MONITORING OF INTERNAL MOISTURE LOADS IN RESIDENTIAL BUILDINGS - RESEARCH DESIGN AND EARLY FINDINGS

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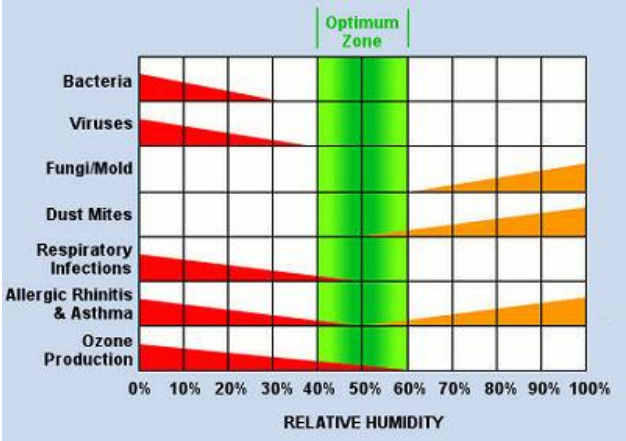
Project Overview

- Funded by the U.S. Department of Housing and Urban Development (HUD) to collect moisture load data that will support research to better understand the impact of moisture on the durability of homes.
- Little to no measured data is available on actual indoor humidity levels in U.S. households.
- One full year of indoor temperature and humidity data for a sample of sixty homes across three different climate regions – the hot/humid southeast, cold northeast and marine northwest



(Source: www.healthgoods.com)

Magnified images of dust mites and mold spores
(Source: www.thermastor.com)

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Today's Presentation

- **Research Design:** including candidate requirements and critical parameters measured/recorded.
- **Results & Discussion:** overview of data collected and discussion of preliminary findings.
- **Conclusions:** general and regional
- **Problems Encountered/Lessons Learned**

Research Design

Objectives of Study

- **Research Support:** provide the research community with critically important field data for defining boundary conditions for use in moisture models, and through that effort, help them better understand the impact of moisture on the durability of homes.
- **Support for Development of Design Criteria:** provide documented support for the interior design loads adopted by the ASHRAE Standing Standard Project Committee 160 and Standard160-2009 "Criteria for Moisture-Control".
- **Identify Influences on the Moisture Levels in Homes:** identify correlations between interior and exterior conditions and moisture levels in typical single family detached homes.

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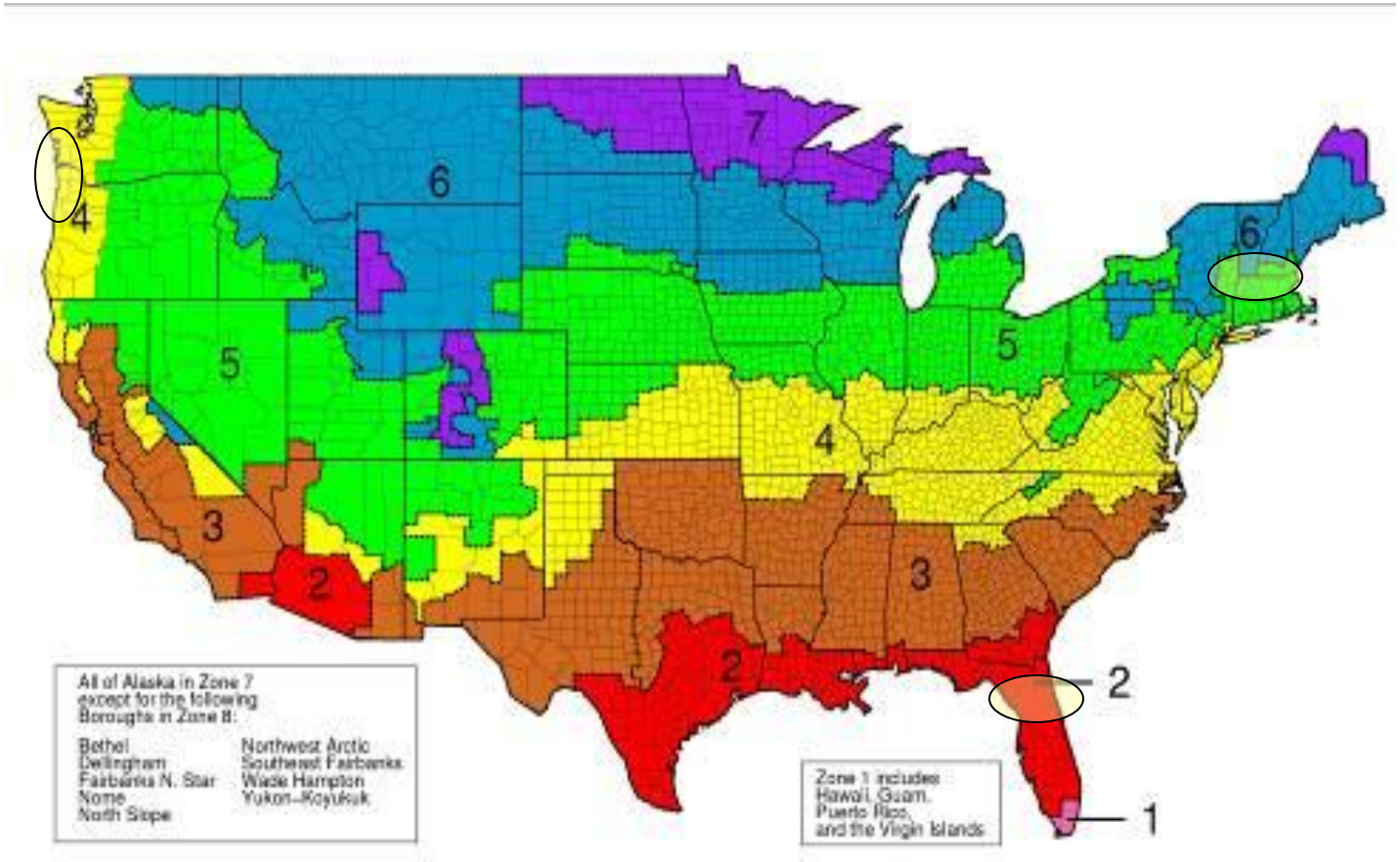
Climates Evaluated



IECC Climate Zone Map of the United States

Desired House Characteristics

- Single-family homes (preferably detached);
- More than one year old;
- Less than 3000 ft^2;
- At least two occupants (preferably more) with no plans to move within the next year;
- No major renovation or remodeling work planned within the next year;
- A range of characteristics and occupant densities was desired within a focused area

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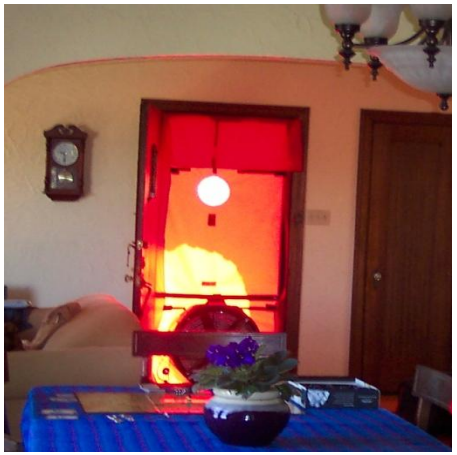
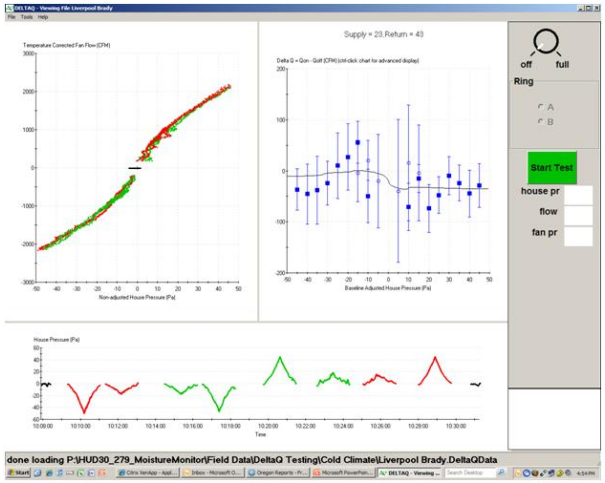
Parameters Measured

- Test home characterization (short-term data collection);
- Internal moisture load monitoring (long-term data collection).

Test Home Characterization

- Envelope tightness;
- Duct leakage to the exterior;
- Envelope detail: insulation type and quantity, siding materials, flooring materials, etc.;
- HVAC equipment: type, capacity, presence and description of humidifiers, dehumidifiers, and mechanical ventilation systems;
- Documentation of the house size, configuration and number of occupants;
- Measurement of exhaust fan air flows;
- Presence of mold &/or moisture sources.





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Internal Moisture Load Monitoring

- Temperature and Relative Humidity for:
  - Ambient
  - Primary living space (family/great room)
  - Master bedroom
  - Primary bathroom (where most showers were taken)
  - Basement or crawlspace
  - Attic - where a slab foundation was present

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Final Monitoring Protocol: Pre-Screening

- Confirm that the home was in fact a good candidate
- Explain the reason for the study
- Explain what was involved if they participated
- Convey length of time their home would be monitored

Final Monitoring Protocol: Site Visits

- **Initial Site Visit (approx. 2-3 hours).**
  - Audit of the home
  - Data loggers were installed (3 inside, 1 outside, and 1 in the attic or basement/crawlspace).
- **Interim Site Visit (1 hour).**
  - First six months of data was collected
  - Condition and location of the data loggers checked
  - Talked to the occupants about any changes that may have occurred over the last 6 months.
  - Collected any house information missed during the initial visit.
- **Final Site Visit (1 hour).** The final site visit was much the same as the interim with the additional task of removing the loggers.

Final Monitoring Protocol: Participation Agreement

- Agreement established the expectations and responsibilities of all parties involved.
- Audit Report as compensation:
  - explained efficiency levels found in their home
  - compared to the study averages for their region and the Energy Star values for a new home built in their area.
  - basic recommendations for improvements were made if applicable.

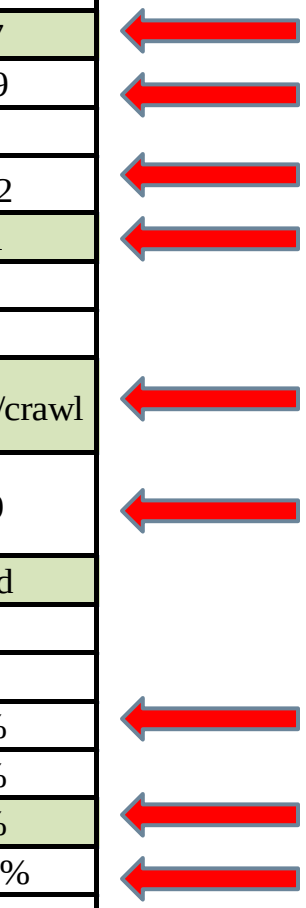
Results & Discussion

Data Analysis

- 285 sensors across 3 regions, 1 year of 15 minute data for 60 homes, almost 10 million rows of data, 5 data points per row
- Overall, less than 2% loss in data
- Combination of Microsoft ACCESS & MATLAB used for analysis
- Oak Ridge National Lab (ORNL) analyzed dataset to validate assumptions for computing internal moisture loads within ASHRAE 160
- Analysis of humidity levels and house characteristics by region

Average Values by Region

Component	Humid	Cold	Marine
Age (years)	11.5	45	61.7
Size (square feet)	1989	3118	2059
# of Occupants	3.45	3.1	3.1
Occupant density (ft^2/occupant)	576.5	1005.8	664.2
Air Leakage (ACH@50)	6	6.1	11.1
Attic R-value	22	36	24
Wall R-value	12	12	7
Dominant Foundation Type	slab	partially finished bsmt	basement/crawl
Duct leakage (cfm/100ft^2 of conditioned floor area)	5.6	4.7	13.9
Dominant heating type	AS heat pump	furnace	mixed
Cooling Efficiency (SEER)	11.54	10.22	14
Dominant Domestic Hot Water Fuel	electric	gas	gas
Homes w/ Moisture Problems (%)	35%	50%	35%
Homes w/ Mechanical Ventilation (%)	0%	25%	30%
Homes w/ Cooling (%)	100%	75%	20%
Average Interior Relative Humidity (%)	51.70%	47.90%	53.10%
Average Interior Humidity Ratio (lb_w/lb_{da})	0.00978	0.00753	0.007588



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Differences in Housing Sets

- Major differences between the housing sets include:
  - **Age** – homes in the marine climate were much older than the other two sets;
  - **Air leakage** – the air leakage rate (ACH50) was almost twice as high in the marine climate as in the other two climates;
  - **Foundation type** –marine climate lots of crawls (some vented) with dirt floors; hot humid homes all slabs; cold climate homes primarily partially finished basements conditioned;
  - **Cooling equipment** – only 20% of the homes in the marine climate had central A/C units as opposed to 75% of the homes in the cold climate and 100% in the hot humid climate;
  - **Heating equipment** – only about 50% of the homes in the marine climate had forced air heating. The other 50% had a mixture of boilers with baseboard radiators or electric heat

Moisture Problems by Region

Zone 2 – Hot/Humid

- Mold or moisture damage was observed on or around the windows and in the bathrooms.
- Mold was visible on several air handlers around the cooling coil.
- There were also several incidents of moldy caulk especially on the newer homes and around windows.

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Moisture Problems by Region

Zone 5 - Cold

- Highest occurrences of moisture problems.
- Moisture in the basements (which was typically in the spring or fall).
- Mold on the windows – usually older, inefficient units.
- Musty smells – upper levels as well as lower.

Moisture Problems by Region

Zone 4 - Marine

- Indoor relative humidity values were highest here: average monthly values above 50% during most of the year.
- On windows.
- In bathrooms.

Comparison of Homes w/& w/out Moisture Problems

	Zone 2		Zone 5		Zone 4	
House Characteristic	Moisture Problems	No Moisture Problems	Moisture Problems	No Moisture Problems	Moisture Problems	No Moisture Problems
House Size (ft^2)	1860	2059	2819	3416	1701	2251
Year Built	2002	1995	1956	1976	1939	1952
Interior Temp (F)	75.7	75.8	68.2	69.8	67.2	67.1
Dehumidifier (% of homes)	0	0	0.8	0.9	0	0.31
Primary foundation	slab	slab	partially finished basement	partially finished basement	crawl/partial crawl	mixed
Air leakage (ACH@50)	5.29	6.38	7.5	4.8	15.4	7.7
Occupant density ($\#/ft^2$)	0.00194	0.00175	0.00103	0.00105	0.00227	0.00144
Bath fans (% of homes)	86%	92%	90%	100%	71%	69%
Mechanical ventilation (% of	0	0	10%	20%	0%	23%
Humidity Ratio (lb_w/lb_{da})	0.00971	0.00986	0.00755	0.00751	0.00767	0.00755

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Conclusions

Conclusions: Zone 2, Hot/Humid

- Newer homes in sample set are having more moisture problems than the older.
- Correlation with more efficient homes and the lack of conditioning needed as compared to less efficient homes?
- Construction failure particular to this community?
- Metal windows and other cold surfaces should be avoided in this region.

States falling under Hot and Humid climate zone *(Source: EERE)*

Conclusions: Zone 5, Cold

- Water seepage into the foundation - common problem in this subset.
- Mold was only found on the inefficient windows in this group – single pane or single pane windows with storms.
- Air change rate affecting homes with moisture problems?
- Association with older homes without good foundation moisture control?

States falling under cold and very cold climate zone
(Source: EERE)

Conclusions: Zone 4, Marine

- Fewest homes with central air conditioning and the most homes with crawlspaces: homes with moisture problems all had at least a partial crawl foundation with exposed dirt floors.
- Some were vented and some not, but none had a well sealed vapor barrier.
- Air change rate one of the factors?
- Association with older homes which coincidentally lack good foundation moisture control?
- Lack of space conditioning due to mild climate conditions?

<u>More research is necessary.</u>

States falling under marine climate zone *(Source: EERE)*

Conclusions: General

- In general, no statistically significant correlations across climate zones could be determined.
- Each region appears to have problems specific to that location that should be addressed.
- No blanket recommendations for moisture control should be made across zones.

- ***Good News – validates many of the recommended moisture control strategies we already know.***

Problems/Lessons Learned

- Delays: (OMB) approval of the survey instrument
- Finding participants: unwilling homeowners & builders
- Data Collection:
  - Three homeowners decided to do some level of remodeling,
  - One sensor was lost (most likely to vermin) and a few stopped collecting along the way.
  - In a couple of instances, the occupants forgot where the sensors were located and moved furniture that had loggers stuck to the back
- Interpretation of conditioned building envelope - i.e., conditioned vs. unconditioned basement.
- Analyzing the data
  - Almost ten million records total with 5 data points for each record
  - Lack of significant correlations from so few homes across such unique climates.

Questions?

Thank You Participants & Sponsors!

- US Dept. of Housing and Urban Devel., Office of Policy Devel. & Research, Affordable Housing Research & Technology Division
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- Participants