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Eliminating Window-Area Restrictions in the IECC

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1. Introduction

The U.S. Department of Energy (DOE) regularly participates in the code change process for the International Energy Conservation Code (IECC),[a] as well as for other relevant private-sector energy codes and standards. DOE participates in these processes to support its mission to advance and advocate energy-efficient and environmentally sound design and construction of U.S. buildings. DOE proposes and/or supports code changes that will either enhance the energy efficiency or increase the adoption and implementation of the IECC.

DOE is currently considering a strategic code change that would eliminate window-area restrictions in the IECC for residential buildings. The change is intended to encourage state/local code jurisdictions to adopt and enforce (with or without an effective code enforcement infrastructure) the IECC and to make code compliance easier for designers, builders, and other building professionals. The change is designed to be approximately stringency-neutral compared to the current version of the IECC, although various improvements to its structure and provisions will result in small average efficiency gains in many situations.

A fundamental premise is that an energy code works best when it is ubiquitous—the more buildings that comply with it and the wider its geographical extent, the more effective it is overall. Widespread adoption and use has benefits beyond the obvious efficiency improvements to more houses. For example, by establishing common "legal minimum" efficiency specifications, the cost of building components (e.g., insulation) can be lowered by the resulting economies of scale. Also, by laying down an unambiguous and well-known baseline, various above- and beyond-code programs can be more effective in moving the housing industry toward exemplary buildings, and consumers will be better able to identify above- and below-code homes.

Over the past couple of decades, the technical state of model codes has been improved dramatically, albeit by a slow evolutionary process. Through the years, marginal efficiency improvements as well as new compliance options have been introduced, bringing the efficiency "floor" ever higher. However, it is now clear that most of the low-hanging fruit has been harvested. Further efficiency improvements will require more careful design and engineering than the simple component improvements that have brought the code to its current state. Many recent code changes (and many code change proposals that were not successful) have attempted to bring more of the esoteric efficiency improvements into the IECC. While DOE applauds these efforts, the reality is that such changes tend to complicate the code and work against its widespread adoption, use, and enforcement.

This code change is intended to facilitate various programs that move the housing industry toward "exemplary" home construction without compromising an ubiquitous and easily enforced efficiency floor. By renormalizing the IECC to take advantage of recent years' efficiency improvements in a greatly-simplified format, DOE hopes to lay a solid foundation on which exemplary-home programs can build.

This paper provides a brief overview and rationale for DOE's proposed code change, discusses problems with window-area restrictions in building energy codes, discusses why eliminating window-area restrictions is not detrimental to residential energy consumption, and provides summaries of data used to determine the effects of this proposed change.

(a) The 1998 version of the IECC, the first edition developed by the International Code Council (ICC), Falls Church, Virginia, is the successor to the 1995 Model Energy Code. The ICC recently published the 2000 IECC to succeed the 1998 edition of the code.

2. Overview

The code change DOE is proposing to the IECC would, among other things, eliminate the code's dependence on window-area percentage for residential buildings. Currently, the IECC performance requirements for "above-grade exterior walls" vary with the amount of glazing included within the walls. The rationale for these requirements is that windows are less energy efficient than the opaque walls they displace, so a penalty should exist for excessive window area in the code.

DOE's proposed change is based on an analysis by Pacific Northwest National Laboratory (PNNL)[a] that suggests the difficulties in implementing and enforcing a window-area-dependent code are nontrivial and may greatly limit the impact of the code. The analysis further suggests that eliminating the window-area dependency would substantially increase overall adoption, compliance, and enforcement of the IECC, while at the same time reduce the cost to demonstrate and enforce compliance. Finally, the analysis shows that the increases in energy use generally expected from homes having more glazed area are in fact nonexistent or negligible compared to the benefits of increased compliance.

DOE is proposing to modify the IECC's structure to eliminate its window-area dependency. The resulting framework will leave ceiling, wall, window (U-factor and solar heat gain coefficient [SHGC]), and foundation requirements unaffected by changes in a home's glazing area.

The rationale for this proposal can be summarized as follows:

- **Eliminating window-area dependence will increase code adoption, compliance, and enforcement**. Simplifying the code will lead to increased compliance in locations that use the IECC and less resistance to adopting the IECC in jurisdictions that have not adopted the code, while reducing the need for jurisdictions to develop and maintain costly enforcement infrastructures.

- **Eliminating window-area restrictions will not have a detrimental impact on energy use**. Although a potential exists for an increase in energy use, the increase is smaller than might be expected (smaller than several other effects that are routinely ignored by the code) and can be easily negated on average by carefully designed revised code provisions. (Our proposal would result in windows that meet or exceed Energy Star specifications in at least half of the United States.)

- **Window-area restrictive codes appear to have little effect on the actual window areas of houses**. Evidence shows that natural market forces keep window areas at reasonable levels even without the presence of an area-restrictive energy code. Further, substantial evidence exists that among jurisdictions that currently use the IECC or another area-restrictive code, enforcement of the area limits is minimal at best.

- **Energy savings will increase overall**. The energy neutrality of the proposed new requirements combined with the increased likelihood of adoption, enforcement, and compliance will lead to increased energy savings.

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3. Background

The IECC regulating window-area percentage discussed in this paper is a simplification; the underlying structure of the code actually regulates the U_o-value─the heat loss rate per unit surface area, which is a function (in part) of the window area. The original IECC set a maximum U_o-value for each of several envelope components (e.g., walls, ceilings, floors) that varies with climate, becoming more stringent in colder climates. This original format persists today along with newer alternative compliance approaches that have been designed to be equivalent.

This U_o-value type of requirement, which originated in ASHRAE 90A standards[a] developed in the 1970s, was included in the first Model Energy Code and has been carried forward into Section 502.2.1 in the current edition of the IECC (ICC 1999). Other compliance approaches in the IECC, such as the prescriptive packages in Chapter 6, were designed to match (or exceed) the U_o-value requirements. The idea of the U_o-value requirement is that an envelope component, such as walls, must meet an average overall performance. This approach means that walls can have some amount of "weak" areas with high heat loss rates as long as the weak areas are reasonably small and the well-insulated areas compensate for them. The IECC implements this concept by defining "walls" to include not only the exterior walls of the house, but the windows and doors contained within them as well.

This U_o-value approach is clean, simple, and logical from a physical and mathematical standpoint. However, the practicalities of this well-intended format impose a burden that may be a severe impediment to high code compliance rates and the associated energy savings.

The areas in walls that are weakest in terms of energy efficiency are windows, doors, and, for framed walls, the wood framing. The most important element of these three areas is the window area because the door area is usually relatively small and the framing area tends to be a constant percentage of the wall area for most houses. Windows generally have a much higher heat loss rate than the rest of the wall (i.e., the opaque areas). Therefore, houses with a high window area as a percentage of the wall area need to have more efficient materials (either better glazing, higher wall R-values, or both) to meet the required heat loss rate compared to an otherwise similar house with a low window-area percentage.

4. The Problem with Window-Area Restrictions

Window-area restrictions in building energy codes are problematic for three reasons:

1. Window-area restrictions **dramatically add to the complexity of the code**, the hassles of demonstrating compliance, and the difficulties in enforcement. Although measuring these elements is difficult, we believe that an area-restrictive code imposes at least ten times the complexity of an area-insensitive code in terms of effort required to understand the requirements, labor needed for plan checking and inspections, and resources needed to develop and maintain necessary compliance tools and code enforcement infrastructures.

2. Window-area restrictions expressed in terms of a percentage of wall or floor area **result in irrational code behaviors,** resulting in the code requirements having exactly the opposite effect as intended by favoring homes with increased energy consumption.

(a) The ASHRAE standards are developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

3. Insulation requirements that are tied to window area result in **home designs that are not cost effective for the consumer**.

4.1 Complexity of the Code

The difficulties of a window-area-sensitive code include

- the impossibility of knowing requirements until design is finalized
- additional labor necessary for plan review and inspection
- difficulty in defining the areas of house elements needed for window-wall ratio (WWR) calculations
- difficulty in establishing a "baseline" design for whole-house performance compliance paths.

4.1.1 Problem in Determining Code Requirements

The requirements of a window-area-dependent code cannot be determined until the overall size, shape, wall height, and window area of a house design are finalized. Any of several common design changes can cause the energy efficiency requirements to change. This type of code affects the already time consuming and iterative design task, potentially complicating a builder's bidding process. Further, the window-area-dependent code will complicate or even eliminate the possibility of many reasonable design changes requested by home buyers before or during construction.

Some codes and standards, in recognition of these difficulties, attempt to lessen the problems by making requirements invariant for all homes below a specified window percentage (i.e., only homes with unusually high window area get more stringent envelope requirements). While this approach does lessen (but not eliminate) the problems of design iteration, it does not relieve the builder, plan reviewer, or inspector of window calculations, take-offs, and measurements (see below). Simply determining whether a house is above or below the threshold requires the same calculation.

4.1.2 Resources Required for Plan Review and Inspection

A code that restricts window area is, of necessity, substantially more complex than a code that is insensitive to window area. Any code that depends on window area, whether that dependency is expressed as a percentage of wall or floor area or expressed in absolute area terms, requires substantial additional effort on the part of the builder, plan reviewer, and inspector. For enforcement staff, doing area take-offs from building plans can easily take more time than all other energy-code-related plan reviews combined. Even more dramatic is the amount of time it takes the inspector to measure not only a house's window area, but the wall (or floor) areas required for window percentage calculations.

4.1.3 Ambiguities in Calculating Window-Wall Ratio

When a code's area dependency is expressed as a percentage (as is the case for most codes), several difficulties result. Some codes are expressed in terms of floor area while others are expressed in terms of wall area. The latter, which is used in the IECC, is the more problematic. It is often difficult to define the wall area, making the code's requirements ambiguous. For example, in a story-and-a-half design with windows in dormers, what is the wall area of the upper floor? Uninsulated knee walls beneath insulated ceilings are quite common—but how should the wall area be defined in such cases? Similar difficulties can clearly arise with mansard roofs, A-frames, and walls partly adjacent to unconditioned spaces and the outdoors.

A related difficulty results from an oddity in the IECC. The code's requirements are expressed in terms of the "gross area of exterior walls," which includes above-grade walls and **all** windows and doors but excludes below-grade walls. The implication is that houses with one story above grade and one story below grade must have substantially higher insulation levels than houses with two stories above grade and none below grade. The IECC's somewhat ambiguous distinction in how above- and below-grade walls are defined further complicates matters for builders and code officials.

4.2 Irrational Code Behaviors

Expressing area dependency in terms of a percentage of wall area or floor area results in irrational or "perverse" code behaviors. For example, the IECC's insulation requirements tend to be less stringent for larger houses than for smaller ones. Similarly, homes with inefficient aspect ratios can generally comply with less insulation than is required for the compact and efficient "box" style homes.

The irrational code behaviors are probably best exemplified when a home buyer requests a minor change to a builder's standard plan. Suppose a builder has a particular plan that just meets the IECC requirements and a prospective buyer wants to reduce the size of the home by making the house a few feet shorter. By reducing the overall size of the house, the modified plan will use less energy than the standard plan. However, because the overall window area is not likely to be reduced in concert with such a small change (egress requirements must still be met, etc.), the home's window-area percentage will increase and the modified plan can therefore fail to comply. Conversely, there are many situations in which one way to get a failing plan into compliance is to make the house larger or increase its wall height, either of which will cause it to use more energy.

4.3 Cost-Effectiveness Issues

Contrary to common thought, a window-area-dependent code forces many individual homes to be insulated to levels that are demonstrably **not** cost-effective. The most cost-effective level of wall insulation is independent of the area of windows contained within it.[a] Forcing homes with more glazing to have higher wall R-values is not cost-effective for the homeowner. Likewise, allowing homes with less glazing to have lower wall R-values is not cost-effective and may be deleterious in terms of occupant comfort and the potential for condensation and other moisture- and humidity-related problems.

For example, consider houses built in a moderate climate like Washington, D.C. This location has about 4500 HDD and an IECC gross wall U-value requirement of about 0.15 Btu/h·f^2-F. Assuming standard 2x4 walls with R-13 insulation are used, a low-price starter home with window area equal to 10% of the wall area would need low-quality aluminum windows with a U-factor of about 0.76 to comply with the code. On the other hand, a higher-end home with a great view and a 30% WWR would need windows

(a) Passive solar designs are an exception to this generalization. However, these homes generally do not fit within the IECC's prescriptive requirements anyway.

with a U-factor of about 0.30 (implying very advanced double-pane or even triple-pane glazings) to comply. It is likely that neither of these houses will have cost-effective windows. The low-end windows in the starter house will result in high energy bills, and the incremental cost of the high energy efficiency of the windows in the luxury house may not pay off for decades.

While some codes and standards avoid the problems of too-low R-values by defining a window percentage cutoff below which envelope requirements are not reduced, the IECC does not. Forcing high-window-area houses to use wall R-values higher than are cost-effective is generally defended as a justifiable penalty for the added amenity of large windows. However, this penalty is difficult to justify given that other amenities that are as bad or worse from an energy standpoint are not penalized (see later discussion in Section 5.2).

5. Why Eliminating Window-Area Restrictions Is Not Bad

Although the disadvantages of a window-area-dependent code are obvious and nontrivial, the fact remains that, **other things being equal**, a house with more windows will usually use more energy than a house with less windows. However, a careful consideration of both the advantages and disadvantages of eliminating window-area restrictions suggests that the advantages outweigh the disadvantages.

This section explains DOE's position that eliminating window-area restrictions will not result in an increase in energy use. While some homes **will** have more window area than they would under the existing IECC, many others will have more insulation than they would have otherwise. We have been able to control the overall effect by carefully selecting the baseline insulation levels of the modified code, the assumption regarding "typical" window-area percentages (used to establish the insulation requirements), and the window U-factor requirements. The reasons why eliminating window-area restrictions is not detrimental to residential energy consumption are as follows:

1. Windows are more energy efficient than they used to be.

2. The energy impact of window area is smaller than that of many other factors the code ignores completely.

3. Market forces prevent runaway window areas (i.e., natural pressure exists on builders to keep window areas relatively low, even without a restrictive code in place).

4. Enforcement of window-area restrictions is very low, even in jurisdictions with active code enforcement infrastructures.

5.1 Modern Windows Can Be Very Efficient

The notion that windows are horrid energy losers is outdated in light of recent advances in window technology. Most codes that restrict window-area percentages were designed when the typical window was aluminum-framed and single-pane. Modern gas-filled, multipaned, vinyl-sashed windows are three times as efficient or more than previous windows. Depending on location and orientation, a good modern window **can** be more energy efficient than the opaque wall it displaces. While this situation is usually not the case, it highlights the fact that modern advances have the potential to make large-window-area buildings much less the energy "disasters" they used to be.

5.2 Window Energy Impact in Perspective

While the amount of glazing in a house strongly impacts the home's energy performance, this effect needs to be viewed in the proper context. First of all, the code is designed to increase the average energy efficiency of residential houses in general, and cannot regulate each and every house in minute detail. For example, the code's envelope requirements are independent of the type of heating fuel and equipment used, even though that choice can easily double (or halve) the cost to the consumer to heat the house. Similarly, the code makes no attempt to limit the overall size of a house; a 10,000-ft^2 home is not penalized in comparison to a 2000-ft^2 home. (In fact, as discussed above, the larger home will often be easier to get into compliance with the IECC.) Orientation is likewise ignored. Window area is similar to these examples in that it reflects consumers' aesthetic preferences. It is an anomaly, however, that the code restricts window area.

Second, it is important to recognize that window **area** increases energy consumption, not window **percentage**.[a] As pointed out earlier, the current IECC allows lower insulation levels for a house with larger window areas, as long as the rest of the house is also (sufficiently) larger. Clearly, expressing a window-area restriction as a percentage regulates the wrong thing. One possible alternative would be to restrict absolute area instead of window-area percentage; then only large residences would encounter the restriction. However, this kind of restriction strikes at a home buyer's personal freedoms and ignores family size and other factors that make it reasonable for people to have large houses. Energy codes have typically shied away from provisions that have too much effect on aesthetics and other personal choices.

Third, depending somewhat on location, the **orientation** and shading of windows can be a more significant factor than their size in terms of energy impacts. In cooling-dominated climates, west-facing windows are terrible from an energy (and utility peak) perspective, whereas north-facing windows or south-facing windows with a proper overhang may result in a third as much energy consumption. Simple window-area (or area percentage) restrictions treat these identically. Appendix A shows the results of a simulation analysis that investigates the relative importance of window area, orientation, and climate. Window percentage is, for many homes, a smaller potential energy effect than the orientation of those windows. And since most new homes are designed to accommodate a relatively small lot frontage, the window area tends to be predominantly located on two sides of the home, making the orientation of the **lot** a more important energy determinant than the window-area percentage.

Appendix A also shows that in heating-dominated climates, the energy effects of changes in window percentage are relatively small within the typical range of window percentages. Only homes with unusually high percentages, which is a small fraction of all homes (see Appendices B and C), can be properly described as energy losers.

5.3 Window Areas Limited by Market Forces

If by eliminating the window-area restrictions of the IECC, builders will be able to put as much window area in a house as desired without upgrading any other energy features of the house, there is reasonable concern that such a move will result in greater energy use by IECC-compliant houses. The important questions are whether or not builders will regularly put more window area into houses if the code allows them and, if so, how much and how often. Our investigation of the available data on typical window areas shows that a significant difference does not exist in the average amount of glazing on homes subject to an area-restrictive code and on homes that are not. In other words, the existence of an area-restrictive

(a) Again, passive solar designs and other nonstandard buildings may be exceptions.

code does not seem to substantially affect the glazing area of homes built in the jurisdiction. This result appears to hold regardless of whether or not an active enforcement infrastructure exists. Windows are simply expensive enough that builders are generally motivated to limit their size and number.

5.3.1 Average Glazing Percentages

Appendix B shows an analysis of several recent studies evaluating the window areas of new homes. Although it varies somewhat by location, all of the studies show average window areas to fall somewhere between about 12% and 17% of conditioned floor area (e.g., Lee 2000; Brown 1999).[a] This average is well below what would generally be considered “excessive.” ASHRAE Standard 90.2, for example, uses 18% as the point above which envelope components must have enhanced efficiencies (ASHRAE 1993). The available data give no indication that average window areas will rise dramatically if the IECC’s area restrictions are relaxed. Indeed, some of the highest average window areas occur in locations with the most rigorous code enforcement.

5.3.2 Distribution of Glazing Percentages

Of course, **average** window percentages are not the whole story. Obviously, a distribution of window areas around the average exists. A secondary question is whether eliminating the IECC’s area restrictions will result in an increase in the number of homes with an exceptionally high window area. Less good data are available at the level of detail necessary to accurately characterize the distribution of window-area percentages. However, a couple of studies have collected sufficient information to gain a preliminary idea of the distribution (see Appendix C). Both studies confirm what logic would suggest—that the number of homes with very high window area is relatively small.

The limited data available confirm our expectations. Appendix C shows the results of two studies that quantified window-area percentages. Very few homes have window areas above 20%. Appendix C also discusses results from the Residential Energy Consumption Survey (RECS, a nationwide survey) that confirms the expected **shape** of the distribution, although RECS did not collect sufficient information to show the actual window-area percentages (DOE 1993).

The available data offer no evidence that window areas will rise significantly in the absence of an area-restrictive code. Although it is certainly possible, even likely, that a few homes will be built with very a high window area that otherwise would have had less glazing and/or higher insulation levels, the number of such homes will be very small. Natural market forces are a much stronger determinant of glazing areas than energy codes.

5.4 Area-Restrictive Codes Not Enforced

A final consideration is the level of enforcement of the IECC’s existing window-area restrictions. Even if area-restrictive provisions are argued to be a necessary technical element of an energy efficiency code, they can have little effect if not enforced.

Appendix D discusses several studies and other anecdotal information indicating that even jurisdictions with active energy code enforcement do not devote the necessary time and effort to check window areas.

(a) The IECC’s window area restrictions are expressed as a percentage of **wall** area rather than floor area. However, for houses of typical size, the wall area tends to be roughly equivalent to the floor area.

Given the budget and time constraints on the vast majority of code enforcement agencies, it is unreasonable to expect that window areas and percentages will be checked in the normal course of code enforcement.

One of the studies referenced in Appendix D was highlighted in a recent issue of *Energy Design Update* (2001), in which a study of energy code enforcement in Massachusetts was discussed. The article states that,

> One of the most striking findings was how often as-built characteristics differed from the characteristics described in the permit documents. In other words, many builders are making significant changes in the structure after the permit is filed and approved. For example, areas and perimeters varied significantly in nearly 80% of the homes, glazing and door U-values varied in 44%, and insulation in about one-third.

The finding that areas, which require the greatest investment of time to verify, are the elements least likely to be enforced is consistent with our conclusion that simpler codes will enjoy significantly higher adoption and compliance. The *Energy Design Update* article goes on to say,

> "The discrepancies in windows are especially important, because the energy code is quite sensitive to the amount and type of glazing used in new homes," Weitz says. "Obviously, we have a lot of underreporting going on. Some of it represents legitimate changes in plans that are made during construction. But some of it is intentional underreporting—that is, cheating—to circumvent the code." Weitz tells *Energy Design Update* that, "it appears that Massachusetts code officials seldom bring the permit documentation (e.g., MAScheck, an adaptation of *MEC*check) back to the site and actually check the home for compliance—a situation that obviously needs to change."

Of course, many jurisdictions have insufficient enforcement infrastructures to check even the simplest energy-related requirements.

A stark difference exists between these Massachusetts findings and findings from a similar study in Oregon. Oregon's code has simple, though relatively stringent, prescriptive requirements with no window-area restrictions (Oregon Office of Energy 2001). In contrast to the Massachusetts experience, Oregon's code has been extremely successful, achieving near total market penetration. Oregon homes do not appear to have measurably more window area than do homes in neighboring Washington, which includes a window-area restriction in its state code. Appendix D discusses this study in more detail. Interestingly, there is an effort underway in Washington to eliminate the window-area dependency from its state code in a manner similar to Oregon's (Murray 2001).

We conclude that area-restrictive code requirements have little chance of making a real impact on the window areas of the vast majority of new homes. Area restrictions are simply not worth their trouble.

6. References

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Appendix A – An Illustrative Evaluation of Window Area and Orientation

To evaluate the relative magnitude of a window area's effect on energy consumption in houses across the United States, the Pacific Northwest National Laboratory (PNNL) conducted a simple simulation analysis of a prototype home in each of 237 U.S. locations (corresponding to the availability of Typical Meteorological Year [TMY] data). The prototype was of average size (about 1800 ft^2) and was designed to have envelope component efficiencies that comply with the current IECC in each location assuming a window-to-wall ratio of about 15%.

In each TMY location, the IECC-compliant prototype was simulated at four different overall window-area percentages (8%, 12%, 15%, and 20% of conditioned floor area) and with five different distributions of that overall area: 1) 20% of the glass facing east and west, 80% facing north and south; 2) 40% east/west, 60% north/south; 3) 50% east/west, 50% north/south (i.e., equal area facing the four cardinal directions); 4) 60% east/west, 40% north/south; and 5) 80% east/west, 20% north/south. Other envelope efficiencies were not varied, but left at the roughly IECC-compliant levels for 15% glazing.

The 20 different area/orientation scenarios show the relative importance of window area and orientation for various climates. Figure A.1 shows the effect glazing area and orientation have on the overall heating load. Each of the 20 panels corresponds to one of the window-area/orientation scenarios. Within each panel is a scatter plot of the 237 locations' heating loads against heating degree-days (HDD base 65ºF). Each plotted point shows the percent change in heating load for the given window-area/orientation scenario, relative to the base case of 15% glazing equally distributed on the four cardinal directions.

Figure A.2 shows the same thing for the cooling load. Figure A.3 shows the percent change in total annual energy cost (heating plus cooling), assuming state average fuel prices and NAECA-minimum equipment efficiencies. Figure A.3 is the most useful for illustrating the important effects of window area and orientation.

Each figure is formatted as follows: Moving up and down the page from the baseline panel, the total window area increases and decreases, respectively, while window orientation remains constant. Moving right and left across the page, total area is constant but orientation varies, with east/west-dominant cases ("bad" orientation) on the left and north/south-dominant cases ("good" orientation) on the right.

The three figures display a very large amount of data and several observations are noteworthy. However, the one key observation for our purposes is that window **area** is often a lesser determinant of energy performance than is window **orientation** (and, by inference, shading). Figure A.3 shows that for locations with substantial cooling load (the low-HDD end of each panel), the orientation can have a larger impact on total operating costs than the overall window area. That is, from a baseline house with 15% window area equally distributed, increasing the area to 20% has less effect on operating costs than redistributing the 15% to a less advantageous orientation. The same is not true for heating-dominated climates, but the window-area effect on operating costs is a much smaller percentage of the total in those places.

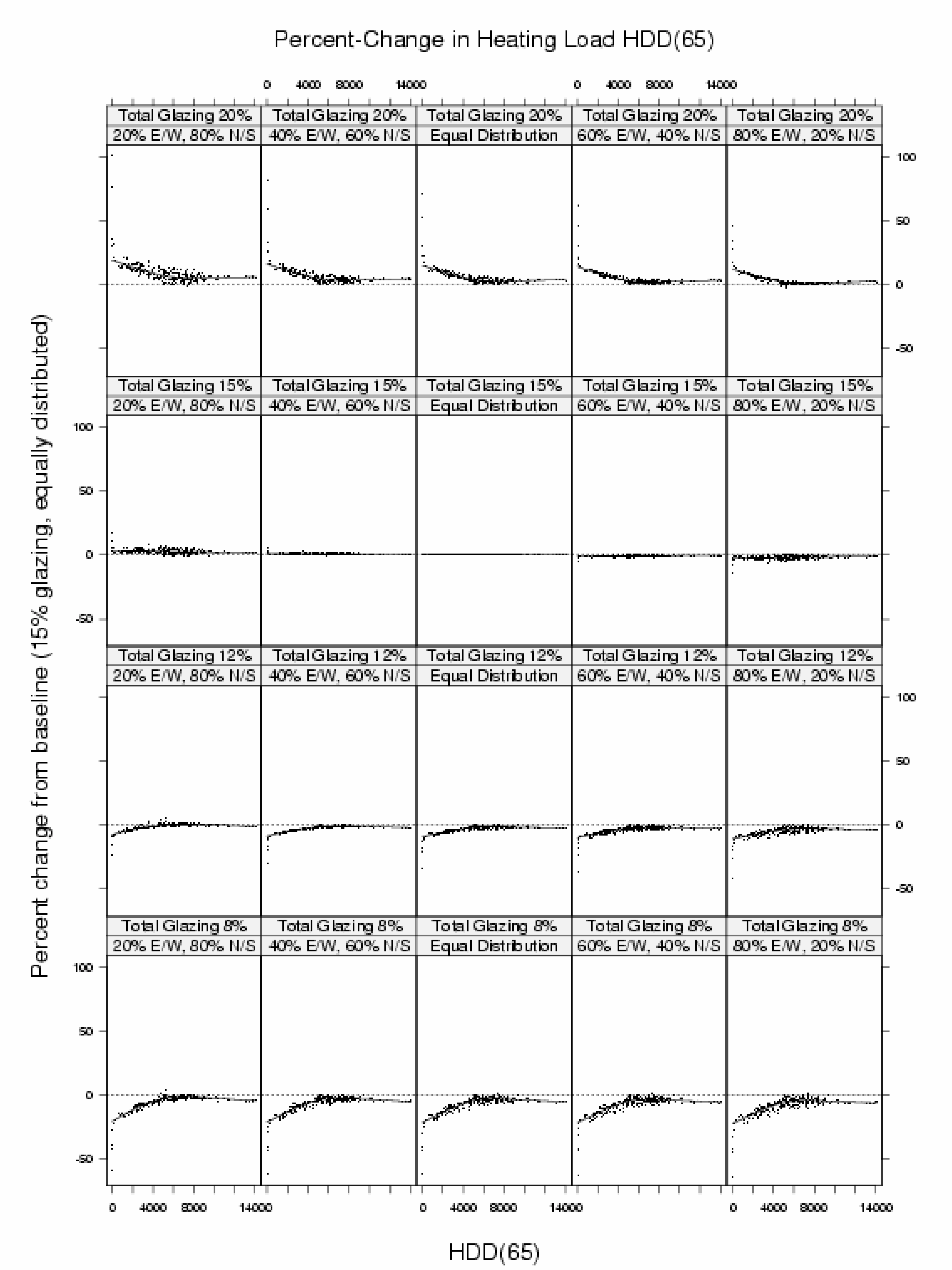

Figure A.1. Percent-Change in Heating Load vs. HDD for Various Window Areas and Orientations

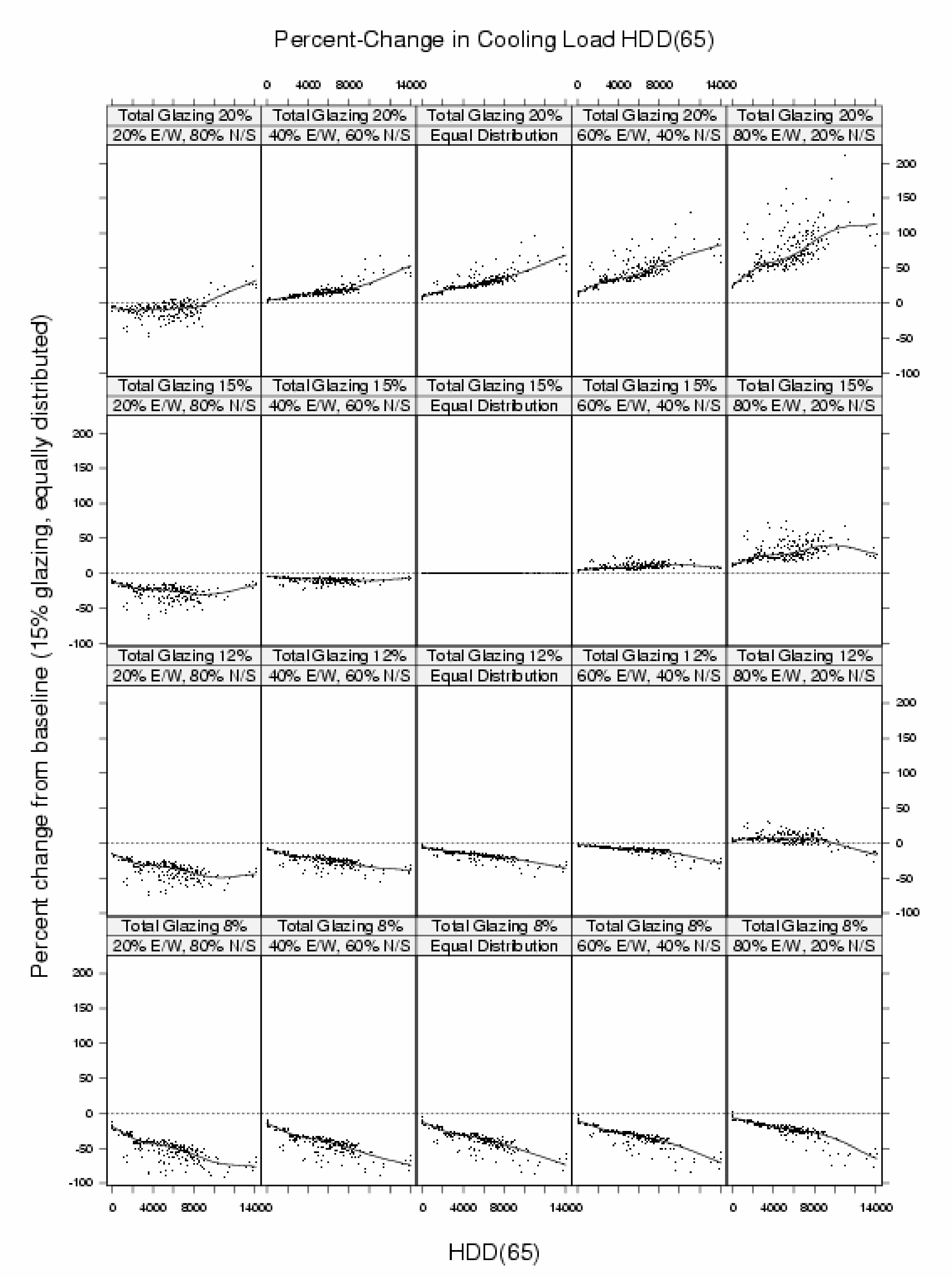

Figure A.2. Percent-Change in Cooling Load vs. HDD for Various Window Areas and Orientations

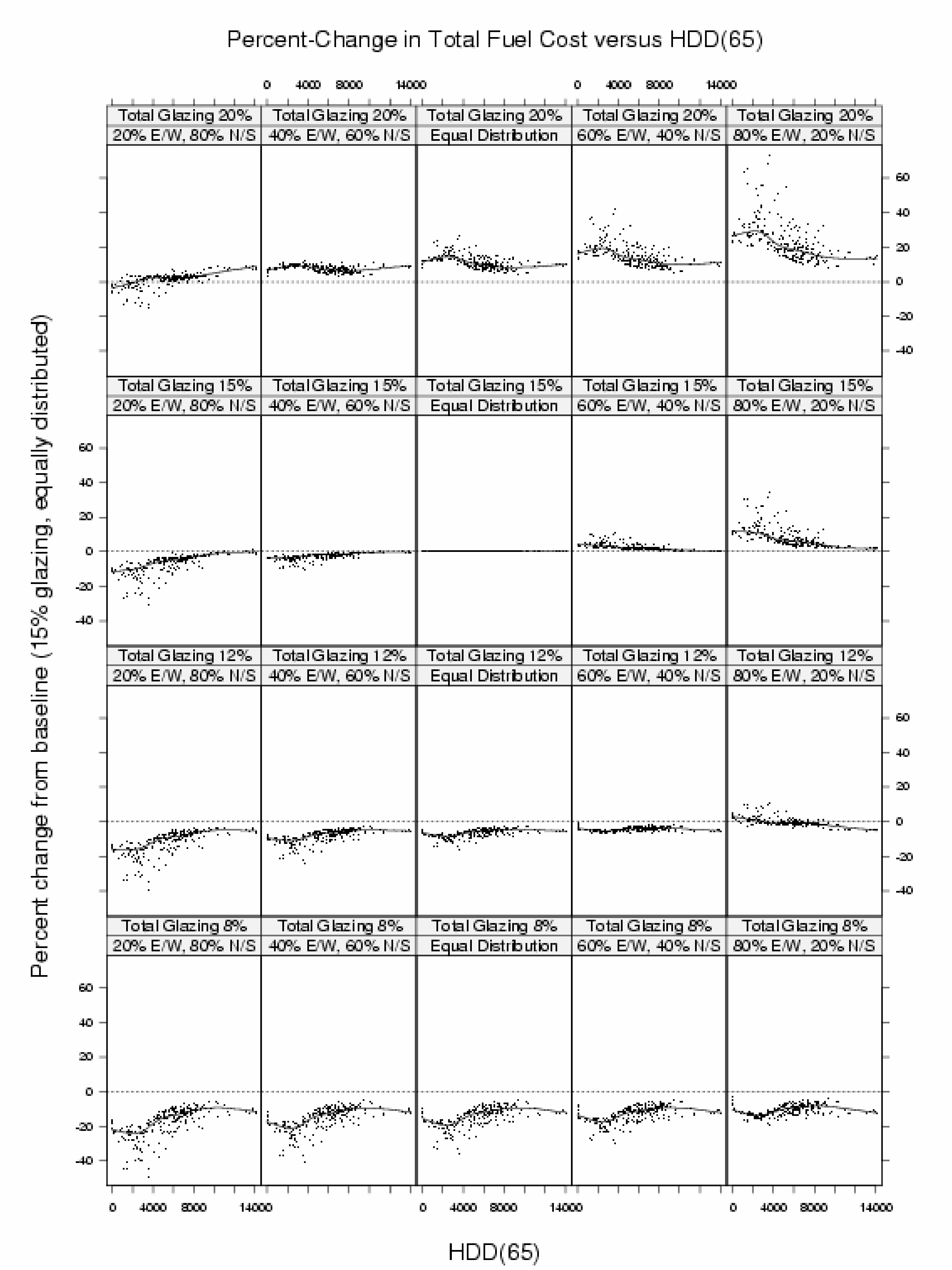

Figure A.3. Percent Change in Total Fuel Cost vs. HDD for Various Window Areas and Orientations

Appendix B – A Summary of Survey Data on Window Areas in New Residences

A key question that must be examined when considering how the IECC and IRC (ICC 1999; ICC 2000) address window areas: What are typical window-area percentages in new residences? Where window-area percentages are low, the current IECC requirements are more lenient in terms of the energy conservation measures that are required. For example, a house with a 12% window-to-wall ratio (WWR) can have substantially higher window U-factors than a similar house design with a 20% WWR (see tables in Section 502.2.4 of the IECC). DOE is proposing to eliminate window-area percentage as a determinant of code requirements and simply require good energy-efficient windows and wall insulation regardless of how low or high the window-area percentage is.

Data on recently built houses, condominiums, and low-rise apartments suggest the average WWR of new residences is close to or a little below 15%. We have developed proposed code requirements based primarily on energy efficiency equivalency to the current IECC prescriptive requirements at a 15% WWR. If the average window area in real residences is no more than 15%, such a proposal will meet or exceed the current IECC in energy efficiency across all new buildings **on average**.

Most available data on window area provide the window area as a function of conditioned floor area, not gross wall area as specified in the IECC. However, conditioned floor area tends to be roughly equal to the gross wall area for houses of typical size and shape, as is illustrated in studies in Massachusetts, Pennsylvania, and Arkansas.

Single-Family Detached Houses

We have identified studies touching nine states from which window-area data on single-family detached houses are available.

Florida

Source: Florida Power and Light. 1995. *New Home Construction Research Project: Findings, Results and Recommendations – Final Report*. Florida Power and Light, Miami, Florida.

Florida Power and Light conducted a survey of 423 single-family homes built in 1991 or 1992 in Florida. The average glass-to-floor area is 16.8%. Interesting, there is a big drop-off from South Florida (about 18%) to Central Florida (about 13%). Forty-five percent of the houses either had the glass areas or orientation reported incorrectly in their code compliance documentation, which was by far the most common inaccuracy when determining code compliance (page ES-3).

California

Source: California Energy Commission. 1990. *Occupancy Pattern and Energy Consumption in New California Houses, 1984-1988*. Sacramento, California.

The CEC surveyed 299 houses in California. In this survey, the average floor area was 1847 ft^2. The average window-to-floor area was 15.2%, with the median appearing to be about 14%. Only about 10%

of houses had more than a 20% area. The average window-area percentage was 14% to 15% in all areas of California except the southern coast, which had 17%.

Source: Pacific Gas and Electric Company. 1992. *Residential New Construction, 1992 Impact Evaluation.* San Francisco, California.

In this study, average window-to-floor area was 18.3% for 238 houses, Zones 12 and 13 (Sacramento Valley and Fresno, respectively).

Source: California Energy Commission. 1995. *Energy Characteristics, Code Compliance and Occupancy*. Sacramento, California.

This study found that about 1100 homes built in the early 1990s had compliance forms analyzed, and 96 building audits were done. The average window-to-floor area was 16% both on the forms and in audits. Sixty-two percent of glazing area reported was incorrect by more than 5% (of the glazing area).

Massachusetts

Source: A. Lee. 2001. *Impact Analysis of the Massachusetts 1998 Residential Energy Code Revisions*. Xenergy, Portland, Oregon.

In this study, detailed on-site inspections were conducted on 186 new houses in Massachusetts. The average floor area was 2538 ft^2. The average window area was 353 ft^2, or 13.9% of the floor area and 14.5% of the wall area (page 5-23). There were errors in envelope area calculations of over 10% in 75% of the houses. A closer examination of the Massachusetts study data revealed that exterior wall area calculations by the designer/builder overestimated the wall area by more than 10% in 57% of the cases. This overestimation improves the probability of the appearance of code compliance because it lowers the average wall U_o-value. Based on the detailed inspections by independent contractors, only 46% of the Massachusetts houses were found to truly comply with the 1995 Model Energy Code (MEC)-based code (MEC 1995). This report found that checking of window and wall areas in building plan specifications by code officials was "uncommon" and site inspections of component areas were "vary rare."

Arkansas

Source: Brown, E. C. 1999. *Energy Performance Evaluation of New Homes in Arkansas*. Arkansas Energy Office, Department of Economic Development, Little Rock, Arkansas.

This study did a detailed site examination of 100 new single-family houses. The average floor area of the houses was 1928 ft^2; the average price was $147,000. The average window area was 12% of the floor area and 12.3% of the wall area (pages E-11 and E-12). Only one house had a window-to-floor area percentage of more than 20%, and only one house had a window-to-wall area percentage of more than 20%. Of these houses, 55% complied with the state code (the 1992 MEC) and 45% of the houses failed (MEC 1992). The houses that failed the code had an average window-to-wall area percentage of 12.9%. The houses that passed the code had a lower average window-to-wall area percentage of 11.4%. This fact that houses with higher window-area percentages more commonly failed the code would seem to give some indication that houses with higher window-area percentages were generally failing to make the energy efficiency improvements necessary to compensate for the high window area.

Idaho, Montana, Oregon, and Washington

Source: Baylon, D., S. Borelli, and M. Kennedy. 2000. *Baseline Characteristics of the Residential Sector in Idaho, Montana, Oregon, and Washington*. Prepared for the Northwest Energy Efficiency Alliance by Ecotope, Seattle, Washington.

This study examined a random sample of 366 new houses in the Pacific Northwest. The average window area across all houses was 14% of the floor area (see Table B.1).

Table B.1. Random Sample Houses Examined in Pacific Northwest

State	Number of Houses	U-Value	% Of Floor Area	Code Requirement U-Value	Code Requirement % Of Floor Area
Idaho	104	0.474	12.7	0.50	17
Montana	61	0.402	13.1	0.50	NA
Oregon	44	0.371	15.2	0.40	NA
Washington	157	0.460	14.8	0.65	15

Pennsylvania

Source: Pennsylvania Housing Research Center. 2000. *Glazing Proportions for New Housing in Pennsylvania*. University Park, Pennsylvania.

In this study, 47 houses with unheated basements had an average window-to-floor area percentage of 12% and an average window-to-wall area percentage of 12%. Thirteen houses with heated basements had an average window-to-floor area percentage of 11% and an average window-to-wall area percentage of 14%.

Multifamily Housing

Fewer studies are available showing multifamily housing window areas. Two studies touching three states were identified.

California

Source: California Energy Commission. 2000. *Low-Rise Multifamily Building New Construction Characteristics Study*. Sacramento, California.

In this study, the average window-to-floor area was about 14% over 142 multifamily buildings surveyed.

Washington and Oregon

Source: Baylon, D., S. Borelli, M. Kennedy, and A. Roberts. 2000. *Baseline Characteristics of the Residential Sector- Oregon, and Washington*. Prepared for the Northwest Energy Efficiency Alliance by Ecotope, Seattle, Washington.

In this study, the average window-to-floor area was about 13% over 49 multifamily buildings surveyed.

Summary

From all the studies described in this appendix, the average window area appears to be close to about 15% window-to-wall area. As shown in Appendix C and in the studies referenced here, the distribution is about 15% with a fairly low standard deviation; most houses are between about 12% to 18%. There are some indications that houses in warmer climates may have a higher average window-area percentage than in colder climates. The houses in Florida and California average somewhat above 15%. The houses in colder climates, like the northeast and northwest, average somewhat less than 15%. If these percentages are true, DOE's proposed change may improve wall U_o-value requirements on average in colder climates and relax wall U_o-value requirements in warmer climates. In cold climates, space heating is generally the biggest energy use in homes. Improving the envelope U_o-value will lower heating energy use. In contrast, the energy impacts of envelope U_o-values on cooling energy use are more modest, particularly for climates where the temperature rarely reaches 100ºF or more. In cooling-dominated climates, the solar gains coming through windows may have much more impact than the conductive losses affected by U_o-values. (Note the DOE code change proposal has the same 0.40 glazing solar heat gain coefficient [SHGC] requirement as the current IECC.)

Based on this data, we believe the DOE proposal should tend to have a modest net improvement on energy efficiency for the nation as a whole (assuming the DOE proposal is as stringent at the IECC 15% window-area prescriptive requirements).

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Appendix C – A Summary of Data on the Distribution of Window-Area Percentages in Recently Built Houses

A key principle in the argument for eliminating window-area restrictions in the IECC is the observation that window areas in real houses are not significantly affected by any energy code, but rather are driven by other factors. We believe the most important factor limiting window area is simply that windows are expensive compared to the opaque wall they displace. We believe a preponderance of low-price starter homes will have a relatively small window area regardless of code restrictions. The financially limited homebuyers simply cannot afford to pay for many windows. On the other end of the spectrum, expensive luxury homes may often have larger window areas. In these cases, the homebuyer can typically afford to pay the extra dollars for more windows.

However, the data indicate that the number of homebuyers that can both afford and want "unreasonably" large window areas is quite limited. The data suggest that this relatively small subsample, for whom our proposed IECC changes would result in lower overall energy efficiency, is more than offset by the substantially larger number of homes that will result in higher efficiency under this proposal and the larger overall number of homes actually complying with the code. Furthermore, many houses that do have a large window **area** may not have as high a window-area **percentage** because the gross wall area is also large, meaning the existing IECC does not penalize these types of houses much anyway.

Below is a summary of a variety of survey data illustrating how window area varies across large samples of actual residential dwelling units. Before examining the data, a thought experiment is useful to frame our expectations. The average window-area percentage is known to be fairly low—between 12% and 18%.[a] Furthermore, there is necessarily a lower limit on window area defined by egress requirements and general aesthetic considerations—obviously there are no homes with 0% window or 2% window. That lower cutoff is not known precisely, but we believe very few homes have less than about 8% glazing. Because the left side of the distribution is thus "truncated" at about 8%, obviously not very many homes have extremely high window areas (say, above 25% to 30%) or else the average would be considerably above the 15% we see in the data. Thus the distribution is expected to be asymmetrical, with a longer but very thin tail to the right.

Detailed data on the distribution of window area is available from recent surveys of 186 new houses in Massachusetts (Lee 2001) and 100 new houses in Arkansas (Brown 1999) (see Figures C.1 and C.2). These figures show the window area as a percentage of conditioned floor area. (Typically sized and shaped houses have gross wall area roughly equal to conditioned floor area on average.)

Several observations are important. First, our expectation of a lower cutoff appears to hold—both studies show very few houses with less window area than about eight percent. Second, the number of houses drops off rapidly as the window-area percentage increases, illustrating that very few houses have very high window percentages (e.g., above 20%). Finally, a large majority of houses have window-area percentages below the 15% level used to develop the DOE proposed code change, meaning far more homes will be more efficient under this change than will be less efficient.

(a) Single-family data: Florida, 16.8%; California, 15.2% to 18.3%; Massachusetts, 16%; Arkansas, 12%; Washington, 14.8%; Oregon, 15.2%; Idaho, 12.7%; Montana, 13.1%; Pennsylvania, 11% to 12%.

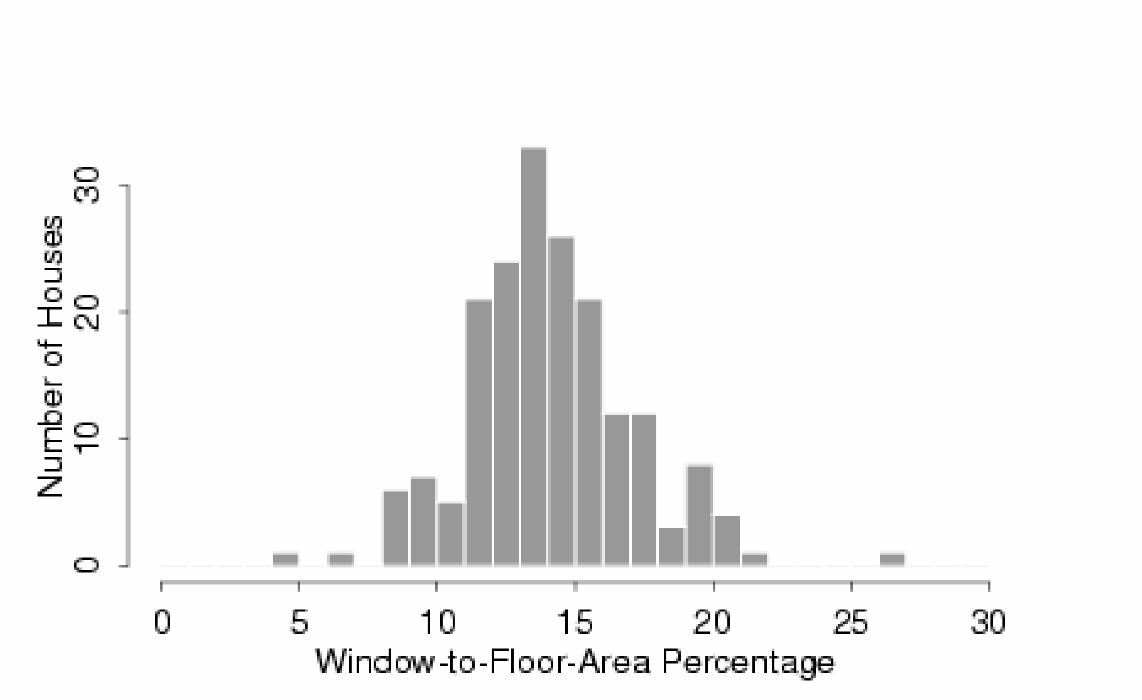

Figure C.1. Histogram of Window-to-Floor Area Percentages in 186 New Houses in Massachusetts

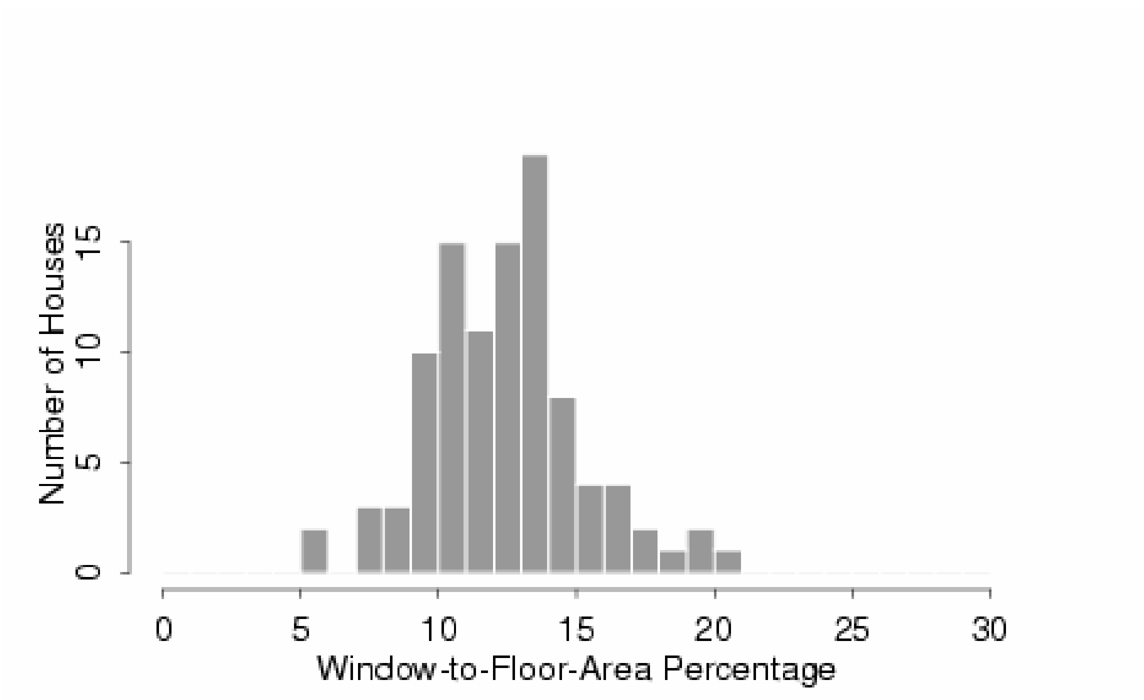

Figure C.2. Histogram of Window-to-Floor Area Percentages in 100 New Houses in Arkansas

Because Massachusetts and Arkansas both have MEC-based codes, one might speculate that the MEC's window-area restrictions are helping to hold down the window area as code compliance becomes more difficult with higher window-to-wall-area percentages (CABO 1995; CABO 1992). However, code compliance rates are known to be generally poor (about 50%), so we do not expect that eliminating the area restrictions will result in substantially more homes in the "unreasonably" high window-area range.

Detailed data sufficient to evaluate the window-area distribution on a national scale are difficult to find. However, the 1993 Residential Energy Consumption Survey (RECS), a detailed survey of 7,111 households, does contain information on the **number** of windows in each house (DOE 1993). This survey included all types of residential units (e.g., single-family detached, apartments, and condominiums—new and old) throughout the United States. The number of windows in the housing units was collected as part of this survey. Figure C.3 shows the number of windows (including sliding glass doors) in each of these 7,111 housing units. Although we cannot infer actual window percentages from these data, we can evaluate the **shape** of the distribution (truncated on left, long thin tail to right), which confirms both our expectations and the limited data from Massachusetts and Arkansas.

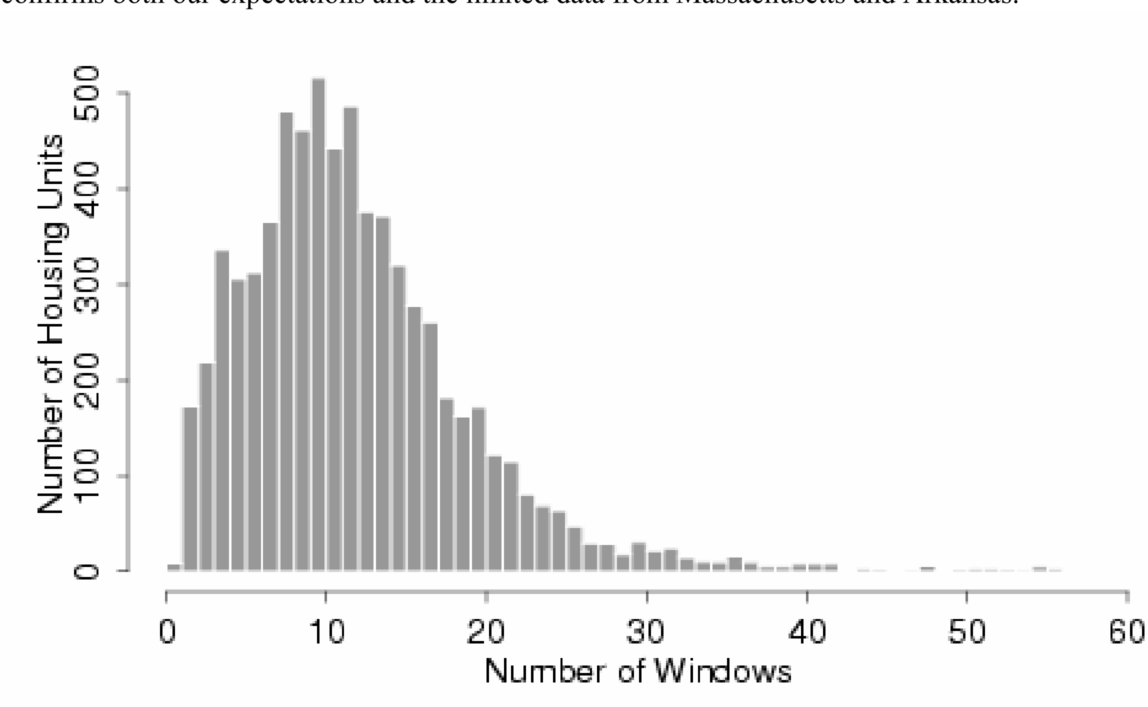

Figure C.3. Histogram of Number of Windows in 7,111 Housing Units from the RECS Survey

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Appendix D – A Survey of Data on Enforcement of Area-Restrictive Code Provisions

As discussed earlier, the calculation of the total window area and in particular the total wall area can be complicated and error-prone. This aspect of the code imposes a burden on both the designer/builder and, perhaps more importantly, on code officials. If the code official does not check the building areas, code compliance and the energy efficiency associated with compliance is in doubt. If the designer/builder happens to err in these calculations on the side that effectively lessens code stringency (lowering the builder's costs), the building will likely be less energy efficient than the code requires.

Code officials generally have little time to check code compliance, and we believe cannot be realistically expected to check the relatively complex calculations of building envelope areas in detail. For example, Fort Collins building inspectors spend an average of 11 minutes to perform each house inspection (*Energy Design Update* 2001). Energy efficiency is likely to be a lower priority in the mind of the code official compared to code requirements related to health, life safety, and important building structural and durability issues. Can code officials who are responsible for literally thousands of individual code requirements be expected to spend five minutes or more on just one element of the energy code?

An informative study is the recent Massachusetts survey of 186 new homes built under the MEC-based Massachusetts energy code (Lee 2001). This study indicates that code enforcement of the envelope area-related requirements in the state's MEC-based code is poor at best. Page D-25 of the Massachusetts report states,

> Though most local building code officials expressed support for the energy code changes, they gave enforcement of those sections of the residential building code lower priority than safety-related issues throughout the application and inspection processes. In the towns we visited, submission of a MAScheck printout showing a passing score was a required part of the application process for a new home construction permit, but in most towns that was about the end of the process. Comparing MAScheck inputs and building plan specifications for net window and wall areas was uncommon. Checking the MAScheck against new homes as they were being constructed was very rare. MAScheck had an important role as a primary piece of documentation, but the lack of follow-up in many communities could encourage permit applicants to "adjust" specifications on plans that might otherwise fail.

(Note: MAScheck is a version of the DOE *MEC*check code compliance software for the Model Energy Code.)

Page D-15 of the Massachusetts report states that, "Some local building code officials closely reviewed the MAScheck printout and checked for correspondence of net wall and window values between MAScheck and the building plans, but most local building code officials said they did not check for correspondence at all."

Page S-4 of the report states that, "As-built characteristics often differed markedly from the characteristics in the permit documents-areas and perimeters varied significantly in nearly 80% of the cases…"

Although all the houses were reported as complying with the code, the detailed inspections done by independent contractors for this study found that 54% of the Massachusetts houses actually failed to comply with the code by varying degrees.

Similar results were found in a study of 100 new houses in Arkansas, a state that adopted the 1992 edition of the MEC (Brown 1999; CABO 1992). Forty-five percent of the Arkansas houses failed to comply with the code. In both the Massachusetts and Arkansas studies, the houses with a higher window-to-wall ratio (WWR) were even less likely to comply. For example, of the ten houses with the highest WWR in the Massachusetts study, nine were found to fail to comply with the code. We also have anecdotal information that the city of Austin, Texas, does not enforce its code's prescriptive requirement of an upper limit of a 16% WWR. Austin is generally considered very progressive in terms of energy efficiency. The concept of requiring houses with high WWRs to have compensating improvements in energy efficiency may be well intended, but it appears to be failing badly in the real world.

In contrast to the experience in states with MEC/IECC-based codes, the Oregon code has uniform prescriptive requirements that do not vary by building design—similar to the format DOE is now proposing for the IECC (Oregon Office of Energy 2001). Oregon simply requires a U-value of 0.4 or better and R-21 wall insulation in every single house as its basic code requirement.

Ecotope surveyed new residences in the Pacific Northwest for the Northwest Energy Efficiency Alliance (Baylon et al 2001). For single-family houses, the Oregon sample of 44 houses had an average window-floor-ratio (WFR) of 15.2% compared to 14.8% in the Washington sample of 157 houses. The Oregon homes have windows with an average U-factor of 0.37, which is considerably more energy efficient than the average of 0.46 in the Washington homes. Very few new houses in Oregon have window U-factors above the code requirement of 0.40.

Ecotope's study, which reviewed a total of 366 new homes in Oregon, Washington, Idaho, and Montana, had the following finding,

> The codes in Oregon appear most successful, both in terms of delivering very efficient homes and in terms of acceptance. In almost no case did we observe significant difference in code compliance; furthermore, this finding is consistent with previous research. This suggests that the code mandated in Oregon has almost completely pervaded the Oregon market.

It is notable that the code compliance rate is very high in spite of Oregon's relatively stringent energy efficiency requirements. Furthermore, Oregon homes do not have a distinctly higher WWR than those in its neighboring state of Washington. Washington and Oregon are similar in climate and demographics, and both have actively enforced energy codes. Washington's code, however, limits window area in a manner similar to that of the IECC (Washington State University Energy Program 2000)

For multifamily buildings, the Oregon sample of 24 buildings actually had a lower average WFR of 12.1% compared to 13.4% in the Washington sample of 25 buildings.

The available data support our conclusion that eliminating the window-area restrictive code provisions will improve compliance without resulting in a substantial increase in average window areas of new houses.

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