STUDY OF VENTILATION PRACTICES AND HOUSEHOLD CHARACTERISTICS IN NEW CALIFORNIA HOMES

Prepared For:
California Energy Commission
Public Interest Energy Research Program

and the

California Air Resources Board
Indoor Exposure Assessment Program

California Environmental Protection Agency
AIR RESOURCES BOARD

Prepared By:
Survey Research Center,
University of California, Berkeley
and
Lawrence Berkeley National Laboratory

PIER COLLABORATIVE REPORT

June 2007
CEC-500-2007-033

Prepared By:
Survey Research Center
Thomas Piazza and Robert H. Lee
2538 Channing Way, #5100
University of California, Berkeley, California 94720-5100

Lawrence Berkeley National Laboratory
Max Sherman and Phil Price
Berkeley, California 94720

Energy Commission Contract No. 500-02-023
ARB Contract No. 03-326

Prepared For:
Public Interest Energy Research (PIER) Program
California Energy Commission

Marla Mueller
Project Manager

Kelly Birkinshaw
Program Area Team Lead and Contract Manager

Laurie ten Hope
Manager
Energy Systems Research

Martha Krebs, Ph.D.
Deputy Director
Energy Research and Development Division

B.B. Blevins
Executive Director

California Air Resources Board

Thomas J. Phillips
Contract Manager
Research Division

Peggy L. Jenkins
Manager, Indoor Exposure Assessment Section
Research Division

DISCLAIMER

This report was prepared as the result of work sponsored by the Air Resources Board (ARB) and the California Energy Commission (Energy Commission). It does not necessarily represent the views of ARB, the Energy Commission, their employees, or the State of California. The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed as actual or implied endorsement of such products. The ARB, the Energy Commission, the State of California, its employees, contractors, and subcontractors make no warrant, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the ARB or the Energy Commission, nor has the Energy Commission passed upon the accuracy or adequacy of the information in this report.

Acknowledgments

The authors wish to thank all of the participants in this study for taking the time to complete and send in the study questionnaire.

This report was submitted in fulfillment of the ARB Contract Number 03-326 and the Energy Commission Contract Number 500-02-023, for the study titled Survey of Ventilation Practices and Housing Characteristics in New California Homes by the Survey Research Center of the University of California at Berkeley and the Lawrence Berkeley National Laboratory under the sponsorship of the California Air Resources Board and the Energy Commission. Work was completed as of December 2005.

Please cite this report as follows:

Price, Phillip P., Max Sherman, Robert H. Lee, and Thomas Piazza. 2007. *Study of Ventilation Practices, and Household Characteristics in New California Homes*. California Energy Commission, PIER Program. CEC-500-2007-033. Final Report, ARB Contract 03-326.

Preface

The California Air Resources Board (ARB) carries out and funds research to reduce the health, environmental, and economic impacts of indoor and outdoor air pollution in California. This research involves four general program areas:

- Health and Welfare Effects
- Exposure Assessment
- Technology Advancement and Pollution Prevention
- Global Air Pollution

For more information about the ARB Research Program please see ARB's website at: www.arb.ca.gov/research/research.htm, or contact ARB's Research Division at 916-445-0753. For more information about ARB's Indoor Exposure Assessment Program, please visit the website at: www.arb.ca.gov/research/indoor/indoor.htm.

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Environmentally-Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Survey of Ventilation Behavior and Housing Characteristics in New California Houses is the final report for the Survey of Ventilation Behavior and Housing Characteristics in New California Houses project, ARB Contract 03-326 and Energy Commission Contract 500-02-023 conducted by the University of California at Berkeley Survey Research Center and the Lawrence Berkeley National Laboratory. The information from this project contributes to the ARB

Environmental Research Area and the PIER Energy-Related Environmental Research Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/pier or contact the Energy Commission at 916-654-5164.

Table of Contents

List of Figures

List of Tables

Abstract

A survey was conducted to determine occupant use of windows and mechanical ventilation devices; barriers that inhibit their use; occupant perception of and satisfaction with indoor air quality (IAQ); and the relationships among these factors.

A questionnaire was mailed to a stratified random sample of 4,972 single-family detached homes built in 2003, and 1,448 responses were received. A convenience sample of 230 houses known to have mechanical ventilation systems resulted in another 67 completed interviews.

Results:

- Many houses are under-ventilated: depending on the season, only 10–50 percent of houses meet the standard recommendation of 0.35 air changes per hour.
- Local exhaust fans are underutilized. For instance, about 30 percent of households rarely or never use their bathroom fan.
- More than 95 percent of households report that indoor air quality is “very” or “somewhat” acceptable,” although about one-third of households also report dustiness, dry air, or stagnant or humid air.
- Except in households where people cook several hours per week, there is no evidence that households with significant indoor pollutant sources get more ventilation.
- Except in households containing asthmatics, there is no evidence that health issues motivate ventilation behavior.
- Security and energy saving are the two main reasons people close windows or keep them closed.

Keywords: Indoor air quality, IAQ, mechanical ventilation systems, ventilation standards, indoor pollutants, asthma, windows, exhaust fans, natural ventilation, thermal comfort

Executive Summary

Background and Purpose

Houses built in California within the last few years were designed to be very airtight to conserve energy. Concerns have been raised that the occupant use of windows, doors, and mechanical ventilation may not provide adequate ventilation with outdoor air and may contribute to unacceptable indoor air quality (IAQ). In setting building energy design standards, the Californian Energy Commission (Energy Commission) assumes a certain level of outdoor air ventilation from occupant use of windows and mechanical devices such as exhaust fans. The Energy Commission needs to determine whether this assumed building ventilation is achieved through occupant practices. If the lack of ventilation contributes to substantial air quality problems in many new homes, changes in building codes or recommended design practices may be required to ensure adequate indoor air quality.

To determine whether such problems occur and how they might be remedied, data on household ventilation practices are needed. Policy makers need information on the patterns of ventilation behaviors and the key factors involved.

The Energy Commission has a program for research and development to advance the state of knowledge on residential ventilation in California, and it supports this research through its Public Interest Energy Research (PIER) Program. An important goal of this effort is to identify changes to existing residential energy efficiency standards (Title 24) that can be incorporated into the 2008 standards to maintain or improve the indoor environment of new homes and reduce the energy-related impacts of these homes.

Information is also needed concerning specific pollutant sources that are sometimes problematic or that can contribute to indoor pollutant levels, such as new carpets, paint, cabinetry, and heating and cooking appliances. This information was needed by the California Air Resources Board (ARB) for assessment of Californians' exposures to indoor and outdoor air pollutants in new homes. Under Health and Safety Code Section 39660.5, ARB is required to assess Californians' exposures to toxic air contaminants.

Methods

Data for this project were collected from self-administered questionnaires that were mailed to residents throughout California. In conjunction with ARB and the Energy Commission, the Survey Research Center (SRC) and Lawrence Berkeley National Laboratory (LBNL) designed a questionnaire to evaluate resident perceptions of IAQ, resident behavior with regard to ventilation practices, and what barriers, if any, inhibited residents from opening windows or using other mechanical or natural ventilation systems. In addition, questions were designed to assess the relationship among ventilation practices, perceived IAQ, and house and household characteristics.

Two samples of households were selected for this project. The main sample was a stratified random sample of 4,972 addresses of single-family detached homes. Separate samples were drawn in each of the three geographic strata. To be eligible for inclusion in the study, the house at a selected address had to have been built in 2003, be a detached, single-family home, and the resident had to have lived in the home for at least nine months. Completed questionnaires were received from 1,448 households, for an overall response rate of 31.2 percent. For this report, the results were broken out into three different strata: the Sacramento Delta area, the Southern Coastal area, and the Rest of the State area. There were 308 completed questionnaires from the Sacramento Delta area, 275 from the Southern Coastal area, and 865 from the Rest of the State area.

The second sample selected for this project was a small convenience sample of 230 addresses of single-family detached houses that were known to have mechanical ventilation systems installed. This small sample was based on information provided by builders and was distributed throughout the state. Sixty-seven of those households completed questionnaires.

Survey data were analyzed to address four basic issues:

- Determine how occupants use windows, doors, and mechanical ventilation. In particular, do occupants provide enough ventilation to ensure adequate IAQ?
- Determine occupants' perceptions of and satisfaction with IAQ in their homes.
- Determine the relationships among ventilation practices, perceived IAQ, and house and household characteristics.
- Determine barriers that prevent or inhibit the use of windows, doors, and mechanical ventilation.

Adequacy of ventilation was assessed by creating a metric called "Effective Specific Leakage Area" (ESLA), which was then used to compare the ventilation provided by window-opening to the amount that would be necessary to provide adequate ventilation. Ventilation is assumed to be "adequate" if it meets or exceeds the level assumed by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) Standard 62.2 criteria (ASHRAE 2004) or the Energy Commission's Title 24 standards. ESLA combines responses to survey questions about the amount of ventilation and the frequency of ventilation in each season to estimate a time-averaged surface area of open windows per unit of living area of the house. The ESLA metric also factors in the effects of cross-ventilation, high-low ventilation, and having windows open part of the time rather than all of the time.

Occupant perceptions of and satisfaction with IAQ and thermal comfort were assessed through survey questions. Summaries are provided in the full report.

Relationships among ventilation practices, perceived IAQ, and house and household characteristics were determined using several standard statistical techniques, including linear regression and logistic regression. These techniques are used to determine the extent to which one variable can be used to predict another. For example, the relationship between household size and ventilation is assessed by determining to what extent the size of the household can be used to predict the amount of ventilation provided.

Barriers that prevent or inhibit the use of windows, doors, and mechanical ventilation were assessed by asking why people open or close windows and doors, and what people do and do not like about their mechanical ventilation system (if they have one).

Results and Discussion

Many people fail to provide ventilation that meets the ASHRAE or Title 24 recommendations. For instance, as Table E-1 indicates, about 10–25 percent of households report very few or no hours with any windows open at all, in all seasons. This table is based on survey questions that asked about hours of windows open in specific rooms. (As discussed in the full report, there were inconsistencies in peoples' reported ventilation behavior between different questions; some other survey questions suggest that some of these people do in fact open some windows sometimes.). In any case, it is clear that a substantial fraction of households provide very low levels of ventilation. Based on estimates of ESLA, determined from the survey responses, it appears that windows provide less than adequate ventilation for about 85 percent of homes in winter, for about 50–60 percent of homes in fall and spring, and for about 40 percent of homes in summer.

For instance, 10 percent of homes report at least two hours with at least one window open, on summer weekdays.

Table E-2 summarizes peoples' perceived IAQ, by season. About one-third of the households report "somewhat acceptable" IAQ or worse for the summer and winter, and smaller percentages were reported for the fall and spring. This is consistent with the finding that about one-third of households also report dustiness, dry air, or stagnant or humid air. In spite of the rather low levels of ventilation reported, very few households—about 3 percent—reported that their IAQ is "not acceptable" or is "barely acceptable."

Table E-1. Summary of the statistical distribution of hours with at least one window open, on weekdays, by season, for the state as a whole

Hours with at least one window open			Percent of Houses						
	Mean	Standard Deviation	5%	10%	25%	50%	75%	90%	95%
Summer	12.6	7.9	0	2	6	12	20	24	24
Fall	10.0	7.8	0	0	3	8	15	24	24
Winter	4.6	6.2	0	0	0	2	6	13	23
Spring	10.8	7.9	0	1	4	9	17	24	24

Table E-2. Acceptability of indoor air quality, by season (%)*

Season	Very acceptable	Somewhat acceptable	Barely acceptable	Not acceptable	NA**
Summer	62	33	2	1	1
Fall	73	24	2	0	1
Winter	65	31	2	1	1
Spring	74	23	1	0	1

* Numbers may not total 100% due to rounding.

** NA = No answer.

Ventilation behavior differs enormously among the seasons, yet people's perceptions of IAQ vary hardly at all: 83 percent of respondents gave the same answer for both summer and winter IAQ acceptability (with most of them rating it "very acceptable" in both cases). Analyses of IAQ acceptability found that people in the Sacramento Delta area tend to be slightly less satisfied with their IAQ than did people elsewhere in the state but found little or no relationship between acceptability of air quality and ventilation.

No strong relationships were found between household characteristics, IAQ acceptability, and ventilation behavior. The strongest relationship was between hours spent cooking and hours of ventilation: households where someone cooks more than 18 hours per week tended to be substantially better ventilated than households where people cook very infrequently. However, although this relationship is true on average, little of the overall variation in ventilation is attributable to differences in cooking behavior. First, few households reported very little cooking, so even though these households tend to be less ventilated, they are only a small fraction of the total. Second, even for households that cook a lot, there is a great deal of variability in ventilation practices.

As discussed above, many houses do not receive substantial ventilation from window opening. An obvious question is, why don't people use more ventilation? The survey asked people to rate the importance of various reasons for opening windows. The most frequent reasons reported as "very important" were "nobody at home," and "security and safety"—these were reported as very important in 80 percent or more of the households statewide. The many households that cited "nobody at home" as a "very important" reason to close windows reported lower levels of ventilation, on average, than the 20 percent of households that did not identify this as a very important issue. However, there was still enormous variation in ventilation behavior among these groups. Moreover, as discussed in detail in the full report, houses that were unoccupied more than eight hours per day were only slightly less ventilated than houses that were almost always occupied.

Conclusions

Objective 1: To determine how occupants used windows, doors, and mechanical ventilation.

- Many occupants do not get substantial ventilation through window opening. Windows provide much less than 0.35 air changes per hour (ACH) for most homes in winter and less than 0.35 ACH in about half of homes in fall and spring.
- Local exhaust fans are underused. Kitchen and bathroom ventilation fans tend to be used based on perception of moisture or odors, rather than being used routinely. Nearly 50 percent of respondents indicate that they sometimes fail to use the bathroom fan even when conditions clearly call for it, most often because they "don't think of it." About 30 percent "rarely" or "never" use the bathroom fan.
- People are not familiar enough with mechanical ventilation systems to meaningfully respond to mail survey questions about them.

Objective 2: To determine occupant perceptions of and satisfaction with IAQ in their homes.

- In all seasons, more than 95 percent of households report that IAQ is "very acceptable" or "somewhat acceptable," although 24–38 percent (depending on season) report dustiness, dry air, or stagnant or humid air.
- Occupants generally perceive their IAQ to be satisfactory, even though some of them report problems that might be expected to bother them:

- Approximately 15–25 percent of households indicate that their house is "too dusty" in any given season. It cannot be determined whether the dust is from inside the house, outside the house, or both.
- The only other specific complaints that occurred in more than about 15 percent of houses were related to thermal comfort: about half the respondents indicate that their house is too hot in summer or too cold in winter. All of the houses have heating and air conditioning systems. It is not clear whether the systems are overwhelmed or whether people do not set them to a comfortable temperature (perhaps to save money).

- Occupant satisfaction with IAQ does not appear to be related to ventilation. Households with low values of ventilation did not report substantially lower (or higher) amounts of ventilation than did other households. Also, most people reported the same level of satisfaction with IAQ in both summer and winter, in spite of a very large difference in ventilation between these seasons.
- Few occupants report problems with mold at more than one location in their house, but those who do are almost all less than completely satisfied with their home's IAQ.

Objective 3: To determine the relationship among ventilation practices, perceived IAQ, and house and household characteristics.

- There is no evidence that households with significant indoor pollutant sources (such as candles and pesticides) get more ventilation than others. The exception is cooking: households where people cook for many hours per week tend to get substantially more ventilation than do other households.
- There is no evidence that health issues motivate ventilation behavior, except that households containing asthmatics appear to get slightly more ventilation than other households, on average.

Objective 4: Determine barriers that prevent or inhibit the use of windows, doors, and mechanical ventilation systems.

- Security, maintaining a comfortable temperature, and saving energy appear to be the main reasons people close their windows or keep them closed. However, houses that are rarely unoccupied receive only slightly more ventilation, on average, than houses that are unoccupied for a large portion of each day. So even homes for which leaving windows open would seem to be relatively safe are often insufficiently ventilated.
- Desire to avoid outdoor allergens is another important reason respondents report keeping windows closed.

- People also closed windows to provide or maintain thermal comfort and (to a somewhat lesser degree) for reasons related to air quality or health.
- Most people who have mechanical ventilation systems do not know how they work or even what kind they have, even if they think they know. Based on this fact, and on other reported experience with mechanical ventilation systems, people cannot be expected to manipulate mechanical ventilation systems to provide adequate ventilation. People are not familiar enough with mechanical ventilation systems to provide accurate information about them in a mail survey.

Recommendations

- Because some of the survey questions about window use and type of whole house mechanical ventilation were clearly misinterpreted or too difficult to answer correctly, field measurements of ventilation-related performance should be made to determine how it relates to reported ventilation behavior. Some studies are being initiated for a subset of these houses.
- A clear definition of IAQ is needed for respondents to have a clear sense of what variables make up air quality. Temperature may be viewed as separate from other issues such as stagnant or dusty air.
- Respondents had a very difficult time understanding the mechanical ventilation questions. A clear list of industry systems might greatly improve respondent comprehension.
- Any standard, whether for mechanical ventilation systems or for providing operable windows, should take into account the fact that respondents do not recognize when their ventilation rate is inadequate and cannot be expected to take actions to increase it when it falls below a given level.
- The study was not designed to focus on thermal comfort issues but reported window behavior suggests that additional studies on warm-weather behavior should be initiated because results indicate that people are using windows for ventilative cooling.
- Field measurements of ventilation-related performance should be made to determine how it relates to reported behavior. There are current studies being initiated for a subset of these houses.

Benefits to California

This was the first large survey to obtain information on occupant ventilation practices in new California homes. The data from this study are of immediate use to the Energy Commission for guiding the development of future building energy design standards that protect IAQ and comfort in California homes, and to ARB for improving exposure assessments of indoor and outdoor air pollutants. Additionally, the data may be used to help design a future field study that will measure pollutant concentrations and other parameters in new California homes.

1.0 Introduction

Houses built within the last few years are designed to be very airtight, to conserve energy. Concerns have been raised that the occupant use of windows, doors, and mechanical ventilation may not provide adequate ventilation with outdoor air, and may contribute to unacceptable indoor air quality (IAQ). In setting building energy design standards, the California Energy Commission (Energy Commission) assumes a certain level of outdoor air ventilation from occupant use of windows and mechanical devices such as exhaust fans. The Energy Commission needs to determine whether this assumed building ventilation is achieved through occupant practices. If the lack of ventilation contributes to substantial air quality problems in many new homes, changes in building codes or recommended design practices may be required to ensure adequate IAQ.

To determine whether such problems occur and how they might be remedied, data on household ventilation practices were needed. Policy makers need information on the patterns of ventilation behaviors and the key factors involved. For example, when, how often, and for how long do people open windows or use mechanical exhaust systems; what fraction of homes have and use mechanical ventilation systems; and what is the perceived IAQ in new homes? In addition to needing information about ventilation behavior, policy makers need information about the reasons for the occupant behavior. For example, are occupants basing their ventilation decisions on concerns for thermal comfort, air pollution, outdoor noise, home security, privacy, convenience, local climate, or other important factors?

This project was required because of the lack of available information about occupant ventilation-related behavior and IAQ in new California houses, Phillips et al. (1990) found that many residential occupants in a statewide survey of California reported extensive periods when all windows were closed, especially in the winter, and reported very little use of exhaust fans. In companion papers Grimsrud and Hadlich (1999) and Hadlich and Grimsrud (1999) have reviewed the relationship between indoor pollutants, ventilation, and indoor air quality for typical pollutants in the residential environment. They have found that there is little known about the interactions of occupant behavior and exposures. Sherman and Hodgson (2002) used this information, in part, to develop minimum ventilation rates for the control of formaldehyde.

More broadly an international study of building occupant behavior was completed in the 1980s, where it was concluded that window-opening behavior is highly dependent on culture, weather, construction type, education, climate, and tradition, but not terribly dependent on health or energy considerations. A detailed literature review is provided in Appendix A of this report.

The Energy Commission has as a funding priority a program of Research and Development (R&D) to advance the state of knowledge on residential ventilation in California. It supports this research through its Public Interest Energy Research (PIER) program. An important goal of this effort is to identify changes to existing residential energy efficiency standards (i.e., Title 24) that can be incorporated into the 2008 standards to maintain or improve the indoor environment of new homes and reduce the energy-related impacts of these homes.

To advance the state of knowledge in this field the PIER program has established a three-part approach to the problem: (1) characterization of the indoor environment of homes built to current standards, (2) development of minimum requirements to achieve acceptable indoor air quality in future construction, and (3) evaluation and development of technologies and associated descriptive algorithms for meeting minimum requirements.

These three elements act synergistically to provide the information the state needs to inform its efforts to modify Title 24. This survey has primarily addressed item 1 (characterization of the indoor environment), and has provided data that can be used for item 2 (development of minimum requirements).

Information was also needed concerning some specific pollutant sources that are sometimes problematic or can contribute to indoor pollutant levels, such as new carpets, paint, cabinetry, and heating and cooking appliances. Such key information is also needed by the California Air Resources Board (ARB) for assessment of Californians' exposures to indoor and outdoor air pollutants in new homes. Under HSC (Health and Safety Code) Section 39660.5, ARB is required to assess Californians' exposures to toxic air contaminants.

This report summarizes data on the presence and use of ventilation features, related occupant ventilation practices, and occupants' perceptions regarding IAQ in a sample of newly built California homes. The results were analyzed to meet the following specific objectives:

- Determine how occupants used windows, doors, and mechanical ventilation devices.
- Determine occupant perceptions of, and satisfaction with, IAQ in their homes.
- Determine the relationship among ventilation practices, perceived IAQ, and house and household characteristics.
- Determine barriers that prevent or inhibit the use of windows, doors, and mechanical ventilation systems.

This was the first large survey of ventilation practices in new California homes. The information obtained is of immediate use for addressing the issues and needs for the Commission and ARB, as described above. It has provided a basis for planning a future field study that will measure pollutant concentrations and ventilation-related parameters in a sample of new California homes.

1.1. Project Objectives

The goals of this project, which will support the programmatic goals of the Energy Commission and ARB, are to obtain some of the information needed to guide the development of future building standards that protect indoor air quality (IAQ) and comfort in California homes, and to obtain information to update and improve the exposure and risk assessments for indoor and outdoor air pollutants in California. This information will be used to begin assessing the adequacy of ventilation, indoor air quality, and thermal comfort in new California single-family homes. It will also be used to assess the effectiveness and problems of mechanical ventilation systems that are currently used in some new homes. A secondary goal is to collect information that will be useful for conducting a future survey that will measure indoor pollutant concentrations and ventilation rates in new homes.

This current project collected information on ventilation-related behavior and IAQ in a sample of new California single-family homes built in 2003. The project objectives are discussed below. Details of the questionnaire topics are discussed in the Project Approach section.

1.1.1. Determine How Occupants Use Windows, Doors, and Mechanical Ventilation

Ventilation in homes is achieved by opening windows and doors (natural ventilation), operating exhaust fans and whole house ventilation systems (mechanical ventilation), and (indirectly) by operating some heating and cooling systems (mechanical). This study asked specific questions about how, when, and why occupants use natural and mechanical ventilation.

Of particular interest is whether occupants get sufficient ventilation to provide "adequate" indoor air quality, based on assumptions made under the California Energy Commission's Title 24 or the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) standards. Title 24 and ASHRAE assume ventilation is adequate if the ratio of the total air flow into the house divided by the volume of the house exceeds a given value; this ratio is known as the "Air Change Rate." Measurement of air flow rates, or related parameters such as the surface area of open windows, requires an on-site experiment; for example, a standard test is a "blower door" test in which a fan is used to pressurize a house to a given level, and the air flow rate that is required in order to do this is measured. This flow rate is related to the airtightness of the house.

There is no way to determine the air change rate from a survey, but it is possible to determine, roughly, the surface area of open windows, at different times of day and different seasons, using the survey responses. The area of open windows can then be compared to the area required to meet the ASHRAE standards. This procedure was carried out and is discussed in detail in this report.

1.1.2. Determine Occupants' Perceptions of and Satisfaction with IAQ in Their Homes

Contaminant concentrations and ventilation rates cannot be measured with a mail-out survey; however, information can be obtained on indicators that are related to indoor contaminant concentrations. To meet this study objective, occupants were asked about their perceptions regarding IAQ. They were al so asked about their satisfaction with IAQ and with the performance of their natural and mechanical ventilation devices.

1.1.3. Determine the Relationships Among Ventilation Practices, Perceived IAQ, and House and Household Characteristics

This study examined how perceived IAQ, comfort, and satisfaction are related to ventilation system characteristics and practices, window and door use, household characteristics, and climate. To accomplish this the research team asked additional questions about the characteristics of the house and household, and statistically analyzed the relationships among these factors and the ESLA.

1.1.4. Determine Barriers that Prevent or Inhibit the Use of Windows, Doors, and Mechanical Ventilation Systems

To understand these barriers to providing ventilation, questions were asked about the various reasons why people may not use their windows, their bath fans, their kitchen fans, or their mechanical ventilation systems.

1.1.5. Other Household Characteristics

To better prepare for the planned field study, more information was needed on the characteristics of the occupants themselves. Questions about the households' general socioeconomic status (SES) were asked to help to identify differences among SES groups that may need to be considered in designing the field study.

1.2. Report Organization

Section 2, "Project Approach," outlines the overall design of the study, which includes a discussion of the target population, and the sample frame. Two samples were selected for this project: a Statewide Probability Sample and a Supplemental Builders' Sample. Following the discussion of the samples are discussions of the processes for the selection of dwellings, the questionnaire design, the mail effort, the eligibility criteria, the calculation of sample weights for analysis, the quality assurance procedures used, and the steps involved in data processing.

Section 3 is devoted to the analysis of the questionnaire data. The results for each of the study objectives will be discussed in full, followed by the conclusions of the project, future recommendations, and how this study benefits California.

Section 4 presents conclusions and recommendations.

2.0 Project Approach / Materials and Methods

Because occupant perceptions of indoor air quality are important indicators of actual indoor air quality problems, a self-administered questionnaire was the methodology used to collect data for this project. While self-reports of ventilation practices in the home cannot measure actual contaminants in the home, a self-administered questionnaire can provide valuable information regarding how an occupant uses windows, doors, and mechanical ventilation systems, their perceptions of and satisfaction with indoor air quality in their home, and what barriers exist that may prevent or discourage the use of windows, doors, and mechanical ventilation systems.

2.1. Target Population

This study surveyed owner-occupants and renters of single-family detached homes in California that were built in 2003. "Detached" was defined as no shared walls with another house. English speaking owners and renters who had lived in the home for at least nine months were eligible to be interviewed.

2.2. General Design of the Sample

Since part of the analysis was to compare results from sampling strata for oversampling, the population of new single-family detached houses was divided into three strata, each of which was defined by a set of zip codes provided by ARB. A separate random sample was drawn in each stratum. In addition, because there was special interest in new homes that contain the new mechanical fresh air ventilation systems, a small supplementary sample was drawn from lists of such homes built in 2003. These lists came primarily from builders.

2.3. Constructing the Sampling Frames

2.3.1. Statewide Probability Sample

For new homes in California, the most accessible sampling frame was the Realty file. That file was complied from public records, including warranty and security deeds. It included the following fields:

- Type of dwelling (single family, etc.)
- Year the home was built
- Name of the current owner
- Address
- Telephone number (when available)

Many companies compile these types of dwelling records. After some evaluation, it was determined that a California company named "DataQuick" had the most adequate collection of records that met this study's needs.

The Energy Commission and ARB defined two specific climate regions of interest: the Sacramento Delta region and the Southern Coastal region. These areas were chosen because they have experienced a lot of new house construction in recent years, and were selected as distinct regions based on climate and wind data. There were 104 zip codes with significant nighttime wind influence in the Sacramento Delta region and 353 such zip codes in the Southern Coastal region. Based on the zip codes defined for these two areas, the whole state was divided into three mutually exclusive geographic strata: (1) the Sacramento Delta region, (2) the Southern Coastal region, and (3) the Rest of the State. The Sacramento Delta region includes houses that almost all come from a single state-defined "climate zone" (climate zone 12), and those from the Southern Coastal region almost all come from climate zones 6, 7, and 9 (all of which are climatically very similar). In contrast, the "rest of the state" stratum includes a wide variety of climates.

The number of houses built in 2003 in the DataQuick database for each stratum was as follows: for the Sacramento Delta region, there were 3,042 houses; for the Southern Coastal region, there were 6,239 houses; for the Rest of the State, there were 15,415 houses. The total number of 2003 DataQuick listings was 24,696. DataQuick drew separate random samples from each of the three strata and sent them to the Survey Research Center (SRC).

The single-family housing listings compiled by DataQuick were known to be incomplete. The research team was informed that some counties take longer than others to report data on the sales of new homes. Nevertheless, since the survey was to be based on new homes, this study could not use listings from past years that presumably would have been more complete by the time of the 2004 sample.

The degree to which the 2003 DataQuick listings were incomplete is difficult to assess without contacting each county assessor's office, which was beyond the scope of the present project. One might compare the number of listings to the number of housing starts in the preceding year, 2002. That number, obtained from ARB, was 108,467. If all of those houses were completed and sold in 2003, and if they all were detached homes, the DataQuick listings would only cover 23% of those housing starts.

In any case, the 2003 DataQuick listings were the best available sampling frame for the survey. The research team ended up using 4,972 of the 24,696 records in the database for 2003.

2.3.2. Supplemental Builders' Sample

The supplementary sample of new houses known to have mechanical fresh air ventilation systems installed was based on addresses provided by three sources: Beutler Builders, The Meyers Group, and ARB.

Beutler Builders (McClellan, California) provided a list of 2,000 addresses in Northern California, predominantly in the Sacramento Delta region, of homes that were built within the last two years. They were grouped into three subgroups: (1) Standard ventilation, which was a normal bath fan only application; (2) 5MHRVFB which is their code for a Modular

Heat Recovery Ventilation (MHRV) that runs continuously 24 hours a day, seven days a week; (3) 5FV5, which is their code for the FreshVent system, whish is a fresh air duct, connected to the HVAC return with a "Cycler" control. The list included 1,200 homes that had the standard bath fan installed, 400 homes with the MHRV system, and 400 homes with the Freshvent system installed. This study only sampled from the 800 in the second and third groups. It did not include the 1,200 addresses that had only the standard ventilation.

The Meyers Group (now owned by Hanley Wood Corp., Costa Mesa, California), a private company that provides data and consulting services for residential real estate developments and new home construction, provided the addresses for houses in Southern Coastal region in the following counties: Los Angeles (N=691), Orange (N=437), Riverside (N=267), and Ventura (N=41). The stipulations to the Meyers Group were that the sample include only single-family detached homes that were built in 2003 or later. Furthermore, it was stipulated that all houses in the sample were built as part of the Building America program, since the majority of those homes were known to have installed mechanical ventilation systems.

Finally, eight homes forwarded by ARB were included as part of the builder supplementary sample. All homes from the supplementary frame were divided into the same three geographic strata as the statewide probability sample.

2.4. Selection of the Dwellings

2.4.1. Statewide Probability Sample

DataQuick drew a random sample of the houses in their database for each of the three geographic strata and sent the addresses to SRC. DataQuick drew 2,000 homes from their database for Sacramento Delta, 2,000 homes from the Southern Coastal region, and 6,000 from the rest of the state. SRC sorted each stratum sample by zip code and selected every other home, after a random start for inclusion in the initial sample. The other half was set aside as a reserve sample, to be used as needed.

A total of 999 addresses were initially sent questionnaires in the Sacramento Delta region; 973 in the Southern Coastal stratum; and 3,000 throughout the Rest of the State, for a total of 4,972 general sample questionnaires. This initial sample size was not quite sufficient for the study, so a few additional cases were selected at random from the reserve sample.

Because homes in the three strata were sampled at different rates, it is necessary to use weights to compensate for different probabilities of selection whenever cases are pooled across strata. Sample weights are described in section 2.10 below.

2.4.2. Supplementary Builders' Sample

All housing units in the frame of the supplementary sample were sorted by zip code within each stratum, and several dozen homes were selected by systematic sampling with a random start from each stratum to ensure obtaining a reasonable number of completed interviews from occupants of homes with a mechanical fresh air ventilation system. A total of 58 questionnaires were mailed out to the Sacramento Delta region, 68 to the Southern Coastal region, and 104 to the Rest of the State, for a total of 230 questionnaires mailed in this frame.

Note that this small supplementary sample of homes with new ventilation systems is not intended to represent all such homes in the state. Its purpose was only to provide some extra cases for analysis, since it was uncertain how many homes with new mechanical ventilation systems would be encountered in the statewide probability sample.

2.5. Questionnaire Design and the Project Objectives

Before beginning the data collection phase of the study, a self-administered questionnaire was developed to ask occupants to report their family's behavior regarding the use of windows, doors, and other mechanical ventilation systems; their perceptions of, and satisfaction with, indoor air in their homes; and what concerns, if any, they have that may limit their use of windows, doors, and mechanical ventilation systems.

As part of the development of the questionnaire, a focus group was conducted for residents of Walnut Creek, Concord, and San Ramon. Six respondents took part in the focus group and gave feedback on all aspects of the questionnaire, from formatting and question wording, to the comprehensibility of the instrument. The final questionnaire was revised accordingly and can be seen in Appendix B. Questions were asked about the following four objectives:

2.5.1. Determine How Occupants Use Windows, Doors, and Mechanical Ventilation

- **Windows and doors**. The key questions are how much, how often, and when occupants open their doors and windows during different seasons. Several questions were asked to determine patterns of window operation and the extent it varies by season.
- **Exhaust fans** can be a key part of assuring good indoor air quality. If exhaust fans are not available or are not used to remove local contaminants such as those from kitchen and bathroom activities, then minimum building ventilation rates may not be sufficient. The research team asked questions to determine the use of exhaust fans.
- **Forced heating and air systems**. The use of forced heating and/or air conditioning systems can affect building ventilation, IAQ, indoor moisture levels, and the occupants' perceptions of stuffiness and the need for window opening. We asked about the home's temperature settings for control systems, the manual operation of central fans, and other related heating and cooling practices.
- **Whole-house ventilation systems**: Some houses known to have outdoor air ventilation systems for the whole house were selected for special study. Information was obtained regarding the system's characteristics, its performance to date, and how the occupants used the system.
- **Natural and mechanical ventilation levels**: The Energy Commission's building energy design standards assume certain levels of natural and/or mechanical

ventilation, which are presumed to provide acceptable outdoor air flow rates if the standards are followed. The research team asked questions to determine whether new home occupants operate the windows, doors, and mechanical ventilation as assumed. Also, questions were asked that allow comparison of ventilation practices to the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) Standard 62.2 criteria (ASHRAE 2004).

Standard 62.2 (or modifications thereof) is being evaluated for inclusion in Title 24. One question to ask is how significant a change that would be or, equivalently, how close current construction is to meeting it. The survey data can be used to qualitatively evaluate this issue.

Standard 62.2 has several requirements. It has a whole-house ventilation requirement; it has an exhaust ventilation requirement in kitchens and bathrooms; it has various source control requirements including such items as appliance venting and particle filtration. Not all of the requirements in Standard 62.2 can be evaluated from the survey data, but several can.

The requirements in Standard 62.2 concern building and ventilation design, not operation. For example, local exhaust fans (such as bathroom fans) must be provided, and must meet certain flow rate criteria, but there is no requirement that they actually be used.

For most of California the Standard 62.2 whole-house ventilation requirement can, in principle, be met by the code-required windows already installed. Thus the issue of meeting that requirement may be moot, so it is not discussed in this section. The issues around window opening and mechanical whole-house ventilation will be dealt with separately.

2.5.2. Determine Occupants' Perceptions of and Satisfaction with Indoor Air Quality in Their Homes

- **Occupant perceptions**: The questionnaire asked people if they find the IAQ acceptable or not, and why. Questions addressed perceptions such as "stuffiness," thermal comfort, odors, and other indicators.
- **Mold and other specific odors**: Musty odors are indicators of unacceptably high moisture levels and possible mold growth. Certain odors can indicate unacceptable levels of volatile organic compounds (VOCs). Chemical odors may result from formaldehyde emissions from pressed wood cabinets, or chemicals from carpets or other sources. Questions were asked about perceptible odors.

2.5.3. Determine the Relationships Among Ventilation Practices, Perceived IAQ, and House and Household Characteristics

- **Size**: House size, household size, and house configuration. These factors can affect the amount and effectiveness of natural and mechanical ventilation, for example, by affecting the air flow rates, cross drafts, and air stratification. Attached garages can also be sources of motor vehicle emissions and emissions from heating appliances.
- **Sources of indoor pollutants**: Smoking, presence and use of unvented combustion appliances, cooking, heating, sources of organic chemicals (VOCs) such as pressed wood products and so-called air fresheners, excessive VOC use (consumer products,

pesticides), and other major indoor pollutant sources can cause unacceptable IAQ, even if there is nominally sufficient ventilation. The study asked questions about these sources.

- **Health status of household members**: In households that have persons susceptible to air pollutants, such as persons with asthma, allergies, or odor sensitivities, their ventilation practices, home designs, and perceived IAQ may differ greatly from those persons in the general population. Questions were asked to identify households with health conditions that might affect their ventilation practices and perception of IAQ, in order to understand better the ventilation behaviors and purchasing decisions of households.
- **Energy efficiency characteristics of house**: Houses have different levels of energy efficiency and features such as heating system types, duct sealing, and building shell tightness. Such differences could impact ventilation rates and indoor air quality. Only those features that could be easily and reliably reported by study participants were included.

2.5.4. Determine Barriers that Prevent or Inhibit the Use of Windows, Doors, and Mechanical Ventilation Systems

- **Comfort, draft, and outdoor air quality**: Opening windows or using mechanical ventilation systems may cause asthma and allergy symptoms, thermal discomfort, and soiling of interiors because of wind, drafts, dust, pollen, and air pollutants. Large ventilation fans can cause local thermal discomfort as well.
- **Noise, security**: Fans and open windows can increase indoor noise. Fans generate noise themselves, while open windows let in outdoor sounds such as traffic, wind noises, etc. Opening windows and doors can also be a security concern.
- **Cost (first, operating):** Mechanical ventilation systems can represent an increased first cost. Any kind of mechanical ventilation system can also increase operating costs, both directly by increasing electricity use for fan operation and indirectly by increasing the need for heating and cooling due to increased air exchange rates.
- **Convenience, complexity, serviceability**: Complex control systems and maintenance needs for mechanical systems can be inhibiting. Some people are confused or frustrated when setting control devices and routine maintenance (such as replacing filters) may be inconvenient. Modern windows can be difficult for some people to open or access.

2.6. Mail Effort

- **Two Batches:** In order to assess respondent comprehension of the questionnaire and to project the number of expected returns, questionnaires were sent out in two batches. The first batch of 1,657 packets containing a cover letter, a ballpoint pen with the study logo imprint, and a copy of the questionnaire was mailed out in mid-December 2004. After reviewing the first 200 questionnaires with ARB, a few minor changes were made to the instrument before mailing the second batch. The revisions to the instrument were predominantly improvements in respondent instructions to minimize confusion. The second batch of 3,315 questionnaires was mailed out at the end of January 2005.

- **Reminder Effort:** In addition to the initial mailings for each batch, there were two additional "reminder mailings." One week after the mailing of the first packet, a reminder postcard was sent to each respondent. Three weeks after the reminder postcard was sent, a second packet with a reminder letter, a second pen, and a second questionnaire was sent to those respondents who had not yet returned a completed questionnaire.

2.7. Eligibility

Two screening questions at the beginning of the questionnaire were used to help the respondent determine whether or not he or she should continue with the questionnaire:

- "Is the house at this address a **detached** single-family house built in 2003? By detached we mean no shared walls with another house."
- "Have you lived in this home since at least January 2004?"

If the respondent answered "no" to either of the screening questions, he or she was not eligible for the study and was asked to return the questionnaire in the enclosed envelope, but keep the pen as a gift. If the respondent answered "yes" to both screening questions, the respondent was eligible and was asked to complete the questionnaire and return it in the enclosed envelope. Once the completed questionnaire arrived at the SRC office, the respondent was sent a $30 check as a token of appreciation.

2.8. Outcome of the Statewide Probability Sample

Table 1 shows the various outcomes for all the selected addresses in this Statewide Probability Sample. In each of the three strata, between 5%–10% percent of the addresses were determined to belong to ineligible households, for the following reasons:

- The house was vacant
- The occupant had resided at that address for less than 9 months
- The housing unit was not a detached unit
- Residents were not able to complete an English questionnaire
- The Post Office returned the packet with a determination that there was no such address.

Overall, 324 selected addresses were determined to be ineligible for the study, leaving 4,648 eligible addresses. Completed questionnaires were received from 1,448 of the eligible addresses for an overall response rate of 31.2%. The response rates did not vary substantially between strata. The rates ranged from 30.2% (Southern Coastal) to 32.8% (Sacramento Delta).

This overall response rate of 31.2% far exceeded researchers' expectations. The research team had planned for a response rate in the neighborhood of 10%–15%, given the length and difficulty of this self-administered survey. Apparently, however, our persistence in pursuing respondents and the freshness of the topic for new homeowners combined to boost the response rate. This higher response rate should add somewhat to the reliability of the results obtained from the survey. See Table 1 for the outcome of the Statewide Probability Sample.

Note that the demographic characteristics of the respondents to the survey are quite different from those of the California population as a whole. Recent home buyers can be expected to have higher incomes and larger families than households in the general population. A comparison of our sample with the 2000 Census bears this out. In the sample, 59% of the households have incomes of $100,000 or more, compared to 17% for the state as a whole. Also, 70% have three or more persons in the household, compared to 47% for the state as a whole.

On the other hand, the ethnic composition of the sample is not so different from the state as a whole, except that the sample is 20% Asian, compared to 13% in the most recent census. There are corresponding reductions in the percent white (58% versus 66%) and the percent black (6% versus 7% in the state as a whole).

Table 1. Outcome of the statewide probability sample by stratum

	Sacramento Delta N	Southern Calif. Coastal Region N	Rest of the State N	Statewide N
Selected	999	973	3,000	4,972
Known Ineligibles	60	63	201	324
(Vacant)	(8)	(5)	(30)	(43)
(< 9 months)	(31)	(39)	(111)	(181)
(Not Detached)	(12)	(13)	(36)	(61)
(Language Barrier)	(2)	(0)	(0)	(2)
(No Such Address)	(7)	(6)	(24)	(37)
Eligible Households	939	910	2,799	4,648
Non-Response	631	635	1,934	3,200
Completed Questionnaires	308	275	865	1,448
Response Rate *	32.8%	30.2%	30.9%	31.2%

*(Completed Questionnaires) / (Eligible Households) * 100

2.9. Outcome of the Supplementary Builders' Sample

Table 2 shows the various outcomes for all the selected addresses in the supplementary builders' sample. About a sixth of the sampled addresses turned out to be ineligible, mostly because the residents had lived in the house less than nine months. Of the 192 eligible households, completed questionnaires were received from 67 households for an overall response rate of 34.9%.

Table 2. Outcome of the builders' sample by stratum

	Sacramento Delta N	Southern Calif. Coastal Region N	Rest of the State N	Statewide N
Selected	58	68	104	230
Known Ineligibles	16	2	20	38
(Vacant)	(5)	(0)	(4)	(9)
(< 9 months)	(8)	(2)	(12)	(22)
(Not Detached)	(2)	(0)	(1)	(3)
(Language Barrier)	(0)	(0)	(0)	(0)
(Not a Real Address)	(1)	(0)	(3)	(4)
Eligible Households	42	66	84	192
Non-Response	23	47	55	125
Completed Questionnaires	19	19	29	67
Response Rate *	45.2%	28.8%	34.5%	34.9%

* (Completed Questionnaires) / (Eligible Households) * 100

2.10. Calculation of Weights for Analysis

In the Statewide Probability Sample the three geographic areas used as strata (Sacramento Delta region, Southern Coastal region, and the rest of the state) were sampled at different rates. And among the households sampled, the response rate was somewhat different in the three areas. For purposes of combining results for the three areas and generating statistics for the state as a whole, a sampling weight was created. The various steps are summarized in Table 3.

The first row of Table 3 shows, for each of the three strata, the number of households in the sampling frame. The second row shows the number of completed interviews in each stratum. The ratio of the first to the second row gives the expansion factor, which is the number of households in each stratum represented by each completed household interview in the sample. As shown in the table, each household in the Sacramento Delta region that completed a questionnaire represents 9.8766 households on the list from which the sample was drawn. The corresponding figures for the other two strata are 22.6873 and 17.8208.

When statewide analyses are being run, the expansion factor could be used as a weight variable. However, tables that are run using that weight would appear to be based on 24,696 cases (the total in the sampling frame). In general it is preferable to scale the expansion factor down and create a relative weight, which preserves the proportionality between strata but produces weighted tables that reflect the actual number of cases in the data file. If the expansion factor for each stratum is multiplied by the constant factor .058633, the result is the relative weight, shown in the final row of Table 3 (rounded to three decimal places). That final relative weight is the sampling weight available in the data file for each completed case in the Statewide Probability Sample. Note that the 67 cases in the Supplementary Builders' Sample have a value of 0 on this weight, since they should not be used to calculate statewide estimates.

Table 3. Calculation of weights

	Sacramento Delta	Southern Calif. Coastal Region	Rest of the State	Statewide
Number in the Frame	3,042	6,239	15,415	24,696
Completed Questionnaires	308	275	865	1,448
Expansion Factor	9.8766	22.6873	17.8208	
Sample Weight	.579	1.330	1.045	

2.11. Quality Assurance and Quality Control Procedures

Several procedures were put in place to check for quality assurance and quality control.

- **Multiple Mailings:** An introductory letter and questionnaire were sent to all households in the sample. If the household did not return a completed questionnaire within approximately 2 weeks, a reminder postcard was sent out. If the household still did not return a completed questionnaire within another 2 weeks, we mailed a second letter and another blank questionnaire. These multiple mailings were carried out in an effort to obtain as high a response rate as possible.

- **Revision of Instrument:** The first 200 completed questionnaires were reviewed to check for comprehension of the instrument and to establish data entry conventions for ambiguous responses or response categories that were outside of the expected range. It was clear that there was some confusion with a few of the questions. Revisions were made to the instrument in consultation with LBNL and ARB to clarify respondent instructions and to reduce the number of ambiguous responses. Both versions of the questionnaire can be found in Appendix B.
- **Data Entry Conventions**: The following data entry conventions were approved by ARB, LBNL, and SRC.

  Conflict with Screening Question: Sometimes there was a conflict between the screening question # B, "Have you lived in this home since at least January 2004?" and question #3, "When did you move into this house?" It was agreed that the screening question # B would be accepted as true. If the date the respondent moved in conflicted with the screening question B, the date in question #3 was changed to Missing Data.

  Answers Outside of Acceptable Range: Sometimes answers were outside of the maximum acceptable range. It was agreed that all answers would be entered as answered, even if outside the acceptable range, and would be handled in the analysis.

  Editing: All completed questionnaires were edited before data entry to check for eligibility and to follow data entry conventions. Once the editing was completed, cases were sent to the Data Management Unit of the Survey Research Center for Data Processing.

2.12. Steps for Data Processing

- After receiving completed self-administered questionnaires from the field, the cases were numbered sequentially and filed according to work assignments.
- A direct data entry (DDE) instrument using CASES (Computer Assisted Survey Execution System) software was designed specifically for this collection instrument. The entry program accepts only valid codes, and logical checks were added to enforce the coding conventions.
- Two different coders entered each case into the computer, at different times. Paired cases were then compared by a computer program, which identified any discrepancies between the two entries. These differences were then checked against the original questionnaire. Once the correction was made to one of the paired entries, the duplicate entry was discarded.
- The "cleaned" batch of data cases was then checked yet again by another computer program, which is very similar to the entry program (i.e., only valid codes are accepted and all logical checks are enforced). The cases, which successfully complete this process, are not only considered "cleaned" but "certified."

- Certified data cases were then submitted for output. The cases became part of an ASCII data file in which each variable was stored in a fixed set of columns.

2.13. Discussion of Some Statistical Issues

This report often reports either "r-squared" values, "p-values," or both, to summarize the statistical or practical significance of a result. The r-squared value is the square of the "correlation," r, between two sets of parameter values, or between predictions and observations. R-squared is usually quoted, rather than r, because r-squared can be directly interpreted as the fraction of the variance in the observed parameter that is "explained" by the predictive variable or variables. R-squared quantifies the *practical* significance of the predictive variables: given the values of the predictive variables for everyone in the state, how accurately can we predict the value of the parameter being predicted? A high value of r-squared usually indicates that a relationship is of practical importance, *assuming* it is not accidental, as is discussed next.

The p-value, in contrast, quantifies how likely it is that random chance would have produced a relationship between predictions and observations that is as strong as the one observed. As described below, a low p-value means it is very unlikely that the observed relationship would arise by chance.

To illustrate both r-squared and p-values, let us consider an example. Suppose there are two groups of 100 people, and that the people in group A have an average height of 170 cm while those in group B have an average height of 174 cm. Further suppose that in each group there are people with a variety of heights, with a standard deviation of 10 cm. It is possible to calculate the answer to the following question: *if* people were assigned randomly to two groups of 100 people each, how likely is it that there would be a difference of at least 4 cm in the average height? For this example the p-value is 0.005: if people were divided at random in this way, there is only a 0.5% chance that the groups would differ by as much as 4 cm difference in average height. This suggests that the people were not assigned randomly to the groups. Low p-values indicate high "statistical significance": they usually indicate that a relationship is not accidental.

What about the r-squared value for the example above? As it turns out, the r-squared value is only about 0.04: there is so much variability within each group that even though the difference in average height between the groups is statistically significant, knowing what group someone is in tells us very little about how tall they are.

As this example illustrates, if there is a lot of variation in the parameter of interest (height) then even an explanatory variable that has high statistical significance (what group the person is in) can have little practical significance (i.e., explains little of the variation between people).

There is another circumstance in which high statistical significance (i.e., low p-value) can occur even when r-squared is very low: this can occur if a characteristic is shared by very few data entries, even if it is highly predictive. For instance, suppose there is a third group of people, Group C, who are all between 205 and 210 cm tall (perhaps they are all professional basketball players). But suppose this group has only 10 people in it. In this case, if we know that someone is in Group C we know their height quite precisely, but since this is true of only 10 out of the 210 people in the sample, it does little to explain the total variation of height among the people.

In this report, many of the analyses have one or more of the characteristics of the examples above: (1) a lot of variability among responses, so that in many cases even a statistically significant relationship, unlikely to be the result of chance variation, still has little practical value in explaining the overall variation; and sometimes (2) a relationship that is statistically significant and perhaps of practical significance, but applies to only a small number of people. One example is the relationship between mold and satisfaction with indoor air quality: almost all of the people who report mold in multiple places in their house are less than completely satisfied with their indoor air quality, but since this describes only a few people in the survey, it does little in terms of letting us predict who, out of the entire sample, is extremely satisfied with their indoor air quality.

Another important point is that all of the statistical estimates presented—of p-values, r-squared values, standard errors, and so on—are based on the assumption that there are no systematic errors or biases in the responses. For example, if people tend to misremember or mischaracterize their window-opening behavior in systematic ways, that will lead to errors in the estimated ventilation parameters that are *not* included in the uncertainty estimates. Or, if people tend to be particularly sensitive of certain phenomena (such as mold) because they are in a new house, or conversely if they tend to be particularly satisfied with their indoor air quality because of a high-satisfaction "honeymoon period" after buying the house, then their answers to questions related to these factors may not correctly represent the situation in the house. These effects (if they occur) are not included in the statistical uncertainty estimates or other quantities.

Statistical analyses were performed using the "R" statistics software package (see Maindonald and Braun 2003 for an introduction).

3.0 Project Outcomes / Results and Discussion

To find more information about types of questions asked in the questionnaire that help to assess the project objectives, please see Section 2.5, Questionnaire Design, and Appendix B which includes both the original and revised versions of the questionnaire.

Univariate data summaries for almost all of the survey questions are provided in summary tables attached to this report. Summary statistics for a few of the questions are reproduced here for convenient reference; all are adjusted for the sampling weight, so that if the respondents are representative of the entire eligible population—that is, if there is no bias due to non-coverage or non-response—these would be valid estimates of the situation for new single-family California homes.

- 17% of homes are below 2000 square feet
- 20% are between 2001 and 2500 square feet
- 27% are between 2501 and 3000 square feet
- 23% are between 3001 and 3700 square feet
- 14% of homes exceed 3700 square feet

- 27% of homes are 1–1.5 stories
- 71% are 2–2.5 stories
- 3% are 3 stories or higher

- 51% of new homeowners are White
- 23% are Asians or Pacific Islanders
- 10% are Hispanics
- 5% are Blacks
- 11% are Mixed Race or Other

- 8.5% report annual household income under $50K,
- 14% have annual household income between $50–$74.9K
- 19% have annual household income between $75–$99.9K
- 31% have annual household income between $100–$149.9K
- 27% have annual household income of $150K or greater

- 90% of households include no adult smokers
- 7% include 1 adult smoker
- 3% include 2 or more adult smokers
- 2% include 1 or more children or young teens that smoke

Seventeen of the 1,515 surveys indicated that the household contains a smoker who is age 0-5, a very unlikely result. These respondents may have filled in the wrong box: perhaps these should be in the "6–17 year old" category (the box immediately to the left on the survey instrument). Or perhaps this is the number of children in the 0–5 age range in those homes, rather than the number of smokers in that age range (the box immediately above this question on the survey instrument).

Results for the ventilation-related questions are summarized and discussed in subsequent sections.

3.1. Determine How Occupants Use Windows, Doors, and Mechanical Ventilation

3.1.1. Use of Local Exhaust Fans

Standard 62.2 requires that each kitchen and bathroom have an exhaust fan that vents outside. In some jurisdictions this is required by building code, but in others it is not. It is possible, however, to get an estimate of the frequency of such home characteristics from the survey.

Question 67 can be used to determine whether or not bath fans are installed and used:

> 27% always use the bathroom fan when someone takes a shower or bath, 16% use one frequently, 19% use one sometimes, and the rest use a fan rarely (16%) or never (13%) or do not have a fan (9%).

It can be assumed that the kitchen requirement is met if there is fan either for the stovetop or the oven.

Question 61 tells us whether the stovetop has an exhaust fan or range hood:

- 13% have a range hood that blows air back into the room
- 80% have a range hood that exhausts to outdoors
- 4% have a downdraft ventilator
- 1% has no kitchen exhaust
- 2% don't know

Question 64 tells us whether the oven is vented to the outside:

> 35% of respondents say their most frequently used *oven* vents to the outdoors, 34% say it doesn't, and 30% don't know. Since 30% don't know, it is hard to draw any conclusions from this. The people who *do* know are split about 50-50 between the two types, so if the "don't knows" follow the same pattern then about half of ovens vent to the outdoors.

Standard 62.2 requires that the fans installed meet certain performance specifications. While many models of fans meet these specifications, the cheapest ones often do not. It is unknown whether the fans responded to in the survey meet the specifications.

3.1.2. Use of Filtration

Standard 62.2 requires that there be a minimum efficiency reporting value (MERV) 6 or higher filter on the air handling equipment. System air handlers with no filters, or systems with "traditional inexpensive fiberglass" filters, would not meet the requirement. Other configurations presumably would. Question 37 addresses this issue—see Table 4 below:

Table 4. Types of filters

Q37: Filter type	Percent of homes
Traditional inexpensive fiberglass	26
Medium-efficiency pleated	15
High-efficiency pleated	21
Electrostatic	6
Electronic	1
Other	1
Don't know	7
Don't have one	4

Even if "traditional inexpensive fiberglass" filters are assumed to be the only category that fails to provide adequate filtration, a substantial fraction of houses have systems that do not have adequate filters. Depending on the disposition of the households for which "don't know" was the answer, somewhere between 25%–30% of new homes do not have filtration that is adequate under Standard 62.2.

3.1.3. Use of Vented Combustion Appliances

When naturally aspirated combustion appliances are inside the building's pressure boundary, Standard 62.2 has special requirements. In some cases these requirements may be difficult to meet. Therefore, the presence of the equipment is important.

Question 35 asked whether or not the central heater is inside the home. Because central gas heating is the most common, this exploratory analysis ignored the fact that the central system may not be gas or that a gas system may not be central.

- 69% of respondents said their central heater is in the attic
- 3% said crawlspace
- 10% said garage
- 4% said other space inside the house
- 6% said other space outside the house
- 7% don't know or did not answer

Although power-vented and condensing furnaces are becoming more common, most domestic water heaters are naturally aspirated, so having them inside the house is more likely to trigger the requirements of Standard 62.2.

Question 42 addresses this issue: Out of all households who answered the question, 94% reported that their home has a gas water heater.

- 87% of these are in the garage
- 5% are in another space outside the house
- Only 3% are inside the house

In houses with detached garages, or with attached garages in which there is not substantial airflow between the garage and the rest of the house, a water heater in the garage will meet the requirements of ASHRAE 62.2. Similarly, placement of a water heater in a "space outside the house" will probably meet the requirements. Thus, only about 3% of houses in the survey appear to be at risk of failing to meet ASHRAE 62.2 when it comes to water heaters. The survey does not provide enough information to know whether the houses in this 3% do or do not meet the special ventilation requirements.

3.1.4. Use of Windows

One of the most important functions of this project is to determine what roles windows do and should play in ventilation and indoor air quality. It is not surprising that more pages of the questionnaire were devoted to window-related questions than any other topic.

Reasons for Opening Windows

In Question 26, respondents were asked about the importance of their various reasons for opening windows. The data can be found in Table 5A (statewide probability sample) and Table 5B (builder's sample). For each reason and each degree of importance, the percentage of respondents is summarized for the Sacramento Delta region, the Southern Coastal region, the rest of the state, and the state as a whole (adjusted for sampling weights).

Calculations summarize responses of people who answered the question (e.g., if 4 of the 19 people in the Builders' Sample in the Sacramento Delta region failed to give any answer for Question 26A, only the result of the 15 households that did respond are summarized). Alternatively one might speculate that "no answer" should be "not at all important" or "never open for this reason," but the research team did not make that assumption. The team assumed if the question was not answered it was to be classified as "missing data." The rationale for handling missing data in this way was based on the way the question was formatted. This was a "check the box" question (see Appendix B). It is impossible to tell if a respondent meant to code "never open for this reason," or if the respondent missed the question. It is safer to assume that the respondent missed or skipped the question rather than answer the question for them. Missing data rates were around 5% in this section.

Table 5A. Reasons for opening windows: statewide probability sample, by region

Reasons to open windows (Percent, adjusted by sampling weight) Sacramento Delta region, Southern Coastal region, Rest of State, **Statewide**	Very Important	Somewhat Important	Slightly Important	Not at all important	Never open for this reason
Cool the house	55,62,57,**59**	21,25,22,**23**	11,8,10,**10**	4,1,3,**3**	7,4,6,**6**
Warm the house	9,11,12,**11**	13,11,12,**12**	14,12,13,**13**	15,14,16,**16**	41,48,44,**47**
Provide air movement	55,53,57,**56**	27,31,28,**29**	9,11,10,**10**	2,1,2,**2**	7,3,4,**5**
Remove odors	47,40,39,**40**	28,30,28,**28**	13,19,19,**18**	4,7,6,**6**	8,5,7,**7**
Remove moisture	22,16,18,**18**	17,17,12,**14**	21,16,17,**17**	12,15,19,**17**	27,36,35,**33**
Air out the house during cleaning	40,31,33,**34**	26,27,27,**27**	18,20,23,**21**	6,6,8,**7**	10,16,9,**11**
Remove smoke	21,13,16,**16**	8,10,8,**8**	8,9,9,**9**	11,10,10,**10**	53,57,57,**56**
Provide draft for fireplace etc.	19,14,11,**13**	9,15,12,**12**	15,15,17,**16**	13,14,13,**13**	45,42,47,**46**
Save energy	52,45,46,**46**	21,26,24,**24**	14,14,13,**13**	3,2,4,**4**	11,13,13,**13**
Allow pet access	11,8,9,**9**	4,6,8,**6**	4,6,8,**7**	6,6,8,**7**	75,75,69,**71**

Table 5B. Reasons for opening windows: builders' sample, by region

Reasons to open windows (Percent, adjusted by sampling weight) Sacramento Delta region, Southern Coastal region, Rest of State, **Statewide**	Very Important	Somewhat Important	Slightly Important	Not at all important	Never open for this reason
Cool the house	52,53,46,**50**	27,11,25,**21**	0,16,14,**11**	0,5,7,**5**	20,16,7,**13**
Warm the house	0,5,7,**5**	8,5,11,**8**	15,32,25,**25**	0,21,14,**13**	78,37,43,**48**
Provide air movement	56,42,55,**52**	13,37,24,**25**	0,11,10,**8**	6,0,3,**3**	25,11,7,**13**
Remove odors	20,26,36,**29**	13,42,18,**24**	20,11,18,**16**	13,5,14,**11**	33,16,14,**19**
Remove moisture	14,6,17,**14**	0,20,10,**10**	14,25,21,**20**	21,13,7,**12**	50,38,45,**44**
Air out the house during cleaning	31,37,46,**39**	0,11,19,**12**	19,16,12,**15**	13,11,12,**12**	38,26,12,**23**
Remove smoke	7,17,11,**12**	7,11,11,**10**	14,11,4,**8**	0,6,11,**7**	71,56,64,**63**
Provide draft for fireplace etc.	7,11,0,**5**	0,11,22,**14**	7,17,19,**15**	0,11,0,**3**	86,50,59,**63**
Save energy	33,37,45,**40**	33,21,31,**29**	13,16,7,**11**	0,0,3,**2**	20,26,14,**19**
Allow pet access	7,11,7,**8**	0,5,14,**8**	0,16,7,**8**	0,16,0,**5**	93,53,71,**71**

These data show a strong preference for opening the windows to cool the house and save energy. Providing air movement, which may be related to providing a breeze to cool the occupants, was also frequently cited as important. Removing odors also seemed to be important, but the more direct IAQ questions of removing smoke, providing draft, and airing out the house were not as high.

Although moisture control was not a major reason for opening windows throughout the house, a more specific question was asked about using the bathroom window for ventilation. Question 71 addresses that issue:

- 8% of homes have at least one bathroom window open all the time
- 18% usually have one open
- 38% sometimes open one for ventilation
- 19% rarely open a bathroom window
- 15% never open a bathroom window
- 3% did not answer the question

Contribution of Window Opening to Ventilation

Questions 10–33 all ask about window opening behavior. Questions 10–25 ask how many hours windows are left open in specific locations, times, and seasons.

Appendix C quantifies the reported hours that houses had windows open in various rooms, by season and time of day. Reported differences between weekend and weekday window-opening behavior are rather small during the evening and night, but somewhat different during the day (6 a.m.–6 p.m.), with fewer people reporting 0 hours with windows open, in every room and during every season.

Nighttime window-open behavior (11 p.m.–6 a.m.) changes substantially from season to season. Although about half of the houses do not have any windows open at night in any season, the other half of houses do have open windows—principally bedroom windows or bathroom/utility windows —for much of the night in summer, and to some extent in fall. Few houses have windows open for more than an hour or two at night in winter.

Information about which windows are open, and when, is not sufficient to determine ventilation rates because windows may be open a little or a lot. Survey questions 28–31 attempted to capture both the duration for which windows were open, and the amount that they were open. Four levels of ventilation were defined:

1. No ventilation: all windows and doors closed.
2. Low: One or two windows or doors open just a crack.
3. Medium: Several windows or doors open at least a crack, or one or two windows open at least several inches.
4. High: Some windows or doors open fully, or several windows or doors open partway, or almost all windows or doors open at least a crack.

Respondents were asked the number of hours in each season that their house ventilation was best described as No, Low, Medium, or High. They were also asked, in questions 32 and 33, how often they provide cross-ventilation and how often they provide high-low ventilation to improve airflow.

Figure 1 shows the cumulative distribution function of reported hours of high ventilation, and of hours of high ventilation plus hours of medium ventilation, for each season, for the Statewide Probability Sample. Sharp features at 6 hours and 12 hours indicate a preference for choosing these values; this may be a reflection of peoples' choices when filling out the questionnaire rather than an indication that people actually open their windows for exactly these numbers of hours.

Appendix C, Tables C9A–C9D, summarize the distribution of hours with no, low, medium, and high ventilation. As discussed above, prior to the survey there was some expectation that people in the Sacramento Delta region might provide more summer ventilation than people in other regions, particularly at night. Reported hours with windows open at night did not support that hypothesis. Similarly, responses concerning No, Low, Medium, and High ventilation suggest that summer ventilation is lower in the Sacramento Delta region than in the state as a whole. (These responses are season-specific but not time-of-day specific, so there is no way to estimate nighttime ventilation separately). Households in the Sacramento Delta region report more summer hours with no ventilation than do households elsewhere: a median of eight hours, compared to six hours in the rest of the state. Households in the Sacramento Delta region also report fewer hours with high ventilation: a median of four hours, compared to six in the rest of the state.

Problems With the Usage Data

Within each season, some people reported a non-zero number of window-open hours for some periods of the day or for some rooms, but left other questions blank; in these cases the research team interpreted blanks as zeros. For questions 10 to 25, where respondents were requested to report a specific number of hours, if the respondent entered nothing in an entire section researchers defined such cases as missing data. On the other hand, if there was at least one number entered in a given cell of a series, researchers assumed that the respondents entered only the hours that were relevant to his or her behavior, and left those not relevant blank. For this reason the research team coded blank answers to questions formatted such as these, as zero (See Appendix B).

For any given season, about 3%–4% of respondents left all of the questions related to that season blank. Many other surveys had other problems: there are substantial inconsistencies between ventilation behaviors reported in questions 10–25 versus questions 28–31. (Questions 10–25 ask about the times of day and durations that various windows were left open, but not how widely they were open; questions 28–31 ask how many hours of no/low/medium/high ventilation were provided, but not the times of day.) These issues are discussed below, along with the way they were handled.

In each time period of each season, it is possible to determine from questions 10–25 the maximum and minimum number of hours of non-zero ventilation that could have been provided. For instance, Questions 10A–13A ask about hours of ventilation in the kitchen, bedrooms, bathrooms/laundry/utility rooms, and other rooms, for summer weekdays from 6 a.m. to 6 p.m. Suppose someone filled in zero hours for kitchen and bath/laundry/utility rooms, 6 hours for the bedrooms, and 4 hours for "all other rooms." In this case, the least number of hours of ventilation during this time period was six hours (if the bedroom and "other rooms" ventilation were provided at the same time), and that the largest possible number of ventilation hours was ten (if the bedroom and "other room" ventilation were provided at different times). By adding the minimum and maximum hours for each time period, and performing a weighted average of the weekday and weekend results, it is possible to determine the minimum and maximum possible hours of non-zero ventilation in each season, and to compare these to the reported ventilation hours from questions 28–31. If the data were consistent, the ventilation hours from questions 28–31 would fall between the minimum and maximum calculated above, but in fact many responses fail in this regard, as discussed below.

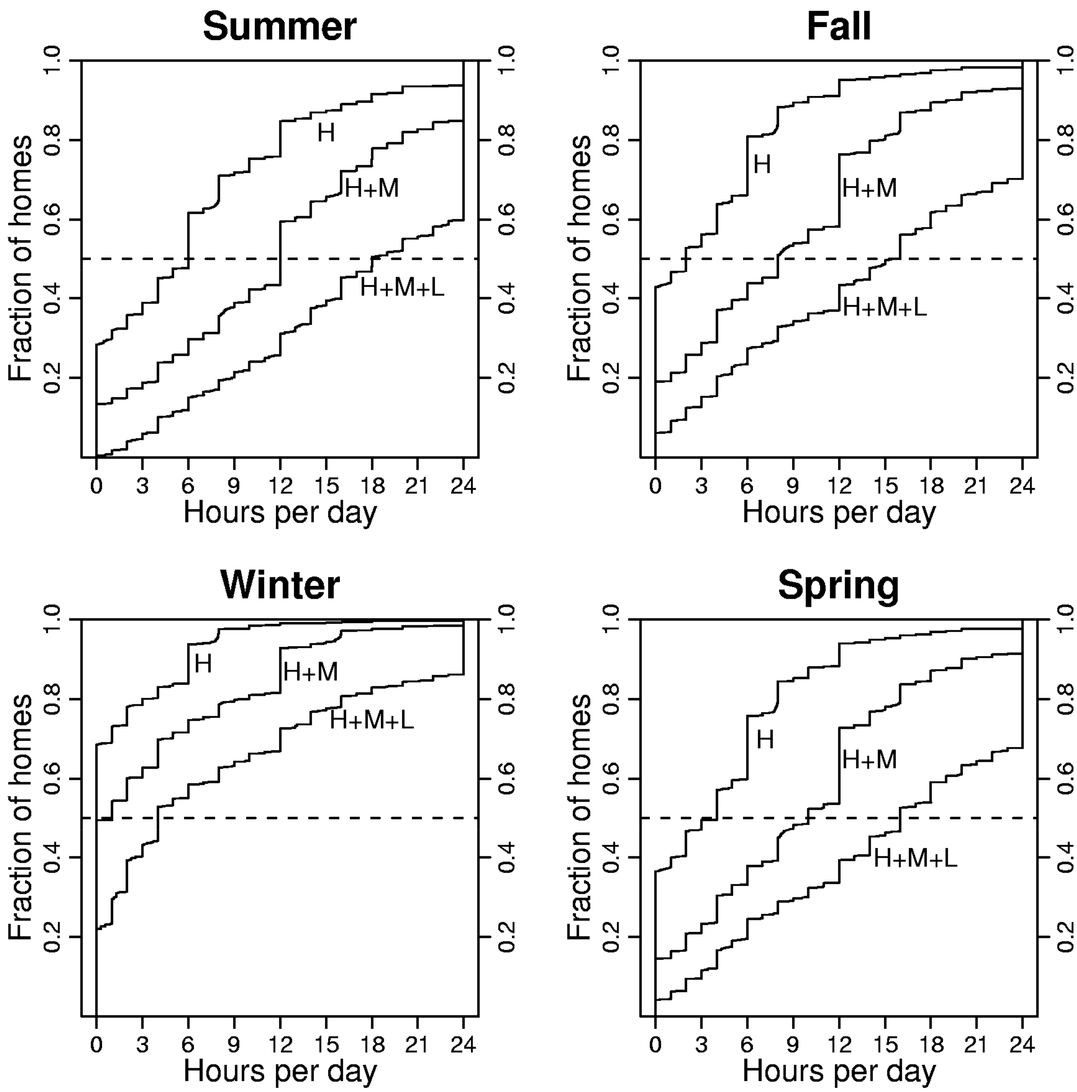


Figure 1. Cumulative distribution function of reported hours of ventilation

Curves show the cumulative distribution function—the fraction of homes that received less than or equal to the hours of ventilation on the x axis—for hours of High ventilation, for hours of High ventilation plus hours of Medium ventilation, and for hours of High ventilation plus hours of Medium ventilation plus hours of Low ventilation. Any hour that is not High, Medium, or Low ventilation is an hour with No ventilation. Dashed line is at fraction = 0.5.

In every season, many people reported in questions 28–31 more hours of ventilation than they accounted for in questions 10–25. The problem is not just a small miscalculation, such as people saying that they have 10 hours of ventilation but only accounting for 9 of them: in many cases, even multiplying the accounted-for hours by 1.5 does not fix the problem. Out of the 1,515 survey respondents, the number with this type of impossible response is shown in the first two columns of Table 6.

Table 6. Inconsistency of ventilation hours reported: reported hours > maximum hours accounted for

Number of surveys with inconsistent answers (out of 1,515 surveys)	L+M+H hours > max. hours accounted for	L+M+H > 1.5 x max hours accounted for	Number who report 24 hours of L+M+H, but account for less than this	Number who report some L+M+H, but account for none at all
Summer	464	251	199	38
Fall	548	335	183	86
Winter	545	447	109	185
Spring	587	340	205	68

The two right-hand columns of Table 6 quantify two of the largest types of discrepancies that cause general ventilation hours to be larger than the maximum that should be possible based on time-of-day-specific reports: many people report 24 hours of ventilation beyond "no ventilation" but fail to account for that amount in the time-of-day-specific reports, and many people do not account for any ventilation at all in the time-of-day-specific reports but do say that they have more than "no ventilation" for at least some period during the day. Except in winter, these two issues account for roughly half of the results in which the responses from questions 28–31 are higher than should be possible based on questions 10–25.

In addition to the type of inconsistency summarized in Table 6, many people had the opposite problem: the hours of low, medium, or high ventilation that they reported in questions 28–31 was smaller than the minimum possible numbers of hours with ventilation based on their responses to questions 10–31. Table 7 summarizes these impossible responses.

Table 7. Inconsistency of ventilation reported: reported hours < minimum hours accounted for

Number of surveys with inconsistent answers (out of 1,515 surveys)	Ventilation hours < minimum hours accounted for	Reported 24 hours with windows/doors open, but reported some hours of "no ventilation"	Reported some hours with windows/doors open, but reported 24 hours of "no ventilation"
Summer	290	79	158
Fall	275	63	149
Winter	271	31	167
Spring	306	60	143

The two right-hand columns of Table 7 quantify the two largest types of discrepancies that cause general ventilation hours to be lower than the minimum that should be possible based on time-of-day-specific reports: (1) many people report leaving some windows or doors open for 24 hours per day, but fail to credit themselves with 24 hours with more than "no ventilation," and (2) many people report 24 hours of "no ventilation" but say in the time-of-day-specific reports that they do have at least some hours with some windows or doors open.

The two tables above summarize two different types of inconsistencies: those in which reported time-of-day-specific ventilation behavior implies more ventilation than the no/low/medium/high-ventilation hours reported in questions 28–31, and those in which it implies less.

The number of surveys that report inconsistent results is quite large. As might be expected, these surveys differ in systematic ways from the surveys that report consistent results on the various ventilation questions. On average, they tend to report more hours of ventilation in questions 28–31 than do the consistent surveys, while reporting substantially fewer hours of ventilation in questions 10–25. (However, some surveys report the opposite problem as discussed above).

One type of inconsistency is straightforward to handle: This study assumes that if the time-of-day-specific reports say that a house has windows or doors open for at least a given amount of time, then the house probably does have at least "low" ventilation for that amount of time. Therefore the research team added hours of "low ventilation" to questions 28–31 as needed to bring the ventilation hours up to the minimum number that is consistent with the time-of-day-specific reports.

A different approach is needed for the several hundred respondents who reported some hours with ventilation (in questions 28–31), but did not account for enough hours in their responses to questions 10–25, as shown in Table 6. For these cases, the study used a modification of the Census Bureau's "hot deck" procedure (described in Little and Rubin 1987). In this study's procedure, if a respondent ("the subject") gave time-of-day-specific information that was inconsistent with the reported level of ventilation, the researcher team did the following. (For purposes of this discussion, it is assumed that the problem was with data from the summer; the same procedure was used for other seasons as well):

1. Select all of the surveys that gave similar responses (as defined below) to the subject's ventilation question (question 28A–28D) *and* gave responses to questions 10–13 that were consistent with the ventilation question;
2. Draw (at random) one of the surveys from the subsample defined in (1) above, and record their responses to all time periods (parts A through F) of questions 10–13;
3. For each time period and for each room, average the hours reported by the subject with the hours recorded in (2) above. Compare the result to the reported number of hours. Take the maximum of these two numbers as the imputed number of hours of use for that room in that time period.

Responses were deemed to be "similar" to the subject, if:

- The total number of hours with some ventilation from the survey average (i.e., not "no ventilation") was within a factor of 2 of the subject's response; and
- The total number of hours with "medium" plus "high" ventilation from the survey average was within a factor of 2 of the subject's response; and

- The average number of weekday hours that the house was reported to be unoccupied from the survey average (questions 80A1–80C1) was within a factor of 2 of the subject's response; and
- The average number of weekend hours that the house was reported to be unoccupied from the survey average (questions 80A2–80C2) was within a factor of 2 of the subject's response.

In fewer than ten cases, applying these rules did not result in finding any "similar" responses; this happened, for example, with a few people who had given inconsistent answers to the ventilation questions and who reported that the house is occupied only a few hours per day during the week but is heavily occupied on weekends. In these cases, the research team dropped first the comparison with weekend hours, then with weekday hours, and finally both if necessary in order to obtain a survey that was deemed "similar" to the subject; dropping both conditions was necessary in only three cases.

Using the "hot deck" procedure described above imputes a new temporal behavior of ventilation, for each person who had accounted for many fewer hours of ventilation than they claimed in questions 28–31. The imputed behavior still does not always account for the full number of ventilation hours, but it is "less inconsistent." The resulting ventilation metric, effective specific leakage area, (ESLA, described below) is a compromise between the ventilation implied by questions 10–25 alone and the ventilation reported in questions 28–31. Homes that reported inconsistent results in the two types of ventilation questions tended to report higher levels of ventilation on their time-independent questions, and lower hours of ventilation on the time-specific questions, than did people who gave consistent answers to both.

In principle, the full procedure could be run many times, to create many realizations of this randomized process. In practice, this study did not do so, because these realizations were used only to summarize large quantities of data in which the effects of the imputation largely cancel out: although each individual's summarized ventilation behavior depends substantially on random aspects of the imputation procedure, the summary statistics of a large population do not.

Figure 2 shows, for each household, the maximum and minimum number of possible hours in the day with at least one window open. As the figure shows, for many households there is a substantial difference between the minimum and maximum number of possible hours. The figure also illustrates that the imputation procedure generates window-open hours in the same range as the hours reported for respondents whose window use was consistent with their reported hours of medium and high ventilation.

Table 8 summarizes the statistical distribution of minimum-possible number of window-open hours, by season, for the statewide representative sample. Additional tables of maximum-possible hours, and tabulations by survey stratum, are in Appendix C.

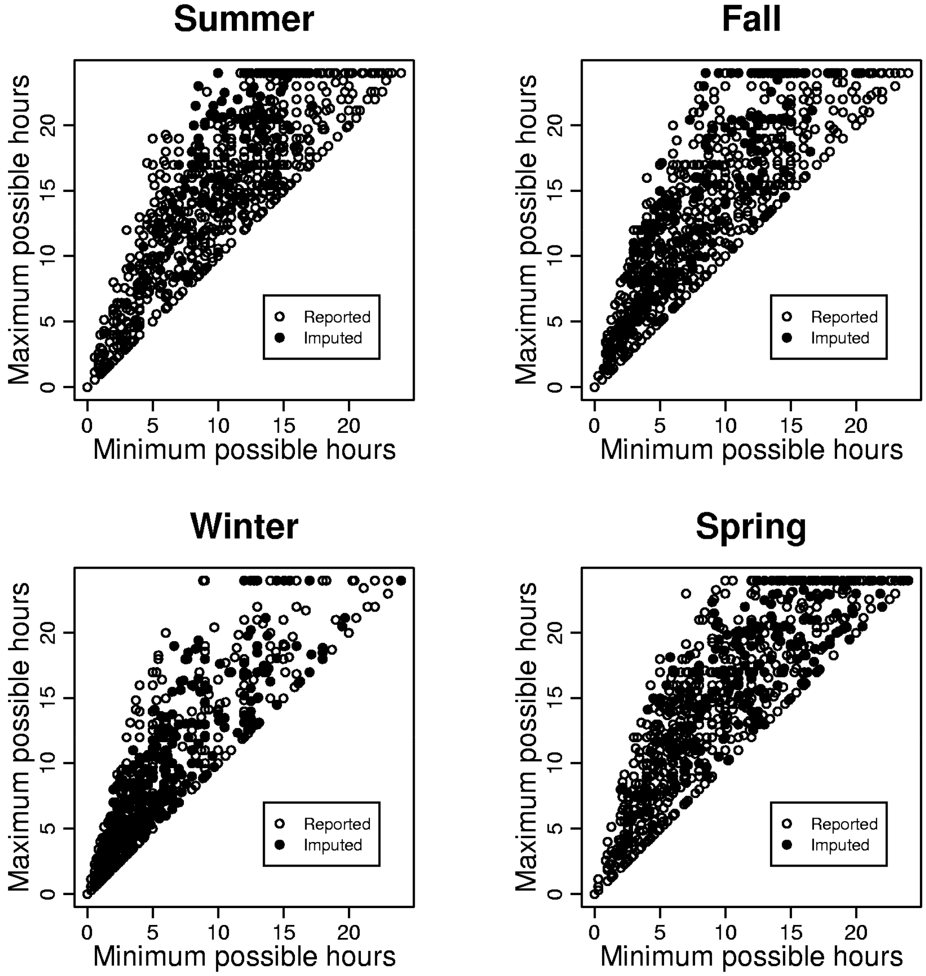


Figure 2. Maximum possible hours of ventilation plotted against the minimum reported. Filled circles show post-imputation results for responses for which additional hours of ventilation were imputed in order to make their hourly reported ventilation less inconsistent with their overall self-assessment of ventilation.

To compare ventilation behavior among respondents and to roughly quantify ventilation effectiveness, the research team converted the information in the questions about window opening (that is, questions 10–25, 28–31, 32, and 33) into a quantitative metric as described below.

A window opening has an Effective Leakage Area (ELA) associated with it; essentially this is just the area of the opening to the outdoors, potentially modified slightly by some geometric factors (e.g., for windows that tilt rather than sliding open). Title 24 uses a normalized ELA term, a dimensionless number, called Specific Leakage Area (SLA) to quantify envelope air leakage: SLA is simply the leakage area divided by the floor area of the house, and then multiplied by 10,000 to bring the numbers into a convenient range. (Equivalently, it is the leakage area in square centimeters, divided by the floor area of the house in square meters). It is a dimensionless number.

Table 8. Summary of the statistical distribution of hours with at least one window open: on weekdays, by season, for the state as a whole. For instance, 10% of homes report at least 2 hours with at least one window open on Summer weekdays.

Hours with at least one window open			Percent of Houses						
	Mean	Standard Deviation	5%	10%	25%	50%	75%	90%	95%
Summer	12.6	7.9	0	2	6	12	20	24	24
Fall	10.0	7.8	0	0	3	8	15	24	24
Winter	4.6	6.2	0	0	0	2	6	13	23
Spring	10.8	7.9	0	1	4	9	17	24	24

The researcher team estimated SLA from the survey data by using a linear combination of the number of hours of Low, Medium, and High ventilation. In the survey instrument, Low and Medium ventilation are defined in terms of the absolute number of windows open and the amount by which they are opened, but High ventilation is defined in terms of either the absolute number ("several doors or windows open part way") *or* the fraction of windows open ("almost all windows or doors open a crack"). The distinction is important because a given number of windows, open by a certain amount, will ventilate a small house more effectively than a large house. For example, consider a large house (120 square meters, or 1,290 square feet) and a small house (40 square meters, or 430 square feet) that each have 0.1 square meters (1 square foot) of open windows. The SLA for the large house is 8, whereas for the small house it is 25. Now consider a large house and a small house that each have most of their windows open. If the ratio of window area to floor area is about the same for both houses, then they will have about the same SLA in this case.

Thus, for Low and Medium ventilation the Specific Leakage Area scales inversely with floor area: "Low ventilation" or "Medium ventilation" as defined in the survey will ventilate a large house less effectively than a small house. In contrast opening "almost all windows" by a given amount will be about equally effective, in terms of promoting air changes per hour, whether the house is large or small, because the number of windows scales with the size of the house; therefore the SLA values for the high-ventilation condition do not scale with floor area.

Cross-ventilation (opening windows on opposite sides of the house) and high-low ventilation (opening windows on different stories, or at ground and ceiling level) substantially increase the ventilation provided, for a given number and area of open windows. Reported use of cross-ventilation and high-low ventilation are summarized in Tables 9 and 10.

If people indicated that they "frequently" use cross-ventilation, the SLA value for periods of Low and Medium ventilation was multiplied by 1.4, compared to providing the same number of open windows but never providing cross ventilation. If they "sometimes" use cross-ventilation, their SLA value for Low and Medium ventilation was multiplied by 1.2, and if they "rarely" use cross-ventilation, their SLA value was multiplied by 1.05. The same multipliers were used for people who "frequently," "sometimes," or "rarely" provide high-low ventilation. These numbers are rough estimates of the increased effectiveness of ventilation for these various conditions; in practice, there is no way to know exactly what people mean when they say they "frequently provide cross-ventilation." No multiplier was applied to periods of "High" ventilation because High ventilation was assumed to always include cross-ventilation and high-low ventilation.

Table 9. Percent of homes that provide cross-ventilation with a given frequency, by survey stratum

Percent of households that report a given amount of cross-ventilation	**Sacramento Delta Region (%)**	**Southern Coast Region (%)**	**Rest of State (%)**	**Statewide (%)**
Frequently	31	36	36	35
Sometimes	43	36	38	39
Rarely	10	18	13	14
Never	11	6	7	7
No answer/Not applicable	5	5	6	6

Table 10. Percent of homes that provide high-low ventilation with a given frequency, by survey stratum

Percent of households that report a given amount of high-low ventilation	**Sacramento Delta Region (%)**	**Southern Coast Region (%)**	**Rest of State (%)**	**Statewide (%)**
Frequently	18	25	23	23
Sometimes	29	35	30	31
Rarely	13	18	13	15
Never	17	11	13	13
No answer/Not applicable	24	12	20	18

Figure 3 shows histograms of SLA in various seasons, including SLA values that were imputed. As discussed above, if respondents reported in questions 10–25 that they do have windows open for some amount of time during the day, but reported total ventilation hours less than that amount in questions 28–31, they were credited with enough low-ventilation hours to make up the difference. Table 11 shows the 25th, 50th, and 75th percentile SLA values by season.

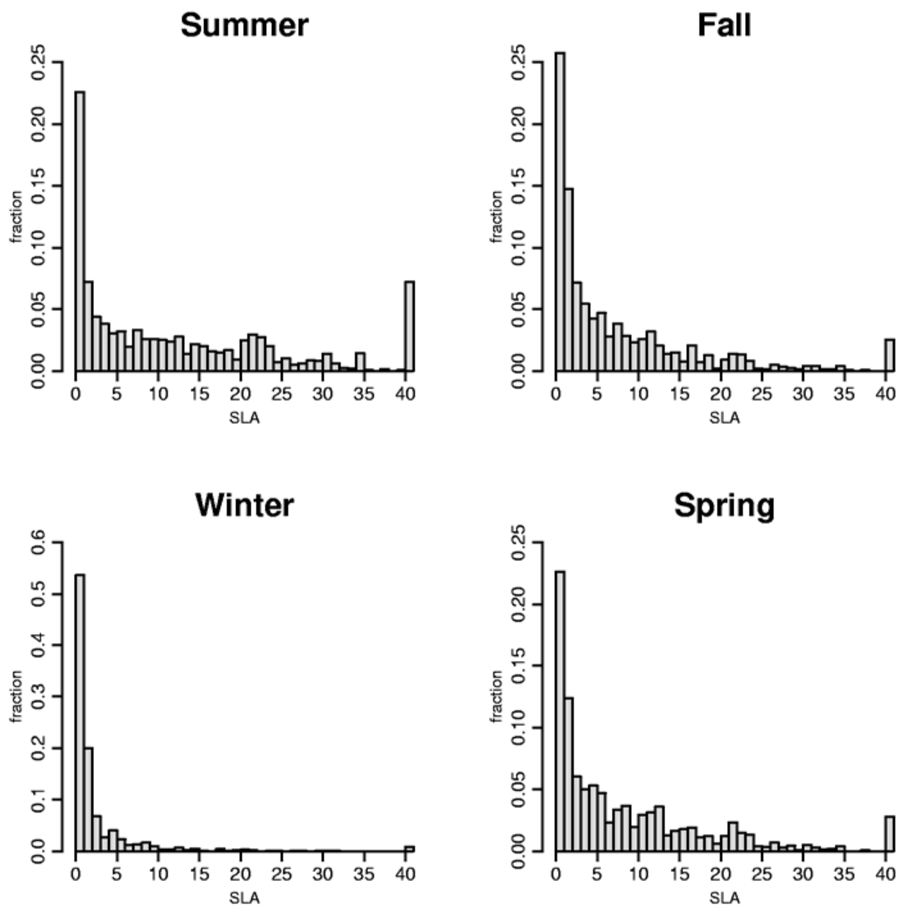


Figure 3. Specific leakage area from window opening

Histograms (for the Statewide Probability Sample, adjusted for sampling weight) of SLA from window openings in various seasons. SLA values at a bin boundary are tallied in the upper of the two bins. The y-axis scale is different for winter than for the other seasons.

Table 11. Quartiles of SLA for the statewide probability sample

	25th percentile	50th percentile	75th percentile
Summer	0.72	7.6	20.0
Fall	0.47	3.0	9.8
Winter	0.16	0.45	1.7
Spring	0.61	4.20	11.8

Appendix D discusses a method for using the questionnaire data to generate the Effective Specific Leakage Area (or ESLA) induced by the window opening behavior. ESLA is a dimensionless number that quantifies the effectiveness of ventilation by taking into account both the amount of ventilation provided, as determined by SLA, as well as the times during the day that it is provided. The temporal behavior makes a difference because, for example, if windows are open for a total of 6 hours per day, the effect on indoor air quality is somewhat better if this is distributed as 3 hours in the morning and 3 hours at night than if the windows are open for 6 hours at night and then closed for 18 consecutive hours.

Although the equation for determining ESLA is complicated, the basic idea is simple: for a particular house, how widely would a window have to be left open *all the time,* in order to achieve the same effectiveness of ventilation that the house achieves with its window-opening behavior? The answer to this question is expressed just like that of SLA: a dimensionless number equivalent to the area of the opening in square centimeters, divided by the floor area of the house in square meters.

The maximum possible ESLA value of 40 (See Appendix D for details) is obtained with 24 hours of high ventilation. As defined in Appendix D, there is a separate "ventilation efficiency" for weekend and weekday in each season, and these efficiencies affect the value of ESLA. The "seasonal ventilation efficiency" is defined as ESLA/SLA in each season. Ventilation efficiencies are summarized in Table 12.

Table 12. Quartiles of ventilation efficiency

Ventilation efficiency	25th percentile	50th percentile (median)	75th percentile
Summer	0.54	0.76	0.98
Fall	0.33	0.65	0.90
Winter	0.01	0.24	0.59
Spring	0.38	0.66	0.94

Ventilation efficiency is generally low in winter because in many households the hours with ventilation are restricted to certain times of day, with all windows closed for most of the day. Someone who reports only 2 or 3 hours of ventilation, in just one time period during the day, will have a very low efficiency; for instance, 2 hours of ventilation during the weekday, with no ventilation at any other time and with no cross-ventilation, leads to an efficiency under 0.01. However, the efficiency climbs rapidly with hours of ventilation (or, more correctly, as the number of unventilated hours decreases). Ventilation efficiencies are much higher in the other seasons.

The ventilation efficiency depends on the temporal behavior of the window-opening, and as discussed above there were many cases in which the reported temporal behavior was inconsistent with people's reported hours of low, medium, and high ventilation. Our imputation procedure credits people with more hours of ventilation than they actually reported in the temporally detailed questions, but not necessarily enough to make their temporally detailed results consistent with their reported hours of low, medium, and high ventilation. (As discussed above, people who reported inconsistent results were likely to report very high levels of ventilation on the time-independent ventilation questions, and rather low numbers of hours of ventilation on the time-dependent questions). There is simply no way to be sure about the efficiency, or, indeed, the number of hours of ventilation, for people who gave inconsistent answers.

A large number of window-open hours necessarily leads to a high ventilation efficiency. A small number of window-open hours leads to a low ventilation efficiency, since (in practice) a low number of window-open hours always leads to long periods of the day with no ventilation at all. Therefore the efficiency and the number of ventilation hours tend to vary together, and there is a high correlation between SLA (which is just a weighted sum of low-, medium-, and high-ventilation hours) and ESLA. In every season, r-squared exceeds 0.9 in a linear model to predict ESLA from SLA. Consequently, histograms of ESLA (not shown) look very much like histograms of SLA shown in Figure 3, although the Winter ESLA values in particular are somewhat lower than the Winter SLA values because of the effect of ventilation efficiency, discussed above. The cumulative distribution of ESLA for the statewide representative sample is shown, by season, in Figure 4.

The statistical distribution of ESLA is skewed because many people reported very low levels of ventilation and thus have very low ESLA values. In the statewide probability sample 20% of households report that they receive less than 2 hours per day of ventilation from window opening in summer, and 6% report no ventilation at all from window opening.

There is no simple mathematical function that describes the statistical distribution of ESLA, so there are problems with applying standard modeling approaches for quantifying how ESLA is affected (on average) by various explanatory variables. Specifically, linear regression (a standard statistical technique) assumes that "residuals"—the differences between observed and predicted values of a quantity —follow a "normal" or "Gaussian" distribution, but that will often not be the case when predicting ESLA. In spite of this problem, this report sometimes uses linear regression to determine whether explanatory variables predict a substantial amount of the variation in ESLA. The answer is that few of the variables are useful in this regard. For this reason, the research team did not perform the substantially more complicated analyses that would be necessary to take the statistical distribution of ESLA into account: variables that do not demonstrate substantial predictive value under our approach would also not demonstrate substantial predictive power under an alternative approach, although the numerical estimates of influence would be different.

The caveats in the previous paragraph apply to predicting ESLA based on explanatory variables. For technical reasons, details of the statistical distribution of ESLA are not important when predicting other variables using ESLA as an explanatory variable, which is an approach used at some places in this report.

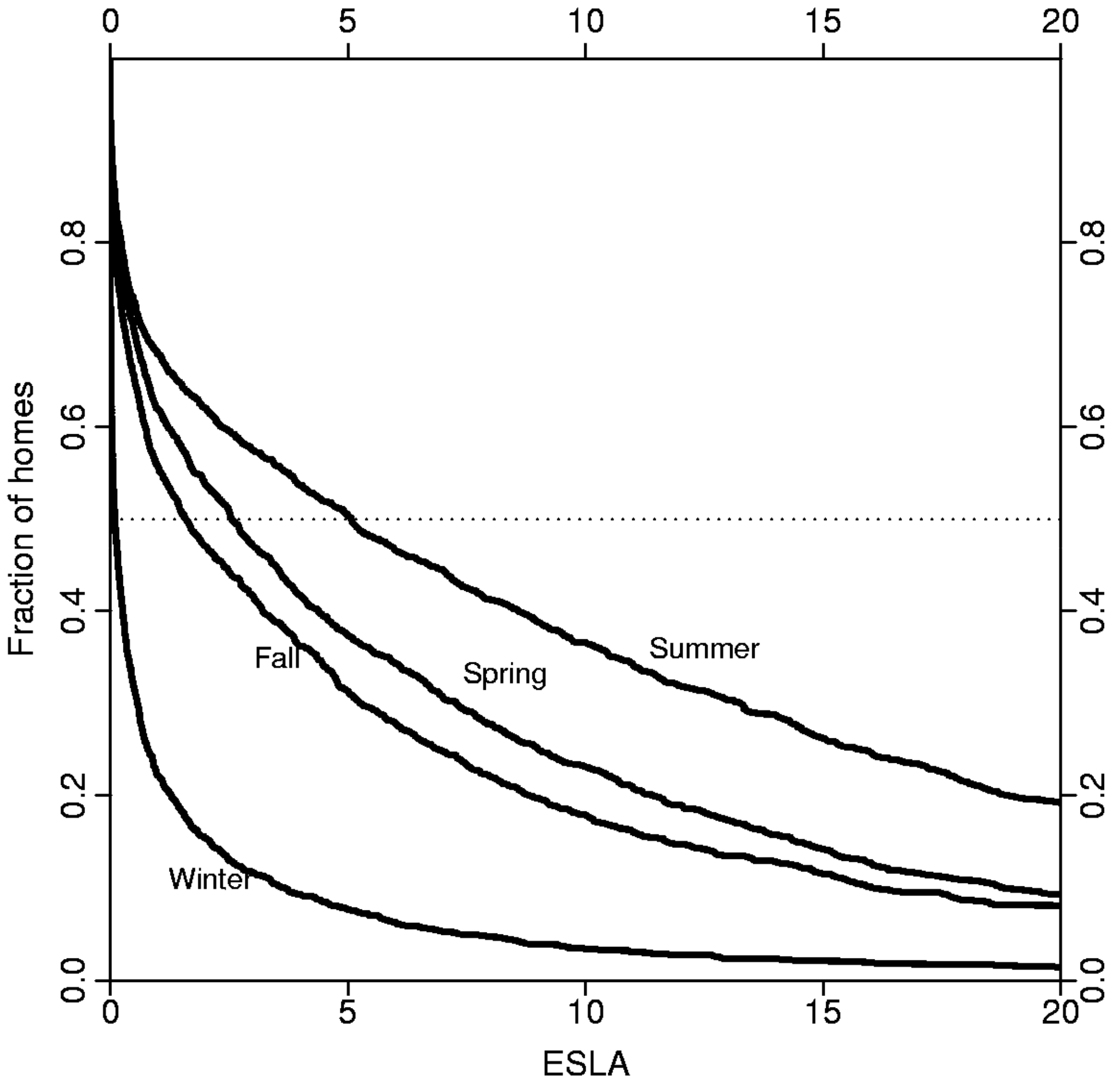


Figure 4. Cumulative probability distribution for ESLA from window opening for the statewide probability sample, by season, (adjusted for sampling weights).

The vertical axis shows what fraction of homes meet or exceed the ESLA value on the horizontal axis. (This reverses the conventional way of presenting cumulative distribution functions). A dashed line helps identify the median.

The Residential Alternative Calculation Method (ACM) for Compliance with California's 2005 Energy Efficiency Standards assumes that "when natural ventilation, infiltration, and mechanical ventilation fall below a threshold value of 0.35 air changes per hour (ACH), the occupants are assumed to open the windows at the beginning of the next hour sufficient to provide a combination of infiltration and ventilation equal to 0.35 ACH for an eight-foot-high ceiling. The windows are assumed to remain partially open to provide a minimum of 0.35 ACH as long as the previous hour's infiltration and mechanical ventilation rate is below the threshold." The ACM also defines an assumed relationship that allows prediction of the air exchange rate from the level of ventilation and the weather conditions. From this relationship, it is possible to determine the total Specific Leakage Area—the combination of envelope leakage and ventilation—that must be provided in order to provide 0.35 ACH.

The SLA from envelope air leakage and the ESLA from window opening can be added together, to yield a "total ESLA" for the house. The total ESLA can be used to estimate the indoor-outdoor air change rate, by following procedures defined in ASHRAE Standard 119-1988 (ASHRAE 1994) and ASHRAE Standard 136-1993 (ASHRAE 2001), where "Normalized Leakage," as defined in ASHRAE 1994, is equal to "total ESLA" divided by 10. ASHRAE 2001 specifies how to combine Normalized Leakage with climate information to estimate the air change rate.

The total ESLA necessary to achieve 0.35 air changes per hour depends on climate zone and season: higher ESLA values (i.e., more windows or windows open wider) are needed in milder climates and seasons, because driving forces (wind, and temperature-induced pressure differentials) are smaller then. In most areas of California, total ESLA values near or above 5 are necessary to achieve 0.35 ACH in summer and fall, and near or above 4 are needed in spring and winter. Using the ASHRAE relationships described in the previous paragraph, the research team back-calculated from California climate information to determine the Normalized Leakage required, and thus the ESLA required, in order to achieve an average of 0.35 ACH. See Appendix D for details on the estimated total ESLA required, by season and climate zone.

Wilcox et al. (1990), Rudd et al. (1993), and Wilson et al. (2003) measured SLA from envelope air leakage—that is, for infiltration through cracks and penetrations through the building shell—for small samples of California houses that were new when they were measured (in 1990, 1992, and 2003, respectively). Results suggest that typical new California houses have envelope air leakage SLA values that are mostly in the range 2–4, but some houses were found to have an SLA below 1.5 or even below 1. Thus, to provide 0.35 ACH, ventilation must provide ESLA of roughly 1.5 to 3.5 for typical new California houses, and 2.5 to 4.5 for relatively tight houses.

As Figure 4 illustrates, although some houses receive adequate ventilation from opening of windows and doors, many houses do not get a significant contribution from window opening, and (unsurprisingly) this is particularly true in winter, when many people report no ventilation at all, and many others report only a few hours of low ventilation.

Exhaust fans (kitchen and bathroom) could theoretically contribute sufficient ventilation to meet the 0.35 ACH recommendation, if they were left on for many hours per day: a continuously operating bathroom fan that exhausts 25 cubic feet per minute (cfm) would provide about 0.1 ACH for a 2000 square-foot house, above and beyond any other ventilation. But (as discussed previously) many people do not even use the bathroom fan when they are in the bathroom; with overall usage of less than an hour per day in most houses, the exhaust fans contribute negligibly to the whole-house ventilation, though they may provide important exhaust of local pollutants.

Assuming envelope leakage provides SLA = 1 in all houses at all times, new California houses are at risk of inadequate ventilation if they provide window ventilation corresponding to ESLA < 3.5 in summer or fall, or less than 2.5 in winter or spring, so: 40% are at risk of inadequate ventilation in summer, 50% are at risk spring, 60% are at risk in fall, and 85% are at risk of inadequate ventilation in winter.

There is little point in providing highly detailed analyses of what fractions of homes do or do not provide various levels of ventilation because, as discussed below, uncertainties in ESLA values are large and ESLA values are also subject to potential bias. Still, it is apparent that many houses fail to achieve the recommendation of 0.35 ACH for substantial portions of the year.

The ESLA estimate for any particular home is subject to inherent imprecision because the survey breaks ventilation into no/low/medium/high-ventilation categories, and each category encapsulates a substantial range of ventilation. Two houses could differ by a factor of more than 3 in specific leakage area and still correctly report that they receive "medium ventilation," if one home is near the lower end of the "medium" definition while the other is near the upper end. The research team has tried to set the constants in the SLA and ESLA definitions so that the definitions are correct for the median house in each category; that is, so that half the people who report "medium" ventilation have higher SLA than assumed, and half lower. Based on experience and judgment, the researchers believe that if people have correctly answered the ventilation questions in the survey, the estimated SLA and ESLA values for any individual house are unlikely to differ from the actual values by more than a factor of three. It also appears likely that the bias in the definitions (when applied to the entire population of houses) is probably less than a factor of 1.5, if people have correctly answered their ventilation questions. However, people may well give answers to the ventilation questions that are in error by a factor of 1.5 or more, in terms of the durations that windows are open and the amount that they are open, so inaccuracy of people's answers may be a substantial contributor to overall error.

This study used the "simple bootstrap" method (Efron 1981) to evaluate the uncertainty in the median ESLA for the Statewide Probability Sample in each season, summarized in Table 13, as the range that contains 68% of the bootstrap simulations. Of course this procedure only estimates the component of uncertainty that is due to stochastic variability. As discussed above, other sources of error are more important for this dataset.

Table 13. Estimated median ESLA for the statewide probability sample

ESLA	Median	68% confidence range for median
Summer	5.1	4.8–5.2
Fall	1.6	1.4–1.8
Winter	0.09	0.08–0.10
Spring	2.6	2.4–2.8

Figure 5 shows the ESLA distribution for homes in the non-representative Builders' Sample. The lines appear choppy because of small sample sizes: each home's response forms the endpoint of a line segment. Summer ELSA values seem to be generally lower than in the Statewide Probability Sample, but other results are similar to the Statewide Probability Sample.

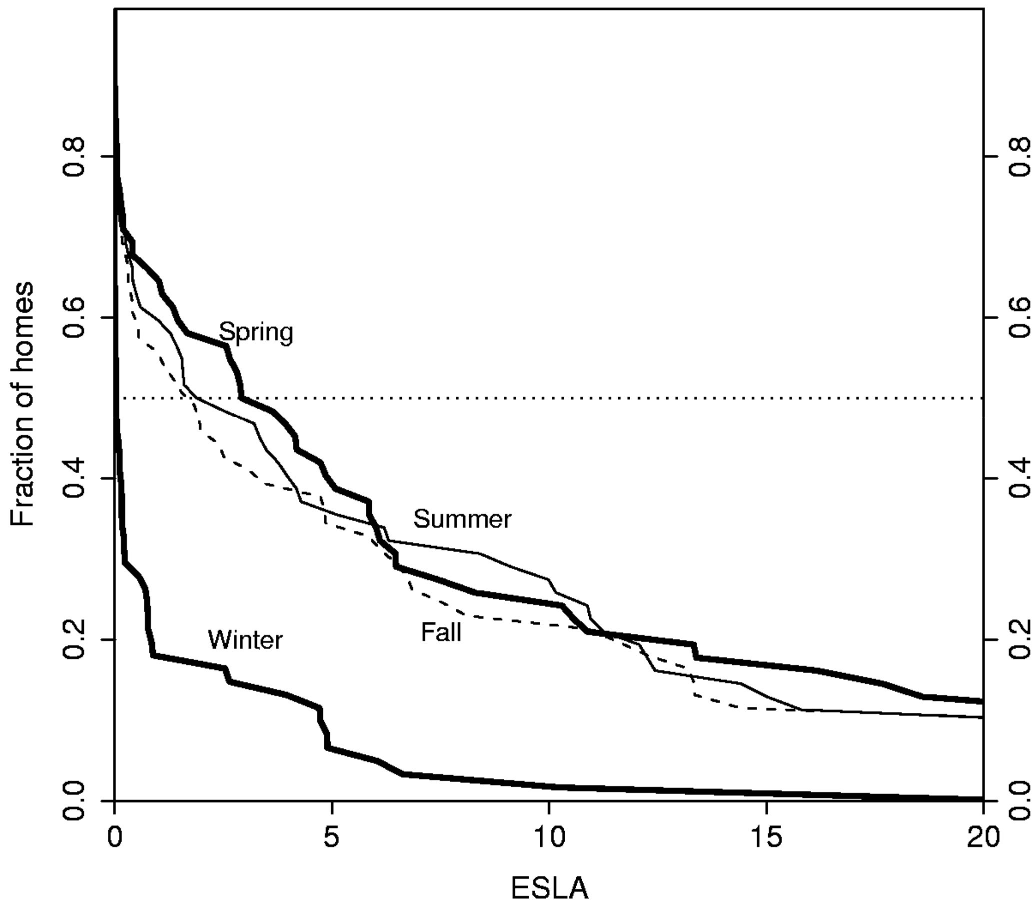


Figure 5. Cumulative probability distribution for ESLA for the builders' sample, by season, (adjusted for sampling weights). The vertical axis shows what fraction of homes meet or exceed the ESLA value on the horizontal axis. (This reverses the conventional way of presenting cumulative distribution functions). A dashed line helps identify the median.

Uncertainties due to small sample sizes are substantial. Even so, errors due to inaccurate answers to the ventilation questions are probably larger than the uncertainties due to small-sample variation. Again, the "bootstrap" method was used to estimate the uncertainty in the median, summarized in Table 14 as the range that contains 68% of the bootstrap simulations.

Table 14. Estimated median ESLA for the builder's sample

ESLA	Median	68% confidence range for median
Summer	2.5	1.6-3.8
Fall	1.8	1.0-2.4
Winter	0.03	0.01-0.11
Spring	3.6	2.8-4.8

3.1.5. Regional Variation in Ventilation

Figure 6 below, shows the ESLA distribution in each season, with a different curve for each of the three regions in the survey. People report slightly less ventilation (and thus lower ESLA) in the Sacramento Delta region than in either the Southern Coastal region or the rest of the state. This effect is strongest in summer: The mean (median) summer ESLA in the Sacramento Delta, Southern Coastal, and the rest of the state respectively are 7.9 (3.1), 10.2 (5.2), and 10.1(5.1). The mean summer ESLA in the Sacramento Delta is about two units lower than in the other parts of the state (p-value 0.02).

Table 15 summarizes the distributions of estimated ESLA by region (i.e., the same information shown in Figure 6) and for the whole state (i.e., as shown in Figure 4). As indicated in Appendix D, an ESLA value in the range 3.5 to 6.5 is necessary (depending on season and climate) to provide 0.35 ACH. Even given the uncertainties in estimating the ESLA values, it is clear that in every season many households fail to achieve ESLA values as high as 3.

The fact that ESLA values in the Sacramento Delta region are slightly lower than in the rest of the state is primarily due to fewer hours of medium and high ventilation, in all seasons. In summer, for example, the 25th percentile of hours of medium or high ventilation is 2.25 hours in the Sacramento Delta region compared to 4 hours in the rest of the state; and the median is 10 hours in the Sacramento Delta region, compared to 12 hours in the rest of the state. Even in winter, when the median is 0 hours of medium or high ventilation in both the Sacramento Delta region and the rest of the state, the 75th percentile is 1 hour in the Sacramento Delta region, compared to 4 hours in the rest of the state.

Except for winter, the difference in ventilation behavior may be partly attributable to allergies. As noted in a later section, households that reported having members who are allergic to outdoor agents reported less ventilation than other households. In the Sacramento Delta region 62% (+/- 4%) of households report having at least one household member who is allergic to an outdoor agent, compared to 48% (+/- 3%) in the rest of the state, a difference well outside the range of stochastic variability (p-value 0.002). However, this factor alone does not explain the difference in ventilation hours between the Sacramento Delta region and the rest of the state: even households without a person who is allergic to outdoor agents get less ventilation in the Sacramento Delta region than in the rest of the state.

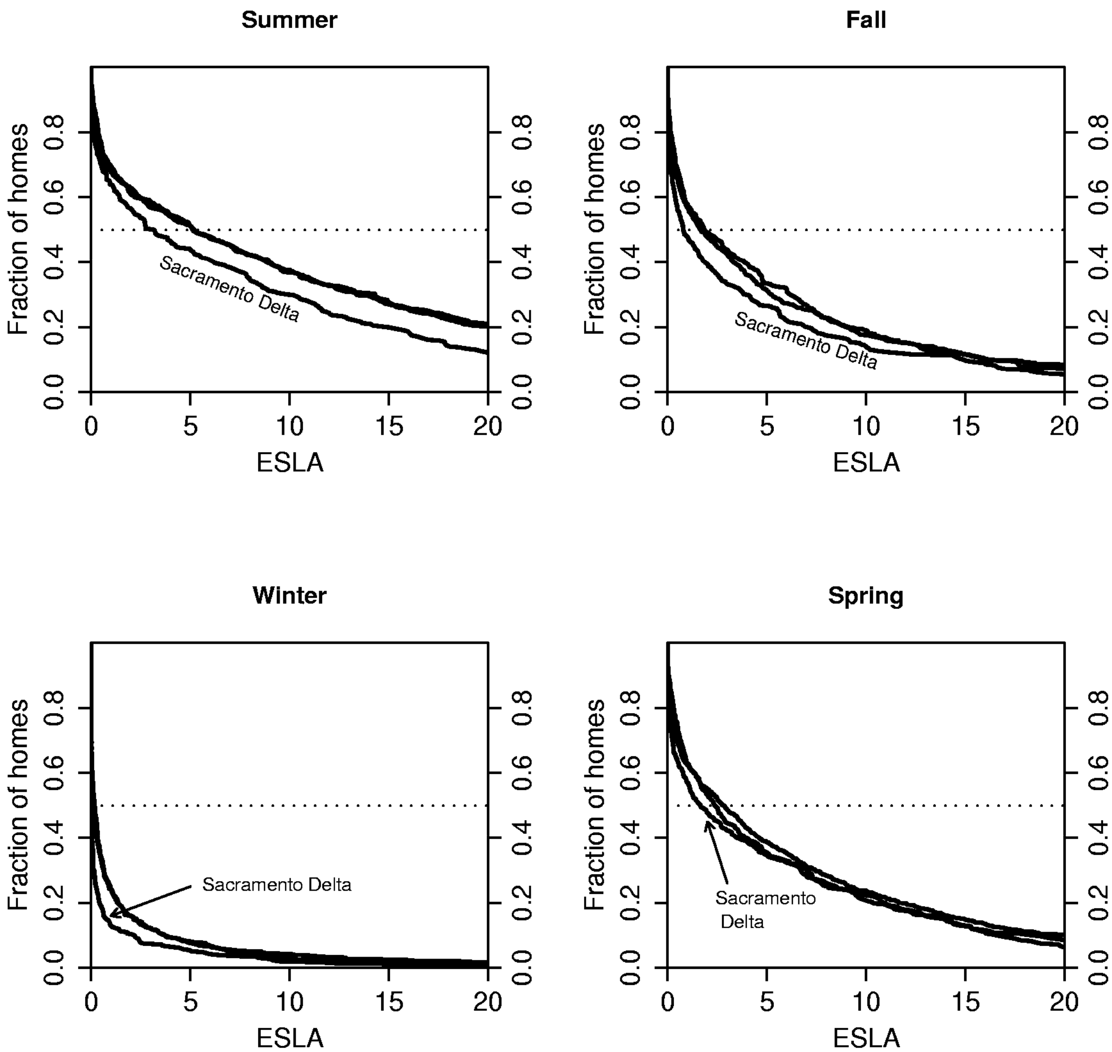


Figure 6. Cumulative probability distribution for ESLA for the statewide probability sample, by season and region, (adjusted for sampling weights).

The vertical axis shows what fraction of homes meet or exceeds the ESLA value on the horizontal axis. (This reverses the conventional way of presenting cumulative distribution functions). A dashed line helps identify the median. In each case, the Sacramento Delta region has slightly lower ESLA values than the other two regions; the other regions overlay each other almost perfectly on the plots.

Table 15. Statistical distribution of estimated ESLA by season, by region, and for the entire state

ESLA distribution by season and region		Percentile						
		5	10	25	50	75	90	95
	REGION							
Summer	Sacramento Delta	0.0	0.0	0.3	3.2	11.6	21.5	31.4
	Southern Coastal	0.0	0.1	0.6	5.2	17.0	30.2	36.2
	Rest of State	0.0	0.0	0.3	5.1	16.1	28.6	39.6
	Statewide	0.0	0.0	0.4	5.1	15.9	28.6	38.8
Fall	Sacramento Delta	0.0	0.0	0.1	0.8	5.6	14.9	22.0
	Southern Coastal	0.0	0.0	0.3	1.9	7.4	16.2	21.5
	Rest of State	0.0	0.0	0.2	1.7	7.3	16.4	25.1
	Statewide	0.0	0.0	0.2	1.6	7.1	16.1	23.5
Winter	Sacramento Delta	0.0	0.0	0.0	0.0	0.2	2.2	5.7
	Southern Coastal	0.0	0.0	0.0	0.2	0.9	3.7	6.9
	Rest of State	0.0	0.0	0.0	0.1	1.0	3.7	8.6
	Statewide	0.0	0.0	0.0	0.1	0.8	3.6	7.5
Spring	Sacramento Delta	0.0	0.0	0.2	1.7	8.1	16.6	24.3
	Southern Coastal	0.0	0.0	0.5	2.4	8.5	18.7	23.2
	Rest of State	0.0	0.0	0.3	2.8	9.2	20.3	25.6
	Statewide	0.0	0.0	0.3	2.5	9.0	18.7	25.1

For the survey as a whole, most households reported that a given window is either open or closed for the entire night; for instance, 75% of households reported either 0 or 7 hours that "any of the bedroom windows" are open during the 7-hour nighttime period in summer.

Table 16 shows the percent of homes in each stratum that report leaving a given window open for more than 5 hours per night during summer weeknights (from 11 p.m. to 6 a.m.).

Table 16. Percent of houses that report > 5 hours per night with at least one window open in summer, by room type and region

Percent of homes	Sacramento Delta region (%)	Southern Coastal region (%)	Rest of State (%)	Statewide (%)
Kitchen area	8	12	11	11
Any of the Bedrooms	29	42	36	38
Any of the bathrooms, laundry room, utility room	14	34	22	24
All other rooms	8	11	12	11

Before the study, there was some expectation that households in the Sacramento Delta region might provide more nighttime summer ventilation than households in the rest of the state. This expectation is not supported by the survey. Fewer houses in the Sacramento Delta region than in other areas reported leaving a window open all night in summer, as Table 16 shows, and 50% of houses in the Sacramento Delta region reported no windows open at all at night, compared to 33% in the Southern Coastal region and 42% in the rest of the state.

Although new houses in the Sacramento Delta region tend to receive slightly less ventilation than houses in the rest of the state, it is not clear that the reason for this variation is attributable to differences in climate. Indeed, differences in climate seem to explain very little of the variation in ventilation behavior among houses, as discussed next.

The California Energy Commission splits California into sixteen "Climate Zones" (CZ) (see Table 17). The research team used the zip code from each survey home to match it to its climate zone. This yielded unambiguous results for 62% of the houses in the survey, but 38% of homes were in zip codes that include multiple climate zones. Usually the climates included in a single zip code are similar to each other. For cases in which the climate zone could not be determined unambiguously, researchers assigned the house to the lowest-numbered of the possible climate zones. Since climate zones that are spanned by a single zip code are almost always very similar to each other, incorrect assignment of climate zones using this procedure is not expected to substantially affect any results. (Researchers also performed the following analyses using just the 62% of houses for which the climate zone could be definitively determined, but that decreased the sample size without leading to substantially different results; those results are not discussed here).

Table 17. Sample size, by California climate zone

Climate Zone Number	Houses in Representative Sample	Zone Description	Example of a City in the Zone
1	0	North coastal	Eureka
2	25	Northern coastal valley	Santa Rosa
3	74	San Francisco bay area	Oakland
4	75	Central coastal valley	San Jose
5	3	Central coastal	Santa Maria
6	144	South coastal – Los Angeles	Long Beach
7	221	South coastal – San Diego	San Diego
8	31	Southern coastal valley – south	Santa Ana
9	186	Southern coastal valley – north	Burbank
10	236	Southern inland valley	Riverside
11	20	Northern inland valley – hot	Red Bluff
12	325	Northern inland valley – moderate	Sacramento
13	0	Central inland valley	Fresno
14	99	Southern high desert	China Lake
15	20	Southern inland valley	El Centro
16	0	Mountain	Mt. Shasta

More than 90% of the surveyed homes in the Sacramento Delta region were assigned to climate zone 12, and almost all of the homes from the Southern Coastal region were from climate zones 6 (n=59), 7 (n=113), and 9 (n=90). The "Rest of the State" survey stratum includes homes from many of the climate zones in California, including climate zones that span parts of the Sacramento Delta region and the Southern Coastal region. The climate zones most heavily represented in the "Rest of the State" stratum are CZ 10 (n=236), CZ 7 (n=108), CZ 14 (n=99), CZ 9 (n=96), and CZ 6 (n=85). Since the Rest of State stratum is a mixture of homes from diverse climate zones, it is not as useful as the Sacramento Delta sample and the Southern Coastal sample for investigating the influence of climate on ventilation behavior.

Note that there are no cases at all from climate zones 1, 13, and 16, and that there are 20 or less cases in climate zones 5, 11, and 15. The sample was stratified only by the three major strata, and there was no guarantee that any particular climate zone would be included in the sample. Climate zones 1 and 16 are very small in terms of population, so it is not surprising that there were no houses from those zones in the sample. Climate zone 13, which includes the Fresno area, is more surprising. An examination of the sampling frame, however, revealed that Fresno County did not report recent home sales to DataQuick in time for them to be included in the sample. The only data for Fresno County was for years that preceded our target period.

Figure 7 shows the cumulative distribution functions for summer hours of high ventilation, and medium or high ventilation, separately for nine of California's sixteen "climate zones," for the statewide probability sample. (The other climate zones had too few samples to include). In each sub-plot, the upper curve summarizes the statistical distribution of high-ventilation hours, and the middle curve summarizes the statistical distribution of high- or medium-ventilation hours, and the lower curve summarizes the statistical distribution of high-medium-or-low-ventilation hours. Four climate zones with very few houses (less than 30 per zone) are not shown. As the similarity of the plots indicates, there is only modest apparent variation between climate zones, from the standpoint of how many summer hours of high and medium ventilation are provided.

Figure 8 is the same as Figure 7, but shows winter rather than summer ventilation. In each sub-plot, the upper curve summarizes the statistical distribution of high-ventilation hours, and the middle curve summarizes the statistical distribution of high- or medium-ventilation hours, and the lower curve summarizes the statistical distribution of high-medium-or-low-ventilation hours.

Figure 9 shows box-and-whisker plots of hours of no-or-low ventilation, by climate zone, separately for each season, for all of the climate zones with at least 30 houses in the survey. This plot is an alternative way of presenting the same information that is shown by the middle curves—the medium- or high-ventilation curves—in Figures 7 and 8. Any hours that are not no-ventilation or low-ventilation are medium- or high-ventilation.

In addition to hours of medium or high ventilation as discussed above, this study also examined the variation of ESLA among climate zones, for all seasons. The research team used climate zone indicator variables in a linear model to predict ESLA, including sampling weights.

Tables 18 through 21 summarize the estimated distributions of ESLA for all of the climate zones with more than 15 houses in the statewide probability sample. The ESLA values can be compared to the minimum ESLA values needed to provide 0.35 ACH, shown in Appendix D. Stochastic variability due to small sample sizes is large even for the more highly sampled climate zones. For example, the median estimated summer ESLA in Zone 6 is 6.9, but the 68% confidence interval estimated using the bootstrap method (Efron 1981) ranges from 5.8–8.8.

There is modest variation in ESLA among climate zones. Analysis of variance (ANOVA) rejects the hypothesis that the mean summer ESLA in each climate zone is identical (p-value less than 0.0001). Linear regression of summer ESLA on climate zone indicator variables suggests that houses in climate zones 6 and 7 are somewhat better-ventilated than houses in other climate zones (by an average of 2.4 +/- 0.9 units in zone 6 and 3.9 +/- 0.7 in zone 7) and that houses in climate zones 9 and 15 are more poorly ventilated (by an average of –2.8 +/- 0.8 units in zone 9 and –8.8 +/- 2.5 in zone 15); p-values are less than 0.01 in all of these cases. However, this modest variation in ESLA among climate zones is almost completely swamped by the enormous variation within climate zones, so the r-squared value is only 0.04. In other words, variability among climate zones explains only about 4% of the overall variance in ESLA.

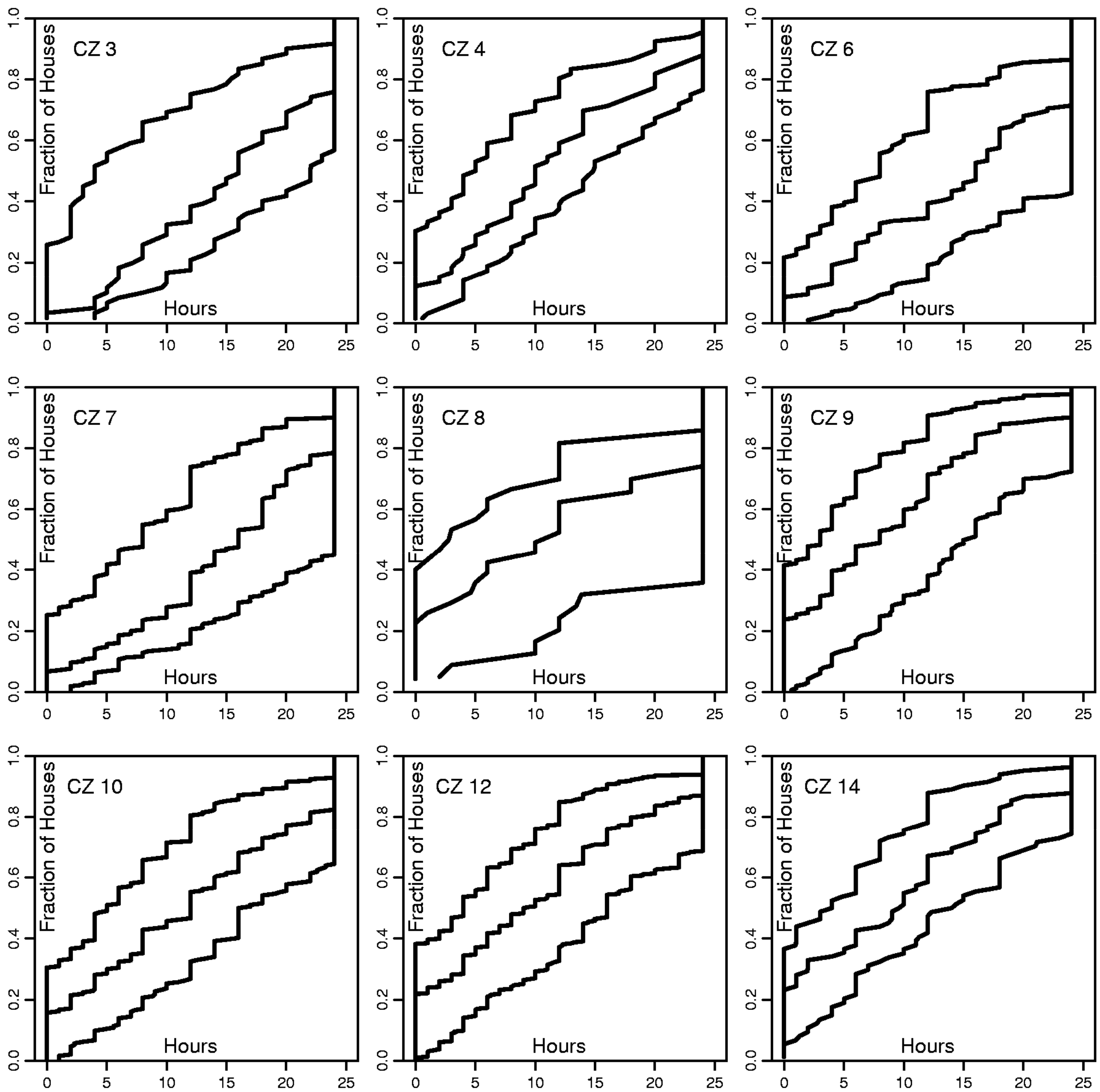


Figure 7. Cumulative distribution of summer hours of ventilation at various levels, for nine of California's sixteen climate zones. Cumulative distribution of hours per day of high ventilation (upper curve), hours of high-or-medium ventilation (middle curve), and hours of high-or-medium-or-low ventilation (lower curve), for nine of California's sixteen climate zones, in summer. Y-axis shows fraction of homes that receive less than or equal to the number of hours of ventilation on the x-axis. All hours that are not high, medium, or low ventilation are hours with no ventilation. Climate zones (CZ) are described in Table 17.

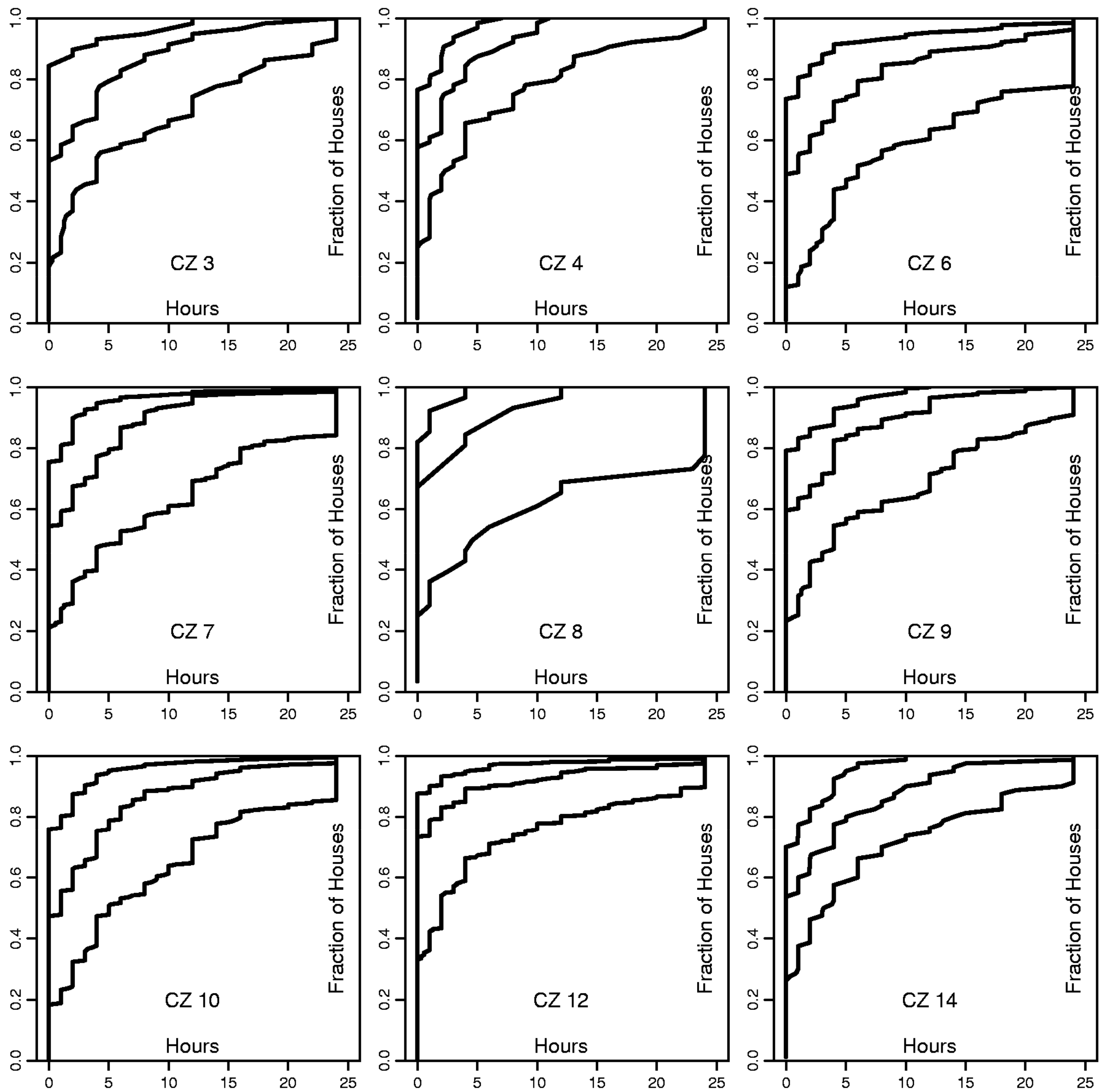


Figure 8. Cumulative distribution of winter hours of ventilation at various levels, for nine of California's sixteen climate zones. Cumulative distribution of hours per day of high ventilation (upper curve), hours of high-or-medium ventilation (middle curve), and hours of high-or-medium-or-low ventilation (lower curve), for nine of California's sixteen climate zones, in Winter. Y-axis shows fraction of homes that receive less than or equal to the number of hours of ventilation on the x-axis. All hours that are not high, medium, or low ventilation are hours with no ventilation. Climate zones (CZ) are defined in Table 17.

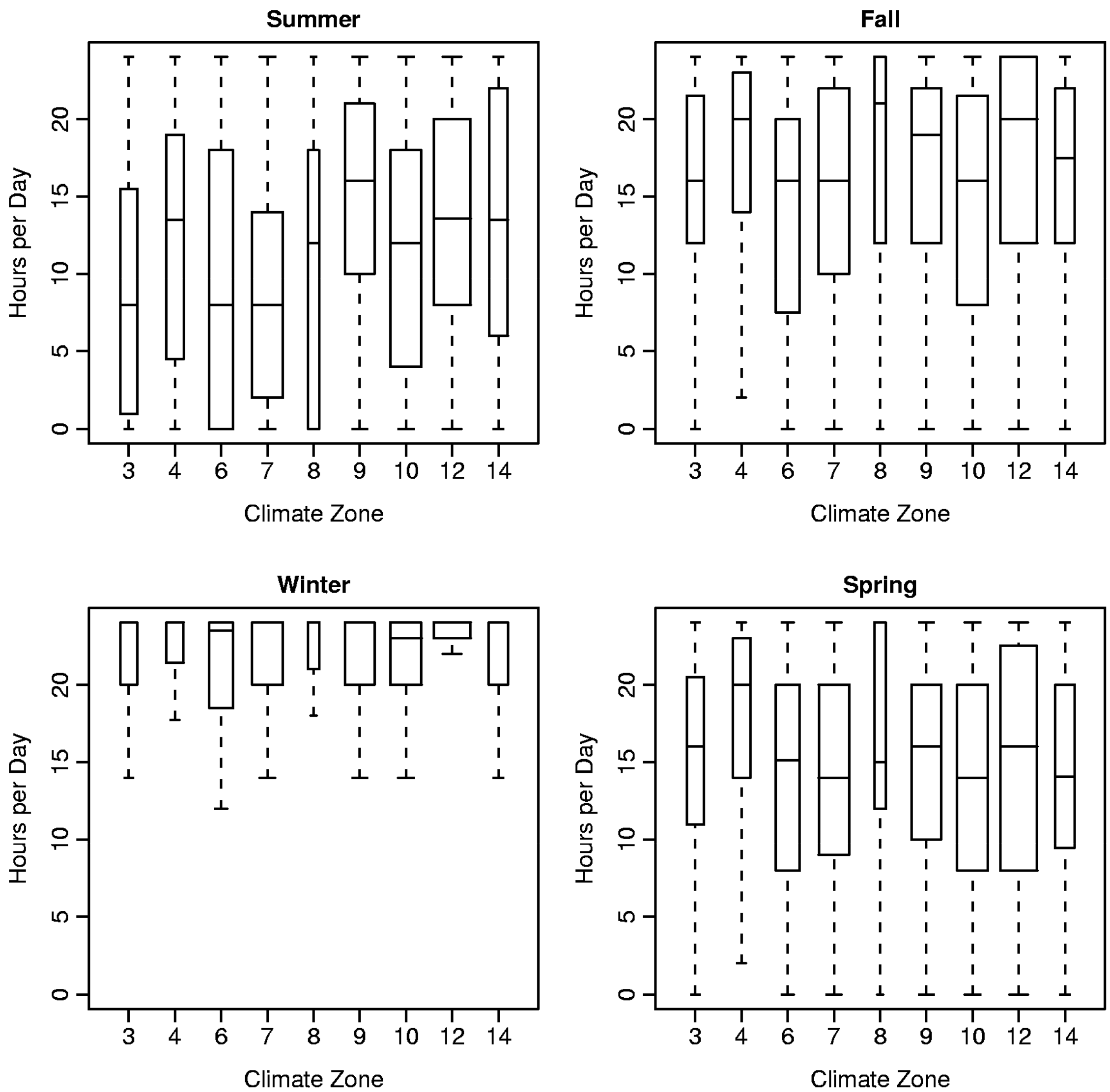


Figure 9. Box-and-whisker plots showing hours of no-or-low ventilation, by climate zone, separately for each season. In each plot, a box contains the central 50% of the data, with a horizontal line marking the median. "Whiskers" contain all of the data that fall within 1.5 interquartile ranges of the median. The width of each box is proportional to the square root of the number of observations in the climate zone. Climate zones are described in Table 17.

Table 18. Distribution of estimated summer ESLA, by climate zone

Stochastic variability is substantial, especially for sparsely sampled climate zones. Climate zones are described in Table 17.

Summer ESLA by Climate Zone		Percent of Houses						
Climate Zone	Number of Houses	5%	10%	25%	50%	75%	90%	95%
2	25	0.0	0.0	3.8	10.2	17.8	24.9	40.0
3	74	0.0	0.1	1.5	5.2	18.0	32.0	40.0
4	75	0.0	0.0	0.4	4.6	13.4	31.7	39.5
6	144	0.1	0.2	0.6	6.9	20.8	33.1	40.0
7	221	0.0	0.2	1.5	10.5	21.4	33.8	40.0
8	31	0.0	0.0	0.2	4.5	14.9	39.8	40.0
9	186	0.0	0.0	0.3	2.9	9.5	19.7	25.5
10	236	0.0	0.0	0.3	4.9	16.6	26.5	38.6
11	20	0.0	0.0	3.0	7.4	8.4	10.2	10.2
12	325	0.0	0.0	0.3	3.3	13.6	24.8	36.3
14	99	0.0	0.0	0.0	3.0	11.4	21.5	28.6
15	20	0.0	0.0	0.0	0.0	0.3	1.3	1.5

Table 19. Distribution of estimated fall ESLA, by climate zone

Stochastic variability is substantial, especially for sparsely sampled climate zones. Climate zones are described in Table 17.

Fall ESLA by Climate Zone		Percent of Houses						
Climate Zone	Number of Houses	5%	10%	25%	50%	75%	90%	95%
2	25	0.0	0.0	0.1	1.9	5.7	9.2	10.5
3	74	0.0	0.0	0.2	1.0	6.3	12.7	15.0
4	75	0.0	0.0	0.0	0.6	4.2	12.3	23.7
6	144	0.0	0.1	0.3	2.2	7.1	22.7	30.6
7	221	0.0	0.0	0.3	2.7	9.1	15.9	21.5
8	31	0.0	0.0	0.1	0.6	5.8	8.4	12.2
9	186	0.0	0.0	0.3	1.7	5.7	12.9	21.5
10	236	0.0	0.0	0.2	2.3	8.1	18.3	22.5
11	20	0.0	0.0	0.4	5.7	7.5	13.5	13.5
12	325	0.0	0.0	0.1	0.9	6.7	17.5	28.9
14	99	0.0	0.0	0.1	1.6	7.8	15.4	20.3
15	20	0.0	0.0	0.1	0.3	5.8	11.7	26.6

Table 20. Distribution of estimated winter ESLA, by climate zone

Stochastic variability is substantial, especially for sparsely sampled climate zones. Climate zones are described in Table 17.

Winter ESLA by Climate Zone		Percent of Houses						
Climate Zone	Number of Houses	5%	10%	25%	50%	75%	90%	95%
2	25	0.0	0.0	0.0	0.0	0.6	3.5	3.6
3	74	0.0	0.0	0.0	0.1	0.9	2.4	7.3
4	75	0.0	0.0	0.0	0.0	0.6	2.3	4.8
6	144	0.0	0.0	0.0	0.2	1.1	5.1	19.9
7	221	0.0	0.0	0.0	0.2	1.1	3.4	6.9
8	31	0.0	0.0	0.0	0.2	0.9	1.7	4.6
9	186	0.0	0.0	0.0	0.1	0.8	4.4	8.7
10	236	0.0	0.0	0.0	0.2	1.1	3.7	7.0
11	20	0.0	0.0	0.0	0.0	0.7	8.8	8.8
12	325	0.0	0.0	0.0	0.0	0.3	2.0	6.1
14	99	0.0	0.0	0.0	0.0	0.9	4.4	7.9
15	20	0.0	0.0	0.0	0.1	1.4	4.0	12.8

Table 21. Distribution of estimated spring ESLA, by climate zone

Stochastic variability is substantial, especially for sparsely sampled climate zones. Climate zones are described in Table 17.

Spring ESLA by Climate Zone		Percent of Houses						
Climate Zone	Number of Houses	5%	10%	25%	50%	75%	90%	95%
2	25	0.0	0.0	0.8	4.0	7.3	10.3	10.9
3	74	0.0	0.0	0.3	1.6	7.4	16.0	22.4
4	75	0.0	0.0	0.0	0.5	4.2	12.5	23.7
6	144	0.0	0.1	0.3	2.6	7.0	21.1	28.6
7	221	0.0	0.0	0.5	3.5	10.2	21.0	30.3
8	31	0.0	0.0	0.3	2.7	5.8	11.8	12.2
9	186	0.0	0.0	0.5	2.4	8.0	15.7	23.2
10	236	0.0	0.0	0.3	2.9	10.5	20.8	24.8
11	20	0.0	0.0	4.1	7.5	8.9	19.6	19.6
12	325	0.0	0.0	0.2	2.3	10.0	19.8	28.3
14	99	0.0	0.0	0.1	3.1	10.7	18.5	22.4
15	20	0.0	0.0	0.2	1.7	4.0	15.2	26.6

3.1.6. Use of Mechanical Ventilation Systems

Mechanical, whole-house ventilation is mandated for new houses in noise abatement areas, but otherwise is not required. Nevertheless many such systems go into new California houses as part of voluntary programs or customer options. (For example, the *Engineered For Life p*rogram used by Building America has installed about 10,000 over 5 years.) For the Statewide Probability Sample, the fraction of people whose homes were built as part of energy efficiency programs can be seen in Question 9:

- 21% of respondents indicate that their home was built under a special energy-efficiency program
- 33% say that it was not
- 44% are not sure

Of those who said that their home was built under such a program, the program was:

- 69% Energy Star
- 1% Building America
- 4% Comfortwise
- 9% SMUD Advantage Home
- 5% SoCalGas Energy Advantage Home
- 11% other or don't know

Participating in these programs, however, does not always imply whole-house mechanical ventilation systems and lack of participation does not necessarily imply their absence.

Reported Installations

Question 43A-D asks about the presence of whole-house mechanical ventilation systems.

Excluding the "builder sample" — which consists of homes known to have whole-house mechanical ventilation — according to the survey:

- 52% of the homes have a whole-house ventilation system; some people say they have more than one type of whole-house system.
- 31% of homes have "a whole-house ventilation system, such as the type … that brings outdoor air into the duct system of a central heating or air conditioning system..." (Question 43A). This question may have been difficult for respondents to understand because it is asking about the presence of *any* whole-house ventilation system and it gives two examples of specific types of whole-house system. A subset of these, 4% of homes, have "FreshVent," a specific version of this type of system.
- 28% have an exhaust fan *whole-house* ventilation system (Q43B)
- 5% have a heat-recovery whole-house ventilator (Q43C,) and
- 5% have some other type of whole-house ventilation system (Q43D)

However Question 43A was interpreted, the responses indicate a much higher penetration of whole-house mechanical systems than the research team believes to be the case. Outside of the specially selected builder sub-sample (which was not included in the results summarized above), the team believes that the respondents had a difficult time interpreting the question and answering correctly. Subsequent information from ongoing field study with this home sample confirmed that a very high proportion of the homes, especially in the Sacramento Delta and Sacramento areas have mechanical ventilation systems. This may be due to intensive marketing by certain HVAC firms.

Question 43N describes the reason they chose the system. The following table applies to respondents who were **not** in the "Builders' sample." One might infer that those who checked something other than "came with the house" might have made a conscious choice and may have an actual system. See Table 22 below.

Use of Mechanical Ventilation Systems, Builders' Sample Only

The "Builders' sample" is a non-representative set of homes that are known to have a whole-house mechanical ventilation system or systems. Unfortunately not all homeowners in this sample know that they have such systems, or else they did not understand that they were being asked about their system: out of the 67 homes in the Builders' sample, only 45 (67%) indicated that they have any kind of whole-house mechanical ventilation system. Out of these 45 homes, some indicated that they have two systems, which is doubtful. Moreover, several people indicated that their home has three systems, which is extremely unlikely.

Table 22. Reason for choosing system: statewide probability sample

Why did you choose the system (percentage among those with a given system)	Whole-house ventilation, such as FreshVent	Exhaust fan ventilation system	Heat-recovery ventilator	Other whole-house ventilation
Came with house	28	73	87	77
Household member has health condition	0	1	2	2
Wanted filtered outdoor air	9	3	9	9
Affordable cost	1	2	4	11
Good reliability	1	3	9	7
Reduced energy costs	7	6	9	3
Other	4	2	3	1

Out of the 45 people who know that they have a whole-house mechanical ventilation system:

Question 43E:

- 60% said the operation of the system was explained to them when they bought the house

- 24% said it wasn't
- 16% didn't answer

Question 43F:

- 60% said they understand how the system works
- 24% said they don't
- 16% didn't answer

Question 43G:

- 49% said they know how to operate it properly
- 33% said they don't
- 18% didn't answer

System Usage

Questions 43H–43K address the perceived usage of a whole-house mechanical system. The researchers believe that most people in the Statewide Probability Sample who said that they have a mechanical ventilation system do not actually have one, so the Statewide Probability Sample cannot be used to clearly answer this question. Instead, the study looks at the Builders' sample only. The following system usage is reported in Table 23:

Table 23. Usage of whole house ventilation system: builders' sample

Whole-house ventilation system usage (percent of Builders' sample)	Continuous	Somewhat frequent	Infrequent	Never	No answer
Summer	18	25	8	3	45
Fall	13	18	20	3	45
Winter	21	18	12	5	45
Spring	13	21	16	5	45

To within statistical error (one standard deviation, p-values greater than 0.3 in all seasons), there was no reported difference in overall IAQ satisfaction (Q48-51) between the homes in the Builders' sample that know they have mechanical ventilation systems and those that have such a system but don't know it. However, statistical power to address this question is rather poor.

Out of the 45 respondents in the Builders' sample who know that they have a mechanical ventilation system, 32 (68%) identified at least one thing that they like about the system. Some people like more than one thing. About half of the respondents said they like the fact that the system provides fresh air; about a third of respondents said they appreciate "reduced concern about indoor air quality (IAQ)." Almost 40% also said that they like the fact that the system is "quiet," but this is more of an absence of a negative characteristic than it is a positive characteristic: after all, it would also be "quiet" to not have a whole house ventilation system. See Table 24.

Table 24. Positive characteristics of system

Characteristic	Pct (out of n=47) (%)
Fresh Air	47
Quiet	38
Reduced odors	22
Reduced energy costs	27
Reduced allergies	13
Reduced concern about IAQ	31
Other	7

Out of the 45 respondents in the Builders' sample who know that they have a mechanical ventilation system, 22 (49%) identified at least one thing that they dislike about the system—noisiness and draftiness were the major complaints. Some people dislike more than one thing about their system. See Table 25.

Some people report having more than one system (which we doubt is true in most cases), so the number of people who report having a system (N=45) is less than the sum of the reported numbers in each system type. Note that with n=45, one respondent is about 2% of the sample; with N=7, one respondent is 14% of the sample.

Table 25. Reasons for dissatisfaction: builders' sample

Reasons for dissatisfaction	Entire Sample N=45 (%)	Inlet system N=25 (%)	Exhaust fan N=29 (%)	Heat-recovery ventilator N=7 (%)	Other whole-house N=15 (%)
Too noisy	22	24	17	0	27
Too drafty	18	24	7	0	20
Increases odors	2	4	0	0	0
Hard to operate	11	16	7	0	7
Hard to maintain	4	4	3	0	0
Too expensive	9	16	10	0	13
Too quiet	2	4	3	14	0
Not effective	4	0	3	14	7
Other	2	0	3	14	7

People who have an exhaust fan system—or think they do—report somewhat less dissatisfaction with draftiness than do people with other systems, but uncertainties are large due to small sample sizes. For instance, the apparent difference in dissatisfaction with draftiness between the Exhaust Fan systems and Inlet systems is barely "statistically significant" at the 10% level ($p=0.09$). Considering that many people do not know that they have a mechanical ventilation system at all, and some people who do have a system think that they have more than one, the questions concerning dissatisfaction cannot be used with confidence to determine actual differences in dissatisfaction among system types.

Out of the 45 respondents in the Builders' sample who know that they have a mechanical ventilation system, 37 (79%) indicated why they have the system. Considering just this subset that indicated why they have a mechanical ventilation system:

- 36 respondents (97%) said it came with the house
- 2 respondents (5%) said they wanted filtered outdoor air; in one of these cases they also said the system came with the house
- 1 respondent (3%) said they chose it for "affordable cost"
- 1 respondent (3%) said they chose it for "good reliability"
- 2 respondents (6%) said they chose it for "reduced energy costs"; one of these also said the system came with the house

3.1.7. Use of Cooling, Heating, and Ventilating Systems: Statewide Probability Sample

Question 34 asked about the number of hours of use of the following systems, by season:

- Central Air Conditioning
- Room Air Conditioning
- Whole House Fan
- Central or Room Dehumidifier
- Central Gas Heating
- Central Electric or Heat-pump Heating
- Gas Wall Heater
- Electric Wall Heater
- Wood stove or gas or wood fireplace with tight doors
- Fireplace without tight-fitting doors
- Freestanding combustion heater
- Freestanding electric heater
- Central or room humidifier
- Central HEPA (High Efficiency Particle Arresting air filter) or electrostatic air filter
- SmartVent or other ventilative cooling system

To summarize the use of these systems, an overall "average use" is not appropriate: that measure would make no distinction between a situation in which half the houses use their system for 0 hours and half for 24 hours, and a situation in which all of the houses use their system for 12 hours. Instead, Table 26 summarizes the 10th, 50th, and 90th percentile of reported use, for homes that have a whole house ventilation system. (If a respondent reported 0 average hours of use in every season, or if they left the answer blank, researchers assumed they did not have the type of system in question).

For instance, as shown in Table 26, 7% of homes report having room air conditioning. The "Summer" column shows that out of those homes, in summer, 10% use the system for 2 hours per day or less, 50% use the system for 6 hours or less per day, and 90% use it for 18 hours per day or less.

Question 41 asked whether people use their central heating or air conditioning fan to circulate air, even when no heating or cooling is going on. Results did not vary substantially among the three strata. Results also did not differ substantially between the Statewide Probability Sample and the Builders' sample.

Statewide Probability Sample /Builder Sample

- 7% / 3% Frequently
- 16% / 18% Sometimes
- 25% / 31% Rarely
- 46% / 42% Never
- 3% / 5% Not applicable
- 2% / 2% No answer

3.1.8. Use of Stand-Alone Air Cleaners

Question 39 asked whether people "use a stand-alone air filter, air purifier, or air cleaner in the house." In the statewide probability sample, 15% of households report using such a system. Respondents were also asked whether their air cleaner "creates ozone, 'supersaturated oxygen,' or something similar"; among the homes with an air cleaner, 31% said yes, 23% said no, and 46% don't know.

In contrast to the 15% of homes in the representative sample that use air cleaners, only 2 homes in the Builder's Sample (3%) report having an air cleaner.

3.1.9. Use of Bath Fans

Questions 67, 69, and 70 ask related questions about why people do or do not use their bathroom fan.

Question 67 asked how often people use their bathroom fan.

- 27% always use it
- 16% frequently use it
- 19% sometimes use it
- 17% rarely use it
- 13% never use it
- 6% said there is no fan

Table 26. Use of appliances and systems: statewide probability sample

10th, 50th, and 90th percentile of hours of reported use, among homes that have the system	Fraction of homes that have a system (%)	Summer	Fall	Winter	Spring
Central Air Conditioning	75	2, 8, 24	0, 0, 6	0, 0, 0	0, 0, 6
Room Air Conditioning	7	2, 6, 18	0, 0, 6	0, 0, 3	0, 0, 8
Whole House Fan	23	1, 6, 19	0, 0, 8	0, 0, 3	0, 1, 10
Central or Room Dehumidifier	3	0, 1, 24	0, 0, 20	0, 2, 10	0, 1, 10
Central Gas Heating	84	0, 0, 0	0, 1, 6	2, 7, 20	0, 0, 4
Central Electric or Heat-Pump Heating	6	0, 0, 0	0, 0, 6	1, 8, 20	0, 0, 6
Gas Wall Heater	3	0, 1, 24	0, 3, 24	0, 6, 24	0, 2, 24
Electric Wall Heater	2	0, 0, 0	0, 0, 6	0, 3, 12	0, 0, 6
Wood stove or gas or electric stove with tight-fitting doors	30	0, 0, 0	0, 0, 3	1, 2, 6	0, 0, 2
Fireplace without tight-fitting doors	13	0, 0, 0	0, 0, 2	1, 2, 5	0, 0, 2
Freestanding combusting heater, not vented	1	0, 0, 2	0, 0, 6	0, 2, 8	0, 0, 4
Freestanding electric heater	13	0, 0, 0	0, 0, 3	1, 2, 8	0, 0, 1
Central or room humidifier	6	0, 0, 12	0, 0, 10	0, 5, 12	0, 0, 8
Central HEPA or electrostatic filter	6	1, 16, 24	0, 8, 24	0, 12, 24	0, 10, 24
Smartvent or other ventilative cooling	3	0, 4, 24	0, 2, 24	0, 0, 24	0, 2, 24

Reported fan usage was much higher in the Sacramento Delta region than elsewhere, with 40% (rather than 27%), indicating that they "always" use the fan (p-value < 0.001).[1] Responses of Sacramento Delta residents to other bathroom fan usage questions were similar to those from the rest of the state, so the reason for the discrepancy in fan usage is not clear.

Question 69: Respondents may indicate more than one reason for using the fan.

- 65% to remove moisture
- 7% to provide noise
- 74% to remove odors
- 7% comes on automatically when light comes on
- 1% Other

Question 70:

49% of respondents sometimes fail to use the fan even when the bathroom is steamy or has an unpleasant odor. Of this 49%, the reasons not to use the fan are (respondents may indicate more than one reason):

- 43% window is open
- 60% don't think of it
- 27% the fan is too noisy
- 12% don't think it helps
- 14% don't want to use the energy
- 1% fan doesn't work
- 6% fan causes a draft

For some people their bathroom fan may be their whole-house ventilation fan and for some it may not be, but they think it is.

3.1.10. Use of Kitchen Fans

Question 67 (discussed above) addresses how often bathroom ventilation fans are run. Questions 65–66 look at similar numbers for the kitchen.

Question 65: When using the *stovetop*,

- 28% of respondents always use the exhaust fan or range hood (if present)
- 32% only use it when odor or humidity seems to be an issue
- 26% "sometimes" use it
- 11% rarely use it
- 2% never use it

---

[1] These figures are from results of this study that are not presented in this report.

Among the homes that use the stovetop exhaust fan or range hood more than "rarely": in 12% the fan exhausts back into the room and in 4% the respondent doesn't know. In the other 82% of the homes that use the fan more often than "rarely," the fan vents to the outdoors.

Question 66: When cooking with the *oven*,

- 15% always use the exhaust fan or range hood
- 12% only use it when odor or humidity seems to be an issue
- 15% "sometimes" use it
- 21% rarely use it
- 35% never use it

Question 64 revealed that only 35% of homes definitely have an oven that vents directly to the outdoors, 34% do not, and 30% don't know. Reasonably, people whose oven vents to the indoors might be expected to use the stovetop exhaust fan to provide needed ventilation, but this is not the case. People who should use stovetop ventilation the most in conjunction with their oven—those whose oven vents to the indoors—use it the least, as shown in Table 27. It is not clear, however, whether most people know if their oven vents to the outdoors.

Table 27. Types of oven vents

Percent of homes with the given type of oven vent that use the *stovetop* fan with the specified frequency in conjunction with the oven	**Oven vents to the outdoors (%)**	**Oven vents to indoors (%)**	**Don't Know (%)**
Always use fan when cooking with oven	29	8	7
Only when odor/humidity is a problem	15	13	8
Sometimes	18	16	12
Rarely	18	21	24
Never	20	41	48

Overall Use of the Kitchen Fan

Cooking time using the stove or oven (Question 59) is summarized as follows:

On both weekdays and weekends: 10% of households cook less than 1 hour, 50% cook less than 2 hours, and 90% cook less than 4 hours.

To determine the overall use of the kitchen fan requires making assumptions about the relative amount of time spent cooking with the stovetop, the oven, or both, as well as assumptions about what respondents mean when they say, for example, that they ``sometimes'' use the fan when they cook with the oven. The research team made the following assumptions:

In questions 65 and 66, which ask about the use of the fan, "always" means 98% of the time, "sometimes" means 40% of the time, "rarely" means 10% of the time, "only when odor/humidity seems to be a problem" means 30% of the time when referring to the stove and 15% of the time when using the oven, and "never" means never.

Using those assumptions, the Statewide Probability Sample has average daily fan usage as follows:

- 10% of homes use it less than 10 minutes per day
- 25% of homes use it less than 20 minutes per day
- 50% of homes use it less than 40 minutes per day
- 75% of homes use it less than 75 minutes per day (1 hour 15 minutes per day)
- 90% of homes use it less than 145 minutes per day (2 hours and 25 minutes per day)

To examine the sensitivity to the study's assumptions about oven usage versus stove usage, and quantitative interpretation of the reported frequency of use, the research team repeated the analysis with the following changes. The team reversed the proportions of stove and oven use; assumed "always" means 90% of the time; assumed "sometimes" means 20% of the time; and assumed "only when odor/humidity seems to be a problem" means 20% of the time for both oven and stove usage. The result is approximately a 30% to 50% reduction in estimated fan use for each quartile (for instance, the estimated median drops to 21 minutes per day rather than 40 minutes per day).

3.2. Determine Occupant Perceptions of and Satisfaction with IAQ in Their Homes

3.2.1. Indoor Air Acceptability

The purpose of ventilation and hence ventilation standards is to provide acceptable indoor air quality. Acceptable IAQ includes pieces that can be directly sensed by the occupants as well as health and safety aspects that may not be apparent. ASHRAE defines it as follows:

> **Acceptable indoor air quality**: Air toward which a substantial majority of occupants express no dissatisfaction with respect to odor and sensory irritation and in which there are not likely to be contaminants at concentrations that are known to pose a health risk.

Acceptable IAQ cannot be directly determined from the survey, but an upper limit can be set on it by looking at the respondents' responses when asked directly and indirectly.

Perceived Indoor Air Acceptability

Questions 48–51 specifically ask about how acceptable occupants find the indoor air quality. Results (adjusted for sampling weights) are shown separately for the representative random samples in each region (Tables 28A) and for the non-representative "builder samples" (Table 28B). There is no apparent difference in reported difference in IAQ acceptability between the Statewide Probability Sample and the Builder's Sample.

Table 28A. Acceptability of IAQ by region and season: statewide probability sample

Acceptability (Percent, adjusted by sampling wt.) Sacramento Delta region, Southern Coastal region, Rest of State, Statewide	**Very acceptable (%)**	**Somewhat acceptable (%)**	**Barely acceptable (%)**	**Not acceptable (%)**	**NA (%)**
Summer	56,62,64,**62**	39,35,32,**33**	3,2,2,**2**	1,0,1,**1**	1,2,1,**1**
Fall	71,72,73,**73**	27,25,24,**24**	1,2,1,**2**	1,1,0,**0**	1,2,1,**1**
Winter	60,63,67,**65**	35,34,28,**31**	2,2,2,**2**	1,0,1,**1**	1,2,1,**1**
Spring	72,75,74,**74**	24,23,23,**23**	2,0,1,**1**	1,0,0,**0**	1,2,1,**1**

Table 28B. Acceptability of IAQ by region and season: builders' sample

Acceptability (Percent, adjusted by sampling wt.) Sacramento Delta region, Southern Coastal region, Rest of State, Statewide	**Very acceptable (%)**	**Somewhat acceptable (%)**	**Barely acceptable (%)**	**Not acceptable (%)**	**NA (%)**
Summer	63,53,69,**63**	37,47,21,**33**	0,0,7,**3**	0,0,0,**0**	0,0,3,**2**
Fall	74,79,72,**75**	26,21,24,**24**	0,0,0,**0**	0,0,0,**0**	0,0,3,**2**
Winter	63,68,69,**67**	37,32,21,**28**	0,0,7,**3**	0,0,0,**0**	0,0,3,**2**
Spring	68,74,69,**70**	32,26,28,**28**	0,0,0,**0**	0,0,0,**0**	0,0,3,**2**

Uncertainties in the percentages are indicated in Table 29, which can also be used for other summaries of the complete sample in each region.

To see how to use the table, consider this example: suppose that in every region, 30% of the people find their winter indoor air quality "somewhat acceptable." In this case, the percentage of returned surveys that report the winter air quality to be "somewhat acceptable" would be expected to be 30 +/- 2.6 in the Sacramento Delta region, 30 +/- 2.8 in the Southern Coastal region, and so on, where the reported uncertainty is one standard error (which implies that the value would fall within the indicated bounds 68% of the time). The uncertainties for the "total representative" sample take into account the variable sampling weights among the three areas, under the assumption that the true percentage is approximately the same in all areas. (Separate uncertainty estimates will be given if there are analyses in which this assumption is substantially violated).

Table 29. Uncertainties in the reported percentage of IAQ

Uncertainty in reported percentage (1 standard error)	**Actual Percent in Population**								
Sample	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
Sacramento Delta Region Statewide Probability Sample (N=308)	1.7	2.3	2.6	2.8	2.8	2.8	2.6	2.3	1.7
Southern CA Coast Statewide Probability Sample (N=275)	1.8	2.4	2.8	3.0	3.0	3.0	2.8	2.4	1.8
Rest of State Statewide Probability Sample (N=865)	1.0	1.4	1.6	1.7	1.7	1.7	1.6	1.4	1.0
Total Statewide Probability Sample (N=1448, weighted)	1.6	2.1	2.4	2.5	2.6	2.5	2.4	2.1	1.6
Sacramento Delta or Southern CA Coast Builders' sample (N=19)	6.9	9.2	10	11	11	11	10	9.2	6.9
Rest of State Builders' sample (N=29)	5.6	7.4	8.5	9.1	9.3	9.1	8.5	7.4	5.6
Statewide Builders' Sample	3.7	4.9	5.6	6.0	6.1	6.0	5.6	4.9	3.7

The vast majority of people report a high degree of acceptability with their indoor air quality. With more than 95% of respondents reporting that their air quality is somewhat or very acceptable, there is little statistical power to determine what characteristics of a house (or of occupant behavior) are associated with unacceptable or barely acceptable air quality.

There is little inter-regional variation in reported satisfaction. In the Statewide Probability Sample, slightly fewer people in the Sacramento Delta region than in the other areas report that indoor air quality is "very" acceptable in both summer and winter: IAQ was judged "very acceptable" in 57% +/- 4% of homes in the Sacramento Delta region, 62%+/-3% in the Southern Coastal region, and 64%+/- 2% of homes in the rest of the state. The difference between the Sacramento Delta region and the rest of the state is small and of borderline statistical significance (p-value 0.06).

IAQ and Thermal Comfort Problems

Although a large fraction of respondents reported satisfaction with the indoor air, they were separately asked whether they had experienced any conditions that might indicate that the IAQ was not, in fact, acceptable. Questions 45–47 asked about specific comfort, odor, and moisture problems that the occupants might have experienced.

Question 45 is summarized in Table 30A and Table 30B, which characterize each region separately (Sacramento Delta region, Southern Coastal region, and Rest of State), as well as the state totals; uncertainties in the percentages are shown in Table 29 above. Most of the reported problems relate to thermal comfort, with approximately half of respondents indicating that the house is sometimes too hot in summer and/or too cold in winter. Since most of the homes have air conditioning and all homes have heating, it is not clear whether these complaints indicate that people are setting their thermostats to a level that is not quite sufficient to keep them comfortable (perhaps to save energy), whether the systems are sometimes overloaded by extreme weather, or something else.

The Statewide Probability Sample shows very little variation in satisfaction between the three strata, perhaps surprisingly, given the climate differences between them.

The data are mildly suggestive of possibly fewer problems occurring in the builder sample, especially with regard to the complaint that air is sometimes "too stagnant" but to a lesser degree in several other categories as well. To quantify the statistical significance of this apparent effect would require a complicated statistical model that takes into account the correlations between responses (e.g., if some people tend to be "complainers" compared to others, then there will be correlation in responses between and within cells of the table, and these correlations will need to be modeled in detail). Since the builder sample is not statistically representative of mechanically ventilated homes in the first place, this effort is probably not worthwhile.

There were more reported problems than might be expected from the questions about the perceived indoor air acceptability: even though many people reported that the air is sometimes too dry, stagnant, or dusty, very few said their IAQ was unacceptable or barely acceptable. This suggests that people expect and are willing to accept a certain amount of moisture and discomfort and do not consider these to be unacceptable. In addition, no description of the elements that constitute acceptable or unacceptable "air quality" was provided to respondents. Therefore, apparent inconsistencies between a general assessment of air quality and the more detailed evaluation of various conditions within the home (too hot, too cold, too stagnant, etc.) were probably not considered by some respondents when answering the acceptability questions.

Table 30A. Problems noticed in IAQ and thermal comfort: statewide probability sample

Problem noticed (Q45) (Percent, adjusted by sampling weight) Sacramento Delta region, Southern Coastal region, Rest of State, **Statewide**	**Summer (%)**	**Fall (%)**	**Winter (%)**	**Spring (%)**
Sometimes too hot	51,55,40,**51**	1,5,2,**3**	0,2,1,**1**	1,3,2,**2**
Sometimes too cold	0,0,0,**0**	3,6,4,**4**	47,49,46,**47**	1,4,1,**2**
Sometimes too dry	8,7,12,**10**	3,7,5,**6**	8,15,12,**12**	2,4,3,**3**
Sometimes too humid	4,6,5,**5**	2,0,1,**1**	3,2,1,**1**	2,1,1,**1**
Sometimes too drafty	3,3,2,**2**	8,6,11,**6**	11,10,10,**10**	3,5,3,**3**
Sometimes too stagnant	15,14,15,**15**	4,5,5,**5**	8,8,10,**10**	5,6,4,**5**
Sometimes too dusty	25,24,24,**25**	17,21,17,**18**	14,16,13,**14**	17,19,16,**17**

Table 30B. Problems noticed in IAQ and thermal comfort: builders' sample

Problem noticed (Q45) (Percent, adjusted by sampling weight) Sacramento Delta region, Southern Coastal region, Rest of State, **Statewide**	**Summer (%)**	**Fall (%)**	**Winter (%)**	**Spring (%)**
Sometimes too hot	32,53,38,**40**	5,0,3,**3**	5,0,7,**5**	5,0,0,**2**
Sometimes too cold	0,0,0,**0**	5,0,3,**3**	26,42,41,**37**	5,0,7,**5**
Sometimes too dry	0,5,14,**8**	0,0,3,**2**	11,11,14,**12**	0,0,0,**0**
Sometimes too humid	0,0,3,**2**	0,0,0,**0**	0,0,3,**2**	0,0,3,**2**
Sometimes too drafty	5,0,0,**2**	5,0,3,**3**	5,5,17,**10**	5,0,7,**5**
Sometimes too stagnant	5,5,7,**6**	0,0,3,**2**	0,5,3,**3**	0,5,0,**2**
Sometimes too dusty	21,11,21,**18**	16,11,14,**13**	5,5,10,**8**	16,5,10,**10**

Parekh (2000) reported that 30% of Canadian homeowners in "conventional" new homes—of which 62% reported having a heat recovery ventilator—complained that their home was "too dusty," 36% complained that it is "too dry," 6% complained that it is "too drafty," and 4% complained that it is "too humid." The present survey reports fewer problems with dryness than were reported by Parekh, although this could reflect a difference in climates rather than a difference related to the houses themselves.

Many people who expressed dissatisfaction with one aspect of their comfort or IAQ also expressed dissatisfaction with others. For example, more than 85% of homes that have a problem with stagnant air in summer also have air that is sometimes too hot.

Reported thermal comfort problems were far higher in summer and winter than in other seasons. Adjusted for sampling weight, 60% of households report at least one IAQ problem or thermal comfort problems in summer, 29% in fall, 58% in winter, and 24% in spring.

Questions 46 and 47 show very little variation among the three regions of the state, so Table 31 and Table 32 summarize just the overall data from the Statewide Probability Sample (weighted to account for the different sampling weights). Some people report bathroom mold or mildew, but few people report problems in other areas. Plumbing leaks and poor site drainage are fairly common complaints.

Table 31. Percent of homes that report occasional mold or mildew

Occasional mold or mildew, Q46 (Percent of homes)	Summer	Fall	Winter	Spring
Bathroom	5	5	7	4
Basement/crawl space	0	0	0	0
Walls or ceilings	0	1	1	0
Carpets	0	0	1	0
Closets	1	1	1	1

Table 32. Conditions experienced

Condition experienced, Q47	Percent of homes
Condensation on windows/surfaces	4
Roof leaks	4
Plumbing leaks	13
Wall or window leaks	8
Flooding	2
Poor site drainage	10
Bothersome carpet odors	2
Bothersome cabinetry odors	1
Other unpleasant odors	3
Other moisture problems	6

3.3. Determine the Relationship Among Ventilation Practices, Perceived IAQ, and House and Household Characteristics

3.3.1. Relationship Between Hours at Home and Ventilation

To investigate the relationship between ventilation and hours that the home is unoccupied, this analysis was restricted to the respondents who gave completely consistent answers on the ventilation questions (questions 10–25 and 28–31). This was done to avoid the possibility that our imputation procedure could create, or obscure, a relationship between ventilation and hours that the home is unoccupied. This is a particular worry because the number of hours that the home is unoccupied was one of the variables used in the imputation procedure.

Many people indicated that worries about security are a major reason for closing windows (to be discussed more fully in Section 3.4). As such, one would expect that homes that are usually occupied might be better ventilated than are homes that are frequently unoccupied. This does appear to be the case, although the effect is rather mild. The research team divided surveys into three groups of roughly the same number of homes: those in which the home is empty on weekdays (1) more than 8 hours per day, (2) from 2-8 hours per day, and (3) less than 2 hours per day.

In all seasons, homes that are empty for more than 8 hours per day tend to report less ventilation than other homes: in summer the median ESLA is about 20% lower in less-occupied homes than in the others, and in winter the median ESLA is about half the median ESLA in the other homes.

The variation in ESLA between homes that are and are not empty for more than 8 hours per day is a tiny fraction of the variation among homes in any given category of hours unoccupied. A linear regression of ESLA on reported hours that the home is empty has an r-squared of less than 0.01, and a coefficient of "unoccupied hours" that is not statistically significant at the p=0.5, 0.10, or even 0.20 level. See Figure 10.

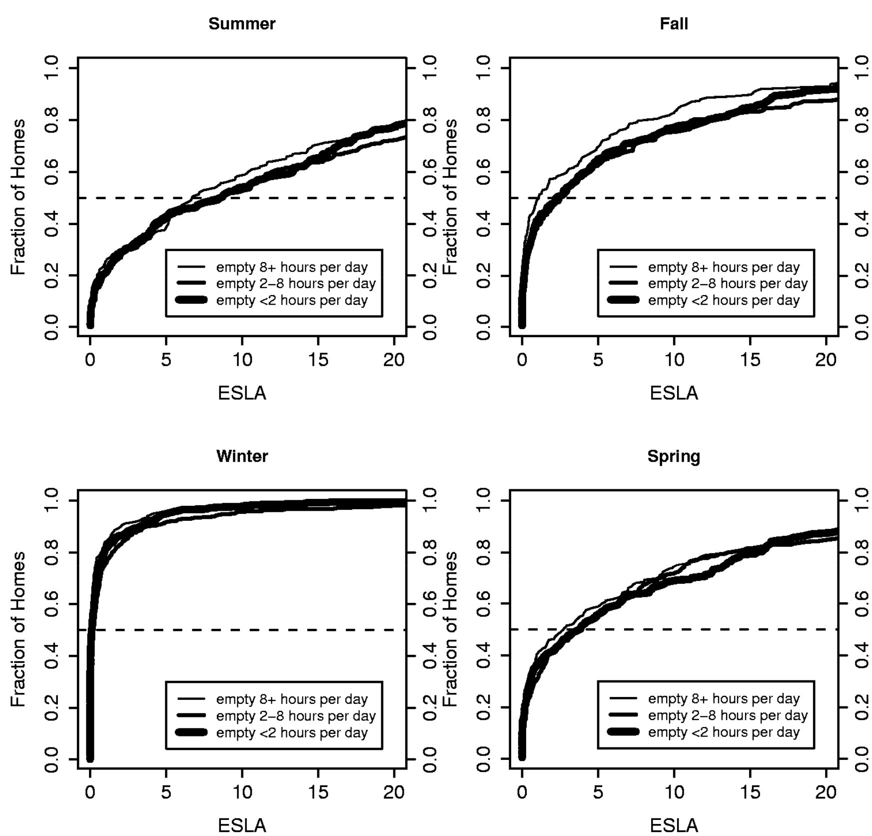


Figure 10. Relationship of hours at home and ventilation

The same picture is obtained by looking at the reported hours of ventilation, from questions 28–31: in the fall—the season with the biggest difference—the median reported hours with no ventilation is 14 for homes that are unoccupied for more than eight hours per day, and is 12 for homes that are unoccupied for eight or fewer hours per day. There is no difference in the median between homes that were unoccupied 2–8 hours per day and homes that were unoccupied less than 2 hours per day.

3.3.2. Relationship Between Ventilation and Household Health Characteristics

Questions 52–58 asked about the number of people in each household who have asthma, allergies, and other breathing problems, as well as the number of adults and children, and the number of adult and child smokers. From the Statewide Probability Sample, 59% reported that at least one household member has at least one of the health problems; 62% reported that at least one household member has at least one of the health problems and/or smokes. The reported levels of health problems seem to be roughly in line with those reported by Parekh (2000) for Canadian homes. Parekh reports 34 cases of "allergy" in 52 homes (34/52=65%), although it is not clear whether this is 34 people with allergies, or 34 households with at least one allergic person. In the present survey, 48% of households reported at least one allergic person. Parekh reports 15 "asthma" in 52 homes (15/52=29%), although again it is unclear whether this is 15 households with an asthmatic, or 15 cases of asthma. In the present survey, 20% of households report at least one asthmatic.

The research team performed linear regressions of seasonal ESLA on indicator variables for the presence in the household of: at least one smoker, at least one asthmatic, at least one person with allergies to indoor agents, at least one person with allergies to outdoor agents, at least one person with allergies to other airborne agents, or at least one person with another breathing or lung problem. The team also used indicator variables for small households (3 people or less) and large households (6 people or more), trying these indicator variables in various combinations. In all cases, indicator variables for each region type were also included. The research team also performed logistic regressions of the probability that ESLA is very low (less than 1) on these indicator variables. In no case was ESLA, or the probability of a low ESLA, predicted with substantial goodness-of-fit. (All r-squared values were less than 0.07).

Only in summer was there some evidence of a relationship between ESLA and some of the health problems. Table 33 shows estimated coefficients, standard errors, and p-values for the coefficients of indicator variables, as they entered the model in various combinations. Each row represents estimates a linear model that includes all of the variables with entries on that row, in addition to regional indicator variables. (Coefficients for the regional variables are not shown). For instance, the first row represents a model in which only an asthma indicator variable is used. As the table shows, presence of an asthmatic in the household is associated with a change in summer ESLA: households with asthmatics report an ESLA value about 1.5 units higher than other households, with or without controlling for other health issues. Regional coefficients, not shown, were stable near –2 +/- 1 (p-value 0.04) for the Sacramento Delta region and 0.3 +/- 0.7 (p-value 0.7) for the Southern Coastal region. The Rest of State coefficient is 0.0 by definition. The stability of the coefficients across the models shows that co-linearity of household parameters is not a concern. There is little indication that conditions other than asthma influence ventilation behavior substantially.

The coefficient of asthma is not statistically significantly different from zero in either fall or winter, but is again positive (coefficient estimate in the "full model" that includes all of the health issues is 1.7 +/- 0.6, p-value 0.01) in spring. Thus there is some evidence that households with asthmatics do indeed provide more window ventilation (1.5 to 2 units higher ESLA) than other households. This effect seems to be weakest (or nonexistent) in the Sacramento Delta region and strong in the Southern Coastal region. In fact, the median summer ESLA for households containing asthmatics is lower than for other households in the Sacramento Delta region (2.08 versus 3.72), but in the Southern Coastal region households containing an asthmatic have a summer ESLA of 9.0 versus 5.0 for non-asthmatics. In the Rest of the State the median is 5.3 for households containing asthmatics versus 5.1 for other households.

Other than asthma, some relationships between ventilation and health are suggestive but far from conclusive. Households that contain someone allergic to an outdoor agent may receive slightly less summer ventilation than others, and households that contain someone allergic to an indoor agent may receive slightly more; however, both of these results are far short of "statistical significance" (p=0.3 in both cases). Households that include someone with some "other lung problem" (besides asthma or allergies) may receive somewhat less ventilation than other households (p=0.1).

The research team also performed several of the regressions using total hours of reported ventilation as the dependent variable, including the "full model" that used all of the health indicator variables. None of the coefficients were reliably "statistically significant," and r-squared values were less than 0.03.

3.3.3. Sources of Indoor Pollution

Question 73 asked whether the household includes "dogs, cats, or other furry animals that regularly spend time inside the house." In the Sacramento Delta region 37% of homes have at least one of these animals, the Southern Coastal region has them in 41% of households, and 44% of homes in the rest of the state have them.

Question 74 asked about various types of built-in cabinetry, some of which can release formaldehyde or other pollutants. Results are shown in Table 34.

Table 33. Coefficient estimates that describe the effect on summer ESLA of presence of different health issues. Each row summarizes the coefficients from a different linear model; coefficients indicate the increase in ESLA associated with the presence of a person in the household with the given characteristic. Region effects (for the Sacramento Delta region and Southern Coastal region) are included in each model, but those coefficients are not shown in the table. P-values are shown in parentheses. * indicates p < 0.05; ** indicates 0.1 > p < 0.05.

Asthma	Smoker	Allergic to Outdoor agent	Allergic to Indoor agent	Allergic to Other or Unknown	Other Lung Problem
1.6 +/- 0.8 (0.04)*					
	-0.8 +/- 1.1 (0.5)				
		0.1 +/- 0.6 (0.9)			
			0.9 +/- 0.7 (0.2)		
				0.5 +/- 0.8 (0.55)	
1.5 +/- 0.8 (0.06)**		-0.7 +/- 0.7 (0.2)	0.9 +/- 0.8 (0.3)		
1.5 +/- 0.8 (0.06)	-0.8 +/- 1.1 (0.5)	-0.8 +/- 0.8 (0.3)	0.8 +/- 0.8 (0.3)	0.3+/- 0.8 (0.8)	
1.8 +/- 0.8 (0.03)*	-0.6 +/- 1.1 (0.6)	-0.8 +/- 0.8 (0.3)	0.9 +/- 0.8 (0.3)	0.4 +/- 0.8 (0.5)	-1.9 +/- 1.1 (0.1)**

Table 34. Type of built-in cabinetry, by survey stratum, for the statewide probability sample

Percentage of homes with a given type of built-in cabinetry	Sacramento Delta region (%)	Southern Coastal region (%)	Rest of State (%)	Statewide (%)
Bare pressed wood or plywood	14	9	11	11
Covered pressed wood or plywood	34	43	41	41
Solid wood	42	39	39	39
Other	0	0	1	1
Don't know	8	6	6	6

Question 78 asked about the presence of specific indoor sources of air pollution: candles or incense, paints or solvents, pesticides, deodorizers, and potpourri. Results are shown in Table 35 where we assumed that the 2% of respondents who checked neither "yes" nor "no" for a particular source should have checked "no."

Table 35. Percentage of homes that "regularly use" certain pollutant sources, by survey stratum, for the statewide probability sample

Percentage of homes that use certain sources of pollutants	Sacramento Delta region (%)	Southern Coastal region (%)	Rest of State (%)	Statewide (%)
Candles or incense	53	54	55	54
Paints, glues, or solvents	12	10	11	11
Pesticide sprays or foggers	12	4	8	7
Plug-in spray deodorizers	47	41	42	43
Potpourri	23	21	24	23
Other sources of fumes/smoke	2	0	2	2

3.3.4. Relationship Between Ventilation and Indoor Sources

The research team created indicator variables for the presence of each of the pollutants in Table 35 and, as with the health issues, performed linear regressions of ESLA on these source variables, in various combinations. None of the models produced an r-squared over 0.01. Over all of the seasons and all of the models, only two variables were statistically significant: paint users in winter and candle users in spring reported higher values of ESLA. This appears to be a statistical accident: checking 5 sources in each of 4 seasons generates 20 comparisons, so on average one would expect to find one "statistically significant" positive result (at the 5% level) even if the variables are random. The lack of persistence over the various seasons—indeed, even the signs of the coefficient estimates change—suggests that there is not in fact a substantial relationship between these sources and ventilation levels.

Question 59 asked about cooking. Households that reported more cooking tended to report more ventilation. Statewide, 67% of households reported cooking 7–18 hours per week, and 28% reported cooking more than 18 hours per week. Table 36 shows the median reported number of hours of medium or high ventilation, for each season, for the Statewide Probability sample.

Table 36. Median number of hours per day with "high" or "medium" ventilation, for different categories of cooking

Median hours with medium or high ventilation	Cook < 7 hours per week	Cook 7–18 hours per week	Cook > 18 hours per week
Fall	3.5	6	8
Summer	6	11	13
Winter	0	0	0
Spring	4	8	12

To evaluate the relationship with ESLA, the research team performed a linear regression, including regional indicator variables. Researchers created two indicator variables: one that identifies households that cook 7 to 18 hours per week, and one that indicates households that cook 18 or more hours per week. For a regression including these indicator variables, R-squared values were quite low in every season, ranging from 0.02 to 0.03. However, the coefficient estimates were substantial and statistically significant. The coefficient estimates (and p-values) describing the effect on ESLA of cooking 7 to 18 hours per week are:

- Summer 1.4 +/- 1.4 (p-value 0.3)
- Fall 1.1 +/- 1.4 (0.4)
- Winter 1.8 +/- 1.4 (0.2)
- Spring 2.7 +/- 1.4 (0.05)

For households that cook 18 or more hours per week, estimates are:

- Summer 3.3 +/- 1.4 (p-value 0.02)
- Fall 3.6 +/- 1.4 (0.02)
- Winter 4.2 +/- 1.5 (0.004)
- Spring 5.3 +/- 1.4 (0.0001)

Thus households that cook a lot report higher levels of ventilation (as quantified by estimated ESLA) than do households that cook less frequently. However, there is still a great deal of variation among people with a given cooking behavior, and most households report cooking between 1–2 hours per day, so variation in cooking predicts little of the overall variation in ESLA.

3.3.5. Relationship Between Perceived Indoor Air Quality and Ventilation

For the Statewide Probability Sample, the research team performed a linear regression, for which the dependent variable was an indicator variable for whether a home's IAQ was judged "very acceptable," using several explanatory variables. As explanatory variables, researchers tried:

- seasonal ESLA; or
- indicator variables for high ESLA (>15) and low ESLA (< 1); or
- number of hours of low, medium, or high ventilation (from question 28 or 30);or
- number of hours of high ventilation.

The research team also included indicator variables for region of the state. In all cases, coefficients of the ventilation variables were negligible, and r-squared values were less than 0.01. All models based on ESLA estimated a coefficient for Region 1 near –0.07 +/- 0.035 in both seasons, with a p-value below 0.05, but no other coefficient approached "statistical significance."

Ventilation behavior varies enormously among the seasons, yet people's perceptions of indoor air quality hardly vary at all: 83% of respondents gave the same answer for both summer and winter IAQ acceptability (with most of them rating it "very acceptable" in both cases). This suggests that any given person (or household) is very insensitive to ventilation, when it comes to assessing air quality. This agrees with findings of Devine (2000), which found that people with adjustable mechanical ventilation systems often turned them down to a level of ventilation below what is recommended, suggesting that they do not perceive IAQ problems even at low ventilation levels. Given the apparent indifference of most people to their ventilation level, it is not surprising that the relationship between overall IAQ acceptability (as assessed through questions 48–51) and ESLA, SLA, or hours with ventilation, is very weak.

The researcher team also created an index based on the individual IAQ issues in Question 45, by simply counting the number of problems that people reported in each season. The team tried models that did or did not include the "sometimes too hot" or "sometimes too cold" variables. These are comfort rather than IAQ variables, so they are not included in the results discussed below.

There was fairly high correlation (r=0.60) between the number of reported problems in summer and in winter. Figure 11 plots the number of problems in summer versus the number in winter for each home in the survey (including the Builders' Sample); random "jitter" has been added in both the x- and y-directions to separate the points.

Figure 11 below shows the number of specific IAQ problems in summer (excluding "too hot") versus number in winter (excluding "too cold"), for the entire survey. Horizontal and vertical "jitter" have been added to separate the points.

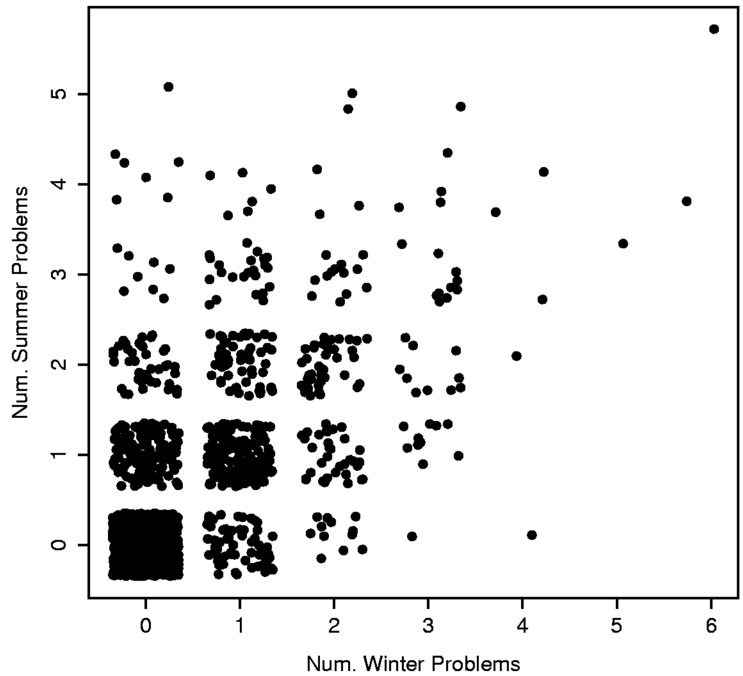


Figure 11. Specific IAQ problems in winter and summer (r^2 value=0.36)

A linear regression was performed with the "problem index" in a given season as the dependent variable, and with the various explanatory variables listed above. None of the models yielded an r-squared value greater than 0.02. The coefficient of ESLA was "statistically significant," however. Table 37 gives the coefficient estimates for the model based on the summer data for the Statewide Probability Sample, using indicator variables for high and low ESLA (this model provided a much better model fit than did a model that includes ESLA as a continuous variable). Controlling for region, people with low ESLA reported about 0.2 fewer problems than those with medium or high, on average. The regression summarized in Table 37 had an r-squared of 0.005.

Table 37. Linear model estimates of the number of reported specific IAQ problems during the summer, other than "too hot"

Variable	Coefficient	Std. Error	t value	P-value
(Intercept)	0.69	0.04	15.5	<0.0001
High ESLA	–0.01	0.06	–0.18	0.85
Low ESLA	–0.18	0.06	–3.05	0.002
Region1	0.00	0.08	0.02	0.99
Region2	0.02	0.06	0.37	0.71

The situation in winter is quite similar: low ESLA was associated with a slight reduction of about 0.2 in the reported number of specific IAQ problems, after controlling for region. The regression had an r-squared of 0.006. Coefficients are summarized in Table 38.

Table 38. Linear model estimates of the number of reported specific IAQ problems during the winter, other than "too cold"

Variable	Coefficient	Std. Error	t value	P-value
(Intercept)	0.56	0.05	11.8	<0.0001
High ESLA	–0.11	0.15	–0.7	0.4
Low ESLA	–0.18	0.05	–3.3	0.001
Region1	0.06	0.07	0.09	0.4
Region2	0.07	0.05	1.3	0.2

Overall, the results are mildly suggestive of the possibility that people who experience fewer specific IAQ problems feel less of a need to try to ventilate in order to avoid the problems. However, there are many other possible explanations for the observed relationship (which is small), including interactions with other variables not included in the models, difference in ventilation behavior or reporting of ventilation behavior between people who do or do not tend to notice IAQ problems if they exist.

3.3.6. Relationship Between Ventilation and Perceived Indoor Air Quality

As discussed in a previous section, very few people felt that their indoor air quality is unacceptable or only barely acceptable. However, a substantial number of people did express the feeling that their IAQ is only "somewhat acceptable" rather than "very acceptable," particularly in summer and winter. There is some evidence that certain people are more likely to be less-than-completely satisfied than are other people, either because they are more sensitive to their environment or for reasons of temperament. For example, people who rated their IAQ less than "very acceptable" in winter were very likely to rate it less than "very acceptable" in summer as well. Considering all of the respondents (unadjusted for sampling weights), 55% said IAQ is "very acceptable" in both summer and winter, 28% said it is less than "very acceptable" in both summer in winter, and only 18% said it is "very acceptable" in one of these seasons but not the other. Some of these respondents might live in houses that have problems that lead to poor IAQ in both seasons. Others may simply be more sensitive to IAQ issues than are other people or may simply be less inclined to agree that something is "very acceptable." Available data do not allow us to distinguish between these cases, or at least not very well.

Question 45 asked whether there is a "significant period" in each season when a given problem was noticed (house too hot, too cold, too dry, etc.). The study investigated the relationship between the specific air quality issues in Question 45 and the general acceptability of air quality by season as reported in Questions 48–51. The research team began by creating a binary "indicator variable" based on acceptability of indoor air quality as reported in Questions 48–51: for a given season, the variable takes a value of 1 for surveys that reported that IAQ in that season is "very acceptable," and a value of 0 for any other response. The research team wished to predict the value of this variable, using as predictive variables the responses to the specific IAQ questions, such as whether the air in the house is too humid, too stagnant, etc.

It would be convenient to fit a model in which each particular IAQ problem is associated with a fixed reduction in expected satisfaction: For example, "Start by assuming a 75% chance that the IAQ is 'very acceptable,' and subtract 15 percentage points if the air is too stagnant, subtract 12 percentage points if the air is too dry…." A statistically correct way of fitting such a model is discussed below, but here we start with an approximation. Such a model can be approximated simply by performing a linear regression of the acceptability indicator variable on indicator variables for the specific IAQ problems. If this is done this, we get coefficient estimates for several variables that are negative (indicating lower IAQ acceptability if these problems are present) and both practically and statistically significant (see Table 39.) However, the specific IAQ complaints do little to explain the variation in peoples' responses to the general IAQ question: the value of r-squared is only 0.11 for this model.

Table 39. Whether summer IAQ is "very acceptable," predicted from presence of specific IAQ problems; linear model parameters. R-squared = 0.11.

Variable	Coefficient	Std. Error	t-value	P-value
(Intercept)	0.77	0.02	42.063	<0.0001
Too hot	-0.11	0.03	-4.212	<0.0001
Too dry	-0.15	0.04	-3.532	<0.001
Too stagnant	-0.18	0.04	-5.052	<0.0001
Too dusty	-0.18	0.03	-6.186	<0.0001
Region 1	-0.07	0.03	-2.373	0.011

There is a slight problem with using ordinary linear regression to analyze data such as these. The issue is both theoretical and practical. The problem is that in most cases the reduction in the response is not linear in the independent variables. If stagnant air leads to an 18-point reduction in the probability that IAQ is judged "very acceptable," and dusty air does as well, then air that is both stagnant *and* dusty may not lead to a 36-point reduction in satisfaction, but to some reduction between 15 and 30 points. (In fact, assuming a linear model for the percentage can lead to a predicted probability less than 0 in some cases, though not in the model summarized above.)

To address this issue, one can use logistic regression, which is a statistical method for investigating the relationship between a binary response and a predictive variable or variables. Logistic regression fits a model that assumes that:

$$\log[p/(1-p)] = b0 + b1*x1 + b2*x2 + \ldots$$

where p is the probability that IAQ is judged "very acceptable," b0…bn are regression coefficients, and x1, x2, … are explanatory variables. In this case, the explanatory variables are indicator variables (0=no, 1=yes) for the presence of specific IAQ problems from Question 45. See Table 40.

Table 40. Whether summer IAQ is "very acceptable," predicted from presence of specific IAQ problems, logistic model parameters

Variable	Coefficient	Std. Error	z-value	Pr(>|z|)
(Intercept)	1.21	0.09	12.9	< 0.0001
Too hot	-0.49	0.12	-4.2	< 0.0001
Too dry	-0.67	0.20	-3.4	0.001
Too stagnant	-0.80	0.17	-4.8	< 0.0001
Too dusty	-0.79	0.13	-6.0	< 0.0001
Region 1	-0.32	0.13	-2.4	0.002

Table 40 summarizes logistic model parameters for a model that predicts whether IAQ is judged "very acceptable," depending on the responses to various complaints about individual IAQ problems.

The research team tried several models using various sets of variables based on Question 45, as well as indicator variables for the region of the state, and to indicate whether the home was in the Builders' Sample. Table 40 shows the results for the summer season, for a model that includes just the variables that had substantial effects on the probability that IAQ would be judged "very acceptable."

To use the coefficient estimates to predict whether the IAQ is likely to be rated "very acceptable," calculate the probability from

Probability "very acceptable" = exp(s)/(1+exp(s))

where s is the sum of the appropriate coefficients, and the exponent is to the base e. For instance, the model predicts that if a home has air that is "too dry" and "too dusty" for a significant portion of the summer, then s = 1.21 - 0.6 - 0.79 = -0.25, and the resulting probability is 43%.

Figure 12 can be used to convert between s and probability. A dot marks the intercept term: s=1.21 implies a probability of 0.77 that the IAQ will be judged "very acceptable." Specific IAQ problems lead to lower values of s (along the x-axis) and thus lower values of the probability. As it happens, only the most extreme responses in our data—those that reported almost every possible IAQ problem and are also in Region 1—have predicted probabilities less than 0.2. Since the probability is fairly linear in s (with a slope near 0.25) from about s=-2 to s=+2, it turns out the linear model discussed above should not be problematic; indeed, multiplying the coefficients from the logistic regression by 0.25 gives values rather close to the coefficients of the linear model.

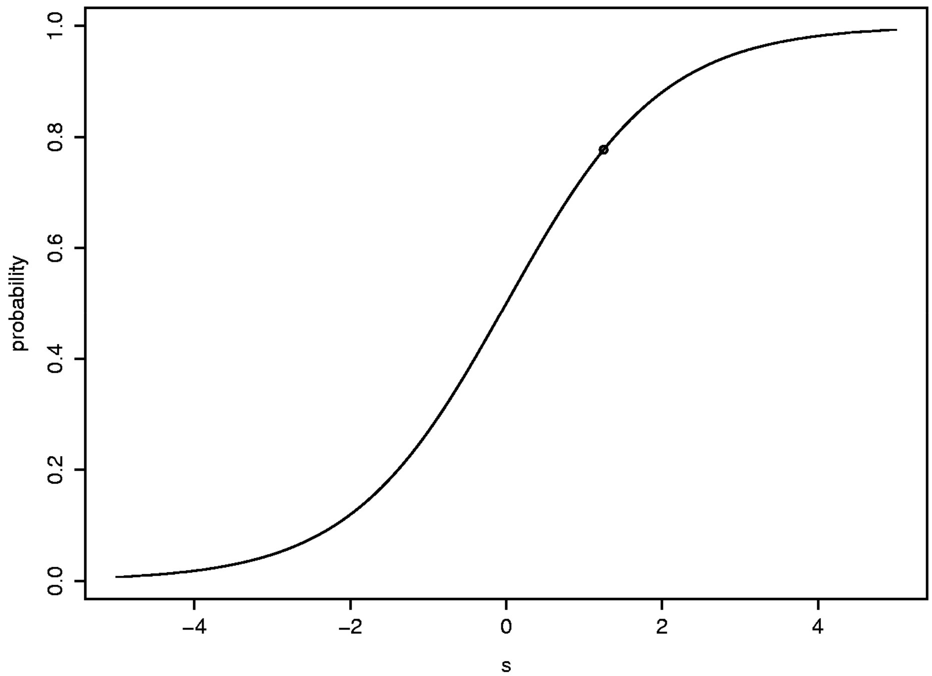


Figure 12. Plot of the predicted probability of indicating that IAQ is "very acceptable" as a function of s. The function is exp(s)/(1+exp(s)). The point corresponding to a response with no specific IAQ complaints is indicated with a dot.

To investigate how well the model actually predicts responses, the predicted probability that the IAQ would be judged "very acceptable" was calculated for each respondent, using the logistic regression results. Respondents were grouped into bins based on expected probability, and their actual response was noted. Table 41 summarizes the results. The last column, "predicted fraction 'very acceptable'," is the mean predicted probability for the responses in the bin. As the table shows, the model performs quite well in the sense that even in the lowest-probability bins, in which respondents indicated that they have most or all of the individual IAQ problems, the fraction that report "very acceptable" IAQ is correctly predicted.

Table 41 compares the predicted response about whether IAQ is "very acceptable" to the actual response. The probability that IAQ will be judged "very acceptable" is predicted for each house, and houses are put into "bins" that span a given range of acceptability. The predicted number of "very acceptable" responses in each bin is compared with the observed number. For instance, from the first row of the table, the model predicts that 37 houses have a probability in the range 0.1–0.2 of finding their IAQ to be "very acceptable"; if the model were perfect, 16% of those houses would in fact judge their IAQ to be very acceptable. The observed fraction was 19%.

Table 41. Summer IAQ acceptability, characteristics of the predictions

Predicted probability of “very acceptable”	Number “very acceptable”	Number in bin	Fraction “very acceptable”	Predicted fraction “very acceptable”
0.1–0.2	7	37	0.19	0.16
0.2–0.3	19	64	0.30	0.28
0.3–0.4	17	46	0.37	0.32
0.4–0.5	105	242	0.43	0.46
0.5–0.6	81	146	0.55	0.56
0.6–0.7	250	377	0.66	0.66
0.7–0.8	458	603	0.76	0.76

The logistic model fits well and the coefficients estimates are highly statistically significant: people who report certain specific IAQ problems, and especially people who report many such problems, are much more likely to report that their general IAQ is less than “very satisfactory.” In both the logit and the linear model, complaints that the air is “too stagnant” or “too dusty” are particularly likely to be associated with less-than-complete satisfaction with IAQ. However, the specific IAQ problems explain very little of the variation in response to the general IAQ question: if we were to guess “very acceptable” for everyone whose predicted probability from the model is greater than 0.5, and “less than ‘very acceptable’” for everyone else, we would correctly guess the response for 68% of the respondents. This is only a little better than the 62% that we would correctly guess if we simply guessed “very acceptable” for everyone. And, as noted above, the linear model generates an r-squared of only 0.11. Some people report no specific IAQ problem but still say they have IAQ that is less than “very acceptable,” while others report one or more specific problems but still judge their overall IAQ to be “very acceptable.”

The situation in winter is much the same: some specific IAQ complaints are highly statistically significant in their effect on the probability that IAQ will be judged “very acceptable,” but very little of the overall variability in acceptability is attributable to those complaints: r-squared of the linear model is only 0.07. As before, people in the Sacramento Delta region were somewhat more likely to report that IAQ was less than “very acceptable” than were people elsewhere in the state. Table 42 presents linear model coefficient estimates, and Table 43 presents logistic model estimates for winter.

Table 42 summarizes the coefficient estimates from a linear model that predicts whether winter IAQ is judged “very acceptable,” depending on the presence of various individual IAQ problems.

Table 42. Whether winter IAQ is "very acceptable," predicted from presence of specific IAQ problems; linear model parameters

	Estimate	Std. Error	t-value	P-value
(Intercept)	0.72	0.01	48.8	< 0.0001
Too dry	-0.26	0.06	-4.7	< 0.0001
Too dusty	-0.23	0.03	-7.0	< 0.0001
Too drafty	-0.13	0.05	-2.4	0.02
Region 1	-0.06	0.03	-2.2	0.03

Table 43 summarizes the coefficient estimates from a logistic model that predicts whether winter IAQ is judged "very acceptable," depending on the presence of various individual IAQ problems.

Table 43. Whether winter IAQ is "very acceptable," predicted from presence of specific IAQ problems; logistic model parameters

	Estimate	Std. Error	z-value	Pr(>|z|)
(Intercept)	0.95	0.07	13.4	< 0.0001
Too dry	-1.14	0.26	-4.5	< 0.0001
Too dusty	-0.97	0.14	-6.7	< 0.0001
Too drafty	-0.56	0.24	-2.3	0.02
Region 1	-0.28	0.13	-2.1	0.03

This study did not look in detail at spring and fall IAQ acceptability data, because very few people reported any specific IAQ problems in those seasons.

Overall, it seems that some people do take specific IAQ complaints into account when assessing overall indoor air quality, but most people do not, or at least not at a level of precision that can be determined through this survey: many people report that IAQ is less than "very acceptable" even though they report none of the specific IAQ problems, and many people report that IAQ is "very acceptable" even though they report one or more specific problems.

3.3.7. Mold

Presence of mold can indicate a problem with indoor air quality (too much humidity); it can also cause perceived air quality problems due to allergies and irritation. Out of the 1,515 respondents, 162 indicated that they have noticed mold in at least one place, in at least one season; 65 of these respondents said they have mold in every season. Most people who reported mold said it occurs in the bathroom, with closets and carpets about a factor of six lower, and a handful of reported problems in basement/crawlspace or walls/ceilings. The scarcity of reported problems in basement or crawlspace may not indicate very much other than the facts that most new California homes do not have basements and many people may not have been into their crawlspace.

Most people who reported mold in one season also reported it in one or more other seasons. About 40% of the people who reported mold in one season reported it in all seasons.

For both summer and winter, the research team created an indicator variable to indicate whether the respondent had noticed mold in one or more locations in their house. Researchers also created separate indicator variables for exactly one location, and for more than one location.

People who noticed summer mold in at least one location were less likely to report that their summer IAQ was "very acceptable." The coefficients of the variables were nearly unchanged in a model that included the mold indicator variable, when such a variable was added to the model described in Table 40, the mold indicator variable has a coefficient estimate of –0.48 +/- 0.23 in the logistic model (p-value 0.04), corresponding to a coefficient of about –0.1 in the linear model; that is, a 10% decrease in the probability of rating their IAQ "very acceptable."

People who noticed winter mold were also less likely to report that their winter IAQ was "very acceptable." This effect was extremely strong for the small number of respondents who reported mold in more than one location in their home; indeed, this effect is so strong that a linear model as discussed above cannot be used to predict IAQ acceptability for this group, because it would predict negative probability of finding IAQ "very acceptable" if they also reported other specific IAQ problems in addition to mold. Out of the 20 homes that reported mold in more than one place in winter, only 3 reported that IAQ is "very acceptable." The coefficients for the variables other than mold in the logistic model for winter, shown in Table 43, are nearly unchanged when the mold variables are added to the model. In the logistic model, the coefficient associated with noticing mold in exactly one location in the house is -0.37 +/- 0.21 (p-value 0.08), and the coefficient associated with noticing mold in multiple locations is -2.29 +/- 0.64 (p-value 0.0003).

3.3.8. Relationship Between Ventilation, Ethnicity, House and Household Size, and Income

Since the summer season had the greatest amount of ventilation and the greatest variability in ventilation, we considered the summer ESLA values when searching for variables that explain or predict the amount of ventilation.

In each region, homes over one story in height were substantially better ventilated (in terms of ESLA) than were single-story homes. The estimated effect was almost the same size in all regions: in Regions 1, 2, and 3 respectively, the estimated effect on ESLA that is associated with a higher-than-one-story home was 2.1 +/- 1.2, 2.4 +/- 2.2, and 2.8 +/- 0.9 units. The r-squared values in all regions are only around 0.01, however. It is possible that the reason taller homes are better-ventilated is partially due to people being more willing to leave upstairs windows open while the house is unoccupied if they live in a multi-story house. Researchers checked to see if, instead, the effect could be a proxy for household size—larger households tend to occupy larger houses—but this does not seem to be the case: the relationship between household size and ventilation is weaker in all regions than is the relationship between taller houses and ventilation.

The research team created indicator variables for the largest ethnic groups in the survey (reported in Question 83): blacks, Hispanics, Asians, and whites, and regressed ESLA on these indicator variables. In every region, no relationship between ethnicity and ESLA approached statistical significance, and r-squared values were all very close to zero. The same null result was found when "hours of medium or high summer ventilation" was used as the dependent variable, rather than ESLA.

Researchers created indicator variables for the income categories reported in Question 82. (More than 93% of respondents indicated their income category.) These categories are: under $35K, $35K–$49,999, $50K–$74,999, $75K–$99,999, $100K–$149,999, and $150K or over. These indicator variables were used in a linear regression to predict summer ESLA in each region, using households in the $100K–$149,999 range as a baseline. Only in the Sacramento Delta region was there a statistically significant relationship between income and ESLA: the lowest-income category had an estimated coefficient of 5.0 +/- 2.5 ($p=0.025$), indicating that homes in the lowest income category get substantially more ventilation than homes of other income levels. However, this relationship was not observed in any of the other regions and may be a statistical artifact or accident; however, given that it is very hot in the Sacramento Delta inland area in the summer, more than in the Southern Coastal region or in the Rest of the State in the summer, and given that air conditioning is expensive, it may be a real result. A linear regression including the entire state, weighted to account for sampling weights, found no significant relationship between ESLA and income, whether or not regional indicator variables were also included.

It is possible in principle that income, ethnicity, household size, and house size could have significant predictive value in combination even though they do not have significant individual effects. To check this, the research team tried both Classification and Regression Trees (Breiman et al. 1984) and multivariate linear regression, using all of the income, ethnicity, and home and household size indicator variables as predictive variables. No significant relationship was found, and r-squared values were negligible.

3.4. Determine the Barriers that Prevent or Inhibit the Use of Windows, Doors, and Mechanical Ventilation Systems

3.4.1. Reasons for Closing Windows

Question 27 asked respondents to report how important various reasons were for closing their windows. Regional estimates are tabulated in Table 44A (for the representative statewide sample) and Table 44B (for the Builders' sample); uncertainties are quantified in Table 29. Variability among areas of the state is small, for most of the reasons for closing windows. Excluding wood smoke, pollen, and insects, all seem to be slightly more important reasons for window-closing in the Sacramento Delta region than in the rest of the state.

Table 44A gives the percent of houses in each region, and in the state, that say that various reasons for closing windows to have a given level of importance.

Table 44A. Reasons for closing windows: statewide probability sample

How important is this reason to close windows (percent of houses) Sacramento Delta region, Southern Coastal region, Rest of State, **Statewide**	**Very**	**Somewhat**	**Slightly**	**Not at all**	**Never close for this reason**
Nobody home	93,84,84,**85**	4,11,10,**9**	2,3,3,**3**	0,1,1,**1**	1,1,2,**2**
Maintain comfortable temperature	74,68,66,**68**	21,24,26,**24**	3,6,6,**5**	1,0,2,**1**	1,1,1,**1**
Reduce pollutants or odors from outdoors	43,37,34,**36**	21,23,19,**20**	15,15,21,**19**	9,14,13,**12**	11,11,14,**12**
Too windy/drafty	44,46,44,**45**	28,26,29,**28**	21,19,18,**19**	3,5,5,**4**	4,4,4,**4**
Keep out noise	40,41,38,**39**	24,25,23,**24**	22,21,19,**20**	7,7,10,**9**	7,6,10,**8**
Keep pets in/out	23,19,22,**22**	6,6,10,**8**	6,8,5,**6**	6,4,8,**7**	59,63,55,**57**
Save energy	68,61,59,**61**	21,21,22,**22**	6,12,10,**9**	2,4,3,**3**	3,3,6,**5**
Keep out rain/snow	73,68,66,**68**	12,12,14,**13**	7,12,11,**10**	2,4,3,**3**	7,4,6,**6**
Keep out woodsmoke	30,21,21,**23**	5,6,5,**6**	8,6,7,**7**	10,12,11,**11**	48,55,55,**54**
Keep out dust	47,37,41,**42**	23,25,23,**24**	16,15,16,**16**	6,8,7,**7**	9,15,13,**12**
Keep out pollen/allergens	45,31,35,**35**	22,18,17,**18**	15,17,18,**17**	5,13,11,**10**	12,21,19,**19**
Keep out insects	62,52,49,**52**	15,20,18,**18**	8,9,14,**12**	5,7,7,**7**	9,12,12,**12**
Privacy from neighbors	38,26,27,**29**	25,26,21,**23**	16,24,22,**21**	8,10,14,**12**	12,15,16,**15**
Security/safety	85,83,78,**80**	8,10,14,**12**	4,4,4,**4**	1,1,1,**1**	2,2,2,**2**
Hard to open/close	3,2,4,**4**	6,5,4,**5**	7,8,6,**7**	19,19,17,**18**	65,66,68,**67**

Table 44B gives the percent of houses in the non-representative “Builders’ Sample” in each region, and in the state, that say that various reasons for closing windows to have a given level of importance. Results are very similar to those for the statewide probability sample, except that “security/safety” is somewhat less frequently reported as a major reason to close windows (very important for 80% of the Statewide sample, and 66% of the Builder’s Sample).

Table 44B. Reasons for closing windows: builders' sample

How important is this reason to close windows (percent of houses) Sacramento Delta region, Southern Coastal region, Rest of State, **Statewide**	**Very**	**Somewhat**	**Slightly**	**Not at all**	**Never close for this reason**
Nobody home	92,74,86,**84**	0,16,3,**7**	0,0,3,**2**	0,10,0,**3**	8,0,7,**5**
Maintain comfortable temperature	86,47,69,**66**	14,42,21,**26**	0,5,0,**2**	0,5,3,**3**	0,0,7,**3**
Reduce pollutants or odors from outdoors	40,44,28,**36**	13,22,24,**21**	13,11,14,**13**	7,11,7,**8**	27,11,28,**23**
Too windy/drafty	27,53,38,**40**	27,32,38,**33**	20,16,21,**19**	13,0,0,**3**	13,0,3,**5**
Keep out noise	13,42,38,**33**	27,32,34,**32**	27,21,14,**19**	7,5,7,**6**	27,0,7,**10**
Keep pets in/out	11,26,28,**23**	11,16,10,**12**	0,5,0,**2**	0,5,10,**6**	78,47,52,**58**
Save energy	67,58,69,**65**	20,5,17,**14**	0,21,0,**6**	7,10,3,**6**	7,5,10,**8**
Keep out rain/snow	53,53,66,**59**	13,21,3,**11**	7,21,14,**14**	0,5,7,**5**	27,0,10,**11**
Keep out woodsmoke	20,16,28,**22**	0,16,10,**10**	13,5,0,**5**	13,10,7,**10**	53,53,55,**54**
Keep out dust	29,53,52,**47**	29,16,21,**21**	29,21,10,**18**	7,10,0,**5**	7,0,17,**10**
Keep out pollen/allergens	20,32,34,**30**	33,10,28,**24**	27,16,14,**18**	0,26,0,**8**	20,16,24,**21**
Keep out insects	53,42,55,**51**	27,21,21,**22**	7,16,3,**8**	0,5,0,**2**	13,16,21,**18**
Privacy from neighbors	21,26,21,**23**	21,32,28,**27**	43,21,17,**24**	7,5,14,**10**	7,16,21,**16**
Security/safety	56,68,69,**66**	25,16,14,**17**	6,10,10,**9**	6,0,0,**2**	6,5,7,**6**
Hard to open/close	0,16,0,**5**	14,5,7,**8**	0,5,14,8	21,37,18,**25**	64,37,61,**54**

As shown in Table 44A for the Statewide Sample, households typically had multiple reasons for opening and closing windows. These reasons fell into three main groups.

1. The most frequent reasons reported as Very Important were Nobody at home, and Security and safety—these were reported as very important in 80% or more of the households, statewide.
2. The next most frequent reasons were Keeping out rain and snow, Maintaining comfortable temperature, and Saving energy—these were reported as very important in 61%–68% of the households, statewide.
3. The next most frequent reasons were Keeping out insects, Too windy or drafty, Keeping out dust, Keeping out noise, Reducing pollutants or odors from outdoors,

Keeping out pollens or allergens, Privacy from neighbors, Keeping out woodsmoke, and Keeping pets in or out—these were reported as very important in 22%–52% of the households, statewide.

These results suggest that overall window closing behavior is mainly driven by security and safety reasons, followed by thermal comfort and economic reasons, and followed closely by various environmental, air quality, and health reasons.

3.4.2. Importance of Reasons to Open or Close Windows

The research team created indicator variables for each reason to open or close windows: for each household, the variable took the value 1 if the indicated reason was "very" or "somewhat" important, and a value of 0 otherwise. The team then used stepwise regression based on the Akaike Information Criterion (Venables and Ripley 2002) to select the subset of predictive variables that best predicts ESLA. Stepwise regression is an automated procedure that is helpful for producing candidate models for detailed consideration. The variables that were identified by stepwise regression were:

- windows are opened to cool the house,
- windows are opened to warm the house,
- windows are open to air out the house during cleaning,
- windows are opened to remove odors,
- windows are opened to provide a draft for cooking appliances or fireplace,
- windows are opened to save energy,
- windows are opened to allow pet access,
- windows are closed because "nobody at home,"
- windows are closed to maintain a comfortable temperature,
- windows are closed if it is too windy,
- windows are closed to keep out noise,
- windows are closed to keep out rain, and
- windows are closed to keep out pollen.

Starting with the set of variables identified by stepwise regression, the research team then eliminated some and included others based on statistical or engineering judgment. For instance, a variable that indicates that "removing odors" was an important reason for opening windows was identified by stepwise regression as being mildly predictive of ESLA. However, its coefficient estimate was slightly negative (indicating slightly lower ventilation in houses that open windows for this reason than in other houses) and well short of statistical significance (p-value 0.3), so this variable was excluded. Additionally, several reasons to close windows were found to be *positively* correlated with summer ESLA, whereas one might expect that if something is a reason to *close* windows, it should be associated with *lower* levels of ventilation. (A likely possibility is that if someone said that something is a reason to close windows, it means that they are likely to have had windows open in the first place.) In retrospect, it might have been better to ask why people do not provide more ventilation than they currently do, rather than to ask separately about reasons to open windows and reasons to close them.

The research team searched for a set of reasons to open or close windows that made sense, if interpreted causally (i.e., the signs of the coefficients were in the right direction) and whose coefficients were at or near statistical significance (i.e., p-values below 0.1). The team also included regional indicator variables, even though they fall short of statistical significance. The resulting model is summarized in Table 45. The table shows the coefficient estimates from a linear model to predict summer ESLA from variables that indicate if a particular factor is a very or somewhat important reason to open or close windows. The r-squared value for this model is 0.08.

Table 45. Predicting summer ESLA

	Estimate	Std. Error	t-value	P-value
(Intercept)	9.5	1.2	7.8	< 0.0001
Open to cool the house	5.2	0.8	6.3	< 0.0001
Open to warm the house	1.6	0.7	2.2	0.03
Open to save energy	2.0	0.7	2.9	0.004
Open to allow pet access	2.2	0.9	2.6	0.01
Close because nobody home	-4.3	1.2	-3.5	< 0.001
Close to keep out pollen	-3.1	0.7	-4.5	< 0.0001
Region 1	-1.4	0.9	-1.5	0.14
Region 2	-0.2	0.7	-0.2	0.79

Table 45 presents coefficient estimates from a linear model that predicts summer ESLA from whether the occupants say that certain reasons for opening or closing windows are very or somewhat important. For instance, the second row shows that households that say that cooling the house is an important reason to open windows have an ESLA value 5.2 units higher, on average, than houses for which cooling the house is not an important reason to open windows.

The relationship between summer ESLA and opening windows to *warm* the house seems counterintuitive. However, the questions about reasons to open and close windows are not season-specific; the people who say that they open windows to warm the house presumably mean that they do so during times of year when the interior of the house is undesirably cool while the outside air is warmer. This might include summer mornings in some areas, or might include seasons other than summer. In any case, the tendency to open windows to warm the house may be associated with a general willingness to open windows more often when appropriate, leading to a positive coefficient.

The research team fit the same regression as described in Table 45, but excluding the "open to warm the house" variable. The "open to cool the house" coefficient estimate increased by 0.2; none of the other coefficients changed by more than 0.1. The r-squared value and p-values were nearly unchanged.

Providing comfort (and retaining comfortable temperatures without using energy) seem to be the most important reasons that people open windows, or at least are the best predictors (among reasons to open windows) of increased ventilation. People who close windows because nobody is home or to keep out pollen tend to have reduced ventilation.

Note that this model is *not* a time-series of analysis of the reasons that any given household opens or closes windows. Instead, it simply finds that households that said that these factors are important are likely to get higher or lower summer ventilation than are other households.

The coefficient estimates shown in Table 45 suggest that the most important predictors of ESLA for window use in the summer may be Opening the windows for cooling, Closing the windows when nobody is home, and Closing windows to keep out pollen. However, the lack of season-specific data for window use, and the inability to determine causation from correlation limit our confidence in these results.

3.5. Variation of Ventilation Behavior Among Houses

The research team fit many different linear models and tree models to attempt to explain the variability in ESLA or in the number of hours with medium or high ventilation. The team included indicator variables for smokers, asthmatics, etc., as well as indicator variables for reasons for opening and closing windows. Researchers also included interaction terms, such as an interaction between the number of hours that the house is unoccupied and an indicator for whether security is an important reason for closing windows. Region indicator variables, number of household members, ethnicity indicators, and hours spent cooking were also included. Even when many variables were included, the research team was unable to find a model that explains more than 25% of the variability in ESLA among houses; that is, more than 75% of the variance remained unexplained. This modeling exercise did not reveal any relationships that are not already discussed above, and coefficients found in these models are difficult to interpret because of the interactions between variables, so they are not reported here. In summary, ventilation behavior varies greatly among households, especially in seasons other than winter, and much of that variation cannot be predicted based on factors investigated by the survey instrument.

4.0 Conclusions and Recommendations

4.1. Summary

In setting building energy design standards, the Energy Commission assumes a certain level of outdoor air ventilation from occupant use of windows and mechanical devices. However, because houses built within the last few years are designed to be very airtight in order to conserve energy, concerns were raised that the occupant use of windows, doors, and mechanical ventilation devices may not provide adequate ventilation with outdoor air, and may contribute to unacceptable indoor air quality.

Information was needed by the Energy Commission on household ventilation practices of occupants. A mail survey was used to collect information on occupants' use of windows and mechanical ventilation equipment in 1,515 new homes in California, and on occupant perceptions of and satisfaction with indoor air quality and ventilation conditions. The survey questionnaire was developed, pre-tested, and sent to households in all regions of California. The results were analyzed to meet the following objectives:

(1) Determine how occupants used windows, doors, and mechanical ventilation;

(2) Determine occupant perceptions of and satisfaction with IAQ in their homes;

(3) Determine the relationship among ventilation practices, perceived IAQ, and house and household characteristics; and

(4) Determine barriers that prevent or inhibit the use of windows, doors, and mechanical ventilation systems.

Information was also needed concerning some specific pollutant sources that are sometimes problematic or can contribute to indoor pollutant levels, such as new carpets, paint, cabinetry, and heating and cooking appliances. Such key information was needed by ARB for assessment of Californians' exposures to indoor and outdoor air pollutants in new homes. Under HSC Section 39660.5, ARB is required to assess Californians' exposures to toxic air contaminants.

4.2. Conclusions

Objective 1: To determine how occupants used windows, doors, and mechanical ventilation.

- Many occupants do not get substantial ventilation through window opening. Windows provide much less than 0.35 ACH for most homes in winter, and less than 0.35 ACH in about half of homes in fall and spring.
- Local exhaust fans are underutilized. Kitchen and bathroom ventilation fans tend to be used based on perception of moisture or odors, rather than being used routinely. Nearly 50% of respondents indicate that they sometimes fail to use the bathroom fan even when conditions clearly call for it, most often because they "don't think of it."

- People are not familiar enough with mechanical ventilation systems to meaningfully respond to mail survey questions about them.

Objective 2: To determine occupant perceptions of and satisfaction with IAQ in their homes.

- Occupants generally perceive their IAQ to be satisfactory, even though some of them report problems that might be expected to bother them:

  Approximately 15%–25% of households indicate that their house is "too dusty" in any given season. It cannot be determined whether the dust is from inside the house, outside the house, or both.

  The only other specific complaints that occurred in more than about 15% of houses were related to thermal comfort: about half the respondents indicate that their house is too hot in summer or too cold in winter. All of the houses have heating and air conditioning systems; it is not clear whether the systems are overwhelmed or whether people do not set them to a comfortable temperature (perhaps in order to save money).

- Occupant satisfaction with IAQ does not appear to be related to ventilation. Households with low values of ventilation did not report substantially lower (or higher) amounts of ventilation than did other households. Also, most people reported the same level of satisfaction with IAQ in both summer and winter, in spite of a very large difference in ventilation between these seasons.
- Few occupants report problems with mold at more than one location in their house, but those who do are almost all less than completely satisfied with the IAQ in their house.

Objective 3: To determine the relationship among ventilation practices, perceived IAQ, and house and household characteristics.

- There is no evidence that households with significant indoor pollutant sources (such as candles, pesticides, etc.) get more ventilation than others. The exception is cooking: households where people cook at home for many hours per week tend to get substantially more ventilation than do other households.
- There is no evidence that health issues motivate ventilation behavior, except that households containing asthmatics appear to get slightly more ventilation than other households, on average.

Objective 4: Determine barriers that prevent or inhibit the use of windows, doors, and mechanical ventilation systems.

- Security, maintaining a comfortable temperature, and saving energy appear to be the main reasons people close their windows or keep them closed. However, houses that are rarely unoccupied receive only slightly more ventilation, on average, than houses that are unoccupied for a large portion of each day, so even homes for which leaving windows open would seem to be relatively safe are often insufficiently ventilated.

- People also closed windows to provide or maintain thermal comfort, and (to a somewhat lesser degree) for reasons related to air quality or health.
- Most people who have mechanical ventilation systems do not know how they work or even what kind they have, even if they think they know. Based on this fact, and on other reported experience with mechanical ventilation systems (Devine 2000), people cannot be expected to manipulate mechanical ventilation systems so as to provide adequate ventilation.

4.3. Recommendations

- Field measurements of ventilation-related performance should be made to determine how it relates to reported behavior. Because some of the survey questions were clearly misinterpreted or too difficult to answer correctly, field measurements of ventilation-related performance are necessary to determine how it relates to reported behavior. Some studies are being initiated for a subset of these houses.
- A clear definition of IAQ is needed for people to have a clear sense of what variables make up air quality. Temperature may be viewed as separate from other issues such as stagnant or dusty air.
- Respondents had a very difficult time understanding the mechanical ventilation questions. A clear list of industry systems might greatly improve respondent comprehension.
- Any standard, whether for mechanical ventilation systems or for providing operable windows, should take into account the fact that people do not recognize when their ventilation rate is inadequate and cannot be expected to take actions to increase it when it falls below a given level.
- The study was not designed to focus on thermal comfort issues, but reported window behavior suggests that additional studies on warm-weather behavior should be initiated because results indicate that people are using windows for ventilative cooling.

4.4. Benefits to California

This was the first large survey to obtain information on occupant ventilation practices in new California homes. The data from this study are immediately useful by the California Energy Commission to guide the development of future building energy design standards that protect indoor air quality and comfort in California homes, and by the California Air Resources Board to improve exposure assessments of indoor and outdoor air pollutants. Additionally, the data may be used to help design a future field study that will measure pollutant concentrations and other parameters in new California homes.

5.0 References

ASHRAE. 1994. "Air Leakage Performance for Detached Single-Family Residential Buildings." ASHRAE 119-1988, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta.

ASHRAE. 2001. "A Method of Determining Air Change Rates in Detached Dwellings." ASHRAE 136-1993, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta.

ASHRAE. 2004. "Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings." ASHRAE 62.2-2004, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta.

Breiman, L., J. Friedman, R. A. Olshen, and C. J. Stone. 1984. *Classification and Regression Trees.* Belmont, California: Wadsworth.

Devine, J. 2000. "Washington State Ventilation and Indoor Air Quality Code, Whole House Ventilation Systems Research Report." Prepared for the Washington State University Energy Program.

Efron, B. 1981. "Nonparametric estimates of standard error: The jackknife, the bootstrap, and other methods." *Biometrika* 68: 589–599.

Grimsrud, D. T., and D. E. Hadlich. 1999. "Residential Pollutants and Ventilation Strategies: Volatile Organic Compounds and Radon." *ASHRAE Transactions* 105: 849–863.

Hadlich, D. E., and Grimsrud, D. T. 1999. "Residential Pollutants and Ventilation Strategies: Moisture and Combustion Products." *ASHRAE Transactions* 105: 833–848.

Leech, J. A., M. Raizenne, and J. Gusdorf. 2004. "Health in occupants of energy efficient new homes." *Indoor Air* 14: 169–173.

Little, R. J. A., and D. B. Rubin. 1987. *Statistical Analysis With Missing Data.* New York: Wiley.

Maindonald, J., and J. Braun. 2003. *Data Analysis and Graphics using R.* Cambridge: Cambridge University Press.

Parekh, A. 2000. "R-2000 Home Health Study: Homeowner Health in R-2000 and New Conventional Homes." Presentation for Office of Energy Efficiency, Health Canada.

Phillips, T. J., E. J. Mulberg, and P. L. Jenkins. 1990. "Activity patterns of California adults and adolescents: Appliance use, ventilation practices, and building occupancy." Paper presented at the 1990 Summer Study on Energy Efficiency in Buildings, American Council for an Energy-Efficient Economy (ACEEE), Vol. 4, Environment: Washington, D.C.

Sherman, M. H., and A. T. Hodgson. 2002. "Formaldehyde as a Basis for Residential Ventilation Rates." LBNL-49577.

Venables, W. N., and B. D. Ripley. 2002. *Modern Applied Statistics with S (*4th ed.). New York: Springer.

Wilson, A. L., J. Bell, D. Hosler, and R. A. Weker. 2003. "Infiltration, Blower Door and Air Exchange Measurements in New California Homes." Presented at: IAQ Problems and Engineering Solutions Specialty Conference, Research Triangle Park, North Carolina, AWMA, July 21.

Additional Information

Fang, L., G. Clausen, and P.O. Fanger. 1998. "Impact of temperature and humidity on the perception of indoor air quality." *Indoor Air* 8(2): 80–90.

Ferng, S. F., and L. W. Lee. 2002. "Indoor air quality assessment of daycare facilities with carbon dioxide, temperature, and humidity as indicators." *Journal of Environmental Health* 65(4): 14–18. Nov.

Hekmat, D., H. E. Feustel, and M. P. Modera. 1986. "Impacts of Ventilation Strategies on Energy Consumption and Indoor Air Quality in Single-family Residences." *Energy and Buildings* 9: 239–251.

Kleipeis, N. E. et al. 2001. "The National Human Activity pattern Survey (NHAPS): A Resource for Assessing Exposure to Environmental Pollutants." *J Expos Anal & Environ Epid* 11: 231–252.

Lubliner, M., D. T. Stevens, and B. Davis. 1997. "Mechanical Ventilation in HUD-Code Manufactured Housing in the Pacific Northwest." *ASHRAE Transactions* 103: 693–705.

Milton, D., P. Glencross, and M. Walters. 2000. "Risk of Sick Leave Associated with Outdoor Air Supply Rate, Humidification, and Occupant Complaints." *Indoor Air* 10(4): 212–221.

Piazza, T., and Y. Cheng. 1991. "Sampling Methods and Field Results for the 1989–90 Activity Pattern Survey of California Children." Survey Research Center Technical Report, University of California, Berkeley.

Piazza, T., and Y. Cheng. 1989. "Sampling Methods for the 1987–88 California Activity Pattern Survey." Survey Research Center Technical Report, University of California, Berkeley.

Rudd, A., S. Chandra, and J. Tooley. 1993. "Measured Air-Tightness and Thermal Insulation Quality of 11 Industrialized Houses." Presented at the 1993 EEBA/NESEA Conference on Building Solutions conference, sponsored by the Energy Efficient Building Association, Minneapolis, Minn., Boston, Mass., March 3–6.

Wilcox, B., and J. Lutz. 1990. "Air Tightness and Air Change Rates in Typical New California Homes." Proceedings of the ACEEE 1990 Summer Study, American Council for an Energy Efficient Economy, Washington, D.C.

6.0 Glossary of Terms, Abbreviations, and Symbols

5FV5	Beutler Code for FreshVent System
5MHRVFB	Beutler Code for Modular Heat Recovery Ventilation
ACH	Air Changes per Hour
ACM	Alternative Calculation Method
ANOVA	Analysis of Variance
ARB	California Air Resources Board
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
CASES	Computer Assisted Survey Execution System
CZ	Climate Zone
DDE	Direct Data Entry
ELA	Equivalent Leakage Area (m^2)
Energy Commission	California Energy Commission
ESLA	Effective Specific Leakage Area
HEPA	High Efficiency Particulate Air Filter
HSC	Health and Safety Code
HVAC	Heating, Ventilating, and Air Conditioning
IAQ	Indoor Air Quality
LBNL	Lawrence Berkeley National laboratory
MERV	Minimum Efficiency Reporting Value
MHRV	Modular Heat Recovery Ventilation
PIER	Public Interest Energy Research
Q	Question
R & D	Research and Development
SES	Socioeconomic Status
SLA	Specific Leakage Area
SRC	Survey Research Center
VOC	Volatile Organic Compound

Appendix A

Review of Literature Related to Residential Ventilation Requirements

LBNL-57236

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Review of Literature Related to Residential Ventilation Requirements

Jennifer McWilliams and Max Sherman

June 2005

LEGAL NOTICE

This report was prepared as a result of work sponsored by the Air Resources Board (ARB) and the California Energy Commission (Commission). It does not necessarily represent the views of ARB, the Commission, their employees, or the State of California. The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed as actual or implied endorsement of such products. The ARB, the Commission, the State of California, its employees, contractors, and subcontractors make no warranty, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the use of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the ARB or the Commission, nor has the ARB or the Commission passed upon the accuracy or adequacy of this information in this report.

Disclaimer

While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor The Regents of the University of California, nor any of their employees, nor any other sponsor of this work makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or The Regents of the University of California or any other sponsor. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, or The Regents of the University of California or any other sponsor.

Ernest Orlando Lawrence Berkeley National Laboratory is an equal opportunity employer.

Abstract

This paper reviews current ventilation codes and standards for residential buildings in Europe and North America. It also examines the literature related to these standards such as occupant surveys of attitudes and behavior related to ventilation, and research papers that form the technical basis of the ventilation requirements in the standards. The major findings from the literature are that ventilation is increasingly becoming recognized as an important component of a healthy dwelling, that the ventilation standards tend to cluster around common values for recommended ventilation rates, and that surveys of occupants showed that people generally think that ventilation is important, but that their understanding of the ventilation systems in their houses is low.

Acknowledgements

The research reported here was funded by the California Institute for Energy Efficiency (CIEE), a research unit of the University of California, under Memorandum Agreement C-03-11, Interagency Agreement No. 500-99-013. Publication of research results does not imply CIEE endorsement of or agreement with these findings, nor that of any CIEE sponsor

This report was supported by work sponsored by the California Energy Commission (Energy Commission). It does not necessarily represent the views of the Energy Commission, its employees, or the State of California. The Energy Commission, the State of California, its employees, contractors, and subcontractors make no warranty, express or implied, and assume no legal liability for the information in this report, nor does any party represent that the use of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the Energy Commission nor has the Energy Commission passed upon the accuracy or adequacy of the information in this report.

This project was also supported through Building Science Corporation and their, **ARTI-funded Project SI/IEQ-30090: Evaluation of Whole-house Mechanical Ventilation System Options – Phase I Simulation Study**.

This Report was submitted in fulfillment of the ARB Contract Number 03-326 and the California Energy Commission Contract Number 500-02-023, for the study entitled “Survey of Ventilation Practices and Housing Characteristics in New California Homes” by the Survey Research Center of the University of California at Berkeley and the Lawrence Berkeley National Laboratory under the sponsorship of the California Air Resources Board and the Energy Commission. Work was completed as of December 2005.

This work was also supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies Program, of the U.S. Department of Energy under contract No. DE-AC02-05CH11231.

Table of Contents

INTRODUCTION

With an increasing public concern about mold and other indoor air quality concerns inside their homes, many jurisdictions and institutions are looking to adopt improved ventilation codes, standards and practices. The State of California, for example, is planning to update the 2008 version of its energy code, known as "Title 24" to address this issue.

Indoor air quality (IAQ) is a complex result of occupant activities, human responses, source emission, and contaminant removal. The key issues that one can set requirements for are usually ventilation and source control. To set those requirements often requires an understanding of the materials and processes typically found in houses and the operational strategies of its occupants.

The purpose of this report is to review the published literature on existing ventilation standards and related research in order to provide a foundation for the current efforts to update Title 24 Residential Building Energy Code.

BACKGROUND

Virtually every building code has requirements in it related to ventilation and indoor air quality, but an integrated approach to looking at residential indoor air quality is usually lacking. The nation's first consensus standard on residential ventilation and indoor air quality was recently published by the American Society of Heating, Refrigerating and Air-conditioning Engineers (ANSI/ASHRAE Standard 62.2-2003). As the first such American National Standard it forms a strong starting point; other codes and standards can be compared to that.

CALIFORNIA PROGRAMMATIC BACKGROUND

The California Energy Commission (CEC) has as a funding priority a program of Research and Development (R&D) to advance the state of knowledge on residential ventilation in California. The Energy Commission will support this research through its Public Interest Energy Research (PIER) program. An important goal of this effort is to identify changes to existing residential energy efficiency standards (i.e., Title 24) that can be incorporated into the 2008 standards to maintain or to improve the indoor environment of new homes and to reduce the energy-related impacts of these homes.

To advance the state of knowledge in this field, the PIER program has established a three-part approach to the problem: 1) characterization of the indoor environments of homes built to current standards, 2) development of minimum requirements to achieve acceptable indoor air quality in future construction and 3) evaluation and development of technologies and associated descriptive algorithms for meeting minimum requirements.

These three elements act synergistically to provide the information the State needs to inform its efforts to modify Title 24. Each piece has been the subject of an independent scoping study (Walker and Sherman, 2003 and McKone and Sherman, 2003). This report provides a review of the literature necessary to achieve the following goals.

Characterization Project Goals: The broad goals of the characterization project are: 1) to determine if ventilation and indoor air quality, in a population of new, production-built, single-family, detached houses built to 2001 Title 24 energy efficiency standards, are acceptable based on available guidelines for comfort and health protection and 2) to describe the influence of selected key factors, including occupant behaviors, on ventilation rates and indoor air quality in these houses. The objective of this project is to answer a series of questions related to ventilation rates and indoor air quality (IAQ) in production-built, new, single-family, detached California homes built to the 2001 Title 24 standards. These questions focus on the topics of ventilation, indoor air quality and occupant behavior.

Requirements Project Goals: The broad goals of the requirements project are to: 1) determine the state of the art in residential ventilation codes and guidelines and their applicability to California; 2) identify and resolve engineering-based issues necessary to define new minimum requirements; 3) determine how to extend engineering-based requirements with R&D to incorporate health protection; and 4) develop draft requirements suitable for inclusion in the 2008 version of Title 24. The objectives of the project are to focus on the technical barriers to improved residential ventilation standards and to resolve these barriers. We will closely coordinate work on this project with the characterization project to identify real-world issues and problems for ventilation and indoor air quality in new construction.

Technology Project Goals: The broad goals of the technology project are to: 1) determine the state of the art in residential ventilation methods and technologies and their application to California: 2) identify and develop suitable technologies that meet new minimum requirements and are not currently used in California; 3) develop models to evaluate the full performance of potential technology using the applicable criteria of energy, ventilation, demand, etc. and 4) work with the compliance industry to incorporate necessary algorithms into future Title 24 compliance tools.

REVIEW OF CURRENT CODES AND STANDARDS

In developing a new standard, code or practice it is important to review what others have done. In this section we look at the ever-changing list of such documents:

The European Union is in the process of bringing the standards of the various countries into alignment with a European Standard. The Union has issued two directives that relate to ventilation: the Construction Product Directive (CPD) issued in 1989, and the Energy Performance of Buildings Directive (EPBD) issued in 2002 (Santamouris, to be published). The area in which the CPD relates to ventilation is that it requires construction product standards that relate to hygiene, health and the environment (among others) to be aligned within the member countries. The EPBD mainly deals with the energy efficiency of buildings, but it does contain the following reference to ventilation: *"These [energy] requirements shall take account of general indoor climate conditions, in order to avoid possible negative effects such as inadequate ventilation,…"*. (CEC, 2003) The European Committee for Standardization (CEN) is the body responsible for most of the standards relating to ventilation. They currently have a standard, *prEN 14788: Ventilation for buildings – Design and dimensioning of residential ventilation systems*, which describes a calculation method for determining the ventilation air volume flow rate required for good health of the occupants based on pollutant production rates and certain indoor and outdoor air conditions. Due to the widely varying methods of specifying ventilation rates in the Regulations and Standards of each of the European member countries, the standard does not attempt to align these requirements, or even tabulate them. It states that *"The required ventilation air flow rates shall be obtained from National or Local Regulations and/or Standards in the country concerned."* (CEN, 2003)

Table 1, excerpted from AIVC Technical Note 57: Residential Ventilation, gives a succinct summary of required whole building and room by room ventilation rates in Europe, the U.S. and Canada (Concannon, 2002). The ventilation must be supplied mechanically in some of the standards, but not in all. Several standards have been updated since the publishing of this paper, and these are shown in Table 2.

Country and Standard Reference	Whole Building Ventilation Rates	Living Room	Bedroom	Kitchen	Bathroom + WC	WC only
Belgium (NBNB62-003)	0.7-1.0 ach 20-30 $m^3/h/p$		1.0 $dm^3/s/m^2$ floor area	50-75 m^3/s	14 dm^3/s	7 dm^3/s
Canada (CSA F361-M1989, ASHRAE 62-1989)	>0.3 ach, 5 l/s/p			Exhaust 50 l/s (inter.) 30 l/s (cont.)	Exhaust 25 l/s (inter.) 15 l/s (cont.)	
Denmark (DS 418)		0.4-0.6 ach		0.7 ach	0.7 ach	
Finland (NBC-D2)		0.5 $l/s/m^2$	4.0 l/s/p 0.7 $l/s/m^2$ floor area	Exhaust 20 l/s	Exhaust 15 l/s	
France (Arrete 24.03.82)				20-135 m^3/h	15-30 m^3/h	15-30 m^3/h
Germany (Din 18017, Din 1946, VDI 2088)		Min. 60-120 m^3/h Max. 60-180 m^3/h		Min. 40 m^3/h Max. 60 m^3/h	Min. 40 m^3/h Max. 60 m^3/h	Min. 20 m^3/h Max. 30 m^3/h
Italy (MD 05.07.75)	0.35-0.5 ach	15 $m^3/h/p$		1.0 ach	1.0-2.0 ach	
Netherlands (NEN 1087)		1.0 $dm^3/s/m^2$ floor area	1.0 $dm^3/s/m^2$ floor area	21 dm^3/s	14 dm^3/s	7 dm^3/s
New Zealand (ASHRAE 62-1989)	Openable Window to 5% of floor area in each room.				25 l/s per room (inter.) 10 l/s per room (cont.)	
Norway (NBC ch47-1987)		Supply: Openable window or inlet bigger than 100cm^2 in external wall.	Supply: Openable window or inlet bigger than 100cm^2 in external wall.	Mech. Extract 60m^3/h or by natural extract at least 150cm^2 duct above roof	Mech. Extract 60m^3/h or by natural extract at least 150cm^2 duct above roof	Mech. Extract 40m^3/h or by natural extract at least 100cm^2 duct above roof
Sweden (BFS 18ch4.1)	Supply: min. 0.35 $l/s/m^2$ floor area	Supply: 0.35 $l/s/m^2$ floor area	Supply: 4.0 l/s/p	Extract: 10 l/s per room	Extract: 10-30 l/s	Extract: 10 l/s
Switzerland (SIA 384/2, SIA 382/1)			80-120 m^3/h		30-60 m^3/h	
UK (BS 5720-1979, BS5925-1991, Building Regs. Approved Doc. F, CIBSE Guides A & B)	Rec. 12-18 l/s/p, Min. 8-12 l/s/p	Vent openings with at least 1/20th floor area & vent openings with total area not less than 4000mm^2	Vent openings with at least 1/20th floor area & vent openings with total area not less than 4000mm^2	Mech. Supply 60 l/s (inter.) or 30 l/s cooker hood & natural vent. Openings with total area not less than 134000mm^2	15 l/s (inter.)	Openings not less than 1/20th floor area or 3ach intermittent with overrun.

USA (ASHRAE 62-1989)	0.35 ach but no less than 7.5 l/s/p			50 l/s (inter.) or 12 l/s (cont.) or openable windows	25 l/s per room (inter.) or 10 l/s per room (cont.) or openable windows	

Table 1: Ventilation Standards in Dwellings, Concannon (2002)

Country and Standard Reference	**Whole Building Ventilation Rates**	**Living Room**	**Bedroom**	**Kitchen**	**Bathroom + WC**	**WC only**
USA (ASHRAE 62.2-2003)	0.05 * (total floor area) + 3.5 l/s/p			50 l/s (inter.) or 5 ach (cont.) or openable windows	25 l/s per room (inter.) or 10 l/s per room (cont.) or openable windows	
Finland (NBC-D2, 2003)		0.5 l/s/m^2	6.0 l/s/p or 0.35 l/s/m^2 floor area	Exhaust 8 l/s (cont.) 25 l/s (boost)	Exhaust 10 l/s (cont.) 15 l/s (boost)	Exhaust 7 l/s (cont.) 10 l/s (boost)

Table 2: Standards that have been updated since the publishing of AIVC TN 57 in 2002

LISTING OF RELEVANT CODES AND STANDARDS

In the sections below we list the most important ventilation codes, standards and practices for dwellings.

AMERICAN NATIONAL STANDARDS

- ASHRAE 62.2-2004: Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings
- ASHRAE 62.1-2004: Ventilation for Acceptable Indoor Air Quality
- ASHRAE 90.2-2003: Energy Code for New Low Rise Residential Buildings
- Uniform Building Code (1994)
- Uniform Mechanical Code (2000) *This code only deals with combustion makeup air and evaporative cooling. It references the Uniform Building Code.*

MODEL CODES

- International Residential Code (2003)
- International Energy Conservation Code (2003)
- CABO MEC (1996) *This code references ASHRAE 62-1989. Many state codes reference CABO MEC.*

STATE AND FEDERAL REGULATIONS

- CA Title 24
- Other States
    - Washington State Ventilation and Indoor Air Quality Code (2000)

- Minnesota Rules Chapter 7672 : Energy Code (2000) *Alternative compliance by Minnesota Rules Chapter 7670: Energy Code (1994).*
  - Florida Building Code. *This code references ASHRAE 62-1989*
  - Vermont Residential Building Energy Standard (2003)
- Department of Housing and Urban Development: Directive Number 3280.103 *This standard applies only to manufactured homes.*

INTERNATIONAL CODES AND STANDARDS

- Sweden: BFS 1998:38: Hygiene, health and the environment
- UK: The Building Regulations 1991 Document F: F1 Means of Ventilation
- France: Arrêtê du 24.03.82 relatif à l'aération des logements (relating to the ventilation of residences)
- Denmark: DS 418:2002 Calculation of Heat Loss from Buildings
- Finland: D2 Finnish Code of Building Regulations, Indoor Atmosphere and Ventilation of Buildings, Regulations and Guidelines, 2003
- Australia: AS 1668.2 – 2002: The use of Ventilation and Air Conditioning in Buildings
- Canada: Residential Mechanical Ventilation Systems CAN/CSA–F326 or alternatively the Canadian National Building Code, Section 9 – Ventilation.

LABELS, GUIDELINES AND OTHER VOLUNTARY PRACTICES

- Energy Protection Agency Indoor Air Quality Standard (Proposed)
- American Lung Association Health House
- NFPA 54 National Fuel Gas Code. *This code addresses only back-drafting*.

COMPARISON OF KEY REQUIREMENTS

Each of these documents is different, but many of them address similar aspects of the problem and consider similar types of requirements. In this section we will compare these documents across some of these requirements:

COMPLIANCE DEMONSTRATION

Many of the standards are prescriptive in nature, meaning that they prescribe that a certain airflow be provided by a mechanical ventilation system. CA Title 24, and the Florida Building Code, and are set up in this way. Testing is not required to verify that the installed system actually provides the airflow required. Some standards are mainly prescriptive with some performance component such as The American Lung Association (ALA) Health House, where the only performance component relates to the airflow of the heating and/or cooling system. In other standards, such as ASHRAE Standard 62.2, the compliance mechanism is performance, with a prescriptive alternative. The airflow required by this standard refers to the delivered airflow, as verified by a test of the installed system. As an alternative to this performance approach, the airflow rating of the fan may be used if the ductwork is also in compliance with the standard. The Canadian standard is framed in the same way, with the National Building Code requiring that ventilation systems conform to CAN/CSA F326

"Residential Mechanical Ventilation Systems", which is performance in nature, or comply with the prescriptive requirements laid out in the National Building Code. The Washington State Ventilation and Indoor Air Quality Code also has dual paths for compliance: performance or prescriptive. The Minnesota State Code and the Energy Protection Agency Indoor Air Quality (EPA IAQ) Standard require that ventilation comply with the ASHRAE Standard 62.2.

WHOLE-HOUSE VENTILATION RATES

Whole house ventilation is needed to dilute pollutants (such as VOC's) originating from the building components and to remove pollutants (such as moisture and CO_2) that are created due to human activity. Whole house ventilation regulations are prescribed on a per square foot basis, a per person basis, or a combination of the two. CA Title 24 and the MN energy code are examples of codes that use a per square foot basis. ASHRAE Standard 62.2 and the ALA Health House use a combination of square footage and number of people. The Washington State Ventilation and Indoor Air Quality Code uses either a standard based on the number of people, or 0.35 air changes per hour (ACH), whichever is bigger. The Canadian Building Code and the Swedish Building Code specify ventilation rates that must be provided to each room. For the Canadian code the rate is 10 cfm (5 l/s) for each room except the master bedroom and basement which require 20 cfm (10 l/s). The Swedish code requires 8 cfm per square foot (0.35 l/s per square meter) of floor area in occupied rooms. In addition it requires 8.5 cfm (4 l/s) per bed space of supply capacity.

Whole house ventilation can be achieved with a continuously operating fan, or by fans operating intermittently at a higher flow rate. Most of the standards are written with the continuous fan operation requirement, and then have some allowance for how that requirement can be met with an intermittently operating fan. ASHRAE Standard 62.2, for example, requires a continuous ventilation rate of 1 cfm per 100 sq ft of building area plus 15 cfm per person. An intermittent fan can meet this requirement if it operates at least one hour out of every twelve, provides the same volume of outdoor air as the continuous scenario plus an additional volume of air to make up for a loss in ventilation effectiveness by the intermittent fan. The current version of CA Title 24 requires 0.047 cfm/square foot of continuous mechanical ventilation if the building has a low leakage design ($SLA < 3$), and it requires the house to be continuously pressurized to 5 Pa if the building is "unusually tight" ($SLA < 1.5$). There is no clause about how this standard can be fulfilled by an intermittently operating fan.

LOCAL EXHAUST RATES

Most of the codes require 100 cfm capacity for kitchen fans, and 50 cfm capacity for bathroom fans. These codes alternatively allow the kitchen and bathroom venting to be performed by a lower capacity, continuously operating fan. The value is usually 20 cfm continuous for bathrooms, and 20-30 cfm (or 5 ACH in the case of ASHRAE Standard 62.2) for kitchens.

INFILTRATION

Ventilation may be provided by infiltration in only two of the standards: ASHRAE Standard 62.2 where a blower door test of the building shell allows the builder to provide some of the ventilation air through infiltration, and CA Title 24 where the mechanical ventilation requirement only holds if the building has a Specific Leakage Area (SLA) less than 3.0.

OPERABLE WINDOWS

The ventilation standards generally do not have specific requirements about operable windows since windows in habitable spaces are addressed in the building codes. The International Residential Code (IRC), for instance, states that all habitable rooms must have a minimum openable area to the outdoors of not less than 4 percent of the floor area. Alternatively, ventilation may be provided by a ventilation system that provides 0.35 air changes per hour to the space, or a whole-house ventilation system that supplies 15 cfm per occupant as determined by the number of bedrooms plus one. Bathrooms are required to have at least 1.5 square feet of openable area to the outside, or a ventilation fan with 50 cfm ventilation capacity or 20 cfm of continuous ventilation. The IRC allows habitable spaces to have no window (operable or not) at all if the space is properly ventilated, and lighted with artificial light.

Two of the ventilation standards do have regulations regarding operable windows: ASHRAE Standard 62.2, which states that each habitable room, and each toilet or utility room must have an operable window and the Swedish standard where every habitable space must have an operable window. These standards do not account for new houses that are designed with an interior bath (meaning all of the bathroom walls are interior partition walls) where this requirement cannot be met.

AIR DISTRIBUTION AND DUCT LEAKAGE

In an ideal ventilation system, fresh air would be provided to every room in the house, and polluted air would be drawn from the rooms in which it is produced. It is especially important that fresh air be provided to the bedrooms since they are occupied longer than any other area of the house. When a mechanical ventilation system is required, virtually every code specifies that a certain volume of air be exhausted from the bathroom and kitchen, however, few codes have requirements for distributing fresh air throughout the dwelling. The exceptions to this are Canada, where fresh air must be distributed throughout the dwelling[1], and Sweden, where 8 cfm per square foot (0.35 l/s per square meter) of floor area must be provided continuously in occupied rooms. The rate may be reduced when the room is unoccupied. Some codes have the requirement of air inlets in every room (ASHRAE 62.2, Washington State, Minnesota), but there must be a negative pressure in the room in order to bring air in through the inlet. So whether the inlets actually provide distributed fresh air depends on equal depressurization of

[1] Residential Mechanical Ventilation Systems, CAN/CSA-F326, requires 10 cfm (5 l/s) for each room except the master bedroom and basement which require 20 cfm (10 l/s), however the National Building Code only specifies that the fresh air be distributed. Compliance in Canada can be met by satisfying either of these codes.

the building by the exhaust system. Similarly, exhaust only systems (without air inlets) rely on an even distribution of leaks throughout the house to deliver fresh air to every room. In a house with a leaky envelope (as we have in the United States) this condition is usually met, but in tight houses such as those in Canada and in Europe, this condition is often not met, hence the need for air distribution requirements.

Duct leakage can be a dominant source of ventilation in houses with tight building envelopes and leaky ductwork. Unfortunately, ventilation air obtained in this manner has a high energy penalty, and likely contains contaminants from the attic or basement where the ducts run. No standards were found that allowed duct leakage as a method to supply indoor ventilation air. However, some of the standards have limits for duct leakage as an IAQ source control issue. Return duct leaks can pull contaminated air into the house from interstitial spaces where the ducts are located, and supply leaks can depressurize the house, pulling unfiltered outside air in through the building envelope. ASHRAE Standard 62.2 limits HVAC return duct leakage to 6% of total fan flow in ducts that run inside garage spaces. The Swedish Building code states that ducts should be tight enough that there is no bypass leakage from supply to return. The EPA IAQ standard says that no ducts are allowed in the garage. Maximum allowable HVAC duct leakage is 3 cfm/100sq ft at 25 pascals. No building cavity ducts (meaning the building cavity is the duct) are allowed. Transfer grilles are required to each room if there is no return in that room except for bathrooms, kitchens and laundry rooms. The ALA Health house limits duct leakage to 0.03 cfm/ sq. ft. of conditioned floor area for ducts outside conditioned space, and to 0.07 cfm/ sq. ft. for ducts inside conditioned space. It also does not allow air handlers or HVAC ducts in the garage or in an unconditioned attic.

COMBUSTION EQUIPMENT

All combustion equipment including furnaces, boilers, hot water heaters, wood stoves, fireplaces, gas cooking appliances, etc. need a certain volume of air as an ingredient for combustion, and to carry the combustion products away from the house occupants. This volume of air is called "combustion air". Safety problems can arise when air does not follow the intended path through the appliance and out the flue. Downdrafting is when outdoor air enters the house by downward movement through the flue when no combustion is occurring. Backdrafting occurs when the combustion appliance is unable to reverse this flow when firing, causing spillage, or entry of combustion gasses into the indoor air. (Wray, 2001)

Some combustion appliances are sealed combustion, meaning that the air supply and exhaust for the appliance does not mix with the air in the house. In these types of appliances spillage cannot occur. Other appliances have a dedicated air inlet to supply combustion air, but are not completely sealed from the house air, and still others take the combustion air directly from the air in the house. Spillage may occur in these appliances if the pressure conditions cause backdrafting. Mechanical ventilation can cause depressurization of the zone around the combustion appliance increasing the likelihood of backdrafting, therefore ventilation standards sometimes include safeguards to prevent this from happening. Many of the newer furnaces are induced draft, meaning that they have a fan to aid the combustion gasses in exiting the flue. Backdrafting is less likely in this type of furnace.

The NFPA 54: National Fuel Gas Code regulates the installation of gas appliances. It states that "A venting system shall be designed and constructed so as to develop a positive flow adequate to remove flue or vent gases to the outside atmosphere." The standard addresses IAQ by requiring that combustion product exhausts must be located at least 6-12 (depending on size of combustion equipment) inches away from air intakes. Makeup air is stipulated by 50 ft^3 per 1000 Btu/hour (4.8 m^3/kW) minimum required room volume for a combustion appliance that uses room air for combustion in a building where infiltration is unknown. If the infiltration rate is known, another method can be used if the air exchange rate is less than 0.60 ach, and must be used if the exchange rate is less than 0.40 ach. This second method stipulates 21 ft^3 (or 15 ft^3 if the appliance has fan assisted draft) divided by the air change rate per 1000 Btu/hour. If the makeup-air volume requirement cannot be met then a permanent opening must be installed between the combustion appliance space and the outside.

Many codes require makeup air to reduce negative pressure caused by exhaust fans or testing for spillage. The ALA Health house simply states to "reduce the depressurization of the building." ASHRAE Standard 62.2 states that the net flow, at full capacity, of the largest two exhaust fans cannot be greater than 15 cfm/100 ft^2 of occupiable space. If this condition is not met, compensating airflow must be provided, maximum flow reduced, or atmospherically vented combustion appliances inside the conditioned space must be tested for spillage. CA title 24 requires that glass doors and an air inlet be provide for each fireplace and each wood, pellet or gas stove. The Minnesota code limits "excessive depressurization" except when all appliances are sealed combustion and 3 biggest exhaust fans have a combined flow less than 425 cfm. There are 4 prescriptive paths or a performance test to show compliance. The Canadian code requires make up air for exhaust flow greater than 150 cfm if there is a chimney vented oil or gas appliance in the house. The EPA IAQ standard goes even farther to require a direct vent or power vented water heater. It also requires a direct vent furnace if the house is located in a climate with more than 4000 Heating Degree Days (HDD).

FILTRATION AND AIR CLEANING

Since the main purpose of ventilation is to provide clean air for people to breathe, filtration can be an important component of a ventilation system. ASHRAE Standard 62.2 requires a heating or cooling system to have at least a MERV 6 filter. The EPA IAQ standard requires MERV 8 filters, and no filter bypass is allowed. A neoprene gasket is required on one side of filter rack to bring the filter into contact with the rack. The ALA Health House requires at least a MERV 10 filter in the heating or cooling system. In Sweden, they require that the return air is filtered, and that there is no return air from bathrooms, kitchens, or other apartments. (The requirement of no return air from bathrooms and kitchens are standard in building codes, and are contained in the IRC.) It is also required that the ducts be clean-able.

OTHER SOURCE CONTROL MEASURES

Clothes dryers are required to be vented to the outside in the IRC, in the Washington State code, and in the ALA Health House. Additionally, the Washington State code requires a pool or spa area to be vented. The EPA IAQ standard requires 100 cfm of continuous exhaust from the garage. ASHRAE Standard 62.2 limits HVAC return duct leakage to 6% of total fan flow in ducts that run inside garage spaces, and it requires that the walls and ceiling between the garage and the house be sealed before insulation is installed, and that doors be gasketed between the garage and living space.

OTHER OCCUPANTS ISSUES

The major occupant issue that is addressed in the ventilation standards is control of the system. A French survey of 10,000 households (Lemaire et al. 2000) found that occupants are more satisfied with ventilation systems that offer occupant control. ASHRAE Standard 62.2, The Minnesota Energy Code and the Canadian Building code all require that the occupant be given override (if not total) control of the ventilation system.

There was only one code that addressed an occupant comfort issue: Swedish code requires the velocity of air supplied to an occupied zone to be less than or equal to 0.15 m/s in heating mode and less than or equal to 0.25 m/s in cooling mode.

NOISE AND OTHER EQUIPMENT ISSUES

Several codes addressed the issue of fan noise. ASHRAE Standard 62.2 gives a maximum noise rating of 1 sone for continuous fans, and 3 sones for intermittent fans. The philosophy is that quiet, unobtrusive fans will get left on, while noisy ones will be turned off by the occupant. Fans with flow greater than 400 cfm are exempt from the noise requirements. This exemption allows noisy (and high flow) kitchen range hood fans to be installed. The Washington ventilation code limits fan noise for ventilation systems where the fan is within 4 feet of the grille at 1.5 sones. The ALA Health House also has the limit of 1.5 sones for fan noise. The Minnesota code has a maximum of 1 sone for surface mounted fans.

The EPA IAQ guideline requires a carbon monoxide alarm outside each sleeping area in homes with combustion appliances.

OUTDOOR AIR

Outdoor air is always a part of a ventilation system, whether it enters the house through dedicated inlets, supply fans, or through unintentional openings in the building shell. The standards that require dedicated air inlets are ASHRAE 62.2, Washington State, Minnesota, Canada and Sweden. Inlets must be 10' from known contamination such as exhausts vents, stack pipes and vehicle exhaust in ASHRAE 62.2, EPA IAQ, ALA Health House, and the IRC.

ENERGY AND DEMAND IMPACTS

Some of the ventilation standards have maximum energy requirements, and others leave the energy regulations to standards dedicated to energy use in buildings. The ventilation standards that have specific requirements for energy usage are the ALA Health House that specifies a maximum of 0.5 watt per cfm for exhaust fans, and 1 watt per cfm for HRV's. Minnesota requires a maximum of 0.8 W per cfm for residential (constant air volume) systems.

California Title 24 is an energy standard so it dictates that when mechanical ventilation is installed, the power of the fans is and the extra infiltration load is added to the building energy usage for performance compliance.

CLIMATIC OR REGIONAL DIFFERENCES

The climates that are significantly different such that they receive special attention from a ventilation perspective are cold climates and warm-humid climates. Cold climates have the issue that ventilation air entering the building shell in the winter will be uncomfortable for the occupants unless it is tempered before it reaches them. Canada, Minnesota, and the EPA IAQ guideline have requirements for tempering incoming air. ASHRAE 62.2 has the requirement that mechanical supply systems exceeding 7.5 cfm/100 ft^2 shall not be used in severe cold climates, which include most of Canada, and the upper half of most US states that boarder Canada.

In warm-humid climates the concern is humidity which can damage building components, if forced into walls. ASHRAE 62.2 has the requirement that mechanical exhaust systems exceeding 7.5 cfm/100 ft^2 shall not be used in hot-humid climates, which include areas that boarder the Gulf of Mexico. The ALA Health house states that vinyl wallpaper may not be used in hot-humid climates due to the concern about mold and mildew growth when water condenses on the back of the vinyl. The EPA IAQ guideline contains three options for controlling humidity inside dwellings in warm-humid climates: controls that ensure humid outdoor air is not supplied to the interior, whole house dehumidification, or enthalpy exchange equipment.

OCCUPANT ACCEPTABILITY, CONTROL AND BEHAVIOR

The purpose of the codes, standards and guidelines we review are generally to provide a minimum amount of health, safety and comfort for the occupants. A part of that is subjective because it involves the perceived acceptability of the indoor environment to those occupants. This section reviews the literature related to ventilation and IAQ-related behaviors and attitudes of residential occupants.

Determining occupant behavior can sometimes be done through objective scientific measurements, but determining occupant acceptability usually requires the use of surveys, questionnaires, etc.

OCCUPANT SURVEYS

The Energy Commission, through the California Air Resources Board, is currently conducting an occupant survey in new California homes. The results of this survey are not yet available, but that survey is based on other surveys of a similar nature.

The surveys that have been done can be broadly divided into those having to do with occupant perception of the ventilation and IAQ of their residence, and the occupant behavior with respect to the ventilation of the residence. Occupant behavior has been extensively studied, by means of interviews and questionnaires and also by more quantitative means such as activity diaries, direct observation, and sensors to monitor for specific behavior. The interviews and questionnaires in the behavior studies sometimes include questions related to perception of the ventilation and IAQ since the perception influences the behavior. All the studies having to do with people's perception of the ventilation in their homes also had a behavior component.

People generally believe that ventilation systems are beneficial. In Canada 60 homes were surveyed to determine the performance and people's perception of heat recovery ventilators (Hill, 1998). Most of the occupants thought the heat recovery ventilator was beneficial and understood the general purpose of the equipment. In the state of Washington 235 households were surveyed (Devine, 1999) to reveal attitudes about ventilations systems such as: "people are concerned about indoor air quality and believe fresh air is important for health." The reasons given for why occupants ventilate (Dubrul, 1988) are: to get fresh air into bedrooms and living rooms, to remove odor, to remove stale air and condensation, to 'air' the dwelling during residential activities, and to remove tobacco smoke. The reasons given for not ventilating are: to prevent draughts, to maintain a preferred temperature, to protect against cold and rain, to maintain privacy and safety, and to reduce external noise and pollution.

The understanding that people have of their ventilation systems is generally fairly low. In a Canadian study, the occupants' knowledge of how to operate and maintain the system was found to be very low (Hill, 1998). In the Washington study (Devine, 1999) one quarter of the people surveyed were not aware that their house had a mechanical ventilation system, perhaps because many of the mechanical ventilation systems were integrated with the forced air heating system. In another Canadian study of exhaust only ventilation systems, almost 10% of the people surveyed had no idea how they operated their ventilation system. Another 70% of those surveyed operated the system incorrectly (Fugler, 2004). A study of 43 Minnesota homes found that people need more information and guidance about the operation and maintenance of their ventilation systems (Sheltersource, 2002).

When considering satisfaction with system, 20% of respondents in a Washington study "considered noise, drafts and/or energy waste a problem with their system" (Devine, 1999.) In a study of 10,000 French households (Lemaire and Trotignon et al. 2000), only 9.2% of people with balanced ventilation systems found noise to be a problem, and 6.7% of people with single flow ventilation systems (exhaust or supply only) found noise a problem. This study also found that overall, 81% of the survey respondents were satisfied with their ventilation systems. Satisfaction increased with the age of the head of the household, household income, number of rooms in the dwelling, and surface area of dwelling. Higher satisfaction is also correlated with people who clean their vents, and with systems that allow occupant control. 22% of the survey respondents reported problems with their ventilation systems such as condensation from humidity, dampness on walls, persistent odors, ventilation noise, cold draughts, or dust/stains due to ventilation. Fewer problems were reported in owner occupied houses (about half the rate of problems reported in rental properties), and in dwellings where the ventilation system could be switched off. The number of problems reported was found to be inversely related to length of time since move in.

Occupant behavior has been widely studied as it relates to ventilation. AIVC Technical Note 53, Occupant Impact on Ventilation (Liddament 2001), offers a comprehensive review on occupant interaction with ventilation systems in residential and non-residential buildings.

Liddament examines:

- basic statistics on housing occupation and ventilation systems
- basic ventilation and indoor climate needs
- observed occupancy interaction with ventilation systems and controls
- occupant impact on the total ventilation/ air exchange rate
- occupant impact on energy consumption
- and lessons learnt and procedures for optimizing occupant interaction

His key findings were:

- Dwellings are often occupied 24 hours a day
- Ventilation is necessary to provide air for metabolism, dilute and remove pollutants, and provide combustion air for fossil fuel heating appliances.
- Pollutants that need to be vented include metabolic CO_2 and odor, moisture from bathing, cooking and clothes washing, combustion products from unvented gas cooking appliances, and tobacco products.
- Occupant behavior has a significant effect on ventilation, particularly in relation to window opening.
- Finally, he provides a set of occupant guidelines to provide good indoor air quality and comfort without excessive energy usage.

Windows have historically been a main source of ventilation in dwellings. 71% of households in California report door or window opening for longer than 1-2 minutes a day according to Phillips et al. (1990) and Wiley (1991). Less window opening was found during the winter (57%), and less was found in the non-costal regions (32%). The conclusion of this survey was that adequate supply of fresh air was not supplied to a substantial portion of homes, particularly during the colder seasons of the year, and in colder climates. It is important to note that when the temperature is cold outside, infiltrative ventilation is increased. This contributes to the decreased need for window opening when it is cold. (Kelly et al. 1993) In a New York state study of 141 households, 30% were found to open windows in the winter, and 78% opened them in the summer. The National Human Activity Pattern Survey 1992-94 provides data on window opening behavior in the United States. Tsang and Klepeis (1996) tabulate the data by many variables including gender, age, race, census region, season, asthma, angina and bronchitis/emphysema. In spring and summer 54% of respondents reported leaving windows open, as opposed to approximately 30% in fall and winter. IEA Annex 8 (Dubrul, 1988) summarized findings from numerous studies on window opening reported in Table 3.

Factor	Observed Trend
Occupancy density	Window opening increases with number of occupants present.
Occupant's age	The amount of window opening and ventilation reduces with the increasing age of the occupants.
Outdoor air temperature	Window opening decreases with decreasing outdoor air temperature, although a significant number are still opened at temperatures as low as -5 deg. C.
Sunshine	More windows tend to be open on the sunny side of buildings than on the opposite side.
Wind speed	Window opening decreases with increasing wind speed.
Day time opening	Windows are usually closed when the building is unoccupied during the day.
Night time opening	A significant number of windows are kept open in bedrooms at night, even in cold weather.
Weekend opening	Windows are open more frequently on weekends than during the rest of the week.
Thermostat setting	The higher a household sets its heating thermostat, the less often windows are opened.
Residential activities	Reasons given for window opening include vacuum cleaning, and airing of bed-clothes, cooking, odour and moisture problems.
Smoking	Windows are opened twice as frequently in smoking households than in non-smoking households.
Energy use	There is only a weak correlation between energy saving intentions and window opening. More window opening tends to take place in buildings in which heating energy is not separately metered to occupants.

Table 3: Factors Relating to Window Opening Behavior, IEA Annex 8, Dubrul (1988)

Another question of interest, which has been widely studied, is **"Do people use their ventilation systems?"** Buildings may have no intended ventilation system, or they may have one of three types of systems: passive systems, mechanical systems with unidirectional flow, or bidirectional mechanical systems. The French study (Lemaire and Trotignon, 2000) reported that 46% of dwellings have passive ventilation systems, meaning intentional air inlets and/or outlets but no fan. In the UK, a study (Oseland 1995) showed that 7-8% of passive stacks were blocked up compared to 13% of all vents (mechanical and natural) reported to be blocked in the French study. The fraction of blocked vents drops to 6-7% in dwellings built after 1982. This shows that most of the passive systems that are installed are in daily use.

Unidirectional mechanical systems consist of exhaust only systems or supply only systems. Exhaust only systems are much more common, and more appropriate in cold climates where cold dry air brought in through leaks in the building shell will not damage the building components, and will be tempered before it gets to the living space. Supply only systems are rarely used, but are appropriate when it is advantageous for the building shell to be pressurized, as in a moist climate where outdoor air must be dehumidified before entering the house, for the comfort of the occupant as well as for the health of the building. In Canada, Fugler (2004) found exhaust only ventilation (EOV) systems as the most common, installed in 76% of the houses. 30% of the EOV system owners never used the system and most of the other owners used the system only for bathroom ventilation, although a significant number of homeowners had window condensation or stuffiness in the house. In California, Phillips et al. (1990) and Wiley (1991) found that only a 3% of the statewide population used exhaust fans. Slightly higher percentages were found in the winter (5%) and in the San Francisco region (7%). In France, 17% of dwellings were found to have extract ventilation (Lemaire and Trotignon, 2000). Almost one quarter of those systems could not be turned off by the occupant, about half of the systems could be turned off, but were rarely or never turned off by the occupant, and another quarter of the systems were often or fairly often turned off.

Bidirectional flow or balanced mechanical ventilation systems are becoming more popular in France. Lemaire and Trotignon (2000) report that 9% of dwellings built since 1989 have this type of system as opposed to 1.5% in buildings built before 1948. Balanced systems are most common in cold countries such as Canada and Scandinavia, where heat recovery ventilators are used to temper the air coming into the house, and to recover the heat from the air leaving. In Canada, Hill (1998) reports that 17% of the houses surveyed had blocked their air intakes, much higher than the number of intakes blocked in the UK and in France, but this may have to do with the colder climate. More than half, 60%, of the houses surveyed had substandard ventilation due to poorly maintained systems. As in the EOV study in Canada, 55% of the occupants who's systems required running the furnace fan at the same time to distribute the air, were not aware of this.

OTHER OCCUPANT STUDIES

The current literature provides clear indications of links between human health and ventilation and of the need for addressing these links through guidelines and standards. In research from office buildings as reviewed by Seppanen et al. (1999, 2002) relatively strong and consistent associations have been found between ventilation and health. In their review of 105 papers dealing with ventilation and health in non-industrial indoor environments, Wargocki et al. (2002) report that ventilation requirements in many existing guidelines and standards may be too low to protect occupants of offices, schools, and homes from health problems and may not be optimal for human productivity. Wargocki et al. (2002) observe that, although higher ventilation rates can increase energy costs in relation to building operation, these can be reduced by several measures such as prudent and systematic maintenance of heating/ventilation/air-conditioning (HVAC) systems and by reducing superfluous pollution sources indoors

KEY ISSUES IN LITERATURE

In our review of codes and standards above, several key issues were identified. In this section we review the literature on those key issues.

DEFINITION OF CONTAMINANT SOURECES

Airborne indoor contaminants have two types of sources: indoor sources and outdoor sources. Indoor sources should be removed from the dwelling or the air contaminated by the source should be vented to outdoors as close to the source as possible, whereas outdoor sources should be removed from the air as much as possible before the air is brought inside the house. Indoor sources include mold and mites, carbon dioxide, indoor generated particulates, tobacco smoke, formaldehyde and other volatile organic compounds (VOC's), and combustion products. The chapter on the affect of ventilation on health in the Ventilation: A State of the Art Review (Santamouris, to be published) describes sources of air pollutants that affect human health, and is summarized with a few additions from other sources below:

Mold and mites both produce substances that are respiratory irritants and allergens. Both populations increase with increasing building humidity, so source venting of humidity (showers, and cooking) is important to reducing these allergens in the building. In climates and seasons when outdoor humidity is significantly higher than indoor humidity simple ventilation is not sufficient to control indoor humidity. Air conditioning systems are generally used to continuously dehumidify indoor air.

Water vapor and carbon dioxide are both products of metabolism, and are released during respiration. It is impractical to vent these pollutants at the source, so whole house ventilation is needed. This explains why many standards are written in terms of a minimum ventilation rate per person.

Indoor particulates are commonly known as dust. Particles with a diameter in the 0.1 μm to 0.5 μm range stay airborne the longest with a deposition loss-rate coefficient on the order of 0.1 h^{-1}. (Thatcher et al., 2002) Particle removal at this rate is could also be achieved by ventilation with an air change rate of 0.1 air changes per hour (assuming particle-free replacement air). Interestingly, the same size particles have the lowest deposition rate (about 20%) in the head airways and lungs. Deposition of particles in the lungs increases from 20% to 100% as particle size decreases from 0.1 μm to 0.001 μm. (Hinds, 1999) Dust particles on surfaces can become airborne by air currents and activities in the room. Effective control of dust contaminants in the air requires a combination of removing dust from surfaces, ventilating air that has dust contamination, and filtering incoming air to remove dust from the exterior.

Tobacco smoke is most effectively controlled by removing the smoker from the house. The ventilation rate required to dilute tobacco smoke to a safe level is 555 l/s per a smoked cigarette in an hour (Santamouris, to be published). This rate is unreasonable to achieve in practice, and this is why the ventilation standards implicitly or explicitly do not address dwellings with smokers.

In the last ten years, research has shown that almost all materials (varnishes, paints, floor coverings, furniture, partitions, sealants, etc...) emit hazardous chemical pollutants. Rates of emission have reduced due to recent labeling systems, but ventilation is still necessary, particularly in new or recently remodeled dwellings to dilute the off-gassed chemicals.

Combustion products that are harmful to health are nitrous oxides (NO_x) and carbon monoxide (CO.) Carbon monoxide is formed in the case of incomplete combustion when not enough oxygen is supplied. Ideally, combustion products would be exhausted directly without mixing with inside air. This is how most water heaters and furnaces are designed, and generally function. Range hoods are necessary to exhaust combustion products of gas cook tops, although the capture efficiency of these hoods is generally about 60% (Santamouris, to be published).

Outdoor air brought into the building should contain as few contaminants as possible. This may mean filtering the air, or placing the inlet vents where they will not bring in contaminated air. Outdoor sources are pollen, combustion products, (nitrogen oxides, carbon monoxide), and ozone. Pollen can be easily filtered out of incoming air because the particle size is large. The most likely outdoor source of combustion products are gasoline powered cars and trucks. Combustion products are controlled by placing inlet vents away from roads, driveways, and parking lots. Ozone generally has a higher concentration outdoors than indoors. It may react with other compounds indoors resulting in harmful chemicals. Ozone can also be produced by electrostatic filters.

WHOLE-HOUSE VENTILATION RATES

Ventilation rates were first stipulated by a physician named Billings in the 1890's at a minimum whole house rate of 30 cfm per person (Roberson, 2004). The concern at this time was about airborne spread of diseases such as tuberculosis. This rate was adopted by the American Society of Heating and Ventilation Engineers (ASHVE) in 1914, although in this early version it was not clear what percentage of the ventilation air should come from outdoors. Subsequent research by Yaglou and others found that only 15 cfm per occupant of outdoor air was necessary (Janssen, 1994) to maintain acceptable air quality as perceived by visitors to occupied laboratory spaces. During the 1970's the American Society of Heating, Refrigeration, and Air-Conditioning Engineers, ASHVE changed names with the advent of refrigeration technology, adopted ASHRAE standard 62-1975 which reduced the recommended ventilation rate to 5 cfm per person. In the 1980's the accepted standard again became 15 cfm per person after experimental work by Ole Fanger showed that this level was necessary in order to control odors indoors. ASHRAE Standard 62-1989 specified a minimum ventilation rate of 0.35 ach or 15 cfm per person, whichever was greater.

The whole house ventilation may be provided by mechanical ventilation (local or distributed) or natural ventilation, i.e. unintentional openings (infiltration) or intentional openings (windows, passive vents). Each of these options are examined in more detail in the following paragraphs.

LOCAL EXHAUST RATES

The first local exhaust was a hole in the roof to let smoke out of the building. Fans were invented by Leonardo DiVinci circa 1500 (Kühnl-Kinel, 2000), however exhaust fans didn't become widely used until the 20th century (Kaplan, 1986). Exhaust rate regulations probably entered the standards as rules of thumb that were introduced into the building codes. Exhaust rates were first regulated by ASHRAE in Standard 62-2001.

AIR DISTRIBUTION AND DUCT LEAKAGE

Ventilation efficiency is a concept that has been discussed in the literature as the ratio of the integrals of the concentrations of tracer gas in the different zones (Maldonado, 1983). One zone is generally taken as the reference zone, and each of the other zones are compared to that zone. It has been found that when an air handler for a whole house air distribution system is running, the zones are well mixed, but when the air handler turns off the zones start to diverge. The rate of divergence depends on temperature and wind conditions as well as the physical characteristics of the building.

Ventilation strategies have been developed which use an exhaust fan at one location to extract air, and require an air distribution system to be turned on to evenly distribute the fresh air brought in through the building shell (Fugler, 2004). Although this strategy offers evenly distributed fresh air at a low initial cost to the builder, it has several drawbacks such as the excessive fan energy required to mix the air (most HVAC fans draw 500W), the likelihood that the HVAC fan will not be turned on as designed unless a control system exists to turn it on, and the energy penalty associated with duct leaks, which scales with the duration of HVAC fan operation.

Duct leakage can be a dominant source of ventilation in houses with tight building envelopes and leaky ductwork. When ductwork is located in an unconditioned space, air infiltration rates typically double when the air handler fan is turned on (Modera, 1989.) Unfortunately, ventilation air obtained in this manner has a high energy penalty. The energy penalty is greatly dependent on where the ducts are located (attic or crawlspace) and the climate that the house is located in, but a simplified hourly model predicts annual energy loss to be 3,500 kWh for attic ducts in Sacramento, CA and up to 10,000 kWh for the same ducts configuration in West Palm Beach, Florida (Modera, 1989.) Ventilation air obtained in this way will contain contaminants (particulate matter, VOC, radon, etc.) from the attic or crawlspace where the ducts are located.

INFILTRATION

Infiltration has historically been the main source of ventilation in residential buildings, and in some buildings it still is. There has been an ongoing debate within the research community over which type of ventilation is better. Liddament (2001) compares the two strategies in Table 4.

While it is a choice in building a new house, to make it tight or conventionally leaky, existing construction does not have this option. Very few existing houses are below the minimum recommended ventilation level, and in most houses it is difficult to seal them enough to bring them below this level.

The major problem with using a leaky building envelope to provide ventilation is that the direction of airflow is uncontrolled. Ideally, polluted air is exhausted from the house close to the source of pollution, and it enters the house evenly in all other areas. This airflow pattern is unachievable with a leaky envelope, even when exhaust fans are installed to aid in air extraction from rooms with source pollutants (Roberson, 2004). In addition, infiltration is wind and temperature driven so the magnitude of air exchange will change seasonally. This will lead to over-ventilation or under-ventilation during certain seasons. However, if the house has the right permeability to provide good IAQ in winter, then additional ventilation can be provided by window opening in mild weather (Howard-Reed et al., 2002).

'Tight' Building	Possible considerations and/or points of attention	'Less Tight' Building
Mechanical extract and balanced ventilation systems can be dimensioned to perform reliable with minimum interference from prevailing weather conditions	**Ventilation Strategy**	Basic ventilation may be dominated by air infiltration
		Passive stacks and/or local extract fans, combined with user controllable trickle ventilators may be used to 'top up' ventilation.
Heat recovery systems can be effective.	**Advantages**	A measure of 'safe background' ventilation is provided by airflow through the natural porosity of the building
Uncontrollable draughts energy loss avoided.		
Severe risk of inadequate ventilation if occupant seals air supply return terminals or switches system off.	**Disadvantages**	Mechanical systems and heat recovery will perform unreliably because of interference from fabric leakage.
Fan energy needed either to overcome high under-pressure (e.g. 10-20 Pa room + 200Pa duct) with an extract system or to operate two fans (balanced system – e.g. 200Pa for each duct network)		Risk of excessive air change especially when driving forces are high (e.g. high temperature difference (winter) and high wind speeds.)
Method of purging needed, either by substantial ventilation boost or by openable windows	**Control Strategy** (People are not capable of correctly managing ventilation devices)	User can control trickle ventilators, fans and openable windows as needed
Adjustable ventilation grilles should not close completely since these represent the only significant source of air supply.		Adjustable openings needed otherwise, if fixed, the occupant might permanently seal them. Air infiltration provides a measure of safety.
Cooler climates where high infiltration losses lead to discomfort and energy loss and where the benefit of heat recovery can be maximized.	**Applications**	Milder climates where cold draughts are less of a problem and heat recovery is economically difficult to justify.
Outcome: By good design and with a thorough understanding of the interaction of air-tightness and climate with ventilation both approaches could lead to good air quality and energy efficient solutions.		

Table 4: Comparison of Tight Envelope versus Average Envelope with respect to Ventilation, Liddament (2001)

WINDOWS AND PASSIVE VENTS

Natural ventilation is the subject of one chapter of Ventilation: A State of the Art Review (Santamouris, to be published). The physics of airflow in urban areas is discussed in detail, and examines the issues of noise and pollution as barriers to using natural ventilation in urban areas. Noise is attenuated by balconies and with increasing height above street level. After a certain threshold level, the level of pollution in an urban area is inversely related to the economic development of the area.

The main problem of using windows for ventilation is that occupants and weather conditions control the ventilation rate, and these are less predictable than a motorized fan. Occupants open windows generally to dilute odor in the dwelling, but research has shown that odor is not necessarily a good predictor of the need for ventilation since contaminants such as radon and carbon monoxide are odorless (Liddament, 1996). Window opening behavior varies among individuals, and with weather conditions so there is no way of ensuring that adequate ventilation is provided by window opening. When windows are open, however, they can ventilate the house as much as or more than infiltration caused by weather effects (Howard-Reed et al., 2002). Window opening in mild weather confounds the theory that natural ventilation is lower in mild weather.

Passive vents may be a solution for natural ventilation that is not controlled by the occupant. It has been shown that constant area passive vents either do not provide adequate ventilation in mild weather (spring and fall) or they over-ventilate in winter (Wilson and Walker, 1992). Some air inlets automatically adjust the size of the opening such that it is larger when the outdoor air is warm and smaller when outdoor air is cold. Other air inlets can be centrally controlled to open or closed in coordinated way with the other ventilation system components (Dorer, 2004). The Residential Hybrid Ventilation project (Dorer, 2004) proposes four hybrid (combined passive and active) ventilation systems, designed for severe cold, cold, moderate and mild climates. All of the designs propose outdoor air supplied to the living spaces and extracted from the bathrooms and kitchen, and all propose a central control system linked to occupancy and humidity sensors in order to provide just the ventilation that is needed and no more.

COMBUSTION EQUIPMENT

Substantial work has been done in the United States and Canada to understand backdrafting and spillage, and the relation of these events to the operation of ventilation equipment, but in spite of these efforts we still cannot reliably predict when backdrafting and spillage will occur, and if the quantity of contaminants released into the house will be harmful to the occupants (Nagda et al, 1995)

FILTRATION AND AIR CLEANING

Filtration is generally thought of as the solution to removing particulate pollution in indoor air. In "A Guide to Energy Efficient Ventilation" Liddament (1996) includes a chapter entitled "Air Cleaning by Filtration" where he describes types of particulates, and types of filters for addressing various particle size and chemical composition. He discusses the European rating system for filtration efficiency ranging from EU1 with a dust spot efficiency of 10% to 20% to EU14 that has a dust spot efficiency of greater than 90%. The equivalent rating system in the United States is the MERV rating, defined in ASHRAE Standard 52.2-1999. This scale ranges from MERV 1 with average particle size efficiency (E_3) of less than 20% to MERV 16 with E_3 greater than 95%.

Liddament refers to filtration systems for all types of buildings, but he gives the following requirements for an effective filtration system, which are applicable to residential buildings:

- It must not be used as a substitute for ventilation air needed for occupants, or for combustion appliances.
- It must be designed to remove the particular problem pollutant (e.g. Tobacco smoke, industrial emissions etc.).
- Recirculatory systems must have sufficient flow rate, e.g. two to three times greater than the ventilation rate to make a sensible reduction of pollutant concentration. This rules out any useful performance form desk top “air fresheners”.
- It must be well sited to intercept the polluted air.
- It must be inexpensive and easy to maintain, and preferably give a clear indication of when filter replacement of cleaning is needed.
- It should be free of operational noise.
- It should be energy efficient.
- It should not cause excessive draughts.
- It should be designed to ensure that filtered air is not directly short circuited back into the air intake.
- It should conform to relevant requirements and performance standards.
- Filters should be well sealed into the assembly frame to ensure that particles do not bypass the filter.
- Ductwork should have provision for cleaning. Contamination of a building with dust and bacteriological products can occur if ductwork and filters are not regularly cleaned.
- Air distribution across a filter should be uniform, otherwise local clogging and premature filter failure will occur.

A recent study by the Canada Mortgage and Housing Corporation (CMHC), Fugler (2000), shows that filtration may not be as effective as we think in removing pollutants from the air. The filter’s effectiveness is maximized when the filtration fan runs all the time, however, this is rarely the case in residences where the filter is generally part of the central heating and cooling system. In addition, airborne pollutants are increased by human activity such as getting out of bed, walking across the carpet, and making toast. People walk around in a “personal cloud” of pollutants, and furnace filters do little to reduce this cloud. Fugler recommends reducing particulates by:

- Removing footwear on entry;
- Keeping major dust generators (smoking, pets, and so forth) out of the house;
- Keeping dust collecting surfaces (open shelves, carpets, upholstered furniture) to a minimum;
- Vacuuming diligently and frequently with an efficient vacuum cleaner (a HEPA vacuum or a central vacuum work best at not re-blowing household dust back into the home.)
- Reducing the entry of particulate-laden outdoor air by closing windows , improving house air-tightness, and installing an intake filter on the air supply; and
- Using as effective a furnace filter as the homeowner's budget permits.

NOISE ISSUES

The Home Ventilating Institute (HVI) publishes noise and energy use data for fans of their members (HVI, 2005). The results of these tests are reported on sones which is a psychophysical measurement of loudness, as opposed to a dB which is a physical measurement of sound power. Historically sound measurements were reported in dB (CAN/CSA, 1990). A study commissioned by the Canadian Mortgage and Housing Company and 10 other clients from the Instiute for Research in Construction (Quirt, 1991) determined that the results of laboratory tests (in dB) used to determine ratings for fans are indeed representative of expected results for the installed unit. No criteria for "acceptable fan noise limits" were found in the literature.

ENERGY IMPACTS

Energy is of concern in ventilation in two ways: energy is required to operate the ventilation system, and energy is required to condition the air that is exchanged by the ventilation system. The first way to reduce energy costs for ventilation is to not over-ventilate by natural or mechanical means. Most of the existing housing stock is over-ventilated by infiltration (Sherman and Dickerhoff, 1994). An average infiltration rate of 29.7 air changes per hour at 50 Pascals was reported which corresponds to a natural air change rate of about 1.5[2]. Most new houses are not over-ventilated by infiltration (Sherman and Matson, 2002). The average infiltration rate for new houses was found to be 5 air changes per hour at 50 pascals, corresponding to a natural air change rate of 0.25. Additional energy may be saved by recovering the heat in the exiting air stream. Research has shown that heat recovery in the building envelope from infiltration air is minimal in insulated walls (Walker and Sherman, 2003). Therefore, minimizing infiltration and supplying ventilation air with a ducted system can save energy by using a heat exchanger to condition the incoming air by removing heat

---

[2] The natural air change rate is dependent on climate, represented by the variable N, which ranges between 16 and 24 for climates in the United States. The value of N=20 has been used for these conversions.

from the outgoing air stream. Heat recovery ventilators are generally cost effective (and frequently used) in severe cold climates.

The energy required to operate a ventilation system can be minimized by making use of passive ventilation whenever possible and by decreasing fan energy by minimizing pressure drop in ducts by using larger diameter, shorter length ducts with a smooth interior surface. The Residential Hybrid Ventilation project (previously mentioned) (Dorer, 2004) gives examples of proposed hybrid (combined passive and active) ventilation systems that minimize the electrical energy needed to operate the ventilation system, as well as minimizing the ventilation rate by using occupancy and humidity sensors in order to provide just the ventilation that is needed for good indoor air quality.

In “A Guide to Energy Efficient Ventilation”, (Liddament, 1996) the author devotes a chapter to the energy impact of ventilation and infiltration. He estimates the energy impact of ventilation (intentional and unintentional) for 11 European countries, the United States, and Canada. The delivered air change energy ranges from 40 GJ for the United States to 8 GJ in Sweden, with the majority of the countries using about 20 GJ.

Wray et al. (2000) examined the energy cost of four ventilation strategies: infiltration, central exhaust, heat recovery ventilator, and forced air-cycler system. They found that the lowest cost system, central exhaust only, would add a marginal cost of $0.50 a day for a typical new house in the United States. This can be compared to the typical cost of $2.00 a day to condition the infiltration air of a typical existing house. Designed passive ventilation systems and hybrid ventilation systems were not investigated.

DISCUSSION OF LITERATURE GAPS

The most significant area where research is needed to fill gaps in our knowledge is in ventilation impact on electricity demand. This type of study would require detailed information about the exact times that the ventilation system is in use and the number of systems operating, thus making it difficult to carry out. The study would have to be linked to a specific ventilation standard or ventilation strategy and a specific geographic area.

KEY FINDINGS

Ventilation is increasingly becoming recognized as an important component of a healthy dwelling. The states of Washington, Minnesota and Vermont now require mechanical ventilation in dwellings, and the state of Maine is considering such a regulation. New guidelines from the American Lung association and Energy Star include mechanical ventilation requirements. Canada requires mechanical ventilation, and many European countries have a ventilation requirement that may be satisfied without a mechanical system.

All the ventilation standards tend to cluster around common values for recommended ventilation rates. Whole house ventilation rates are generally 0.35 ach, although some standards do stipulate values as high as 1.0 ach. Kitchens are often required to be vented at a rate of 50 l/s, intermittently or at some lower continuous value. The continuous ventilation requirement is as high as 30 l/s (in Canada and the UK) or as low as 6 l/s (in France.) Regulations for bathrooms are similarly prescribed with a higher intermittent rate, often 25 l/s, and a lower continuous rate, with a range of 15 l/s to 4 l/s.

Surveys of occupants showed that people generally think that ventilation is important, but that their understanding of the ventilation systems in their houses is low. The majority of people are satisfied with their ventilation systems. As to whether people actually use their ventilation systems, studies showed that 90% of passive ventilation systems were in use, as opposed to mechanical systems which are used much less often. The use of such systems varied widely between studies from 3% (bath fans) in a California study to 70% (exhaust only ventilation system) in a Canadian study to 82% (HRV system) in another Canadian study.

American Lung Association. 2004. “American Lung Association Health House Builder Guidelines.” American Lung Association, Saint Paul, MN.

ASHRAE. 1999. “ANSI/ASHRAE Standard 52.2-1999, Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size”. Atlanta, GA; American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

ASHRAE. 1989. “ANSI/ASHRAE Standard 62-1989 - Ventilation for Acceptable Indoor Air Quality”. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 2004. “ASHRAE Standard 62.1-2004 - Ventilation and Acceptable Indoor Air Quality”. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 2004. “ASHRAE Standard 62.2-2004 - Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings”. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 2001. “ANSI/ASHRAE Standard 90.2-2001, Energy Efficient Design of Low-Rise Residential Buildings”. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 1994. “ANSI/ASHRAE Standard 119-1988 (RA 94), Air Leakage Performance for Detached Single-Family Residential Buildings”. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 1993. “ANSI/ASHRAE Standard 136-1993, A Method of Determining Air Change Rates in Detached Dwellings”. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Bohac, D., M. Cheple. 2002. “Ventilation and Depressurization Information for Houses Undergoing Remodeling” Minnesota Department of Commerce State Energy Office

California Energy Commission. 2005. “Title 24, Part 6, of the California Code of Regulations: California's Energy Efficiency Standards for Residential and Nonresidential Buildings.” California Energy Commission, Sacramento, CA.

CAN/CSA. 1991. “F326-M91 Residential Mechanical Ventilation Systems” Canadian Standards Association, Mississauga, Ontario.

CAN/CSA. 1990. “C260-M90 Rating the Performance of Residential Mechanical Ventilation Equipment”. Canadian Standards Association, Mississauga, Ontario.

Council of the European Community (CEC). 2003. "Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings". Official Journal of the European Communities, Brussels, January 4 2003.

Comité Européen de Normalisation (CEN). 2003. CEN prEN 14788. 2003. Ventilation for buildings: Design and dimensioning of residential ventilation systems, CEN, Brussels, 2003.

Concannon, P. 2002. "Residential Ventilation". AIVC Technical Note 57. Air Infiltration and Ventilation Centre, Sint-Stevens-Woluwe, Belgium.

Department of Housing and Construction. 2003. "D2 Finnish Code of Building Regulations, Indoor Atmosphere and Ventilation of Buildings, Regulations and Guidelines". Ministry of the Environment, Helsinki, Finland.

Department of the Environment and the Welsh Office. "Ventilation, The Building Regulations 2000 Approved Document F 1995." Her Magesty's Stationary Office. Norwich, UK.

Design Regulations BKR. 1998. "BFS 1998:38: Hygiene, health and the environment." Swedish Board of Housing, Building and Planning, Karlskrona, Sweden

Devine, J. 1999. "Whole House Ventilation Systems Research Report". Washington State Ventilation and Indoor Air Quality Code report.

Devine, J., Lubliner, M., and Kunkle, R. 1999. "Occupant Interaction with Washington State Ventilation and Indoor Air Quality Code mandated whole house ventilation systems: Telephone survey results." ASHRAE Transactions, Vol. 105, Part 2.

Dorer, V., A. Pfeiffer, A. Weber. 2004. "Parameters for the design of demand controlled hybrid ventilation systems for residential buildings" Air Infiltration and Ventilation Centre. (RESHYVENT)

Dubrul, C. 1988. "Inhabitant Behaviour with Respect to Ventilation – a Summary Report of IEA Annex 8". AIVC Technical Note 23. Air Infiltration and Ventilation Centre, Sint-Stevens-Woluwe, Belgium.

EPA. 2005. "Energy Protection Agency Indoor Air Quality Specifications." Energy Protection Agency, Washington, DC.

Florida, State of. 2001. "Florida Building Code, Section 409, Ventilation." Florida Building Commission, Tallahassee, FL.

Fugler, D. 2004. "Analysis of Ventilation System Performance in New Ontario Houses" Research Highlight Canada Mortgage and Housing Corporation, Ottawa, Onterio.

Fugler, D. 2002. “Compliance of Ventilation Systems Installed to meet Proposed Changes to the 1995 NBCC.” Research Highlight Canada Mortgage and Housing Corporation, Ottawa, Onterio.

Fugler, D. 2000. “Is it Worth Putting in a Better Furnace Filter?” Home Energy Volume 17, Number 3. May/June 2000. Berkeley, CA.

Grimsrud, D.T. and Hadlich; D.E. “Residential Pollutants and Ventilation Strategies: Volatile Organic Compounds and Radon”, ASHRAE Transactions 105(2), pp. 849-863, 1999.

Hadlich, D.E. and Grimsrud; D.T. “ Residential Pollutants and Ventilation Strategies: Moisture and
Combustion Products”, ASHRAE Transactions 105(2), pp. 833-848 1999.

Hinds, William. 1999. “Aerosol Technology: properties, behavior and measurement of airborne particles” John Wiley and Sons, New York.

Hill. 1998. “Field Survey of Heat Recovery Ventilation Systems.” Research Highlight Canada Mortgage and Housing Corporation, Ottawa, Onterio.

Home Ventilating Institute (HVI). 2005. “HVI Certified Products Directory”. Home Ventilating Institute, Wauconda, IL

Howard-Reed, C., L. Wallace, W. Ott. 2002. “The Effect of Opening Windows on Air Change Rates in Two Homes”. Journal of the Air and Waste Management Association 52:147-159.

ICC. 2003. “International Residential Code for One and Two-family Dwellings.” International Code Council, Country Club Hills, IL.

ICC. 2003. “International Energy Conservation Code.” International Code Council, Country Club Hills, IL.

Janssen, John E. 1994. “The V in ASHRAE: An Historical Perspective”. ASHRAE Journal. August. Vol 36 no. 8, pg 126-132 American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.

Janssen, John E. 1999. “The History of Ventilation and Temperature Control”. ASHRAE Journal. October. Vol 41 no. 10, pg 48-70 American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.

Kaplan, J. 1986. “Development of Material Safety Data Sheets” Proceedings of the 191st American Chemical Society national meeting. New York, NY. (http://www.phys.ksu.edu/area/jrm/Safety/kaplan.html)

Kelly, K., M. Brien, and R. Stemp. 1993. “Occupant use of Ventilation Controls and Humidifiers during Cold Seasons”. Proceedings of Indoor Air ’93 Vol. 5, pp.69-72.

Klepeis, N., W.C. Nelson, W.R. Ott, J.P. Robinson, A.M. Tsang, P. Switzer, J.V. Behar, S.C. Hern, W.H. Engelmann. 2001. "The National Human Activity Pattern Survey (NHAPS) A Resource for Assessing Exposure to Environmental Pollutants". LBNL-47713. Lawrence Berkeley National Laboratory.

Kühnl-Kinel, J. 2000. "The History of Ventilation and Air Conditioning: Is CERN up to Date With the Latest Technological Developments?" Proceedings of the Third ST Workshop, Chamonix, France. CERN Geneva, Switzerland.

Lemaire M-C, Trotignon R. 2000. "Ventilation in the French Homes: Survey of the attitudes and Behaviour of Private Citizens". Proceedings of Innovations in Ventilation Technology, 21st Annual AIVC Conference, 2000.

Liddament, M. 1996. "A Guide to Energy Efficient Ventilaion". Air Infiltration and Ventilation Centre, Sint-Stevens-Woluwe, Belgium.

Liddament, M. 2001. "Occupant Impact". AIVC Technical Note 53. Air Infiltration and Ventilation Centre, Sint-Stevens-Woluwe, Belgium.

Maldonado, E.A.B., J.E. Woods. 1983. "Ventilation Efficiency as a Means if Characterizing Air Distribution in a Building for Indoor Air Quality Evaluation." ASHRAE Transactions. Vol 89, Part 2B, pp.496-506. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.

McKone, T.E., and Sherman, M.H., 2003. "Residential Ventilation Standards Scoping Study." LBNL-53800. Lawrence Berkeley National Laboratory, Berkeley, CA.

Ministère de l'équipment, des transports et du logement. 1982. "Arrêté du 24.03.82 relatif à l'aération des logements." Journaux Officiels du 27 mars 1982, Paris, France.

Minnesota, State of. 2000. "Minnesota Rules Chapter 7672: Energy Code". Department of Public Service, Minneapolis, MN.

Modera, M.P., 1989. "Residential Duct System leakage: Magnitude, Impacts and Potential for Reduction,'' ASHRAE Transactions 95 (2): 561-569. LBL-26575.

Nagda, N.L., R. W. Krug and M.D. Koontz. 1995. "Depressurization, Backdrafting and Spillage from Vented Gas Appliances – A Literature Review". Report of ENERGEN Consulting, Inc. and GEOMET Technologies, Inc. to Gas Research Institute and Pacific Gas and Electric Company, GRI-95/0426. November.

NFPA. 1999a. "NFPA 54-1999 National Fuel Gas Code". Quincy, MA: National Fire Protection Association.

NFPA. 1999b. "National Fuel Gas Code Handbook" 4th Edition. Editor: T.C. Lemoff. Quincy, MA: National Fire Protection Association.

NRC. 1995. “National Building Code of Canada 1995.” National Research Council Canada, Ottawa, ON.

Oseland, N. 1995. “Occupant Response to Passive Stack Ventilation: A UK Postal Survey.” 16th AIVC Conference Proceedings, Vol 2. Air Infiltration and Ventilation Centre, Sint-Stevens-Woluwe, Belgium.

Phillips, T., E. Mulberg, P Jenkins. 1990. “Activity Patterns of California Adults and Adolescents: Appliance use, Ventilation Practices, and Building Occupancy”. Proceedings, 1990 ACEEE Summer Study on Energy Efficient Buildings, Vol. 4. pp.187-196. Washington, D.C.: American Council for an Energy-Efficient Economy.

Quirt, J.D. 1991. “Field measurement of sound from residential ventilation fans”. CMHC (client report prepared by the Institute for Research in Construction, National Research Council of Canada), Ottawa.

Roberson, J. 2004. “Effect of Building Airtightness and Fan Size on the Performance of Mechanical Ventilation Systems in New U.S. Homes: A Critique of ASHRAE Standard 62.2-2003”. Master of Science Thesis, University of California, Berkeley.

Santamouris, Matteous, Ed. To be published. "Ventilation: A State of the Art Review." James & James, London, UK.

Seppanen, O., W.J. Fisk and M.J. Mendell. 1999. Association of ventilation rates and CO2 concentrations with health and other responses in commercial and institutional buildings, Indoor Air 9(4):226-252.

Seppanen, O., W.J. Fisk and M.J. Mendell. 2002. Ventilation rates and health. ASHRAE Journal 44(8):56-58.

Sheltersource, Inc. 2002. “Evaluating Minnesota Homes Final Report.” Prepared for the Minnesota Department of Commerce.

Sherman, M.H., Chan W. R., 2004. "Building Airtightness: Research and Practice" LBNL-53356. Lawrence Berkeley National Laboratory, Berkeley, CA.

Sherman, M.. 2004. "ASHRAE's First Residential Ventilation Standard"   Submitted to Buildings IX Conf, Clearwater FL, LBNL-54331.

Sherman, M.H. and Matson, N.E. 2002. "Air Tightness of New U.S. Houses: A Preliminary Report " LBNL-48671 Lawrence Berkeley National Laboratory, Berkeley, CA.

Sherman, M., and Matson, N., "Residential Ventilation and Energy Characteristics", LBL-39036 Lawrence Berkeley National Laboratory, Berkeley, CA.

Sherman, M. and Dickerhoff, D. 1994. "Air-tightness of U. S. Dwellings.", LBL-35700 Lawrence Berkeley National Laboratory, Berkeley, CA.

Thatcher, T., A. Lei, R. Moreno-Jackson, R. Sextro, W. Nazaroff. 2002. "Effects of room furnishings and air speed on particle deposition rates indoors". Atmospheric Environment 36 (2002) 1811-1819.

Tsang, Andy and Neil Klepeis. 1996. "Descriptive Statistics Tables from a Detailed Analysis of the National Human Activity Pattern Survey (NHAPS) Data." Report for the National Exposure Research Laboratory, Las Vegas, NV, July 1996.

Walker, I.S. and M.H. Sherman. 2003. "Ventilation Technologies Scoping Study." LBL-53811 Lawrence Berkeley National Laboratory, Berkeley, CA.

Walker, I.S. and M.H. Sherman. 2003. "Heat Recovery in Building Envelopes." Proceedings AIVC BETEC Conference, Washington, DC, October 2003. INIVE eeig, Brussels, Belgium. LBNL-53484.

Wargocki P., J. Sundell, W. Bischof G. Brundrett, P.O. Fanger, F. Gyntelberg, S.O. Hanssen, P. Harrison, A.Pickering O. Seppanen P. Wouters. 2002. Ventilation and health in non-industrial indoor
environments: report from a European Multidisciplinary Scientific Consensus Meeting (EUROVEN)
Indoor Air 12(2):113-128.

Washington State Building Code Council. 2000. "Washington State Ventilation and Indoor Air Quality Code." Washington State Building Code Council, Olympia, WA

Wiley, J., J.P. Robinson, T. Piazza, K. Garrett, K. Cirksena, Y. Cheng, G. Martin. 1991. "Activity Patterns of California Residents". Final Report to the Air Resources Board. Contract Number A6-177-33.

Wilson, D.J. and I.S. Walker. 1992. "Feasibility of Passive Ventilation by Constant Area Vents to Maintain Indoor Air Quality in Houses." Proceedings of Indoor Air Quality '92 Conference. Joint Conference: ASHRAE/ACGIH/AIHA. San Francisco, CA.

Wray, Craig. 2001. "Guidelines for Residential Commissioning" LBNL-48767. Lawrence Berkeley National Laboratory, Berkeley, CA.

Wray, C., Matson, N., Sherman, M., 2000. "Selecting Whole-House Ventilation Strategies to meet proposed ASHRAE standard 62.2: Energy Cost Considerations" LBNL-44479. Lawrence Berkeley National Laboratory, Berkeley, CA.

Appendix B

03-326 Study Questionnaires

This Appendix contains the following:

Original Cover
Original Questionnaire
Revised Cover
Revised Questionnaire

California Ventilation Practices and Indoor Air Quality Study

QUESTIONNAIRE

Here's how to fill out the Survey:

- Please try to answer each question.
- Most questions can be answered by checking a box or writing a number or a few words on a line.
- Never check more than one box, except when it says **Check all that apply.**
- Sometimes we ask you to skip one or more questions. An arrow will tell you what question to answer next, like this:

  1 ○ YES

  2 ○ NO ⟶ **GO TO Q42**

- If none of the boxes is just right for you, please check the one that fits you the best. Feel free to add a note of explanation.
- If you need help with the survey, call Jackie Hayes collect at 0-510-643-2226.
- Consult with other household members as needed to answer the questions.

After you complete the survey, please mail it back to us in the enclosed envelope. No stamps are needed. Thank you for your prompt help.

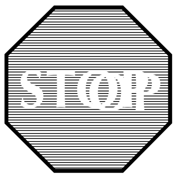
Survey Research Center, University of California at Berkeley

A Is the house at this address a **detached** house built in 2002 or 2003?

☐ Yes ☐ No

B Have you lived in this home since at least JANUARY 2004?

☐ Yes ☐ No



- IF YOU ANSWERED "NO" TO QUESTION A OR B ABOVE, DO NOT COMPLETE THE REST OF THE SURVEY. INSTEAD, JUST RETURN THIS SURVEY AND KEEP THE ENCLOSED PEN AS OUR GIFT FOR YOU.

- IF YOU ANSWERED "YES" TO QUESTIONS A AND B ABOVE, PLEASE CONTINUE WITH THE REST OF THE SURVEY QUESTIONS. WHEN YOU MAIL BACK YOUR COMPLETED QUESTIONNAIRE, WE WILL SEND YOU $30.

1. What is today's date?

_______ _____ ______
Month Day Year

GENERAL HOUSE CHARACTERISTICS

2. Are you or any other adult in your household the owner of this home?

[1] ☐ Yes [2] ☐ No

3. When did you move into this house?

_______ _____
Month Year

4. How large is your house, rounded to the nearest 100 square feet?

________ square feet

5. How many stories are at or above ground?

[1] ☐ 1
[2] ☐ 1.5
[3] ☐ 2
[4] ☐ 2.5
[5] ☐ 3 or more

6. Would you describe the foundation of the house as **primarily** being a …

[1] ☐ concrete slab-on-grade (first floor rests on a concrete slab),
[2] ☐ crawlspace, or
[3] ☐ basement, or
[4] ☐ Other (DESCRIBE: For example, combinations of the types above)?

____

7. How many bedrooms are in your house?

__________ bedrooms

8. How many bathrooms including half-baths? (For example: 2.5)

__________ bathrooms

9. A. Was your home built under a special energy efficiency program offered by the utility company or builder?

[1] ☐ Yes
[2] ☐ No ⟶ **GO TO Q10, PAGE 2**
[3] ☐ Don't know ⟶ **GO TO Q10, PAGE 2**

B. **IF YES:** Which program was that?

[1] ☐ Energy Star
[2] ☐ Building America
[3] ☐ Health House
[4] ☐ Comfortwise
[5] ☐ SMUD Advantage Home
[6] ☐ SoCalGas Energy Advantage Home
[7] ☐ Other (SPECIFY: ____________________)

WINDOWS

The next series of questions will ask you about how long you ventilate your house with outdoor air across the year as home heating and cooling needs change. For the purposes of this survey, we need to define seasons by their general weather patterns, rather than by months. Please use the following definitions of seasons, relative to your region:

- **Summer:** when heating is not needed, but air conditioning may be needed
- **Fall:** when little heating or cooling is needed
- **Winter:** when cooling is not needed, but substantial heating is needed
- **Spring:** when little heating or cooling is needed

For each question in this section, enter the average number of hours per day that any window, door, or skylight is open more than one inch, for the time frames indicated. If there are no windows, doors, or skylights in that room or they are never opened, enter zero.

In **summer**, what is the average number of hours during the following periods that any windows, doors, or skylights are open more than 1 inch in the following rooms?

	WEEKDAYS				WEEKENDS		
	Daytime 6 AM to 6 PM	Evening 6 PM to 11 PM	Nighttime 11 PM to 6 AM		Daytime 6 AM to 6 PM	Evening 6 PM to 11 PM	Nighttime 11 PM to 6 AM
10. Kitchen area	______	______	______		______	______	______
11. Any of the bedrooms	______	______	______		______	______	______
12. Any of the bathrooms, laundry room, utility room	______	______	______		______	______	______
13. All other rooms	______	______	______		______	______	______

In **fall**, what is the average number of hours during the following periods that any windows, doors, or skylights are open more than 1 inch in the following rooms?

	WEEKDAYS				WEEKENDS		
	Daytime 6 AM to 6 PM	Evening 6 PM to 11 PM	Nighttime 11 PM to 6 AM		Daytime 6 AM to 6 PM	Evening 6 PM to 11 PM	Nighttime 11 PM to 6 AM
14. Kitchen area	______	______	______		______	______	______
15. Any of the bedrooms	______	______	______		______	______	______
16. Any of the bathrooms, laundry room, utility room	______	______	______		______	______	______
17. All other rooms	______	______	______		______	______	______

In **winter**, what is the average number of hours during the following periods that any windows, doors, or skylights are open more than 1 inch in the following rooms?

		WEEKDAYS				WEEKENDS		
		Daytime 6 AM to 6 PM	Evening 6 PM to 11 PM	Nighttime 11 PM to 6 AM		Daytime 6 AM to 6 PM	Evening 6 PM to 11 PM	Nighttime 11 PM to 6 AM
18.	Kitchen area	_______	_______	_______		_______	_______	_______
19.	Any of the bedrooms	_______	_______	_______		_______	_______	_______
20.	Any of the bathrooms, laundry room, utility room	_______	_______	_______		_______	_______	_______
21.	All other rooms	_______	_______	_______		_______	_______	_______

In **spring**, what is the average number of hours during the following periods that any windows, doors, or skylights are open more than 1 inch in the following rooms?

		WEEKDAYS				WEEKENDS		
		Daytime 6 AM to 6 PM	Evening 6 PM to 11 PM	Nighttime 11 PM to 6 AM		Daytime 6 AM to 6 PM	Evening 6 PM to 11 PM	Nighttime 11 PM to 6 AM
22.	Kitchen area	_______	_______	_______		_______	_______	_______
23.	Any of the bedrooms	_______	_______	_______		_______	_______	_______
24.	Any of the bathrooms, laundry room, utility room	_______	_______	_______		_______	_______	_______
25.	All other rooms	_______	_______	_______		_______	_______	_______

26. How important are each of the following reasons why you and members of your household typically **open** windows, doors, or skylights to the outdoors? (CHECK ALL THAT TYPICALLY APPLY. DO NOT INCLUDE WHEN YOU OPEN THEM FOR A MINUTE OR TWO, OR TO ENTER OR EXIT YOUR HOME. IF YOU NEVER OPEN WINDOWS, DOORS, OR SKYLIGHTS FOR THAT REASON, PLEASE CHECK THE BOX FOR "NEVER OPEN FOR THIS REASON.")

	Very Important	Somewhat Important	Slightly Important	Not at all Important	Never open for this reason
A. To cool the house	1	2	3	4	5
B. To warm the house					
C. To provide air movement.........					
D. To remove odors......................					
E. To remove moisture					
F. To air out during house cleaning					
G. To remove smoke, such as from cigarettes, fireplace, woodstove, etc. (SPECIFY TYPES: ________________).....					
H. To provide draft for fireplace, wood stove, cooking appliance or exhaust fan					
I. To save energy.........................					
J. To allow pets frequent or easy access					
K. Other: (SPECIFY: ___________ __________________________)					

27. How important are each of the following reasons why you and members of your household typically **close** windows, doors, or skylights? (CHECK ALL THAT TYPICALLY APPLY. IF YOU NEVER CLOSE WINDOWS, DOORS, OR SKYLIGHTS FOR THAT REASON, PLEASE CHECK THE BOX FOR "NEVER CLOSE FOR THIS REASON")

	Very Important	Somewhat Important	Slightly Important	Not at all Important	Never close for this reason
A. Nobody at home	1	2	3	4	5
B. Maintain comfortable indoor temperature					
C. Reduce pollutants or odors from outdoors					
D. Too windy or drafty					
E. Keep out noise					
F. Keep pets in or out					
G. Save energy					
H. Keep out rain or snow					
I. Keep out woodsmoke					
J. Keep out dust					
K. Keep out pollen or other allergens					
L. Keep out insects					
M. Privacy from neighbors					
N. Security or safety					
O. Hard to open or close windows					
P. Other: (SPECIFY: ____________ ____________________________)					

In each "season" in the past year, how many hours out of the 24 hours in a day—on average—did your house have no ventilation, or low, medium or high ventilation, as defined below?

No ventilation: All windows and doors closed.

Low: One or two windows or doors open just a crack (up to 1 inch).

Medium: Several windows or doors open at least a crack, or one or two windows open part-way (at least several inches).

High: Some windows or doors fully open, or several windows or doors open part-way, or almost all windows or doors open at least a crack.

(**NOTE:** THE NUMBER OF HOURS FOR NO VENTILATION, LOW, MEDIUM, AND HIGH SHOULD ADD TO 24 FOR EACH SEASON)

		No ventilation		Low		Medium		High	Total hours per day
28.	Summer .	____	+	____	+	____	+	_____	= 24
29.	Fall.........	____	+	____	+	____	+	_____	= 24
30.	Winter ...	____	+	____	+	____	+	_____	= 24
31.	Spring	____	+	____	+	____	+	_____	= 24

32. How often, if ever, do you provide for cross-ventilation by opening windows on opposite sides of your house?

1 Frequently
2 Sometimes
3 Rarely
4 Never
5 Not Applicable

33. When you open windows, doors, or skylights, how often, if ever, do you provide for high and low venting (for example, by opening ground floor and ceiling level windows, or by opening windows on different stories?)

1 Frequently
2 Sometimes
3 Rarely
4 Never
5 Not Applicable

COOLING, HEATING, AND VENTILATING SYSTEMS

34. For each season, how many hours of the 24 hours per day are the following heating or cooling devices used on an average day. If you do not have a specific piece of equipment, enter zeros for all seasons:

	Summer	Fall	Winter	Spring
A. Central Air Conditioning	_____	_____	_____	_____
B. Room Air Conditioning	_____	_____	_____	_____
C. Whole House Fan	_____	_____	_____	_____
D. Central or Room Dehumidifier........	_____	_____	_____	_____
E. Central Gas Heating	_____	_____	_____	_____
F. Central Electric or Heat-pump heating	_____	_____	_____	_____
G. Gas Wall Heater ...	_____	_____	_____	_____
H. Electric Wall Heater..................	_____	_____	_____	_____
I. Wood stove or gas or wood fireplace with tight-fitting doors ..	_____	_____	_____	_____
J. Other Fireplace without tight-fitting doors	_____	_____	_____	_____
K. Freestanding combustion heater (such as gas, kerosene) not vented to the outdoors..............	_____	_____	_____	_____
L. Freestanding electric heater.......	_____	_____	_____	_____
M. Central or room humidifier............	_____	_____	_____	_____
N. Central HEPA or electrostatic filter ..	_____	_____	_____	_____
O. "SmartVent" or other similar ventilative cooling system	_____	_____	_____	_____
P. Other (SPECIFY: ________________)	_____	_____	_____	_____

35. Where is your central heater located? (NOTE: This is the unit, or the part of the unit, that circulates heated or cooled air within your house.)

1 Attic
2 Crawlspace
3 Garage
4 Other space <u>inside</u> the house (SPECIFY: ______________________)
5 Other space <u>outside</u> the house (SPECIFY: ______________________)
6 House does not have central heater.
7 Don't know

36. Where is the particle air filter for your heater or central system located?

1 Ceiling register
2 In the central unit
3 Other (SPECIFY: ____________________)
4 Don't know
5 Don't have one

37. What kind of filter is it?

1 Traditional inexpensive fiberglass
2 Medium efficiency pleated filter (usually removes 40-70% of particles)
3 High efficiency pleated filter (usually removes 95% or more of particles)
4 Electrostatic filter (you wash it instead of replacing)
5 Electronic filter (usually built in, you wash it instead of replacing)
6 Other (SPECIFY: ____________________)
7 Not sure
8 Don't have one

38. How often, if ever, do you replace or clean the filter?

1 Once a month
2 Once a quarter
3 Twice a year
4 Once a year or less often
5 Never
6 Don't know
7 Don't have one

39. A. Do you use a stand-alone air filter, air purifier or air cleaner in the house?

1 Yes (SPECIFY BRAND OR MODEL: ______________________________)
2 No ——► **GOTO Q40**

B. <u>**IF YES**</u>: Did the literature for that unit say that it creates ozone, "supersaturated oxygen," or something similar?

1 Yes
2 No
3 Don't know

40. Thinking of how you operate your heating and air-conditioning system, what temperature settings on the thermostat do you usually use when the house is occupied during waking hours and sleeping hours? (PLEASE ENTER THE TEMPERATURES IN THE TABLE BELOW)

	Degree (F)	Don't know	Does not apply
Heating mode:			
Waking	______	_____	_____
Sleeping	______	_____	_____
Cooling mode:			
Waking	______	_____	_____
Sleeping	______	_____	_____

41. How often, if ever, do you use the thermostat's fan switch to circulate air in the home without any heating or cooling going on? (This is normally done by putting the fan switch to "On" or "Manual" and not by adjusting the heating or cooling settings.)

1 Frequently
2 Sometimes
3 Rarely
4 Never
5 Not Applicable

42. A. Do you have a gas water heater?

1 Yes
2 No ⟶ **GO TO Q43**

B. Where is your gas water heater located?

1 Garage
2 Other space outside the house
3 Other space inside the house
4 Attic
5 Crawlspace
6 Don't know

WHOLE-HOUSE VENTILATION SYSTEMS

43. A whole-house ventilation **system** is one that is designed and intended to provide ventilation with outdoor air to meet the needs of the whole house. Whole-house ventilation systems may run continuously or intermittently throughout the day and are controlled automatically rather than manually. (*Note that for the purposes of this survey a whole-house **fan**, which is a large exhaust fan that is mounted in the ceiling and is usually operated manually to bring in cooler air to cool off the house during summer evenings and nights, is <u>not considered a whole-house ventilation system</u>.*)

Do you have a whole-house ventilation system, such as …

A. … the type of whole-house ventilation system that has air inlets that bring <u>outdoor air</u> into the duct system of a central heating and air conditioning system and uses that duct system to distribute fresh air throughout the house. A variation of this type of system has an outside air inlet and fan that is connected to its own duct system rather than to the duct system connected to the central heating and air conditioning system.

1 Yes (PLEASE INDICATE THE NAME OF THE SYSTEM, OR BRAND OR MODEL, IF KNOWN) ____________________

____

2 No

B. … an exhaust fan system, which usually consists of one or more continually or intermittently operating exhaust fans often in a bathroom or laundry room? These exhaust fans are more efficient and quieter than a normal bathroom fan.

1 Yes (PLEASE INDICATE THE NAME OF THE SYSTEM, OR BRAND OR MODEL, IF KNOWN) ____________________

____

2 No

C. … a heat-recovery ventilator or an energy-recovery ventilator system that is designed to provide ventilation to the whole house?

1 Yes (PLEASE INDICATE THE NAME OF THE SYSTEM, OR BRAND OR MODEL, IF KNOWN) ____________________

____

2 No

D. Does your house have some other type of whole-house ventilation **system** that is designed to bring in outdoor air automatically to provide ventilation to the whole house?

1 Yes (PLEASE INDICATE THE NAME OF THE SYSTEM, OR BRAND OR MODEL, IF KNOWN) ____________________

____

2 No

IF YOU ANSWERED "YES" TO ANY OF THE 4 QUESTIONS (A, B, C, or D) ABOUT WHOLE-HOUSE VENTLATION SYSTEMS, PLEASE CONTINUE.

IF YOU ANSWERED "NO" TO ALL FOUR OF THESE, THAT YOU DO NOT HAVE SUCH A SYSTEM, PLEASE GO TO QUESTION 44 ON PAGE 10.

E. Was the operation of the system explained to you when you bought or moved into the house?

1 Yes
2 No

F. Do you feel you understand how the system works?

1 Yes
2 No

G. Do you feel you understand how to operate it properly?

1 Yes
2 No

How is the system typically used in each season? Indicate whether the system use is continuous (left on all the time), somewhat frequent, infrequent, or is never used in that season. (PLEASE CHECK ONLY ONE BOX FOR EACH SEASON.)

	Continuous	Somewhat frequent	Infrequent	Never
H. Summer	1	2	3	4
I. Fall				
J. Winter				
K. Spring				

L. What do you like about the system? (CHECK ALL THAT APPLY)

1 Fresh air
2 Quiet
3 Reduced odors
4 Reduced energy costs
5 Reduced allergies
6 Reduced concern about indoor air quality
7 Other (SPECIFY: ____________________)
8 None of the above

M. What ***don't*** you like about the system? (CHECK ALL THAT APPLY)

1 Too noisy
2 Too drafty
3 Increases odors
4 Hard to operate
5 Hard to maintain
6 Too expensive
7 Too quiet
8 Not effective (SPECIFY WHAT MAKES THE SYSTEM NOT EFFECTIVE: ____________ ____________________________________)
9 Other (SPECIFY: ____________________)
10 None of the above

N. Why did you choose the system? (CHECK ALL THAT APPLY)

1 Came with the house
2 A household member has health condition
3 Wanted filtered fresh outdoor air
4 Affordable cost
5 Good reliability
6 Reduced energy costs
7 Other (SPECIFY: __________________)

O. Please list any additional problems or provide any additional comments you have on the system.

1 NONE or SPECIFY: _________________
____
____
____

SPECIAL CHOICES

44. What special measures or choices have you or the builder taken to improve the quality of the air in your home? (CHECK ALL THAT APPLY)

- a None
- b Upgraded my central air filter
- c High efficiency vacuum cleaner with special features such as better filters to trap more particles
- d Whole house vacuum
- e Low-emission carpets, furniture, paint, or cabinets
- f Hard flooring instead of carpeting
- g Carbon monoxide alarm
- h Special range hood (e.g. higher air flow, lower noise, etc.)
- i Extra exhaust fans
- j Whole house ventilation system
- k Other (SPECIFY: ________________________)

COMFORT AND ODORS

45. For any of the previous four seasons, please indicate if you have noticed a significant period when your house has experienced each of the conditions listed below. (IF NONE, LEAVE BLANK)

	Summer	Fall	Winter	Spring
A. Too hot........	1	2	3	4
B. Too cold.......				
C. Too dry				
D. Too humid ...				
E. Too drafty				
F. Too stagnant (not enough air movement)				
G. Too dusty				

46. Similarly, have you noticed, seen, or smelled mold or mildew in the following locations? (IF NONE, LEAVE BLANK)

	Summer	Fall	Winter	Spring
A. Bathroom..	1	2	3	4
B. Basement or crawl space				
C. Walls or ceilings......				
D. Carpets				
E. Closets				

47. Since you have lived in this house, has it had any of the following conditions?

	Yes	No
A. Significant condensation on windows or other indoor surfaces?...................................	1	2
B. Roof leaks?		
C. Plumbing leaks?		
D. Wall or window leaks?		
E. Flooding?..................................		
F. Poor site drainage?.....................		
G. Bothersome carpet odors?..........		
H. Bothersome cabinetry odors?		
I. Other unpleasant odors? (SPECIFY: ________________)...		

J. Other moisture problems?

2 No   1 Yes (SPECIFY: ______________)

How would you rate the air quality in your home during each season of the past year? Indicate whether the air quality in your home was typically very acceptable, acceptable, barely acceptable, or not acceptable. (PLEASE CHECK ONLY ONE BOX FOR EACH SEASON.)

	Very acceptable	Somewhat acceptable	Barely acceptable	Not acceptable
48. Summer ...	1	2	3	4
49. Fall...........				
50. Winter				
51. Spring				

HEALTH

Please answer the following questions for your household. Enter zero or a number under each age group category for each characteristic.

Characteristics of Household Members	Number of Adults: 18 yrs old or older	Number of Children	
		6-17 years old	5 years old or younger
52. Total number in household	#_____	#_____	#_____
53. Number who smoke	#_____	#_____	#_____
54. Number who have allergies to outdoor pollen, mold, or grass (doctor-diagnosed)...............	#_____	#_____	#_____
55. Number who have allergy to common indoor agents such as household pets, dust mites, or cockroaches (doctor-diagnosed)...............	#_____	#_____	#_____

Characteristics of Household Members	*Number of Adults: 18 yrs old or older*	*Number of Children*	
		6-17 years old	*5 years old or younger*
56. Number who have allergy to other (or unknown) airborne agents (doctor-diagnosed)...............	#_____	#_____	#_____
57. Number who have asthma (doctor-diagnosed)...............	#_____	#_____	#_____
58. Number who have other breathing/lung problems (doctor-diagnosed)...............	#_____	#_____	#_____

COOKING

59. On average how many total hours a day does someone cook in the house using either the stovetop or the oven, counting only the time that the stovetop or oven is turned on? Do not include use of a microwave oven.

Weekday	Weekend
# ______ hours/day	# ______ hours/day

60. What type of stovetop do you use most often?

1 Gas

2 Electric

61. Does that stovetop have an exhaust fan or “range hood”?

1 Yes, it has a range hood with a fan in it that blows air back into the room
2 Yes, it has a range hood with a fan that exhausts the air to the outdoors
3 Yes, it has a downdraft ventilator built into it
4 No
5 Don’t know

62. Is the (most frequently used) oven gas or electric?

1 Gas
2 Electric

63. Where is it located?

1 Directly above or below the stovetop
2 Built-in, not near the stovetop
3 Other (DESCRIBE: ____________________)

64. Does it have its own exhaust vent to the outdoors?

1 Yes
2 No
3 Don’t know

65. When someone cooks with the stovetop, how often, if ever, do they use the exhaust fan or range hood?

1 Always
2 Only when odor or humidity seems to be an issue
3 Sometimes
4 Rarely
5 Never

66. When someone cooks with the oven, how often, if ever, do they use the exhaust fan or range hood?

1 Always
2 Only when odor or humidity seems to be an issue
3 Sometimes
4 Rarely
5 Never

BATHROOM VENTILATION

67. When someone in the house takes a shower or bath, how often, is the bathroom exhaust fan used?

1 Always
2 Frequently
3 Sometimes
4 Rarely
5 Never
6 There is no fan ——► **SKIP TO Q71, PAGE 13**

68. How many bathroom fans do you have that are controlled as follows:

1 With a timer knob or switch #_____
2 Come on when the light comes on #_____
3 Have a separate on/off switch #_____
4 Are on all the time #_____

69. Why are bathroom fans used? (CHECK ALL THAT APPLY)

a To remove moisture
b To provide noise
c To control odor
d Comes on automatically when light is turned on
e Other (PLEASE SPECIFY: _______________)

70. A. Are there times when the fan isn't used, even though the bathroom is steamy or has an unpleasant odor?

1 Yes
2 No ——► **SKIP TO Q71**

B. **IF YES**: Then, why is the fan not used? (CHECK ALL THAT APPLY)

1 Window is open
2 Don't think of it
3 Too noisy
4 Doesn't seem to help
5 Don't want to use the energy
6 Doesn't work
7 Causes draft

71. How often, if ever, do people in your household open the bathroom window for ventilation?

1 It is always open
2 It is usually open
3 Sometimes
4 Rarely
5 Never

ADDITIONAL HOUSE CHARACTERISTICS

72. On average, how many times per week does your household do the following activities in your house? (ENTER NUMBER OF TIMES PER WEEK, OR ZERO IF NEVER)

	Number of times used per week
Use the shower, or indoor Jacuzzi, or bath	#_________
Use the dishwasher or washing machine	#_________
Hang clothes to dry indoors..................	#_________
Boil water for cooking rice, pasta, etc. ...	#_________

Create other sources of steam or water vapor (SPECIFY SOURCES AND NUMBER OF TIMES PER WEEK: ______________________________)

73. Are there dogs, cats, or other furry animals that regularly spend time in the house?

1 Yes (SPECIFY: ________________________)
2 No

74. What is the most common type of built-in cabinetry in the kitchen and bathrooms?

1 Pressed wood or plywood that has no obvious covering (is bare) on the inside of the cabinets
2 Pressed wood or plywood that is laminated on the inside of the cabinet, such as with a white melamine surface
3 Solid wood
4 Other (SPECIFY: ______________________)
5 Don't know

75. Approximately how many square feet of each of the following flooring types do you have? (Note: If you have area rugs, consider only the flooring underneath them.)

a Vinyl or linoleum flooring #_____ sq ft
b Wood or wood-based flooring #_____ sq ft
c Carpeting #_____ sq ft
d Stone or ceramic tile #_____ sq ft
e Concrete or brick #_____ sq ft
f Other: (SPECIFY: __________________)#_____ sq ft

76. How often are the carpets or rugs in your most heavily used rooms normally vacuumed?

1 Twice per week or more often
2 About once per week
3 About every 2 weeks
4 About every 3 to 4 weeks
5 Less often

77. Which best describes the walls in your house?

1 Mostly wallpaper
2 Some wallpaper and some painted
3 Mostly painted
4 All painted
5 Other (SPECIFY: ______________________)

78. Do you or other household members regularly use any of the following in your home? (CHECK ALL THAT APPLY)

	Yes	No
A. Burn candles or incense.....	1	2
B. Paints, glues, or solvents (for hobbies, home repairs, or other purposes)		
C. Pesticide sprays or foggers..		
D. Plug-in or spray deodorizers		
E. Potpourri...........................		
F. Other sources of smoke or fumes (SPECIFY: ______________________)		

79. A. Does the house have an attached garage, or a parking area beneath the home?

1 Yes
2 No ⟶ **GOTO Q80**

B. **IF YES**: How many functioning cars or trucks are typically parked there?

1 One
2 Two
3 Three or more

80. Please enter the average number of hours per day that no one is home on weekdays and weekends , for the daytime, evening, and nighttime periods indicated below. Enter zero for any period in which someone is always in the home.

		Weekday	Weekend
Daytime	6 AM - 6 PM	# ________	# ________
Evening	6 PM - 11 PM	# ________	# ________
Nighttime	11 PM 6 AM	# ________	# ________

81. After this survey, we would like to make some measurements of the air quality in the homes of some of the people who answered this questionnaire. Participants would receive their results and a small incentive payment. Would you be willing to participate in this second part of the study?

1 Yes
2 No

The next questions will help us interpret the results of the study. All responses will be kept confidential.

82. What is your household income?

1 Under $35,000
2 $35,000 - $49,999
3 $50,000 - $74,999
4 $75,000 - $99,999
5 $100,000 - $149,999
6 $150,000 or more

83. What ethnic or racial group do you consider yourself? (CHECK ALL THAT APPLY)

a Black or African-American
b Native American
c Hispanic or Latino
d Filipino
e Asian
f Pacific Islander
g White or Caucasian, or
h Some other group? (SPECIFY: ______________)
i Mixed race (SPECIFY: ____________________)

84. A. Who in your household is most familiar with how the windows, doors, and fans are used to ventilate your home? (PLEASE CHECK THE ONE THAT BEST FITS)

1 You
2 Another person (SPECIFY OTHER PERSON: ________________________________)
3 Both you and another person (SPECIFY OTHER PERSON: __________________)
4 Don't Know

B. **<u>IF YOU ANSWERED 2 OR 3 TO QUESTION 84 ABOVE</u>**, did you consult with this other person to help complete this survey?

1 Yes
2 No

Thank you for taking the time to help us with this important research.

If you have any comments about the survey, or further information about indoor air quality or ventilation in your home, please provide them in the space below.

COMMENTS: ____________________________________

____

____

____

____

____

____

IMPORTANT ⟶ **GO TO LAST PAGE**

85. We want to send you a check for $30 to thank you for your help with this important study. To make sure our records are correct and that the check will reach you, please fill in your name and address. Please print.

Name: ____

Address: __________________________________ Apt # ______

______________________ ________ __________
City State Zip code

Thank you very much for your help

Now please mail this survey back to us in the enclosed envelope.
You don't need stamps.

B2

California Ventilation Practices and Indoor Air Quality Study

QUESTIONNAIRE

Here's how to fill out the Survey:

- Please try to answer each question.
- Most questions can be answered by checking a box or writing a number or a few words on a line.
- Never check more than one box, except when it says **Check all that apply.**
- Sometimes we ask you to skip one or more questions. An arrow will tell you what question to answer next, like this:

  1 ○ YES

  2 ○ NO ⟶ **GO TO Q42**

- If none of the boxes is just right for you, please check the one that fits you the best. Feel free to add a note of explanation.
- If you need help with the survey, call Jackie Hayes collect at 0-510-643-2226.
- Consult with other household members as needed to answer the questions.

After you complete the survey, please mail it back to us in the enclosed envelope. No stamps are needed. Thank you for your prompt help.

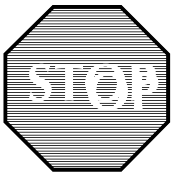
Survey Research Center, University of California at Berkeley

A Is the house at this address a **detached** single family house built in 2002 or 2003? By "detached" we mean no shared walls with another house.

☐ Yes ☐ No

B Have you lived in this home since at least JANUARY 2004?

☐ Yes ☐ No



- IF YOU ANSWERED "NO" TO QUESTION A OR B ABOVE, DO NOT COMPLETE THE REST OF THE SURVEY. INSTEAD, JUST RETURN THIS SURVEY AND KEEP THE ENCLOSED PEN AS OUR GIFT FOR YOU.
- IF YOU ANSWERED "YES" TO QUESTIONS A AND B ABOVE, PLEASE CONTINUE WITH THE REST OF THE SURVEY QUESTIONS. WHEN YOU MAIL BACK YOUR COMPLETED QUESTIONNAIRE, WE WILL SEND YOU $30.

1. What is today's date?

________ ______ ________
Month Day Year

GENERAL HOUSE CHARACTERISTICS

2. Are you or any other adult in your household the owner of this home?

1 ☐ Yes 2 ☐ No

3. When did you move into this house?

________ ______
Month Year

4. How large is your house, rounded to the nearest 100 square feet?

________ square feet

5. How many stories are at or above ground?

1 ☐ 1
2 ☐ 1.5
3 ☐ 2
4 ☐ 2.5
5 ☐ 3 or more

6. Would you describe the foundation of the house as **primarily** being a …

1 ☐ concrete slab-on-grade (first floor rests on a concrete slab),
2 ☐ crawlspace, or
3 ☐ basement, or
4 ☐ Other (DESCRIBE: For example, combinations of the types above)?

____

7. How many bedrooms are in your house?

__________ bedrooms

8. How many bathrooms including half-baths? (For example: 2.5)

__________ bathrooms

9. A. Was your home built under a special energy efficiency program offered by the utility company or builder?

1 ☐ Yes
2 ☐ No → **GO TO Q10, PAGE 2**
3 ☐ Don't know → **GO TO Q10, PAGE 2**

B. **IF YES:** Which program was that?

1 ☐ Energy Star
2 ☐ Building America
3 ☐ Health House
4 ☐ Comfortwise
5 ☐ SMUD Advantage Home
6 ☐ SoCalGas Energy Advantage Home
7 ☐ Other (SPECIFY: ____________________)

WINDOWS

The next series of questions will ask you about how long you ventilate your house with outdoor air across the year as home heating and cooling needs change. For the purposes of this survey, we need to define seasons by their general weather patterns, rather than by months. Please use the following definitions of seasons, relative to your region:

- **Summer:** when heating is not needed, but air conditioning may be needed
- **Fall:** when little heating or cooling is needed
- **Winter:** when cooling is not needed, but substantial heating is needed
- **Spring:** when little heating or cooling is needed

For each question in this section, enter the **average number of hours per period per day** that any window, door, or skylight is op more than one inch, for the time frames indicated. If there are no windows, doors, or skylights in that room or they are never opened, enter zero.

In **summer**, what is the **average number of hours per period per day** that any windows, doors, or skylights are open more than 1 inch in the following rooms?

	WEEKDAYS				WEEKENDS		
	Daytime 6 AM to 6 PM **(up to 12 hours)**	Evening 6 PM to 11 PM **(up to 5 hours)**	Nighttime 11 PM to 6 AM **(up to 7 hours)**		Daytime 6 AM to 6 PM **(up to 12 hours)**	Evening 6 PM to 11 PM **(up to 5 hours)**	Nighttime 11 PM to 6 AM **(up to 7 hours)**
10. Kitchen area	_______	_______	_______		_______	_______	_______
11. Any of the bedrooms	_______	_______	_______		_______	_______	_______
12. Any of the bathrooms, laundry room, utility room	_______	_______	_______		_______	_______	_______
13. All other rooms	_______	_______	_______		_______	_______	_______

In **fall**, what is the **average number of hours per period per day** that any windows, doors, or skylights are open more than 1 inch in the following rooms?

	WEEKDAYS				WEEKENDS		
	Daytime 6 AM to 6 PM **(up to 12 hours)**	Evening 6 PM to 11 PM **(up to 5 hours)**	Nighttime 11 PM to 6 AM **(up to 7 hours)**		Daytime 6 AM to 6 PM **(up to 12 hours)**	Evening 6 PM to 11 PM **(up to 5 hours)**	Nighttime 11 PM to 6 AM **(up to 7 hours)**
14. Kitchen area	_______	_______	_______		_______	_______	_______
15. Any of the bedrooms	_______	_______	_______		_______	_______	_______
16. Any of the bathrooms, laundry room, utility room	_______	_______	_______		_______	_______	_______
17. All other rooms	_______	_______	_______		_______	_______	_______

In **winter**, what is the **average number of hours per period per day** that any windows, doors, or skylights are open more than 1 inch in the following rooms?

		WEEKDAYS				WEEKENDS		
		Daytime 6 AM to 6 PM **(up to 12 hours)**	Evening 6 PM to 11 PM **(up to 5 hours)**	Nighttime 11 PM to 6 AM **(up to 7 hours)**		Daytime 6 AM to 6 PM **(up to 12 hours)**	Evening 6 PM to 11 PM **(up to 5 hours)**	Nighttime 11 PM to 6 AM **(up to 7 hours)**
18.	Kitchen area	_______	_______	_______		_______	_______	_______
19.	Any of the bedrooms	_______	_______	_______		_______	_______	_______
20.	Any of the bathrooms, laundry room, utility room	_______	_______	_______		_______	_______	_______
21.	All other rooms	_______	_______	_______		_______	_______	_______

In **spring**, what is the **average number of hours per period per day** that any windows, doors, or skylights are open more than 1 inch in the following rooms?

		WEEKDAYS				WEEKENDS		
		Daytime 6 AM to 6 PM **(up to 12 hours)**	Evening 6 PM to 11 PM **(up to 5 hours)**	Nighttime 11 PM to 6 AM **(up to 7 hours)**		Daytime 6 AM to 6 PM **(up to 12 hours)**	Evening 6 PM to 11 PM **(up to 5 hours)**	Nighttime 11 PM to 6 AM **(up to 7 hours)**
22.	Kitchen area	_______	_______	_______		_______	_______	_______
23.	Any of the bedrooms	_______	_______	_______		_______	_______	_______
24.	Any of the bathrooms, laundry room, utility room	_______	_______	_______		_______	_______	_______
25.	All other rooms	_______	_______	_______		_______	_______	_______

26. How important are each of the following reasons why you and members of your household typically **open** windows, doors, or skylights to the outdoors? (CHECK ALL THAT TYPICALLY APPLY. DO NOT INCLUDE WHEN YOU OPEN THEM FOR A MINUTE OR TWO, OR TO ENTER OR EXIT YOUR HOME. IF YOU NEVER OPEN WINDOWS, DOORS, OR SKYLIGHTS FOR THAT REASON, PLEASE CHECK THE BOX FOR "NEVER OPEN FOR THIS REASON.")

	Very Important	Somewhat Important	Slightly Important	Not at all Important	Never open for this reason
A. To cool the house....................	1	2	3	4	5
B. To warm the house..................					
C. To provide air movement					
D. To remove odors					
E. To remove moisture.................					
F. To air out during house cleaning					
G. To remove smoke, such as from cigarettes, fireplace, woodstove, etc. (SPECIFY TYPES: ________________)					
H. To provide draft for fireplace, wood stove, cooking appliance or exhaust fan..........................					
I. To save energy..........................					
J. To allow pets frequent or easy access.......................................					
K. Other: (SPECIFY: ___________ __________________________)					

27. How important are each of the following reasons why you and members of your household typically **close** windows, doors, or skylights? (CHECK ALL THAT TYPICALLY APPLY. IF YOU NEVER CLOSE WINDOWS, DOORS, OR SKYLIGHTS FOR THAT REASON, PLEASE CHECK THE BOX FOR "NEVER CLOSE FOR THIS REASON")

	Very Important	Somewhat Important	Slightly Important	Not at all Important	Never close for this reason
A. Nobody at home..........................	1	2	3	4	5
B. Maintain comfortable indoor temperature................................					
C. Reduce pollutants or odors from outdoors.....................................					
D. Too windy or drafty					
E. Keep out noise............................					
F. Keep pets in or out					
G. Save energy					
H. Keep out rain or snow.................					
I. Keep out woodsmoke					
J. Keep out dust					
K. Keep out pollen or other allergens					
L. Keep out insects..........................					
M. Privacy from neighbors.................					
N. Security or safety..........................					
O. Hard to open or close windows....					
P. Other: (SPECIFY: ____________ ___________________________)					

In each "season" in the past year, how many hours out of the 24 hours in a day—on average—did your house have no ventilation, or low, medium or high ventilation, as defined below?

No ventilation: All windows and doors closed.

Low: One or two windows or doors open just a crack (up to 1 inch).

Medium: Several windows or doors open at least a crack, or one or two windows open part-way (at least several inches).

High: Some windows or doors fully open, or several windows or doors open part-way, or almost all windows or doors open at least a crack.

(**NOTE:** The number of hours for no ventilation, low, medium, and high **SHOULD TOTAL 24** for each season)

	No ventilation		Low		Medium		High	Total hours per day
28. Summer.	____	+	____	+	____	+	_____	= 24
29. Fall	____	+	____	+	____	+	_____	= 24
30. Winter...	____	+	____	+	____	+	_____	= 24
31. Spring....	____	+	____	+	____	+	_____	= 24

32. How often, if ever, do you provide for cross-ventilation by opening windows on opposite sides of your house?

1 Frequently
2 Sometimes
3 Rarely
4 Never
5 Not Applicable

33. When you open windows, doors, or skylights, how often, if ever, do you provide for high and low venting (for example, by opening ground floor and ceiling level windows, or by opening windows on different stories?)

1 Frequently
2 Sometimes
3 Rarely
4 Never
5 Not Applicable

COOLING, HEATING, AND VENTILATING SYSTEMS

34. For each season, how many hours of the 24 hours per day are the following heating or cooling devices used on an average day. If you do not have a specific piece of equipment, enter zeros for all seasons:

	Summer	Fall	Winter	Spring
A. Central Air Conditioning........	______	______	______	______
B. Room Air Conditioning........	______	______	______	______
C. Whole House Fan	______	______	______	______
D. Central or Room Dehumidifier	______	______	______	______
E. Central Gas Heating................	______	______	______	______
F. Central Electric or Heat-pump heating.................	______	______	______	______
G. Gas Wall Heater...	______	______	______	______
H. Electric Wall Heater	______	______	______	______
I. Wood stove or gas or wood fireplace with tight-fitting doors...	______	______	______	______
J. Other Fireplace without tight-fitting doors..........	______	______	______	______
K. Freestanding combustion heater (such as gas, kerosene) not vented to the outdoors	______	______	______	______
L. Freestanding electric heater	______	______	______	______
M. Central or room humidifier	______	______	______	______
N. Central HEPA or electrostatic filter...	______	______	______	______
O. "SmartVent" or other similar ventilative cooling system......	______	______	______	______
P. Other (SPECIFY: _______________)	______	______	______	______

35. Where is your central heater located? (NOTE: This is the unit, or the part of the unit, that circulates heated or cooled air within your house.)

1 Attic
2 Crawlspace
3 Garage
4 Other space <u>inside</u> the house (SPECIFY: ______________________________)
5 Other space <u>outside</u> the house (SPECIFY: ______________________________)
6 House does not have central heater.
7 Don't know

36. Where is the particle air filter for your heater or central system located?

1 Ceiling register
2 In the central unit
3 Other (SPECIFY: ______________________)
4 Don't know
5 Don't have one

37. What kind of filter is it?

1 Traditional inexpensive fiberglass
2 Medium efficiency pleated filter (usually removes 40-70% of particles)
3 High efficiency pleated filter (usually removes 95% or more of particles)
4 Electrostatic filter (you wash it instead of replacing)
5 Electronic filter (usually built in, you wash it instead of replacing)
6 Other (SPECIFY: ______________________)
7 Not sure
8 Don't have one

38. How often, if ever, do you replace or clean the filter?

1 Once a month
2 Once a quarter
3 Twice a year
4 Once a year or less often
5 Never
6 Don't know
7 Don't have one

39. A. Do you use a stand-alone air filter, air purifier or air cleaner in the house?

1 Yes (SPECIFY BRAND OR MODEL: ______________________________)
2 No ⟶ **GOTO Q40**

B. **<u>IF YES</u>**: Did the literature for that unit say that it creates ozone, "supersaturated oxygen," or something similar?

1 Yes
2 No
3 Don't know

40. Thinking of how you operate your heating and air-conditioning system, what temperature settings on the thermostat do you usually use when the house is occupied during waking hours and sleeping hours? (PLEASE ENTER THE TEMPERATURES IN THE TABLE BELOW.)

	Degree (F)	Don't know	Turn Off/ Does not apply
Heating mode:			
Waking..........	______	_____	_____
Sleeping.........	______	_____	_____
Cooling mode:			
Waking..........	______	_____	_____
Sleeping.........	______	_____	_____

41. How often, if ever, do you use the thermostat's fan switch to circulate air in the home without any heating or cooling going on? (This is normally done by putting the fan switch to "On" or "Manual" and not by adjusting the heating or cooling settings.)

1 Frequently
2 Sometimes
3 Rarely
4 Never
5 Not Applicable

42. A. Do you have a gas water heater?

1 Yes
2 No ——► **GO TO Q43**

B. Where is your gas water heater located?

1 Garage
2 Other space outside the house
3 Other space inside the house
4 Attic
5 Crawlspace
6 Don't know

WHOLE-HOUSE VENTILATION SYSTEMS

43. A whole-house ventilation **system** is one that is designed and intended to provide ventilation with outdoor air to meet the needs of the whole house. Whole-house ventilation systems:

- run continuously or intermittently throughout the day
- are controlled automatically rather than manually by a switch

A. Do you have a whole-house ventilation system, such as the type of whole-house ventilation system that has air inlets that bring outdoor air into the duct system of a central heating and air conditioning system and uses that duct system to distribute fresh air throughout the house. A variation of this type of system has an outside air inlet and fan that is connected to its own duct system rather than to the duct system connected to the central heating and air conditioning system.

1 Yes, Freshvent
2 Yes, other (Please indicate the name of the system, or brand or model, if known)

____

3 No

B. Do you have an exhaust fan system, which usually consists of one or more continually or intermittently operating exhaust fans often in a bathroom or laundry room? These exhaust fans are more efficient and quieter than a normal bathroom fan. (*Do **not** include a whole-house fan, which is a large exhaust fan that is mounted in the ceiling and is usually operated manually to bring in cooler air to cool off the house during summer evenings and nights.)*

1 Yes (Please indicate the name of the system, or brand or model, if known)

____

2 No

C. Do you have a heat-recovery ventilator or an energy-recovery ventilator system that is designed to provide ventilation to the whole house?

1 Yes (Please indicate the name of the system, or brand or model, if known)

____

2 No

D. Does your house have some other type of whole-house ventilation **system** that is designed to bring in outdoor air automatically to provide ventilation to the whole house?

1 Yes (Please indicate the name of the system, or brand or model, if known)

____

2 No

IF YOU ANSWERED "YES" TO ANY OF THE 4 QUESTIONS (A, B, C, or D) ABOUT WHOLE-HOUSE VENTLATION SYSTEMS, PLEASE CONTINUE.

IF YOU ANSWERED "NO" TO ALL FOUR OF THESE, THAT YOU DO NOT HAVE SUCH A SYSTEM, PLEASE GO TO QUESTION 44 ON PAGE 10.

E. Was the operation of the system explained to you when you bought or moved into the house?

1 Yes
2 No

F. Do you feel you understand how the system works?

1 Yes
2 No

G. Do you feel you understand how to operate it properly?

1 Yes
2 No

How is the system typically used in each season? Indicate whether the system use is continuous (left on all the time), somewhat frequent, infrequent, or is never used in that season. (PLEASE CHECK ONLY ONE BOX FOR EACH SEASON.)

	Continuous	Somewhat frequent	Infrequent	Never
H. Summer	1	2	3	4
I. Fall				
J. Winter				
K. Spring				

L. What do you like about the system? (CHECK ALL THAT APPLY)

1 Fresh air
2 Quiet
3 Reduced odors
4 Reduced energy costs
5 Reduced allergies
6 Reduced concern about indoor air quality
7 Other (SPECIFY: ____________________)
8 None of the above

M. What ***don't*** you like about the system? (CHECK ALL THAT APPLY)

1 Too noisy
2 Too drafty
3 Increases odors
4 Hard to operate
5 Hard to maintain
6 Too expensive
7 Too quiet
8 Not effective (SPECIFY WHAT MAKES THE SYSTEM NOT EFFECTIVE: ____________ ____________________________________)
9 Other (SPECIFY: ____________________)
10 None of the above

N. Why did you choose the system? (CHECK ALL THAT APPLY)

1 Came with the house
2 A household member has health condition
3 Wanted filtered fresh outdoor air
4 Affordable cost
5 Good reliability
6 Reduced energy costs
7 Other (SPECIFY: __________________)

O. Please list any additional problems or provide any additional comments you have on the system.

1 NONE or SPECIFY: ________________

____

____

____

SPECIAL CHOICES

44. What special measures or choices have you or the builder taken to improve the quality of the air in your home? (CHECK ALL THAT APPLY)

- a Upgraded my central air filter
- b High efficiency vacuum cleaner with special features such as better filters to trap more particles
- c Whole house vacuum
- d Low-emission carpets, furniture, paint, or cabinets
- e Hard flooring instead of carpeting
- f Carbon monoxide alarm
- g Special range hood (e.g. higher air flow, lower noise, etc.)
- h Extra exhaust fans
- i Whole house ventilation system
- j Other (SPECIFY: ________________________)
- k None of the above

COMFORT AND ODORS

45. For any of the previous four seasons, please indicate if you have noticed a significant period when your house has experienced each of the conditions listed below. (IF NONE, LEAVE BLANK)

	Summer	Fall	Winter	Spring
A. Too hot.........	1	2	3	4
B. Too cold				
C. Too dry.........				
D. Too humid....				
E. Too drafty.....				
F. Too stagnant (not enough air movement)				
G. Too dusty......				

<u>IF ALL ARE NONE</u>: Check here

46. Similarly, have you noticed, seen, or smelled mold or mildew in the following locations? (IF NONE, LEAVE BLANK)

	Summer	Fall	Winter	Spring
A. Bathroom ..	1	2	3	4
B. Basement or crawl space.........				
C. Walls or ceilings				
D. Carpets......				
E. Closets.......				

<u>IF ALL ARE NONE</u>: Check here

47. Since you have lived in this house, has it had any of the following conditions? (CHECK ALL THAT APPLY)

- a Significant condensation on windows or other indoor surfaces?
- b Roof leaks?
- c Plumbing leaks?
- d Wall or window leaks?
- e Flooding?
- f Poor site drainage?
- g Bothersome carpet odors?
- h Bothersome cabinetry odors?
- i Other unpleasant odors? (SPECIFY: _________ ______________________________________)
- j Other moisture problems? (SPECIFY: _______ ______________________________________)
- k None of the above

How would you rate the air quality in your home during each season of the past year? Indicate whether the air quality in your home was typically very acceptable, acceptable, barely acceptable, or not acceptable. (PLEASE CHECK ONLY ONE BOX FOR EACH SEASON.)

	Very acceptable	Somewhat acceptable	Barely acceptable	Not acceptable
48. Summer....	1	2	3	4
49. Fall				
50. Winter......				
51. Spring.......				

HEALTH

Please answer the following questions for your household. Enter zero or a number under each age group category for each characteristic.

Characteristics of Household Members	Number of Adults: 18 yrs old or older	Number of Children	
		6-17 years old	5 years old or younger
52. Total number in household................	#_____	#_____	#_____
53. Number who smoke	#_____	#_____	#_____
54. Number who have allergies to outdoor pollen, mold, or grass (doctor-diagnosed)...............	#_____	#_____	#_____
55. Number who have allergy to common indoor agents such as household pets, dust mites, or cockroaches (doctor-diagnosed)...............	#_____	#_____	#_____

Characteristics of Household Members	*Number of Adults: 18 yrs old or older*	*Number of Children*	
		6-17 years old	*5 years old or younger*
56. Number who have allergy to other (or unknown) airborne agents (doctor-diagnosed)	#_____	#_____	#_____
57. Number who have asthma (doctor-diagnosed)	#_____	#_____	#_____
58. Number who have other breathing/lung problems (doctor-diagnosed)	#_____	#_____	#_____

COOKING

59. On average how many total hours a day does someone cook in the house using either the stovetop or the oven, counting only the time that the stovetop or oven is turned on? Do not include use of a microwave oven.

Weekday	Weekend
# ______ hours/day	# ______ hours/day

60. What type of stovetop do you use most often?

1 Gas
2 Electric

61. Does that stovetop have an exhaust fan or "range hood"?

1 Yes, it has a range hood with a fan in it that blows air back into the room
2 Yes, it has a range hood with a fan that exhausts the air to the outdoors
3 Yes, it has a downdraft ventilator built into it
4 No
5 Don't know

62. Is the (most frequently used) <u>oven</u> gas or electric?

1 Gas
2 Electric

63. Where is it located?

1 Directly above or below the stovetop
2 Built-in, not near the stovetop
3 Other (DESCRIBE: ____________________)

64. Does it have its own exhaust vent to the outdoors?

1 Yes
2 No
3 Don't know

65. When someone cooks with the <u>stovetop</u>, how often, if ever, do they use the exhaust fan or range hood?

1 Always
2 Only when odor or humidity seems to be an issue
3 Sometimes
4 Rarely
5 Never

66. When someone cooks with the <u>oven</u>, how often, if ever, do they use the exhaust fan or range hood?

1 Always
2 Only when odor or humidity seems to be an issue
3 Sometimes
4 Rarely
5 Never

BATHROOM VENTILATION

67. When someone in the house takes a shower or bath, how often, is the bathroom exhaust fan used?

1 Always
2 Frequently
3 Sometimes
4 Rarely
5 Never
6 There is no fan → **SKIP TO Q71, PAGE 13**

68. How many bathroom fans do you have that are controlled as follows:

#_____ With a timer knob or switch
#_____ Come on when the light comes on
#_____ Have a separate on/off switch
#_____ Are on all the time

69. Why are bathroom fans used? (CHECK ALL THAT APPLY)

a To remove moisture
b To provide noise
c To control odor
d Comes on automatically when light is turned on
e Other (PLEASE SPECIFY: _______________)

70. A. Are there times when the fan isn't used, even though the bathroom is steamy or has an unpleasant odor?

1 Yes
2 No ——► **SKIP TO Q71**

B. **IF YES**: Then, why is the fan not used? (CHECK ALL THAT APPLY)

1 Window is open
2 Don't think of it
3 Too noisy
4 Doesn't seem to help
5 Don't want to use the energy
6 Doesn't work
7 Causes draft

71. How often, if ever, do people in your household open the bathroom window for ventilation?

1 It is always open
2 It is usually open
3 Sometimes
4 Rarely
5 Never

ADDITIONAL HOUSE CHARACTERISTICS

72. On average, how many times PER WEEK does your HOUSEHOLD do the following activities in your house? (Enter number of times PER WEEK, or zero if never)

	Number of times used PER WEEK by ALL household members
Use the shower, or indoor Jacuzzi, or bath..	#_________
Use the dishwasher or washing machine	#_________
Hang clothes to dry indoors	#_________
Boil water for cooking rice, pasta, etc.…	#_________

Create other sources of steam or water vapor (SPECIFY SOURCES AND NUMBER OF TIMES PER WEEK: ________________________________)

73. Are there dogs, cats, or other furry animals that regularly spend time in the house?

1 Yes (SPECIFY: ________________________)
2 No

74. What is the most common type of built-in cabinetry in the kitchen and bathrooms?

1 Contains **any bare pressed wood or plywood** (no obvious covering on inside of cabinet)
2 Contains **any covered pressed wood or plywood** (with laminate such as white melamine on inside of cabinet)
3 Solid wood
4 Other (SPECIFY: ______________________)
5 Don't know

75. Approximately how many square feet of each of the following flooring types do you have? (Note: If you have area rugs, consider only the flooring underneath them.)

#______sq ft Vinyl or linoleum flooring
#______sq ft Wood or wood-based flooring
#______sq ft Carpeting
#______sq ft Stone or ceramic tile
#______sq ft Concrete or brick
#______sq ft Other: (SPECIFY: __________ ________________________)

76. How often are the carpets or rugs in your most heavily used rooms normally vacuumed?

1 Twice per week or more often
2 About once per week
3 About every 2 weeks
4 About every 3 to 4 weeks
5 Less often

77. Which best describes the walls in your house?

1 Mostly wallpaper
2 Some wallpaper and some painted
3 Mostly painted
4 All painted
5 Other (SPECIFY: ________________________)

78. Do you or other household members regularly use any of the following in your home? (CHECK ALL THAT APPLY)

	Yes	No
A. Burn candles or incense	1	2
B. Paints, glues, or solvents (for hobbies, home repairs, or other purposes)............		
C. Pesticide sprays or foggers .		
D. Plug-in or spray deodorizers		
E. Potpourri..........................		
F. Other sources of smoke or fumes (SPECIFY: ______________________)		

79. A. Does the house have an attached garage, or a parking area beneath the home?

1 Yes
2 No ——► **GOTO Q80**

B. **<u>IF YES</u>**: How many functioning cars or trucks are typically parked there?

1 Zero
2 One
3 Two
4 Three or more

80. Please enter the <u>average number of hours per day</u> that no one is home on weekdays and weekends , for the daytime, evening, and nighttime periods indicated below. Enter zero for any period in which someone is always in the home.

		Weekday	Weekend
Daytime (up to 12 hours)	6 AM - 6 PM	# __________	# __________
Evening (up to 5 hours)	6 PM - 11 PM	# __________	# __________
Nighttime (up to 7 hours)	11 PM 6 AM	# __________	# __________

81. After this survey, we would like to make some measurements of the air quality in the homes of some of the people who answered this questionnaire. Participants would receive their results and a small incentive payment. Would you be willing to participate in this second part of the study?

1 Yes
2 No

The next questions will help us interpret the results of the study. All responses will be kept confidential.

82. What is your household income?

1 Under $35,000
2 $35,000 - $49,999
3 $50,000 - $74,999
4 $75,000 - $99,999
5 $100,000 - $149,999
6 $150,000 or more

83. What ethnic or racial group do you consider yourself? (CHECK ALL THAT APPLY)

a Black or African-American
b Native American
c Hispanic or Latino
d Filipino
e Asian
f Pacific Islander
g White or Caucasian, or
h Some other group? (SPECIFY: ______________)
i Mixed race (SPECIFY: ____________________)

84. A. Who in your household is most familiar with how the windows, doors, and fans are used to ventilate your home? (PLEASE CHECK THE ONE THAT BEST FITS)

1 You
2 Another person (SPECIFY OTHER PERSON: ________________________________)
3 Both you and another person (SPECIFY OTHER PERSON: __________________)
4 Don't Know

B. **<u>IF YOU ANSWERED 2 OR 3 TO QUESTION 84 ABOVE</u>**, did you consult with this other person to help complete this survey?

1 Yes
2 No

Thank you for taking the time to help us with this important research.

If you have any comments about the survey, or further information about indoor air quality or ventilation in your home, please provide them in the space below.

COMMENTS: ____________________________________

____

____

____

____

____

____

IMPORTANT ⟶ **GO TO LAST PAGE**

85. We want to send you a check for $30 to thank you for your help with this important study. To make sure our records are correct and that the check will reach you, please fill in your name and address. Please print.

Name: ____

Address: ________________________________ Apt # ________

____________________________ ___________ ____________
City State Zip code

Thank you very much for your help

Now please mail this survey back to us in the enclosed envelope.
You don't need stamps.

Appendix C

Summary of Window and Door Usage by Season and Weekend/Weekday

Appendix C

Summary of Window and Door Usage by Season and Weekend/Weekday

The tables in this appendix show the percentage of homes with windows open less than the specified number of hours during the period specified. For example, from the first table (Hours during weekdays 6 p.m.–6 p.m.), the first row shows that 40% of homes had kitchen windows open 0 hours in summer; 49% had kitchen windows open 1 hour or less; 61% had windows open 2 hours or less; and so on. These tables summarize the raw data, excluding people who did not answer the questions (questions 10–25) about the temporal details of their ventilation behavior. Specifically, the results in these tables have not been modified to impute additional hours in order to make them less inconsistent with reported total hours of ventilation as reported in questions 28–31. All respondents indicated an integer number of hours, so percentiles can be determined from these tables without interpolation. For instance, Table C-1 shows see that 49% of houses report less than or equal to 1 hour of summer kitchen ventilation, and 61% report less than or equal to 2 hours. Therefore all of the percentiles from 49% to 61%, including the median (50%), are exactly 2 hours.

A small fraction of people (less than 2% in each case) indicated a number of hours greater than the total number of hours in the time period in question. We did not exclude those respondents. If those respondents intended to indicate that the window is open for the entire time period, then changing the final entry in each column to 100% will correctly handle the problem. For instance, in the second table (Weekday evenings 6 p.m.–11 p.m.), about 1% of respondents indicated (impossibly) that they leave their kitchen windows open for *more* than 5 hours during this time period in summer; if these people leave their windows open for the full 5 hours during that time slot, then changing the last entry in that row to 100 (from 99) will give the correct result.

Table C-1. Percent of homes with windows open less than or equal to a given number of hours on weekday days, by season and room

Percent of homes with windows open less than (or equal to) the given number of hours	Room	Hours During Weekday Days (6 p.m.–6 p.m.)												
		0	1	2	3	4	5	6	7	8	9	10	11	12
Summer	Kitchen	40	49	61	68	73	77	83	84	88	89	92	92	100
	Bedrooms	40	47	58	64	70	73	78	79	83	84	86	87	100
	Bath/laundry/ utility	56	61	68	70	73	75	78	79	81	81	83	83	100
	Other	58	64	72	77	82	84	87	88	91	91	93	93	100
Fall	Kitchen	39	50	63	71	78	82	87	88	92	92	94	95	100
	Bedrooms	42	51	64	69	75	79	83	84	88	88	91	91	100
	Bath/laundry/ utility	58	65	71	74	78	80	82	83	86	87	88	88	100
	Other	61	69	78	81	85	88	91	92	94	94	95	95	100
Winter	Kitchen	52	71	85	90	93	95	96	97	98	98	99	100	100
	Bedrooms	57	73	85	89	92	93	95	95	96	97	97	100	100
	Bath/laundry/ utility	64	75	82	85	88	89	90	90	92	92	93	93	100
	Other	75	85	93	94	96	97	98	99	99	100	100	100	100
Spring	Kitchen	37	45	60	69	76	80	86	87	92	92	94	95	100
	Bedrooms	38	46	60	68	75	78	84	85	88	89	91	91	100
	Bath/laundry/ utility	58	64	71	74	78	80	82	83	87	87	88	88	100
	Other	59	66	75	80	85	87	91	91	94	94	95	95	100

Table C-2. Percent of homes with windows open less than or equal to a given number of hours on weekday days, by season and room

Percent of homes with windows open less than (or equal to) the given number of hours	Room	Hours During Weekday Evenings (6 p.m.–11 p.m.)					
		0	1	2	3	4	5
Summer	Kitchen	36	44	65	77	87	99
	Bedrooms	30	37	53	64	73	98
	Bath/laundry/utility	57	62	70	74	78	99
	Other	53	59	72	82	88	99
Fall	Kitchen	42	57	74	85	91	100
	Bedrooms	41	52	68	79	84	99
	Bath/laundry/utility	63	70	79	82	85	99
	Other	62	71	82	89	92	99
Winter	Kitchen	69	86	95	97	98	100
	Bedrooms	70	84	91	94	95	100
	Bath/laundry/utility	74	84	89	91	92	100
	Other	83	92	97	98	98	100
Spring	Kitchen	39	53	73	84	90	99
	Bedrooms	37	49	66	78	84	99
	Bath/laundry/utility	62	69	78	82	85	99
	Other	62	70	80	88	92	99

Table C-3. Percent of homes with windows open less than or equal to a given number of hours on weekday evenings, by season and room

Percent of homes with windows open less than (or equal to) the given number of hours	Room	Hours During Weekday Nights (11 p.m.–6 p.m.)							
		0	1	2	3	4	5	6	7
Summer	Kitchen	83	85	87	87	88	89	91	100
	Bedrooms	49	52	55	57	60	63	67	98
	Bath/laundry/utility	68	70	72	73	74	76	78	99
	Other	80	83	86	88	89	90	91	100
Fall	Kitchen	87	90	92	93	94	95	96	100
	Bedrooms	66	70	74	77	79	81	84	99
	Bath/laundry/utility	78	81	83	84	85	87	88	99
	Other	86	88	91	92	93	94	95	100
Winter	Kitchen	95	96	98	98	99	99	99	100
	Bedrooms	86	90	92	92	93	94	94	100
	Bath/laundry/utility	86	90	92	92	92	93	93	100
	Other	94	97	98	98	99	99	99	100
Spring	Kitchen	86	90	92	93	94	95	96	100
	Bedrooms	66	71	75	77	80	82	84	100
	Bath/laundry/utility	77	80	83	84	85	87	88	100
	Other	86	89	91	92	93	94	95	100

Table C-4. Percent of homes with windows open less than or equal to a given number of hours on weekend days, by season and room

Percent of homes with windows open less than (or equal to) the given number of hours	Room	Hours During Weekend Days (6 a.m.–6 p.m.)												
		0	1	2	3	4	5	6	7	8	9	10	11	12
Summer	Kitchen	30	35	46	54	63	67	76	77	85	86	90	90	100
	Bedrooms	30	35	47	54	61	64	71	72	79	80	83	10 0	100
	Bath/laundry/ utility	51	56	63	65	70	72	75	76	79	79	82	82	100
	Other	50	56	65	69	76	79	83	84	89	89	92	92	100
Fall	Kitchen	28	37	49	58	68	74	82	83	89	90	93	94	100
	Bedrooms	33	41	53	61	69	74	79	80	85	86	89	89	100
	Bath/laundry/ utility	53	61	67	70	75	78	80	81	85	85	87	87	100
	Other	54	60	69	75	80	83	88	88	92	92	94	94	100
Winter	Kitchen	37	56	77	84	91	92	94	95	97	98	98	98	100
	Bedrooms	46	64	78	84	90	91	94	94	96	96	96	97	100
	Bath/laundry/ utility	58	71	79	83	86	88	89	90	92	92	93	94	100
	Other	67	79	89	92	94	96	97	98	98	99	99	99	100
Spring	Kitchen	26	33	47	56	67	72	80	82	88	89	93	93	100
	Bedrooms	29	37	49	58	66	72	79	80	85	86	89	89	100
	Bath/laundry/ utility	52	59	66	70	75	78	80	81	85	85	87	87	100
	Other	51	58	68	73	80	82	88	88	92	93	94	94	100

Table C-5. Percent of homes with windows open less than or equal to a given number of hours on weekend evenings, by season and room

Percent of homes with windows open less than (or equal to) the given number of hours	Room	Hours During Weekend Evenings (6 p.m.–11 p.m.)					
		0	1	2	3	4	5
Summer	Kitchen	34	42	60	73	83	99
	Bedrooms	29	35	50	62	71	97
	Bath/laundry/ utility	56	61	69	73	77	98
	Other	52	58	71	80	87	99
Fall	Kitchen	41	54	72	83	90	99
	Bedrooms	40	51	66	77	83	99
	Bath/laundry/ utility	63	70	78	82	85	99
	Other	61	70	80	88	91	99
Winter	Kitchen	68	84	94	96	98	100
	Bedrooms	69	81	90	94	95	100
	Bath/laundry/ utility	75	83	88	91	92	100
	Other	82	91	96	97	98	100
Spring	Kitchen	39	51	70	82	90	99
	Bedrooms	36	46	64	75	83	98
	Bath/laundry/ utility	62	68	76	80	84	99
	Other	60	69	79	86	91	99

Table C-6. Percent of homes with windows open less than or equal to a given number of hours on weekend nights, by season and room

Percent of homes with windows open less than (or equal to) the given number of hours	Room	**Hours During Weekend Nights (11 p.m.–6 a.m.)**							
		0	1	2	3	4	5	6	7
Summer	Kitchen	81	84	86	87	88	89	91	100
	Bedrooms	48	51	55	57	59	63	67	98
	Bath/laundry/ utility	68	70	72	73	74	76	78	99
	Other	80	82	85	87	88	89	90	99
Fall	Kitchen	86	89	92	93	94	95	96	100
	Bedrooms	66	70	73	76	79	81	83	99
	Bath/laundry/ utility	79	81	83	84	85	86	87	100
	Other	86	88	90	91	93	94	94	100
Winter	Kitchen	94	96	98	98	98	99	99	100
	Bedrooms	85	89	91	92	93	93	94	99
	Bath/laundry/ utility	88	91	92	92	92	93	94	100
	Other	94	97	98	98	98	99	99	100
Spring	Kitchen	86	89	91	93	93	94	95	100
	Bedrooms	66	70	74	76	79	81	84	99
	Bath/laundry/ utility	77	80	82	83	84	86	87	100
	Other	86	88	91	91	92	93	94	100

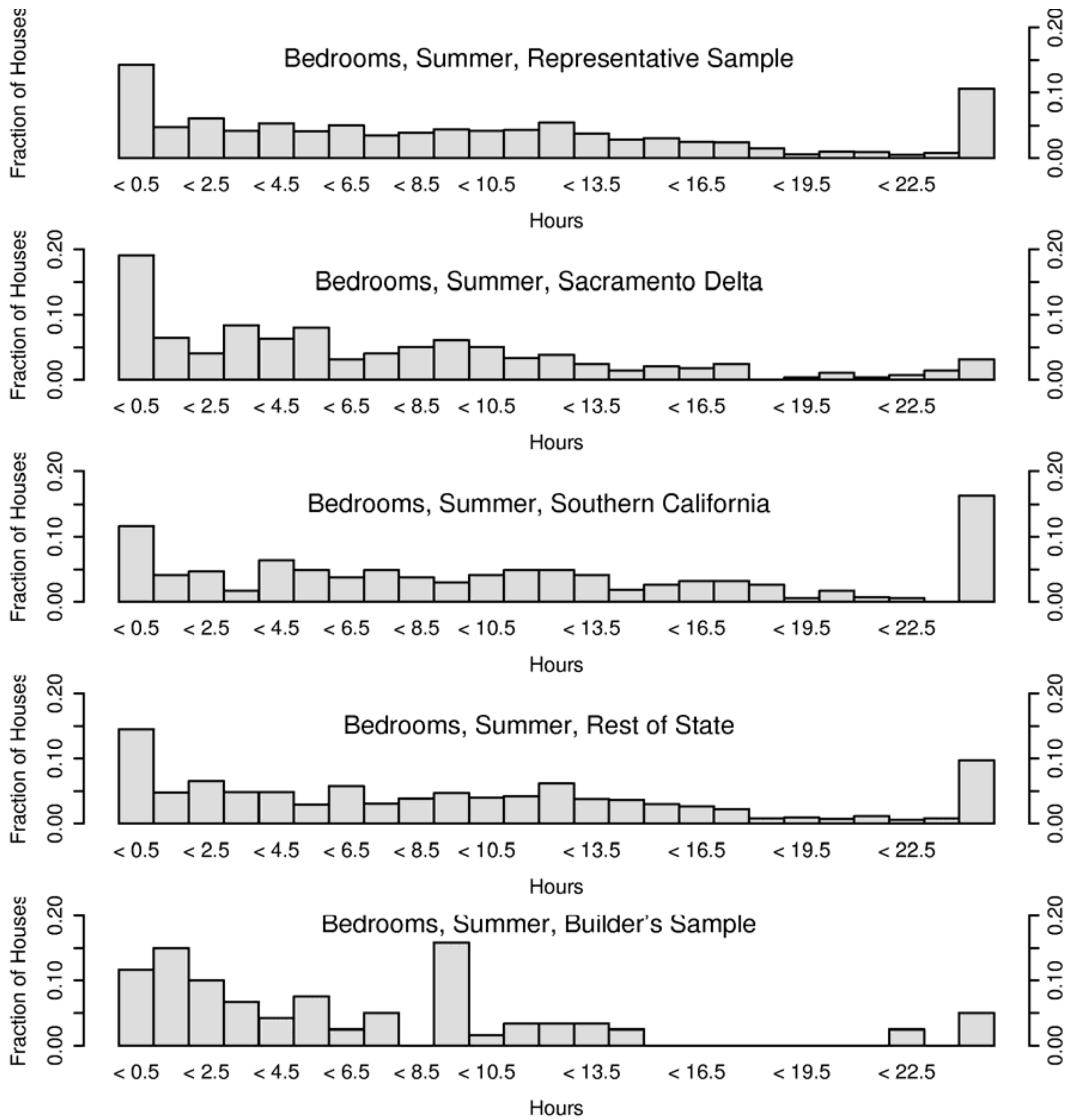


Figure C-1. Histogram showing fraction of homes that report specific hours of window opening in summer, for each survey stratum

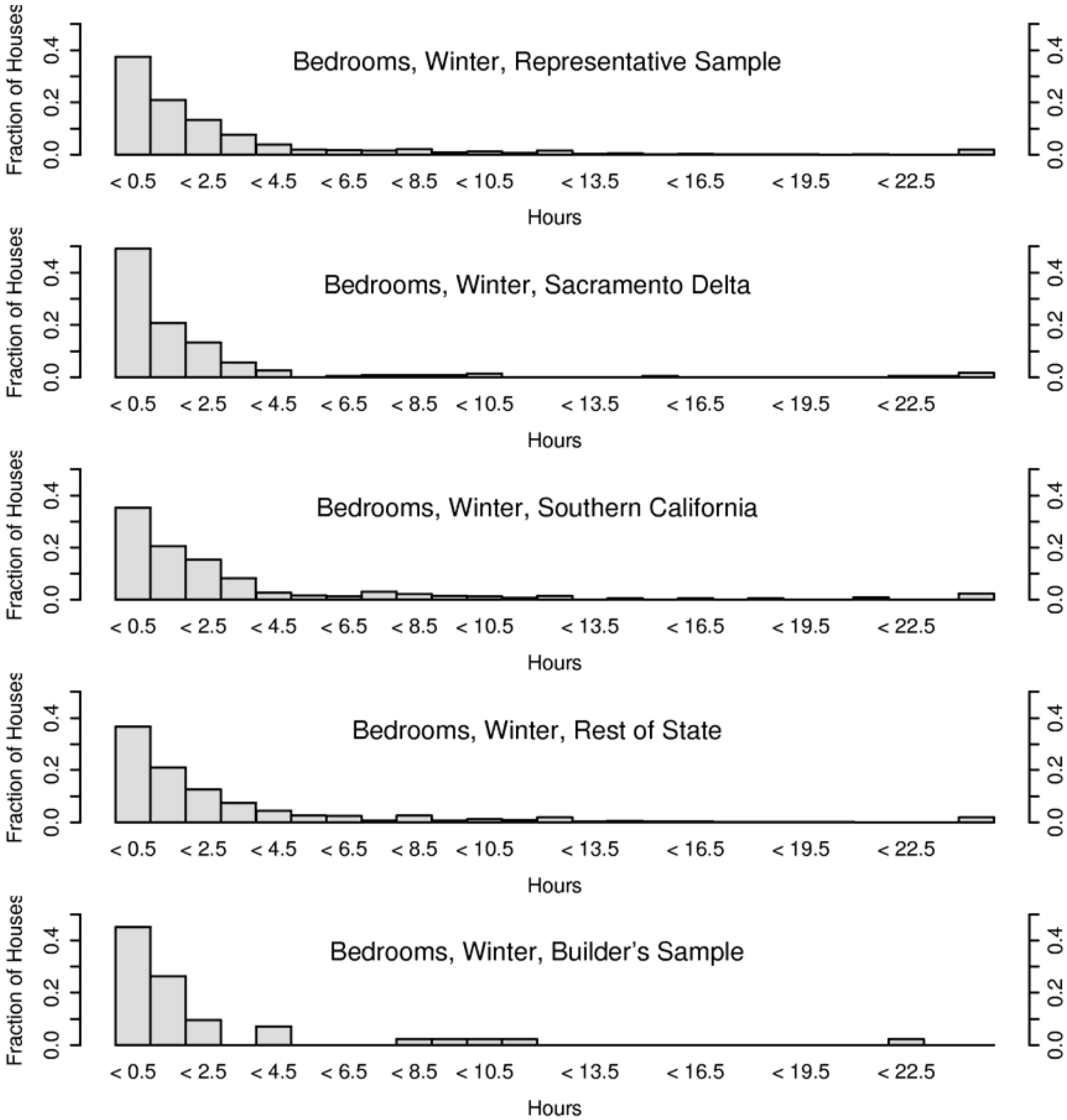


Figure C-2. Histogram showing fraction of homes that report specific hours of window opening in winter, for each survey stratum

From the time-specific data on periods of time with windows open in various rooms, it is possible to determine the minimum and maximum possible number of hours in each time slot during which windows are open. For instance, if someone reports that on average a bedroom window is open for 3 hours on a weekday evening, and that a bathroom window is open for 2 hours, this could represent as little 3 hours during which at least one window is open (if both windows are open at the same time) or as many as 5 hours (if the windows are open at different times). Table C-7A through C-7D summarize the minimum possible numbers of hours with windows open, by time slot and season, for each sampling region. Tables C-8A through C-8D summarize the maximum possible number of hours with windows open, by time slot and season, for each sampling region. These tables do not have direct bearing on estimating ventilation effectiveness because they do not include the amount by which the windows are open: windows open a crack are counted the same as windows open wide. See the discussion of Effective Specific Leakage Area, or ESLA, in the body of the report, for an investigation of ventilation effectiveness.

In every season and every stratum, at least one survey reported 0 hours with a window open, and at least one survey reported 24 hours with a window open.

Table C-7A. Statistical distribution of the minimum possible number of daily hours with at least one window open in summer, by region and weekend/weekday

Hours with at least one window open, in Summer		Mean	Standard Deviation	Percent of Houses						
				5%	10%	25%	50%	75%	90%	95%
Sacramento Delta Area	Wkend	9.2	7.0	0	0	4	9	13	20	24
	Wkday	10.1	7.0	0	1	4	9	15	24	24
Southern California Coast	Wkend	14.2	7.9	1	3	8	13	24	24	24
	Wkday	14.9	7.8	1	3	8	15	24	24	24
Rest of State	Wkend	11.4	7.9	0	1	5	11	17	24	24
	Wkday	12.2	7.9	0	1	6	12	18	24	24
Entire State	Wkend	11.8	8.0	0	1	5	12	18	24	24
	Wkday	12.6	7.9	0	2	6	12	20	24	24

Table C-7B. Statistical distribution of the minimum possible number of hours with at least one window open in fall, by region and weekend/weekday

Hours with at least one window open, in Fall		Mean	Standard Deviation	Percent of Houses						
				5%	10%	25%	50%	75%	90%	95%
Sacramento Delta Area	Wkend	7.1	7.0	0	0	2	5	11	18	24
	Wkday	7.7	7.1	0	0	2	6	12	19	24
Southern California Coast	Wkend	10.8	8.1	0	1	4	10	17	24	24
	Wkday	11.9	8.1	0	1	6	11	19	24	24
Rest of State	Wkend	8.9	7.7	0	0	3	7	13	24	24
	Wkday	9.6	7.8	0	0	3	8	15	24	24
Entire State	Wkend	9.2	7.8	0	0	3	7	14	24	24
	Wkday	10.0	7.8	0	0	3	8	15	24	24

Table C-7C. Statistical distribution of the minimum possible number of hours with at least one window open in winter, by region and weekend/weekday

Hours with at least one window open, in Winter		Mean	Standard Deviation	Percent of Houses						
				5%	10%	25%	50%	75%	90%	95%
Sacramento Delta Area	Wkend	2.5	5.2	0	0	0	0	2	8	12
	Wkday	2.7	5.1	0	0	0	0	3	8	13
Southern California Coast	Wkend	5.1	7.2	0	0	0	2	7	18	24
	Wkday	5.4	7.1	0	0	0	2	7	18	24
Rest of State	Wkend	4.0	6.0	0	0	0	2	5	12	18
	Wkday	4.4	6.0	0	0	0	2	6	13	18
Entire State	Wkend	4.1	6.3	0	0	0	1.5	5	13	24
	Wkday	4.6	6.2	0	0	0	2	6	13	23

Table C-7D. Statistical distribution of the minimum possible number of hours with at least one window open in spring, by region and weekend/weekday

Hours with at least one window open, in Spring		Mean	Standard Deviation	Percent of Houses						
				5%	10%	25%	50%	75%	90%	95%
Sacramento Delta Area	Wkend	7.9	6.7	0	0	2	6	12	18	24
	Wkday	8.8	7.1	0	0	3	7	13	21	24
Southern California Coast	Wkend	11.7	8.1	0	1	5	10	19	24	24
	Wkday	12.5	8.0	0	2	6	11	21	24	24
Rest of State	Wkend	9.8	7.9	0	0	3	8	15	24	24
	Wkday	10.5	7.9	0	1	4	9	16	24	24
Entire State	Wkend	10.0	7.9	0	1	3	8	16	24	24
	Wkday	10.8	7.9	0	1	4	9	17	24	24

Table C-8A. Statistical distribution of the maximum possible number of hours with at least one window open in summer, by region and weekend/weekday

Hours with at least one window open, in Summer		Mean	Standard Deviation	Percent of Houses						
				5%	10%	25%	50%	75%	90%	95%
Sacramento Delta Area	Wkend	13.0	8.3	0	0	5	12	20	24	24
	Wkday	14.2	8.1	0	1	8	16	22	24	24
Southern California Coast	Wkend	16.9	7.6	2	5	12	18	24	24	24
	Wkday	18.0	7.3	3	6	13	21	24	24	24
Rest of State	Wkend	14.7	8.3	0	1	8	16	24	24	24
	Wkday	15.7	8.2	0	2	10	17	24	24	24
Entire State	Wkend	15.0	8.2	0	2	9	16	24	24	24
	Wkday	16.1	8.1	0	2.5	11	17	24	24	24

Table C-8B. Statistical distribution of the maximum possible number of hours with at least one window open in fall, by region and weekend/weekday

Hours with at least one window open, in Fall		Mean	Standard Deviation	Percent of Houses						
				5%	10%	25%	50%	75%	90%	95%
Sacramento Delta Area	Wkend	10.2	8.3	0	0	2	9	17	24	24
	Wkday	11.1	8.5	0	0	3	11	19	24	24
Southern California Coast	Wkend	13.9	8.1	0	1	8	15	24	24	24
	Wkday	15.5	7.8	0	3	12	17	24	24	24
Rest of State	Wkend	12.4	8.4	0	0	5	12	20	24	24
	Wkday	13.3	8.4	0	0	6	14	22	24	24
Entire State	Wkend	12.5	8.4	0	0	5	12	20	24	24
	Wkday	13.6	8.3	0	0	6	15	23	24	24

Table C-8C. Statistical distribution of the maximum possible number of hours with at least one window open in winter, by region and weekend/weekday

Hours with at least one window open, in Winter		Mean	Standard Deviation	Percent of Houses						
				5%	10%	25%	50%	75%	90%	95%
Sacramento Delta Area	Wkend	3.6	6.2	0	0	0	0	4	12	19
	Wkday	4.1	6.3	0	0	0	0	6	14	19
Southern California Coast	Wkend	6.9	8.1	0	0	0	4	12	24	24
	Wkday	7.7	8.0	0	0	0	5	12	24	24
Rest of State	Wkend	5.8	7.1	0	0	0	3	9	17	24
	Wkday	6.6	7.3	0	0	0	4	12	18	24
Entire State	Wkend	5.8	7.4	0	0	0	2.5	9	18	24
	Wkday	6.5	7.4	0	0	0	4	11	19	24

Table C-8D. Statistical distribution of the maximum possible number of hours with at least one window open in spring, by region and weekend/weekday

Hours with at least one window open, in Spring		Mean	Standard Deviation	Percent of Houses						
				5%	10%	25%	50%	75%	90%	95%
Sacramento Delta Area	Wkend	13.0	8.3	0	0	4	12	18	24	24
	Wkday	14.2	8.1	0	0	6	13	20	24	19
Southern California Coast	Wkend	16.9	7.6	0	2	9	17	24	24	24
	Wkday	18.0	7.3	0	3	11	17	24	24	24
Rest of State	Wkend	14.7	8.3	0	0	6	13	23	24	24
	Wkday	15.7	8.2	0	1	8	16	24	24	24
Entire State	Wkend	15.0	8.2	0	1	6	14	23	24	24
	Wkday	16.1	8.1	0	1	8	16	24	24	24

Table C-9A. Statistical distribution of summer hours of no-, low-, medium-, and high-ventilation hours, by stratum. Percentiles summarize the cumulative distribution function; for instance, 50% of homes in the Sacramento Delta area reported eight or fewer hours with "no ventilation."

Hours of ventilation at specified level				Percentage of homes						
Hours with specified ventilation	Vent. Level	Mean	Std Dev	5%	10%	25%	50%	75%	90%	95%
Sacramento Delta Area	No	8.6	7.9	0	0	0	8	15	20	22
	Low	4.5	5.9	0	0	0	2	7	12	19
	Med	4.7	5.8	0	0	0	3	7	12	17
	High	6.3	6.9	0	0	0	4	10	16	24
Southern California Coast	No	5.9	7.4	0	0	0	0	11	18	20
	Low	4.9	5.8	0	0	0	4	7	12	20
	Med	6.0	6.6	0	0	0	4	9	14	24
	High	7.2	7.7	0	0	0	5	12	20	24
Rest of State	No	7.6	7.6	0	0	0	6	13	20	21
	Low	4.0	5.2	0	0	0	2	6	10	12
	Med	4.7	5.5	0	0	0	4	8	12	16
	High	7.7	7.6	0	0	0	6	12	20	24
Entire State	No	7.2	7.6	0	0	0	6	13	20	21
	Low	4.3	5.4	0	0	0	2	6	12	16
	Med	5.1	5.9	0	0	0	4	8	12	18
	High	7.4	7.5	0	0	0	6	12	20	24

Table C-9B. Statistical distribution of fall hours of no-, low-, medium-, and high-ventilation hours, by stratum. Percentiles summarize the cumulative distribution function; for instance, 50% of homes in the Sacramento Delta area reported11 or fewer hours with "no ventilation."

Hours of ventilation at specified level				Percentage of homes						
Hours with specified ventilation	Vent. Level	Mean	Std Dev	5%	10%	25%	50%	75%	90%	95%
Sacramento Delta Area	No	11.4	8.8	0	0	2	11	20	23	24
	Low	5.3	6.6	0	0	0	3	8	15	22
	Med	3.9	5.5	0	0	0	2	6	12	14
	High	3.3	5.5	0	0	0	0	4	10	14
Southern California Coast	No	8.5	8.7	0	0	0	6	17	22	24
	Low	6.7	6.8	0	0	0	6	10	18	24
	Med	5.4	6.0	0	0	0	4	8	12	20
	High	3.5	5.1	0	0	0	1	6	10	12
Rest of State	No	10.1	8.4	0	0	0	9	18	22	24
	Low	5.2	6.0	0	0	0	4	8	12	19
	Med	4.8	5.6	0	0	0	4	8	12	16
	High	3.9	5.8	0	0	0	1	6	12	18
Entire State	No	9.8	8.6	0	0	0	9	18	22	24
	Low	5.6	6.3	0	0	0	4	8	14	20
	Med	4.9	5.7	0	0	0	3	8	12	16
	High	3.7	5.6	0	0	0	1	6	12	16

Table C-9C. Statistical distribution of winter hours of no-, low-, medium-, and high-ventilation hours, by stratum. Percentiles summarize the cumulative distribution function; for instance, 50% of homes in the Sacramento Delta area reported 22 or fewer hours with "no ventilation."

Hours of ventilation at specified level				Percentage of homes						
Hours with specified ventilation	Vent. Level	Mean	Std Dev	5%	10%	25%	50%	75%	90%	95%
Sacramento Delta Area	No	18.5	7.7	0	2	16	22	24	24	24
	Low	3.7	6.1	0	0	0	1	4	11	20
	Med	1.2	3.3	0	0	0	0	1	4	6
	High	0.7	2.7	0	0	0	0	0	2	3
Southern California Coast	No	15.0	9.0	0	0	8	20	23	24	24
	Low	6.3	7.8	0	0	0	2	10	20	24
	Med	1.7	3.3	0	0	0	0	3	6	8
	High	1.0	2.9	0	0	0	0	0	3	5
Rest of State	No	15.8	8.4	0	0	10	20	23	24	24
	Low	5.0	6.8	0	0	0	2	7	15	24
	Med	2.0	3.8	0	0	0	0	3	6	10
	High	1.2	3.4	0	0	0	0	0	4	6
Entire State	No	15.9	8.5	0	0	10	20	23	24	24
	Low	5.2	7.0	0	0	0	2	7	16	24
	Med	1.8	3.6	0	0	0	0	2	6	8
	High	1.1	3.2	0	0	0	0	0	3	6

Table C-9D. Statistical distribution of spring hours of no-, low-, medium-, and high-ventilation hours, by stratum. Percentiles summarize the cumulative distribution function; for instance, 50% of homes in the Sacramento Delta area reported 9 or fewer hours with “no ventilation.”

Hours of ventilation at specified level				Percentage of homes						
	Vent. Level	Mean	Std Dev	5%	10%	25%	50%	75%	90%	95%
Sacramento Delta Area	No	10.5	8.6	0	0	0	9	19	23	24
	Low	5.0	6.3	0	0	0	3	8	12	21
	Med	4.2	5.4	0	0	0	3	6	12	13
	High	4.5	5.8	0	0	0	2	6	12	16
Southern California Coast	No	7.8	8.1	0	0	0	6	15	20	22
	Low	6.5	6.6	0	0	0	5	10	16	22
	Med	5.6	5.9	0	0	0	4	8	12	20
	High	4.1	5.5	0	0	0	2	6	12	16
Rest of State	No	9.2	8.3	0	0	0	8	18	21	23
	Low	4.9	5.7	0	0	0	4	8	12	18
	Med	5.3	5.7	0	0	0	4	8	12	16
	High	4.6	6.0	0	0	0	2	8	12	18
Entire State	No	9.0	8.3	0	0	0	8	18	22	23
	Low	5.3	6.1	0	0	0	4	8	12	20
	Med	5.2	5.7	0	0	0	4	8	12	16
	High	4.5	5.8	0	0	0	2	7	12	17

Appendix D

Effective Specific Leakage Area (ESLA)

This Appendix contains the information for the Effective Specific Leakage Area (ESLA)

Appendix D:

Effective Specific Leakage Area

The purpose of this appendix is to calculate the effective specific leakage area (ESLA) resulting from window opening behavior. The ESLA will serve as a derived parameter that can be compared to envelope air leakage and the used to estimate a contribution towards meeting minimum ventilation requirements.

Specific Leakage Area (SLA) is related to Effective Leakage Area (ELA) as follows:

$$SLA \equiv 10,000 \cdot \frac{ELA}{FloorArea}$$

Where the ELA and floor area are measured in the same units. (NOTE: The 10,000 above is part of the definition and is dimensionless,; it will not change. The numbers in the equation below have units and also may change as we work the problem.)

For our purposes the equation becomes as follows with floor area coming from Question 4 (i.e., in sq. ft).

$$SLA_{season} = \frac{1}{24}\left(\frac{2000 \cdot LOW_{season} + 10,000 \cdot MED_{season}}{FloorArea / \sqrt{n_{x1}}} + 40 \cdot HIGH_{season}\right)$$

Where *LOW*, *MED*, and *HIGH* are the numbers of hours entered in questions 28-31; and where n_{x1} =1 plus
If Q32=1 add 1 to n_{x1}; if Q32=2 add .5; if Q32=3 add 0.1
If Q33=1 add 1 to n_{x1}; if Q33=2 add .5; if Q33=3 add 0.1
The coefficients in the above equation are our best estimates of what people mean when they respond to the LOW, MED, HIGH queries of Q28-31. Specifically,

- LOW: We assume 1-2 windows of 2'-4' width open 1 inch with a discharge coefficient of 0.3-0.6. This leads to a range of possible values, but we choose 0.2 sq. ft. of ELA as being a representative number
- MED: We assume 1-2 windows open 4-12 inches with a discharge coefficient of 0.4-0.6. We choose a representative value of 1 sq. ft. which is also equivalent to five times LOW
- HIGH[1]: In this case we are assuming that the number of windows open will scale with the size of the house. A house typically has between 5-15% openable area (as a function of floor area). Here we assume that almost all of it is open at 1-5% of maximum with a discharge coefficient of 0.5-0.6. We choose an SLA of 40 as the representative value in this range. (For a cross-ventilated 1700 sq. ft. house HIGH is roughly 4 times MED, but can go higher.)

[1] This level is "high" from the point of view of indoor air quality purposes, but it is not high from the point of view of ventilative cooling purposes. A common assumption is that one needs 5-10 ACH for ventilative cooling which would require a 3-5 times larger window opening than is required to meet our high level for IAQ. Thus the number of "high" hours is biased high if one wished to interpret them for ventilative cooling.

It may be interesting to see this variable on its own, but it must be convolved with the Q10-25 to find out how much it really matters.

First we need to find the total number of average Number-of-Open-Windows -in-a-season. We will generate this from the raw data starting from questions 10-25. We convert that data in those tables into hours-Windows-are-Open-by-Room-Season-and-Time, or *WORST* for short:

$$NOW_{season} = \frac{1}{24} \sum_{room,time} \left[\frac{5}{7} \cdot WORST_{season,room,time,\mathrm{WEEKDAY}} + \frac{2}{7} \cdot WORST_{season,room,time,\mathrm{WEEKEND}} \right]$$

Which means that the average window opening has an SLA (i.e., a Specific SLA) of

$$SSLA_{season} = \frac{SLA_{season}}{NOW_{season}}$$

Which tells us how much each person opens their average window(s).

TEMPORAL VENTILATION EFFECTIVENESS

Before we can compare this to a steady SLA such as envelope leakage we need to estimate the efficiency of the reported window opening pattern. There are some intermediate calculations to get us there.

$$X1_{season,room,time,dayofweek} = \left(1 - \frac{WORST_{season,room,time,dayofweek}}{HOP_{time}}\right)^{n_{x1}}$$

(which is the effective fraction of time each room does not supply ventilation)
Where HOP_{time} is the number-of-Hours-Open-Possible for each time slot (i.e. 5, 7, or 12)

$$X2_{season,time,dayofweek} = X1_{season,\mathrm{ALLOTHER},time,dayofweek} \cdot X1_{season,\mathrm{BEDROOM},time,dayofweek} \cdot \frac{(X1_{season,\mathrm{BATHROOM},time,dayofweek} + X1_{season,\mathrm{KITCHEN},time,dayofweek})}{2}$$

(which is the effective fraction of time the house is not ventilated)

So the efficiency in each time period becomes the following:

$$ESP_{season,time,dayofweek} = (1 - X2^2_{season,time,dayofweek})^{\frac{HOP_{time}}{6}}$$

We then average the efficiency over each time slot to take into account the seasonal temporal ventilation efficiency:

$$ESP_{season} = \sum_{time} \left(\frac{5}{168} HOP_{time} \cdot ESP_{season,time,WEEDAY} + \frac{2}{168} HOP_{time} \cdot ESP_{season,time,WEEKEND} \right)$$

ESLA

We can now define the Effective SLA f for each season

$$ESLA_{season} = SSLA_{season} \cdot ESP_{season} \cdot \sum_{room,time} \left(\frac{5}{7} WORST_{season,room,time,WEEKDAY} + \frac{2}{7} WORST_{season,room,time,WEEKEND} \right)$$

The Fractional-Standard-Deviation is

$$FSD_{season} = \frac{1}{ESLA_{season}} \cdot \sqrt{\sum_{time} \frac{1}{24} \left[\begin{array}{l} \frac{5}{7} \cdot \left(ESLA_{season,time,\mathrm{WEEKDAY}} - ESLA_{season} \right)^2 + \\ \frac{2}{7} \cdot \left(ESLA_{season,time,\mathrm{WEEKEND}} - ESLA_{season} \right)^2 \end{array} \right]}$$

The ESLA for windows (combined with infiltration) needs to be compared to that necessary to meet ventilation standards. The data in the table below was generated from weather files for each of the climate zones and a target rate of 0.35 ach. The specific infiltration for each season of the 16 climate zones was generated and then used to estimate the specific leakage area necessary to generate 0.35 air changes per hour. This value may or may not meet standard 62.2 depending on the size of the house, but it is a reasonable target. Typically about 1/3 of this value could be expected from infiltration from typical air leakage.

Minimum ESLA necessary to meet 0.35 ACH				
	Spring	Summer	Fall	Winter
CZ1	3.99	4.84	4.83	4.05
CZ2	5.23	5.83	5.72	4.55
CZ3	3.85	4.23	4.69	3.95
CZ4	4.74	5.57	5.37	4.30
CZ5	4.30	4.81	4.91	4.51
CZ6	4.42	5.44	5.39	4.64
CZ7	4.60	5.39	5.49	4.68
CZ8	5.40	6.47	6.19	5.09
CZ9	5.42	5.63	5.87	5.16
CZ10	5.41	7.15	6.47	5.29
CZ11	4.47	4.98	4.54	3.50
CZ12	4.47	4.61	4.95	3.80
CZ13	4.86	5.75	5.56	4.26
CZ14	4.68	5.36	5.15	4.20
CZ15	5.14	4.61	5.89	5.07
CZ16	3.87	5.36	4.01	3.34

Note 1) This table is the ESLA necessary to provide 0.35 ACH. This may or may not meet 62.2 depending on the size of the house.

Note 2) Standard 62.2 assumes there is infiltration of 2 cfm/100 sq. ft (floor area). The base (mechanical) rate of 62.2 should be compared to the window part of the ESLA.

Note 3) To generate the numbers in the table above the 16 standard Title 24 climate zone files were used generate a default specific leakage (see ASHRAE Standard 119) for each climate in each zone and then back solved for the ESLA that would yield 0.35 ACH.