Field Studies of Indoor Air Quality in New U.S. Homes

Panelist
Rengie Chan – Lawrence Berkeley National Laboratory

Moderator
Linh Truong – National Renewable Energy Laboratory

July 11, 2018
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Agenda

✓ Welcome and Introductory Remarks
✓ Overview of Building America (buildingamerica.gov)
  ➢ Linh Truong – National Renewable Energy Laboratory
✓ Speaker
  ➢ Rengie Chan, Lawrence Berkeley National Laboratory
✓ Questions and Answers
✓ Closing Remarks
Field Studies of Indoor Air Quality in New U.S. Homes

Rengie Chan, Yang-Seon Kim, Brett Singer, Iain Walker
wrchan@lbl.gov  Lawrence Berkeley National Lab
July 11, 2018
Agenda

1. Preliminary results from Healthy Efficient New Gas Homes (HENGH) Field study (2016-2018) in 70 new California homes
In 2008, mechanical ventilation requirements were added to California Title 24 to address adverse impacts that could potentially result from air sealing envelopes to reduce infiltration and improve energy efficiency.
Agenda

1. Preliminary results from Healthy Efficient New Gas Homes (HENGH) Field study (2016-2018) in 70 new California homes

2. Overview of Building America IAQ New Homes Study
   Field study (2018-2020) in 128 new homes across US
   Field teams: Pacific Northwest National Lab (PNNL) Florida Solar Energy Center (FSEC)
   N = 4 climate zones x 32 homes each
Prior California Studies of IAQ and Ventilation

2004-2005 Survey of 1,500 new homes*
  • Few open windows in winter; many did not ventilate in other seasons.
  • Kitchen and bath ventilation not used regularly

2007-2008 Measurements in 108 new homes** (mostly 1 day)
  • 9 of 16 homes with ducted mechanical ventilation had grossly insufficient flow
  • Many homes did not use windows for ventilation; 67% below code requirement
  • Majority of homes exceeded formaldehyde health guidelines

** Offermann (2009) California New Homes Study (CNHS)
US Studies of Ventilation Equipment

**Florida Solar Energy Center (FSEC)** inspected mechanical ventilation systems in 21 new Florida homes*

- 1-9 ACH$_{50}$
- 9 of 21 were not operational
- 12 of 21 “capable of operating”
  - Only 3 had ventilation airflows close to design targets
    - 2 of the 3 disabled by occupants

**LBNL** measured airflows in 15 new homes

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* Sonne et al. (2015) Investigation of the effectiveness and failure rates of whole-house mechanical ventilation systems in Florida
LBNL Study of Ventilation System Airflows

Healthy Efficient New Gas Homes (HENGH)
Field Study (2016–2018) of 70 New Homes

- All homes have mechanical ventilation
  - Whole house ventilation [ON]
  - Bathroom exhaust fan
  - Kitchen range hood exhaust to outside
- Indoor air quality, occupant activities and ventilation use monitored for one week in each home
IAQ Monitoring

**PM2.5**

**CO₂, T, RH**

**NO₂**

**Formaldehyde**

Concurrent Outdoor Monitoring

**PM2.5** monitor

**NO₂, formaldehyde passive samplers**

**T, RH**
Diagnostic Testing

Envelope and Duct Leakage

Exhaust Fan Airflow

Range Hood Airflow
Activity Monitoring

Range hood use

Cooking (cooktop, oven)

Exhaust fan use
Activity Monitoring

External door use (patio, garage)

Clothes dryer

Heating/Cooling
B. Air Quality In and Around Your Home

7. To what extent are you satisfied or dissatisfied with the indoor air quality in your home?

<table>
<thead>
<tr>
<th>Very D Dissatisfied</th>
<th>Neutral</th>
<th>Very Satisfied</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

8. How would you rate the outdoor air quality near where you live?

<table>
<thead>
<tr>
<th>Very P Poor</th>
<th>Neutral</th>
<th>Excellent</th>
</tr>
</thead>
<tbody>
<tr>
<td>☒</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

9. How would you rate your home in protecting you from outdoor air pollution?

<table>
<thead>
<tr>
<th>Very I Ineffective</th>
<th>Neutral</th>
<th>Very E Effective</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

C. Comfort Level in Your Home

10. In winter, how often is the temperature in your home uncomfortable to any occupants because some room(s) are too hot or too cold?

<table>
<thead>
<tr>
<th></th>
<th>Never</th>
<th>Few times a year</th>
<th>Few times a month</th>
<th>Few times a week</th>
<th>Everyday</th>
</tr>
</thead>
<tbody>
<tr>
<td>Too hot in some room(s).</td>
<td>☒</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Too cold in some room(s.)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☒</td>
</tr>
</tbody>
</table>

11. In summer, how often is the temperature in your home uncomfortable to any occupants because some room(s) are too hot or too cold?

<table>
<thead>
<tr>
<th></th>
<th>Never</th>
<th>Few times a year</th>
<th>Few times a month</th>
<th>Few times a week</th>
<th>Everyday</th>
</tr>
</thead>
<tbody>
<tr>
<td>Too hot in some room(s).</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☒</td>
</tr>
<tr>
<td>Too cold in some room(s).</td>
<td>☒</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

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Occupant Survey and Activity Log

Healthy Efficient New California Homes Study
Occupancy and Indoor Activities Data Log

Instructions: Please fill out this data log each day, or on the following day.

Please enter your estimates. If you are unsure, estimate your best guess. Do not list times of any people.

Code number for home: 13

Day 1: Date 11-30-16

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Midnight to 7am</th>
<th>7am to 11am</th>
<th>11am to 1pm</th>
<th>1pm to 5 pm</th>
<th>5pm to 9pm</th>
<th>9pm to Midnight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of people in home</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Cooktop use</td>
<td>Number of minutes</td>
<td>0</td>
<td>30</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Oven use</td>
<td>Number of minutes</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BBQ/outdoor grill</td>
<td>Number of minutes</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Vacuuming</td>
<td>Number of minutes</td>
<td>0</td>
<td>0</td>
<td>25</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Window Use</td>
<td>Number of minutes</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other notable indoor/outdoor events</td>
<td>3no cleaners, 24Jan, 11Feb, 1Mar, 1Apr, 1May, 1Jun, 1Jul, 1Aug, 1Sep, 1Oct, 1Nov, 1Dec</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*For example, use of fireplace, candle, air freshener, air cleaner, humidifier, unusual outdoor air quality (wood smoke, wildfire), and so on.*
Whole-House Mechanical Ventilation

In most cases, the measured airflow of the exhaust fan exceeded the required whole-dwelling ventilation needs.

- Continuous exhaust (N=55)
- Intermittent exhaust (N=9)
- Continuous inline fan connected to central forced air system (N=4)
- Supply ventilation provided by central fan integrated system with a motorized damper (N=2)
Comparison of measured exhaust fan flow and Title 24 mechanical ventilation requirement (N=56)
Rated versus measured exhaust fan airflows (N=56)

The only way to know a fan’s flow: MEASURE IT
Bathroom exhaust fans mostly meeting 50 cfm airflow requirement (intermittent)
Supply Ventilation
Supply Ventilation
Air Filter
Only 1 in 4 homes with whole-house ventilation system running as found.
<table>
<thead>
<tr>
<th>Whole-House Ventilation Control</th>
<th>Controller Labelled?</th>
<th>% On As-Found</th>
</tr>
</thead>
<tbody>
<tr>
<td>On/Off Switch</td>
<td>No (N=42)</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>Yes (N=12)</td>
<td>58%</td>
</tr>
<tr>
<td>Programmable Controller</td>
<td>No (N=10)</td>
<td>50%</td>
</tr>
<tr>
<td>Thermostat</td>
<td>No (N=2)</td>
<td>0%</td>
</tr>
<tr>
<td>Breaker Panel</td>
<td>No (N=1)</td>
<td>100%</td>
</tr>
<tr>
<td>No Controller</td>
<td>No (N=3)</td>
<td>100%</td>
</tr>
</tbody>
</table>
To maintain minimum levels of outside air ventilation required by the State of California, this fan should be on at all times when the building is occupied, unless there is outdoor air contamination.

Whole House Ventilation Control. Leave on except for severe outdoor air quality.
Manual switches associated with a whole-building ventilation system should have a clear label such as,

“This controls the ventilation system of the home. Leave on except for severe outdoor contamination.”

In addition, guidance on operations and maintenance procedures should be provided to occupants.
Keep fan "ON" at all times except in case of outdoor air contamination or if home is vacant for more than 7 days.
DeltaQ Test – Envelope and Duct Leakage Results
Envelope Leakage

- Most homes between 3 and 6 ACH50
- Only 4 out of 70 homes <3 ACH50, IECC 2018 requirement
### Duct Leakage

<table>
<thead>
<tr>
<th>Duct Leakage (DeltaQ*)</th>
<th>% of 70 Homes</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;50 CFM</td>
<td>25%</td>
</tr>
<tr>
<td>50–100 CFM</td>
<td>30%</td>
</tr>
<tr>
<td>100–200 CFM</td>
<td>31%</td>
</tr>
<tr>
<td>&gt;200 CFM</td>
<td>14%</td>
</tr>
</tbody>
</table>

*DeltaQ test measures duct leakage at working pressure, not at 25 Pa.

Data from HERS registry (CF-6R)
21 of 23 homes reported duct leakage measured at 25 Pa ranging between 50 and 100 CFM.
Indoor Air Quality Results

Comparisons of formaldehyde, PM$_{2.5}$, and NO$_2$ with a prior study of new homes in California suggest that contaminant levels are lower than measured from about 10 years ago.

<table>
<thead>
<tr>
<th>Mean Indoor Concentration</th>
<th>HENGH</th>
<th>California New Home Study* (Offermann 2009)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formaldehyde</td>
<td>19.8 ppb</td>
<td>36.3 ppb</td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>8.3 µg/m$^3$</td>
<td>13.3 µg/m$^3$</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>6.1 ppb</td>
<td>5.4 ppb</td>
</tr>
</tbody>
</table>

*Almost all homes (98%) use electric ranges for cooking.
Formaldehyde

OEHH Reference Exposure Level, Chronic (7 ppb)
Formaldehyde Emission Standards

The ATCM to control formaldehyde emissions from composite wood products became effective January 1, 2009.

https://www.arb.ca.gov/toxics/compwood/compwood.htm
PM2.5

CalEPA ambient air quality annual standard = 12 ug/m³
CNHS - Almost all homes (98%) use electric ranges for cooking.
HENGH – All kitchen range hood exhaust to outside, most met Title 24 (100 cfm)
HENGH – Particle Filtration

- Exhaust ventilation in homes with reasonably tight building envelope
- Medium to high efficiency air filters

<table>
<thead>
<tr>
<th>MERV Rating</th>
<th>Number of Air Filters (N=112)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 - 7</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>57</td>
</tr>
<tr>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>11</td>
<td>22</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>9</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
</tr>
</tbody>
</table>
Other Results

• AER
  • Comparison with CNHS that 2/3 of homes with overall AER below 0.35/h

• Time-resolved formaldehyde and NO2
  • Formaldehyde levels during occupied versus unoccupied
  • NO2 from cooking, with and without range hood use

• CO2
  • Overnight concentrations in excess of 1100 ppm in some homes

• T, RH
  • Comparison with self-reported comfort satisfaction
<table>
<thead>
<tr>
<th>Problems Affecting Occupant Comfort a Few Times per Week or More Frequently</th>
<th>Field Study (N=70)</th>
<th>HENGH Survey (N=2271)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Too hot in summer</td>
<td>31%</td>
<td>41%</td>
</tr>
<tr>
<td>Too cold in winter</td>
<td>29%</td>
<td>20%</td>
</tr>
<tr>
<td>Not enough air movement</td>
<td>21%</td>
<td>18%</td>
</tr>
<tr>
<td>Too hot in winter</td>
<td>14%</td>
<td>10%</td>
</tr>
<tr>
<td>Indoor air too dry</td>
<td>9%</td>
<td>11%</td>
</tr>
<tr>
<td>Too cold in summer</td>
<td>4%</td>
<td>9%</td>
</tr>
<tr>
<td>Too much air movement</td>
<td>1%</td>
<td>5%</td>
</tr>
<tr>
<td>Musty odor</td>
<td>1%</td>
<td>3%</td>
</tr>
<tr>
<td>Indoor air too damp</td>
<td>1%</td>
<td>2%</td>
</tr>
</tbody>
</table>
Building America IAQ New Home Study

- Collect IAQ data in 32 homes each in four climate zones
  - Portland, OR
  - Boulder/Denver, CO
  - Southeast: FL, AL, GA, NC, SC
- Regional variations in system designs, performance, and occupant behaviors
Motivating Questions

• What is the IAQ in new homes with/out mechanical ventilation?
• What ventilation equipment is provided in new U.S. homes designed (or not) to comply with ASHRAE 62.2?
• What are airflows as installed?
• Do designs and performance vary by climate zone?
• Are there discernible differences in IAQ between homes that meet / don’t meet 62.2?
• How do people use ventilation? Is it discernibly relatable to IAQ?
Study Scope

• Characterization
  • Envelope & duct airtightness
  • MV equipment – rated and measured flows

• One-Week Monitoring
  • Use of ventilation equipment and natural ventilation
  • Time-resolved pollutant concentrations & environmental parameters
    • PM$_{2.5}$, formaldehyde, CO$_2$, T, RH
  • Time-integrated
    • NO$_2$, PM$_{2.5}$ mass (filter)

In addition to HENGH
• SVOCs
• Radon
• T/RH in attic, basement, crawlspace
• Consumer-grade IAQ sensor
Analysis Plan

• Investigate associations of humidity and contaminants with controls
  • ASHRAE 62.2 compliant mechanical ventilation
  • Envelope air tightness
  • Mechanical system commissioning
  • Other factors (low-emitting materials, ventilation system use, etc.

• Characterize variations of equipment, usage, and IAQ by climate zone
  & home type
Berkeley Lab Indoor Air Quality Survey

Our goal is to learn how people like you feel about your home environment and about the factors that can affect your indoor air quality, or "IAQ".

The survey asks about your satisfaction, perceptions, activities and product use. There are also questions about your home and household.
The data from these studies will inform builders and manufacturers, as well as industry ventilation standards and code provisions, to better protect indoor air quality and health as building infiltration is reduced to save energy.
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