grocery	Ref Warehouse	Total
R22	26.39	46.19	7.48	**39.96**
R404a	73.61	32.07	0.00	**28.64**
R507	0.00	21.74	0.00	**17.92**
R717	0.00	0.00	92.52	**13.48**
Total	**100.00**	**100.00**	**100.00**	**100.00**

8.2. Refrigerated Cases

To evaluate refrigeration loads, auditors detailed the type and lineal feet of cold food and beverage cases, as well as record design loads from schedules where possible. The industry typically divides these cases into three main categories: low-temperature (below zero) which characterizes frozen foods; medium-temperature (coil surfaces below or near freezing) designed to maintain product temperatures in the 30s up to the mid-40s; and high-temperature (above 45 degrees) for fresh fruits, vegetables, and fresh meats. The medium and high-temperature cases were combined for this study.

8.2.1. Grocery Applications

Refrigerated cases used in grocery applications were grouped into five distinct types: coffin, multi-deck, reach-in, service, and single-deck:

- Coffin cases are horizontal with an open top and users reach down into the case to access the product. These are usually low-temperature cases although they are also used for medium-temperature applications for some product types.
- Multi-deck cases are open with multiple shelves vertically arranged with cold air running vertically through the cases. These cases have no covering, are prone to spillage of cold air, and require a great deal of energy. These cases are almost always medium-temperature.
- Reach-in cases are vertical cases with shelving which have glass doors. They are typically used for frozen food and dairy products. The great bulk of low-temperature cases in this sample were reach-ins. Reach-in cases are also prevalent when the case is rear loading and is adjacent to a larger walk-in cold storage area. Such cases are stocked from the rear from a room that is maintained at roughly the temperature of the product.
- Service cases are found in deli, fish, and sometimes meat areas. They typically have a solid glass front and sliding glass doors in the back for staff access.
- Single-deck cases are usually produce or meat cases with the product set on a single surface that can be accessed directly. These cases are most commonly used in higher temperature applications.

In addition to these five types, cases with other specialty applications were classified as "other," and were scattered throughout the grocery sector. These are usually maintained from the central refrigeration system but occasionally use stand-alone refrigeration systems to serve beverage dispensers, ice dispensers, or other applications. Also, included are cases of unknown type. Table 8.4 shows the distribution of these six case types in grocery applications as a percent of overall length. Average total case length in grocery style applications in groceries is 12.3 lineal feet of case for every 1000 sq. ft. of floor area. In retail, buildings with refrigeration average 3.4 lineal feet of case for every 1000 sq. ft. of floor area.

Table 8.4: Case Type Saturation within the Grocery Sector (% Length)

Case Type, Grocery	Temperature		Total
	Low	Medium	
Coffin	9.31	6.69	**15.99**
Multi-deck	0.16	35.20	**35.36**
Other	0.28	3.88	**4.16**
Reach-In	21.97	5.06	**27.03**
Service	0.07	6.89	**6.96**
Single-deck	0.07	10.43	**10.50**
Total	**31.87**	**68.13**	**100.00**

Table 8.4 illustrates that within the grocery sector, low-temperature cases are typically either coffin or reach-in, with reach-in designs dominating. Low-temperature cases thus represent about a third of the lineal feet of cases observed in the grocery sector. The medium-temperature and high-temperature cases represent the remaining two thirds of the lineal feet, and are dominated by open cases with either exposed racks such as a multi-deck system or an exposed single-deck system. About 80% of the medium and high-temperature cases had no doors or other coverings as part of their design.

8.2.2. Food Service Applications

For food service compressor applications, the casework itself is quite similar to the grocery applications. Small, food-related retail operations such as convenience stores and delicatessens often use these systems. Table 8.5 summarizes the case types and saturation in the food service sector.

Table 8.5: Case Type Saturation within the Food Service Sector (% Length)

Case Type, Food Service	Temperature		Total
	Low	Medium	
Coffin	22.82	5.43	**28.25**
Multi-deck	0.00	5.18	**5.18**
Other	10.44	25.27	**35.70**
Reach-In	0.00	11.51	**11.51**
Service	0.00	19.36	**19.36**
Total	**33.25**	**66.75**	**100.00**

In this application, relatively few reach-in cases are used for low-temperature applications; the coffin cases are more common, sometimes with doors, but usually open to the store. The food service sector has a much higher percentage of specialty stand-alone systems, such as beverage dispensers, pie, cheese, and other delicatessen displays. Case designs are often specialized to specific product lines. The distribution of medium and low-temperature cases is similar to that found in grocery stores with about a third of total cases devoted to low-temperature applications.

In grocery applications, the auditors were able to separate the loads associated with the medium and low-temperature cases. On average, low-temperature cases represented 41% of the horsepower capacity in the grocery systems but only 30% of the total case length.

8.3. Walk-In Coolers/Freezers

Walk-in coolers and freezers are common in many building types. They are an especially significant load in grocery and food service areas. Walk-in coolers provide storage and staging areas for groceries and beverages in storage rooms adjacent to the cases and are not generally part of the retail operation. Table 8.6 summarizes the density of walk-in coolers by building type. Note that this is the density of walk-ins in buildings with walk-ins. The auditors did not collect a significant amount of information on walk-ins other than their operating temperatures and size.

Table 8.6: Density of Walk-In Rooms (sq. ft./1000 sq. ft. Building Area)

Building Type	Walk-in area	% Low temp.	N
Assembly	5.6	87	2
College	1.9	18	2
Schools	3.2	42	34
Grocery	60.5	18	17
Health Services	1.0	64	2
Hospital	3.1	51	7
Institution	4.7	60	4
Office	0.4	32	4
Other	3.6	0	1
Residential/Lodging	1.9	22	14
Restaurant / Bar	66.5	40	8
Retail	28.6	29	34
Warehouse	66.3	48	4
All Building Types	**33.9**	**35**	**133**

8.4. Subcooling

In grocery systems, the auditors attempted to determine if the system uses mechanical or ambient subcooling. Subcooling is used to increase the capacity of the refrigeration system and improve the function of the expansion valve. In general, the subcooling was noted on the refrigeration schedule and associated with a particular rack of compressors operating at similar suction temperatures. The majority of the low-temperature systems use this technique and about 30% of the high and medium-temperature systems employ subcooling. Table 8.7 shows that this technique, which typically increases the efficiency of the compressor rack by almost 10%, is used about half the time throughout the grocery refrigeration systems.

Table 8.7: Compressor Systems with Subcooling

Sub-cooling	Compressor Systems (% of HP)		
	All Systems	Low temp	Med/High temp
No	49.1	19.8	70.3
Yes	50.9	80.2	29.7
Observations	103	50	59

8.5. Refrigeration Lighting

Refrigeration lighting is a significant factor in grocery and big-box retail stores that utilize display cases. Table 8.8 summarizes the case lighting in grocery stores and retail per square foot of project area. Grocery store refrigeration case lighting adds about .23 watts/sq. ft. of LPD. This amounts to about a 15% increase in the entire LPD in groceries. Case lighting in retail stores results in an increase of about 8%, but these stores are more than twice the size of the groceries.

Table 8.8: Refrigeration LPD in Grocery Applications (Watts/Sq. Ft. of Building)

Building Type	Refrigeration case system lighting (Watts/Sq. Ft.)
Grocery	0.23
Retail	0.12
Average	**0.15**

The case lighting typically uses specialized T8, and sometimes T5 linear fluorescent fixtures; none of the new cases observed include any other types of lighting. One smaller store utilizes second hand cases with older magnetically ballasted T12 lamps.

Walk-in lighting has been included under the appropriate code categories in the LPD. Generally the spaces are either storage or kitchen preparation spaces. Fixture types are generally linear T8 lamps or induction HID lighting.

8.6. Observations and Opportunities

In general, the refrigeration systems have remarkably similar compressor type systems, controls, and cases. Indeed, these observations indicate that in both the retail and grocery sectors, there is little distinction of big-box applications between the grocery and large chain superstore or dry goods store. The distinctions among cases and retail display are largely a function of marketing or market positioning and represent essentially no particular change in the refrigeration systems.

A small number of stores use heat recovery for space heating although virtually all of them use heat recovery for domestic water. The use of heat recovery is discussed in Section 5.3. Because grocery applications generate tremendous amounts of waste heat and draw heat from the store in the form of heat gain to the refrigerated cases, interaction with the refrigeration system dominates the space heating requirements in the stores. This is true even in big-box stores where the refrigeration systems are concentrated in one particular area. Typically, the impact of these systems on hot water can be helpful. However, hot water applications represent only a fraction of the recoverable refrigeration heat and virtually all of the waste heat associated with refrigeration is exhausted through roof-mounted condensers.

In food service applications, occasionally heat recovery to hot water is used. Since these systems are dramatically smaller and the service water needs of food service are higher, heat recovery to hot water in these cases may well be the best use of this waste heat.

Condenser technology is air-cooled except for a single chain of stores that utilize evaporative condensers in most of their stores. There are some applications of remote decentralized compressor systems applied to the grocery. Two such stores were observed in the sample and this seems to be a fairly rare occurrence and is done largely for the convenience of the store, where central racks are either disruptive or have impractical space requirements.

9. Interviews

Interviews were conducted predominately with architects, mechanical engineers, and specialty contractors throughout Idaho, Montana, Oregon, and Washington. An additional 12 firms based outside of the Pacific Northwest were also interviewed. Appendix B includes a complete summary of the interview questions and responses. Interview results are compared to the previous study. The interviews in that study were conducted in 1999 on projects completed in 1998 and 1999. In the most recent set of interviews, conducted in 2007, the projects in the study were completed by the end of 2005 and often the professionals interviewed completed their involvement several years before that. As a result, some of these interviews addressed details beyond the memory of the interviewees.

The goals of the interviews were to:

- Understand what energy codes were used and how they were enforced.
- Learn about current trends in attitudes toward energy efficiency/energy codes.
- Determine how energy efficiency is viewed in the design process.

Since the previous study, significant changes in both attitude and practice have occurred regarding aspects of design, code enforcement, and client demand for energy efficient buildings. Given the timing of the two studies, this shift occurred over the period from 1998 to 2007.

9.1. Interview Sample

Table 9.1 shows the sample distribution of the interviewees by design role and state. Interviews were conducted for 151 projects (42% of the total sample). Fifty-five percent of interviewees are architects, 38% are mechanical engineers, 3% are specialty contractors, and 4% are other (i.e., building managers or corporate managers).

Table 9.1: Interview Sample Distribution by Design Role

Design Role	ID		MT		OR		WA		Total	
	N	%	N	%	N	%	N	%	N	%
Architect / Envelope Designer	19	61	9	60	18	56	37	51	**83**	**55**
Mechanical Engineer	11	36	6	40	8	25	33	45	**58**	**38**
Mechanical Contractor	0	0	0	0	4	13	0	0	**4**	**3**
Other	1	3	0	0	2	6	3	4	**6**	**4**
Total	**31**	**100**	**15**	**100**	**32**	**100**	**73**	**100**	**151**	**100**

As Table 9.2 shows, medium-size firms (11-100 employees) made up the majority of the firms involved in these projects. While there was some variation between states, this size firm appears to have been consistently responsible for more than half of all projects in the sample (56%). This is about the same size as firms that participated in the previous baseline study.

Table 9.2: Firm Size by Number of Employees (%)

No. of Employees	ID	MT	OR	WA	Total
1-5	13	27	18	8	**13**
6-10	10	0	9	7	**7**
11-25	48	13	33	18	**27**
26-100	19	20	24	37	**29**
Over 100	10	40	15	30	**24**
Total	**100**	**100**	**100**	**100**	**100**

9.2. Energy Codes

Interviewees were asked to identify the primary decision maker responsible for energy code compliance and energy efficiency within building envelopes, mechanical systems, and lighting systems. The following three tables display the responses for each of these categories. Overall, responses showed that individual design professionals make the majority of decisions. As expected, architects most commonly make envelope decisions (45%, Table 9.3), individual mechanical engineers make most of the mechanical system decisions (46%, Table 9.4), and lighting engineers make lighting system decisions (39%, Table 9.5). However, a growing number of firms are now using a team approach to make energy efficiency and energy code decisions. Interview responses indicate that teams of architects, engineers, and developer/clients made between 32 and 37% of these decisions. This indicates a major change from 1999 where teams were not mentioned. This change is most likely due to the design profession's increased emphasis on an integrated design approach.

Table 9.3: Energy Efficiency Decision Maker: Envelope (%)

Decision Maker	ID	MT	OR	WA	Avg.
Architect	48	40	55	41	**45**
Team	39	47	18	33	**32**
Code	13	0	15	12	**12**
Owner	0	7	12	7	**7**
Other	0	0	0	4	**2**
Consultant	0	0	0	1	**1**
Structural Engineer	0	7	0	0	**1**
Corporate Manager	0	0	0	1	**1**
Total	**100**	**100**	**100**	**100**	**100**

Table 9.4: Energy Efficiency Decision Maker: HVAC (%)

Decision Maker	ID	MT	OR	WA	Avg.
Mechanical Engineer	52	27	48	47	**46**
Team	35	60	36	33	**37**
Owner	0	13	9	8	**7**
Code	10	0	3	7	**6**
Architect	0	0	3	3	**2**
Other	0	0	0	3	**1**
HVAC Contractor	3	0	0	0	**1**
Total	**100**	**100**	**100**	**100**	**100**

Table 9.5: Energy Efficiency Decision Maker: Lighting (%)

Decision Maker	ID	MT	OR	WA	Avg.
Electrical Engineer	38	40	34	41	**39**
Team	45	47	44	29	**37**
Architect	0	7	9	12	**9**
Code	14	0	3	11	**9**
Owner	3	7	6	4	**5**
Other	0	0	0	1	**1**
Lighting Contractor	0	0	3	0	**1**
Consultant	0	0	0	1	**1**
Total	**100**	**100**	**100**	**100**	**100**

Table 9.6 shows the energy codes used as reported by the interviewees. Nearly all of Oregon and Washington professionals said they were governed by their state's nonresidential energy code or, in the case of Seattle projects, the City of Seattle's energy code. Approximately 60% of the professionals in Idaho and Montana used either IECC's 2000 or 2003 code. It is interesting to note that 30% of professionals from these two states said they did not use any energy code (14 of the 46 respondents from these two states).

Table 9.6: Energy Code Used as Reported by Interviewees

What Code	ID		MT		OR		WA		Total	
	N	%	N	%	N	%	N	%	N	%
ASHRAE 90.1	2	7	1	7	0	0	0	0	**3**	**2**
IECC 2000	14	45	4	27	0	0	0	0	**18**	**12**
IECC 2003	6	19	5	33	1	3	0	0	**12**	**8**
None	9	29	5	33	0	0	0	0	**14**	**9**
Oregon	0	0	0	0	31	97	0	0	**31**	**21**
Seattle	0	0	0	0	0	0	18	25	**18**	**12**
Washington	0	0	0	0	0	0	55	75	**55**	**36**
Total	**31**	**100**	**15**	**100**	**32**	**100**	**73**	**100**	**151**	**100**

Interviewees were asked if they received feedback from plan reviewers or building officials for their projects. Table 9.7 compares the answers to this question to the answers from the previous study. The most pronounced changes in responses were in Idaho and Montana. In Idaho, 24% of respondents said they received feedback, which is an improvement from the 3% previously reported. Montana also reported an increase in feedback from 11 to 43% and Washington went from 36 to 52%. In Oregon, on the other hand, feedback decreased from 54 to 44%. The reason for this is unknown.

Table 9.7: Plan Reviewer or Building Official Feedback (%)

Feedback after Plan Examination	ID		MT		OR		WA	
	2007	1999	2007	1999	2007	1999	2007	1999
Yes	24	3	43	11	44	54	52	36
No	76	97	57	89	56	46	41	64
Don't Remember	0	0	0	0	0	0	7	0

The amount of feedback from officials can be viewed as a surrogate for enforcement. Notably, the code was not being enforced in Idaho previously and was considered advisory only. Several interviewees confirmed this and said they do not like to fill out code forms when they know the building officials will not look at them or enforce the code.

It is interesting to note that when interviewees were asked if energy code compliance was a particularly challenging problem for any aspect of the building systems (envelope, mechanical, lighting), 79% said no. Respondents reported that the most difficult aspects include lighting requirements, code language, and envelope requirements. Firms from outside the Pacific Northwest had more problems complying with energy codes. These firms tried to resolve this problem by hiring local firms to ensure energy code requirements were satisfied.

Interviewees were asked if there were any elements of the energy code they considered to be poorly thought-out or not cost-effective**.** The "yes" and "no" responses were nearly equal to the 1999 study.

Table 9.8 shows the areas of energy code dissatisfaction. The most common response was that the code was "too strict." However, 7% of respondents said they thought the code was "too lenient."

Another category mentioned was "poor wording." One common example of this was the definition of "other commercial" in the code, which most commonly refers to buildings with mixed residential and commercial uses. Buildings that fall into this category are usually required to meet commercial requirements. Many interviewees found this to be problematic, especially when commercial spaces occupy only one or two stories and residential spaces are several stories.

Several respondents also mentioned the inherent conflict between energy codes and air quality codes, and what happens when buildings are too air-tight. Overall, the list in Table 9.8 is roughly comparable to the 1999 interview results in which roughly 50% of the respondents mentioned difficulties with the wording or provisions of the energy code. Like in the 1999 study, fewer complaints of energy code provisions were noted where code enforcement was more minimal (Montana, Idaho).

Table 9.8: Reactions to Energy Code Provisions

Code Problems	ID		MT		OR		WA		Total	
	N	%	N	%	N	%	N	%	N	%
Too Strict	9	45	2	50	4	15	28	58	**43**	**44**
Too Lenient	2	10	0	0	4	15	1	2	**7**	**7**
Poor Wording	1	5	1	25	7	27	7	15	**16**	**16**
Internal Conflicts	5	25	0	0	3	11	7	15	**15**	**15**
Not Enforced	1	5.	0	0	0	0	2	4	**3**	**3**
Flexible	0	0	0	0	1	4	0	0	**1**	**1**
Good Code	0	0	0	0	2	8	0	0	**2**	**2**
Deficient Coverage	2	10	1	25	5	19	3	6	**11**	**11**
Total	**20**	**100**	**4**	**100**	**26**	**100**	**48**	**100**	**98**	**100**

The majority of respondents said they design their buildings in accordance with their state's energy code. Respondents also indicated that they sometimes worked to exceed minimum lighting, HVAC, and envelope requirements. This response has significantly changed since 1999.

Table 9.9: Percent of Respondents Claiming "Beyond Code" in Their Designs

Component	ID		MT		OR		WA		2007 Regional Total		1999 Regional Total	
	2007 (n=27)	1999 (n=14)	2007 (n=17)	1999 (n=1)	2007 (n=40)	1999 (n=73)	2007 (n=102)	1999 (n=27)	N	%	N	%
Lighting	21	14	27	0	43	44	43	21	**53**	**37**	**52**	**25**
HVAC	39	9	47	6	53	40	53	34	**74**	**49**	**60**	**28**
Envelope	31	9	40	0	33	34	47	25	**59**	**40**	**47**	**22**

Montana respondents are now claiming they exceed minimum code requirements in all areas, not just HVAC as previously reported. Idaho and Washington respondents have increased their "beyond code" claims as well. Oregon respondents in this study claimed they exceed minimum HVAC requirements more often than in the previous study. The reasons most commonly cited for incorporating more energy efficiency measures than mandated were: cost effectiveness, obligation to do "the right thing," normal procedures, LEED project requirements/credits, owner or architect requests, and participation in utility programs/incentives.

9.3. Attitudes Toward Energy Efficiency

Interviewees were questioned about how important incorporating energy efficient features were to members of the design team. Table 9.10 shows a change in the attitudes toward energy efficiency. The respondents had far fewer middling answers than in the previous interviews. Both the "very important" and the "not important at all" increased significantly while the "don't know" answer is almost completely absent from the responses. While this trend is somewhat anomalous it shows that energy efficiency and attending issues of "sustainable design" and "green buildings" have become impossible to ignore in any state or design practice. The two main reasons given for the "not important at all' response were that the team was following the owners/clients lack of interest and the building was developed before "being green" was important.

Table 9.10: Importance of Energy Efficiency to the Design Team (%)

Level of Importance	ID		MT		OR		WA	
	2007	1999	2007	1999	2007	1999	2007	1999
Not at All	53	50	14	67	41	6	26	15
Limited	n/a	0	n/a	33	n/a	3	n/a	8
Moderate	23	0	43	0	10	17	30	6
Very	23	0	43	0	45	28	44	24
Don't know	0	50	0	0	4	47	0	47

Attitudes toward energy efficiency have significantly changed since 1999. At that time, about 45% of respondents from Oregon and 30% from Washington said it was "very important or important." No one interviewed in Idaho or Montana indicated this level of importance. Today, energy efficiency is important. Responses to questions covering energy efficiency in design and LEED reflect current opinions. The interviews did develop questions that expanded on the retrospective questions in Table 9.10. These attitudes and approaches are likely more representative and reliable of current thinking than the questions related to the individual building projects.

Table 9.11 shows the percent of building owners that requested energy efficiency measures in their buildings (as reported by the architects and engineers). Except in Washington, the trend here is inconclusive. The results are inconsistent across states. Apparently, the owners of these projects (at least in retrospect) had not adjusted their attitudes since the 1999 survey. However, these observations may reflect the results of the design and construction process where budget and time constraints eroded the good intentions of both the owners and the design team.

Table 9.11: Percent of Owners Requesting Energy Efficiency in the Building Design.

Request Efficiency	ID		MT		OR		WA	
	2007	1999	2007	1999	2007	1999	2007	1999
	% (n=31)	% (n=unk)	% (n=15)	% (n=unk)	% (n=32)	% (n=unk)	% (n=73)	% (n=unk)
Yes	36	65	47	44	47	63	60	36
No	64	35	53	56	53	37	40	64

It is a bit difficult to compare 1999 and 2007 answers because the question in 1999 asked whether the owner had ever mentioned energy efficiency as part of the design element rather than specifically requesting it. However, with semantics aside, the responses have changed. In 1999, 65% of Idaho respondents said the owner did mention energy efficiency. Today, this number has dropped almost in half. The fact that project team members or building tenants are now requesting energy efficiency more than building owners may explain these results. Montana's response was consistent with the previous study, but Washington and Oregon reported a significant increase in the number of owners requesting energy efficiency. This change is partly due to changing markets and the demand for green, LEED, or sustainable buildings, especially in Seattle and Portland.

9.3.1. LEED Rating System

As Table 9.12 shows, only 10% of interviewees stated that building owners requested LEED certification. The majority of owners requesting LEED were associated with public buildings (city halls and schools). This question is a bit misleading, however, because many of the study's buildings were designed either before LEED became prominent or before states required LEED certification among public buildings. It was included here for comparison in future studies.

Table 9.12: LEED Requested by Owner

Request LEED	ID		MT		OR		WA		Total	Avg.
	N	%	N	%	N	%	N	%	N	%
Yes	0	0	0	0	4	13	11	15	**15**	**10**
No	30	100	15	100	26	87	6	85	**132**	**90**
Total	**30**	**100**	**15**	**100**	**30**	**100**	**72**	**100**	**147**	**100**

9.4. Energy Efficiency in the Design Process

The interviews assessed how energy efficiency decisions are made and if design practices have changed since the 1999 interviews. As previously illustrated, individual design professionals still make the majority of energy efficiency decisions. However, team decision making is becoming more prevalent and design professionals are changing their practices to reflect a growing client demand for energy efficiency. Questions in this section were phrased to assess current attitudes and practices within the design teams responding to the current building climate.

Interviewees were asked "In your opinion, has client demand for an energy efficiency design changed your design practices in general?" Table 9.13 shows the extent of changes in design practices. In every state, design professionals have changed their practices.

Table 9.13: Extent of Changes to Design Practices

Have Design Practices Changed?	ID		MT		OR		WA		Total	
	N	%	N	%	N	%	N	%	N	%
Yes	22	71	9	60	20	63	49	67	**100**	**66**
No	9	29	6	40	12	38	24	33	**51**	**34**
Total	**31**	**100**	**15**	**100**	**32**	**100**	**73**	**100**	**151**	**100**

The second part of this question was open-ended "If yes, what design elements?" Table 9.14 presents the individual design elements that have changed. A third of the respondents said their clients are more aware of energy efficiency and are demanding it in their projects. Clients (38%) are requesting more energy efficient equipment, daylighting, and envelope measures. Interestingly, 9% of respondents said they had changed their design practice themselves and were now pushing their clients toward energy efficiency. Nine percent of respondents are also requesting LEED.

Table 9.14: Descriptions of Design Elements That Have Changed

What Design Elements Changed?	ID		MT		OR		WA		Total	
	N	%	N	%	N	%	N	%	N	%
Lighting	2	7	0	0	8	22	6	8	**16**	**10**
HVAC	2	8	2	14	9	24	16	19	**29**	**18**
Envelope	0	0	2	14	7	19	7	9	**16**	**10**
Client Requesting Energy Efficiency	14	54	5	36	4	11	29	35	**52**	**33**
Pushing Their Clients to Energy Efficiency	1	4	3	21	1	3	10	12	**15**	**9**
LEED	2	8	2	14	3	8	7	8	**14**	**9**
Holistic Team Approach	1	4	0	0	4	10	3	4	**8**	**5**
Clients Looking at Long Term not Just First Costs	4	15	0	0	1	3	4	5	**9**	**6**
Total	**26**	**100**	**14**	**100**	**37**	**100**	**82**	**100**	**159**	**100**

Respondents mentioned the following reasons for the increased client interest in energy efficiency:

- Increased energy costs.
- More knowledge and media exposure about global warming and environmental issues.
- State and local governments and school districts requiring buildings to be sustainable.
- Owners and developers catering to market pressures to be "green."
- U.S. Green Building Council and LEED requirements.

When asked specifically if their clients were requesting LEED, 81% of respondents said yes some of their clients did request LEED at the outset of a project (Table 9.15). The actual percentage of total clients with a LEED request was typically less than half in these firms as summarized in Table 9.16. In contrast when this response is compared to the specific question about the project in this study the percentage of positive response drops to about 10% (Table 9.12). The two most common reasons for not pursuing LEED certification were the cost and the time requirements of the certification process. When probed a bit more respondents said they would rather put the money into energy efficiency measures and other "green" measures rather than pay for LEED certification.

Table 9.15: Percent of Designers with Some Clients that Requested LEED

LEED Requested	ID		MT		OR		WA		Total	
	N	%	N	%	N	%	N	%	N	%
Yes	24	77	13	93	27	87	58	79	122	81
No	7	23	2	7	4	13	13	18	26	17
N/A	0	0	0	0	0	0	2	3	2	1
Total	**31**	**100**	**15**	**100**	**31**	**100**	**73**	**100**	**150**	**100**

Table 9.16: Percent of Clients Who Utilized LEED Rating System

Percent Requesting LEED	ID		MT		OR		WA		Total	
	N	%	N	%	N	%	N	%	N	%
None	1	4	0	0	1	4	1	2	**3**	**2**
Fewer than 20 %	18	72	10	77	15	54	17	29	**60**	**48**
20 to 50	5	20	2	15	5	18	22	37	**34**	**27**
50 to 75	1	4	1	8	4	14	18	31	**24**	**19**
More than 75 %	0	0	0	0	3	11	1	2	**4**	**3**
Total	**25**	**100**	**13**	**100**	**28**	**100**	**59**	**100**	**125**	**100**

A significant change has occurred in the region with regard to perceived barriers to increasing energy efficiency. The number of respondents saying "first cost" is the major barrier has dropped from 77 to 48% (Table 9.17 and Table 9.18). Forty percent of respondents said there were no barriers to increasing energy efficiency. Increased knowledge and familiarity in the design community likely led to a more realistic attitude toward costs. As Table 9.17 shows, owner's lack of interest was the most common response in the "other" category; the 1999 interviews presented this response separately.

Table 9.17: 2007 Biggest Barriers to Increased Energy Efficiency

Efficiency Barriers	ID		MT		OR		WA		Total	
	N	%	N	%	N	%	N	%	N	%
First Cost	15	10	6	4	17	11	29	22	**72**	**48**
None	15	10	8	5	8	5	34	23	**60**	**40**
Other[†]	1	1	1	1	6	4	9	6	**17**	**11**
No Response	0	0	0	0	2	1	0	0	**2**	**1**

[†] "Other" was most commonly defined as "owner disinterest."

Table 9.18: 1999 Biggest Barriers to Increased Energy Efficiency

Efficiency Barriers	ID		MT		OR		WA		Total	
	N	%	N	%	N	%	N	%	N	%
First Cost	37	90	8	73	21	62	52	76	**118**	**77**
Design Criteria	1	2	0	0	2	6	4	6	**7**	**5**
System Complexity	1	2	0	0	2	6	1	1	**4**	**3**
Owner Disinterest	1	2	2	18	2	6	2	3	**7**	**5**
Other	1	2	1	9	7	21	9	13	**18**	**12**

Interviewees were asked to suggest the best opportunities to promote energy efficiency. Table 9.19 presents the set of responses to this request. Respondents indicated that the best way to promote energy efficiency is to provide more education on life-cycle costs to owners, developers, decision makers, and the public. Developing case studies showing "real" world buildings and their energy use was the most common educational tool mentioned. Providing more financial incentives in the form of either utility rebates/incentives or tax credits was another way of increasing energy efficiency.

Table 9.19: Opportunities to Promote Energy Efficiency

Best Opportunities	ID		MT		OR		WA		Total	
	N	%	N	%	N	%	N	%	N	%
Education	24	77	8	57	23	58	51	61	**106**	**63**
Financial Incentives	3	10	1	7	10	25	11	13	**25**	**15**
Stronger code	1	3	2	14	1	3	8	10	**12**	**7**
Increase Energy Costs	1	3	2	14	0	0	5	6	**8**	**5**
Technology Changes	1	3	0	0	1	2	5	6	**7**	**4**
Keep-up with the Jones Marketing	0	0	1	7	3	7	1	1	**5**	**3**
LEED	1	3	0	0	2	5	1	1	**4**	**2**
Enforce code	0	0	0	0	0	0	2	2	**2**	**1**
Total	**31**	**100**	**14**	**100**	**40**	**100**	**84**	**100**	**169**	**100**

Responses to this question were completely different from the 1999 study. In the 1999 study, more than 70% of respondents said considering energy efficiency earlier in the design phase would be the biggest opportunity available, while only 5% of respondents suggested education as a way of increasing energy efficiency. No one in this study expressed the need to consider energy efficiency earlier. This change is most likely due to the rise in client requests at the outset of the project and the uncertainty on the part of architects as to the measures and approaches available to meet the clients' requests. As mentioned before, a growing number of firms are now using a team approach to make energy efficiency and energy code decisions.

10.Conclusions and Observations

This baseline study creates an overview of the region's new commercial building sector for buildings constructed in the 2002-2004 time frame. The sample that formed the basis for the study provides at least 90% confidence that the study results are within 10% of the true population values for the following groupings:

- All commercial buildings (aggregated) at a regional level
- All commercial buildings (aggregated) within each individual Northwest state
- Hospitals and healthcare buildings at a regional level
- Grocery stores at a regional level
- Retail stores at a regional level
- Office buildings at a regional level
- Schools at a regional level
- All commercial buildings (aggregated) within the Energy Trust of Oregon service territory
- All commercial buildings (aggregated) within the combined service territories of Snohomish PUD, Puget Sound Energy, and Tacoma Public Utilities.
- All commercial buildings (aggregated) within the Seattle City Light service territory

10.1. Lighting

Lighting technologies found in this study are fairly similar to previous work. Notable changes include: the virtual elimination of T12 fluorescent fixtures; fluorescent low and high bay lighting went from negligible to 25% of the high/low bay connected wattage; and T5 linear fluorescent increased from none to 12% of all linear fluorescent connected wattage. Several technologies that have been introduced in the last decade are widely available, yet few have been adopted in this vintage of buildings. The overall result is relatively little change in the LPD between the 1998 buildings and these 2002-2004 buildings.

New technologies that were only found in small quantities include Ceramic Metal Halide (CMH) and high performance T8 fixtures.

Egress and security lighting was not explicitly surveyed in this work. However, during the course of the audits it became apparent that a significant number of facilities energized the egress circuit 24/7. Several sites were observed with very high egress lighting levels making the uncontrolled operation a serious concern. Of the facilities where egress circuit operation was surveyed, 70% were energized 24/7.

10.1.1. Controls

The most dramatic changes were observed in lighting control technologies and implementation. The use of central controls for lighting, which has been an integral part of larger buildings, has now become almost universal for both large and middle-sized buildings. These controls are largely designed around "sweep" control strategies and allow the operator considerable scheduling flexibility. In single-story, retail strip malls and big box-stores where previous samples found relatively few controls, centralized lighting scheduling has become almost ubiquitous.

Daylighting controls were found in a significant number of buildings. Overhead skylight-based systems are very successful, particularly in big-box retail applications, and these systems often operate without notice. Side daylighting systems in offices and schools are less successful and have resulted in difficulties in building operations, often resulting in discontinuation of their use. If these are to become more widely adopted, more attention to design and sensor placement will be essential.

Occupancy sensor control of lighting and, in some cases, of HVAC systems, has nearly quadrupled since the 1996-1998 study. These controls offer more localized response to spaces with varying occupancy. This can be effective in spaces such as classrooms but it also should be considered as part of the operation of larger spaces in schools and other occupancies such as warehouses.

10.2. HVAC

Mechanical systems remain very similar to previous studies. The biggest changes occurred with the advent of more centralized controls, the increased use of CO_2 and *occupancy sensor* controls to manage ventilation air, and the notable use of more complex system designs. In addition, higher efficiency equipment, especially boilers, was observed in many larger building types.

10.2.1. Controls

The use of controls in HVAC systems has expanded dramatically since the 1996-1998 new buildings study. Automatic and local ventilation control using occupancy and CO_2 sensors have been implemented in some fashion in a third of the region's building square footage, an improvement from only 6% ventilation control in the previous study. Ventilation control based on OS has appeared in several building types especially schools. These technologies were totally absent in the earlier baseline study. Many of these controls were funded by utility programs and may not have been installed otherwise.

The use of central HVAC controls, which has always been an integral part of larger buildings, has now become reasonably universal for both large and middle-sized buildings, even where the systems controlled are relatively simple and the individual equipment or zone controls they displace are relatively inexpensive. These buildings are now often controlled by central controllers, sometimes even from remote offices around the country.

On the other hand, there are central control systems that have been ignored, are too complex to operate, or have been abandoned due to occupant complaints. In these cases, the control has reverted to manual overrides and individual zone controls. Such systems, when backed up by occupancy sensors, could sometimes perform as well as a centralized control system. In schools, for example, local zone control is probably as important as any centralized control system in the system's overall efficiency.

For HVAC and ventilation control, the use of CO_2 sensors showed a dramatic increase over the previous study. However, often there was not a corresponding decrease in the minimum damper settings and outside air settings in these buildings. This seems like an oversight since almost all of the savings potential related to CO_2 sensors is realized by reducing outside air fractions when the building is at less than full occupancy.

It is clear, especially in buildings that have a traditional 24/7 operation schedule (such as hospitals), that a great many of the buildings' functions have a regular schedule where controls could substantially reduce energy use. Auditors observed night operations that were only partially using the HVAC system or the lighting system, but had no basis for controlling the systems for that schedule. Using scheduling control for hospital areas that do not operate 24/7 (i.e., doctor's offices, clinics, exam rooms, etc.) would improve their performance. This is in part a design problem since parts of these buildings need to maintain conditioning and pressure even if other areas are not operating.

10.2.2. Building Operations

Building operator training was observed in only about 15% of conventional buildings, but in about 75% of chains where central control might be present. Ongoing review of control settings and schedules is critical to achieve and maintain efficient operations.

10.2.3. System Design

Some very sophisticated engineering designs were used for several buildings in this study. It is clear that engineers are being encouraged to develop alternative design approaches to improve HVAC efficiency. This trend has also introduced more careful ventilation control. However, the implementation of ASHRAE Standard 62 has increased the amount of outside air required in many building types. Even with more sophisticated controls this change has the potential to increase energy requirements.

Engineers typically use temperature reset as a strategy to reduce reheat or central cooling. In most buildings this could be very effective. However, auditors observed several examples where the range of temperature reset was limited by a critical zone that had severe cooling requirements even when the rest of the building is in heating. This zone was typically a computer server room or equipment room. Even though the codes require that such spaces have separate conditioning, in practice, drawings may not clarify the space requirement and the engineer may not know where critical zones exist in the final analysis. In a few cases, a separate system (usually a heat pump loop) was installed to provide conditioning to critical zones and improve the functioning of the entire system. Separate critical-zone conditioning should be reviewed in any utility program, particularly in office and healthcare settings.

Less electric heat was observed largely due to the reduction in electric reheat since the previous study. The use of electric reheat in multi-zone and VAV systems has fallen from 60% in the 1996-1998 study to 35% in this study. This trend is especially important since reheat not only meets the building heating load but also reheats cooled ventilation air year round. One consequence of this trend is that buildings use more hydronic systems than in the previous study and have a much higher fraction of condensing gas boilers.

There were several efforts to remove mechanical cooling from buildings. In Montana, the use of mechanical cooling is optional under many circumstances. This represents no change from the previous findings. There were several attempts in schools and offices to reduce cooling capacity, but it is not clear that these attempts were successful. In most cases, occupants are unhappy without mechanical cooling, and in several cases, the mechanical cooling was retrofit after the building was occupied. If cooling is to be one of the main focuses of energy efficiency in these buildings, better design of economizers and better effort to accommodate peak cooling loads will be necessary. While some projects may not require a full cooling system, the use of low-capacity systems that offset some of the cooling load may provide a compromise.

10.3. Envelope

Little improvement was found in the opaque components of building shells; this is not surprising considering there was essentially no change in code requirements between the 1996-1998 study and 2001 (when most of these buildings were designed). Building components are relatively similar throughout the region—even in Montana where no building code existed. The main difference between this study and previous studies is the use of high performance glass with extensive amounts of low-ε coatings (occasionally more than one in a glazing system). Over the course of the last decade, the use of low-ε coatings used for both heat loss and solar heat gain control has become nearly universal throughout the region.

Another positive trend in window performance is the increase in use of wood and vinyl frames (as opposed to metal) from 11% to 20% of windows. This was especially apparent by the breadth of building types adopting these technologies.

However, while window performance has increased, there has been a consistent increase in overall glazing area, especially in building types where smaller amounts of glazing were observed in the past. In the five to ten years between the design window of the previous baseline buildings and the design window of the current buildings, increased glazing area seems to have become the architectural norm. This is particularly prevalent in high-profile offices and institutional buildings with extensive design budgets. While increased glazing may satisfy local aesthetics, it usually has a negative impact on building energy consumption.

10.4. Energy Efficiency and Energy Codes

Probably the most significant change is the dramatic increase in energy efficiency as a design consideration noted by building designers and engineers. In the previous study, energy efficiency was important to at most 25% of the architects in Washington and Oregon and essentially none of the architects and engineers in Idaho and Montana. This situation has changed. There is an ever-increasing interest in energy efficiency in Washington and Oregon, and the interest is now reasonably comparable in Idaho and Montana. While the implementation of energy efficiency may be lagging, presenting energy efficient alternatives to the design community may be more productive now than previously expected.

An important caution for review of the impact of (and compliance to) the energy codes is that these buildings were permitted beginning in about 2001 (and in some cases earlier) and built between 2002 and 2005. In most cases, they do not reflect the jurisdiction's current codes and in some cases, such as Montana, they do not reflect the modern codes that were available elsewhere in the region at the time of construction. This is further complicated by the fact that some parts of the building may well have been permitted under more recent codes either as part of tenant improvements or as part of an agreement with local code officials. This is especially true for lighting systems.

Altogether, the increase in energy code compliance is striking. In the 1996-1998 study, code compliance topped out around 70% in lighting and a comparable number in other end uses. In this study, code compliance with the lighting standards is about 80% with reasonably consistent efforts to get higher efficiency lighting into many buildings. Other parts of the codes, such as building shell, had nominal compliance rates that approached 90%.

There is little indication that codes were a major issue. Architects and engineers interviewed regarded compliance with energy codes as part of the design process. In the previous baseline studies architects and engineers were struggling to ensure code compliance.

11. Regional Opportunities

Table 11.1 lists various technologies that have become standard practice throughout the region as observed by auditors and thus seem ripe for intervention by energy efficiency organizations. The high level concepts presented in the program idea list in the table could be adapted to serve the needs and interests of utilities, public benefits administrators, state and local governments, market transformation organizations, the Western Climate Initiative or any number of other groups interested in reducing energy use in the Northwest. A more expansive explanation of these ideas is provided below.

Table 11.1: Current Standard Practices and Program Suggestions per Baseline Study Findings

Component	Current Standard Practices	Program Ideas
Lighting	T12s are nearly gone	High Performance T8s – Retrofit and New
		OS lighting control of large open and common areas
	High saturation of electronic ballasts	OS control in warehouse space
	98% of buildings use advanced exit lighting (84% LED, 14% luminescent/zero-watt)	Reduce and design security lighting circuits, especially in schools
		CMH – increase use in retail and lighting display to replace standard incandescent lamps
	Substantial increase in lighting controls	A program to design, commission, and operate lighting systems
HVAC	VFD saturation is very high in variable loads, and is beginning to affect traditional CV areas	OSA ventilation control with CO_2
		OSA and fan control with OS
		OSA lock-out on night cycling and morning warm-up in small equipment
		Work with hospitals on night operations
		On-site short-term efficiency managers
		Require lower-speed ventilation fan setting for single-zone equipment
Envelope	Low-ε glass is wide spread	Less glazing
		Better frames (better thermal break) and more complete documentation
Other	Heat recovery to DHW in all large refrigeration systems including smaller walk-ins	Focus on the uses of refrigeration heat recovery to space heat in groceries
		Improve code language and enforcement on the use of compensating hood in food service and other cooking applications.

11.1.1. Lighting

The most important of these ideas is the encouragement of high-performance T8s. High-performance lighting fixtures use high phosphorus tubes and higher efficiency ballasts. These components reduce the overall energy requirements of individual fixtures in linear fluorescents by 15%. The cost of high-performance T8s is somewhat higher than the current T8 fixtures, but lamp costs are three times less than competing high performance fixtures based on T5 technologies. This makes the T8 much more likely to dominate efficient fixture in the near future. In the same context, the use of higher efficiency ballasts and lamps in HID fixtures also offers some improvement. Note that no matter how important HID fixtures may be in particular uses such as retail and display lighting, they represent a relatively small fraction of the building lighting.

A similar opportunity exists to increase the use of CMH technologies. The biggest impact here would be on retail and other display lighting where incandescent lamps still hold a substantial market share. Since the CMH lamps offer a direct change out, incentives could affect both new store designs and existing display designs.

Despite the increased prevalence of lighting controls there is still potential for OS control in large open spaces such as warehouses and school gyms, multipurpose rooms, and corridors. Typically, these spaces have lights controlled from a central place and are on extended schedules to allow for intermittent use of the space. There were spaces in each of these categories with OS control and satisfied occupants.

The amount of security and emergency lighting in some applications likely offsets the available savings from improved lighting technologies. Emergency circuit lighting must be reduced or managed during off hours. Current emergency circuit lighting levels warrant use of OS controls. More careful design and control of these circuits would provide a significant savings opportunity.

11.1.2. HVAC

The efficiency with which ventilation air is delivered and controlled is another area of potential improvement. Implementation of CO_2 controlled ventilation can be improved. Programs and codes should pay attention to minimum outside air (OSA) setpoints and space exhaust air requirements before implementing CO_2 control. CO_2 control should not be supported in spaces with exhaust flow above ASHRAE 62 minimums.

Occupancy sensor control of OSA is another measure to control OSA and reduce fan and system energy. Some school classrooms and conference rooms are already using this control. It is appropriate where CO_2 is not used and the space use is intermittent. It can also be used in tandem with CO_2 control to shut down systems in gymnasiums and comparable spaces. This measure is applicable to spaces that have irregular schedules or are likely to be on after hours.

Another OSA control is the elimination of ventilation air during morning warm-up using the control systems to shut dampers during scheduled unoccupied periods. This control is currently required by code in large systems, but not in small systems. This lock-out option has been available on standard programmable thermostats for 10 years. The only requirement is that installers learn how to wire the damper controls to the occupied signal rather than the fan signal.

Building plans should be required to have specific, system-by-system ventilation calculations. This should include the floor area served by the system and an estimate of the ASHRAE 62 (or some other engineering standard) minimum ventilation with CO_2 sensor even where it is not specified.

Fan motor efficiency needs to be encouraged in all cases. No equipment should be considered high efficiency if the motor is not premium efficiency. Even package equipment usually offers options for premium efficiency motors. VFD control of fan motors in CV equipment should also be encouraged. This control can be used similar to the single-zone VAV systems, or single-zone equipment can simply be operated at lower fan speeds for heating/ventilating. VFD costs to equipment manufacturers are diminishing rapidly and there is significant potential for market transformation in this area.

11.1.3. Envelope

Glazing performance has improved to the point that low-ε coatings are ubiquitous. Remaining improvements in this area are limited to better saturation of argon fill and adventures into triple glazing. Unfortunately, the improvement in glazing performance is often offset by increasingly large glazing areas. A large glazing fraction may meet current architectural aesthetic standards; however, architects, owners, developers, and engineers need to understand that extensive glazing lowers the building's overall energy efficiency. This is particularly applicable to offices, schools, and mixed-use residential buildings.

Window frames are a glaring example of inadequate information leading to a lack of accountability during specification, code compliance, and installation. There is a strong need to either require NFRC ratings in all cases or have some frame specification or rating that is required in code and can be used at all levels to ensure reasonable products are installed.

11.1.4. Building Operations

As more centralized controls and more complex control systems are used in buildings, building operators and managers need more training and access to consultation. Training and on-call consultation could be provided by in-house resource conservation staff in larger utilities, or by "circuit-riders" in smaller utilities. Possible work tasks include reviewing current control strategies and identifying areas where additional control features should be used or could be more optimally set.

11.1.5. Other

Refrigeration systems. These have improved incrementally since the previous study. Over the last two decades, the use of heat recovery for building service hot water has become universal; however, refrigeration systems generate far more waste heat than most service water systems require, especially in grocery stores. The use of heat recovery for space heat could be expanded greatly, at least in grocery applications. In this study, scarcely 15% (almost all from one chain) of the grocery area utilized this type of heat recovery.

CO_2 sensors. The use of non-compensating exhaust is common in the grocery and retail sectors. The result is that OSA dampers are set to make up a large quantity of air for these hoods. As a result, there is effectively no incremental control offered by CO_2

sensors. The primary measures in this case would have to include both substantial compensation in the food prep hoods coupled with ventilation control. This combination would reduce OSA and the demands on the heating and cooling capacity.

Non-air conditioned schools. One critical consideration for improving the effectiveness of no-cooling systems within schools is to condition the administrative offices and classrooms equally. However, the comfort difference between these spaces (however small) will not be acceptable. Moreover, since these schools almost never have significant occupancy in peak summer months, a design that allows some cooling for limited summer use, but focused on economizers and outside air, may be acceptable in most schools in the region.

11.2. Overall observations

Design practices have clearly advanced somewhat since the 1996-1998 study. It is also clear that there have been incremental changes to some building components. However, while the use of technologies as the major focus of utility programs and recommendations has resulted in significant improvements in the efficiency of building components, this study showed that trade-offs used by architects and designers may negate these improvements—most notably in regards to display lighting and glazing area. To dramatically improve the overall performance of commercial buildings, trends for better control and scheduling must be matched by trends for more integrated design and direct understanding of how high-performance buildings must be constructed.

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