Energy Consequences of Non-Compliance with 1994 Washington Nonresidential Energy Code

Mike Kennedy

August 1, 1997

ECOTOPE

2812 E. Madison, Seattle, Wa. 98112 (206) 322-3753

Summary

This report examines the energy use consequences of non-compliance with the 1994 Washington State Nonresidential Energy Code (NREC). In addition, the reduction in energy use resulting from changes in building practices between 1990 and 1995 is examined. The traits and characteristics of buildings built in Washington state during 1995 have been determined and presented in *Compliance with the 1994 Washington State Nonresidential Energy Code* (Baylon et al, 1997). Characteristics determined from that work are used here to evaluate the energy use consequences of non-compliance with the 1994 energy code. They have also been compared to characteristics of buildings built in 1990 under the previous energy code, as determined in Baylon et al, 1992, to determine changes in building practices and energy use between the two samples. This report is meant to convey estimates of energy use only. Information describing and discussing code infractions is included in the report by Baylon et al, 1997.

The evaluation was conducted using the DOE2.1E building energy use analysis program and the Bonneville Power Administration (BPA) new commercial building prototypes (SBW 1990). Energy use simulations were conducted with the prototypes reflecting average as-built conditions and with the same prototypes adjusted to reflect average complying conditions. The difference in energy use between the as-built and complying simulations was taken to be the savings that would result from code compliance. In order to compare the 1995 sample to the 1990 sample, the average as-built conditions of each stock were used in the prototype simulations.

The energy estimates were normalized by prototype area and adjusted to reflect different heating fuel types and HVAC systems. The adjusted energy savings predictions were extended to each sector based upon the fuel type/heating system saturation and floor area estimates found by Baylon et al (1997). This set of estimates reflect the energy savings for the sample population and reflect new construction floor area permitted in 1995 with construction costs greater than $250,000. A second set of predictions was made using floor area estimates based upon Northwest Power Planning Council (NPPC) floor area forecasts (Harris, 1997) and reflect average annual floor area of new construction, additions and renovations.

For the 1995 sample population, savings from achieving full code compliance would be approximately 1.04 average megawatt of electricity and 51,000 therms of natural gas per year. For the forecast population, savings from achieving full code compliance would be 1.93 average megawatt of electricity and 9,500 therms of natural gas per year.

There is significant uncertainty in the natural gas savings predictions, due to uncertainty in characterizing semi-heated space HVAC controls. This is particularly true in the 1995 sample population, where approximately half of the gas savings from code compliance and the gas increase between samples result from this one provision. In the forecast population, warehouses form a much smaller portion of the total floor area so this provision is less significant.

Other more general sources of error (such as year to year variation in the frequency of violations, building type distribution, amount of construction, and design and fuel type trends in different sectors) mean that results from the sample population are only a rough indicator of potential energy savings. The forecast estimates (with regional construction forecasts for building type and floor area) provide a more robust savings estimate.

The difference between the as-built 1995 and as-built 1990 simulation results represent the change in building practices between the samples. The efficiency improvement resulted in electricity savings of 4.2 average megawatts per year, and an increase in gas use of 585,000 therms for the sample population. Using the forecast population, the electric savings are 10.2 average megawatts per year, and gas use increases 743,000 therms. If all efficiency improvements are attributed to the 1994 energy code and to code enforcement, then this number is the total achieved savings from the code and its implementation. The addition of the full compliance numbers yields the total potential of the code.

Overall, a significant reduction in electric use has occurred. The sample population electric savings estimated here are 30% greater than the predicted code electric savings in Kennedy and Baylon (1992) under the aggressive Scenario Two. The savings are largely attributable to lighting efficiency improvements (lighting improved in almost all buildings). Indeed, the average, minimum and maximum LPD decreased in all but the small retail building type. This supports the idea that the code tends to improve all buildings.

The increase in gas use is also significantly above previous predictions. This can be attributed to the creation of the semi-heated space provision, which was not analyzed in the previous work, and lighting levels which are below those anticipated.

Methodology

The methods used in this evaluation are derived from the 1993 evaluation of the proposed Oregon nonresidential code (Kennedy 1993). Building characteristics and the frequency of non-compliance in the commercial building sector were determined from a sample of buildings examined by Ecotope in 1997. Sampled buildings were assigned to BPA commercial sub-sector categories (e.g. small office, large office, grocery, etc.) and thermal, structural, and equipment characterizations were derived for each sub-sector. A second set of characterizations was completed, reflecting changes needed to ensure code compliance in each case. Energy use simulations were conducted on prototype buildings reflecting average 1995 as-built conditions, average 1995 complying conditions, and average 1990 as-built conditions for each sub-sector. The difference in energy use between the 1995 as-built and complying simulations was taken to be the savings that would result from achieving full code compliance. The difference between the 1995 and the 1990 as-built simulations represents the impact of changes in building efficiency.

To determine the impact of achieving full code compliance, the 1994 energy code was "applied" to each building. This was done using 1995 as-built and applicable code value data from the 1997 report. For each characteristic, a "complying" value was calculated. If the component was out of compliance in a particular building, then the "complying" value was substituted for that component only. This assumes that building components better than code would not change as non-complying aspects are improved. If a prescriptive path was applicable, it was used to establish compliance. However, if the building was not in compliance, the the "complying" building component was developed using the performance standards of the code. In this way, a complying LPD and UA were calculated for each building in the data set. Once the impacts of the code were established for each building, average characteristics were calculated by building type. For lighting LPD, for example, the average installed, the average code, and the average complying LPD were calculated for each building type. The complying LPD is the smaller of the installed LPD and the code LPD. Averaging the installed and complying LPD for all buildings of a given type gave the category characteristics with and without full code compliance. Average as-built characteristics were also generated for buildings sampled from the 1990 construction year.

These average characteristics were modeled using the building energy analysis program DOE2.1E and the BPA commercial building prototypes to assess the energy impacts. All buildings were modeled using Seattle TMY weather data (5250DD). Nine building prototypes were used, specifically characterizing 70% of the 1995 sample. These were: small office, large office, small retail, large retail, restaurant, grocery, school, and heated and semi-heated warehouse. The prototype model inputs were adjusted to agree with key as-built characteristics. Prototype window areas, window U-values, heat loss per square foot, heating and cooling equipment efficiency and lighting power density were set to values calculated from the audit data. Other parameters (except those directly reflecting code issues) were held fixed.

Six scenarios were created for each prototype: as-built, as-built with complying shell, as-built with complying equipment, as-built with complying lights, full compliance, and as-built 1990. Energy use simulations were conducted for each scenario/prototype combination. The difference in energy use between the as-built and full compliance scenarios was taken as the savings from achieving code compliance. Separate savings estimates for envelope, equipment and lighting sections of the code were also made. The end use savings were summed for the three individual cases and the fraction contribution for each case calculated. These fractions were applied to savings calculated from the full compliance run, thus accounting for end use interactions.

The energy savings estimates were normalized by prototype area and adjusted to reflect three heating system scenarios: fossil fuel combustion, electric resistance and heat pump. Energy consumption was adjusted from the base system used in the DOE2.1 runs assuming an 80% combustion efficiency and a heat pump COP of 2. These are rough estimates of the seasonal efficiency of gas furnaces and heat pumps. The saturation of combustion, electric resistance, and electric heat pump heating equipment found in the 1995 sample is presented in Table 1.

To calculate sample energy savings, the normalized energy savings predictions for each sector were combined with the fuel type/heating system saturation and floor area projections found in the sample (Baylon et al, 1997). In addition, the predictions and the fuel type/heating system saturation were combined with NPPC floor area estimates to calculate savings estimates representing the whole commercial sector. The current NPPC floor estimates are also presented in Table 1. This value represents the average of projected values for the period 1998-2002. Divisions between small and large, and heated and unheated buildings have been made, based upon the 1995 sample. The primary difference between the forecast area and the sample area is the inclusion of renovations and additions in the forecast (because these would be subject to the energy code and so are properly included).

In comparing the 1990 and 1995 samples, the fuel saturation in the 1995 sample and the NPPC floor area estimates were used. The comparison captures the future energy impacts of 1995 standards compared to 1990 standards, consistent with the NPPC long form regional forecast.

The use of the prototype descriptions, the normalization of energy use characteristics based upon square footage, and the use of a single weather station made this work possible within the finite constraints of the time allowed. Error introduced by this approach is well within sampling error and year to year variation associated with this work. Issues of climate zone are impossible to determine from this data set with any statistical precision since the sample was designed to reflect state-wide conditions.

An important systematic consideration is the true applicability of the prototypes to their sectors. Many facets of the prototypes differ from buildings found in this sample. If the sample was more typical of general building trends, then use of erroneous prototypes could lead to substantial errors. If the prototypes, which have been developed in the context of several data sources, are more typical of the sector (which is represented by as few as two buildings in one case), then use of the prototype could actually lead to better results than if the buildings were modeled exactly.

Table 1. Distribution of Conditioning Levels and Heating Types (Percent of Floor Area, 1995 data)

Building Type	Sample N obs	Population Floor Area	NPPC Area	Conditioning Type			Heat Fuel Type		
				Heated	Semi-heated	Not Heated	Gas	Electric	Heat Pump
Small Office	7	1,013,998	3,632,395	100.0%	0.0%	0.0%	84.0%	16.0%	0.0%
Large Office	3	1,295,389	4,640,408	100.0%	0.0%	0.0%	74.6%	25.2%	0.3%
Small Retail	2	186,621	276,542	100.0%	0.0%	0.0%	100.0%	0.0%	0.0%
Large Retail	11	3,649,300	5,407,662	98.7%	1.3%	0.0%	97.5%	2.0%	0.5%
Grocery	6	1,443,053	1,014,895	100.0%	0.0%	0.0%	77.4%	19.7%	2.9%
Restaurant	6	373,580	2,611,100	100.0%	0.0%	0.0%	100.0%	0.0%	0.0%
School	7	2,159,267	4,753,901	100.0%	0.0%	0.0%	79.7%	0.8%	19.5%
Warehouse-Heated	6	2,285,406	895,627	89.4%	0.0%	10.6%	100.0%	0.0%	0.0%
Warehouse-Semi	9	3,166,087	1,240,757	11.8%	82.4%	5.7%	100.0%	0.0%	0.0%
Other	31	6,408,216	18,577,390	91.0%	4.5%	4.5%	80.7%	11.8%	7.5%
Total	88	21,980,917	43,050,678	83.4%	13.4%	3.2%	88.1%	7.4%	4.4%

Code Compliance Violations

Tables 2 through 5 summarize code violations and 1995 building characteristics used in this work. Percentages represent the portion of applicable floor area that was found to be out of compliance or have the given characteristic. These percentages reflect sample weights determined by Baylon, et al, and the applicable floor area. Average characteristic values are calculated using a combined area and sample weight. The applicable area differs from case to case. Parameters related to heated space are weighted only by the heated floor area and semi-heated parameters are weighted by the semi-heated area. Summaries were calculated only for those floor areas where lighting data was available. "As-Built" values are the average characteristic in the actual buildings in the 1995 sample. "Comply" values are the average characteristic of the buildings in the 1995 sample with those components not in compliance changed to exactly meet the energy code.

Table 2 presents summary information on heating and cooling equipment. Code failure rates are the percent of conditioned floor area failing the given code specification, unheated floor area has been excluded. Overall, very little equipment fails code. The average cooling EER includes units with SEER ratings and chillers with COP ratings. The units of the COP ratings have been converted to compare with EER units. Combustion equipment performance is summarized under the heading "Comb. Heating Eff." This excludes all electric equipment with an efficiency of 100%.

Table 3 presents summary envelope information. Heat loss values include all shell components but exclude infiltration. All averages are weighted by floor area in addition to the sample weights. Heated space values are weighted by heated floor area, and semi-heated values by semi-heated floor area.

Building envelopes tended to fail the energy code on numerous points: high glazing levels, inadequate insulation, and inadequate window shading coefficient. For this simulation, buildings were assumed to reduce glazing area to the maximum allowed by prescriptive standards, and then improve envelope insulation until the building met code, rather than try to maintain excessive window areas. For code calculations, the "default" window U-values were used (except where test data was available) to determine compliance. The overall heat loss rate calculated this way is presented in the "Default Window" column. Once a building was determined to pass or fail code, the "actual" window U-value determined by the auditor was used in determining the "Actual Window" heat loss rate. This is the true heat loss rate of the building.

Differences between the default and actual heat loss rates highlight the inadequacy of the commercial window default U-value table. In several cases, the actual non-complying window would probably pass code if tested. With only a few default glazing entries, it is also possible to get windows failing the code that actually have comparable U-values to the windows that comply, even though the default entries differ dramatically. The "Comply" value is the average overall heat loss rate (with adjustments to make all non-complying components comply with the code).

Table 4 presents summary information on window characteristics in heated spaces. This does not include windows in unheated spaces. Window averages are weighted by heated floor area, window U-value is weighted by window area. "Percent Window" is calculated as window and skylight area divided by the gross wall area. Shading coefficient was reported by the field personnel to be unreliable and so was not evaluated.

Table 5 presents summary interior lighting characteristics. Values are weighted by the sum of the areas associated with the lighting data. In some cases, this is larger than the enclosed floor area where there is unenclosed retail space. Interior lighting power densities were compared with code levels, and lighting fixture types compared with the prescriptive provisions of the code. Buildings meeting either of these criteria were deemed compliant. Non-compliant buildings were assigned the maximum allowed LPD for a compliance value. Most of the reduction in LPD results from a few buildings that exceeded code by large amounts.

Table 2. Equipment Code Failures and Characteristics Summary (1995 sample)

Building Type	Cooling Eff. (EER)			Comb. Heating Eff (Et)			Economizer		
	Fails	As-Built	Comply	Fails	As-Built	Comply	Fails	As-Built	Comply
Small Office	0.0%	10.03	10.03	0.0%	81.1	81.1	0.0%	73%	73%
Large Office	0.0%	16.61	16.61	100.0%	83.5	83.5	0.0%	99%	99%
Small Retail	0.0%	9.59	9.59	0.0%	80.0	80.0	0.0%	58%	58%
Large Retail	0.0%	9.65	9.65	6.7%	81.0	81.3	0.0%	77%	77%
Grocery	0.0%	9.38	9.38	20.0%	80.6	80.6	0.0%	36%	36%
Restaurant	0.0%	9.19	9.19	0.0%	80.4	80.4	16.7%	72%	84%
School	14.8%	10.93	10.94	0.0%	81.2	81.2	0.0%	70%	70%
Warehouse-Heated	0.0%	10.13	10.13	55.6%	79.9	80.1	0.0%	37%	37%
Warehouse-Semi	0.0%	9.97	9.97	0.0%	79.7	79.7	10.3%	58%	64%
Other	0.0%	9.88	9.88	0.0%	81.6	81.6	0.8%	49%	50%
Total	0.7%	10.33	10.33	4.3%	80.9	81.0	3.3%	60%	61%

Table 3. Summary of Envelope Code Failures and Characteristics (1995 sample)

Building Type	Overall Envelope Fails[1]	Heated Space				Semi-Heated Space		
		Fails[1]	Heat Loss Rate (UA/ft²) Default Window[2]	Actual Window[3]	Comply[4]	Fails[1]	Heat Loss Rate (UA/ft²) Actual Window[3]	Comply[4]
Small Office	17.9%	17.9%	0.211	0.196	0.190	0.0%	----	----
Large Office	0.0%	0.0%	0.077	0.069	0.069	0.0%	----	----
Small Retail	0.0%	0.0%	0.224	0.214	0.214	0.0%	----	----
Large Retail	15.4%	15.8%	0.138	0.135	0.126	0.0%	0.096	0.096
Grocery	0.0%	0.0%	0.117	0.115	0.115	0.0%	----	----
Restaurant	10.9%	10.9%	0.270	0.245	0.240	0.0%	----	----
School	0.0%	0.0%	0.122	0.116	0.116	0.0%	----	----
Warehouse-Heated	31.8%	31.8%	0.129	0.127	0.118	0.0%	----	----
Warehouse-Semi	19.6%	3.4%	0.257	0.245	0.238	21.9%	0.369	0.367
Other	19.4%	19.3%	0.164	0.160	0.148	22.5%	0.529	0.522
Total	15.1%	14.1%	0.148	0.142	0.135	21.6%	0.375	0.373

1 Percent of floor area failing the envelope code. Overall, Heated space only, and Semi-heated space only respectively
2 Building heat loss rate excluding infiltration using the default window table and certified test results for window U-values.
3 Building heat loss rate excluding infiltration using auditor estimated window U-values
4 Building heat loss rate excluding infiltration that has non-complying components brought up to code.

Table 4. Window Characteristics (1995 sample)

Building Type	Percent Window[1]		Average	Fails
	As-Built	Comply	Window U	SC code[2]
Small Office	26.4%	23.6%	0.591	23.8%
Large Office	31.9%	31.6%	0.547	11.4%
Small Retail	18.3%	18.3%	0.552	42.0%
Large Retail	11.4%	11.4%	0.710	6.7%
Grocery	6.6%	6.6%	0.701	0.0%
Restaurant	16.9%	16.9%	0.590	11.7%
School	15.1%	15.1%	0.612	6.5%
Warehouse -Heated	4.5%	4.5%	0.607	0.0%
Warehouse -Semi	12.9%	12.9%	0.746	5.0%
Other	7.7%	7.7%	0.573	0.1%
Total	12.0%	11.8%	0.605	5.0%

1 Window and skylight area as percent of wall area.
2 Percentage of window area with inadequate shading coefficient

Table 5. Lighting Code Failures and Average LPD (1995 sample)

Building Type	Lights Fail Code Based On			Average LPD	
	Prescrip.	LPD	Both	As-Built	Comply
Small Office	100.0%	27.3%	27.3%	1.28	1.15
Large Office	100.0%	0.0%	0.0%	1.00	1.00
Small Retail	100.0%	100.0%	100.0%	3.18	1.18
Large Retail	81.5%	25.5%	17.0%	1.48	1.43
Grocery	100.0%	31.4%	31.4%	1.56	1.38
Restaurant	100.0%	49.3%	49.3%	1.26	1.12
School	100.0%	0.0%	0.0%	1.15	1.14
Warehouse-Heated	100.0%	9.4%	9.4%	0.49	0.47
Warehouse-Semi	100.0%	19.8%	19.8%	0.61	0.57
Other	96.5%	8.8%	8.8%	1.11	1.09
Total	95.8%	15.7%	14.2%	1.09	1.03

Semi-Heated Space Violations

Semi-heated spaces are classified based upon heating equipment capacity, and thermostat location and capability. Ceiling insulation is the sole insulation requirement for spaces meeting the system requirements for semi-heated space. Evaluating code violations of this provision are problematic. A building with excess heating capacity can be considered to have too much capacity or to have not enough insulation to meet the heated space code. This evaluation relied upon the field personnel to make the distinction regarding whether a building was a heated space with too little insulation or a semi-heated space with too much capacity.

To complicate the evaluation, the thermostat requirement is vaguely stated to imply, but not require, that the spaces not be heated above 44 degrees. The field visits generally found semi-heated spaces being heated to much higher temperatures. The capacity limit only appears to limit the temperature during cold weather. The impact of insulation or the capacity limit greatly changes depending upon the set point used. The savings potential would be tremendous if the difference between observed control practice and the 44°*F* fixed setpoint implied by the code were the basis of code impact For this analysis, the observed control practice was used to calculate energy impacts.

Lighting, equipment, and envelope performance improvements were modeled in a similar fashion to the other prototypes. Heating capacity was set to the average installed capacity of the buildings complying with the code capacity requirements. To evaluate excess capacity, a separate set of simulations has been generated, modeling only the change in capacity from as-built to complying conditions. Runs were completed using a 58°*F* set point. If the evaluation had used a 44°*F* setpoint savings, compliance would be reduced 80%. This variation means that the energy predictions for this category are very uncertain. A reasonable set of bounds yields a difference that can vary by a factor of 5.

Comparison of 1995 and 1990 Efficiency Levels

Comparison of characteristics between the 1990 and 1995 samples provides a look at the how buildings have changed and how the code has influenced building practices. The building type composition of the two samples differs dramatically. Large numbers of schools and offices were being built during 1990, while warehouse space dominates in the 1995 sample. Table 6 presents floor area estimates derived from both the 1990 and 1995 samples. Left alone, these differences would make comparisons meaningless, because lighting levels and construction types are strongly related to building type. Since any given year typically has a skewed distribution due to the market's focus on a particular building type, we have used the average floor area from the NPPC forecast for 1998-2002. This provides the proper balance between building types, but substantially increases the floor area, since it includes all additions and renovations as well as new construction.

Table 6. Sample and Forecast Populations

Building Type	1990 Sample		1995 Sample		NPPC Forecast Floor Area
	Obs	Population Floor Area	Obs	Population Floor Area	
Small Office	13	976,000	7	1,013,998	3,632,395
Large Office	4	4,084,000	3	1,295,389	4,640,408
Small Retail	5	541,000	2	186,621	276,542
Large Retail	4	1,540,000	11	3,649,300	5,407,662
Grocery	4	761,000	6	1,443,053	1,014,895
Restaurant	3	172,000	6	373,580	2,611,100
School	18	2,246,000	7	2,159,267	4,753,901
Warehouse	3	3,925,000	14	5,451,493	2,136,384
Other	11	3,114,000	31	6,408,216	18,577,390
Total	65	17,360,000	87	21,980,917	43,050,678

The comparison of characteristics between the two samples is complicated by many uncontrolled factors. Separating data affected by these factors would leave the samples too small to provide an adequate confidence interval, so no data has been removed.

The 1990 sample had a large number of "program" buildings, while the 1995 sample has relatively few. Ten buildings participated in utility incentive programs and 17 in state programs during construction in 1990. No direct incentives were offered in 1995, so this was ignored in the data collection effort.

However, it is known that all schools went through the state "program". Most significant are the utility programs since they involve direct incentives for measures. Utility program buildings as a group have significantly lower lighting levels. These aspects of the buildings have been improved using incentives and therefore represent better-than-standard practice. In general, the state programs involved design assistance or simply paperwork to ensure that all possible conservation measures were reviewed during the design process. The utility programs targeted large commercial buildings, while the state programs primarily affect schools.

Climate zone determines the envelope code path applied to each building in both the 1990 and 1994 codes. Fourteen percent of the 1995 sample was located in climate zone 2, versus 9% of the 1990 sample. This factor, combined with the code fuel considerations in the 1994 code, add some uncertainty to comparisons of envelope thermal performance.

Lighting control credits and tradeoffs with exterior lighting complicate comparisons between lighting codes. The 1990 code allowed interior and exterior lighting budgets to be traded off; the 1994 code did not. In addition, occupancy controls are required in a large number of spaces under the new code. This is a significant improvement in the code, which is not reflected in the code LPD. The inclusion of occupancy controls in many buildings is a major improvement, which has not been considered in the modeling.

Tables 7 through 12 compare characteristics found in the 1995 sample with those found in the 1990 sample. For each table, the first set of columns are data from the 1990 sample, the second from the 1995 sample. Three total rows are presented. The first is the average value using the relevant population floor area to weight the values. The second total row is calculated using the NPPC population forecast to weight building type average values. Thus the second totals are comparable between the two samples, but the total values will differ significantly from other values reported for the 1990 sample.

In addition, sector values have been weighted by heated floor area or where appropriate lighted floor area in addition to the sample weights determined in the data collection document. Therefore, some values will differ from Baylon et al, 1997.

Table 7 presents the average lighting power density (LPD). The reduction in LPD is very significant. The impact of the code and changes in lighting technology are clearly demonstrated. The exclusion of program buildings serves to magnify the differences though due to sampling issues this has not been explored. The increase in small retail lighting is attributable to a small sample and one very bad building. With a larger sample this would show a reduction as well.

Table 8 presents the average heat loss rate per square foot of floor area. The increase in building heat loss rate is significant, however the difference here is more difficult to interpret due to climate zone impacts and program buildings. Notice the use of the forecast floor area changes the average value substantially. This is partly attributable to the extreme amount of warehouse space in the 1995 sample which skewed the heat loss rate. Warehouse heat loss rates are strongly impacted by the semi-heated clause in the code. Warehouse spaces were removed from the average to assess the importance. Again, since the NPPC forecast has relatively less warehouse space the impact was minimized.

Exclusion of the state program buildings changes the picture substantially completely doing away with the difference.

Tables 9 through 12 present various other factors which do not show a statistically significant change. Window areas and equipment efficiencies have remained relatively stable. Furnace and heat pump efficiency have fallen slightly. Differences in both these areas are insignificant.

Table 7. Summary of Interior LPD (W/ft^2)

Building Type	1990 Sample		1995 Sample	
	Mean	Std Dev	Mean	Std Dev
Small Office	1.968	0.748	1.281	0.313
Large Office	1.087	0.470	1.003	0.042
Small Retail	2.043	0.880	3.177	0.335
Large Retail	2.244	0.774	1.483	0.400
Grocery	1.713	0.478	1.555	0.323
Restaurant	2.023	0.506	1.263	0.429
School	1.638	0.292	1.153	0.208
Warehouse	0.553	0.000	0.561	0.250
Other	1.169	0.487	1.110	0.364
Sample Average	1.455	0.677	1.093	0.494
Forecast Average	1.454		1.170	

Table 8. Summary of Envelope Heat Loss (UA/ft^2)

Building Type	1990 Sample		1995 Sample	
	Mean	Std Dev	Mean	Std Dev
Small Office	0.162	0.058	0.196	0.047
Large Office	0.097	0.074	0.069	0.077
Small Retail	0.216	0.041	0.214	0.012
Large Retail	0.120	0.014	0.134	0.038
Grocery	0.129	0.046	0.115	0.009
Restaurant	0.271	0.040	0.245	0.064
School	0.119	0.053	0.116	0.065
Warehouse	0.109	0.159	0.262	0.135
Other	0.131	0.053	0.177	0.137
Sample Average	0.121	0.076	0.175	0.118
Forecast Average	0.135		0.162	
Forecast Average[1] exc. Warehouse	0.137		0.157	

1 - excludes warehouse buildings

Table 9. Summary of Window Area (% gross wall area)

Building Type	1990 Sample		1995 Sample	
	Mean	Std Dev	Mean	Std Dev
Small Office	13.7	5.9	26.4	15.4
Large Office	38.8	11.4	31.9	0.3
Small Retail	18.2	5.2	18.3	4.7
Large Retail	5.7	3.3	11.4	6.5
Grocery	4.6	2.9	6.6	3.8
Restaurant	20.2	8.5	16.9	6.2
School	12.8	7.3	15.1	6.6
Warehouse	2.8	0.7	5.8	6.9
Other	13.4	8.0	7.7	5.8
Sample Average	17.4	15.6	12.0	9.9
Forecast Average	14.8		13.7	

Table 10. Summary of Combustion Equipment Efficiency

Building Type	1990 Sample		1995 Sample	
	Mean	Std Dev	Mean	Std Dev
Small Office	81.5	0.064	81.1	2.630
Large Office	79.8	0.007	83.5	0.000
Small Retail	79.0	0.000	80.0	.
Large Retail	82.0	0.055	81.0	2.510
Grocery	76.9	0.009	80.6	1.738
Restaurant	77.6	0.016	80.4	0.535
School	80.5	0.051	81.3	1.311
Warehouse	89.0	0.052	79.8	0.791
Other	80.3	0.024	81.6	3.032
Sample Average	82.6	0.052	80.9	2.230
Forecast Average	80.8		81.5	

Table 11. Summary of Heat Pump Efficiency

Building Type	1990 Sample		1995 Sample	
	Mean	Std Dev	Mean	Std Dev
Small Office	2.720	0.881	----	----
Large Office	----	---	2.051	0.000
Small Retail	3.127	0.000	----	----
Large Retail	----	---	2.041	.
Grocery	3.040	0.000	2.523	0.000
Restaurant	----	---	----	---
School	3.736	0.148	3.493	1.091
Warehouse	----	---	----	---
Other	2.539	0.000	2.450	0.428
Sample Average	2.826	0.601	2.643	0.753

Table 12. Summary of Cooling Equipment EER

Building Type	1990 Sample		1995 Sample	
	Mean	Std Dev	Mean	Std Dev
Small Office	9.435	1.386	10.027	1.230
Large Office	13.604	2.642	16.611	4.018
Small Retail	9.131	0.426	9.588	0.977
Large Retail	8.688	0.487	9.669	0.834
Grocery	9.282	0.662	9.378	0.595
Restaurant	9.047	0.509	9.194	0.477
School	9.960	1.167	10.925	1.877
Warehouse	8.356	.	10.066	0.697
Other	11.548	3.587	9.767	0.533
Sample Average	10.165	3.056	10.370	2.237
Forecast Average	10.678		10.612	

Simulation Results

Results from the code compliance analysis are presented in Tables 13 and 14. Table 13 presents total energy savings over as-built conditions from achieving full code compliance within the sample population. Four sets of results are presented: modeled building types; modeled building types plus projection to other building types; modeled building types excluding semi-heated space capacity provision; and modeled building types excluding semi-heated space capacity provision plus projection to other non-modeled building types.

The total energy savings over as-built conditions is 9122 mWh (1.04 average mW) of electricity and 10,000 therms of natural gas, excluding capacity provisions of the semi-heated space code. Including the capacity provisions, evaluated at 55°*F*, increases natural gas savings to 51,000 therms. This is the energy savings which would have resulted if the sample population had achieved full code compliance. The additional savings from the capacity provisions should be viewed with caution. It is unclear that compliance with this aspect of the code is possible to achieve. and there is much uncertainty with the prediction of savings from this provision, as discussed in the section on semi-heated space. A set of reasonable bounds resulted in a factor of five difference in gas savings.

Table 14 presents the same results using the NPPC forecast as the base floor area. Savings are much larger due to the total floor area being larger, and due to the differences in the distribution of floor area between the sectors. The table reflects the impact of achieving full code compliance in all new construction, additions and renovations. The total energy savings over as-built conditions is 16,865 mWh (1.93 average mW) of electricity and an increase of 10,000 therms of natural gas, excluding capacity provisions of the semi-heated space code. Including the capacity provisions, evaluated at 55°*F*, changes the increase in natural gas usage into a 9,500 therm savings. Note the impact of the semi-heated provisions of the code are greatly reduced in Table 14. This results from a greatly reduced fraction of warehouse floor area in the forecast compared with the sample population.

Sample size and frame, and the nature of a prototype building analysis, diminishes the reliability of the building type sub-sector savings predictions. Therefore, we present aggregated savings. This is in line with the original sampling strategy which did not account for building type. Any number of trends could alter this analysis. If the penetration of electric heat changed, or was not represented correctly in our sample, then the electric savings for the envelope could vary substantially. Trends in new construction building type have a large impact and severely compromise the sample population estimate. The use of a single year building population gives only one possible snapshot of the distribution of new construction. In this case warehouses appear to be very important. Use of forecast data provides a much better basis for analysis.

Table 13. Energy Savings Due to Energy Code Non-Compliance - Sample Population

End Use	Area	Electric Savings			Gas Savings		Total Savings	
	(1000s)	mWh	AvgMW	kWh/ft^2	MMBtu	kBtu/ft^2	MMBtu	kBtu/ft^2
Modeled Sectors Only								
Equipment Code	15,573	42	0.00	0.003	2967	0.190	3112	0.200
Envelope Code	15,573	209	0.02	0.013	6266	0.402	6980	0.448
Lighting Code	15,573	6211	0.71	0.399	-5610	-0.360	15,589	1.001
Total	15,573	6463	0.74	0.415	3623	0.233	25,680	1.649
Scaled to include OTHER building types								
Equipment Code	21,981	60	0.01	0.003	4187	0.190	4392	0.200
Envelope Code	21,981	295	0.03	0.013	8845	0.402	9852	0.448
Lighting Code	21,981	8767	1.00	0.399	-7919	-0.360	22,004	1.001
Total	21,981	9122	1.04	0.415	5114	0.233	36,248	1.649
Modeled Sectors Only - Excluding semi-heated capacity provision								
Equipment Code	15,573	42	0.00	0.003	66	0.004	211	0.014
Envelope Code	15,573	209	0.02	0.013	6266	0.402	6980	0.448
Lighting Code	15,573	6211	0.71	0.399	-5610	-0.360	15,589	1.001
Total	15,573	6463	0.74	0.415	722	0.046	22,780	1.463
Scaled to include OTHER building types, excluding semi-heated capacity provisions								
Equipment Code	21,981	60	0.01	0.003	93	0.004	298	0.014
Envelope Code	21,981	295	0.03	0.013	8845	0.402	9852	0.448
Lighting Code	21,981	8767	1.00	0.399	-7919	-0.360	22,004	1.001
Total	21,981	9122	1.04	0.415	1020	0.046	32,154	1.463

Table 14. Energy Savings Due to Energy Code Non-Compliance - Forecast Population

End Use	Area	Electric Savings			Gas Savings		Total Savings	
	(1000s)	mWh	AvgMW	kWh/ft²	MMBtu	kBtu/ft²	MMBtu	kBtu/ft²
Modeled Sectors Only								
Equipment Code	24,473	297	0.03	0.012	1236	0.050	2249	0.092
Envelope Code	24,473	420	0.05	0.017	8582	0.351	10,017	0.409
Lighting Code	24,473	8870	1.01	0.362	-9278	-0.379	20,995	0.858
Total	24,473	9587	1.09	0.392	540	0.022	33,261	1.359
Scaled to include OTHER building types								
Equipment Code	43,051	522	0.06	0.012	2173	0.050	3956	0.092
Envelope Code	43,051	740	0.08	0.017	15096	0.351	17,621	0.409
Lighting Code	43,051	15603	1.78	0.362	-16320	-0.379	36,933	0.858
Total	43,051	16865	1.93	0.392	950	0.022	58,510	1.359
Modeled Sectors Only - excluding semi-heated capacity provision								
Equipment Code	24,473	297	0.03	0.012	99	0.004	1112	0.045
Envelope Code	24,473	420	0.05	0.017	8582	0.351	10,017	0.409
Lighting Code	24,473	8870	1.01	0.362	-9278	-0.379	20,995	0.858
Total	24,473	9587	1.09	0.392	-597	-0.024	32,125	1.313
Scaled to include OTHER building types - excluding semi-heated capacity provisions								
Equipment Code	43,051	522	0.06	0.012	174	0.004	1957	0.045
Envelope Code	43,051	740	0.08	0.017	15,096	0.351	17,621	0.409
Lighting Code	43,051	15,603	1.78	0.362	-16,320	-0.379	36,933	0.858
Total	43,051	16,865	1.93	0.392	-1050	-0.024	56,510	1.313

Results of the comparison of 1995 construction with 1990 construction are presented in Tables 15 and 16. Table 15 shows the efficiency improvement between the two samples applied to the 1995 sample population results, Table 16 to the forecast population. In the 1995 sample population, electric savings are 4.2 average megawatts per year, and gas use increases between 320,000 and 585,000 therms. In the forecast population, electric savings are 10.2 average megawatts per year, and gas use increases between 640,000 and 740,000 therms.

The increase in gas use is mostly attributable to two factors. First, the increase in lighting efficiency leads to greatly increased heat demands as can be seen by looking at the lighting code rows. Second, the creation of the semi-heated warehouse category significantly decreased the integrity of warehouse envelope in the 1995 sample. This is complicated by the difficulties of accurately characterizing the control strategy of these buildings. The energy attributed to this code provision has a high level of uncertainty. A set of reasonable bounds resulted in a factor of five difference in the change of gas use. The low bound excludes semi-heated warehouse gas impacts and the high bound includes them. The rows explicitly denoting the semi-heated warehouse category clearly indicate the portion of the increase attributable to this. In the forecast population this is relatively unimportant.

Overall, a significant reduction in electric use has occurred. The sample population electric savings estimated here are 30% greater than the predicted code electric savings in Kennedy and Baylon (1992) under the aggressive scenario two. This savings is largely attributable to lighting efficiency improvements and indicates that lighting improved in most all buildings. The most efficient buildings in the 1990 sample were significantly improved upon in the 1995 sample. The increase in gas use is significantly above previous predictions. This can be attributed to the creation of the semi-heated space provision which was not analyzed in the previous work and lighting levels which are below those anticipated.

Table 15. Energy Savings Due to Efficiency Improvements 1990-1995 - Sample Population

End Use	Area	Electric Savings			Gas Savings		Total Savings	
	(1000s)	mWh	AvgMW	kWh/ft^2	MMBtu	kBtu/ft^2	MMBtu	kBtu/ft^2
Modeled Sectors excluding Semi-heated Warehouse								
Equipment Code	12,407	716	0.08	0.058	2357	0.190	4800	0.387
Envelope Code	12,407	509	0.06	0.041	-4184	-0.337	-2445	-0.197
Lighting Code	12,407	23,815	2.72	1.920	-21,894	-1.765	59,385	4.787
Total	12,407	25,040	2.86	2.018	-23,720	-1.912	61,740	4.976
Semi-Heated Warehouses Only								
Equipment Code	3166	0	0.00	0.000	3047	0.962	3047	0.962
Envelope Code	3166	-695	-0.08	-0.219	-26,424	-8.346	-28,795	-9.095
Lighting Code	3166	-684	-0.08	-0.216	823	0.260	-1513	-0.478
Total	3166	-1379	-0.16	-0.436	-22,553	-7.123	-27,261	-8.610
Scaled to include OTHER building types, excluding semi-heated warehouse envelope and capacity								
Equipment Code	21,981	1086	0.12	0.049	6622	0.301	10,327	0.470
Envelope Code	21,981	772	0.09	0.035	-6345	-0.289	-3708	-0.169
Lighting Code	21,981	35,431	4.04	1.612	-32,379	-1.473	88,546	4.028
Total	21,981	37,289	4.26	1.696	-32,102	-1.460	95,165	4.329
Scaled to include OTHER building types, includes semi-heated warehouse envelope and capacity								
Equipment Code	21,981	1086	0.12	0.049	6622	0.301	10327	0.470
Envelope Code	21,981	78	0.01	0.004	-32,768	-1.491	-32,503	-1.479
Lighting Code	21,981	35,431	4.04	1.612	-32,379	-1.473	88,546	4.028
Total	21,981	36,594	4.18	1.665	-58,526	-2.663	66,369	3.019

Table 16. Energy Savings Due to Efficiency Improvements 1990-1995 - Forecast Population

End Use	Area	Electric Savings			Gas Savings		Total Savings	
	(1000s)	mWh	AvgMW	kWh/ft²	MMBtu	kBtu/ft²	MMBtu	kBtu/ft²
Modeled Sectors excluding Semi-heated Warehouse								
Equipment Code	23,233	1621	0.19	0.070	11,898	0.512	17,432	0.750
Envelope Code	23,233	1894	0.22	0.082	852	0.037	7316	0.315
Lighting Code	23,233	46,353	5.29	1.995	-49,163	-2.116	109,041	4.693
Total	23,233	49,869	5.69	2.147	-36,413	-1.567	133,789	5.759
Semi-Heated Warehouses Only								
Equipment Code	1241	0	0.00	0.000	1194	0.962	1194	0.962
Envelope Code	1241	-272	-0.03	-0.219	-10,355	-8.346	-11,285	-9.095
Lighting Code	1241	-268	-0.03	-0.216	323	0.260	-593	-0.478
Total	1241	-541	-0.06	-0.436	-8838	-7.123	-10,683	-8.610
Scaled to include OTHER building types								
Equipment Code	43,051	2918	0.33	0.068	22,607	0.525	32,565	0.756
Envelope Code	43,051	3409	0.39	0.079	1533	0.036	13,167	0.306
Lighting Code	43,051	83,150	9.49	1.931	-88,152	-2.048	195,640	4.544
Total	43,051	89,477	10.21	2.078	-64,013	-1.487	241,372	5.607
Scaled to include OTHER building types, excludes semi-heated warehouse envelope and capacity codes								
Equipment Code	43,051	2918	0.33	0.068	22,607	0.525	32,565	0.756
Envelope Code	43,051	3137	0.36	0.073	-8823	-0.205	1882	0.044
Lighting Code	43,051	83,150	9.49	1.931	-88,152	-2.048	195,640	4.544
Total	43,051	89,205	10.18	2.072	-74,368	-1.727	230,088	5.345

References

Baylon, David, A. Houseknecht, J. Heller, and L. Tumidaj. 1997. ***Compliance with the 1994 Washington State Nonresidential Energy Code (NREC).*** For the Utility Code Group, Bellevue, WA.

Baylon, David, M. Frankel, and C. Clark. 1992. ***Energy Code Compliance in Commercial Building in Washington and Oregon.*** For the Washington State Energy Office, Olympia, WA and the Oregon Department of Energy, Salem, OR.

Harris, Jeff. 1997. Personal Communication: ***Summary of Forecast Results (EXCEL™ spreadsheet).***

Kennedy, Mike and D. Baylon. 1992. ***Energy Savings in Commercial Buildings: Impact of 1993 Proposed Washington Energy Code***. For the Northwest Power Planning Council, Portland, OR.

Kennedy, Mike. 1993. ***Energy Savings in Commercial Buildings: Impact of the Proposed 1995 Oregon State Energy Code***. For the Northwest Power Planning Council, Portland, OR.

SBW Consulting, 1990. ***Analysis of Commercial Model Conservation Standards Study***. For Bonneville Power Administration, Portland, OR.