Analysis of window energy savings in commercial buildings in the Pacific Northwest

Market Research Report

PREPARED BY

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Background and Context for "Analysis of window energy savings in commercial buildings in the Pacific Northwest -- *Final Report*"

In September 2002, NEEA launched the Commercial Windows Initiative (CWI) with the goal of increasing sales of already efficient commercial window products and encouraging the design, manufacture and sale of new, more efficient products. CWI had an explicit goal of increasing market share to 50% from an assumed baseline of 12% for the specific market category of factory-built products for punched openings.

An evaluation conducted during 2005 documented a variety of market changes attributable to the program but the principal finding was that the goal of increasing market share could not be accurately measured; the planned approach, which relied on data collected from manufacturers, led to either uninterpretable or untenable conclusions. Alternative methods were considered but were either not within the evaluation budget or could not guarantee better results.

In part as a result of these evaluation findings CWI was not re-funded and ceased operations at the end of 2005. However, because of the market changes that were documented in the evaluation, NEEA has a continuing interest in estimating the energy savings that may have resulted from its funding of CWI. Two barriers generating savings estimates were identied: (1) lack of data on the percentage of windows in the commercial marketplace that meet CWI qualifications and (2) disagreement on per unit (per square foot) savings estimates, due to lack of a systematic methodology.

The first of these barriers is being addressed through a NEEA-funded regional Commercial New Construction Study of building characteristics including the thermal characteristics of windows. This study is currently underway with results expected in early 2008. When finished, it will provide a statistical summary of the percentage of commercial windows with a given set of characteristics. This will allow NEEA to gauge market penetration of the level of windows that CWI was promoting.

To address the second barrier of generating per unit estimates, NEEA hired Lawrence Berkeley National Laboratory (LBNL) to develop prototype energy simulation models and run them with a wide variety of window types. The development of the prototypes was done jointly with Northwest stakeholders to ensure a consensus on methodology. The methodology and results of that effort are described in this report.

The report does not provide savings estimates directly; rather, the research created a series of equations that estimate energy consumption (as opposed to savings) from windows having any user-defined combination of thermal characteristics. These equations allow the user to compare the consumption from any two window types and, by taking the difference in consumption, to generate a savings estimate.

When the analysis of the Commercial New Construction Study data is complete, NEEA will have an estimate of the market share for each unique combination of window thermal characteristics, including those that meet the CWI qualifications. The different types of windows will then be entered into the LBNL equations to generate consumption estimates. Savings estimates will then be generated based on the difference between CWI-qualified window consumption and the consumption of all other window types, extrapolated to the total square footage they represent in the market. What this approach will not do is determine the share of those savings attributable to the efforts of CWI. There are no current plans to address this situation.

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Analysis of window energy savings in commercial buildings in the Pacific Northwest

Final Report

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Overview

As part of their work to make affordable, energy-efficient products and services available in the marketplace, the Northwest Energy Efficiency Alliance (NEEA) is interested in knowing the energy performance and savings potential for different window products in the commercial buildings in the Pacific Northwest. NEEA contracted with LBNL to analyze these potentials through computer energy simulations of prototypical commercial buildings.

Starting in the early 1990's, LBNL developed building descriptions and DOE-2 input files for a large collection of prototypical commercial buildings covering 12 building types of three vintages in different regions of the United States (Huang et al. 1990, Huang and Franconi 1999). For this project, NEEA, its contractor Mike Kennedy, and LBNL agreed on the large and small offices as the most relevant building types to be modeled. LBNL modified its available office prototypes to better reflect building and system conditions in the Pacific Northwest, relying heavily on the prior work of, and the review and comments received from, the NEEA staff during the revision process.

After several months of review and iterations of the prototypical building models, final sets of computer simulations were done for the Large and Small Office prototypes in two locations (Seattle, Boise), with two vintage variations (*Old* and *New*), three lighting power densities (0.8, 1.0, and 1.2 kWh/ft^2), and 146 variations of window U-value, Solar Heat Gain Coefficient (SHGC), and drapery shading condition, as agreed between the project team and Mike Kennedy representing NEEA. The results are contained in spreadsheet tables showing the buildings' energy use by different end-uses, i.e., heating, cooling, cooling tower, fans, pumps, lighting, and service hot water, and the differences in energy use for changes in window U-factor and SHGC.

Building Prototypes

The original LBNL building prototypes were created to represent typical building conditions in the four Energy Information Agency (EIA) regions - Northeast, North Central, South, and West (Huang et al. 1990) - or, in a later version, two larger geographical regions, simply North or South (Huang and Franconi 1999). In the latest 1999 version, two vintages were defined, with the thermal characteristics for the *Old* vintage taken from the 1983 Non-residential Building Energy Consumption Survey or NBECS (EIA 1983), and those for the *New* vintage based on the latest ASHRAE 90.1 requirements. The modeling of the internal conditions, schedules, building geometry, system and plant configurations, was based on review of available survey data and studies, combined with judicious application of "engineering judgment".

The large and small office prototypes for the North region in Huang and Franconi 1999 were chosen as the starting points for the building models used in this project (see Appendix C), with the shell conditions modified to current energy code requirements or typical conditions in the Northwest as described in Appendix A. Other changes were made to the building models following review of the original DOE-2.1E building files and discussions with NEEA staff (see Appendix B and D). Following are the final building descriptions agreed upon between LBNL and NEEA for the two prototypes.

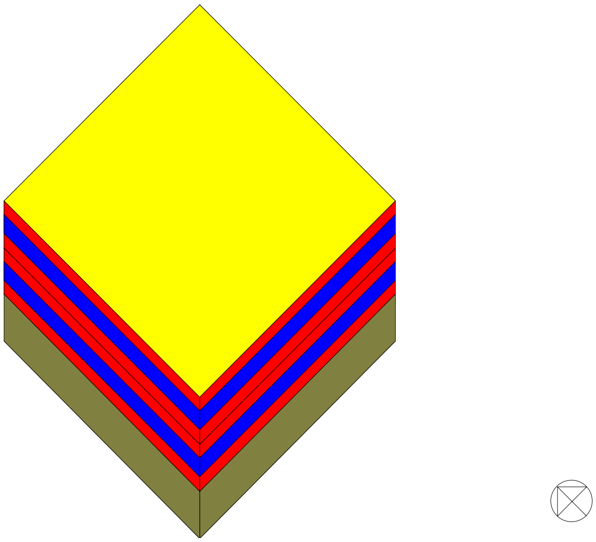
Small Office

Four variations of the small office prototype have been developed for two vintages (*Old* and *New*) in two locations (Seattle and Boise).

Building Geometry

The building floor area is 5500 ft^2 for the *Old* vintage and 6400 ft^2 for the *New* vintage small office. For both cities and vintages, the building has been modeled having two floors plus a basement. The dimensions of the roof are 52.4 ft x 52.4 ft for the *Old* vintage and 56.6 ft. x 56.6 ft. for the *New* vintage small office. Total window area is 923 ft^2 for the *Old* vintage and 996 ft^2 for the *New* vintage. The Window-to-Wall Ratio has been fixed at 0.20. The windows are modeled as strip windows around the building, 2.2 ft in height, and evenly distributed on all four sides of the building. The building aspect ratio (length-to-width ratio) is modeled as one, i.e., the building is assumed to be square. The wall height is 10 ft. The exterior wall dimensions on each side of the building are 56.6 ft x 10 ft. for the *New* and 52.4 ft x 10 ft for the *Old* vintage small offices. A schematic of small office building is shown in Figure 1.

Figure 1. schematic drawing of small office prototype



Shell Characteristics

The exterior wall construction consists of (from outside to inside), a 1" stone cladding, wall insulation, 4" vertical air layer, and 5/8" gypsum board. The insulation R-value is set to R-10 for both the *Old* and *New* vintages to meet the U-value requirement of 0.084 for metal-frame walls in Zone 2 of the Northwest energy code.

The roof construction consists of (from outside to inside), a 3/8" built-up roof, 4" lightweight (80 lbs. per ft^3) concrete slab, roof insulation, 4" horizontal air layer, and ½" acoustic tile. The insulation R-value is set to R-9.1 for the *Old* vintage building in both cities, and to R-21 in Seattle and R-25 in Boise for the *New* vintage building.

The window conditions have been parameterized to differing U-factors and SHGCs. The window U-factor ranges from 0.25 to 0.55 (Btu/hr-ft^2-°F) in 0.05 increments. The SHGC ranges from 0.30 to 0.60 (dimensionless) in 0.05 increments. Additional window shading for the effects of drapes and blinds has been modeled as constant shading reductions of 0.60, 0.75, and 0.90 on all windows.

Zone Conditions

Each floor is modeled as a single thermal zone. The internal loads and occupancy are assumed to be the same for both vintages, and modeled with a peak or design value multiplied by a schedule that varies by hour of day and day of week. The peak occupancy is assumed to be 244 ft^2/person, the peak equipment energy intensity 0.75 W/ft^2, but three levels of lighting intensity have been considered: 0.8, 1.0, and 1.2 W/ft^2. The hot water usage is calculated as 0.0011 gallons/min per person. The infiltration rate is set to 0.3 air change per hour, and the zone Floor Weight is set to *Heavy,* or 130 lbs/ft^2, to account for the internal thermal mass of interior surfaces and furnishings.

Schedules

The prototypical small office building is modeled with a 12-hour normal operating schedule. The hourly schedules for different days of the week for people, equipment, lighting, and hot water are shown in Table 1.

Systems

The HVAC system is modeled as a Packaged Single-Zone (PSZ), and auto-sized for both the *New* and *Old* vintages. In both vintages, the zones are served with SVAV terminals. The system heat source is assumed to be a furnace with natural gas, but zone-level heating is modeled as electric resistance. Cooling is provided by direct-expansion within the packaged HVAC system.

The amount of outside air is set to a fixed value of 15 CFM/person for the *Old* vintage buildings, but for the *New* vintage buildings, the fresh air requirement of ASHRAE 62 is calculated as follows:

$$\text{OA-CFM/person} = \{ [(1 / \text{OCC} * a_1) + a_2] / a_3\} * \text{Zone Area} \qquad \text{[Eqn 1]}$$

where OCC = occupancy in ft^2/person
a_1 = 5 CFM/person
a_2 = 0.06 CFM/ft^2
a_3 = 0.8 for the ventilation effectiveness

Table 1. Hourly schedules for people, hot water, lights, equipment, and elevators (in large offices only) in small and large offices

(WD = weekdays, WEH = weekends and holidays)

		Hour of Day																							
Parameter	**Day Type**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
People, Hot Water	WD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.67	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00
" "	WEH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.13	0.20	0.20	0.20	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lights	WD	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.30	0.30	0.30	0.30	0.30	0.30	0.30
"	WEH	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.40	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Equipment,	WD	0.17	0.17	0.17	0.17	0.17	0.17	0.17	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Elevators	WEH	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17

The reset schedule was set to WARMEST for both *Old* and *New* vintage buildings. The schedules for heating, cooling, and fans are given in Table 2.

Large Office

Four variations of the large office prototype have been developed for two vintages (*Old* and *New*) in two locations (Seattle and Boise).

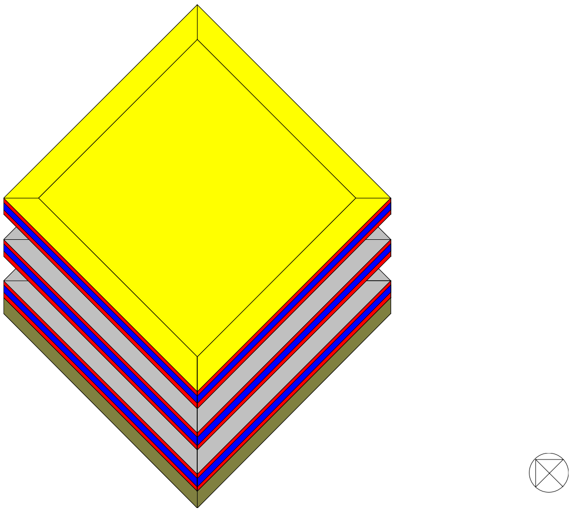
Building Geometry

The building floor area is 103,000 ft^2 for the *Old* vintage and 137,000 ft^2 for the *New* vintage large offices. For both cities and vintages, the building has been modeled having seven floors plus a basement. The dimensions of the roof are 139.9 ft by 139.9 ft for the *New* vintage and 121.3 ft. by 121.3 ft. for the *Old* vintage large office. The Window-to-Wall Ratio has been fixed at 0.40, resulting in total window areas of 13,586 ft^2 for the *Old* and 15,669 ft^2 for the *New* vintage large offices. The windows are modeled as strip windows around the building, 4 ft in height, and evenly distributed on all four sides of the building. The building aspect ratio (length-to-width ratio) is modeled as one, i.e., the building is assumed to be square. The wall height is 10 ft. The exterior wall dimensions on each side of the building are 139.9 ft. x 10 ft. for the *New* and 121.3 ft. x 10 ft. for the *Old* vintage large offices. A schematic drawing of the large office prototype is shown in Figure 2.

Table 2. Schedules for HVAC operation in small and large offices
(WD= weekday, WEH = weekend and holidays)

		Hour of Day											
Parameter	**Day type**	1	2	3	4	5	6	7	8	9	10	11	12
Fan	WD	off	off	off	off	off	off	on	on	on	on	on	on
"	WEH	off	off	off	off	off	off	on	on	on	on	on	on
Cooling	WD	90	90	90	90	90	90	75	75	75	75	75	75
"	WEH	90	90	90	90	90	90	75	75	75	75	75	75
Heating	WD	55	55	55	55	55	55	70	70	70	70	70	70
"	WEH	55	55	55	55	55	55	70	70	70	70	70	70
Vent	WD	off	off	off	off	off	off	off	vent	vent	vent	vent	vent
"	WEH	off	off	off	off	off	off	off	vent	vent	vent	vent	vent
		Hour of Day											
Parameter	**Day type**	13	14	15	16	17	18	19	20	21	22	23	24
Fan	WD	on	on	on	on	on	on	off	off	off	off	off	off
"	WEH	on	off	off	off	off	off	off	off	off	off	off	off
Cooling	WD	75	75	75	75	75	75	90	90	90	90	90	90
"	WEH	75	90	90	90	90	90	90	90	90	90	90	90
Heating	WD	70	70	70	70	70	70	55	55	55	55	55	55
"	WEH	70	55	55	55	55	55	55	55	55	55	55	55
Vent	WD	vent	vent	vent	vent	vent	off	off	off	off	off	off	off
"	WEH	off	off	off	off	off	off	off	off	off	off	off	off

Figure 2. schematic drawing of large office prototype



Shell Characteristics

The shell characteristics of the large offices are the same as those for the small offices described earlier.

Zone Conditions

Each floor is divided into five zones, consisting of four perimeter zones and one core zone. The internal loads and occupancy are assumed to be the same for both vintages, and modeled with a peak or design value multiplied by a schedule that varies by hour of day and day of week. The peak occupancy is assumed to be 460 ft^2/person for the *Old* vintage and 390 ft^2/person for the *New* vintage large offices. The peak equipment energy intensity 0.75 W/ft^2, but three levels of lighting intensity have been considered: 0.8, 1.0, and 1.2 W/ft^2. The hot water usage is calculated as 0.0039 gallons/min per person. The infiltration rate is set to 0.3 air change per hour, and the zone Floor Weight is set to *Heavy*, or 130 lbs/ft^2, to account for the internal thermal mass due to interior surfaces and furnishings. Automatic "Custom Weighting Factors", i.e., FLOOR-WEIGHT = 0, is not used as that would have necessitated explicit modeling of the internal walls and office furnishings.

Schedule

The prototypical large office building is modeled with a 12-hour normal operating schedule. The hourly schedules for different days of the week for occupancy, equipment, lighting, hot water, and elevators are shown in Table 1.

Systems

The HVAC system is modeled as a Packaged Variable-Air-Volume System with powered terminal boxes (Power-induction Units or PIU in *DOE-2* abbreviation) in the *New* vintage, and with non-powered damper boxes (PVAVS in *DOE-2* abbreviation) in the *Old* vintage buildings. The system is auto-sized using *DOE-2* for each parametric simulation in the *New* vintage buildings, but a fixed size has been used for the window parametrics in the *Old* vintage buildings. The reasoning for this difference in modeling is that, in a new building, the HVAC system should be sized based on the actual windows installed. However, in an old building, it is unlikely that a window retrofit will also entail replacement of the HVAC system, making it misleading to attribute to the windows savings that are actually due to system downsizing. The impact of sizing on the window savings is quite significant and investigated in the Discussion section later in this report.

The fixed system parameters for heating capacity, cooling capacity, and supply fan CFM for the *Old* vintage simulations are obtained using an auto-sized *DOE-2* run for the worst case cooling condition (U-factor 0.55 Btu/hr-ft^2-°F, SHGC 0.60, lighting power density 1.2 W/ft^2, and drapery shading of 0.90). The heating capacities have also been corrected for elevation, the factors being 1.01 for Seattle and 1.11 for Boise. The system heat source is modeled as a gas furnace, but zone-level heating is modeled as electric resistance. Cooling is provided by a central centrifugal chiller. For the *New* vintage large offices, the core zones are served with SVAV terminals and the perimeter zones by Series

Power Induction Unit (PIU) terminals that mix in "induced" air from the core zones. The system minimum flow rate ratio is set to 0.5 for the *Old* vintage and 0.4 for the *New* vintage buildings.

Zone air flows are dynamically calculated by the DOE-2 program with a minimum constraints of 0.75 CFM/ft^2 for the *Old* vintage and 0.5 CFM/ft^2 for the *New* vintage buildings. The outside air amount for the *Old* vintage buildings is equivalent to a fixed rate of 15 CFM/person. For the *New* vintage large office buildings, ASHRAE 62 fresh air requirements are calculated according to Equation 1 (see previous description for the small office prototype).

The reset schedule was set to WARMEST for *New* vintage buildings. For the *Old* vintage building, COOL-CONTROL was set to CONSTANT with the following schedule:

SUPPLY-HI = 62
SUPPLY-LO = 55
OUTSIDE-HI = 75
OUTSIDE-LO = 40

The schedules for heating, cooling, and fans are given in Table 2.

Parametric Simulations

In consultation with NEEA, a set of parametric simulations for each of the four prototypical buildings were defined. These include three lighting power densities and 146 combinations of window U-factor and SHGC (see Table 3).

Table 3. Parametric simulation for NEEA prototypical buildings

3 Lighting power densities (W/ft^2)	0.8, 1.0, 1.2
7 Window U-factors (BTU/hr-ft^2-ºF)	0.55, 0.50, 0.45, 0.40, 0.35, 0.30, 0.25
7 Window SHGCs (dimentionless)	0.6, 0.55, 0.50, 0.45, 0.40, 0.35, 0.30
3 Window Shading Conditions (dimensionless, fractional reduction)	0.90, 0.75, 0.60
Total number of parametrics	3 x 7 x 7 x 3 = 441 runs

Results

The complete results of the parametric simulations have been saved as *Excel* spreadsheets showing the energy use from each simulation for the following eight end-uses: lighting, equipment, cooling, fan, cooling tower, and heating electricity, heating and service hot water natural gas. These files are contained in the CD that accompanies this report. For brevity, Table 4 shows an example for the *New* vintage large office in Seattle at a lighting power density of 1.0 W/ft^2, roughly 1/6 of the total number of parametrics that have been analyzed. For the sample runs in Table 4, the following energy end-uses are constant and therefore omitted: lighting electricity 574.2 MWh, equipment electricity 522.3 MWh, and service hot water gas 244.1 MBtu. There is no natural gas consumed for space heating, all of which is met by zone-level electric resistance heating.

Table 5 is a corresponding table to Table 4, except for the *New* vintage small office, also in Seattle. For this sample set of runs, lighting electricity is 21.3 MWh, equipment electricity 4.74 MWh, and service hot water gas 18.1 MBtu. There is space heating gas usage, which is shown in Table 5.

Tables 6 through 7 take the same end-use energy use data from Table 4, but display them in a format that is more relevant to NEEA, i.e., as energy savings or penalties per square foot of window for changes in window U-factor or SHGC.

These data are plotted in Figures 3 through 10. Although the heating curves are well behaved, there are some instances of switchover in the cooling curves, particularly for the cooling differences for incremental changes in window U-factor. A considerable effort was expended to investigate these anomalies, but no mistakes were found in the modeling. Since the anomalies affected only the *New* vintage large office runs, we suspected they were due to the effect of auto-sizing on part-load performance, but this was found not to be the cause because the anomalies persisted even when we looked at the changes in cooling loads, which are unaffected by system performance.

A detailed comparison of the change in zone cooling loads for 0.05 U-factor differences at two differing SHGCs clarifies the situation. Figure 11 looks into detail at the same window parametric as shown in the top left plot of Figure 2, but only the curves for the 0.3 and 0.6 SHGC cases are shown for clarity. The top left plot on Figure 11 shows the changes in cooling loads for the entire building, while the following plots show the change in zone cooling loads, for the core zones, top floor perimeter zones, and bottom floor perimeter zones. It is clear that the shapes of the zone-level curves are well-behaved, but because of their differing slopes, their sum can result in the apparent anomalies at the building level change in cooling loads or energy uses. Lastly, it is important to put these anomalies into perspective. They are occurring almost entirely for cooling savings as a function of window U-factor, which is a relatively small effect because window cooling loads are dominated by solar heat gain, rather than temperature differences. Thus, the anomalies are inconsistencies in quite small numbers.

Table 4. Sample results of total energy usage for new large offices in Seattle with a lighting power density of 1.0 W/ft^2 (CoolE = Chiller + Tower, AuxE = Fan + Pump)

		CoolE	AuxE	HtgE			CoolE	AuxE	HtgE			CoolE	AuxE	HtgE
U-factor	SHGC	mWh	mWh	mWh	U-factor	SHGC	mWh	mWh	mWh	U-factor	SHGC	mWh	mWh	mWh
U-factor changes for constant SHGC for Drape=0.9					U-factor changes for constant SHGC for Drape=0.75					U-factor changes for constant SHGC for Drape=0.60				
0.55	0.60	132.1	249.1	102.4	0.55	0.60	123.8	231.9	103.1	0.55	0.60	114.7	214.8	104.6
0.50	0.60	132.8	248.7	91.1	0.50	0.60	124.5	231.5	91.4	0.50	0.60	115.4	214.3	92.4
0.45	0.60	133.6	248.4	80.0	0.45	0.60	125.4	231.2	80.0	0.45	0.60	116.1	214.0	80.6
0.40	0.60	134.3	248.1	69.1	0.40	0.60	126.1	230.9	68.8	0.40	0.60	117.0	213.9	69.1
0.35	0.60	135.0	247.9	58.7	0.35	0.60	126.8	230.7	58.0	0.35	0.60	117.8	213.8	58.0
0.30	0.60	135.7	247.7	48.7	0.30	0.60	127.4	230.5	47.8	0.30	0.60	118.5	213.8	47.5
0.25	0.60	136.3	247.7	39.3	0.25	0.60	128.0	230.4	38.1	0.25	0.60	119.2	213.9	37.5
0.55	0.55	127.9	240.5	102.7	0.55	0.55	120.0	224.7	103.5	0.55	0.55	111.6	209.1	105.4
0.50	0.55	128.7	240.1	91.2	0.50	0.55	120.7	224.4	91.8	0.50	0.55	112.4	208.7	93.1
0.45	0.55	129.5	239.8	79.9	0.45	0.55	121.5	224.0	80.1	0.45	0.55	113.2	208.5	81.1
0.40	0.55	130.2	239.4	68.9	0.40	0.55	122.3	223.7	68.8	0.40	0.55	114.1	208.5	69.5
0.35	0.55	130.9	239.2	58.3	0.35	0.55	123.0	223.5	57.8	0.35	0.55	114.9	208.4	58.2
0.30	0.55	131.7	239.1	48.2	0.30	0.55	123.7	223.3	47.5	0.30	0.55	115.6	208.4	47.5
0.25	0.55	132.2	239.1	38.7	0.25	0.55	124.5	223.5	37.8	0.25	0.55	116.3	208.5	37.4
0.55	0.50	123.8	231.9	103.1	0.55	0.50	116.3	217.6	104.3	0.55	0.50	108.7	203.9	106.7
0.50	0.50	124.5	231.5	91.4	0.50	0.50	116.9	217.2	92.2	0.50	0.50	109.5	203.6	94.2
0.45	0.50	125.4	231.2	80.0	0.45	0.50	117.7	216.8	80.4	0.45	0.50	110.3	203.4	82.0
0.40	0.50	126.1	230.9	68.8	0.40	0.50	118.5	216.6	68.9	0.40	0.50	111.1	203.2	70.2
0.35	0.50	126.8	230.7	58.0	0.35	0.50	119.3	216.5	57.9	0.35	0.50	112.0	203.1	58.6
0.30	0.50	127.4	230.5	47.8	0.30	0.50	120.0	216.5	47.4	0.30	0.50	112.7	203.0	47.7
0.25	0.50	128.0	230.4	38.1	0.25	0.50	120.7	216.7	37.6	0.25	0.50	113.3	203.0	37.4
0.55	0.45	119.2	223.3	103.7	0.55	0.45	112.4	210.5	105.2	0.55	0.45	105.8	199.0	108.3
0.50	0.45	120.0	222.9	91.9	0.50	0.45	113.1	210.1	92.9	0.50	0.45	106.6	198.6	95.5
0.45	0.45	120.7	222.6	80.1	0.45	0.45	113.9	209.9	81.0	0.45	0.45	107.4	198.4	83.1
0.40	0.45	121.5	222.3	68.8	0.40	0.45	114.8	209.8	69.4	0.40	0.45	108.2	198.2	71.0
0.35	0.45	122.2	222.0	57.8	0.35	0.45	115.6	209.8	58.2	0.35	0.45	109.1	198.1	59.3
0.30	0.45	123.0	222.0	47.5	0.30	0.45	116.3	209.7	47.5	0.30	0.45	109.9	198.0	48.1
0.25	0.45	123.7	222.1	37.7	0.25	0.45	117.0	209.8	37.4	0.25	0.45	110.5	198.0	37.6
0.55	0.40	114.7	214.8	104.6	0.55	0.40	108.7	203.9	106.7	0.55	0.40	102.8	194.1	110.0
0.50	0.40	115.4	214.3	92.4	0.50	0.40	109.5	203.6	94.2	0.50	0.40	103.6	193.8	97.1
0.45	0.40	116.1	214.0	80.6	0.45	0.40	110.3	203.4	82.0	0.45	0.40	104.5	193.5	84.5
0.40	0.40	117.0	213.9	69.1	0.40	0.40	111.1	203.2	70.2	0.40	0.40	105.4	193.3	72.1
0.35	0.40	117.8	213.8	58.0	0.35	0.40	112.0	203.1	58.6	0.35	0.40	106.2	193.1	60.1
0.30	0.40	118.5	213.8	47.5	0.30	0.40	112.7	203.0	47.7	0.30	0.40	107.0	193.0	48.7
0.25	0.40	119.2	213.9	37.5	0.25	0.40	113.3	203.0	37.4	0.25	0.40	107.7	193.0	37.9
0.55	0.35	110.2	206.4	106.0	0.55	0.35	105.0	197.7	108.7	0.55	0.35	99.9	189.3	112.0
0.50	0.35	110.9	206.1	93.5	0.50	0.35	105.9	197.4	95.9	0.50	0.35	100.7	188.9	98.8
0.45	0.35	111.7	205.9	81.5	0.45	0.35	106.7	197.1	83.5	0.45	0.35	101.6	188.6	85.9
0.40	0.35	112.6	205.8	69.8	0.40	0.35	107.5	196.9	71.3	0.40	0.35	102.5	188.4	73.4
0.35	0.35	113.4	205.7	58.4	0.35	0.35	108.4	196.8	59.5	0.35	0.35	103.4	188.2	61.2
0.30	0.35	114.1	205.7	47.6	0.30	0.35	109.2	196.7	48.2	0.30	0.35	104.2	188.1	49.4
0.25	0.35	114.8	205.7	37.4	0.25	0.35	109.8	196.8	37.7	0.25	0.35	104.9	188.1	38.4
0.55	0.30	105.8	199.0	108.3	0.55	0.30	101.3	191.7	111.0	0.55	0.30	97.0	184.5	114.2
0.50	0.30	106.6	198.6	95.5	0.50	0.30	102.2	191.3	97.9	0.50	0.30	97.8	184.1	100.6
0.45	0.30	107.4	198.4	83.1	0.45	0.30	103.1	191.1	85.2	0.45	0.30	98.6	183.8	87.5
0.40	0.30	108.2	198.2	71.0	0.40	0.30	103.9	190.8	72.7	0.40	0.30	99.5	183.6	74.8
0.35	0.30	109.1	198.1	59.3	0.35	0.30	104.8	190.7	60.7	0.35	0.30	100.6	183.5	62.3
0.30	0.30	109.9	198.0	48.1	0.30	0.30	105.6	190.6	49.0	0.30	0.30	101.3	183.4	50.3
0.25	0.30	110.5	198.0	37.6	0.25	0.30	106.3	190.6	38.2	0.25	0.30	102.0	183.4	39.0

Table 5. Sample results of total energy usage for new small offices in Seattle with a lighting power density of 1.0 W/ft^2 (CoolE = Chiller + AuxE = Fan + Pump)

		CoolE	FanE	HtgG			CoolE	FanE	HtgG			CoolE	FanE	HtgG
U-factor	SHGC	mWh	mWh	MBtu	U-factor	SHGC	mWh	mWh	MBtu	U-factor	SHGC	mWh	mWh	MBtu
U-factor changes for constant SHGC for Drape=0.9					U-factor changes for constant SHGC for Drape=0.75					U-factor changes for constant SHGC for Drape=0.60				
0.55	0.60	4.26	7.38	141.3	0.55	0.60	3.78	6.90	147.6	0.55	0.60	3.29	6.42	154.5
0.50	0.60	4.34	7.32	136.5	0.50	0.60	3.84	6.84	142.7	0.50	0.60	3.36	6.36	149.5
0.45	0.60	4.41	7.26	131.6	0.45	0.60	3.91	6.78	137.7	0.45	0.60	3.43	6.30	144.3
0.40	0.60	4.49	7.20	126.7	0.40	0.60	3.99	6.72	132.6	0.40	0.60	3.50	6.24	139.0
0.35	0.60	4.58	7.14	121.6	0.35	0.60	4.07	6.66	127.4	0.35	0.60	3.58	6.18	133.6
0.30	0.60	4.67	7.08	116.4	0.30	0.60	4.16	6.60	122.0	0.30	0.60	3.66	6.12	128.1
0.25	0.60	4.76	7.01	111.1	0.25	0.60	4.26	6.53	116.6	0.25	0.60	3.75	6.06	122.5
0.55	0.55	4.02	7.14	144.4	0.55	0.55	3.57	6.70	150.4	0.55	0.55	3.13	6.26	156.9
0.50	0.55	4.09	7.08	139.5	0.50	0.55	3.64	6.64	145.5	0.50	0.55	3.20	6.20	151.8
0.45	0.55	4.16	7.02	134.6	0.45	0.55	3.71	6.58	140.4	0.45	0.55	3.27	6.14	146.6
0.40	0.55	4.24	6.96	129.6	0.40	0.55	3.79	6.52	135.2	0.40	0.55	3.34	6.08	141.3
0.35	0.55	4.33	6.90	124.4	0.35	0.55	3.87	6.46	129.9	0.35	0.55	3.42	6.02	135.9
0.30	0.55	4.42	6.84	119.2	0.30	0.55	3.95	6.40	124.5	0.30	0.55	3.50	5.96	130.3
0.25	0.55	4.51	6.77	113.8	0.25	0.55	4.04	6.34	119.0	0.25	0.55	3.58	5.90	124.5
0.55	0.50	3.78	6.90	147.6	0.55	0.50	3.37	6.50	153.3	0.55	0.50	2.97	6.10	159.4
0.50	0.50	3.84	6.84	142.7	0.50	0.50	3.44	6.44	148.3	0.50	0.50	3.04	6.04	154.2
0.45	0.50	3.91	6.78	137.7	0.45	0.50	3.51	6.38	143.2	0.45	0.50	3.11	5.98	149.0
0.40	0.50	3.99	6.72	132.6	0.40	0.50	3.58	6.32	137.9	0.40	0.50	3.18	5.92	143.6
0.35	0.50	4.07	6.66	127.4	0.35	0.50	3.66	6.26	132.5	0.35	0.50	3.26	5.86	138.2
0.30	0.50	4.16	6.60	122.0	0.30	0.50	3.74	6.20	127.0	0.30	0.50	3.33	5.80	132.5
0.25	0.50	4.26	6.53	116.6	0.25	0.50	3.83	6.14	121.5	0.25	0.50	3.42	5.74	126.7
0.55	0.45	3.53	6.66	151.0	0.55	0.45	3.17	6.30	156.3	0.55	0.45	2.82	5.94	162.0
0.50	0.45	3.60	6.60	146.0	0.50	0.45	3.24	6.24	151.2	0.50	0.45	2.88	5.88	156.8
0.45	0.45	3.67	6.54	140.9	0.45	0.45	3.31	6.18	146.0	0.45	0.45	2.95	5.82	151.5
0.40	0.45	3.75	6.48	135.7	0.40	0.45	3.38	6.12	140.8	0.40	0.45	3.02	5.77	146.0
0.35	0.45	3.83	6.42	130.4	0.35	0.45	3.46	6.06	135.3	0.35	0.45	3.09	5.71	140.5
0.30	0.45	3.91	6.36	125.0	0.30	0.45	3.54	6.00	129.7	0.30	0.45	3.17	5.64	134.8
0.25	0.45	4.00	6.30	119.5	0.25	0.45	3.62	5.94	124.0	0.25	0.45	3.25	5.58	128.9
0.55	0.40	3.29	6.42	154.5	0.55	0.40	2.97	6.10	159.4	0.55	0.40	2.67	5.77	164.7
0.50	0.40	3.36	6.36	149.5	0.50	0.40	3.04	6.04	154.2	0.50	0.40	2.73	5.72	159.4
0.45	0.40	3.43	6.30	144.3	0.45	0.40	3.11	5.98	149.0	0.45	0.40	2.79	5.66	154.0
0.40	0.40	3.50	6.24	139.0	0.40	0.40	3.18	5.92	143.6	0.40	0.40	2.86	5.61	148.5
0.35	0.40	3.58	6.18	133.6	0.35	0.40	3.26	5.86	138.2	0.35	0.40	2.93	5.55	142.9
0.30	0.40	3.66	6.12	128.1	0.30	0.40	3.33	5.80	132.5	0.30	0.40	3.01	5.49	137.1
0.25	0.40	3.75	6.06	122.5	0.25	0.40	3.42	5.74	126.7	0.25	0.40	3.09	5.42	131.2
0.55	0.35	3.05	6.18	158.1	0.55	0.35	2.78	5.89	162.6	0.55	0.35	2.52	5.61	167.4
0.50	0.35	3.12	6.12	153.0	0.50	0.35	2.84	5.84	157.4	0.50	0.35	2.58	5.56	162.1
0.45	0.35	3.19	6.06	147.8	0.45	0.35	2.91	5.78	152.1	0.45	0.35	2.64	5.50	156.7
0.40	0.35	3.26	6.00	142.5	0.40	0.35	2.98	5.72	146.6	0.40	0.35	2.71	5.45	151.1
0.35	0.35	3.34	5.94	137.0	0.35	0.35	3.06	5.67	141.1	0.35	0.35	2.78	5.39	145.4
0.30	0.35	3.41	5.88	131.4	0.30	0.35	3.13	5.60	135.4	0.30	0.35	2.85	5.33	139.6
0.25	0.35	3.50	5.82	125.6	0.25	0.35	3.22	5.54	129.5	0.25	0.35	2.93	5.26	133.6
0.55	0.30	2.82	5.94	162.0	0.55	0.30	2.59	5.69	166.0	0.55	0.30	2.37	5.45	170.3
0.50	0.30	2.88	5.88	156.8	0.50	0.30	2.65	5.64	160.7	0.50	0.30	2.43	5.40	164.9
0.45	0.30	2.95	5.82	151.5	0.45	0.30	2.72	5.58	155.3	0.45	0.30	2.49	5.34	159.4
0.40	0.30	3.02	5.77	146.0	0.40	0.30	2.78	5.53	149.8	0.40	0.30	2.56	5.29	153.7
0.35	0.30	3.09	5.71	140.5	0.35	0.30	2.86	5.47	144.1	0.35	0.30	2.62	5.23	148.0
0.30	0.30	3.17	5.64	134.8	0.30	0.30	2.93	5.41	138.3	0.30	0.30	2.69	5.17	142.1
0.25	0.30	3.25	5.58	128.9	0.25	0.30	3.01	5.34	132.4	0.25	0.30	2.77	5.11	136.0

Table 6. Sample results of energy differences per window area (kWh/ft^2) for 0.05 reduction in U-factor in new large offices in Seattle with a lighting power density of 1.0 W/ft^2 $^-$(CoolE = Chiller + Tower and AuxE = Fan + Pump)

	Base U-factor = 0.55				Base U-factor = 0.50				Base U-factor = 0.45			
Drape = 0.90					Drape = 0.90				Drape = 0.90			
SHGC	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec
0.60	0.049	-0.024	-0.721	-0.696	0.047	-0.023	-0.710	-0.685	0.045	-0.020	-0.692	-0.667
0.55	0.051	-0.028	-0.733	-0.710	0.051	-0.022	-0.721	-0.692	0.045	-0.021	-0.704	-0.680
0.50	0.048	-0.027	-0.746	-0.725	0.053	-0.019	-0.729	-0.695	0.050	-0.018	-0.714	-0.682
0.45	0.046	-0.028	-0.753	-0.735	0.049	-0.021	-0.748	-0.720	0.051	-0.019	-0.723	-0.691
0.40	0.042	-0.029	-0.775	-0.761	0.048	-0.023	-0.756	-0.731	0.059	-0.007	-0.737	-0.686
0.35	0.048	-0.023	-0.792	-0.766	0.048	-0.013	-0.770	-0.735	0.059	-0.005	-0.746	-0.693
0.30	0.054	-0.023	-0.811	-0.780	0.052	-0.018	-0.791	-0.758	0.052	-0.013	-0.773	-0.734
Drape= 0.75					Drape= 0.75				Drape= 0.75			
SHGC	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec
0.60	0.048	-0.024	-0.746	-0.721	0.053	-0.019	-0.729	-0.695	0.050	-0.018	-0.714	-0.682
0.55	0.046	-0.024	-0.751	-0.730	0.050	-0.020	-0.745	-0.715	0.050	-0.019	-0.721	-0.690
0.50	0.042	-0.028	-0.769	-0.755	0.048	-0.022	-0.752	-0.726	0.053	-0.018	-0.736	-0.700
0.45	0.047	-0.027	-0.787	-0.766	0.051	-0.012	-0.759	-0.719	0.057	-0.004	-0.739	-0.686
0.40	0.051	-0.018	-0.797	-0.764	0.052	-0.014	-0.778	-0.741	0.054	-0.009	-0.754	-0.709
0.35	0.057	-0.020	-0.817	-0.780	0.049	-0.020	-0.794	-0.764	0.054	-0.013	-0.778	-0.737
0.30	0.053	-0.021	-0.836	-0.804	0.058	-0.018	-0.813	-0.773	0.055	-0.017	-0.797	-0.758
Drape = 0.60					Drape = 0.60				Drape = 0.60			
SHGC	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec
0.60	0.042	-0.028	-0.775	-0.761	0.048	-0.023	-0.756	-0.731	0.059	-0.007	-0.737	-0.686
0.55	0.048	-0.025	-0.788	-0.765	0.050	-0.010	-0.761	-0.721	0.060	-0.003	-0.740	-0.684
0.50	0.051	-0.018	-0.797	-0.764	0.052	-0.014	-0.778	-0.741	0.054	-0.009	-0.754	-0.709
0.45	0.054	-0.020	-0.811	-0.778	0.052	-0.018	-0.791	-0.758	0.052	-0.013	-0.773	-0.734
0.40	0.054	-0.020	-0.827	-0.793	0.056	-0.019	-0.805	-0.768	0.057	-0.015	-0.789	-0.747
0.35	0.049	-0.023	-0.844	-0.818	0.057	-0.019	-0.821	-0.783	0.059	-0.015	-0.801	-0.757
0.30	0.052	-0.025	-0.864	-0.837	0.051	-0.019	-0.835	-0.802	0.058	-0.013	-0.815	-0.770
	Base U-factor = 0.40				Base U-factor = 0.35				Base U-factor = 0.30			
Drape=0.9					Drape = 0.90				Drape = 0.90			
SHGC	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec
0.60	0.046	-0.013	-0.670	-0.637	0.042	-0.008	-0.633	-0.598	0.037	-0.001	-0.601	-0.564
0.55	0.046	-0.013	-0.677	-0.645	0.048	-0.006	-0.643	-0.601	0.034	-0.004	-0.605	-0.575
0.50	0.041	-0.017	-0.690	-0.665	0.039	-0.011	-0.652	-0.624	0.040	-0.004	-0.618	-0.582
0.45	0.046	-0.016	-0.702	-0.673	0.046	-0.004	-0.660	-0.618	0.048	0.010	-0.621	-0.563
0.40	0.050	-0.003	-0.707	-0.660	0.044	-0.001	-0.670	-0.627	0.044	0.007	-0.635	-0.584
0.35	0.052	-0.004	-0.728	-0.680	0.047	-0.001	-0.690	-0.644	0.042	0.004	-0.650	-0.604
0.30	0.057	-0.006	-0.748	-0.696	0.046	-0.006	-0.716	-0.676	0.043	0.001	-0.669	-0.625
Drape= 0.75					Drape= 0.75				Drape = 0.75			
SHGC	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec
0.60	0.041	-0.017	-0.690	-0.665	0.039	-0.011	-0.652	-0.624	0.040	-0.004	-0.618	-0.582
0.55	0.045	-0.016	-0.700	-0.672	0.044	-0.009	-0.659	-0.625	0.049	0.011	-0.621	-0.561
0.50	0.052	-0.003	-0.702	-0.653	0.042	-0.001	-0.668	-0.626	0.048	0.009	-0.628	-0.571
0.45	0.050	-0.004	-0.717	-0.671	0.046	-0.001	-0.680	-0.635	0.043	0.005	-0.642	-0.594
0.40	0.056	-0.005	-0.736	-0.685	0.040	-0.009	-0.701	-0.669	0.041	0.002	-0.655	-0.613
0.35	0.056	-0.007	-0.753	-0.704	0.049	-0.004	-0.719	-0.674	0.042	0.001	-0.672	-0.629
0.30	0.057	-0.009	-0.768	-0.720	0.048	-0.007	-0.742	-0.700	0.048	0.000	-0.694	-0.646
Drape = 0.60					Drape = 0.60				Drape = 0.60			
SHGC	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec
0.60	0.050	-0.003	-0.707	-0.660	0.044	-0.001	-0.670	-0.627	0.044	0.007	-0.635	-0.584
0.55	0.050	-0.004	-0.722	-0.676	0.045	-0.001	-0.683	-0.639	0.043	0.005	-0.645	-0.597
0.50	0.056	-0.005	-0.736	-0.685	0.040	-0.009	-0.701	-0.669	0.041	0.002	-0.655	-0.613
0.45	0.057	-0.006	-0.748	-0.696	0.046	-0.006	-0.716	-0.676	0.043	0.001	-0.669	-0.625
0.40	0.054	-0.011	-0.764	-0.721	0.051	-0.003	-0.731	-0.683	0.044	0.000	-0.685	-0.641
0.35	0.059	-0.009	-0.776	-0.727	0.049	-0.007	-0.750	-0.707	0.049	0.000	-0.703	-0.655
0.30	0.065	-0.007	-0.793	-0.735	0.047	-0.007	-0.767	-0.728	0.046	-0.001	-0.721	-0.675

Table 7. Sample results of energy differences per window area (kWh/ft^2) for 0.05 reduction in SHGC in new large offices in Seattle with a lighting power density of 1.0 W/ft^2 - (CoolE = Chiller + Tower and AuxE = Fan + Pump)

	Base SHGC = 0.6				Base SHGC = 0.55				Base SHGC = 0.50			
Drape = 0.90					Drape = 0.90				Drape = 0.90			
U-factor	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec
0.55	-0.265	-0.551	0.018	-0.798	-0.264	-0.548	0.025	-0.787	-0.289	-0.548	0.037	-0.799
0.50	-0.263	-0.550	0.005	-0.808	-0.267	-0.549	0.013	-0.803	-0.291	-0.549	0.030	-0.810
0.45	-0.260	-0.549	-0.006	-0.815	-0.264	-0.546	0.004	-0.806	-0.296	-0.551	0.011	-0.835
0.40	-0.260	-0.551	-0.017	-0.828	-0.259	-0.543	-0.006	-0.808	-0.295	-0.551	0.002	-0.844
0.35	-0.261	-0.551	-0.025	-0.836	-0.263	-0.546	-0.019	-0.828	-0.290	-0.551	-0.011	-0.852
0.30	-0.255	-0.549	-0.035	-0.839	-0.273	-0.551	-0.028	-0.852	-0.284	-0.544	-0.019	-0.847
0.25	-0.258	-0.552	-0.040	-0.849	-0.267	-0.552	-0.041	-0.859	-0.275	-0.530	-0.022	-0.828
Drape = 0.75					Drape = 0.75				Drape = 0.75			
U-factor	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec
0.55	-0.241	-0.457	0.029	-0.668	-0.239	-0.453	0.046	-0.647	-0.247	-0.455	0.060	-0.642
0.50	-0.243	-0.458	0.024	-0.677	-0.244	-0.457	0.028	-0.672	-0.241	-0.454	0.042	-0.653
0.45	-0.246	-0.459	0.008	-0.697	-0.245	-0.459	0.021	-0.683	-0.238	-0.444	0.035	-0.647
0.40	-0.246	-0.460	0.001	-0.705	-0.242	-0.457	0.007	-0.693	-0.234	-0.431	0.032	-0.633
0.35	-0.242	-0.460	-0.010	-0.712	-0.236	-0.444	0.005	-0.675	-0.236	-0.432	0.017	-0.651
0.30	-0.237	-0.458	-0.017	-0.712	-0.237	-0.435	-0.004	-0.676	-1.679	-0.432	0.005	-2.106
0.25	-0.228	-0.443	-0.020	-0.690	-0.239	-0.437	-0.011	-0.687	-0.238	-0.436	-0.009	-0.683
Drape = 0.60					Drape = 0.55				Drape = 0.50			
U-factor	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec
0.55	-0.197	-0.363	0.052	-0.508	-0.187	-0.333	0.081	-0.438	-0.187	-0.313	0.101	-0.399
0.50	-0.191	-0.360	0.039	-0.512	-0.184	-0.326	0.073	-0.437	-0.184	-0.316	0.086	-0.414
0.45	-0.189	-0.348	0.034	-0.503	-0.183	-0.329	0.055	-0.457	-0.184	-0.319	0.073	-0.431
0.40	-0.188	-0.344	0.031	-0.501	-0.189	-0.335	0.042	-0.483	-0.186	-0.322	0.054	-0.455
0.35	-0.188	-0.345	0.017	-0.517	-0.183	-0.336	0.027	-0.492	-0.185	-0.323	0.042	-0.466
0.30	-0.187	-0.346	0.004	-0.528	-0.188	-0.344	0.009	-0.523	-0.179	-0.320	0.027	-0.473
0.25	-0.188	-0.347	-0.006	-0.542	-0.190	-0.347	-0.002	-0.538	-0.177	-0.321	0.013	-0.485

	Base SHGC = 0.45				Base SHGC = 0.40				Base SHGC = 0.35			
Drape=0.90					Drape = 0.90				Drape = 0.90			
U-factor	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec
0.55	-0.289	-0.544	0.059	-0.775	-0.290	-0.537	0.088	-0.739	-0.281	-0.473	0.147	-0.607
0.50	-0.293	-0.548	0.037	-0.804	-0.284	-0.529	0.071	-0.742	-0.276	-0.473	0.127	-0.621
0.45	-0.294	-0.550	0.029	-0.814	-0.285	-0.519	0.057	-0.747	-0.272	-0.478	0.105	-0.644
0.40	-0.286	-0.538	0.016	-0.808	-0.284	-0.517	0.047	-0.754	-0.279	-0.485	0.079	-0.685
0.35	-0.282	-0.525	0.011	-0.796	-0.283	-0.518	0.027	-0.774	-0.273	-0.487	0.059	-0.701
0.30	-0.283	-0.521	0.001	-0.804	-0.280	-0.518	0.007	-0.791	-0.274	-0.492	0.033	-0.733
0.25	-0.287	-0.525	-0.013	-0.825	-0.282	-0.521	-0.008	-0.812	-0.273	-0.494	0.013	-0.753
Drape=0.75					Drape = 0.75				Drape = 0.75			
U-factor	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec
0.55	-0.236	-0.423	0.095	-0.564	-0.235	-0.391	0.129	-0.497	-0.234	-0.387	0.148	-0.474
0.50	-0.232	-0.414	0.085	-0.561	-0.229	-0.393	0.109	-0.514	-0.238	-0.388	0.129	-0.498
0.45	-0.232	-0.416	0.065	-0.583	-0.232	-0.399	0.093	-0.538	-0.229	-0.387	0.110	-0.506
0.40	-0.235	-0.421	0.050	-0.606	-0.232	-0.402	0.069	-0.565	-0.228	-0.390	0.091	-0.527
0.35	-0.229	-0.422	0.031	-0.620	-0.232	-0.404	0.053	-0.583	-0.227	-0.392	0.075	-0.543
0.30	-0.234	-0.430	0.010	-0.654	-0.224	-0.400	0.035	-0.588	-0.227	-0.394	0.053	-0.569
0.25	-0.236	-0.433	-0.003	-0.672	-0.222	-0.400	0.017	-0.605	-0.222	-0.395	0.032	-0.585
Drape=0.0.45					Drape = 0.40				Drape = 0.35			
U-factor	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec	CoolE	AuxE	HtgE	Total Elec
0.55	-0.190	-0.311	0.114	-0.386	-0.185	-0.308	0.126	-0.367	-0.183	-0.304	0.138	-0.349
0.50	-0.189	-0.311	0.098	-0.401	-0.190	-0.310	0.109	-0.391	-0.181	-0.306	0.118	-0.369
0.45	-0.185	-0.312	0.084	-0.412	-0.189	-0.310	0.093	-0.406	-0.186	-0.305	0.104	-0.387
0.40	-0.180	-0.314	0.068	-0.426	-0.186	-0.310	0.081	-0.415	-0.188	-0.303	0.090	-0.401
0.35	-0.184	-0.319	0.052	-0.450	-0.181	-0.309	0.068	-0.422	-0.181	-0.301	0.073	-0.409
0.30	-0.179	-0.316	0.037	-0.458	-0.183	-0.313	0.050	-0.446	-0.183	-0.301	0.056	-0.429
0.25	-0.177	-0.317	0.021	-0.474	-0.179	-0.313	0.032	-0.460	-0.186	-0.302	0.038	-0.449

Figure 3. Changes in heating and cooling energy use per window area (kWh/ft^2) for 0.05 reduction in U-factor or SHGC in new large Office building in Seattle with a light power density of 1.0 and a drapery shading of 0.9

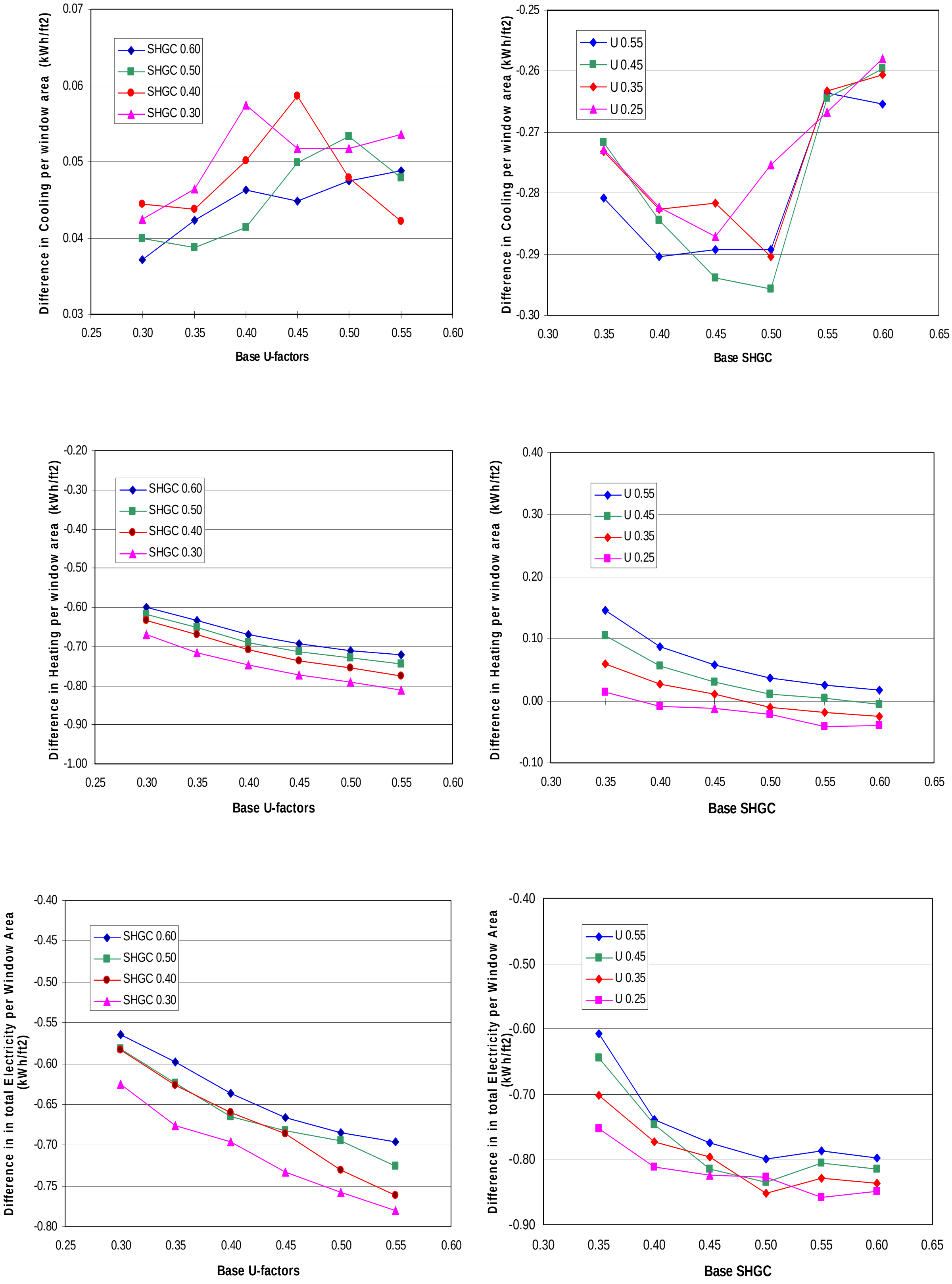


Figure 4. Changes in heating and cooling energy use per window area (kWh/ft^2) for 0.05 reduction in U-factor or SHGC in new large Office building in Seattle with a light power density of 1.0 and a drapery shading of 0.6

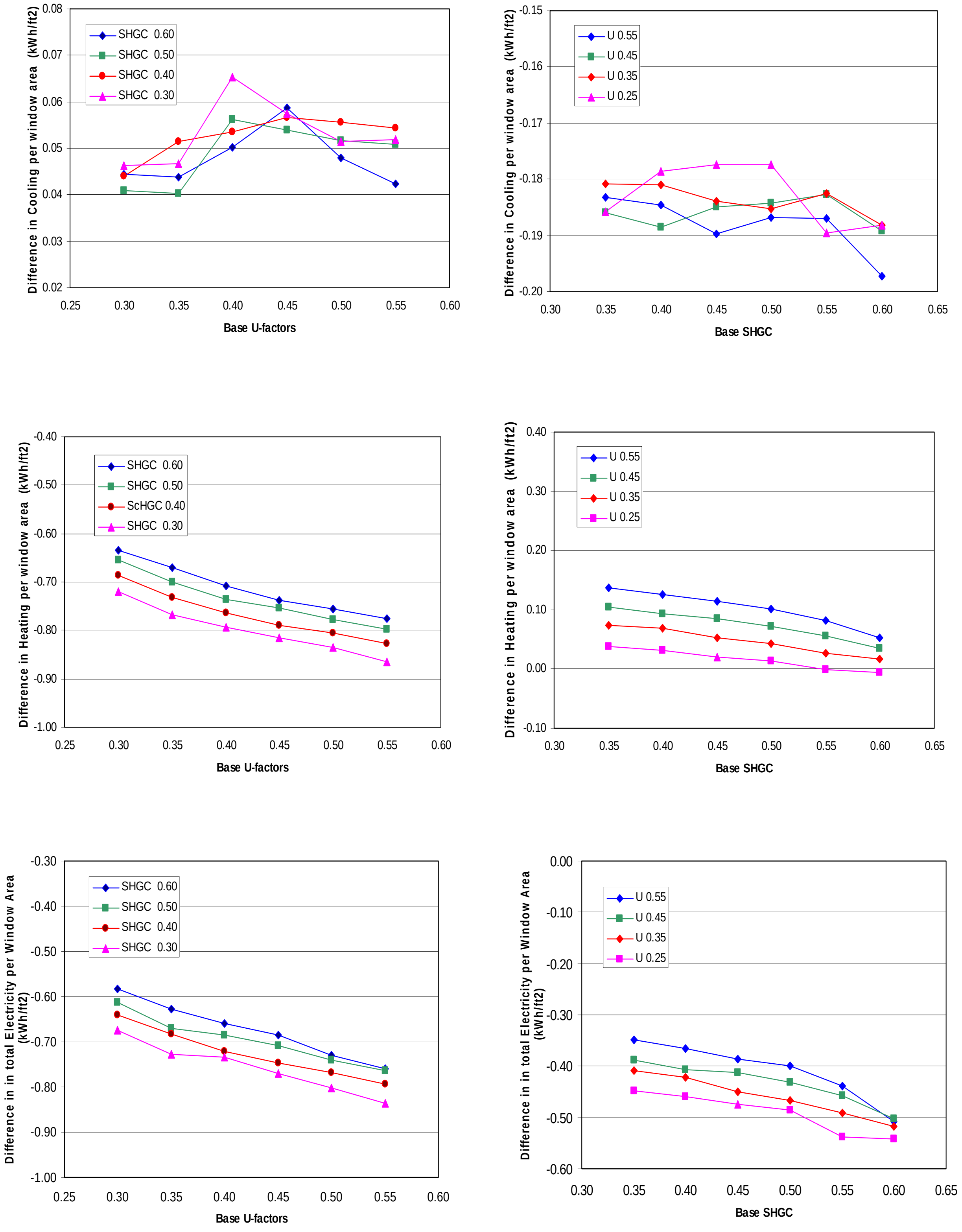


Figure 5. Changes in heating and cooling energy use per window area (kWh/ft^2) for 0.05 reduction in U-factor or SHGC in old large Office building in Seattle with a light power density of 1.0 and a drapery shading of 0.9

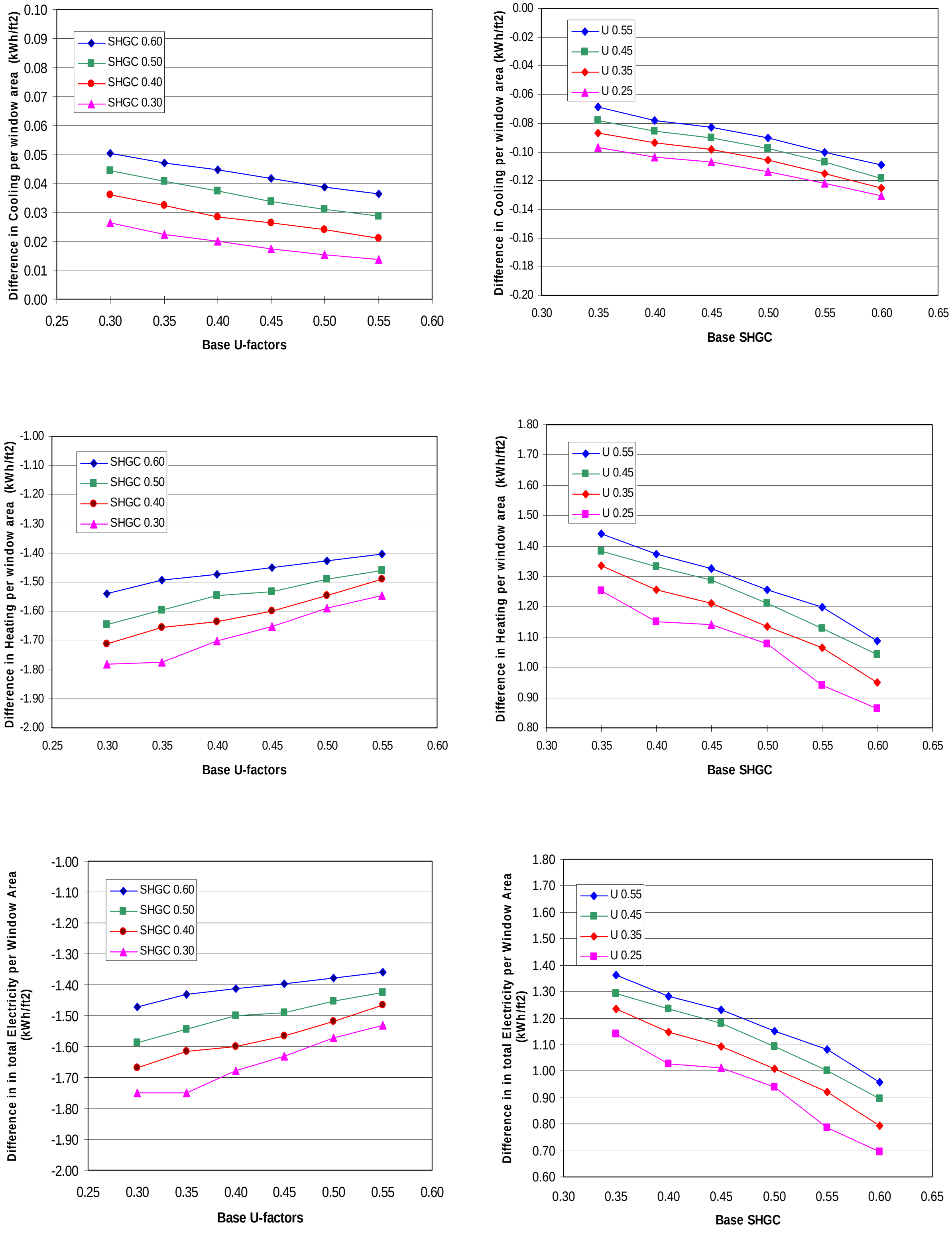


Figure 6. Changes in heating and cooling energy use per window area (kWh/ft^2) for 0.05 reduction in U-factor or SHGC in old large Office building in Seattle with a light power density of 1.0 and a drapery shading of 0.6

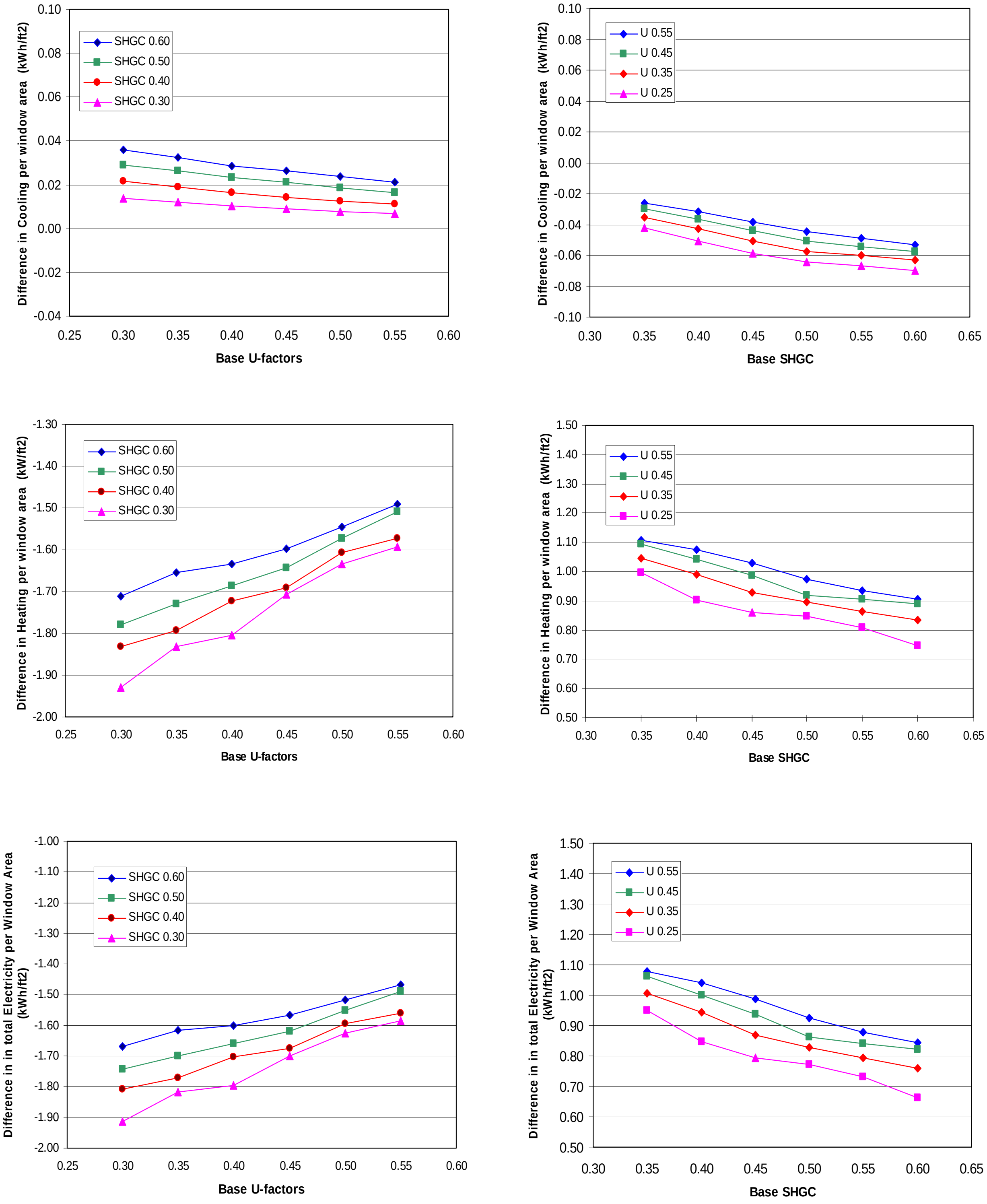


Figure 7. Changes in heating and cooling energy use per window area (kWh/ft^2) for 0.05 reduction in U-factor or SHGC in new small Office building in Seattle with a light power density of 1.0 and a drapery shading of 0.9

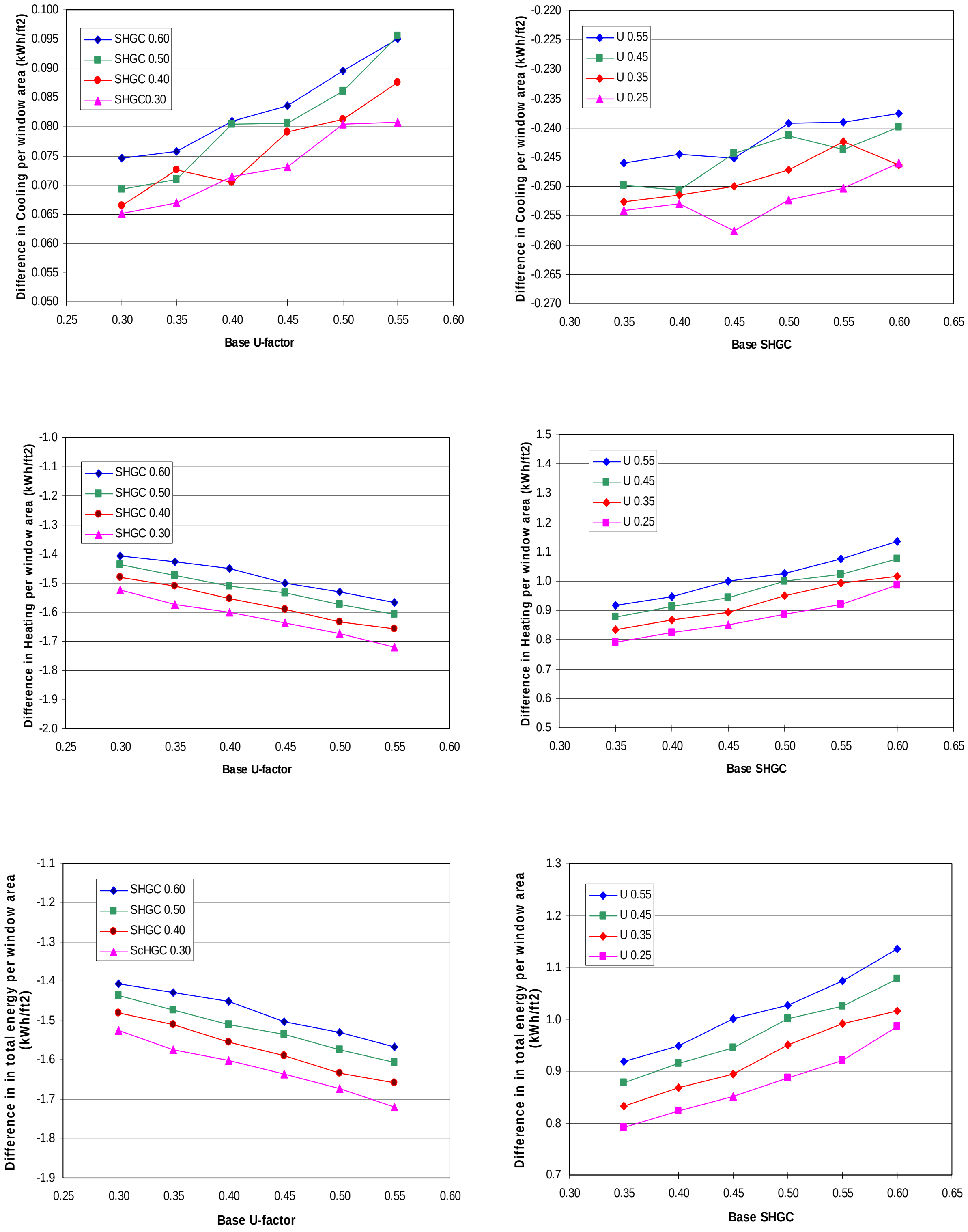


Figure 8. Changes in heating and cooling energy use per window area (kWh/ft^2) for 0.05 reduction in U-factor or SHGC in new small Office building in Seattle with a light power density of 1.0 and a drapery shading of 0.6

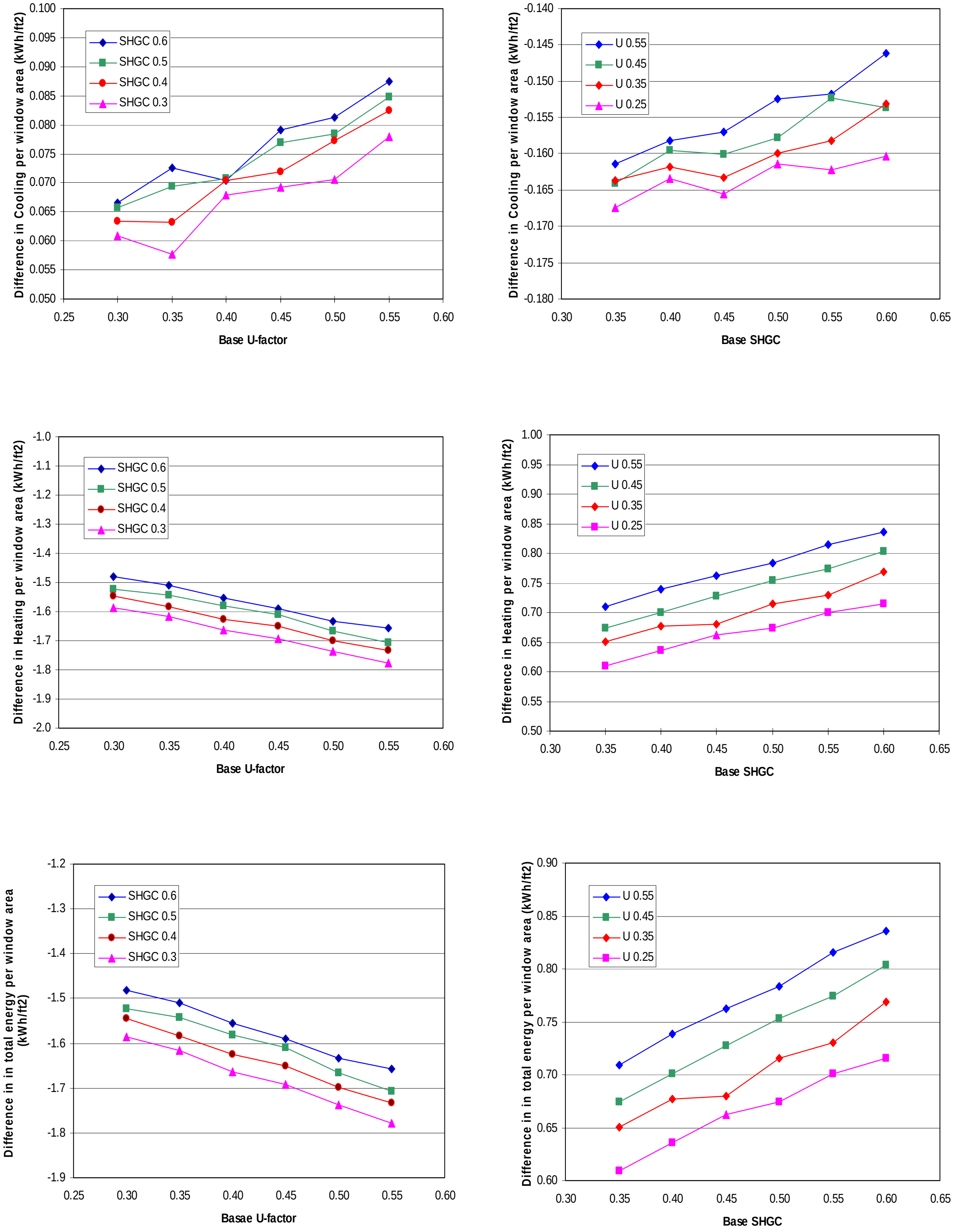


Figure 9. Changes in heating and cooling energy use per window area (kWh/ft^2) for 0.05 reduction in U-factor or SHGC in old small Office building in Seattle with a light power density of 1.0 and a drapery shading of 0.9

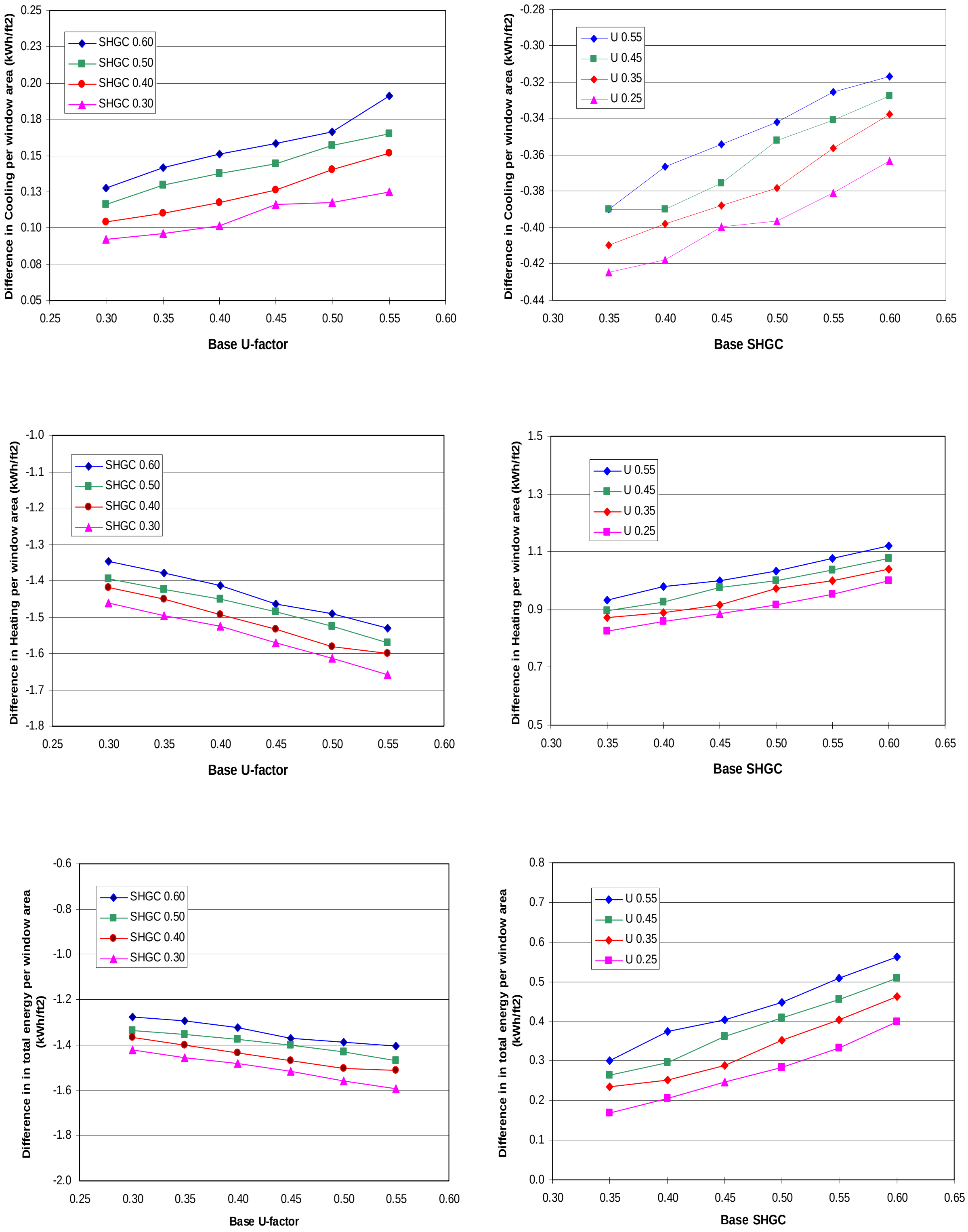
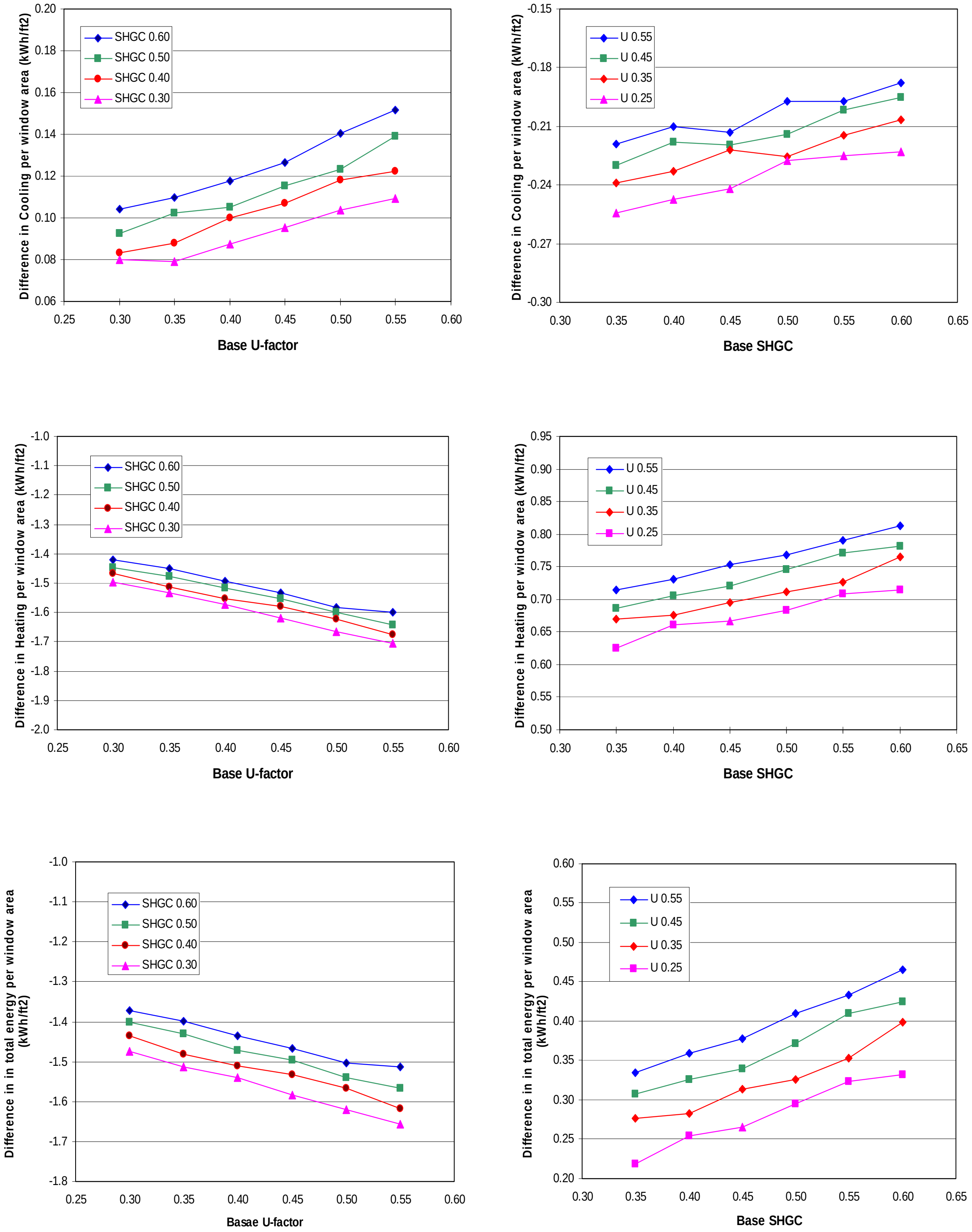


Figure 10. Changes in heating and cooling energy use per window area (kWh/ft^2) for 0.05 reduction in U-factor or SHGC in old small Office building in Seattle with a light power density of 1.0 and a drapery shading of 0.6



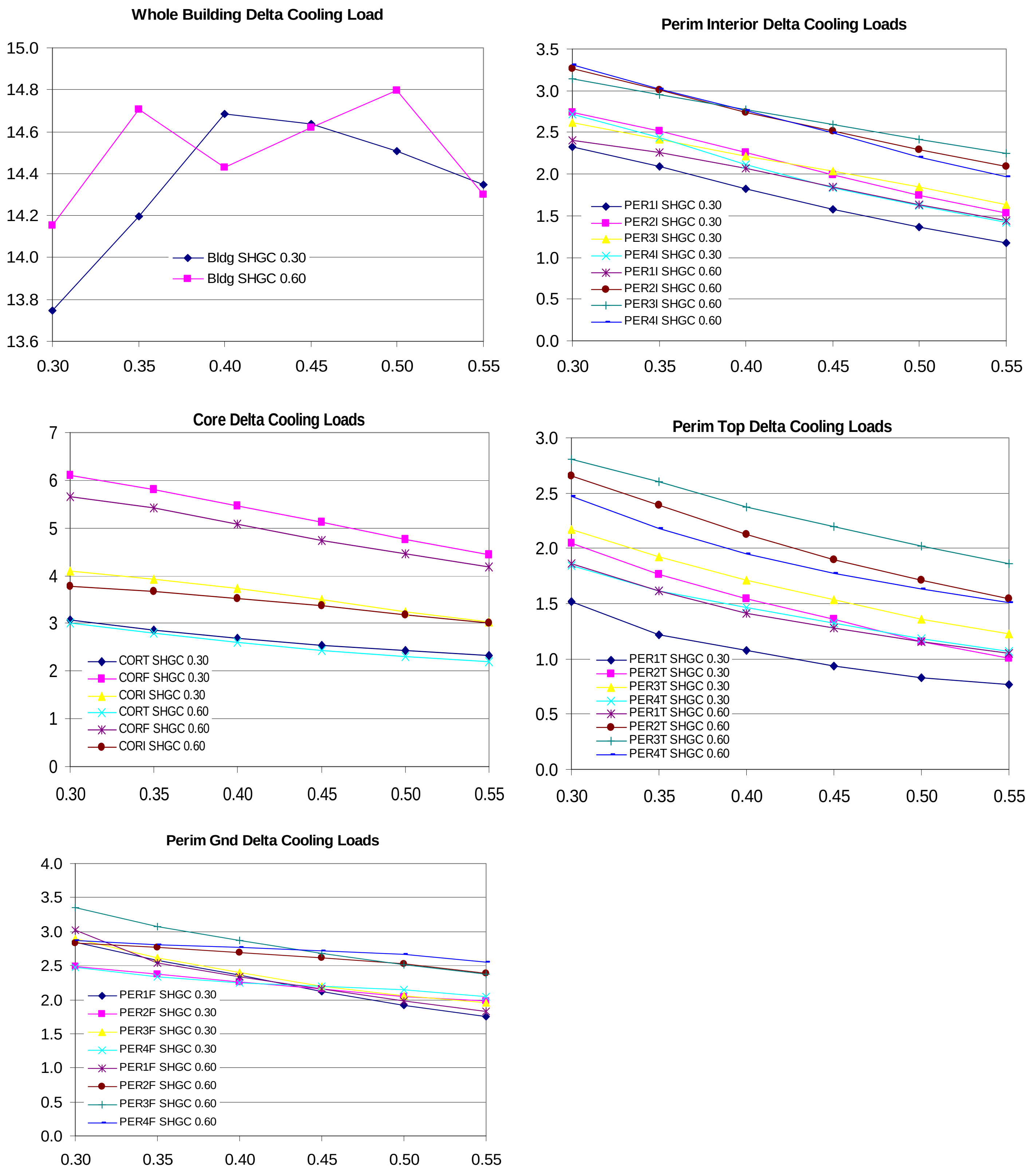


Figure 11. Change in building and zone cooling loads for changes in Window U-factor at two SHGCs (0.30 and 0.60) in new large office building in Seattle with a light power density of 1.0 and a drapery shading of 0.90.

Conclusions

The main objective of this simulation effort is to provide NEEA with the energy savings or penalties for changes in window U-factor or SHGC. Although the spreadsheets can be used as look-up tables given a specified location, building type, lighting power density, window shading condition, etc., this would be tedious and overly precise, especially in light of the cooling anomalies just mentioned.

Rather than using the specific values from the spreadsheet, it is preferable to use, instead, the general trends obtained by regression analysis of all the window parametrics for eachbuilding type, vintage, and location. Although some of the plots in Figures 2 to 9 show slight curvatures, we decided to keep the analysis simple and do multi-linear regressions using the following equation:

$$\Delta \text{ heating or cooling energy} = a_1\text{*LPD} + a_2\text{*DS} + a_3\text{*U-factor} + a_4\text{*SHGC} + a_5 \quad \text{[Eqn 2]}$$

where heating energy = heating electricity use
cooling energy = electricity consumption for chiller and cooling tower
LPD = Lighting Power Density
DS = Drapery Shading Coefficient
a_1, a_2, a_3, a_4, a_5 = regression coefficients

The resultant regression coefficients, t statistics and R^2's (an indication of the goodness of fit) are shown in Table 8.

Table 8. Regression coefficients for Δ heating and Δ cooling energies

	Regression Coefficients and t-statistics										R2
	a_1		a_2		a_3		a_4		a_5		
	coeff	t-stat	coeff	t-stat	coeff	t-stat	coeff	t-stat	coeff	t-stat	
Seattle Large Office Old											
Δ Heating	0.594	45.25	0.878	57.03	0.358	33.37	0.268	33.33	-2.796	-193.00	0.953
Δ Cooling	0.070	92.34	-0.052	-58.00	0.042	67.11	0.032	68.90	-0.047	-56.60	0.983
Seattle Large Office New											
Δ Heating	0.287	31.32	-0.615	-57.30	0.167	22.23	0.030	5.27	-0.756	-75.00	0.928
Δ Cooling	0.028	9.60	0.044	12.67	-0.016	-6.51	-0.094	-52.10	0.148	45.73	0.890
Seattle Small Office Old											
Δ Heating	0.335	76.40	0.772	150.20	0.200	55.88	0.121	44.91	-2.274	-471.00	0.989
Δ Cooling	0.135	53.72	-0.177	-60.00	0.081	39.52	0.055	35.43	0.020	7.19	0.961
Seattle Small Office New											
Δ Heating	0.415	91.41	0.732	137.60	0.248	66.78	0.177	63.65	-2.447	-489.00	0.990
Δ Cooling	0.033	34.80	-0.079	-71.30	0.020	25.47	0.016	27.75	0.063	60.44	0.954
Boise Large Office Old											
Δ Heating	0.459	42.75	1.115	88.78	0.277	31.58	0.184	28.04	-2.878	-244.00	0.970
Δ Cooling	0.076	79.60	-0.058	-51.90	0.046	58.41	0.030	50.85	-0.041	-38.90	0.976
Boise Large Office New											
Δ Heating	0.556	55.04	-0.622	-52.80	0.326	39.36	0.137	22.20	-1.306	-118.00	0.955
Δ Cooling	0.056	14.90	0.009	1.96	-0.031	-10.10	-0.054	-23.40	0.094	22.77	0.701
Boise Small Office Old											
Δ Heating	0.251	39.93	0.988	134.30	0.155	30.28	0.054	13.92	-2.481	-359.00	0.982
Δ Cooling	0.072	25.82	-0.111	-34.10	0.044	19.25	0.032	18.99	0.030	9.68	0.873
Boise Small Office New											
Δ Heating	0.424	34.85	1.000	70.24	0.260	26.24	0.108	14.49	-2.801	-209.00	0.949
Δ Cooling	0.022	15.47	-0.061	-37.40	0.013	11.46	0.013	15.49	0.042	27.85	0.844

Figures 12-19 compares the predicted versus calculated changes in heating and cooling energies for the *New* vintage large office and small office in Seattle and Boise. Although there is some scatter, as expected due to the anomalous curves, the overall relationship between predicted and calculated is quite strong and shows no bias. Therefore, it is recommended that NEEA use the following coefficients on Table 8 for Equation 2 to estimate the changes in heating and cooling energy due to changes in window U-factor or SHGC.

Figure 12. Comparison of predicted vs calculated Δcooling energy for a large office in Seattle

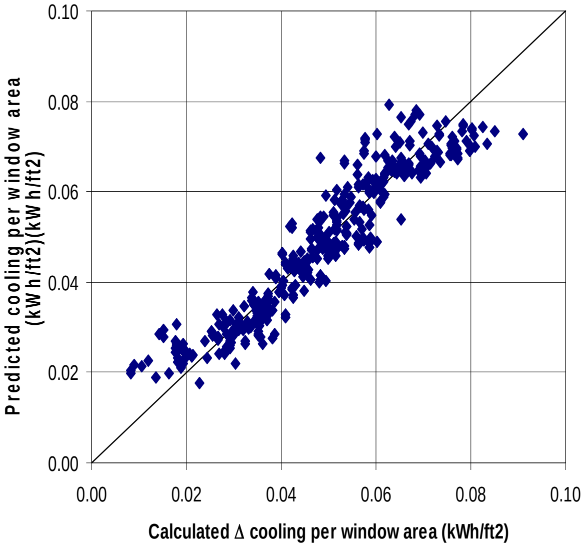


Figure 13. Comparison of predicted vs calculated Δheating energy for a large office in Seattle

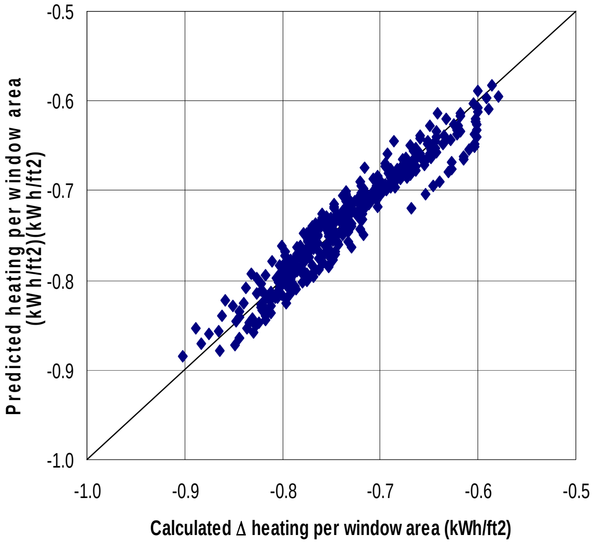


Figure 14. Comparison of predicted vs calculated Δcooling energy for a large office in Boise

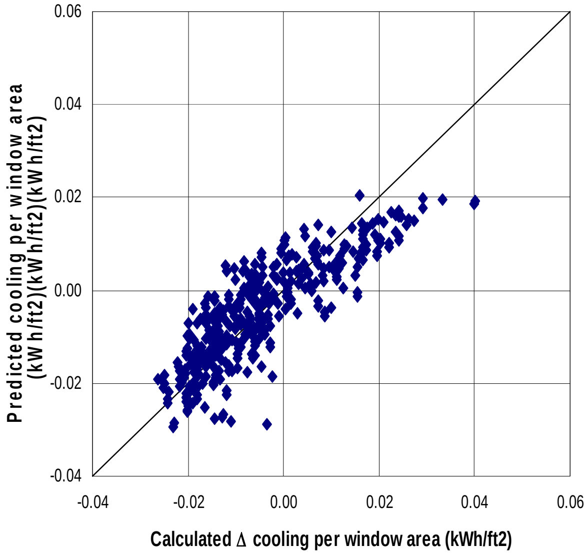


Figure 15. Comparison of predicted vs calculated Δheating energy for a large office in Boise

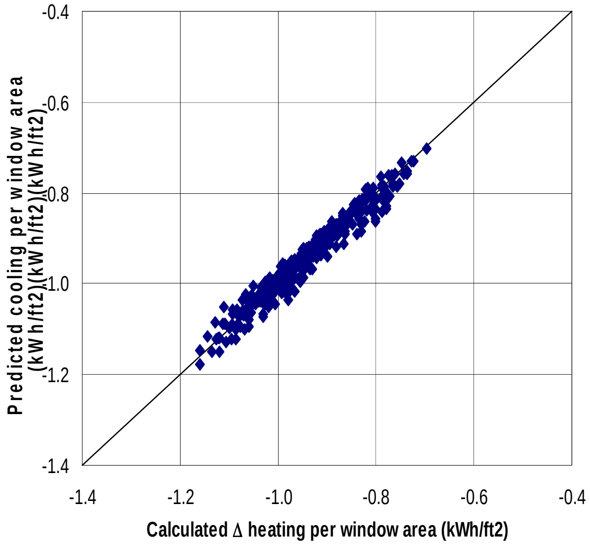


Figure 16. Comparison of predicted vs calculated Δcooling energy for a small office in Seattle

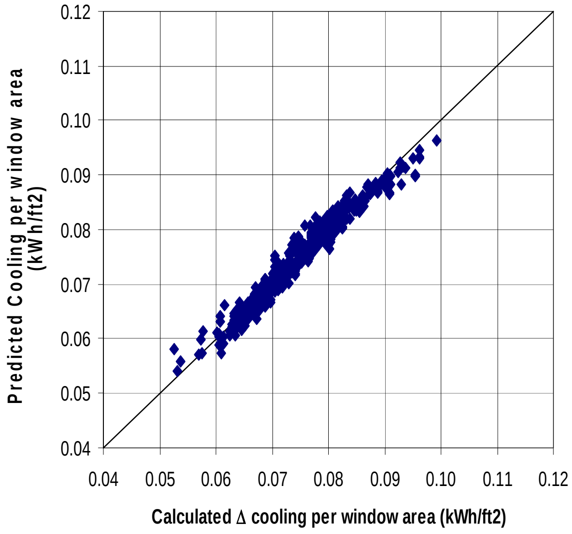


Figure 17. Comparison of predicted vs calculated Δheating energy for a small office in Seattle

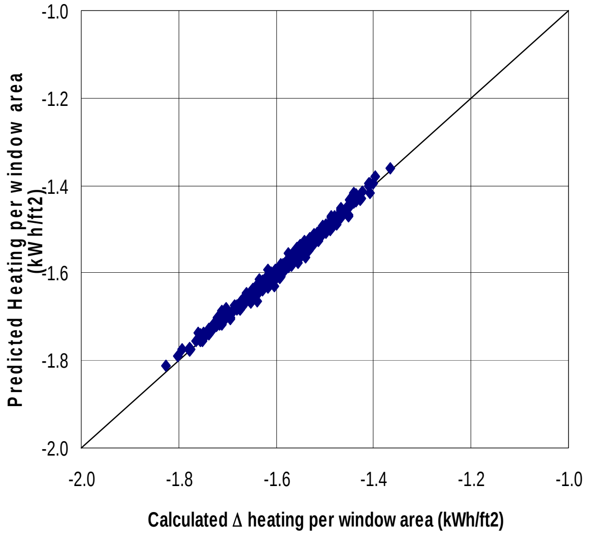


Figure 18. Comparison of predicted vs calculated Δcooling energy for a small office in Boise

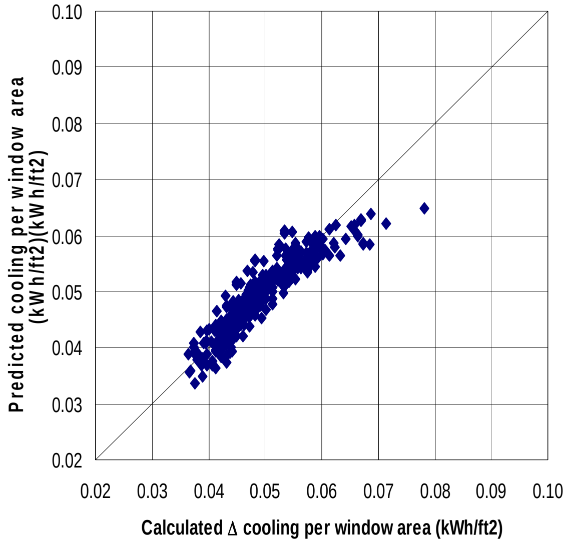
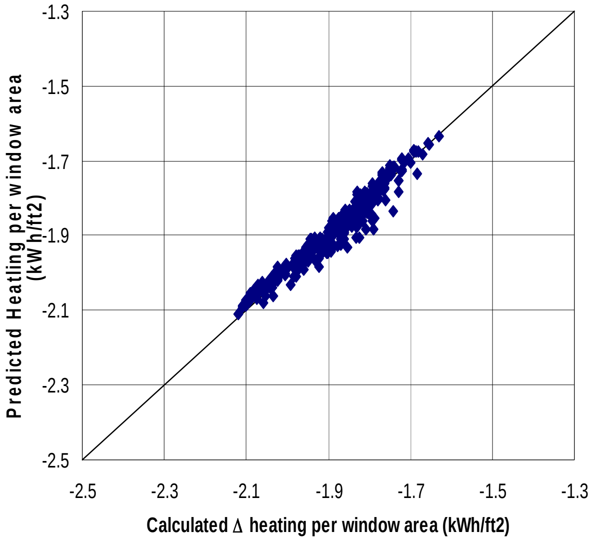


Figure 19. Comparison of predicted vs calculated Δheating energy for a small office in Boise



Figures 20 and 21 repeat the top left plots of Figures 3 and 5, except using the regression equations to estimate the changes in cooling energies for different window U-factors. These show that the equations basically smooth out the anomalous curves in the individual runs.

Figure 20. Comparison of predicted and calculated changes in cooling energy use per window area (kWh/ft^2) for 0.05 reduction in U-factor or SHGC in *New* Large Office building in Seattle with a light power density of 1.0 and a drapery shading of 0.9

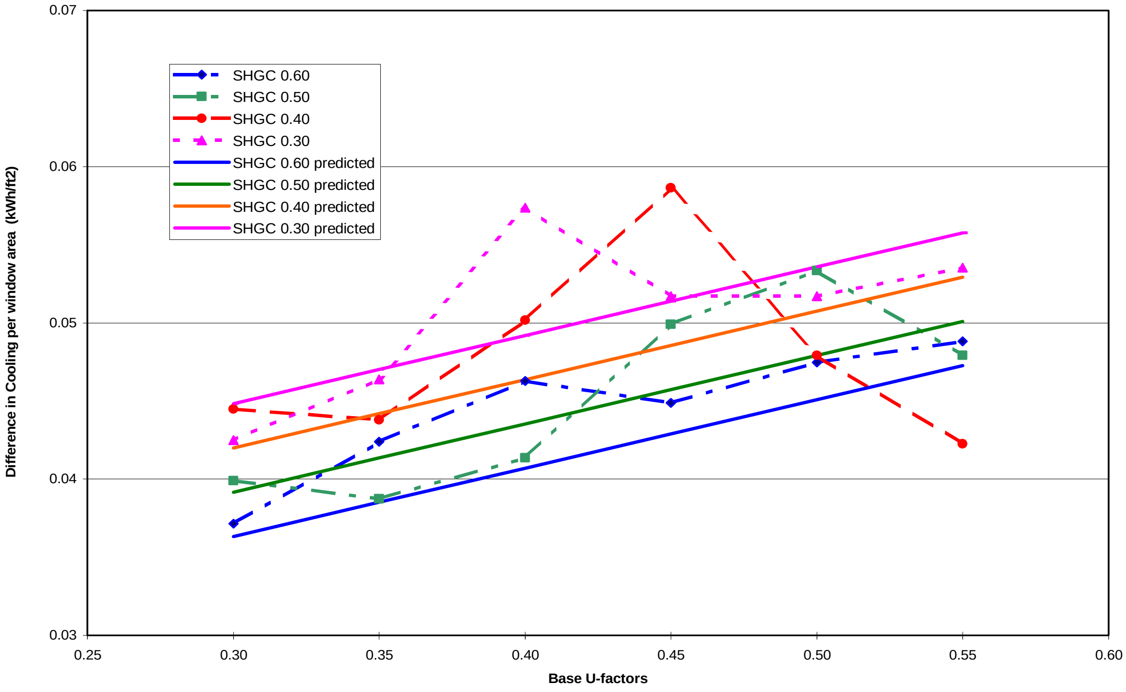
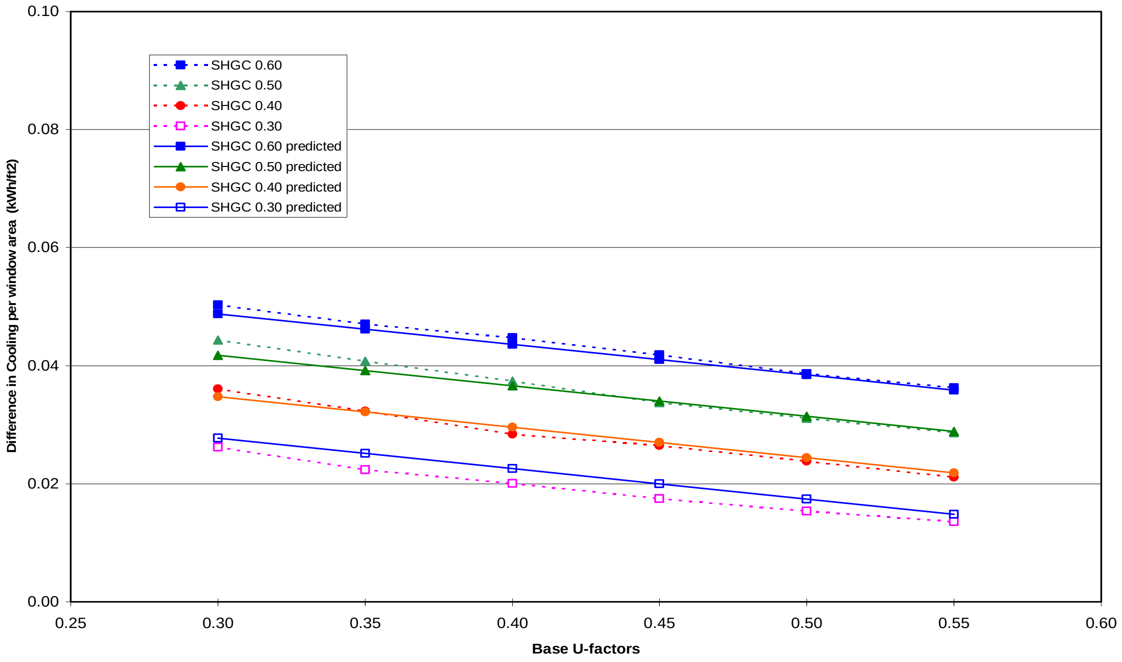


Figure 21. Comparison of predicted and calculated changes in cooling energy use per window area (kWh/ft^2) for 0.05 reduction in U-factor or SHGC in *Old* Large Office building in Seattle with a light power density of 1.0 and a drapery shading of 0.9



Discussion

Comparison of savings estimates to those from previous LBNL analysis. It is difficult to compare the results of this study directly with those from previous LBNL studies because the simulations did not include Seattle or Boise, nor were parametric analysis done for windows. To see what impact the modeling changes for this project have on the results, eight test simulations were done with the original unaltered LBNL large and small office prototypes from 2000 for two vintages *(New* and *Old)* and the two extremes of window thermal integrity (U-factor 0.55 and SHGC 0.60, and U-factor 0.25 and SHGC 0.30). As described in previous sections, the major modeling changes are: (a) envelope conditions set to current building energy standards for the Northwest, (b) lower lighting and equipment densities, (c) addition of a Drapery Shading Coefficient, (d) PIU instead of PVAV system for the *New* vintage, and PVAVS instead of RHFS (Reheat Fan) system for the *Old* vintage, and (e) COOL-CONTROL WARMEST for the *New* vintage large office building, and fixed HVAC size for the *Old* vintage, instead of autosized systems.

The results for total building energy use, normalized to kBtu/ft^2 of floor area, and for window energy savings from the two window conditions, normalized to kBtu/ft^2 of window area, are shown in Table 9 and plotted in Figures 22 and 23.

Table 9. Comparison of simulated energy use and window energy savings between original LBNL (2000) and modified NEEA (2005) prototypes

Vint	LPD	U	SHGC	Drapes	total Elec (kWh)	Δ Elec (kWh/ft^2 window)	total Gas (MBtu)	Δ Gas (kBtu/ft^2 window)	Energy* (kBtu/ft^2 flrarea)	Δ Energy* (kBtu/ft^2 window)
Original LBNL large office prototype in Seattle (2000)										
new	1.30	0.25	0.30	1.00	1632586		1635.5		134.0	
new	1.30	0.55	0.60	1.00	1730822	4.91	2819.3	59.2	149.9	109.5
old	1.80	0.25	0.30	1.00	1857145		2468.8		208.6	
old	1.80	0.55	0.60	1.00	2105933	14.35	4121.1	95.3	249.4	242.3
Original LBNL small office prototype in Seattle (2000)										
new	1.70	0.25	0.30	1.00	61378		112.1		111.2	
new	1.80	0.55	0.60	1.00	63595	3.88	117.7	9.8	115.4	49.5
old	2.20	0.25	0.30	1.00	67122		99.9		137.5	
old	2.20	0.55	0.60	1.00	70867	5.30	107.4	10.6	145.5	64.9
Modified NEEA large office prototype in Seattle (2005)										
new	1.20	0.25	0.30	0.90	1513232		244.1		114.9	
new	1.20	0.55	0.60	0.90	1633334	7.66	244.1	0.0	123.9	78.5
old	1.20	0.25	0.60	0.90	1368386		155.6		137.5	
old	1.20	0.55	0.60	0.90	1476314	7.94	155.6	0.0	148.3	81.3
Modified NEEA small office prototype in Seattle (2005)										
new	1.20	0.25	0.30	0.90	49803		119.9		98.4	
new	1.20	0.55	0.60	0.90	52611	3.04	132.6	13.8	104.9	44.9
old	1.20	0.25	0.30	0.90	45487		137.5		109.7	
old	1.20	0.55	0.60	0.90	48511	3.04	148.0	10.5	117.2	41.6

* fuel multiplier of 3 used when converting electricity to fuel

Figure 22. Comparison of total building energy use between LBNL 2000 and NEEA 2005 prototypical large and small offices in Seattle

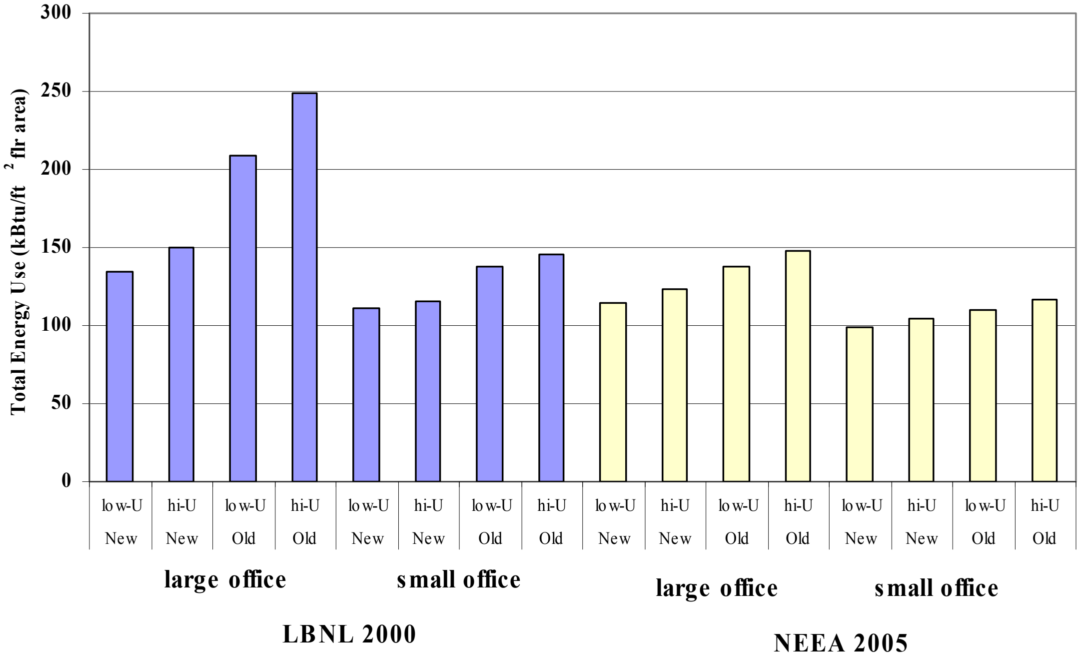


Figure 23. Comparison of energy savings between U 0.55/SHGC 0.60 and U 0.25 /SHGC 0.30 windows between LBNL 2000 and NEEA 2005 prototypical large and small offices in Seattle

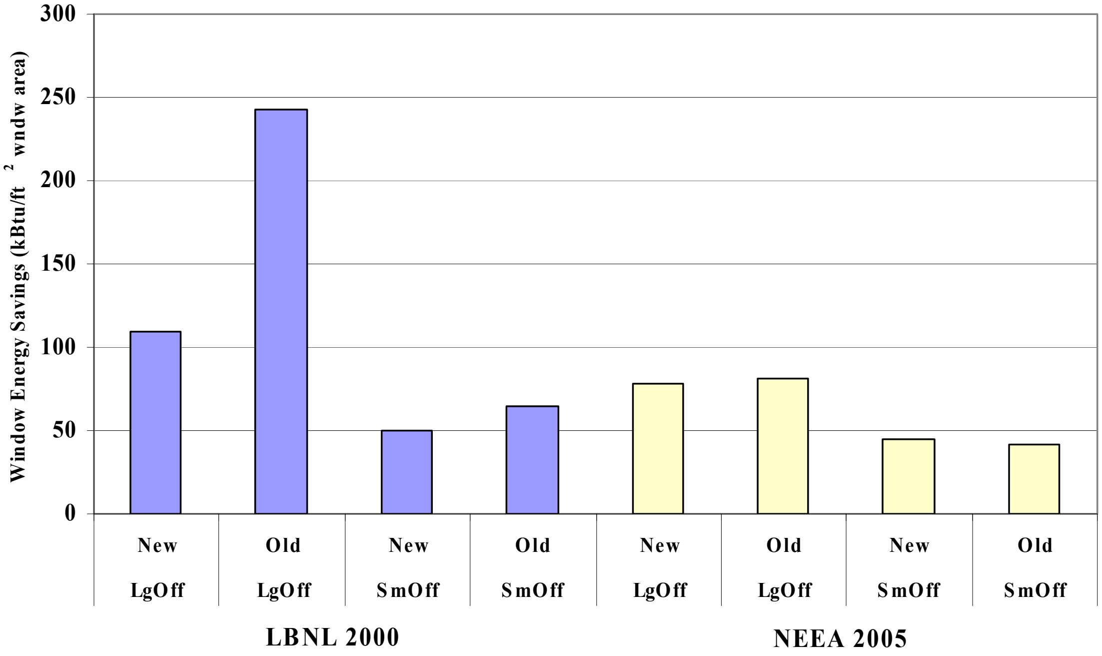


Figure 22 shows that the modified NEEA prototypes have lower energy consumptions of 85% for the *New* and 60-66% for the *Old* vintage large offices, and of 90% for the *New* and 80% for the *Old* vintage small offices, compared to the original LBNL prototypes. The main reason for the large energy difference in the *Old* vintage large offices is that different HVAC system types have been assumed (RHFS for the LBNL 2000, PVAVS for the NEEA 2005). Figure 23 shows that the calculated energy savings from changing the window properties from a U-factor of 0.55 and a SHGC of 0.60 to a U-factor of 0.25 and a SHGC of 0.30 are somewhat reduced in the *New* vintage NEEA prototypes (72% in the large office and 91% in the small office), but significantly reduced in the *Old* vintage NEEA prototypes (34% in the large office and 64% in the small office). Here, too, the main reason for the large difference in window energy savings in the *Old* vintage large office is probably due to the differing HVAC system types.

Overall, the modifications for the NEEA study can be regarded as a shift in time in defining what constitutes a *New*, and especially, an *Old* building prototype. By switching from a RHFS to a PVAVS system for the *Old* vintage large office, the NEEA study is recognizing that this system type has become the norm, even among existing buildings. The resultant calculated window energy savings are clearly reduced, especially for the *Old* vintage large offices, but represent a conservative or prudent assessment in light of the evolving condition of the building stock.

The impact of sizing and supply air temperature on building energy use and window energy savings. The amount of energy used for space conditioning, and in particular the energy savings from window measures, are highly sensitive to the sizing of the HVAC system. If the HVAC system size remains unchanged, much of the loads reduction from improved windows may not be translated into energy savings because of the performance of that HVAC system is increasingly degraded due to oversizing. Much of these negative interactions can be counteracted by changing the HVAC system control to WARMEST, i.e., varying the supply air temperature to meet the requirements of the warmest zone, and thus reducing the amount of reheating to be done. For this project, the decision is made to model the *New* vintage buildings using both auto-sizing and WARMEST control, but to model the *Old* vintage buildings with constant HVAC size and CONSTANT supply air temperature control. This modeling assumption for the *Old* vintage buildings reduces the benefits of window upgrades for the reason mentioned, but is judged more realistic because (1) it is unlikely that a HVAC system will be replaced during window replacement, and (2) WARMEST control is difficult to implement in the controls of older HVAC systems.

To investigate the impact of this modeling decision on building energy use and window energy savings, the *Old* vintage large office building has been simulated with windows at two extremes of cooling loads: (1) design condition of U-factor 0.55, SHGC 0.60, drapery shading 0.90, and lighting power density 1.2 W/ft^2. and (2) a “best case” condition with U-factor 0.25, SHGC 0.30, drapery shading 0.60, and lighting power density 0.8 W/ft^2 - in both Seattle and Boise, while switching the HVAC system size between fixed to auto-sized, and the control option between CONSTANT and WARMEST. The results are shown in Table 10. The modeling strategy for *Old* vantage buildings has been to keep the HVAC system size fixed based on the design condition, as indicated for 5 of the 6 runs for each city in Table 10 (see Column 4). Runs 1 and 2 are both at the design condition, but with the Cool Control at either CONSTANT or WARMEST. Run 3 is with the same window as in the design condition, but with lighting power density and drapery shading the same as in the best case. Runs 4 – 6 are for the "best case" with different HVAC options and controls. Run 4 is for the default condition of a fixed size HVAC system and CONSTANT Cool Control; Run 5 is for an auto-sized HVAC system with CONSTANT Cool Control; while Run 6 is for a fixed size HVAC system with WARMEST Cool Control.

Table 10. Heating and cooling energies for *Old* large office with design condition of LPD 1.2 W/ft^2 , DS 0.90, U 0.55, and SHGC 0.60, and "best case" condition of LPD 0.8 W/ft^2 DS 0.60, U 0.25, and SHGC 0.30 in Boise and Seattle with different sizing and cool-control options

								All electrical energy in kWh							
Run	Light W	Drap S	Window U/SHGC	Sizing	Cool Control	Fan CFM	Cool Cap (KBtu/hr)	CoolE	ΔCoolE	FanE	ΔFanE	HeatE	ΔHeatE	TotE	ΔTotE
Boise															
1	12	0.9	0.55/0.60	fixed	constant	103793	2582.5	184046		123020		353400		1571423	
2	1.2	0.9	0.55/0.60	fixed	warmest	103793	2582.5	177948	6098	123514	-494	134829	218571	1347249	224174
3	0.8	0.6	0.55/0.60	fixed	constant	103793	2582.5	159804		118203		537705		1553944	
4	0.8	0.6	0.25/0.30	fixed	constant	103793	2582.5	150974	8830	117110	1093	486292	51413	1492608	61336
5	0.8	0.6	0.25/0.30	auto	constant	85748	2149.6	133326	26478	97749	20454	352063	185642	1321370	232574
6	0.8	0.6	0.25/0.30	fixed	warmest	103793	2582.5	122579	37225	117378	825	88253	449452	1066448	487496
Seattle															
1	12	0.9	0.55/0.60	fixed	constant	88682	2317.7	138641		111580		315155		1476314	
2	1.2	0.9	0.55/0.60	fixed	warmest	88682	2317.7	122278	16363	111950	-370	115981	199174	1261149	215165
3	0.8	0.6	0.55/0.60	fixed	constant	88682	2317.7	129449		109876		498157		1475695	
4	0.8	0.6	0.25/0.30	fixed	constant	88682	2317.7	127444	2005	109653	223	444326	53831	1419636	56059
5	0.8	0.6	0.25/0.30	auto	constant	78022	2042.8	113509	15940	96567	13309	344677	153480	1292966	182729
6	0.8	0.6	0.25/0.30	fixed	warmest	88682	2317.7	83207	46242	110019	-143	69369	428788	1000814	474881

The different sizing and control options have a large impact on window energy savings. Under the design condition, i.e., when the HVAC system is properly sized, using WARMEST rather than CONSTANT Cool Control reduced heating by 62% and total energy use by 14% (Row 2). With the same size HVAC system and CONSTANT Cool Control, using the "best case" window in place of the design condition window resulted in an energy savings of 4% in both Boise and Seattle (Row 4). However, auto-sizing the HVAC system increases the energy savings to 15% in Boise and 12% in Seattle (Row 5), while keeping the same size HVAC system but using a WARMEST rather than CONSTANT Cool Control produces even larger energy savings of 31% in Boise and 32% in Seattle (Row 6). With auto-sizing, cooling and fan energy use are both reduced by 12-16%, while heating energy use is reduced by 31-34%. With WARMEST Cool Control, the fan energy savings are minimal, but cooling energy use is reduced by 23-36%, and heating energy use by over 80%.

This analysis clearly shows that HVAC system sizing and Cool Control have major impacts on the energy savings from window measures. Since the *New* vintage large office buildings are modeled with auto-sized systems and WARMEST Cool Control, while the *Old* vintage large office buildings are modeled with fixed HVAC system size and CONSTANT Cool Control, this difference probably accounts for much of the observed differences in energy savings for window measures.

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Energy Information Administration 1983. *Commercial Buildings Consumption and Expenditures* (Nonresidential Buildings Energy Consumption Survey), US Department of Energy , Washington DC.

Huang, Y.J., Akbari, H., Rainer, L., and Ritschard, R.L. 1990. "481 prototypical commercial buildings for twenty urban market areas (Technical documentation of building loads data base developed for the GRI Cogeneration Market Assessment Model)", LBL Report 29798, Lawrence Berkeley National Laboratory, Berkeley CA.

Huang, Y.J. and Franconi, E. 1999. “Commercial Heating and Cooling Loads Component Analysis”, LBL Report 37208, Lawrence Berkeley National Laboratory, Berkeley CA.

Appendix A. NEEA memo on building conditions in the Northwest

(sent 28 June 2005 by Mike Kennedy)

Commercial Windows Savings Model - Prototype Selection

Charlie Grist has assembled a fairly complete collection of regional building characteristics and code performance requirements. LBL has posted a summary of their prototypes. This memo summarizes my thoughts on the material. Charlie has contributed to this as well. It is meant as a starting point. The primary interest of this discussion is the characterization of advanced window energy savings in newly constructed buildings. There is interest in savings from high performance replacement windows as well but the increments are over new windows.

The goal of this work is stated as "to come to consensus on a single set of modeling inputs and window energy performance results that can be used by the Northwest Power & Conservation Council (NWPCC or Council) for the regional power plan and by the Alliance for program planning". Impetus for this project comes from the perceived difference in energy savings estimates of recent work by LBL and estimates used in the NPPC power plan. While some of this difference is attributable to differing baseline window conditions, some may be due to differences in the window modeling or to the prototypes themselves.

To achieve the project goals a few prototype buildings developed by LBL need to be chosen, adapted to northwest conditions, and used to predict energy savings for various window increments. Rather than model specific base and target windows, a grid of U-factor and SHGC combinations should be modeled for each prototype/climate to adapt to future needs.

Prototypes

The Window Area by Building Type table is the regional summary of window area based upon the CBSA data for new construction since 1995 (from NPPC Window Inputs.xls). As can be seen office is the dominant building type in terms of region window square footage. In total 40% of the regional windows occur in buildings primarily categorized as office. In addition, significant amounts of window in some other categories (warehouse) occur within office areas associated with those building types.

The non-grocery retail sector combines to account for 7% of the installed window area. This includes large atrium spaces associated with malls, and lots of street level retail display windows. K-12 schools, lodging and Other Health (medical offices, clinics, nursing homes) are other significant types accounting for 4%, 6%, and 5% of regional window area respectively. The "other" building type represents 26% of the glass. In past work savings in the identified building types have been assumed to be representative of this category.

Window Area by Building Type

Btype	Window to Floor Ratio	Pct of New Regional Floor	Annual New Window Area (ksf)	Fraction of Annual Regional New Window Area
Large Off	15%	8%	712	17%
Medium Off	15%	6%	543	13%
Small Off	15%	5%	441	10%
Big Box	1%	7%	44	1%
Small Box	5%	5%	139	3%
High End	15%	1%	104	2%
Anchor	3%	1%	26	1%
K-12	5%	6%	187	4%
University	7%	3%	135	3%
Warehouse	3%	17%	294	7%
Supermarket	3%	0.4%	7	0.2%
MiniMart	15%	0.5%	46	1.1%
Restaurant	18%	0.9%	93	2%
Lodging	8%	5%	253	6%
Hospital	8%	2%	118	3%
OtherHealth	8%	5%	220	5%
Other	6%	26%	926	22%
			4,289	

Not addressed in this table are HVAC system types. The BPA regional prototypes have package single zone (PSZ) equipment for all building types except large and medium office and hospital. The large and medium office buildings have VAV with primary gas furnaces and electric reheat in the series fan powered terminal units. This generally conforms to the regional building stock. Deviations from this are downtown retail spaces which often are served by VAV systems, schools which are served by a mix of heat pump loops, two & four pipe ventilators, central VAV and in room furnaces, and laboratory/university buildings which tend to use VAV with hot water reheat.

Clearly offices need to be well represented in any analysis work. At a minimum two office prototypes should be considered, a "large" office in the 100000-200000 square foot, six plus stories range, and a medium office in the 50000 square foot range with 2-3 floors. Both prototypes should have VAV systems. An additional small office prototype should be considered with a PSZ system. Alternatively the medium office could be modeled with PSZ system.

The retail sector is rather difficult to simply characterize with respect to windows. First floor retail window traits vary widely. Some are heavily shaded with first floor awnings or plastered with signage while others are un-shaded, some open into the store while others open to unconditioned window display cases. Atrium spaces have their own completely different thermal characteristics. These factors make this category difficult to model with a small number of prototypes. An additional consideration is that code window requirements for street level retail are very different from other windows due to the need for visibility from the outside. This will add more variation, but also means savings increments might be larger and that the owners of these spaces might be less interested in the "improved" windows. If retail windows are included in this work the prototype situations should be chosen carefully and different shading and base conditions need to be parameterized.

Lodging also represents a significant amount of window area. Variability of window shades and shading, occupancy and other human factors will have a disproportionate impact on the results. Using average or reasonable characteristics will bias the results unless there is a clear basis for the assumptions. This type may require more detail in the modeling grid to capture sensitivity, perhaps a low and high-shading case.

Schools, though not representing the largest window area, are unique from an HVAC and schedule point of view and also a fairly homogenous group. To the extent that they can be included in the modeling results may be valuable to inform initiatives and designs. . Two or three system types should be looked at with at least one without cooling and one with. A heat pump system would also be interesting.

Multifamily was mentioned as a building type of interest in the last phone call. This would add another prototype to the mix. Characterization of replacement windows in existing buildings would also add additional variation that might require additional parameterization.

Based upon the information above and discussions with Charlie Grist, David Cohan and Jeff Harris, I generated this prioritized prototype list. Each of these prototypes would be modeled in Seattle/Portland, Spokane, and Boise to get a fair range of regional climates. Resources will dictate how many prototypes are looked at in how much detail. As mentioned above there is interest in having a grid of window U-faction and SHGC values. Some additional bounding would be of interest if resources permit. This detail needs to be balanced with the number of prototypes.

Prioritized Prototype List

Prototype	LBL Designation	System	glass %	Other notes
Office	New, Large, North 137,000sf 7 stories	VAV, electric reheat, gas furnace preheat, series fan powered boxes at perimeter.	40%	Assume control with pressure and/or temperature reset.
Office	New, Small, North 6,400sf 2 stories	LBL default. PSZ, gas heat	20%	Economizer (non-integrated, 60F changeover)
Office	New, Large, North 137,000sf 7 stories	VAV, LBL default hot water reheat	40%	Assume good control with pressure and/or temperature reset.
Retail	New, Small, North 6,400sf 1 story	PSZ	20%	Economizer (non-integrated, 60F changeover)
School	New, North	??????	15%	Sept-June school year, single story if possible
Office	New, Large, North 137,000sf 7 stories	Advanced	40%	

There is no LBL medium office prototype. This would be nice to remedy but the cost of developing a new prototype may preclude it. The LBL large office prototype is somewhat thin at just under 20,000sf per floor compared with 25,000-30,000sf per floor in CBSA but is probably fine. The small office is perfect. It would be nice to look at both hot water reheat and electric reheat for the large office prototype. The Schools prototypes seem quite small and a bit atypical in that they all have 2 floors.

Systems need to be modified for the large office to have electric reheat. Also, some thought should be given to the possible development of an “advanced” system with a low pressure drop distribution system for the large office prototype.

Window Increments

The Window Requirements table below presents all regional code window requirements depending upon location, space heat type, and window percent and type. Some of these are much more common code paths particularly when projects are weighted by window area. The maximum glazing allowed when using code prescriptive paths is the maximum glazed path in the table below. In all regional codes, buildings can exceed these levels using performance trade offs

or system analysis. Survey work has indicated a relatively small number of buildings exceed the maximum prescriptive glazing levels.

Determination of a realistic window base level is complicated by the fact that installed windows have been found to typically exceed code in at least one trait (U or SHGC) and often both due to the discrete product options available. A good exercise would be, for each code path, to assign windows that represent the common window used to comply. There might be more than one in many cases. In the original NWPPC window estimates, window selection was assumed to use different paths depending upon whether 0.04 low-emissivity windows or tinted windows were used to comply with the SHGC requirements. This led to two different base u-values for the same glazing level. Due to the large range in code u-values and the importance of offices, it would be prudent to examine at least two different glazing code paths for the office prototypes.

In addition, careful consideration of the “program” window or windows is warranted to ensure useful results. Frame types and thermal properties are one factor in particular that needs some thought. Metal-framed windows may be required for some applications for structural integrity and this may limit available u-values.

For the current purpose, rather than identify specific window increments now, it is preferable to parameterize the window performance characteristics. Ideally using a U-factor and SHGC increment of 0.05, a starting point of U 0.55/ SHGC 0.50, and an ending point of U0.25/SHGC 0.30.

Other Parameters

Window shading, lighting power densities, equipment levels, envelope thermal integrity and space intensity of use are all factors that impact the building thermal dynamics and therefore the results. If possible it would be interesting to look at 3 levels of window shading, light levels, and thermal integrity for each prototype. The sensitivity of results to these factors would significantly enhance the understanding of the variation possible.

LBL Prototypes

The LBL prototype summaries are brief but provide a basis for determining whether the prototypes comply with basic aspect of local practice and codes. Standard practice as gauged by the CBSA data set is likely out of date with current practice. Changes in regional energy codes over the last 4 years have made significant changes in windows and lighting requirements. As such using codes is probably the preferred and easiest approach to approximating the current baseline.

Northwest codes influence this project in two ways. First, they establish light and insulation levels that influence the building thermal dynamics, and second they establish a technical base case for windows. All envelope and lighting assumptions in the prototypes should be brought into compliance with local codes. The Opaque Envelope Requirements table below summarizes the regional code requirements. The Window Requirements table summarizes the regional code requirements as they vary for different building conditions. I would suggest the Washington Other Fuels envelop path and either the Washington or Oregon code lighting values be used as the baseline. Lighting should be assumed to be somewhat better than code (5-10%) since average lighting densities will on average be better than code.

The LBL summary pages do not provide enough detail to comment on schedules, equipment use, or the system descriptions. A more in depth review would be useful once prototypes have been chosen.

Window Requirements – Northwest Energy Codes

Region	Heat or Window Type	Percent Window	Max. U-Value	Max. SHGC	Window Rating Method
WA	Electric Heat[1]	0%-30%	0.4	0.4	NFRC Rated or WSEC Default table 10-6
WA	Other Heat[1]	0%-30%	0.55	0.45	NFRC Rated or WSEC Default table 10-6
WA	Other Heat[1]	30%-45%	0.45	0.4	NFRC Rated or WSEC Default table 10-6
SCL	Electric Heat[1]	0%-30%	0.4	0.4	NFRC Rated or WSEC Default table 10-6
SCL	Other Heat[1]	0%-30%	0.55	0.4	NFRC Rated or WSEC Default table 10-6
SCL	Other Heat[1]	30%-45%	0.45	0.4	NFRC Rated or WSEC Default table 10-6
SCL	Other Heat[1]	45%-50%	0.4	0.4	NFRC Rated or WSEC Default table 10-6
OR zone 1	All Fuels	0%-30%	0.54	0.57[2]	NFRC Rated or ASHRAE Fundamentals Table 4.
OR zone 1	All Fuels	30%-40%	0.37	0.35[2]	NFRC Rated or ASHRAE Fundamentals Table 4.
OR zone 2	All Fuels	0%-25%	0.5	0.57[2]	NFRC Rated or ASHRAE Fundamentals Table 4.
OR zone 2	All Fuels	25%-35%	0.37	0.43[2]	NFRC Rated or ASHRAE Fundamentals Table 4.
IEEC 2003	All Fuels	0%-10%	0.7	0.5	NFRC Rated or IECC Default table 102.5.2
IEEC 2003	All Fuels	10%-25%	0.5	0.5	NFRC Rated or IECC Default table 102.5.2
IEEC 2003	All Fuels	25%-40%	0.4	0.5	NFRC Rated or IECC Default table 102.5.2
IEEC 2003	All Fuels	40%-50%	0.4	0.4	NFRC Rated or IECC Default table 102.5.2
IEEC 2004	Factory Built Windows	0%-40%	0.35	0.4	NFRC Rated or IECC Default table 102.5.2
IEEC 2004	Site Built Windows	0%-40%	0.55	0.4	NFRC Rated or IECC Default table 102.5.2
Best of Zone 1	All Fuels	0%-30%	0.54	0.4	Assumes non-electric commercial windows. Factory built windows need to comply with IECC 2004
Best of Zone 1	All Fuels	30%-40%	0.37	0.4	
Best of Zone 2	All Fuels	0%-25%	0.5	0.4	
Best of Zone 2	All Fuels	25%-35%	0.37	0.4	

1- Heating Fuel. Other Heat includes all non-electric plus heat pumps and VAV electric reheat.
2- Center of glass shading coefficient.

Opaque Envelope Requirements – Northwest Energy Codes

		Washington		OR		Idaho/ Montana			
Case/Region=>	Seattle	Zone 1	Zone 2	Zone 1	Zone 2	<10% win	10-25% win	25-40% win	40-50% win
Component									
Roof/Ceiling									
Attic Nom Ins	30	30	38	19	19	25	25	30	30
Attic U-value	0.036	0.036	0.031	0.05	0.05				
Roof Nom Ins	21	21	25	19	19	25	25	30	30
Roof U-value	0.05	0.046	0.039	0.05	0.05				
Roofdeck R-value				19	19	19or20	19or20	23or24	23or24
Roofdeck U-value				0.05	0.05				
Metal Roof Nom Ins				19	19	R30 /w tb	R30 /w tb	R30 /w tb	R30 /w tb
Metal Roof U-value				0.05	0.05				
Wall Nom Ins	19	19	19	13	19	11	11	11	13+R4 rig
Wall U-value	0.062	0.062	0.062	0.13	0.09				
Metal Frame Wall Nom Ins	13+3.8rig	19	13+3.8rig	13	19	13+3rig	13+3rig	13+3rig	13+7rig
Metal Frame Wall U-value	0.084	0.109	0.084	0.13	0.09				
BG Wall Nom Ins	12	10	12	7.5	7.5	0	8	8	8
BG Wall U-value	0.061	0.07	0.061	0.11	0.11				
Metal Wall Nom Ins				13	19				
Metal Wall U-value				0.13	0.09				
Mass Criteria	avg all walls >9btu/sf			individual walls > 45lbs/sf					
Mass Wall Nom Ins	7	5.7	7.6	win<15%- R1.4, else 2.8	win<15%- R1.8, else 4.3	R5-continuous or R11 framed			
Mass Wall U-value	0.12	0.15	0.123	win<15%- U0.3, else U0.21	win<15%- U0.27, else U0.16				
Mass Wall Interior Nom R	19	19	19	11	13				
CMU integral R	filled cores	filled cores	7.6	<15%- 50% filled cores, rigid inserts all but beams		filled cores +R5continuous or R11 framed			
CMU integral U	0.12	0.15	0.123	win<15%- U0.3, else U0.21	win<15%- U0.3, else U0.16				
Door R-value									
Door U-value	0.6	0.6	0.6	0.2 - hinged <4ft exempt					
Door (rollup)R-value									
Door (rollup)U-value	0.6	0.6	0.6	0.2 - coil/rollup exempt	0.2 - coil/rollup exempt				
Floor Nom Ins	19	19	21	11	11	25	25	25	25
Floor U-value	0.056	0.056	0.047	0.07	0.07				
Slab Nom Ins	R10 for 2'	R10 for 2'	R10 for 2'	0	0	0	8	8	8
Slab F value	0.54	0.54	0.54	----	----				
Mass Floor ext ins						22	22	22	22

Maximum Lighting Power Density Requirements.

Building/Space Use		WA 2004	Seattle 2004	Oregon 4/1/2004	IECC 2003/2004	Base Level
Retail						
	Retail	1.5	1.5	1.5	1.5	1.5+1.5
	General Sales Area		1.5 + 1.5	2	1.7	1.5+1.5
	"Specialty" Items		1.5 + 1.5			1.5+1.5
	"Fine" Merchandise		1.5 + 1.5			1.5+1.5
	Jewelry & Art		1.5 + 1.5	4		1.5+1.5
	Grocery	1.5	1.5	1.5	1.5	1.5
	space by space grocery area			2	1.6	1.6
	active storage			0.8		0.8
	Wholesale stores (pallet rack shelving)	1.5	1.5			1.5
	Mall concourses	1.4	1.4	1.5		1.4
Institutions/Public						
	Hospitals (institution)	1.5	1.5	1.2		1.2
	Nursing homes	1.5	1.5	1.2		1.2
Schools						
	Schools buildings (Group E Occupancy only), school classrooms, day care centers	1.35	1.2	1.1	1.2	1.1
	classroom	1.35	1.2	1.4	1.4	1.4
	corridor			0.5		0.6
Office						
	Office buildings, office/administrative areas in facilities of other use types (including but not limited to schools, hospitals, institutions, museums, banks, churches)5,7,11	1	1	1	1	1
	Offices Enclosed <150sf	1.2	1.2	1.1	1.1	1.1
	Offices Open Plan	1	1	1.1	1.1	1
	Lobby			1.3	1.3	1.3
	Corridor			0.5	0.9	0.5
	Restroom			0.9	0.9	0.9
	Medical offices, clinics12	1.2	1.2	1	1.2	1
Assembly						
	Atria (atriums)	1	1	0.6+0.2 for each story over 3	0.6	0.6+0.2 for each story over 3
	Hotel banquet/conference/exhibition hall3,4	2	2	1.3	1.2 conference ?? 1.3 exhibition	
	Assembly spaces, auditoriums, gymnasium, theaters	1	1		1.8	1
	Gymnasium	1	1	1.1		1
	court area	2.6	2.6	1.4	1.4	1.4
	seating	1	1	0.4		0.4
Lodging						
	Hotels			1 (non-room area only)	1 (non-room area only)	1
	guest rooms	1.5	1.5	exempt	exempt	1.5
	Banquet/Conference/Exhibition	2	2	1.3		1.3
	Lobby	1	1	1.1	1.1	1
	Reception	1	1			1
	Corridor	1	1	0.5	0.9	0.5
	Motels			1	1 (non-room area only)	1
	guest rooms	1.5	1.5	exempt	exempt	1.5
	Lobby	1	1	1.1	1.1	1
	Reception	1	1			1
	Corridor	1	1	0.5	0.9	0.5

	Group R-1 and R-2 common areas	1	1	0.7		0.7
Space by Space types						
	Lobby			1.3		
	Hallway/Corridor			0.6		0.6
Plans Submitted for Common Areas Only						
	Main floor building lobbies3 (except mall concourses)	1.2	1.2			
	Common areas, corridors, toilet facilities and washrooms, elevator lobbies	0.8	0.8			
	Restrooms					

Appendix B. review of LBNL prototypes by Mike Kennedy,

Memorandum

To: David Cohan
CC: David Baylon, Joe Huang
From: Mike Kennedy
Date: 10/18/2005
Re: Comparison of LBL and BPA Prototypes

This memorandum summarizes the comparison work done between the BPA small and large office prototypes and the LBL prototypes. Several new issues have been discovered and are discussed below. Item by item results are in the attached spreadsheet with recommendations about appropriate input. A very simple incremental modeling of the differences was used to determine factors of most importance and is the basis for energy savings impacts.

Several differences occur across both the small and large office prototypes.

Both small and large prototypes have the following issues.

- LBL uses window U-value directly, WSEO & BPA uses u-value with exterior film coefficient removed since program adds it back in. Double counting the film coefficient changes the modeled conductance increment by 16% and decreases savings in the LBL model.
- LBL uses shade coefficient directly with no additional shading, WSEO & BPA assume additional 5% shading. Both are obviously way below average real world shading which tends to inflate predicted savings for increased shading coefficient. Something on the order of 25% would likely better capture the impact of other buildings, dirt, and shades.
- LBL uses setpoints of 70/75, BPA 72/74.
- LBL uses inverse of nominal R-value for the insulation layer, and adds additional wall layers. This essentially assumes no framing at all, and combined with using the nominal code R value yields very high wall performance. The wall u-value should be equal to the code metal wall u-value for the large office and probably the small office too. This will significantly change building energy use but will probably only shift savings from cooling to heating.
- LBL has much lower outside air ventilation rate. This results from a much lower occupant density estimate. The air flows are below what I would think of as typical design values, and in general, they are far below the floor area term of the ASHRAE 62 calculation.

Small Office Comparison

The spreadsheet tab Small Office Comparison presents a detailed listing of traits in the two prototypes. In general, the small office prototypes were very comparable in their electric savings predictions but different gas heat savings. The BPA prototype predicts ~10 percent additional electric savings and about 50% addition gas savings.

The most important difference was the specification method of outside air. The LBL model specifies a fixed amount of ventilation based upon the number of people. The BPA model specifies an amount of ventilation based upon a fraction of the air handler flow. If a window change happens that allows the system to be smaller the LBL method will keep the ventilation component constant. Since both prototypes use DOE2 autosizing, the BPA method will reduce the amount of outdoor air giving credit to the window change for the reduction in ventilation. Switching from the LBL to the BPA method increased window energy savings 70%.

The LBL method is the more correct version but it assumes that someone is calculating the ventilation air and they are setting it based upon CFM of outdoor air. In larger buildings this is probably the case. In small office where single zone rooftop equipment is installed installers generally provide air based upon a damper opening size to get a percent outdoor air. This is more in keeping with the BPA method but it assumes that someone is re-sizing the system because of the glass specification. I do not think these systems are sized that carefully, so feel more comfortable with the LBL approach here. It also is closer to demand ventilation which should slowly gain traction in this market as the liability of having random outdoor air hits contractors.

Also important was the overall amount of ventilation. The LBL model specifies 15 cfm per person and one person for every 470 square feet. For the 6400sf prototype this amounts to 204 cfm, or 0.03cfm/sf. ASHRAE 62 suggests minimum ventilation should be 0.06cfm/sf plus 5 CFM/person with an occupancy of 200sf/person. Corridor and storage areas do not require an occupant loading but meeting rooms and lobbies require much higher loadings. Assuming the LBL density overall ventilation would be 0.07 cfm/sf. Assuming a more reasonable 244sf/person ventilation would be 0.08 cfm/sf. The ventilation system effectiveness should probably be 0.8 resulting in a ventilation of 0.1 cfm/sf. Changing the LBL prototype ventilation reduced window heat savings by 10%.

A second issue is the difference in the floor. The LBL prototype assumes an uninsulated floor over an uninsulated basement. This needs to change. Either it needs to be changed to a crawl or slab with insulation, or insulation needs to be added to the floor between. Adding insulation to the floor increased window energy savings 12%.

Heating and cooling setpoints lead to a 6% difference in cooling and 16% in heating energy use. The BPA system is over all 14% efficient than the LBL system during operation.

Large Office

Window energy savings predictions from the large office prototypes diverge significantly between the two models. The LBL model produced savings more than double those predicted by the BPA or the WSEO model. There are very significant differences between the prototypes. Details can be found on the Large Office Comparison. To make these comparison we changed the LBL prototype to electric reheat. The main issues are presented here and need to be addressed before modeling is considered.

Main Issues:

LBL lets DOE2 size systems and equipment and sets no limits on the equipment selected. This is common practice but can lead to completely fictitious systems. The design air flow for the core zones in some of the LBL runs is less than 0.25CFM/sqft, and the system average is as low 0.54cfm/sqft. Real world systems have significantly higher design air flow rates. The impact of this on window savings is significant. Just forcing the core zones to have 0.75cfm/sqft causes window energy savings to decrease 23% in the one case checked. Using 0.9cfm/sqft reduced savings 34%. In general, systems should be sized assuming much higher peak equipment loads, or perhaps a minimum air flow. It would be nice to get some system credit for more efficient windows but then an explicit sizing run would be required. Alternatively the minimum sizing could be left off of east, south, and west perimeter zones.

LBL uses custom weighting factors. BPA uses precalculated weighting factors. The impact of this issue is extremely complex and significant. The precalculated weighting factors led to 32% less savings in one case, and 20% more in another. In another there was no difference. The dependence is impacted by the amount of interior detail modeled. Clearly the preferred approach is to use custom weighting factors but enough internal structures need to be modeled to get the proper response. Interior partitions in the BPA prototype are “air walls”, massless walls that simulate open air transfers. These walls would need to change to mass walls or other internal walls specified. LBL has a real “delayed construction” wall in this location. This adds to the internal mass and also isolates the perimeter zone, maximizing the impact of perimeter effects. This is exacerbated by the fact that the wall is insulated. Removing the insulation reduces window energy savings 10%.

LBL uses a VAV system with squeeze boxes only. This sort of system was common in the northwest in the early nineties but now most systems have some sort of fan powered terminals. The fan power terminals greatly reduce the minimum amount of primary air required which reduce reheat energy requirements significantly. Exactly how this would impact the saving predictions is another matter. A quick model indicated savings might be reduced 25% or more. This however would be dependant upon control strategy.

LBL uses a hot water heat generated by a boiler for primary coils and zone reheat. This system configuration is only common in buildings with higher than normal ventilation needs such as laboratories and hospitals, and in some education facilities with district heating and cooling systems. More common is electric resistance in the terminal units and staged modulating gas furnaces for the primary heat. Gas heat savings are commonly converted to electric equivalents using an efficiency factor. Care needs to be taken to insure this factor captures all system effects. Better would be to model electric reheat directly.

LBL is using the LBL version of DOE2 release 114. Recent modeling by Ecotope has used the Hirsch version of the model DOE2 release 136. It is not clear what differences there are but results definitely differ. The LBL large office, modeled just fine with the LBL version, has one zone with 40% of the hours with loads not met when modeled in release 136. Correcting this reduces savings only slightly (5%-10%) but it does point out that we are using yesterdays technology. Both models are orphans and most recent model improvement and bug fixes have gone into DOE 2.2 or Energyplus.

Hours of operation are very different between the models. The LBL prototype runs HVAC equipment 3840 hours per year while the BPA prototype assumes 3010 hours of operation plus morning warmup. Reducing the LBL hours from 3840 to 3364 reduces savings 5-10%. Increasing the BPA hours would likely have the opposite effect.

Conclusions

Simple adoption of the LBL prototypes is not a significant update on the regional prototypes. Neither set of prototypes are particularly special in terms of representing modern buildings. Both the regional prototypes and the LBL models are in need of careful review and update. Cumulative fixes and changes have introduced problems and system advances have changed basic control strategies.

This said the LBL small and large office prototypes are in general satisfactory for the present window savings work. However, several items found during the comparison should be addressed and possible changed. Detailed comments on lots of inputs are provided in the spreadsheet. Only main items are discussed here.

The small office prototypes produce essentially the same results once the ventilation issue is resolved, but several items listed below should be addressed in the LBL prototypes.

- remove the furnace pilot lights
- increase minimum outside air to 0.1cfm/sqft (keep system independence)
- use a lower wall r-value so the component u-value is between 0.062 and 0.1
- change floor specification to some sort of insulated floor
- have more miscellaneous equipment use at night
- have tighter set points (71/74).
- Infiltration should probably be constant or slightly lower during hours the HVAC is operating.
- need to consider better treatment of baseline internal and external shading. The LBL assumption of none, and BPA assumption of 5% plus a frame setback are clearly wrong. Landscaping, adjacent buildings, dirt and blinds are common in small office settings. Shading should be at least 25% in this prototype.
- consider use custom weighting factors (need to add interior partitions)

The large office prototype issues are more problematic to resolve. Two general issues need to be addressed. First, what sort of system and controls should be used to model typical systems, and second, are the inputs correct for that system. Errors and ill-considered inputs have been found in both sets of prototypes, but they are mostly dwarfed by the first question. What is typical?

Reviewing and updating the VAV model should be a priority. VAV characteristics are not well known for the region. Even in new construction there is uncertainty. The only regional study to provide detailed VAV characteristics was the SCL characterization work which found 100% VAV with series fan powered boxes in new construction, yet personal at ODOE think this system is not dominant in Oregon. Older survey work has lumped all VAV systems together. Given that HVAC energy can vary by more than 4 to 1 depending upon system configuration, this lack of detail is a critical oversight. LBL maybe able to bring information to the process that will help fill in the blanks. But short of additional information a fan powered box system should be used for new construction.

Reviewing the internal structures should also be a priority. In particular, the interior walls separating the perimeter from the core zones. The BPA prototype uses air walls which are appropriate for open office and offices with glass wall perimeter offices with doors typically open. It does cause complications with using custom weighting factors. The LBL prototype clearly goes to far by specifying insulated walls in this position. At a minimum, removing the insulation from the LBL interior wall should be done. Use of the air seems ideal if it can be properly done with custom weighting factors.

Other items needing modification are:

- Realistic system sizing
- Electric reheat
- Overall wall u-values that correspond to the Washington zone 1 and 2 metal frame wall values
- increase minimum outside air to 0.106cfm/sqft (keep system independence)
- have more miscellaneous equipment use at night
- have tighter set points (71/74).
- Changing the hours of operation and system type are less clear without actual regional characteristics data. My own opinion is the hours of operation should be reduced somewhat (~3400 hours) to better reflect average conditions.
- The floor to floor structure should also be reviewed. The BPA prototype specifies adiabatic floors and a plenum space while LBL connects every interior floor with a mass wall to the first floor.
- Baseline window shading should be examined carefully for large office. This is another area that could use actually data to inform the decision. It is also a critical assumption when looking at changes in glazing shading coefficient.

Appendix C. Description of original office prototypes from Huang and Franconi, 1999

Table 10. Stock, Climate, Shell, Operation, Lighting and System Characteristics of Modeled Office Prototype

	Large Offices >=25,000 ft^2				Small Offices >=25,000 ft^2			
	Old		New		Old		New	
	North U.S.	South U.S.	North U.S.	South U.S.	North U.S.	South U.S.	North U.S.	South U.S.
STOCK FLOOR AREA DATA *								
Total area (million of ft^2) *	2,706	1,593	1,117	2,805	1,747	1,593	234	711
% of total U.S. office area	23	13	9	24	15	13	2	6
LOCATION WEIGHT FACTORS								
Minneapolis	10	0	11	0	21	0	17	0
Chicago	52	0	66	0	56	0	93	0
Washington	41	21	50	13	31	12	17	14
Los Angeles	0	54	0	55	0	43	0	51
Houston	0	19	0	20	0	37	0	26
FLOOR-AREA WEIGHTED AVERAGES								
Building area (ft^2)	103,000	96,000	137,000	90,000	5,500	5,800	6,400	6,600
Floors	7	6	7	6	2	2	2	1
SHELL								
Percent glass	40		50		20		15	
Window R-value	1.44	1.39	1.71	1.67	1.76	1.34	1.99	1.58
Window shading coefficient	0.80	0.77	0.69	0.71	0.79	0.82	0.71	0.75
Wall R-value	2.5	2.5	4.6	6.0	4.9	3.9	6.3	5.6
Roof R-value	9.1	11.2	9.1	12.6	11.9	10.5	13.3	12.6
Wall material	masonry				masonry			
Roof material	built-up				built-up			
OCCUPANCY								
Average occupancy (ft^2/pers)	460		390		420		470	
Weekday hours (hrs/day)	12				11			
Weekend hours (hrs/day)	5				4			
EQUIPMENT								
Average power density (W/ft^2)	0.75				0.50			
Full equipment hours (hrs/year)	3,580				3,360			
LIGHTING								
Average power density (W/ft^2)	1.8		1.3		2.2		1.7	
Full lighting hours (hrs/year)	4,190				3,340			
SYSTEM AND PLANT CHARACTERISTICS								
System type	Constant volume reheat fan		Variable-air-volume with economizer		Packaged single-zone		Packaged single-zone with economizer	
Heating plant	Gas boiler				Gas furnace			
Cooling plant	Hermetic centrifugal chiller				Direct expansion			
Service hot water	Gas boiler				Gas			

* stock data based on 1989 CBECS.