Air Tightness of New Houses in the U.S:

A Preliminary Report

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Most dwellings in the United States are ventilated primarily through leaks in the building shell (i.e., infiltration) rather than by whole-house mechanical ventilation systems. Consequently, quantification of envelope air-tightness is critical to determining how much energy is being lost through infiltration and how much infiltration is contributing toward ventilation requirements.

Envelope air tightness and air leakage can be determined from fan pressurization measurements with a Blower Door. Tens of thousands of unique fan pressurization measurements have been made of U.S. dwellings over the past decades. LBNL has collected the available data into its Residential Diagnostics Database database, which it is expanding on behalf of the U.S. Department of Energy. This report documents what is in the envelope air leakage section of the LBNL database with particular emphasis on new construction.

The work reported here is an update of similar efforts carried out a decade ago, which used extant data largely focused on the housing stock rather than on new construction. The current effort emphasizes shell tightness measurements made on houses soon after they are built. These newer data come from over two dozen datasets, including over 22,000 measurements spread over a majority of the U.S. Roughly one-third of the measurements are for houses identified as energy-efficient through participation in a government or utility program. As a result, the characteristics reported here provide a quantitative estimate of the impact that energy efficiency programs have on envelope tightness in the US as well as on trends in construction.

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Keywords: Infiltration, Ventilation, Air Leakage, Indoor Air Quality, Energy, Blower Door, Fan Pressurization, Measurements

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INTRODUCTION

Virtually all knowledge about the air tightness of buildings comes from field measurements using *fan pressurization* with *Blower Door* technology. Blower Doors measure air tightness of the building envelope, or equivalently, *air leakage*. Sherman (1995) reviewed the history of the Blower Door and how its results can be used. ASTM Standards such as E779 define the appropriate test method to use.

Air leakage data are now used for a wide variety of purposes from the qualitative (e.g. construction quality control) to the quantitative (e.g. envelope tightness standards). As the key envelope property related to airflow, it is used in one form or another for infiltration-related modeling. Infiltration is the interaction of this envelope tightness with driving forces such as those caused by weather. Given such diverse uses, it is not surprising that it is often treated as a stand-alone quantity, even though air leakage is only an intermediate value.

Sherman and Dickerhoff (1994) have previously summarized the leakage of U.S. housing. Sherman and Matson (1997) based their analysis of residential ventilation rates and associated energy costs on those data. That dataset gave a good snapshot of the air tightness of U.S. building stock at the time it was taken, but the stock has changed in the intervening years. More importantly, that dataset under representes new construction. While such under representation does not materially impact conclusions for the stock of dwellings as a whole, it does not allow any conclusions to be drawn regarding newly built houses.

Beginning in the 1980s, concern for energy caused the energy efficiency of new houses to improve through a variety of regulatory and voluntary means. As dwellings became more air tight, the concern for new construction became whether new houses were too tight. Sherman and Matson (1997) investigated optimal tightness levels for the stock. Wray et al. (2000) have looked at how tightness levels would interact with proposed residential ventilation standards in the U.S.

The Lawrence Berkeley National Laboratory has an on-going activity to upgrade its database on the air leakage of dwellings. Data collection continues, but at the time of this writing, there are over 80,000 individual entries in the database. Only about a quarter of these data, however, has been vetted sufficiently for use in analyses. Since the purpose of this report is to summarize the current state of knowledge with particular emphasis on the air tightness of new construction, our data screening efforts have given priority to the screening of new construction.

LEAKAGE DATA

Very little of the leakage data used in this report was actually taken by the authors. Instead, others generated the vast majority of the data as part of a program for some other purpose. Not surprisingly, the data were not taken in any single uniform manner or using a single protocol. For the purposes of this study, all data were converted to the same set of variables. Some of the key parameters are listed below:

- *NL*, the Normalized Leakage[1] is the single most important variable as it is the primary leakage variable. It is normalized for dwelling size. Methods for converting from other leakage variables can be found in Sherman and Dickerhoff (1994) or other air leakage references. All entries must have enough data from which Normalized Leakage can be calculated to be included in the database. This is the primary variable used to quantify leakage in this report.

[1] Roughly, the normalized leakage is 1/20 of the air changes at 50 Pascals pressure, but the defining relations can be found in ASHRAE Standard 119, in Sherman and Matson (1993), or in the references above.

- *n;* the pressure exponent from the power-law fit to the data is not always provided nor can it always be calculated from the data provided. In such cases, the exponent is assumed to be 0.65. Because very few of the new house observations included measured exponent data, we will not consider the exponent further in this report.
- *A;* Floor Area is the most basic size parameter, but volume and building height are also included. Often, at least one of them is calculated. The primary value of the floor area in this analysis is to normalize the blower door data to calculate the Normalized Leakage.
- Date of construction. For some datasets, especially in older dwellings, date of construction is poorly defined; for some others, it is not known at all. For all the data in this report, the date of construction is either known or can be inferred.
- Date of leakage test: Usually, but not always, the date of the leakage test is known. There may be more than one leakage test on the same house. The data for "new" houses include only leakage tests made during the year of construction or in the following year.

The Normalized Leakage for the approximately 22,000 data points considered in this report averaged NL=0.95. The standard deviation, however, was almost as big as the mean at 0.92. Figure 1XXX is a histogram of all of these data points.

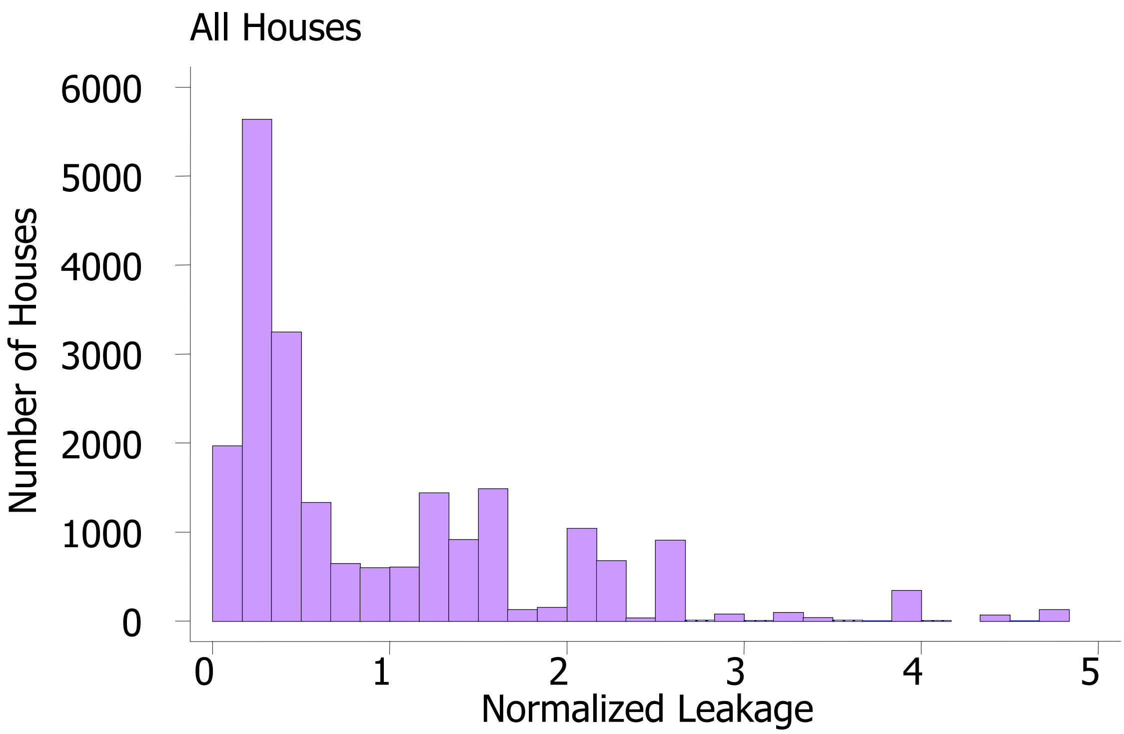

FIGURE 1: Distribution of Normalized Leakage (NL) for approximately 22,000 measured houses currently in LBL Database. Mean is 0.95.

A careful examination of these data shows that there appear to be two distributions superposed. There is a narrow distribution of tight houses and a broad distribution of leaky houses. As we shall see below, these two distributions resolve into new vs. existing houses.

For the purposes of this report, we are using the term "new" to mean that the tightness of the house was measured when new. The house could have been built in any year, but if it was tested in that or the following year, we label it is "*new*". Approximately 8,300 of the houses in our dataset of almost 22,000 qualify as new by this definition. Table 1 gives a breakdown of the location within the U.S. of our data.

Table 1 : Location of measured leakage data used in this report.

State	Existing Houses	New Conventional	New Energy-Efficient
Alabama	30		
Alaska	3264		4437 (AKWarm)
Arizona	27	98	369
Arkansas	430		
California	425	93	6
Colorado	13	38	79
Connecticut	1	2	7
Florida	267	72	468
Georgia	7	1	1
Idaho	84		5
Illinois	258		165
Indiana	1		
Iowa	2		
Kansas			305
Maine	3		
Massachusetts	3	13	164
Michigan			
Minnesota	50	1	101
Missouri	11		2
Montana	19		
Nevada	30		198
New Hampshire	1		11
New York	236		
North Carolina	113	55	57
Ohio	2	2	70
Oklahoma	108		23
Oregon	106		
Pennsylvania			6
Rhode Island	4299	3	21
South Carolina	2	6	8
Texas	96	16	97
Vermont	1087		823
Virginia	2		
Washington	258		
Wisconsin	1820	301	113
Unknown	338		4
Total	**13393**	**701**	**7540**

If we separate out the new houses, the remaining dataset for existing houses has an average leakage of NL=1.4 and is spread out quite broadly. Although it includes data for different existing houses, the general size and shape of the distribution remains consistent with that reported by Sherman and Dickerhoff (1994).

RESULTS FOR NEW CONSTRUCTION

The distribution of new houses is quite different from that of existing construction. The average leakage of the new houses in this dataset is NL=0.27, with a standard deviation approximately half the mean. The ACH50 of 5 this represents would be considered leaky for Northern Europe, but is quite an improvement in the U.S. Figure 2 is the histogram of all the new houses in our dataset and displays this effect.

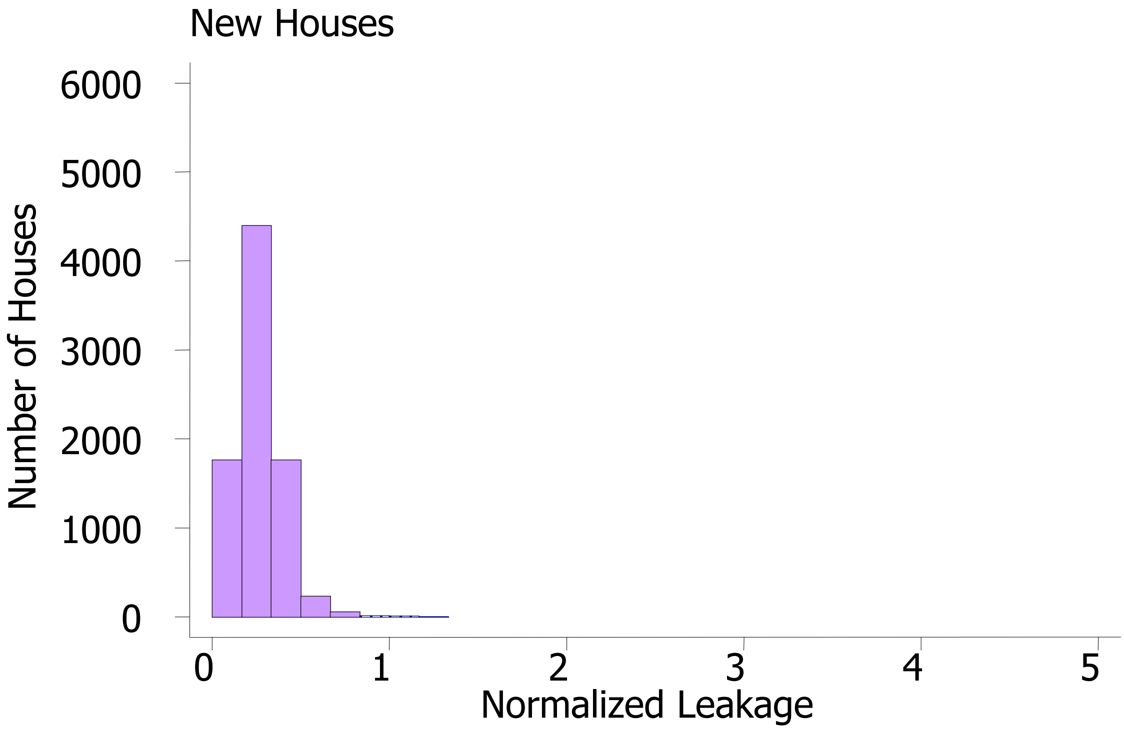

FIGURE 2: Distribution of Normalized Leakage (NL) for approximately 8,300 *new* houses currently in LBL Database. Mean is 0.27.

Energy Efficiency Programs

Energy efficiency programs have had a major impact on reducing the overall energy requirements of new construction, but it is not clear how they have impacted air tightness. Few programs in the United States require that specific leakage performance targets be met. It is much more common for programs to have prescriptive requirements for caulking, weather-stripping, etc. One objective of this paper is to determine the impact of these programs.

To evaluate this effect, we have broken up the new home dataset into three broad categories:

- *Conventional:* Conventional houses are ones that were not built as part of any energy efficiency program. Most of them were measured as part of some voluntary program. Many of the builders knew that their houses would be tested, but no special energy efficiency features were installed. Approximately 700 houses fall into this category.

- *AKWarm*: Approximately 7,500 new houses were identified as energy efficient, but most of them come from a single program of a single state, the AKWarm program in Alaska. We have, therefore, separated out this dataset because it is quite possible that a large broad-based program could behave quite different from other programs that may try to focus more on early adopters. There are approximately 4,400 houses in this category.

- *Energy Efficient.* There are many federal, state, and local programs that try to attract leading edge builders to demonstrate improved construction techniques for new homes. In this type of program, resources are provided to the builder to help him improve the energy efficiency of his new homes with the hope that techniques will find their way from these early adopters to main-stream builders. Approximately 3100, non-Alaskan houses fall into this category and mostly come from either the *Energy Star* or *Building America* programs.

The summary of this analysis in included in Table 2 below:

Table 2: ***Breakdown of Leakage for New Construction Programs***

Program	Normalized Leakage (NL)	Standard Deviation
Convetional	0.29	0.15
Energy Efficient	0.31	0.13
AKWarm	0.23	0.10

As one might expect, the energy-efficient programs produced tight. Surprisingly though, the control houses were tighter than that and the AKWarm houses were even tighter. These differences are statistically significant, but the relatively small number of control houses and the uneven regional distribution of the three categories suggest the possibility of non-representative samples.

If we apply ASHRAE Standards 136-93 and 62-99 to these tightness levels, we can calculate the contribution that infiltration can make to meeting ventilation requirements for new construction. Taking any of these categories, we find that very few can meet the requirements using infiltration alone. Because of the extreme climate and increased leakage, the new houses in Alaska come close; for most of the rest, it appears that infiltration can make up only about half the ventilation requirements.

Trends over Time

Because our definition of “new” has nothing to do with today’s date, but only the test date and the construction date, our dataset contains “new” houses that were built over broad time period. This allows us to see how the air tightness of new construction has changed over time. Figure 3 is a trend plot for all houses constructed since 1993, showing both the means and standard deviations for each year.

It appears that there may have been a trend toward tighter houses that bottomed out around 1997. The trend appears stronger that it is because of the impact of 1993 and 1994, which have a relatively small sample size. The apparent trend may have more to do with changes in the size and location of the construction each year than in overall size.

As indicated by the spread bars in the figure, this trend is smaller than the variation between houses. The data suggests that the trend toward tighter envelope construction may be over and that it has reached steady state. Further improvements in air tightness, if desired, would require new kinds of programs.

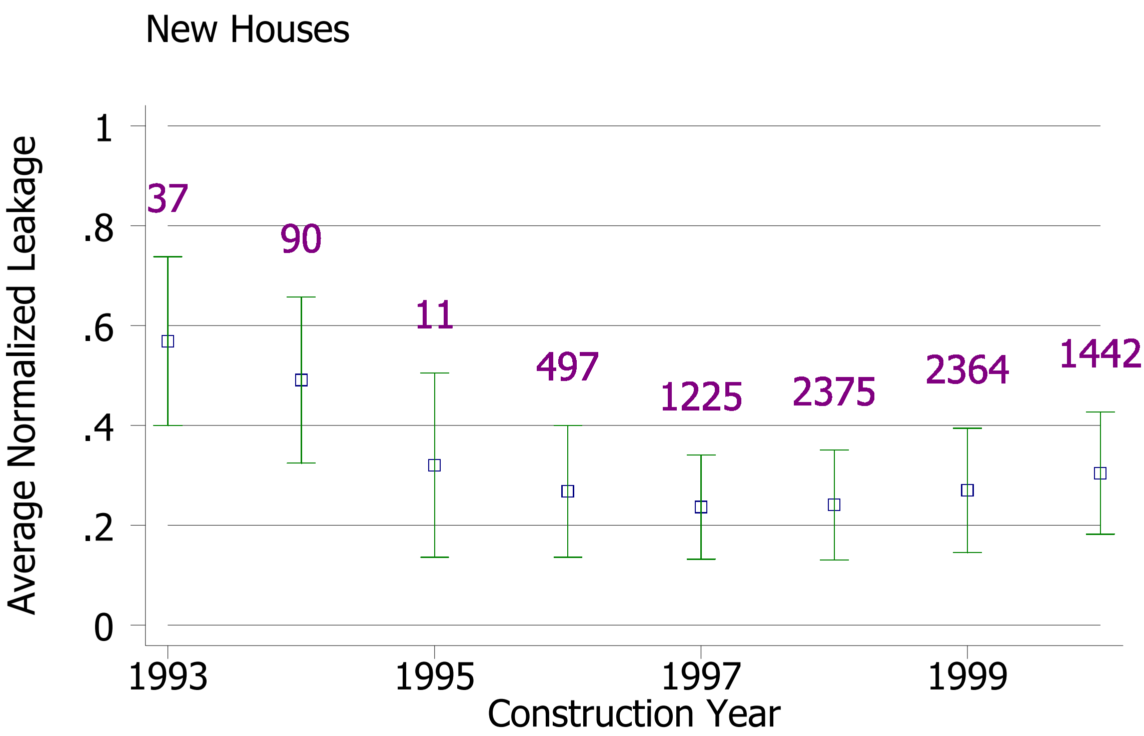

FIGURE 3: Normalized Leakage for new houses by year of construction. Size of bars indicates the standard deviation of the sample for each year. Numbers above bars indicate sample size.

DISCUSSION AND CONCLUSIONS

Sherman and Matson (1997) estimated average NL of the U.S. stock to be about 1.2. The uncorrected data in this study corroborates that general size, but more importantly demonstrates that new construction is significantly tighter than the stock as a whole.

Sherman (1999) evaluated how air leakage could contribute to meeting the residential ventilation standard currently being proposed by ASHRAE and found that air leakage alone is rarely good enough to meet minimum ventilation standards in houses having a normalized leakage less than 0.5. Our data suggest that most new houses in the U.S. need some form of additional ventilation. Natural ventilation, passive ventilation, and mechanical ventilation can all be used effectively in some situations to meet minimum requirements.

Our data also suggest that the air tightness of new construction is no longer improving. Builders have made a step change of improvement at some time in the past. While this level of air tightness is insufficient to meet ventilation requirements alone, there are still energy savings opportunities available through further tightening, but they require looking at the house as a system, since air leakage can either be a positive or negative contributor[2] to a designed ventilation system.

The most surprising result is that leading-edge energy efficiency programs in the United States are apparently not producing houses that are significantly tighter than more conventionally constructed new houses. While there certainly are builders who can make very tight houses, the majority of those builders in many energy efficiency programs apparently do not. We can speculate that this is due to the voluntary nature of some of the programs, which often does not require performance verification. More detailed investigation is warranted, however, to understand this issue more fully.

The AKWarm houses appear to be substantially tighter than other energy efficient houses. Given the severe climate in Alaska it is not unreasonable to expect a greater sensitivity to air leakage

[2] The topic of how air leakage and infiltration impact total ventilation is too extensive an issue to discuss in this report. Many of the references cited discuss it in more detail. Other references can be found in AIRBASE at http://www.aivc.org

issues. Some of this difference, however, may be due to different construction and operating practices used there. For example, it is not uncommon for attached garages to be fully part of the conditioned area of the house and to have tight fitting doors to outside. Because of the way NL is normalized the addition of the garage area could reduce the normalized leakage.

The conclusions of this study are subject to revision as the size of our usable database increases. Twenty thousand non-representative houses can allow us to draw conclusions, but still could contain bias errors that are not easily visible. The authors are continuing to both collect data from people who are taking it and to process those data into a form suitable for the database.

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