CHAPTER 2: Air-Tightness

2.1 Residential Diagnostics Database

Air leakage is a key factor in determining air infiltration, which provides most of the ventilation in existing dwellings. Leaky homes use more energy to heat and cool them. Occupant comfort can also be a problem in drafty homes. On the other hand, homes that are built with a very tight envelope may need mechanical ventilation to maintain good indoor air quality. Therefore, to improve residential energy efficiency and indoor environmental quality, it is important to understand the current air leakage characteristics of U.S. and California homes and the factors that are associated with excess air leakage.

To characterize the U.S. housing stock, researchers analyzed air leakage data of 134,000 single-family detached homes, including 4,500 homes in California. This data was used to develop the Residential Diagnostics Database (ResDB) which contains blower door measurements and other diagnostic test results, such as duct leakage measurements, of U.S. homes. Approximately two-fifths of the data were contributed by various sources in response to a call-for-data issued in 2011. The remaining three-fifths of the data had been analyzed previously by LBNL. A comparison of the house characteristics between the recently gathered data and the previously analyzed data are described in Chan and Sherman (2011). Overall, about half of the data were contributed by low-income qualified Weatherization Assistance Programs (WAPs). Two other major sources of data included residential energy-efficiency programs that are often sponsored by utilities and new homes tested for air leakage to obtain an energy-efficiency rating or to meet air-tightness guidelines. Forty-three states are represented in ResDB. Even though ResDB is not a representative sample of U.S. homes, the median floor area of 140 square meters (m^2) and year built (1970) are similar to the characteristics of the U.S. housing stock (160 m^2 and built in 1974), based on data from the American Housing Survey. The California homes in ResDB have a similar median floor area of 170 m^2, and they tend to be newer. Approximately 20% of the California data are from new houses built in 2000s. The remaining houses have a median year built of 1973.

In California, there are ongoing efforts by WAPs and residential energy efficiency programs to improve the air-tightness of homes. The analysis of both types of data quantifies the reduction in air leakage by comparing the pre- and post-retrofit measurements, which has a direct impact on the energy savings achieved by these programs. Another important question for California homes is how the air-tightness of new homes compares with the standard design value used in Title 24. For dwellings with ducted heating, ventilating and air -conditioning (HVAC) systems, the specific leakage area (SLA) design value is 3.8, which corresponds roughly to 6 ACH_{50}.[1]

Air Leakage Analysis of U.S. Homes

[1] Air changes per hour induced by a 50 pascal pressure from a blower door.

Normalized leakage (NL) is the air leakage metric used in the regression analysis. Blower door data measured at a 50 pascal (Pa) pressure difference were converted to NL such that the relative air leakage of residences of different sizes can be compared. The normalization is based on house height and floor area. Chan, Joh et al. (2012a) describes the method used to compute NL and the assumptions that are made to approximate house height and floor area if data are missing. The distribution of NL is roughly lognormal, with a geometric mean of 0.61 and a geometric standard deviation of 2.5. Most of the blower door data only provided a single value of air leakage flow (e.g., CFM_{50}[2]). In those cases, the pressure exponent[3] is assumed to equal the common value of 0.65 when computing NL. In cases where the pressure exponent is given, the reported value is used. There are 7,000 such measurements in ResDB, the distribution of pressure exponent is normal, around 0.65, with a standard deviation of 0.057.

Multiple linear regression is used to identify the housing characteristics that explain the observed variability in NL. Details of the models used, transformation of the explanatory variables, and the regression results are described in Chan, Joh et al. (2012a). The housing characteristics considered include year built, International Energy Conservation Code (IECC) climate zone, floor area, house height, foundation type, duct location, and whether the home participated in WAPs or were energy-efficiency rated homes. Only floor area and house height are continuous variables; all others are indicator variables. Six categories of year built are used to represent homes built from prior-1960 to after-2000. Homes are divided into twelve climate zones following IECC classifications:[4] five in humid (A) climate, three in dry (B) climate, and two each in marine (C) and Alaska (AK) climate (Chan, Joh et al. 2012a). These classifications are used to represent potential differences in the air leakage of homes situated in various climate zones in the US. The foundation types considered were slab, basement (conditioned or unconditioned), and crawlspace (vented or unvented). Ducts were classified as located inside the conditioned space, in the attic or basement, or in the crawlspace.

Different methods were used to account for missing data. For example, only three-quarters of the data provided year built. Using this subset of "year built" data, the analysis showed an inverse relationship between year built and logarithm of Normalized Leakage decreasing by 0.14 per decade. Missing data for year built were calculated using this relationship. A different approach was used to handle missing data for foundation type and duct location. Since only very few data provided this information (12,500 houses with known foundation type, and 526 with known duct locations), the regression analyses were performed step-wise: first leaving out

[2] CFM_{50} is the airflow (measured in cubic feet per minute) that is needed to create a 50-pascal change in building pressure.

[3] The relationship between airflow and pressure difference across the building envelope is commonly expressed as a power law function, where the pressure exponent is the power of the function.

[4] See http://energycode.pnl.gov/EnergyCodeReqs/ for IECC climate zone classification.

these two parameters using the entire dataset, and then using a subset of the data where the parameter is known. The final regression model simply assumed that the coefficient estimated from each step of the analysis applied to all homes.

Year Built and Climate Zone

The regression model explains 68 percent of the observed variability in NL. Much of the variability observed in NL is associated with climate zone and year built. For example, the study found that the difference in NL between the warmest, humid climate in the United States (Southern Florida), Texas, and other southern states and the coldest (Alaska) was a factor of 2.7 (Chan, Joh et al. 2012b). The difference in NL between prior-1960 and after-2000 homes is a factor of 2.2. The least-squares fitted coefficient is statistically significant at the 95 percent confidence interval. The only exception is IECC climate zone B-4,5, meaning that the model found homes in climate zone B-4,5 to be somewhat more airtight than homes in the reference zone A-6,7, but the difference is small and may have occurred by chance in the data sample. The final model includes all twelve climate zones for completeness, and also because combining homes in B-4,5 and A-6,7 has little effect on the resulting coefficient estimates.

Energy-Efficiency-Rated Homes

Energy-efficiency-rated homes tend to have NL 30 percent less than comparable homes. New homes that are ENERGY STAR certified are examples of homes in this category, but there are differences in how the efficiency ratings are defined in ResDB. Such definitions have also changed over time. For example, between 1995 and 2006, ENERGY STAR Version 1 was used. Version 2 became effective in 2007. The current Version 3 specifies ACH_{50} to be less than 6 (or 3 in certain climate zones). Even so, the regression model consistently found energy-efficiency-rated homes to have about 30 percent lower NL throughout these time periods. Therefore, it appears that homes that are rated for energy efficiency continue to be built with a more airtight building envelope than the average U.S. housing stock.

Weatherization Assistance Programs

The regression model suggests homes that participated in WAPs are leakier than conventional homes; they tend to have (pre-weatherization) NLs that were 50 percent higher than comparable homes. Eligibility for WAPs is based on household income, so it is reasonable to assume that the result applies more broadly to homes that are occupied by low-income households in general. In 2009, WAPs used an income upper-limit of 200 percent of the federal poverty level lines as the eligibility criteria, but over the years this had varied between 125 percent and 150 percent. There are 13,100 WAPs homes in ResDB with pre- and post-weatherization blower door measurements. Paired comparison shows a median reduction in air leakage of 30 percent. In comparison, data from 10,000 homes in ResDB that were retrofitted by other non-WAP residential programs show a median reduction of 20 percent (WAPs homes possibly showed greater improvements in air-tightness because they were leakier before they were weatherized and therefore, had more opportunities for air sealing. This is supported by an

analysis that showed that the magnitude of air leakage reduction is correlated with NL pre-improvement.

Foundation Type, Duct Location, and Other Factors

The remaining factors considered in the regression model, namely floor area, house height, foundation type, and duct location, each explain some differences in NL in the 10 to 20 percent range. In comparison, their importance is secondary for predicting NL. Houses built on concrete slab are common in some parts of California. The regression results suggest that homes with either a conditioned basement or an unvented crawlspace tend to have NL 16 percent higher than homes on slab. Homes with either an unconditioned basement or a vented crawlspace tend to have NL 24 percent higher than homes on slab. Estimates of the coefficients indicating duct location are more uncertain because the analysis is based on very few homes. In California, homes typically have ducts in the attic or the basement. The regression results suggest homes with ducts inside the conditioned space tend to have NL 18 percent lower in comparison, and homes with ducts in the crawlspace tend to have NL 12 percent higher.

Air-Tightness of California Homes

A separate regression analysis was performed on 4,500 California single-family detached homes. These homes represent 13 of the 16 Energy Commission climate zones; there are no data from zones 1 and 5, and too few data from Zone 15 for our analysis. Some of the climate zones are further grouped together such that they are more equally represented in the model. For example, the initial regression model using all 13 climate zones suggests that houses located in the Central Valley and inland (zones 10 to 16) tend to have lower NL, all else being equal. Houses in the coastal areas have higher NL in comparison, especially in zone 2. This resulted in seven groups of climate zones being modeled (ordered from the leakiest to the most airtight, and the representative city):

- Zone 2 (Santa Rosa)
- Zones 7 and 8 (San Diego and El Toro)
- Zones 3 and 6 (Oakland and Los Angeles)
- Zones 4 and 9 (Sunnyvale and Pasadena)
- Zones 11 and12 (Red Bluff and Sacramento)
- Zones 10 and 16 (Riverside and Mt Shasta)
- Zones 13 and 14 (China Lake and Fresno)

Figure 2.1.1 shows the NL of California homes in the different climate zones and year built predicted by the regression model. The model predictions are for a single-story (height at 3.5 meters, m) home with a floor area of 150 m^2. The corresponding air changes at 50 Pa (ACH_{50}) predicted is shown on the right x-axis.

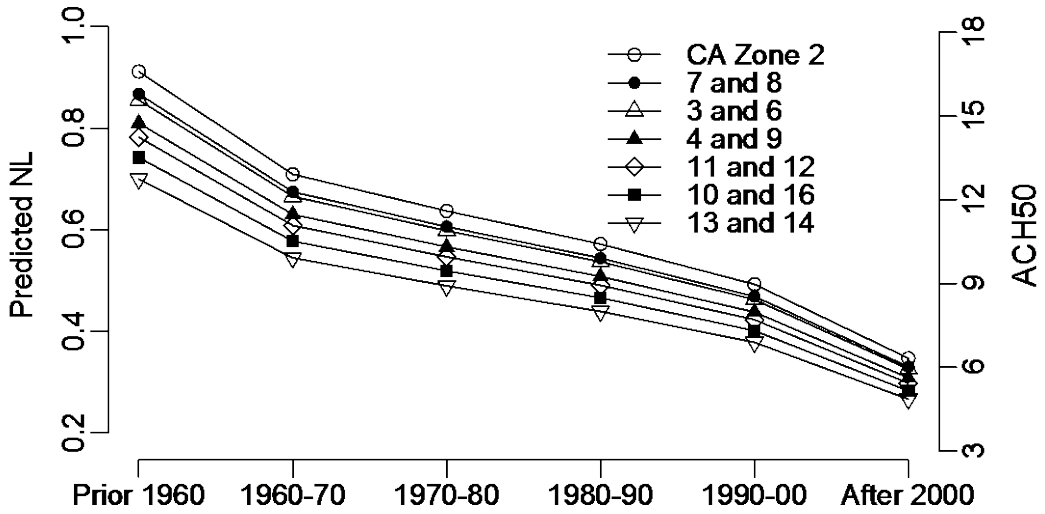

Figure 2.1.1: Normalized Leakage (NL) of California Homes in Different Climate Zones, and as a Function of Year Built, Predicted Using the Regression Model

The regression model explains 76 percent of the observed variability in NL among the California homes. Houses in zones 13 and 14 are predicted to be 23 percent more airtight than houses in zone 2. The NL of houses in other climate zones are somewhere in between these two extremes. The California model shows a slightly stronger dependency on NL with respect to year built than the U.S. model. Houses built in 1980s tend to have NL 60 percent higher than houses built in 2000s. In comparison, the U.S. model predicts the difference to be 50 percent The California model also predicts a stronger relationship between NL and house height. It predicts that two-story houses tend to have NL 32 percent higher) on average, compared to single-story houses. On the other hand, houses that participated in WAPs in California are less different from non-WAP houses, with a difference of 30 percent compared to 50 percent nationally. The improvement from retrofit for California homes is 20 percent, including WAPs and other energy-efficiency programs. The relationship between NL and floor area for California houses is similar to the U.S. model.

California homes that are rated for energy efficiency tend to have NL 30 percent lower than typical homes. However, it is important to note that data from most of the 170 energy-efficient houses in California used in the study were collected prior to 2001, so this result may be outdated. With the current Title 24 having a standard design value that is equivalent to the envelope air-tightness guideline in ENERGY STAR, it is possible that this difference of 30 percent no longer applies for California homes built to meet Title 24 in 2008. To further explore the changes in air-tightness of California houses that can be attributable to construction improvements, only measurements that were collected within five years of construction were considered. This subset of California data included only houses built since 1985, because prior to this time blower door testing was not a common diagnostic test. After adjusting for other parameters, such as climate zone and floor area, the NL of this subset of California houses

continue to decrease with construction year. In the past ten years between 2001 and 2011, this analysis suggests a 23 percent reduction in NL.

Research Implications and Relationship to Home Energy Saver

The regression models for California and the United States can be used to estimate a distribution of normalized leakage based on housing characteristics. This basic information is required to estimate air infiltration rates, and subsequently for evaluating the energy use and ventilation needs of single-family homes. To make these research results more accessible to the building community, the regression model is available online (http://resdb.lbl.gov/). The online calculator accepts user inputs of housing characteristics and gives estimates of NL and ACH_{50} accordingly.

This model enables software tools such as Home Energy Saver to more reliably predict the energy benefits from air sealing based on housing characteristics. This analysis shows that homes with certain attributes tend to have higher air leakage than others. This information can be used to target homes that would benefit the most from air sealing as a measure to reduce their energy consumption on heating and cooling. The pre-and-post retrofit comparisons from WAPs and other residential energy-efficiency programs provide data on air-tightness improvements currently being achieved. This important information is needed by Home Energy Saver to calculate the energy impact of air infiltration, and to recommend energy saving measures that are suitable for homes given their characteristics.

2.2 Multizone Leakage Methods Analysis

Inter-zone leakage can have a negative impact on indoor air quality, through chemical transport from an attached garage to a house or between units in multifamily housing. Inter-zone leakage testing methods are also used for energy-efficiency objectives to identify leakage pathways in multifamily homes or single-family homes with adjacent attic or basement zones, so that these leakages can be reduced to improve energy efficiency of the homes. While a number of strategies have been used to determine inter-zone leakage, currently no standard exists for this measurement. The objective of this subtask was to identify the most accurate methods to quantify the inter-zone leakage using fan-pressurization testing. Various data collection and analysis methods were compared using both synthesized datasets and field data. Results of the field data and simulations are used to identify the most robust methods and to quantify the uncertainty of the different methods. Additional details of this analysis can be found in Hult, Dickerhoff and Price. (2012).

2.2.1 Measurements of House Garage Leakage

A set of field data was collected and analyzed to determine the leakage between a single-family house and an attached garage. The same methods could be used for any adjacent zones, such as townhouses. Data for six homes were collected in a variety of test configurations using one or two blower doors and a variety of test procedures and corresponding analysis techniques. For the homes tested, leakage area between the garage and house averaged 5 percent of the leakage

area between the house and outdoors. This varied considerably from home to home; the fraction was as high as 45 percent in one home. These results are consistent with previous studies, which found that the garage-to-house leakage area is typically only 5 to 15 percent, but can be large—as high as 50 percent—in a minority of homes. Estimates for the calculated inter-zone leakage varied over an order of magnitude, depending on the testing and calculation method used, with certain methods providing much more consistent results than others do.

2.2.2 Measurement Technique Analysis

To assess the accuracy of different testing methods under a wide range of conditions, synthesized data analysis using Monte Carlo simulations was used. These simulations varied the magnitude of the leakage area and the magnitude of fluctuations in the systematically generated synthetic data for measured pressure and flow rate. The placement and number of blower doors was also varied. We also explored different assumptions in the calculation process, including measuring the flow through the blower door at a single pressure rather than at a range of pressure stations.

The synthesized data analysis to test the methods and conditions described above first involved generating the exact leakage parameters for a two-zone leakage case. Then measurement noise and bias was added to the exact solution to get a synthesized dataset. Various analysis methods were then applied to the synthesized dataset to determine how accurately the exact parameters could be determined. Because certain quantities in the generation of the synthesized dataset are randomly selected, this process was repeated for a large number of iterations to determine not only the median result, but also the result one standard deviation above and below the median result, to describe the distribution of the uncertainty resulting from different methods. This approach allowed direct comparison between a range of testing and calculation methods by applying the different methods under the same conditions.

2.2.3 Key Results

- The best of the measurement and analysis methods was the method developed by Herrlin and Modera (1988), which uses two blower doors simultaneously to determine the inter-zone leakage to within 16 percent, over the range of expected conditions.
- When two blower doors are used simultaneously, there is a large range of combinations of pressure stations at which testing can be performed. While some two blower door methods consistently obtained accurate results, many did not give accurate results. If using two blower doors, care should be taken to follow a recommended testing procedure such as the Herrlin and Modera method.
- The best single blower door methods (the 991/190 method in Hult et al. (2012)) were able to determine the inter-zone leakage to within 20 percent of its value.
- Poor testing and calculation methods can lead to errors of up to 100 percent in the inter-zone leakage area.

- The choice of analysis method can reduce uncertainty in the calculation of house-garage leakage significantly. Making the assumption that the pressure exponent for the inter-zone wall is 0.65 was better than fitting for that pressure exponent, regardless of how many pressure stations were used. Additionally, the uncertainty was reduced by fitting a single set of parameters to both pressurization and depressurization data, rather than having separate parameters for pressurization and depressurization.
- The single pressure station approach could not reliably be used to determine inter-zone leakage due to uncertainty in measured quantities and the pressure exponents in the different interfaces. If the objective is simply to identify which inter-zone partitions may have high leakage flows for air-sealing purposes, using a single point testing may be sufficient.
- If it is determined that the zone to outdoor leakage of the two zones is comparable, however, then it is possible to use the single pressure station approach to determine the inter-zone leakage to within 20 percent.
- Analysis of field datasets confirmed a level of variation between test methods that was consistent with the analysis of synthesized datasets.
- The Monte Carlo approach was also applied to the air leakage of a single zone, to illustrate the contribution of different assumptions to the overall uncertainty in the leakage area.

2.2.4 Implications

As California homes become more energy efficient, exterior building envelopes will get tighter. For multizone spaces the issue of interzonal leakage will rise in importance, particularly for understanding the transfer of contaminants. This study has shown that it is possible to develop an optimized test method that allows one to measure inter-zonal leakage for two adjacent zones. Furthermore, the optimized test methods are dramatically better than other possible methods to test inter-zonal leakage. In addition, a substantial fraction of homes in California are multifamily structures, and the ability to measure interzonal leakage is crucial for examining IAQ and energy issues in these buildings.

For homes with attached garages, there is ambiguity on where the air barrier and pressure boundary should be. If there is high leakage between the house and the garage, garage contaminants might be drawn into the occupied space when simple exhaust ventilation systems are used. In addition to the leakage area, the operational pressure difference between two adjacent zones will have a strong influence on the transport across inter-zone boundaries, and this pressure difference is not well characterized for homes with attached garages. Further research is necessary to model the impact of this and to set measurable and achievable limits on the house garage leakage. Such research is part of the necessary efforts to ensure that future versions of Title 24 do not create health or safety risks by enhancing contaminant transport.

Interest in energy efficiency in multifamily buildings requires a better understand of the leakage between apartments. Leakage between apartments is an indirect energy issue and a direct indoor air quality issue. This effort has helped to define optimal measurement techniques and reasonable expectations for what could be measured, but they are not yet developed to the point where they can be used programmatically. For example, if more than two adjacent zones are present, as is the case in many multifamily housing buildings, the methods developed here can be extended to determine the leakage between any two adjacent zones. Future work could refine and demonstrate the protocols that have been developed in this section so that they can be more widely implemented in practice.

2.3 Energy Benefits of Air Sealing

Effective residential envelope air sealing reduces infiltration and associated energy costs for thermal conditioning, yet often creates a need for mechanical ventilation to supply acceptable indoor air quality. Current best practice seeks to make homes as airtight as possible and provide controlled ventilation with mechanical systems. Ventilation is required to remove indoor-generated pollutants and excess moisture, and to provide a sufficient supply of outdoor air to ensure acceptable IAQ.

To develop effective programs and protocols for practitioners, it is necessary to develop the analytical capability to predict the benefits of increasing residential envelope air tightness and the costs and IAQ benefits of various ventilation system approaches and technologies.

The potential benefits of air sealing and the costs of mechanical ventilation vary widely across individual homes and for sub-populations by climate; baseline air-tightness and other building structural characteristics; the performance characteristics of existing or replacement HVAC equipment; and occupant-influenced equipment operational schedules and settings.

RESAVE developed an Incremental Ventilation Energy (IVE) model to enable analysis of air sealing and ventilation impacts across sub-populations of homes by type, location, and other factors. A very useful feature of the model is that it provides results in the form of distributions across the housing sub-populations examined. It provides robust estimates of variations of costs and benefits across homes, as well as the uncertainties associated with unknown or poorly understood parameters.

The IVE model applies empirically verified approximation approaches to calculating airflow impacts of air sealing or adding mechanical ventilation to a large sample of homes that have been characterized in existing databases. In the Logue, Turner, Walker and Singer (2012) report (www.homes.lbl.gov), the IVE model is described and applied to predict results for a range of home types, climates, and ventilation systems that span those features of the U.S. residential housing sector . The energy changes predicted by the IVE model are compared against those predicted by the REGCAP model, which is an extensively validated, physics-based simulation model of air, energy, and moisture flows for residential buildings.

The IVE model was also used to estimate the potential energy savings of implementing air sealing or absolute standards for air-tightness along with mechanical ventilation throughout California and the entire U.S. housing stock (Logue, Sherman, Walker and Singer 2012). We calculated the change in energy demand for each home in a nationally representative sample of 50,000 virtual homes developed from the 2009 Residential Energy Consumption Survey. Ventilation was provided as required by ASHRAE 62.2-2010 and the proposed 2013 versions of the standard. The estimated impacts of achieving envelope tightening and mechanical ventilation for the entire U.S. housing stock are summarized in Table 2.3.1. Ensuring that all current homes comply with 62.2-2010 would increase U.S. residential site energy demand by 0.07 quads annually. Improving air-tightness of all homes at current average retrofit performance levels would decrease demand by 0.7 quads annually. Upgrading each home to be as airtight as the top 10 percent of similar homes would double the savings (1.4 quads), leading to roughly $22 billion in annual savings in energy bills. The impacts of achieving envelope tightness for California are summarized in Table 2.3.2.

We also analyzed the potential benefits of bringing the entire stock to air-tightness specifications of IECC 2012, Canada's R2000, and Passive House standards. The results indicated that significant benefits would result from increasing the tightness of weatherization and energy-efficiency programs, though most of the potential benefit of bringing all homes to an absolute air-tightness standard would be achieved at the level of the IECC standard. Additional research should be done to compare the incremental cost of progressively tighter home envelopes with the energy savings derived from the measures. Currently, Title 24 does not have an envelope tightness requirement although it does allow builders to take a credit for energy efficiency based on measured envelope tightness.

Table 2.3.1: Change in Annual Energy Demand Resulting from Air Sealing Improvements or Achieving Air Tightness Standards While Also Ensuring Adequate Ventilation According to ASHRAE 62.2 for the Entire U.S. Housing Stock

	Site Energy Demand (Quads)		Energy Cost (billion$ 2010)	
	ASHRAE 2010	ASHRAE 2013	ASHRAE 2010	ASHRAE 2013
Baseline: Making stock comply with the ASHRAE 62.2 Standard				
Exhaust	0.07	0.06	$1.6	$1.3
HRV	0.10	0.08	$2.6	$2.2
Savings compared to baseline: Average Tightening				
Exhaust	-0.72	-0.72	-$11.8	-$11.7
HRV	-0.72	-0.72	-$11.5	-$11.5
Savings compared to baseline: Advanced Tightening				
Exhaust	-1.42	-1.39	-$22.9	-$21.2
HRV	-1.41	-1.41	-$23.2	-$21.9
Savings compared to baseline: IECC Standard				

Exhaust	-2.10	-1.89	-$33.8	-$29.8
HRV	-2.23	-2.12	-$35.0	-$32.2
Savings compared to baseline: R2000 Standard				
HRV	-2.63	-2.44	-$41.8	-$36.7
Savings compared to baseline: Passive House Standard				
HRV	-2.86	-2.62	-$45.5	-$39.3

HRV = heat recovery ventilator

Table 2.3.2: Change in Annual Energy Demand Resulting from Air Sealing Improvements or Achieving Air Tightness Standards While Also Ensuring Adequate Ventilation According to Title 24 for California

	Site Energy Demand (Quads)		Energy Cost (billion$ 2010)	
	ASHRAE 2010	ASHRAE 2013	ASHRAE 2010	ASHRAE 2013
Baseline: Making stock comply with Title 24				
Exhaust	0.010	0.009	$0.24	$0.20
HRV	0.014	0.012	$0.44	$0.36
Savings compared to baseline: Average Tightening				
Exhaust	-0.022	-0.021	-$0.33	-$0.31
HRV	-0.020	-0.019	-$0.19	-$0.10
Savings compared to baseline: Advanced Tightening				
Exhaust	-0.044	-0.037	-$0.65	-$0.51
HRV	-0.049	-0.043	-$0.62	-$0.46
Savings compared to baseline: IECC Standard				
Exhaust	-0.063	-0.045	-$0.94	-$0.58
HRV	-0.074	-0.062	-$1.00	-$0.63
Savings compared to baseline: R2000 Standard				
HRV	-0.091	-0.074	-$1.27	-$0.74
Savings compared to baseline: Passive House Standard				
HRV	-0.101	-0.081	-$1.43	-$0.81

HRV = heat recovery ventilator

State-specific distributions of benefits are calculated in the analysis reported by Logue, et al. (2012). Figure 2.3.1 shows California-specific distributions. This figure shows both the variation in benefits across homes and the differences between idealized policy options. It is particularly noteworthy that the benefits of advanced air sealing are substantially greater than the benefits of air sealing at current performance levels, and that such effective air sealing would overlap with the distribution of benefits from achieving the IECC 2012 standard. Advanced air sealing should be seen as a difficult, but not impossible, technical challenge, since it just requires that all homes be brought up to the level currently achieved by the top 10 percent of similar homes.

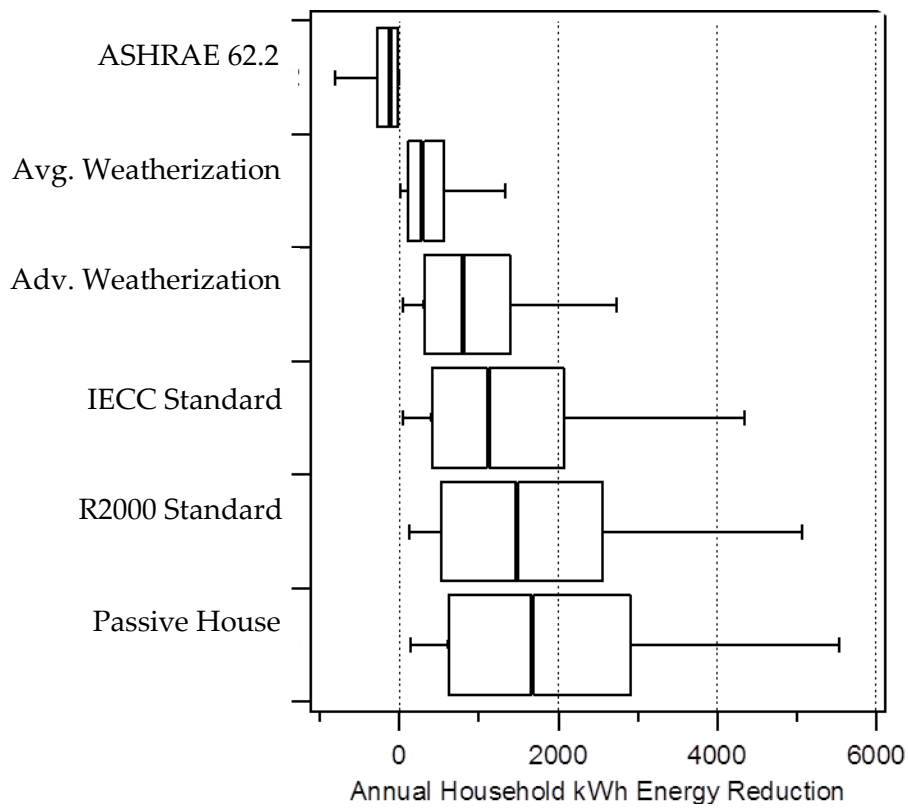

Figure 2.3.1: Impact of Envelope Tightening on the California Housing Stock. The graph shows the distribution of home energy savings from retrofitting the entire housing stock to comply with Title 24 and tightening the housing stock by various levels. Scenarios are described in the text. Change in household kilowatt-hours is for site energy.