# EXECUTIVE SUMMARY

The California Energy Commission funded the multi-project RESAVE R&D program to focus on residential energy savings, air-tightness, and ventilation excellence for California homes. This report focuses on that program's results and its associated conclusions and recommendations.

RESAVE's overall goal was to facilitate the substantial reduction of energy and peak power spent in homes to condition air that enters from outdoors.

The program was intended to facilitate the "Built Tight, Ventilate Right" strategy, which implies a process of first constructing a high-quality building (with low leakage and low source emissions indoors) and then installing the most efficient ventilation system, to provide acceptable indoor air quality (which ensures health and comfort).

Infiltration and ventilation are responsible for one-third to one-half of the space- conditioning load, but are often underappreciated by occupants because it is difficult to notice air losses. They cannot, however, be arbitrarily reduced below a level that supplies acceptable indoor air quality without providing mechanical ventilation or some other mechanism for doing so.

Therefore, RESAVE was designed to address two issues: (1) to reduce direct losses from infiltration while controlling key emission sources, and (2) to find the most energy-efficient methods available to supply the needed whole-house ventilation. The "Built Tight, Ventilate Right" strategy generally is accepted as the best approach for building high-quality homes, but it is not easy to implement without strong technical backup and appropriate standards to follow.

## Indoor Air Quality

The RESAVE program (in cooperation with the U.S. Department of Energy, U.S. Environmental Protection Agency, and U.S. Department of Housing and Urban Development) devised a mechanism to monetize indoor air quality. This mechanism has been published in peer-reviewed journals and is based on existing scientific principles and published data.

The program estimated that the annual health impact of pollutants in residential indoor air is $400 to $1,100 per person. For California, the annual health impact of chronic exposure to the pollutants in residential indoor air is $15 to $40 billion annually. Good ventilation is a primary strategy to reduce that cost, but air cleaning and source control options may be more cost-effective or provide lower energy solutions. Particle filtration appears to be especially promising and deserving of further examination.

## Energy

Complying with Title 24 ventilation requirements (such as the ASHRAE 62.2 standard) for the entire California housing stock is projected to increase residential site energy by 2,600 gigawatt-hours (GWh) annually at current building envelope air leakage levels, compared with not ventilating at all. Tightening residential envelopes has the potential to decrease residential energy demand by as much as 25,000 GWh annually, and the vast majority of that reduction (72 percent) could be achieved by tightening to the International Energy Conservation Code residential tightness standard. Tightness beyond that standard will be subject to decreasing returns, but more research is necessary to determine the best range for air-tightness and to recommend optimal systems. Currently Title 24 does not have a specific requirement for home leakage although it does require measures to reduce leakage such as caulking around fenestrations. Title 24 does have default leakage value from which savings can be claimed, but that default is substantially leakier than the IECC levels. In addition to overall energy savings, there are opportunities to reduce peak power. Up to 30 percent of the peak space-conditioning load can be reduced using smart ventilation controls.

## Combined Optimization and Commissioning

This research allows indoor air quality to be monetized; that is, to determine a monetary value of exposures to contaminates in terms of occupant health. By doing so, these costs can be combined with energy costs; so that the total consumer operating costs of optimizing both energy use and indoor air quality can be identified.

The RESAVE program developed the procedure to do so using a vetted methodology to monetize health impacts. It conducted a preliminary demonstration based on prototype California homes and typical volatile organic compound emissions, to show that current mechanical ventilation rates are optimal for low-emitting houses (from the California New Homes Study emission levels) but that consumers would benefit from increased ventilation rates in higher-emitting households. Although this demonstration illustrated the technique, it is not yet fully developed because it did not account for several other contaminants known to be important (such as particles at or below 2.5 microns), nor has the result been demonstrated across the varied population of California homes.

## Specific Research Areas

As part of the general results above, the RESAVE program worked on several research areas that produced stand-alone results, including the following:

### Air Leakage

There is a potential for large energy savings by minimizing air leakage through the building envelope in California residences. Infiltration, which is attributed to air leakage, typically accounts for one-third to one-half of the energy used for residential space conditioning in the existing home stock. The air-tightness of new homes being built in California has improved over the years. However, the lack of representative air leakage data on California and U.S.

homes makes is difficult to evaluate trends and retrofit improvements. The air leakage test for a single-zone space, such as a detached house, is well established, but there is no consensus on the preferred approach to measure air leakage in multizone spaces, such as a house with an attached garage. An evaluation of air leakage test methods for multizone spaces will also benefit retrofit programs in multifamily homes to more reliably measure the improvements in air-tightness.

The RESAVE program gathered a great deal of measured air leakage data from a wide variety of contributors in California and the United States and compiled them into a database. These data are used to characterize the air-tightness of the housing stock in California and the United States and to determine attributes (such as climate zones, dwelling size, and year built) that are useful for explaining the variability in the air-tightness of homes. The resulted statistical model to estimate the building envelope air leakage based on user inputs of house attributes, and its location is available online. It is useful to practitioners and researchers, and a similar capability is being incorporated into Home Energy Saver (http://hes.lbl.gov). From this analysis, RESAVE also estimates the potential energy savings if the air-tightness of homes in California and the United States were to improve to different levels by measures such as air-sealing. If all U.S. homes were retrofitted for improved tightness, the estimated energy saving would be 0.7 quad annually, which is nearly one percent of the total U.S. energy demand.

The RESAVE program also identified a preferred method to measure air leakage in multizone spaces that measures inter-zonal and to-outside air leakages more accurately than other methods. This method, once further developed, will be able to be used to quantify the energy savings and indoor air quality benefits in multifamily retrofits as a result of reducing air infiltration and air exchange between dwelling units.

Besides building envelope air-tightness, RESAVE also collected some ad-hoc data on duct system air leakage. Typically, retrofit programs will address both sources of air leakages, but different programs might put more focus on one over the other due to practical reasons of costs, time, or other factors. To evaluate the combined energy savings, more data on duct system air leakage need to be collected. A more comprehensive dataset will support the analysis of energy saving potentials, as well as the indoor air quality impacts of retrofitting California homes. The program's analysis of air leakage data suggested that the air-tightness of homes is not constant but rather tends to decline as the homes age. If proven, energy could be saved by targeting homes of a certain age to air-seal to reduce energy loss through air leakage.

Multifamily homes account for 30 percent of the residential energy demand in California. As in single-family homes, energy loss through a leaky building envelope or an ineffective air distribution system in these buildings can be important. RESAVE identified several viable approaches of measuring air leakage in multizone spaces, but mostly the analysis focused on single-family houses with an attached garage. More air leakage data need to be collected from multifamily homes. Currently, there is no performance credit in Title 24 for air leakage testing in multifamily homes. The ultimate goal of this work is to either establish a testing method capable of generating the data needed for obtaining credits, or suggest alternative incentives to

promote air-tightness in multifamily homes. The work done by RESAVE takes important steps toward achieving those goals.

### Residential Integrated Ventilation Energy Controller (RIVEC)

Typical residential ventilation systems provide the same ventilation each hour of the day. The system's energy use, however, changes over the course of the day in response to larger indoor-outdoor temperature differences; the system may, furthermore, do less to improve indoor air quality, depending on the pollutants (such as ozone) present in outdoor air. Currently, there is no automated mechanism to vary ventilation rates to account for this variability in the cost and efficacy of mechanical ventilation. To address this issue, Lawrence Berkeley National Laboratory (LBNL) previously developed and patented the Residential Integrated Ventilation Energy Controller (RIVEC) to provide acceptable indoor air quality and lower the cost of ventilation. It is a smart ventilation controller that can manage a mechanical ventilation system to optimize peak load, energy, and indoor air quality; thus saving the user money and improving indoor air quality consistent with the intent of Title 24 2008 ventilation requirements. It uses the principle of equivalent ventilation to ensure that a variable ventilation rate results in the same or better (i.e., less) exposure to pollutants as a continuous ventilation system that complies with Title 24 2008.

The performance potential of RIVEC was demonstrated by simulations. The results showed that it can: (1) save 20 to 70 percent of the annual energy used to provide and condition ventilation air (or about 10 to 25 percent of the total space conditioning load), (2) reduce 100 percent of the four-hour peak electrical load associated with providing and conditioning ventilation air, and (3) time-shift ventilation away from periods of poor outdoor air quality (such as those experienced in ozone nonattainment areas). The next steps for RIVEC are to find a commercialization partner, and further algorithm development to include occupant and contaminant sensing to further optimize energy use and indoor air quality. Incorporating this type of technology into Title 24 would result in energy savings, but requires some changes to the code or action by the Commission to implement.

### Ventilation Guide

As houses have become more energy efficient over the past twenty years, they have also become much tighter, and the indoor air quality has suffered. Much research and industry input has led to the development of consensus-based ventilation standards such as Title 24 and ASHRAE Standard 62.2. However, mechanical ventilation requirements are complicated and relatively new in California. Designers, contractors, and installers do not have ready sources of information on how to meet ventilation requirements or how to optimize the choices. To address this issue, Lawrence Berkeley National Laboratory through the RESAVE program began to create an authoritative tool to provide optimal ventilation solutions for California homes; whether for low-income weatherization, energy upgrades, or new construction. The state-of-the-art knowledge was assembled into an online guide to ventilation for existing California homes.

The information was vetted by Californian and national experts, including academics, practitioners, and industry members. It reflects the state of the art in compliance with California Title 24 and the only national residential standard (ASHRAE 62.2). The information reflects the requirements of ASHRAE 62.2-2007 as adopted by the California Energy Commission in the 2008 Title 24 Energy Code. It also reflects the hybrid version of ASHRAE 62.2-2010 with the 2011 Supplement changes and two 2012 addenda (Addendum j and Addendum n), as adopted by the Energy Commission for the 2013 Title 24 Energy Code. This information was published as a website (http://resaveguide.lbl.gov/) so that it could be easily accessed and updated.

The next steps will be to promulgate the availability of the website to appropriate user groups in California and to revise it regularly to keep the information current. Over time, it will be important to revise the information to be consistent with Title 24-2013, as final documentation is developed and disseminated.