Characterizing indoor humidity for comparison studies: the moisture balance approach

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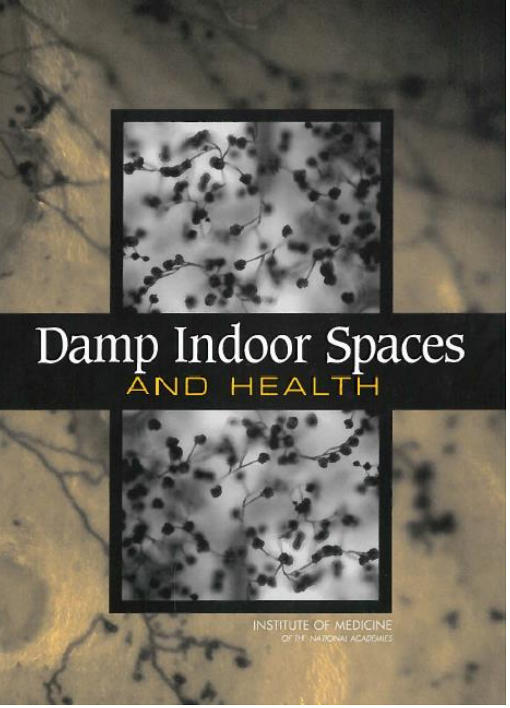
Problem statement

- We want to assess building indoor dampness pre- and post-intervention for energy saving
  - Always involves air-tightening **and** ventilation
- We place temperature and RH measurement instruments
  - For 1 week to one month, pre- and post-.
- How to normalize for outdoor conditions when answering the question:

Is the building wetter or drier following intervention?

- What is dampness?
  - Subjective assessment
  - Vapor pressure difference, indoors and outdoors
  - RH, surface RH, surface moisture content, mold growth index?

BACKGROUND



Institute of Medicine (Fisk et al.), 2004

TABLE 2-1 Examples of Reported Prevalence of Signs of Building Dampness

Reference	Country	Population	Dampness Metric	Prevalence, %
Residential buildings				
Brunekreef et al., 1989	United States	homes of 6,273 school children in 6 cities	Questionnaire (city averages reported)	
			Ever water in basement	11–42
			Ever water damage to building	12–23
			Ever mold or mildew on any surface	21–38
			Any of above	46–58
Dales et al., 1999	Canada	homes of 3,444 children	Questionnaire	
			Dampness stains in last 2 years	24
			Visible mold in last 2 years	15
			Either of above	25
Engvall et al., 2001	Sweden	4,815 apartments	Questionnaire	
			Condensation on windows	7
			High relative humidity in bathroom	9
			Water leakage in last 5 years	13
			Any of above	22
Evans et al., 2000	United Kingdom	8,889 homes of adults	Questionnaire	
			Damp or condensation a serious problem	1
			Damp or condensation a minor problem	9
Haverinen et al., 2001a	Finland	390 homes and 240 apartments	Inspections	
			Grade 1, no to minor moisture damage	16
			Grade 2, intermediate moisture damage	18
			Grade 3, high moisture damage	15
Jaakkola et al., 2002	Finland	932 adults who were controls in asthma case-control study	Questionnaire about homes	
			Water damage in last year	2
			Damp stains or peeling paint in last year	9
			Visible mold in last year	3
Kilpeläinen et al., 2001	Finland	homes of 10,667 university students	Questionnaire (regarding any of the students' homes in the last year)	
			Visible mold	5
			Visible mold or damp stains	12
			Visible mold or damp stains or water damage	15

(continued on next page)

TenWolde, Walker, 2000.

Interior Moisture Design Loads for Residences

Anton TenWolde
Member ASHRAE

Iain S. Walker, Ph. D.
Member ASHRAE

$$w_i = 0.004 + 0.4 w_o \quad (4)$$

where w_i = indoor humidity ratio

w_o = coincident design outdoor humidity ratio (cooling)

This algorithm has been applied to 219 locations in the United States and has been found to be extremely robust (i.e.,

Kalamees, Vinha, Kurnitski, 2005

Indoor Humidity Loads and Moisture Production in Lightweight Timber-frame Detached Houses

TARGO KALAMEES* AND JUHA VINHA
Laboratory of Structural Engineering
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HVAC-Laboratory, Helsinki University of Technology
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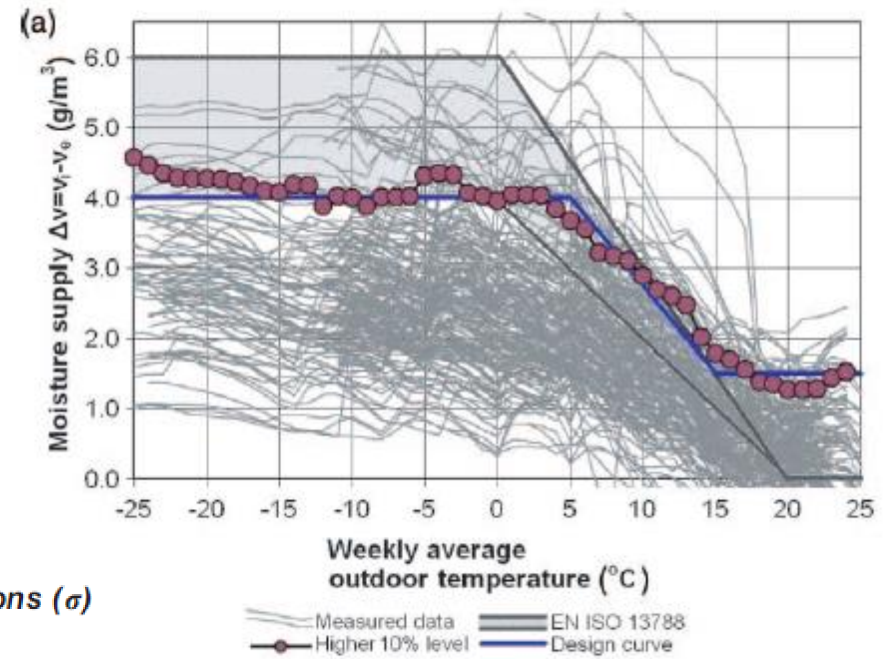

Table 4. Average (AVG) moisture supply and their standard deviations (σ) during the cold period ($T_{out} \leq 5°C$) and during the remaining time ($T_{out} > 5°C$).

	Weekly average moisture supply (g/m^3)			
	Outdoor temperature ≤5°C		Outdoor temperature >5°C	
	AVG	σ	AVG	σ
Bedrooms	+1.9	0.9	+0.5	0.8
Living rooms	+1.7	0.9	+0.4	0.7
Natural ventilation	+2.1	0.9	+0.9	0.7
Exhaust ventilation	+2.0	1.2	+0.5	0.9
Balanced ventilation	+1.7	0.7	+0.4	0.6
Permeable envelope	+1.7	0.8	+0.4	0.8
Vapor-tight envelope	+1.8	0.9	+0.5	0.6
≤3 occupants	+1.7	0.9	+0.4	0.6
>3 occupants	+1.8	0.9	+0.5	0.8

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Available online at www.astm.org/JAI

Patrick Roppel,[1] Mark Lawton,[2] and William C. Brown[3]

Roppel, Lawton, Brown, 2008

Setting Realistic Design Indoor Conditions for Residential Buildings by Vapor Pressure Difference

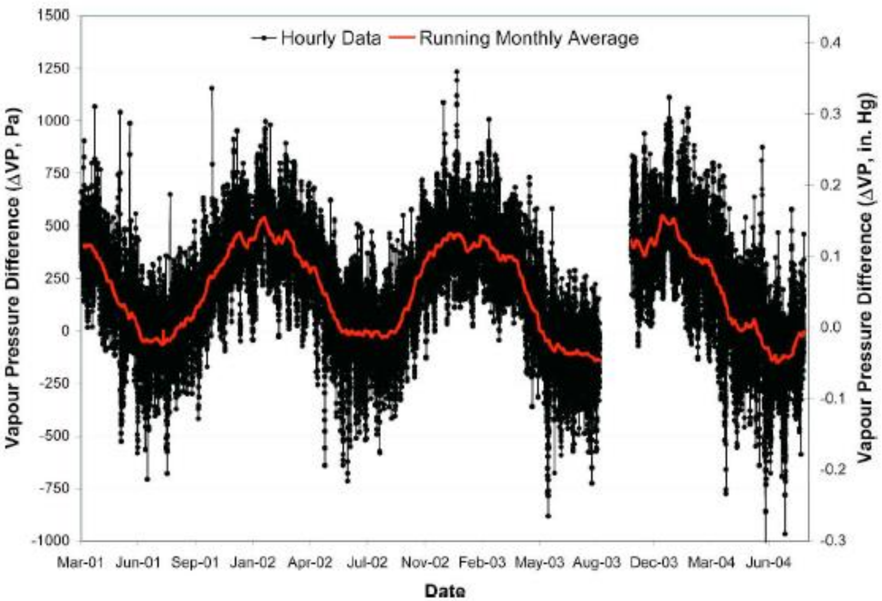


FIG. 13—*Vancouver, Building 1: Vapor pressure difference* (ΔVP, *Pa*).

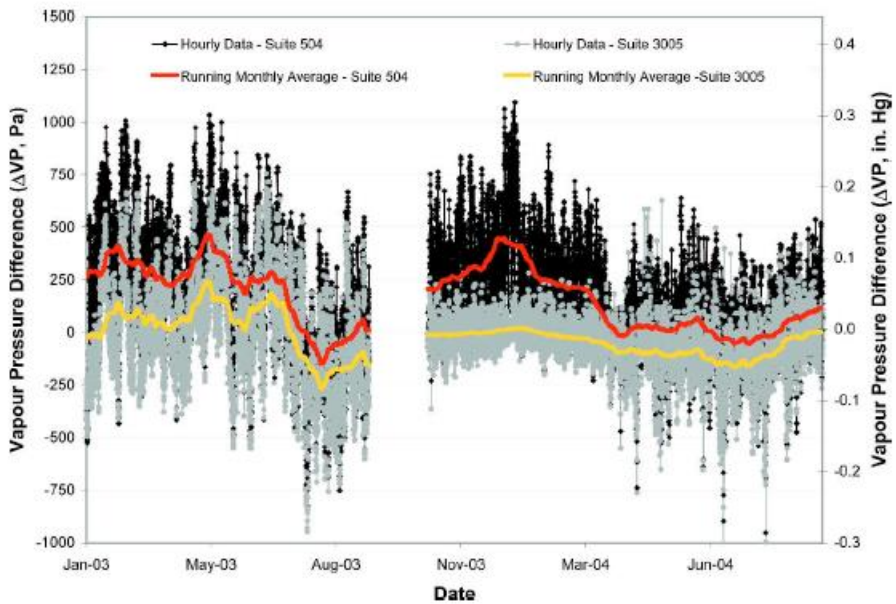
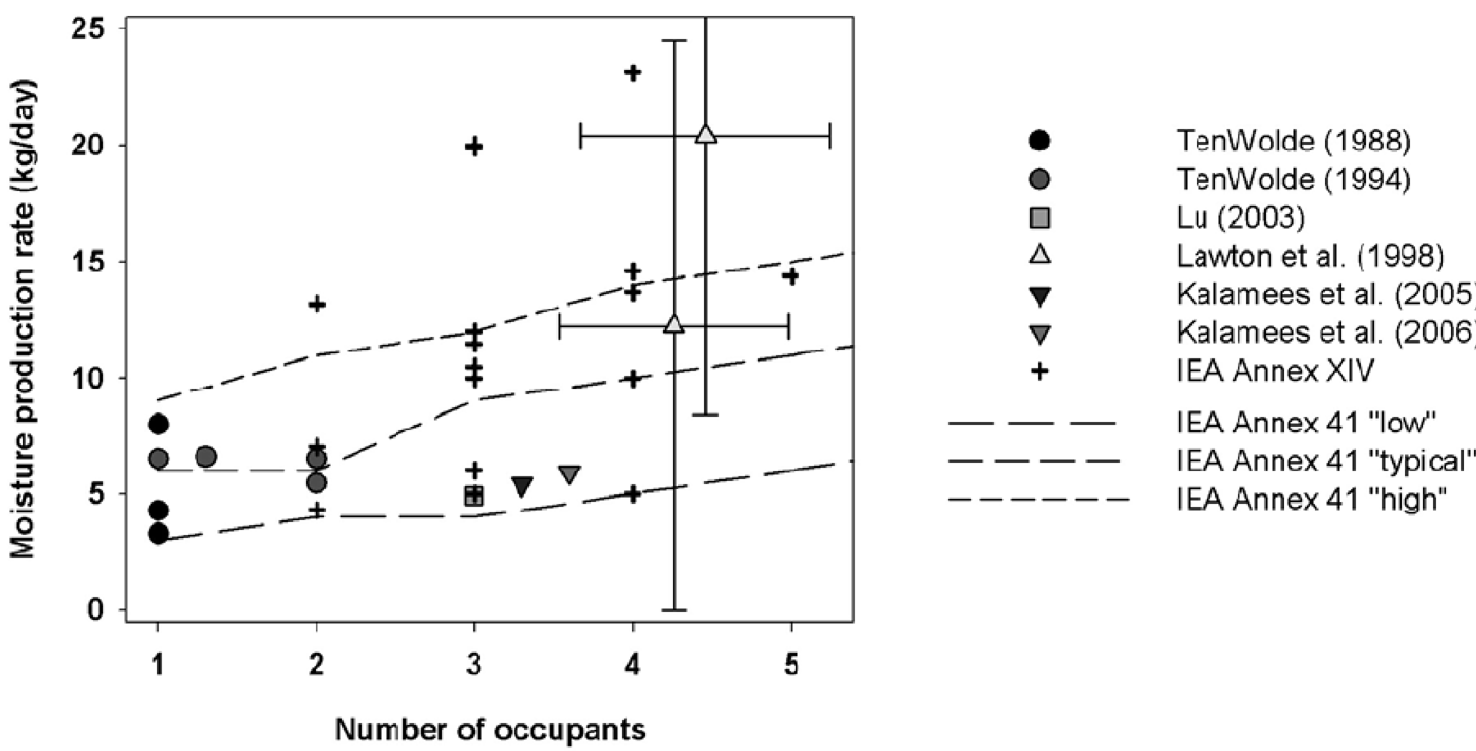


FIG. 27—*Vancouver, Building 5: Vapor pressure difference* (ΔVP, *Pa*).

Glass, TenWolde, 2009

REVIEW OF MOISTURE BALANCE MODELS FOR RESIDENTIAL INDOOR HUMIDITY

Samuel V. Glass and Anton TenWolde
U.S. Forest Products Laboratory
Madison, Wisconsin, USA



ISO 13788, 2012

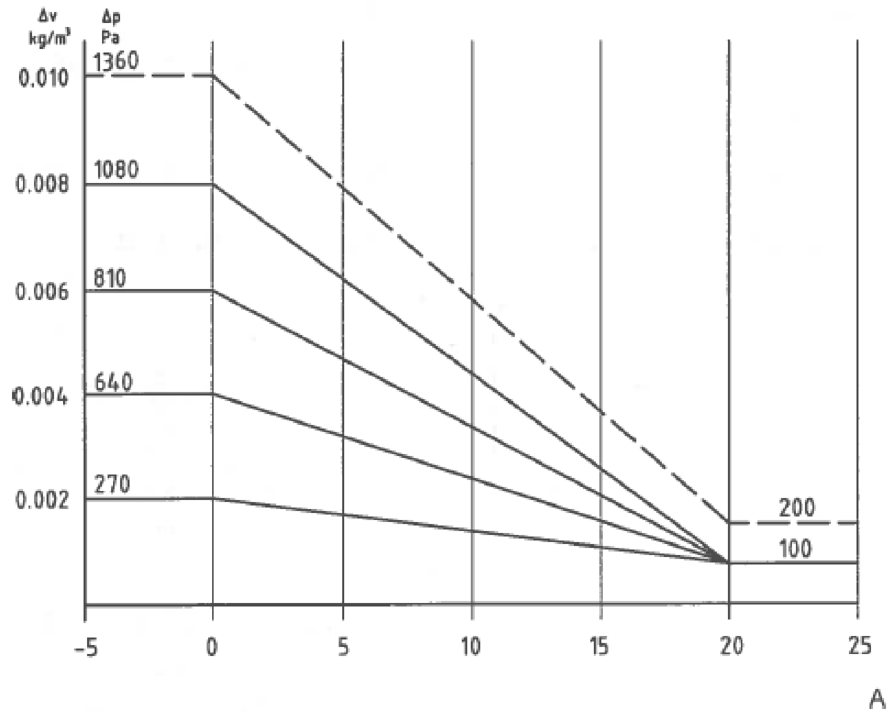
I.S. EN ISO 13788:2012

INTERNATIONAL STANDARD

ISO 13788

Second edition
2012-12-15

Hygrothermal performance of building components and building elements — Internal surface temperature to avoid critical surface humidity and interstitial condensation — Calculation methods



Francisco, Rose, 2010

Temperature and Humidity Measurements in 71 Homes Participating in an IAQ Improvement Program

Paul W. Francisco
Member ASHRAE

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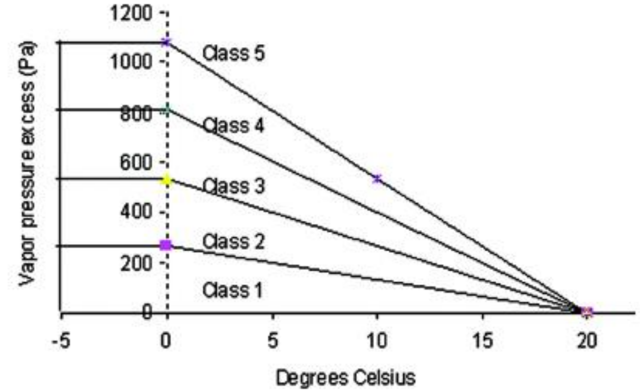


Figure 1 *Graphic representation of* ISO Standard 13788 *climate classes.*

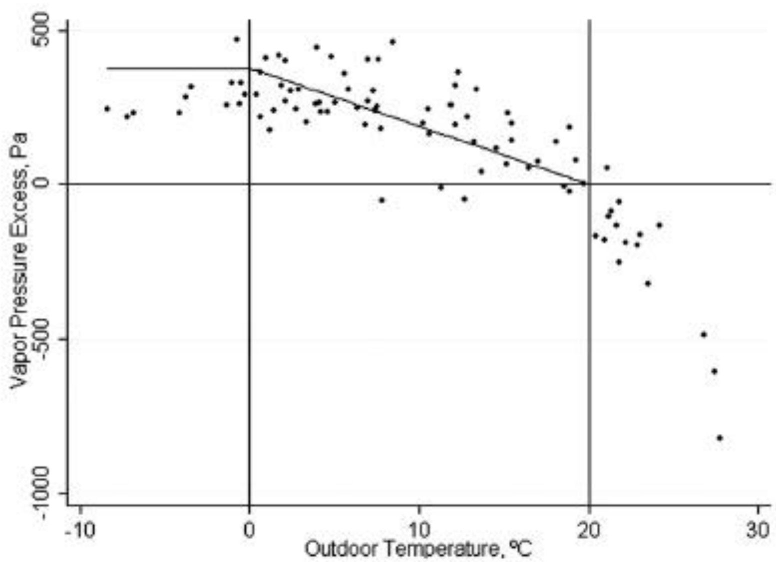
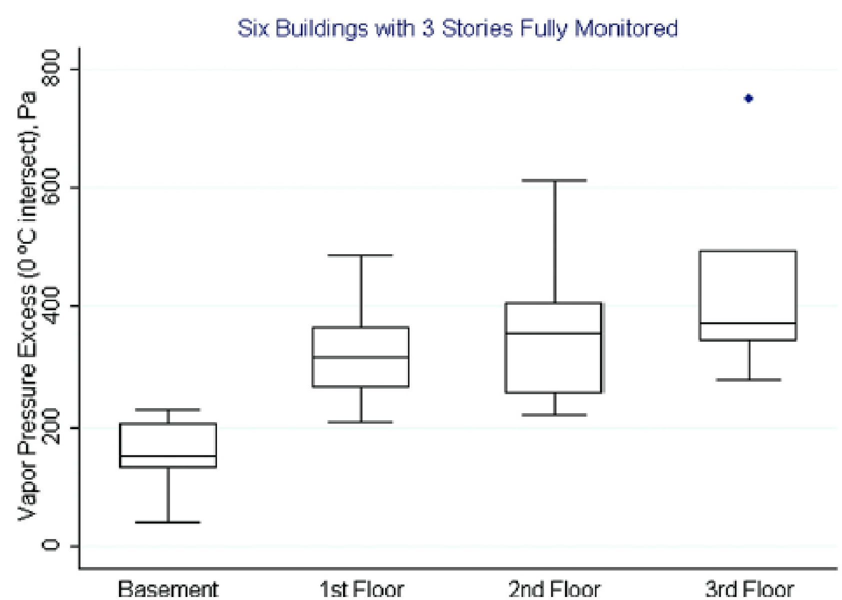


Figure 5 *Site 4 first-floor data with* ISO Standard 13788 *representation.*



Francisco et al. 2016—Health-V

Ventilation, indoor air quality, and health in homes undergoing weatherization

P. W. Francisco[1] | D. E. Jacobs[2,3] | L. Targos[2] | S. L. Dixon[3] | J. Breysse[3] | W. Rose[1] | S. Cali[2]

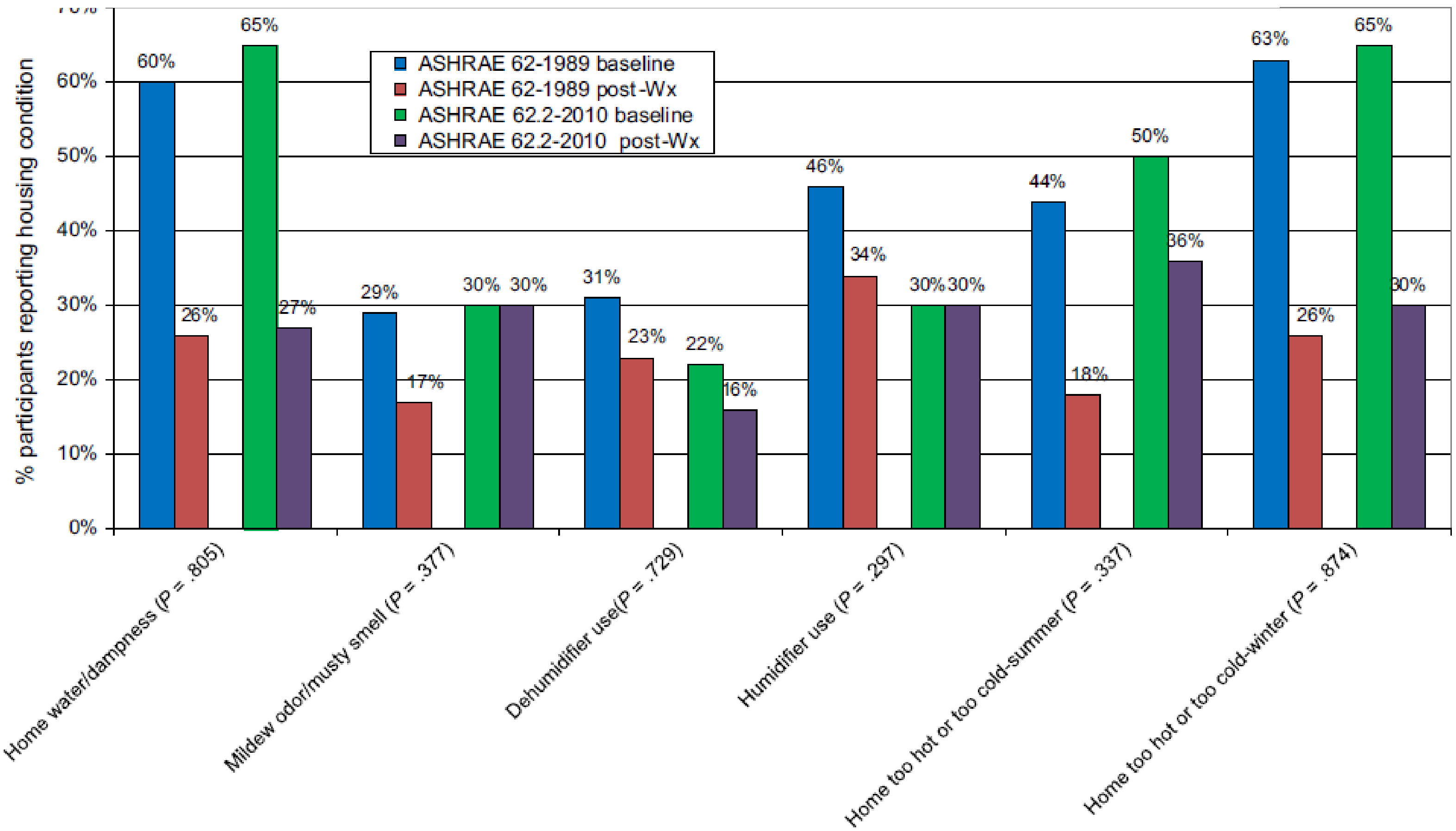
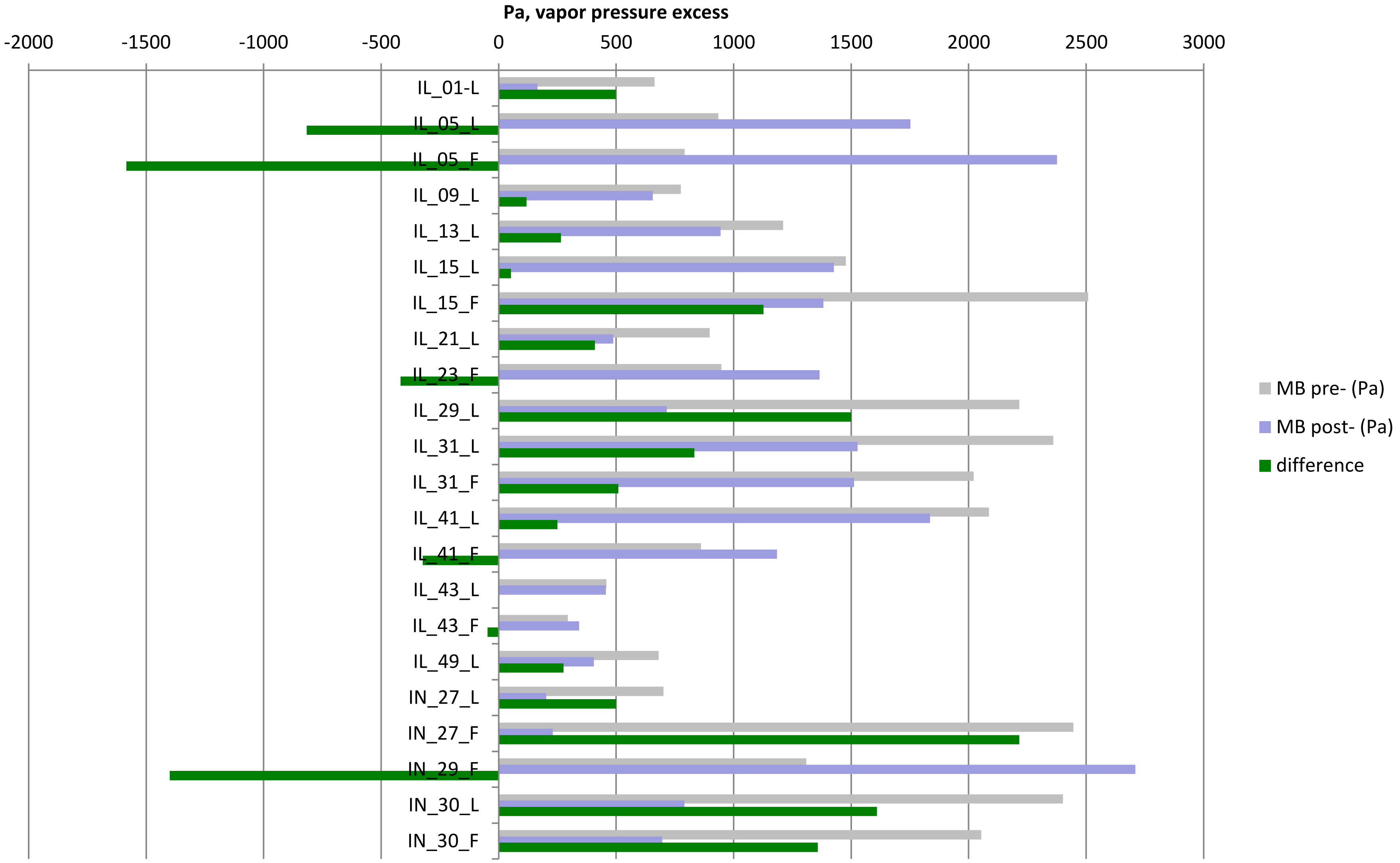
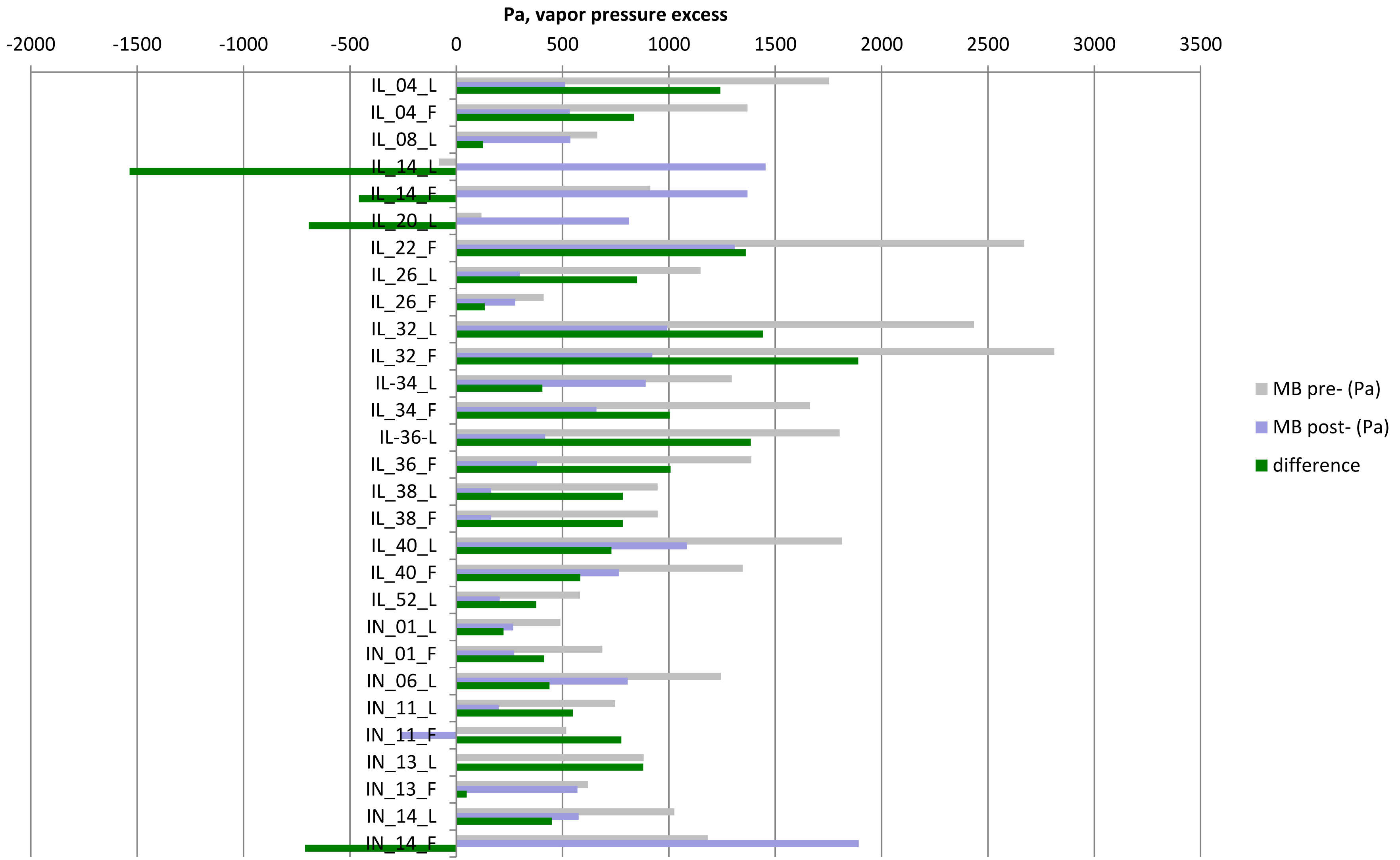


FIGURE 2 Changes in reported housing moisture and comfort conditions (*P* values shown are from tests to determine whether the change in percent yes from baseline to post-Wx is different for the two groups)

Moisture balance: Controls (ASHRAE 62-1989)



Moisture balance: Treatments (ASHRAE 62.2)



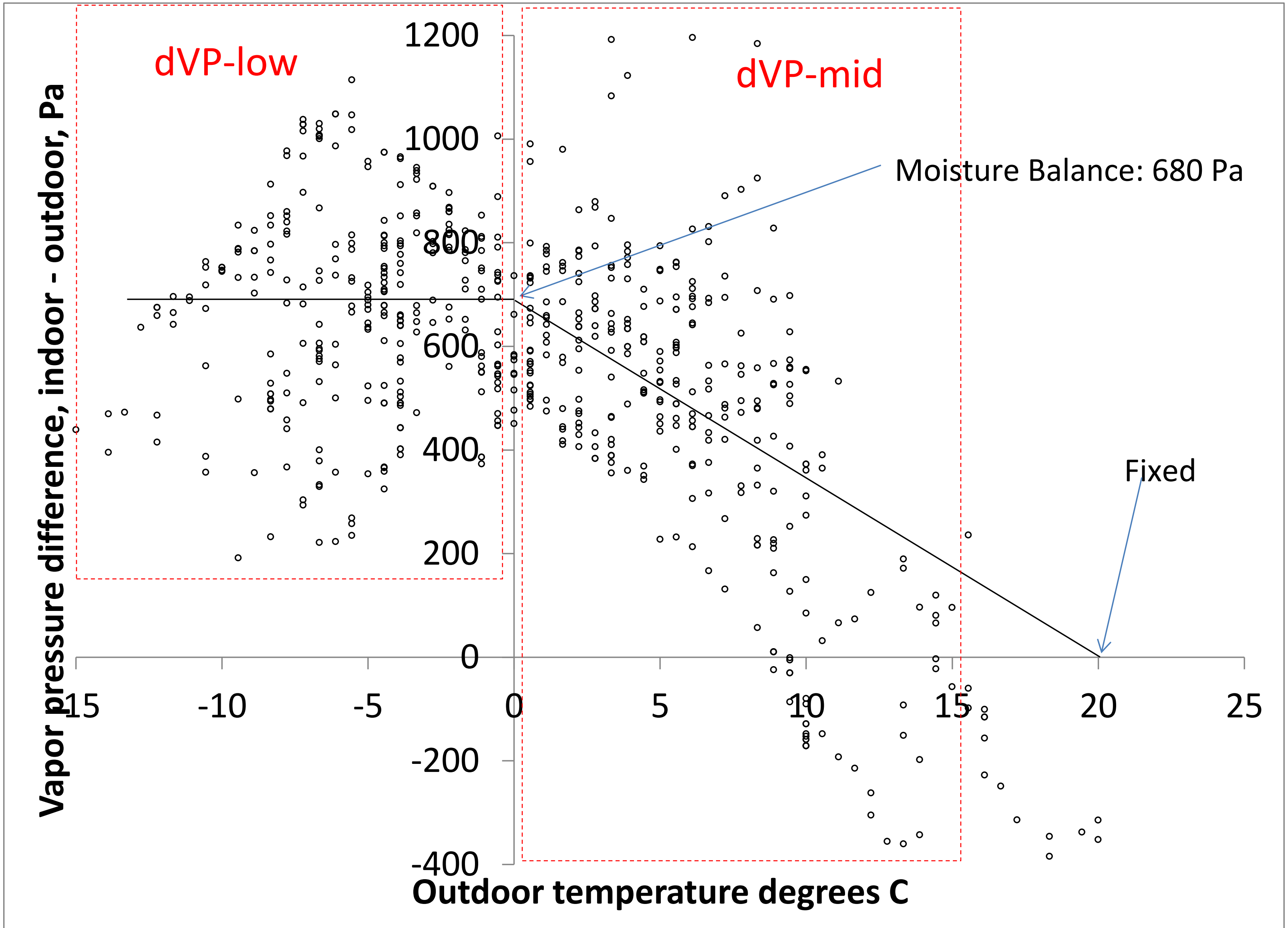
Summary: Background

- Health impacts based on subjective assessment of "dampness"
- Vapor pressure difference (VP_i – VP_o) primary unit
- Main intent: characterize indoor humidity from measured data, to establish boundary conditions for envelope studies
- Lot of noise
- North America only: air conditioning impact

- Vapor pressure difference **regression** applied in 2 studies

APPROACH

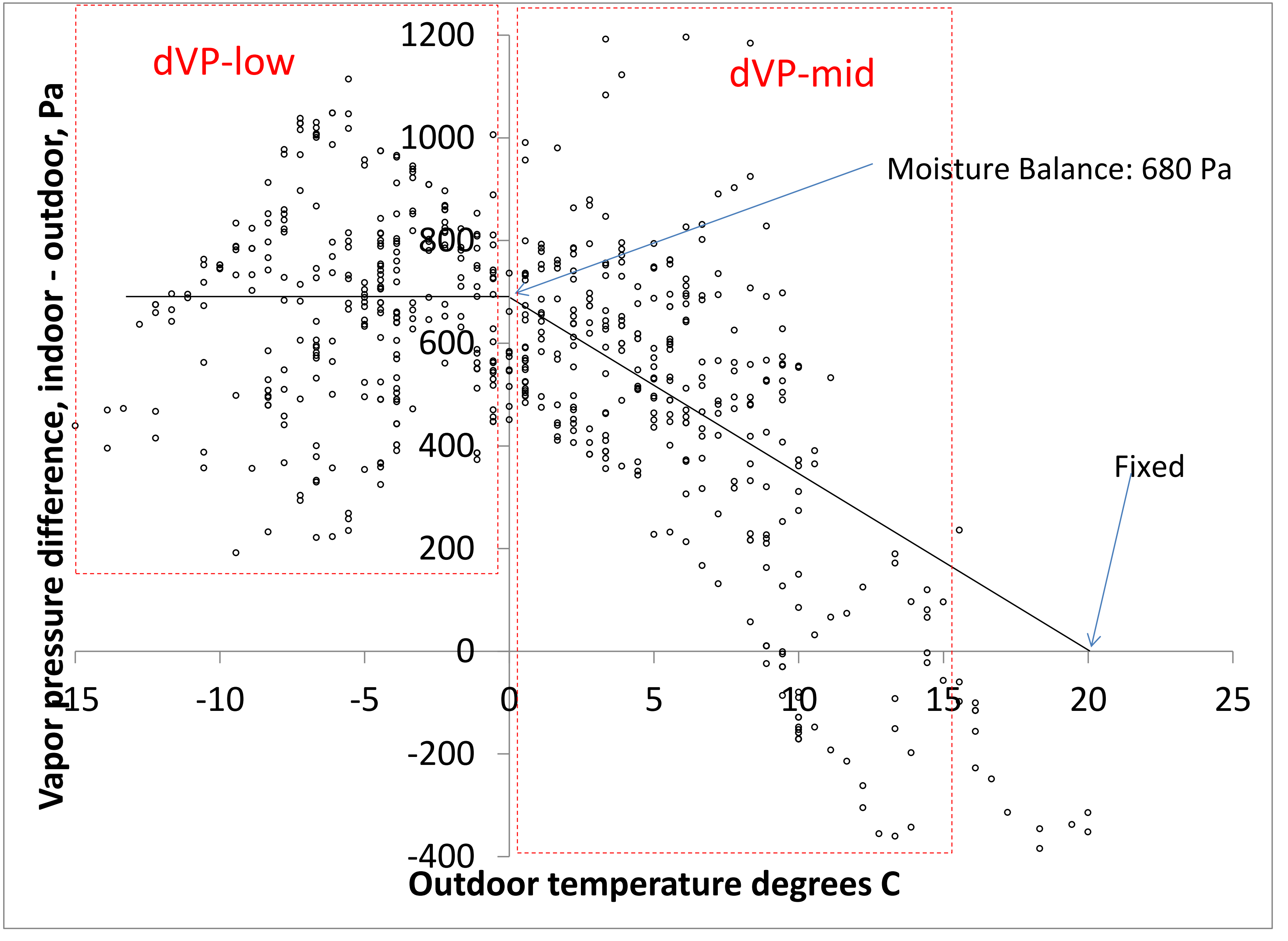
T< 0: average ΔVP. T: sloped ΔVP. 15° cutoff



Moisture balance calculation

- Inputs:
  - **To** Outdoor temperature (C)
  - **VPo** Outdoor vapor pressure (Pa)
  - **VPi** Indoor vapor pressure (Pa)
- Calculate dVP: (VPi – VPo)
- For To < 0
  - Calculate average dVP. Call it dVP-low
- For 0 < To < 15
  - Regress dVP against To, with regression fixed thru 0 dVP at 20C
  - Find intersection of the regression at 0C. Call it dVP-mid
- Find the number of values
  - To < 0 count-low and
  - 0 < To < 15 count-mid
- Weight dVP-low and dVP-mid by the number of values
- MB = dVP-low + dVP-mid (count-mid / (count-low + count-mid))

T< 0: average ΔVP. T: sloped ΔVP. 15° cutoff

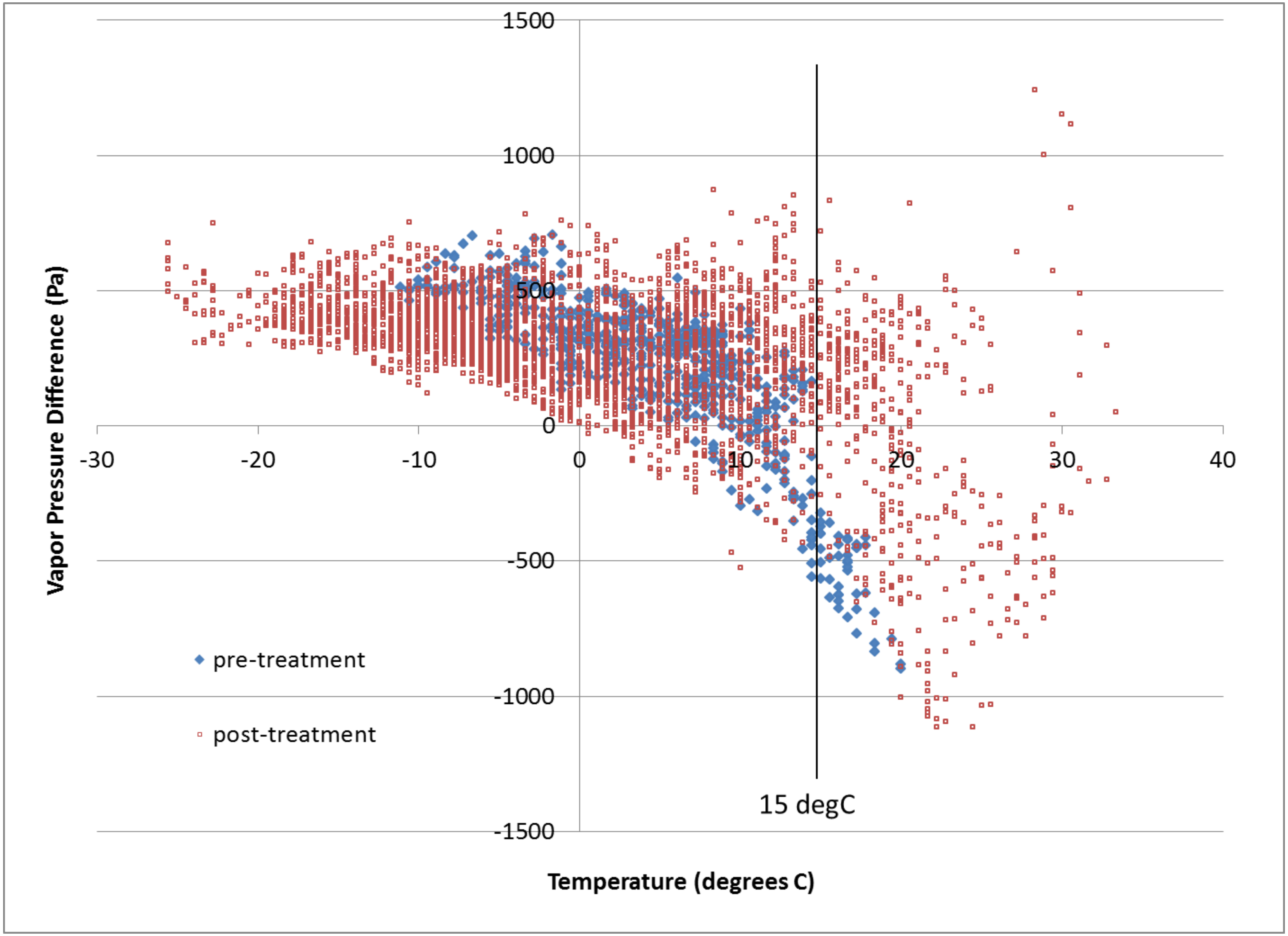


FINDINGS

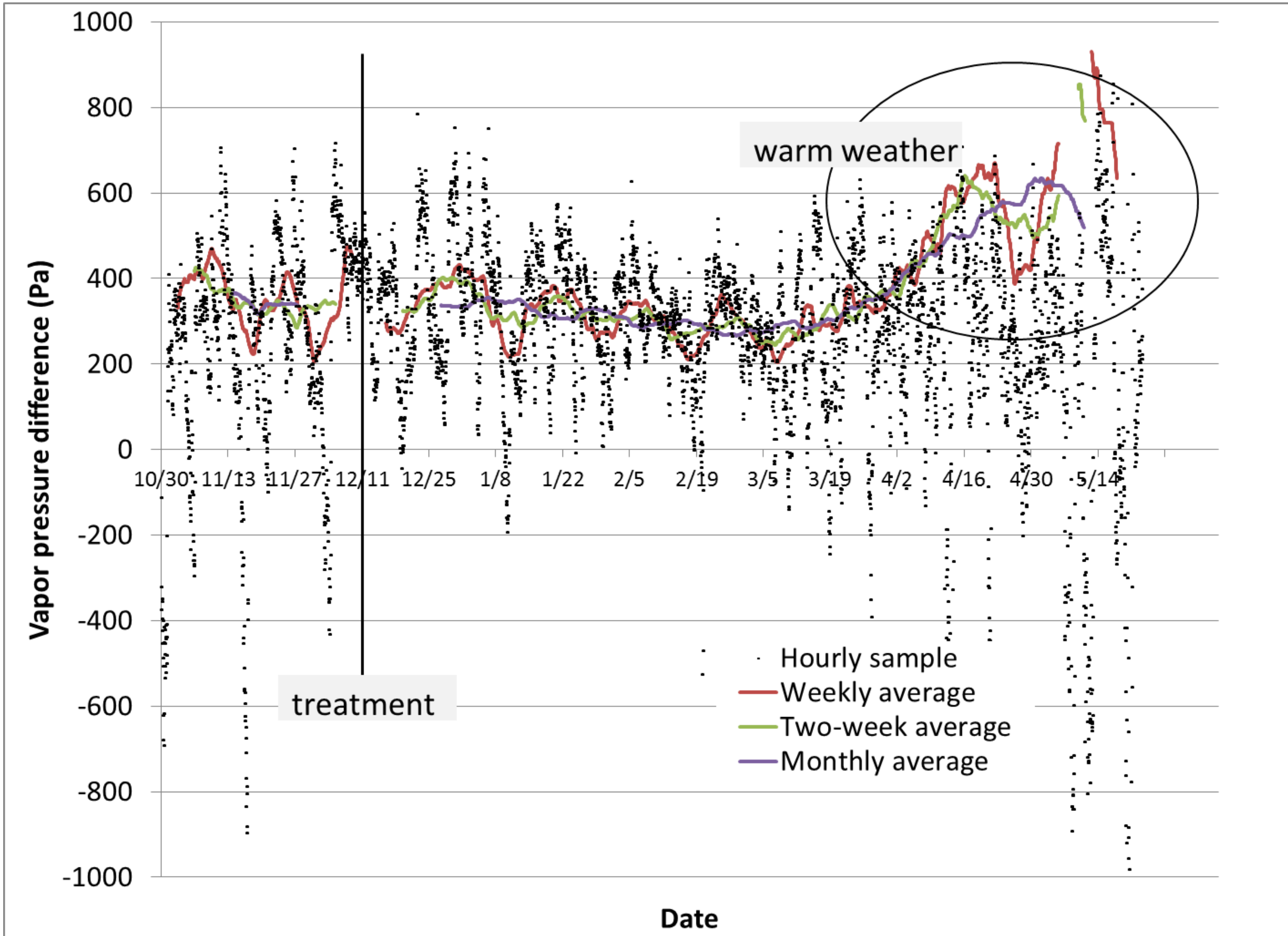
From the study of 45 homes in Health-V

- Revisit the data
- Is there bias depending on the season in which monitoring took place?
  - Discard all data with $T_o > 15°$ C.
- Study individual homes in detail

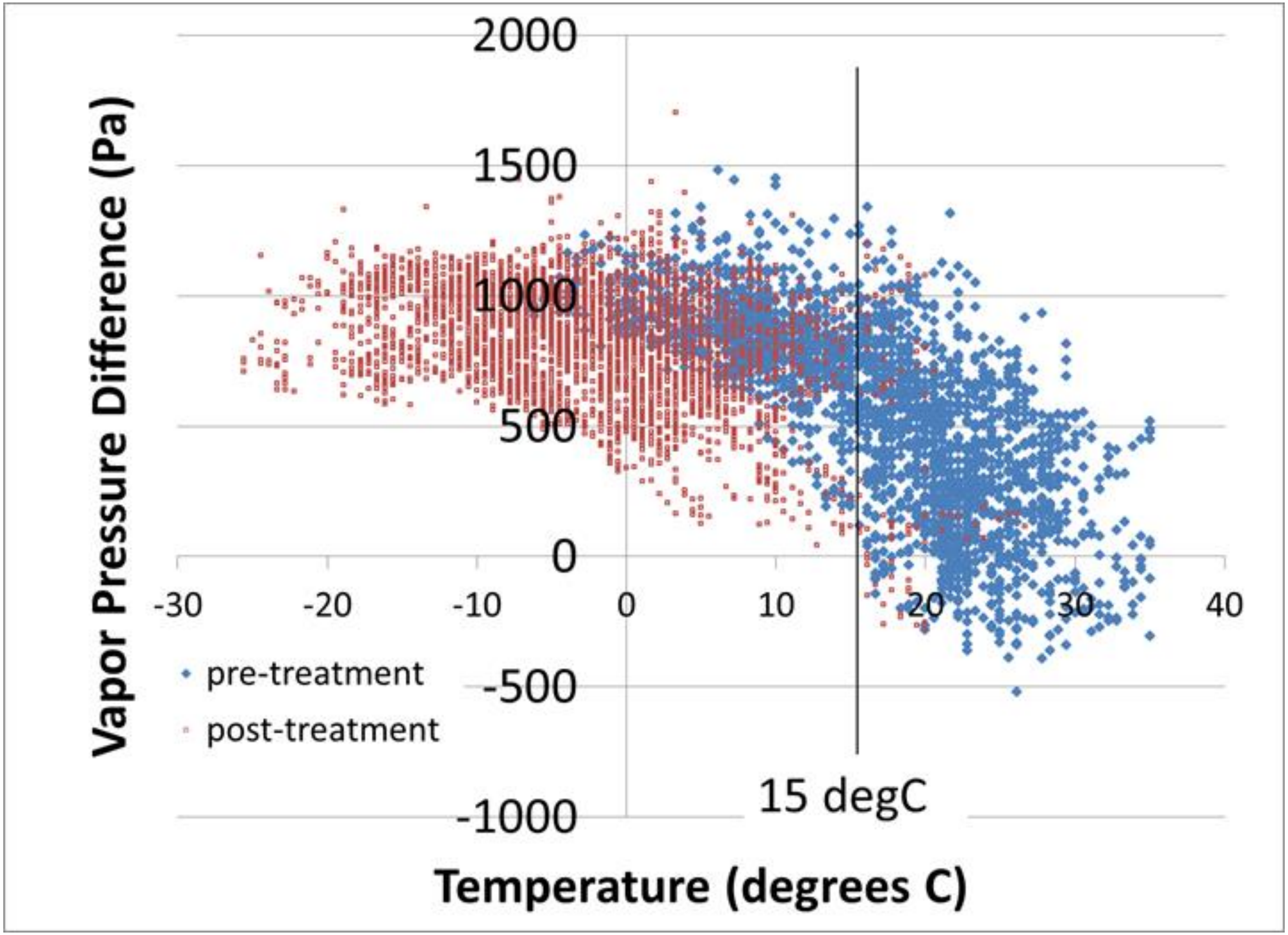
dVP plotted against T_o. IL-43F



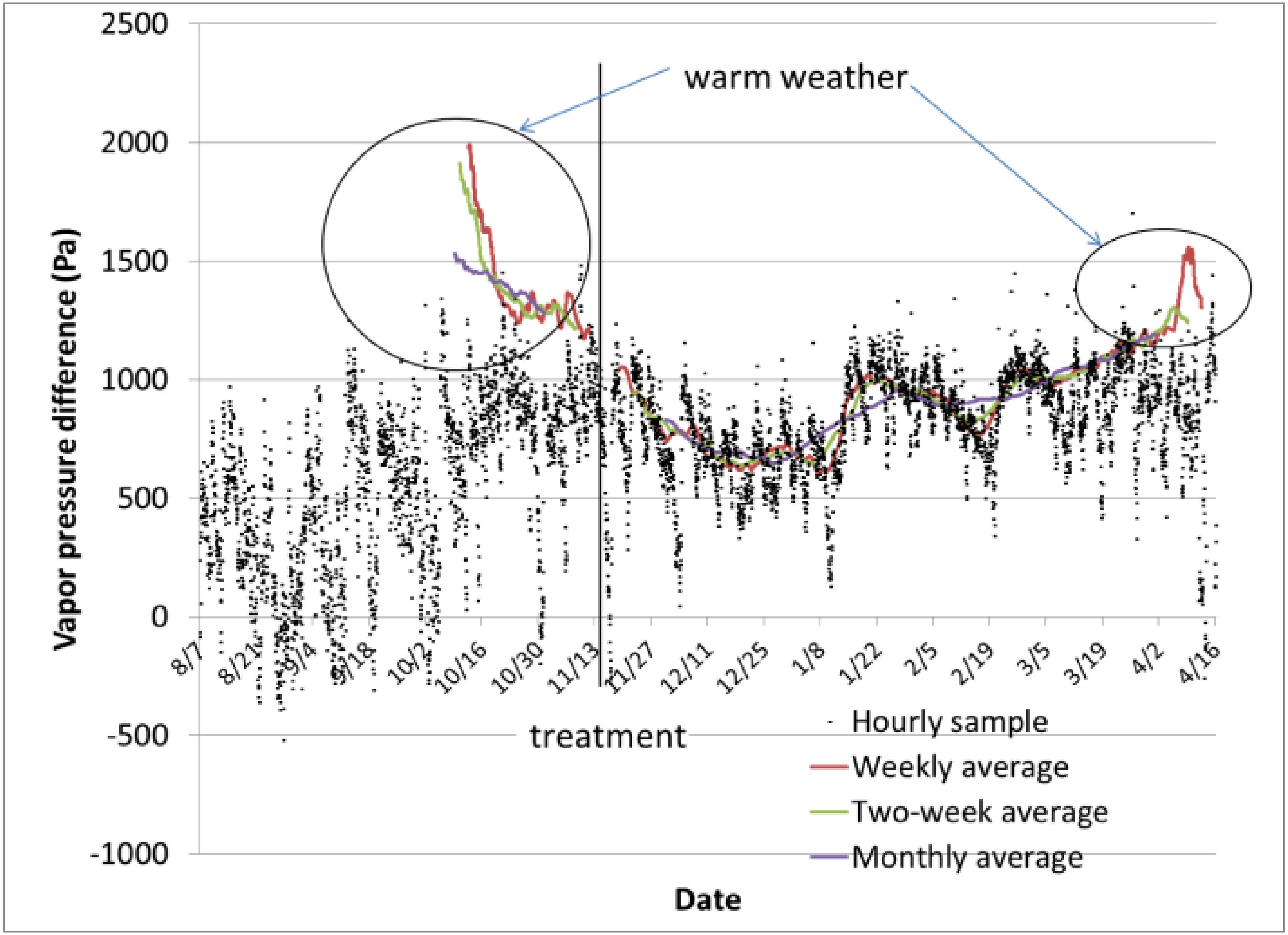
Cold weather v. warmer weather (IL-43F)



House IL-029. Includes hot weather.



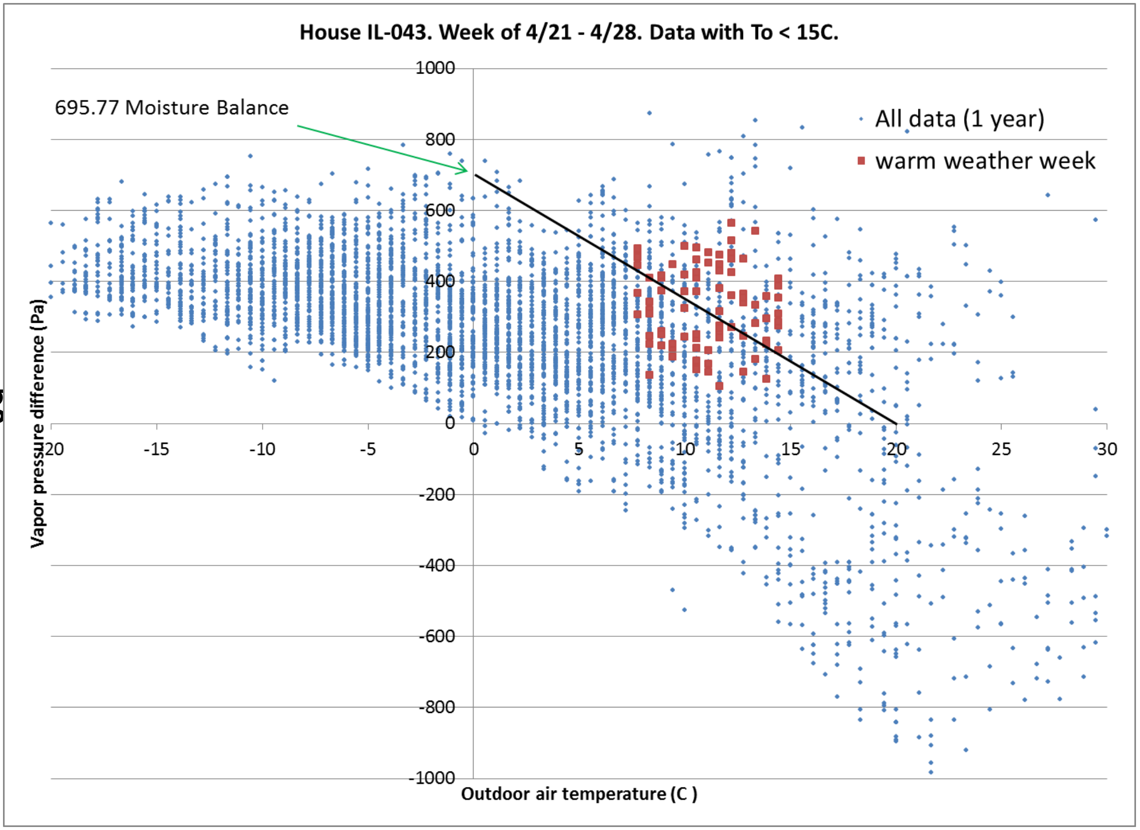
House IL-029L



Finding: warm weather estimates

- Warm weather Moisture Balance estimates (10° C to 15° C)
  - Deviate from dVP averages
  - Err on the high side
  - Show wider variance

- Why err on high side?
  - Warm weather dVP does not vanish to 0 as To goes to 20C.
  - During air-conditioning summer conditions, cool nights may have very low dVP.



Finding: measurement duration

- For houses measured over the long term, the mean and standard deviation of moisture balance was calculated for three different measurement durations.
  - See previous charts with running averages
  - One week, two weeks and one month durations.
- Results

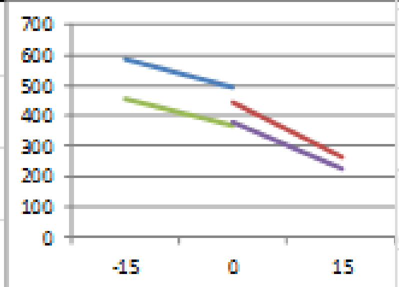
Table 1. Moisture Balance statistics for 7 houses			
	all	Pre-	Post-
MB total	494	568	451
1wk average	497	583	475
1wk sd	167	135	145
2wk average	483	556	469
2wk sd	132	82	121
1mo average	481	543	469
1mo sd	125	47	113

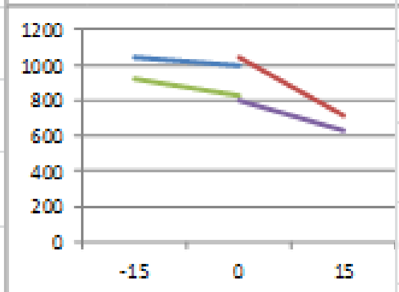
DISCUSSION

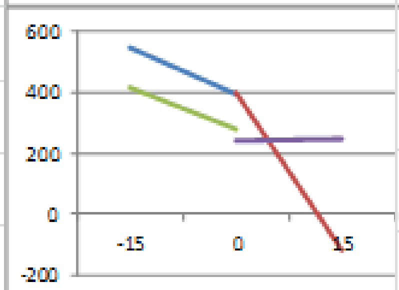
How far off is the MB approach?

- For 45 homes in the study, linear regressions of the MB data were calculated.
  - Pre-treatment, outdoor temperatures <0° C, (blue)
  - Pre-treatment, outdoor temperatures >=0° C and <=15° C, (red)
  - Post-treatment, outdoor temperatures <0° C, (green)
  - Post-treatment, outdoor temperatures >=0° C and <=15° C. (purple)
- Calculated results
  - For outdoor temperatures <0° C, average slope is -5.4 (Pa/K),
  - For outdoor temperatures >=0° C and <=15° C, average slope is -11 (Pa/K)
- And for your visual delight…if there is time

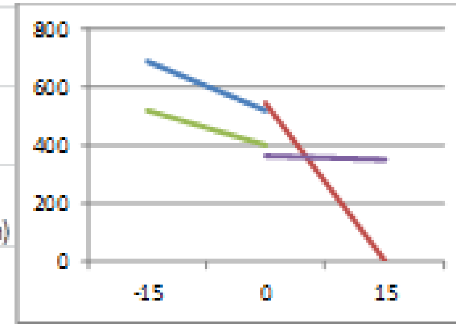
house	slope	interce	count	
IL-001	-6.41	492	80	low pre- (blue)
	-12.20	446	1110	hi pre- (red)
	-5.72	369	1607	low post- (green)
	-10.19	378	2642	hi post- (purple)
IL-029	-3.23	992	64	
	-21.84	1040	882	
	-5.71	832	2283	
	-11.40	802	1292	
IL-043F	-10.39	391	385	
	-34.89	401	601	
	-9.12	281	1951	
	0.39	241	1513	

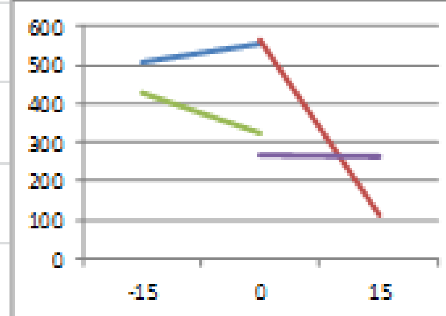


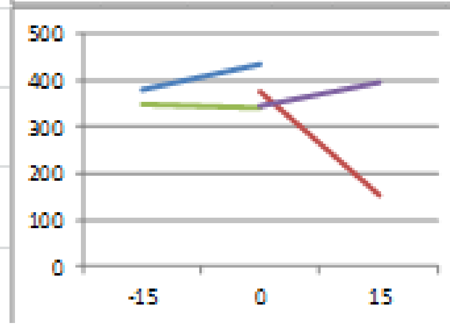




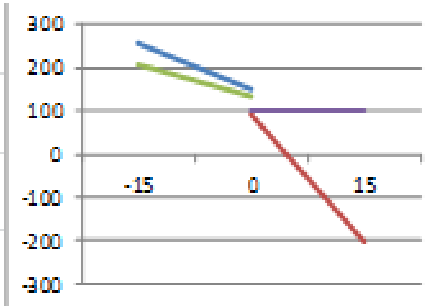
IL-043	-11.35	518	385	low pre- (blue)
	-36.05	544	601	hi pre- (red)
	-8.09	400	1951	low post- (green)
	-1.12	367	1513	hi post- (purple)
IL-049	3.09	555	879	
	-29.92	563	463	
	-6.74	325	1404	
	-0.22	267	1439	
IL-052F	3.84	436	914	
	-14.84	374	439	
	-0.59	342	1360	
	3.55	343	1362	

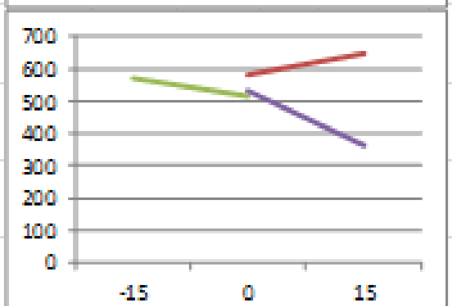


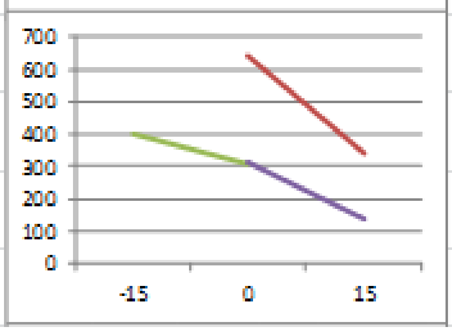




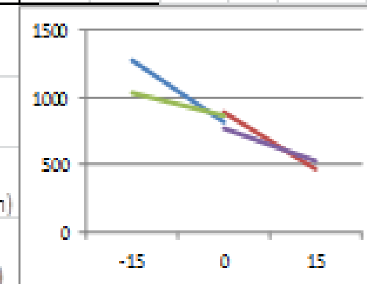
IL-053	-6.92	151	793	low pre- (blue)
	-19.60	91	359	hi pre- (red)
	-4.97	134	1361	low post- (green)
	-0.08	101	1387	hi post- (purple)
IL-41L	0.00	0	0	
	4.45	579	229	
	-3.58	515	2347	
	-11.52	533	1934	
IL-41F	0.00	0	0	
	-20.26	644	229	
	-6.36	305	2347	
	-11.59	314	1934	

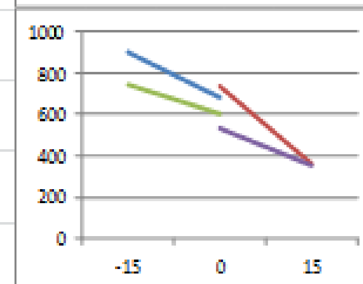


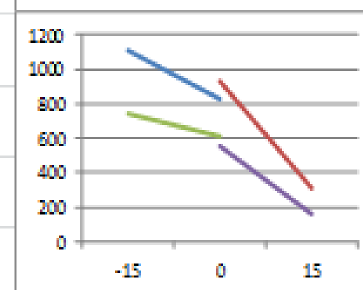




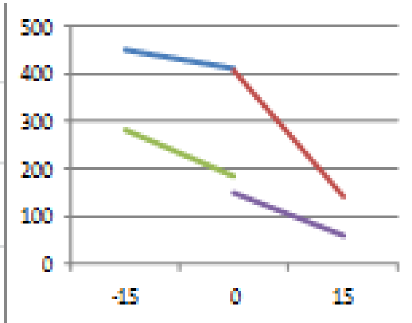
house	slope	interce	count	
IL-040	-30.54	819	73	low pre- (blue)
	-28.05	891	966	hi pre- (red)
	-10.79	869	2274	low post- (green)
	-15.95	769	1719	hi post- (purple)
IL-040F	-14.64	680	73	
	-25.08	735	966	
	-9.24	606	2274	
	-12.11	532	1719	
IL-038	-18.84	824	75	
	-41.25	928	1015	
	-8.72	615	2272	
	-26.02	555	1672	

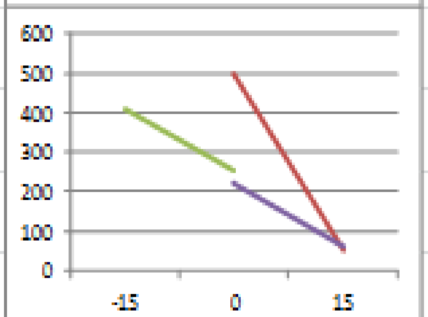


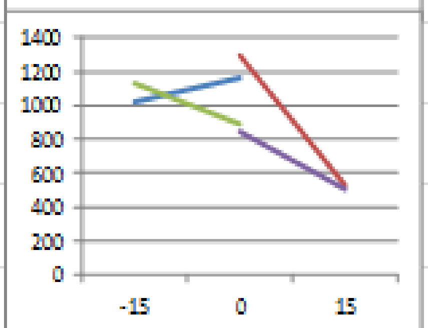




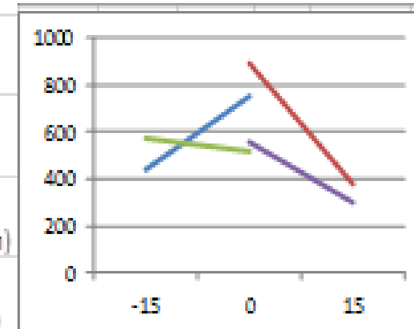
IL-38F	-2.65	409	75	low pre- (blue)
	-17.52	406	1016	hi pre- (red)
	-6.50	185	2272	low post- (green)
	-5.96	148	1672	hi post- (purple)
IL-037	0.00	0	0	
	-29.77	500	53	
	-10.22	254	2326	
	-10.81	222	1868	
IL-032	9.84	1163	73	
	-50.75	1291	993	
	-15.80	891	2253	
	-22.73	847	944	

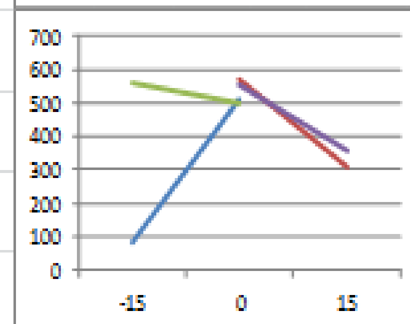


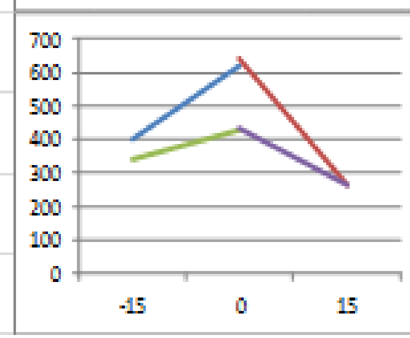




IL-004L	20.78	753	19	low pre- (blue)
	-34.23	893	1186	hi pre- (red)
	-3.58	518	826	low post- (green)
	-17.26	555	2002	hi post- (purple)
IL-004F	28.30	509	19	
	-17.75	572	1193	
	-3.88	502	826	
	-13.23	554	1995	
IL-005F	14.55	621	19	
	-25.13	640	1027	
	5.83	428	1284	
	-11.47	434	2336	

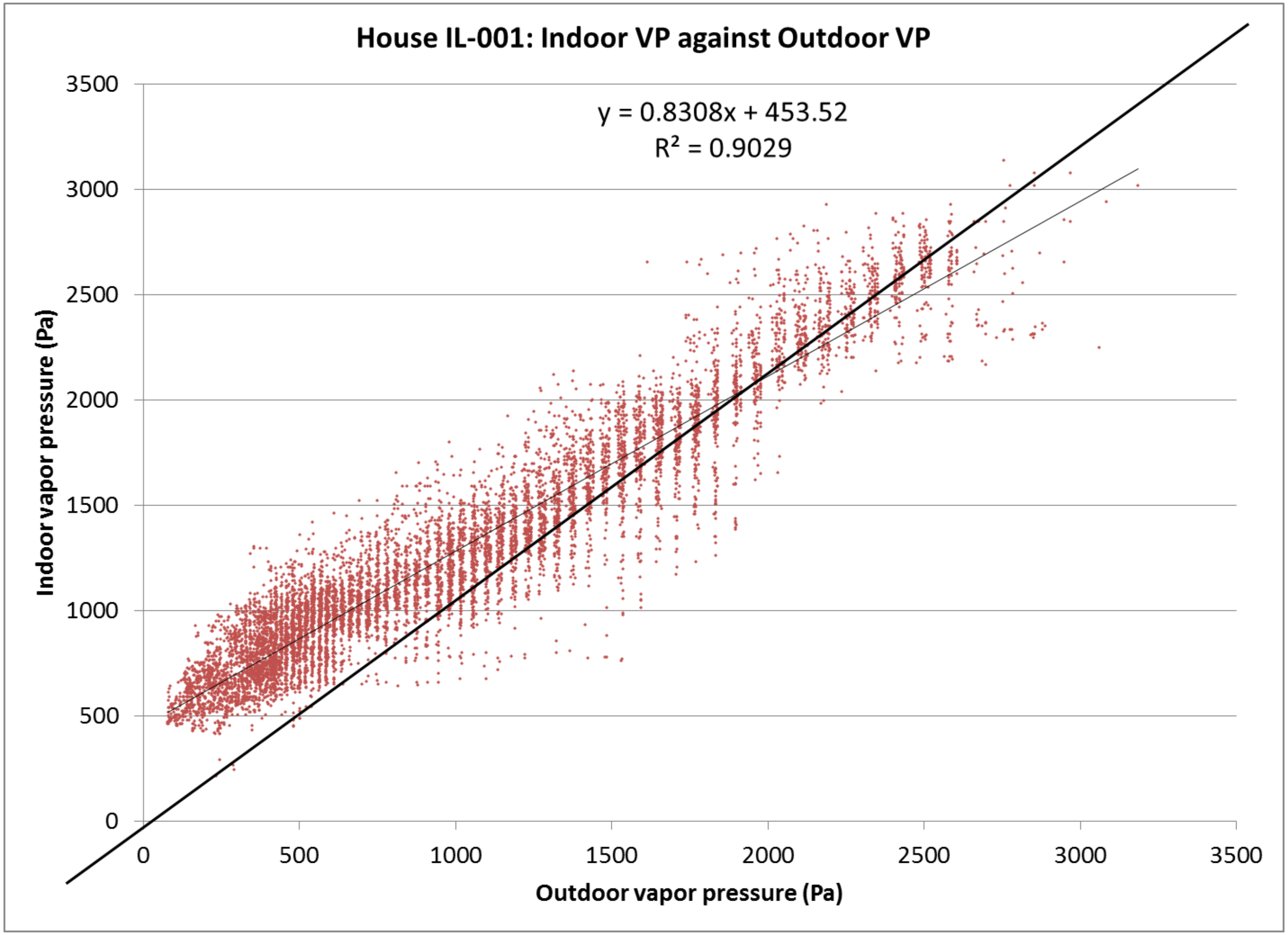






Alternatives?

- Plot indoor vapor pressure against outdoor vapor pressure?



CONCLUSIONS

Conclusions

- The paper seeks to address how to characterize the wetness (or dampness or dryness) of a space by analyzing data of indoor temperature and humidity. The starting point for the analysis is the application of a vapor pressure excess profile presented in ISO 13788 to calculate Moisture Balance. Warm weather data must be excluded from the analysis, because vapor pressure excess at high temperatures in the US is driven primarily by use of air conditioning, which gives information about equipment operation, not about cold-weather wetness of the space.
- The MB approach has been used in previous papers. In the earlier papers, the data cutoff was 20° C. It became apparent in reviewing the earlier data that that cutoff was too high—it included much data that skewed the results. In this paper a cutoff of 15° C was used.

Conclusions

- Close analysis of the resulting data shows that mild-weather estimates of MB taken with a 15° C cutoff, do not correspond to the MB of the same house for measurements during cold weather.
- Estimates of the standard deviation for MB measurements taken at 1-week, 2-week and 1-month intervals are presented. Of course, longer terms of measurement show less variance in the calculations.
- This paper introduces a caution in the use of the MB method for data where the outdoor temperature is >10° C. Improved methods that achieve greater correspondence between MB results for the same house at cold temperatures and at mild temperatures must await further investigation.

Acknowledgements

Housing and Urban Development (HUD) funded HEALTH-V Study:

Housing Environmental Aspects Linked To Health through Ventilation

- School of Public Health, University of Illinois at Chicago
- National Center for Healthy Housing, Columbia MD
- Community and Economic Development Association of Cook County (CEDA), who collected field data
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- Reviewers of this paper (significant contributions)