Passive building in Hot and Humid Climates

Lisa White

Overview

1. Thermal Comfort
2. Drivers of sensible and latent cooling loads
3. Passive cooling strategies
4. Active cooling strategies
5. Capabilities of WUFI Passive – static
6. Capabilities of WUFI Passive - dynamic
7. Two Humid Climate Case Studies
8. WUFI Passive Dynamic Modeled Results

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1. Thermal Comfort

Thermal Comfort Factors

PHYSICAL FACTORS

- Clothing – CLO
- Activity level – MET

MENTAL

- Experiences, expectations, influence of other conditions

USER FACTORS

- Clothing insulation
- Metabolic activity
- State of mind

ENVIRONMENTAL FACTORS

- Air temperature
- Relative humidity
- Air speed
- Radiant conditions

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2. Main drivers of sensible and latent cooling loads in buildings

Sensible cooling drivers in buildings

- Internal loads: plug loads, cooking, etc.
- Occupants
- Solar gains through transparent components
- Transmission through opaque components
- Natural Ventilation
- Mechanical Ventilation
- Infiltration

Latent cooling drivers in buildings

- Internal loads
- Occupants
- Exchange through opaque partitions
- Natural Ventilation
- Mechanical Ventilation
- Infiltration

Passive Solar Opportunities (and Challenges)

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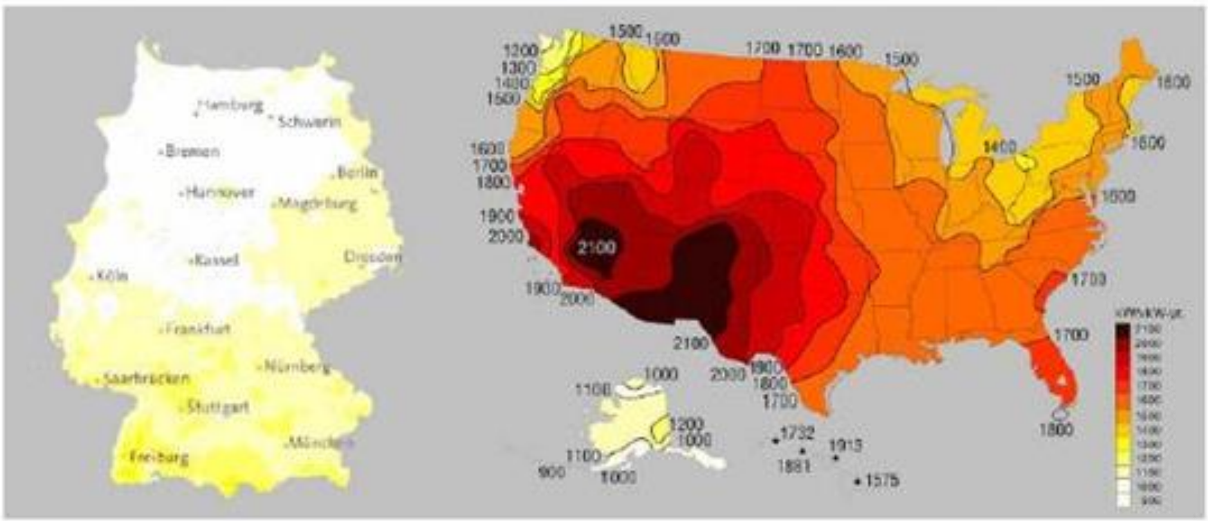
Solar energy: High potential in the U.S.

Germany is the world's largest solar market, despite a climate less conducive to solar power than the United States. A solar panel placed in Ohio will produce 20-25% more energy than the exact same panel in Germany, due to climate variances.



Source: Solar maps: National Renewable Energy Laboratory, European Commission

Passive Hous

VLI: “the load generated by one cubic foot per minute of fresh air brought from the weather to space-neutral conditions over the course of one year”

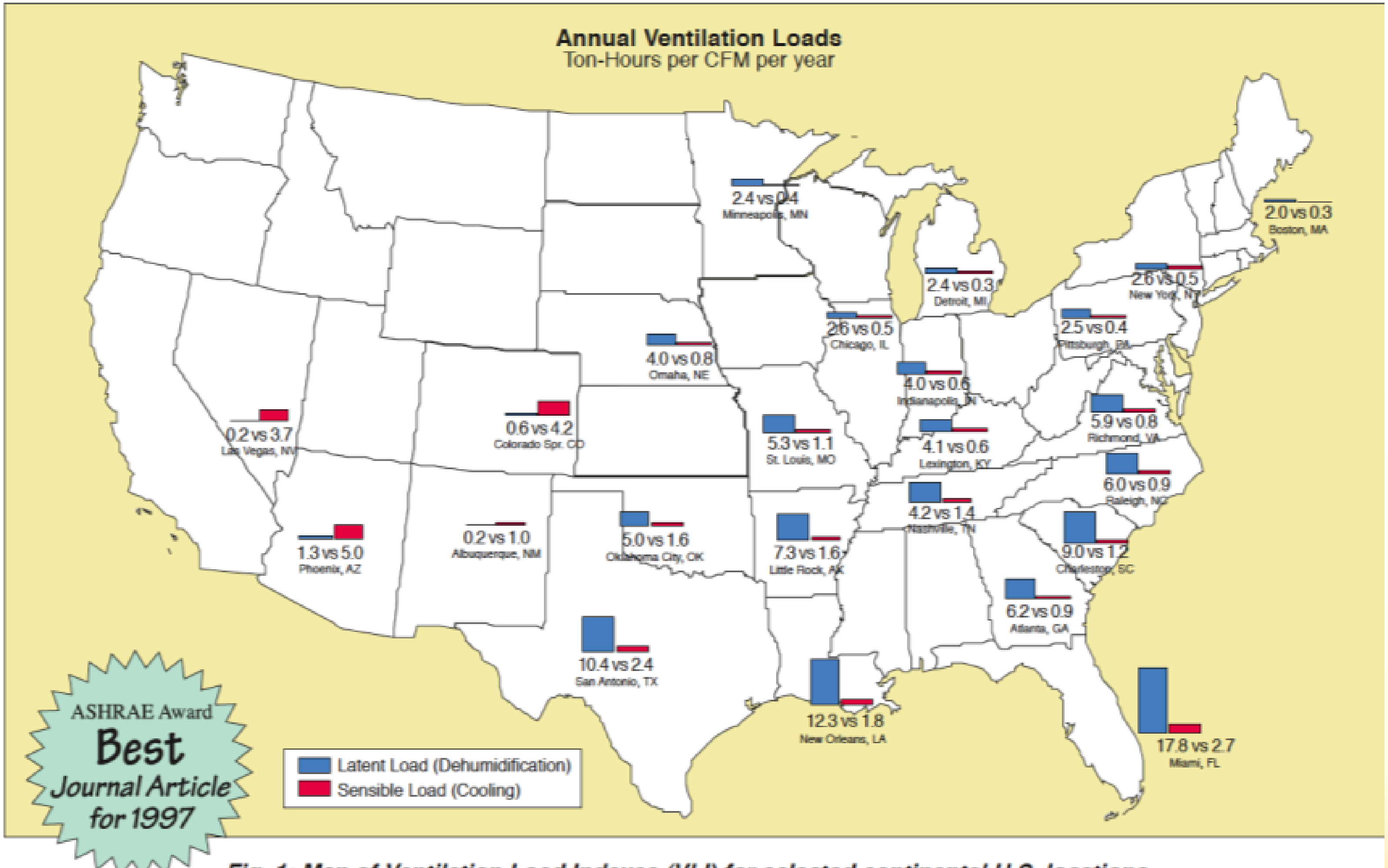
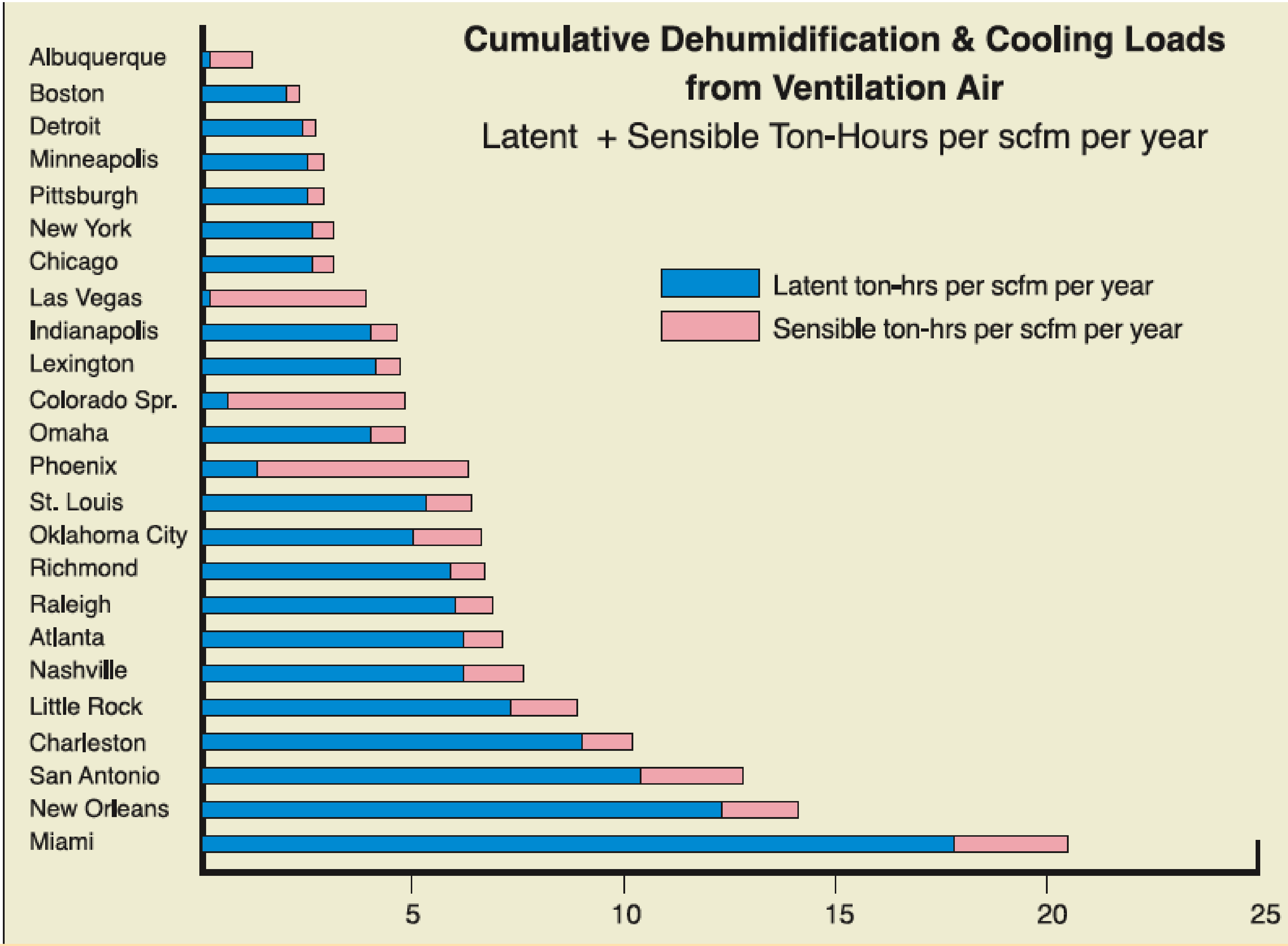


Fig. 1: Map of Ventilation Load Indexes (VLI) for selected continental U.S. locations



Cumulative Dehumidification & Cooling Loads
from Ventilation Air
Latent + Sensible Ton-Hours per scfm per year
Latent ton-hrs per scfm per year
Sensible ton-hrs per scfm per year
Albuquerque
Boston
Detroit
Minneapolis
Pittsburgh
New York
Chicago
Las Vegas
Indianapolis
Lexington
Colorado Spr.
Omaha
Phoenix
St. Louis
Oklahoma City
Richmond
Raleigh
Atlanta
Nashville
Little Rock
Charleston
San Antonio
New Orleans
Miami
5
10
15
20
25

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Air-tightness
Moisture Migration

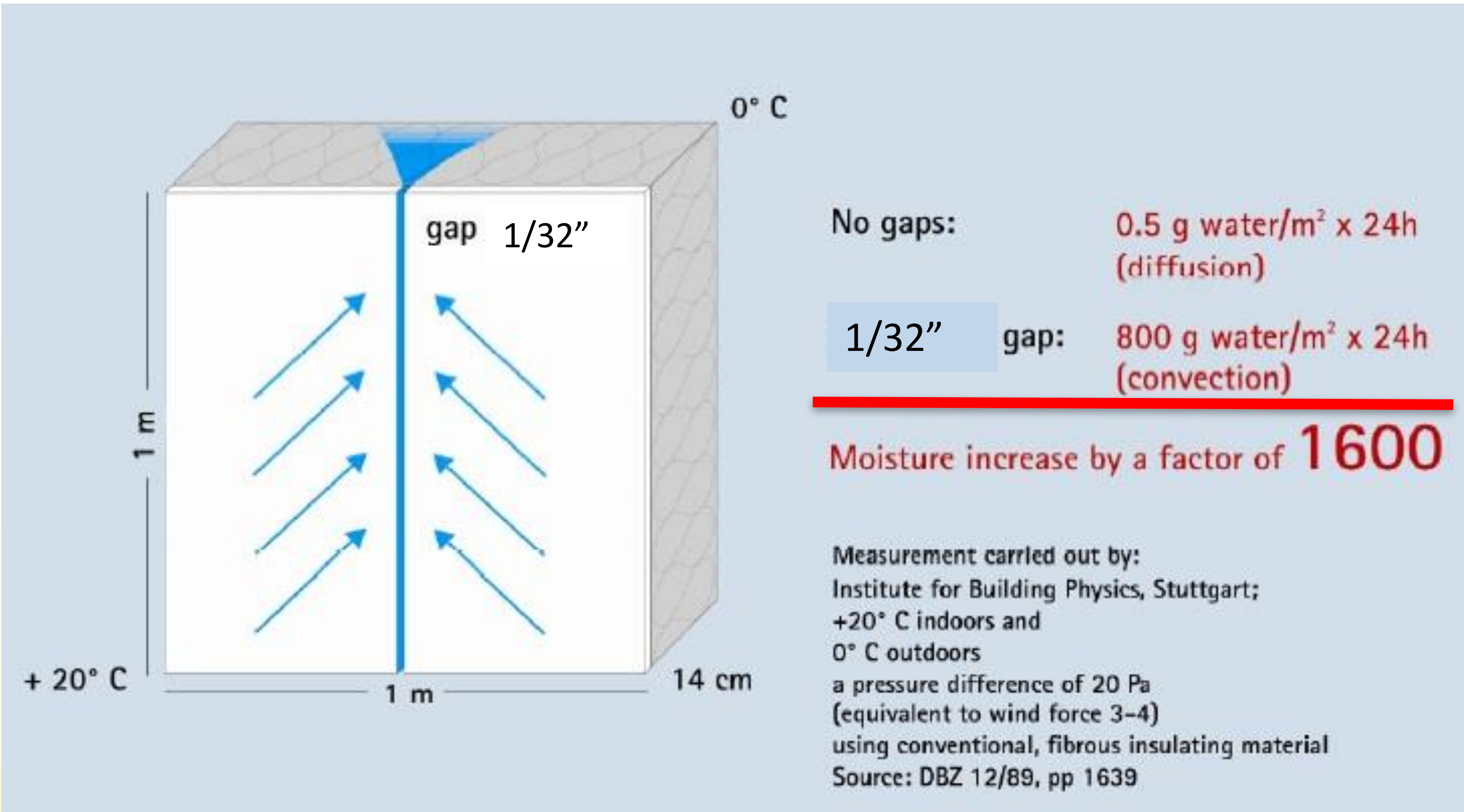
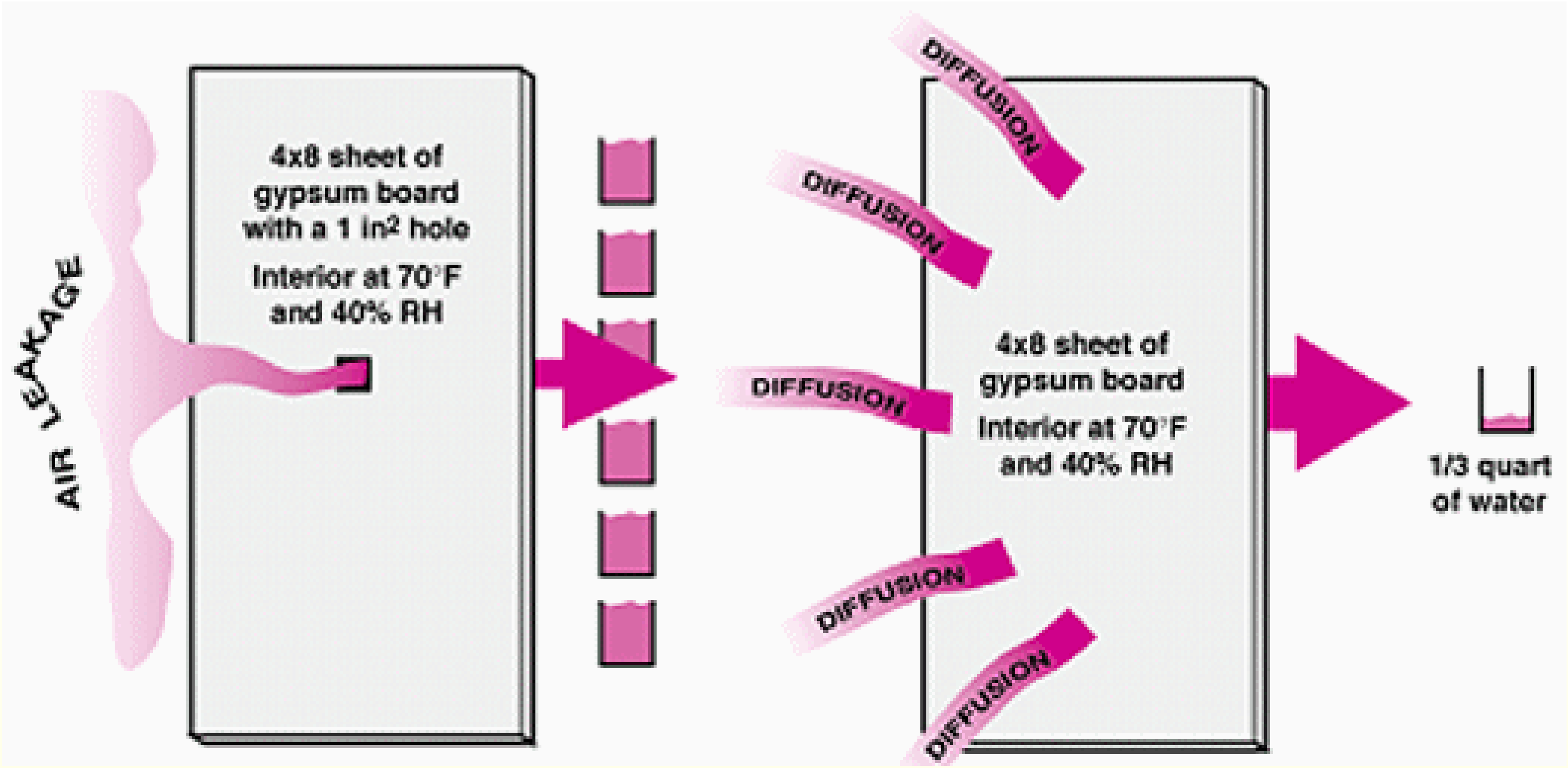


Image Source: Study by Fraunhofer Institute for Building Physics IBP

Infiltration vs. Diffusion



Source: Building Science Corp

Infiltration = In Quickly

Diffusion = Out SLOOOWLY

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3. Passive Sensible and Latent Cooling Strategies

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Passive Cooling Strategies

- Shading
  - Trees, overhangs, reveal shading, in-set windows
  - Especially South & West
- Attach a garage or buffer zone to south or west
- Ventilation
  - Vent the roof
  - Cross ventilate
- Daylighting to the North
- Thermal mass
- Phase Change Materials

Passive Design Cooling Strategies

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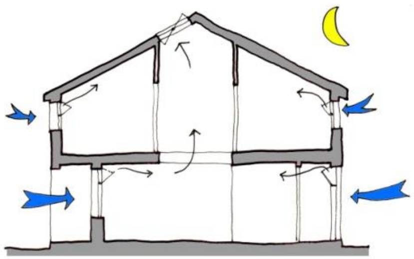
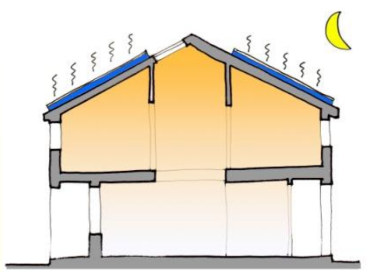
Passive Cooling

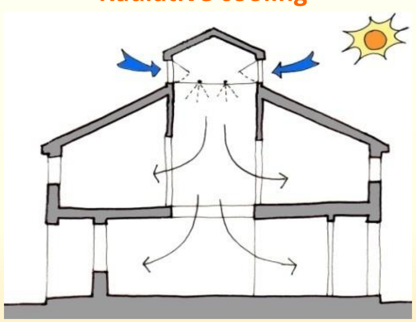
(Image Source: passive-on.org)



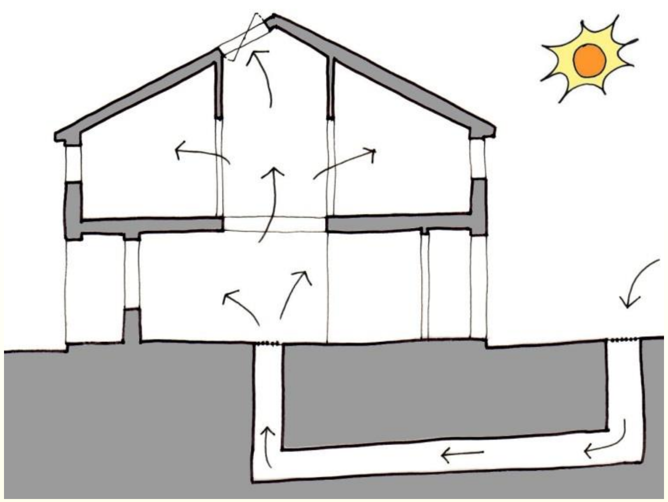
Night-time cooling



Radiative cooling

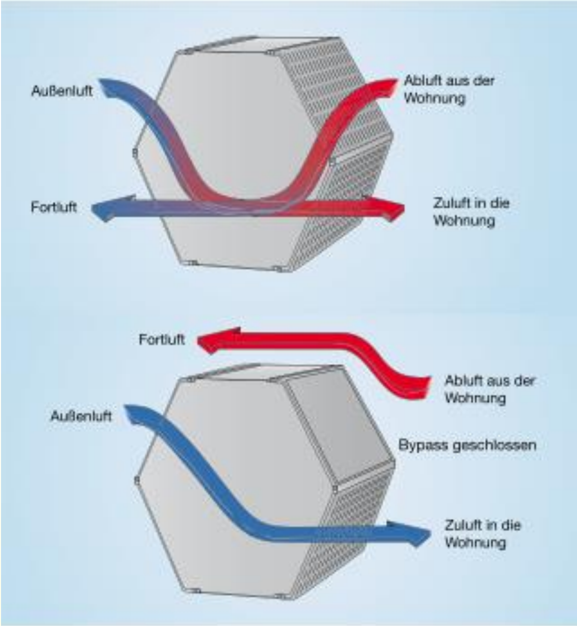


Evaporative cooling
(more for dry climates)



Ground cooling

Ground Temperature @ 10-13 ft =
Annual Mean Air Temperature ±4 ºF



Source: Zehnder
Heat Recovery Bypass

Passive Cooling Strategies

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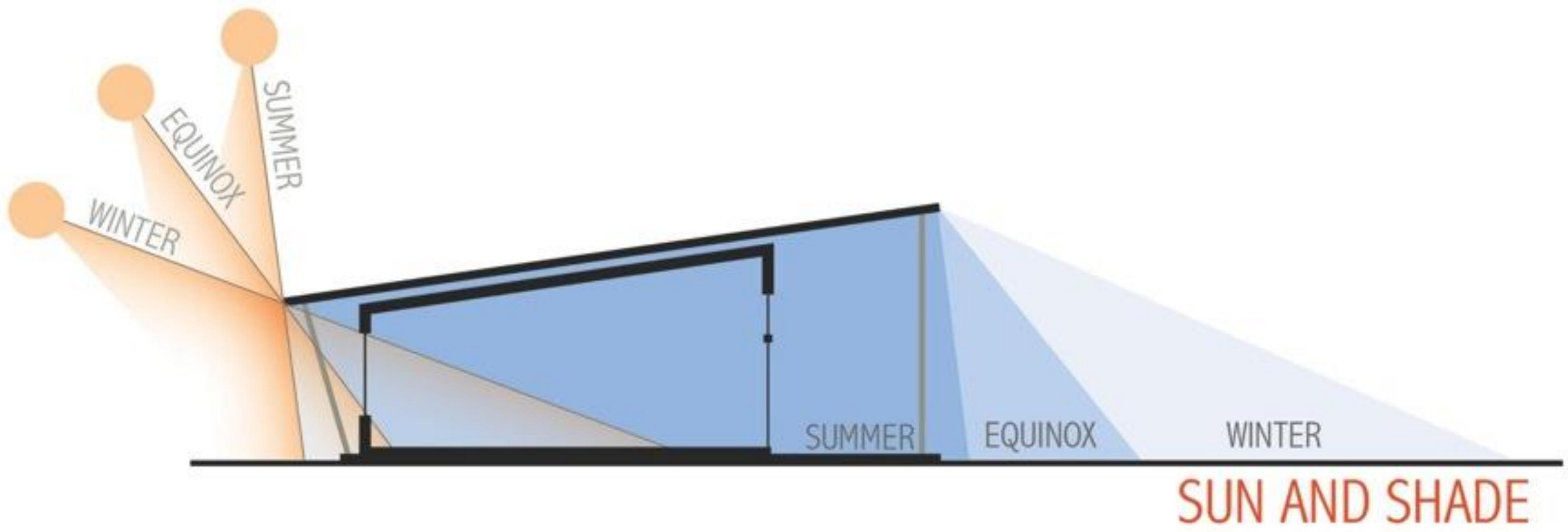

- Utilize the sun angle

Exterior Shading Devices

Venetian Blinds, trellises, overhangs, balconies, decks, trees etc.

http://www.warema.com

PHIUS+ Certified
Konkol Passive House
Hudson, WI

Passive Latent Cooling Strategies

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- Not nearly as many
- Using insulation with hygric buffering (to reduce peak latent loads)
- Latent loads are largely independent from insulation levels, unlike sensible cooling loads and heating loads
- Earth coupling: Earth is endless heat sink
  - Earth tube
  - Subsoil heat exchanger
  - ‘pre-cooling’ supply air

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- Now that you've dramatically reduced the heating and sensible cooling loads with passive strategies, how do you satisfy a high latent load?

4. Active Sensible and Latent Cooling Strategies

(Mechanical Systems)

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What loads need to be covered?

1. Heating (sometimes)
2. Cooling (reduced)
3. Dehumidification

Mini-split systems

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- Ducted into ventilation air, duct into own system, or stand-alone

Samsung EH slim ducted Mini-Split, integrated in ventilation ductwork

Samsung Mini-Split Air-to-Air Heatpump 20 SEER, point source

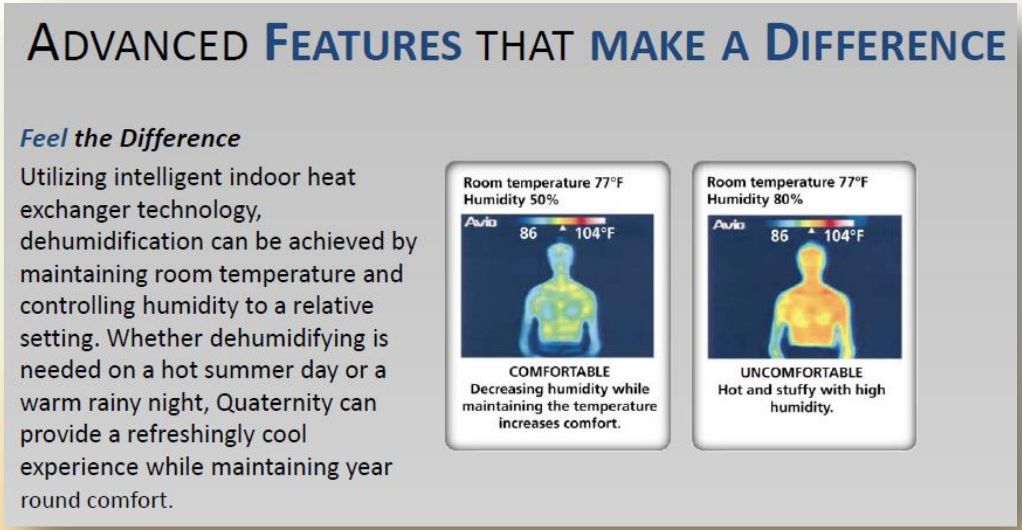
(Images:http://compressors.danfoss.com/)

Mini-split systems

– Issues with removing latent loads when no sensible loads are present

– Some equipped with "dehumidify mode"

- Daikin Quaternity – independently controllable RH and temperature settings



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Dehumidification

- Stand-alone dehumidifiers
  - Duct into supply air OR
  - Single point supply
- Split coil dehumidifiers
  - Newer technology
  - No additional heat load added to interior space, released from outdoor condensing unit
  - First stage cooling

Mechanical Ventilation Options

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- Continuous Ventilation with heat recovery:
  - Heat/Energy Recovery Ventilator
- Exhaust only ventilation:
  - If the climate is mild enough that it doesn't need the heat recovery
- Demand Controlled ventilation:
  - Defined by IAQ set points, occupancy (CO2), or temperature
  - Reduces redundant ventilation

Build Equinox CERV

Options for Mechanical Systems

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- Future options:
  - Using more demand controlled ventilation to reduce redundant ventilation (ventilate for the people, not for the building)
  - Mini-split systems with dehumidification only modes, separate RH set-points
  - ERV's with higher latent efficiency
    - PHIUS Tech Committee protocol: In ASHRAE Climate Zone 3 and below, the summer test point data from HVI must be used, and the values must be separated into sensible and latent efficiencies

5. Capabilities of WUFI Passive/PHPP Static Modeling

Inputs critical to calc'ing cooling demand

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- **Material properties:** thermal resistance (R/in) is only value considered
  - no specific heat capacity, or anything related to moisture transmission/storage
- **Thermal Mass:** Single entry applied to whole building based on # of heavy surfaces per room
- **Ventilation:** Only option is continuous rate
- **Internal heat gains:** default or calculated value, but single constant value
  - Single default value for humidity loads [0.00041 lb/ft2.hr]

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6. Capabilities of WUFI Passive Dynamic Modeling

Capabilities of WUFI Passive

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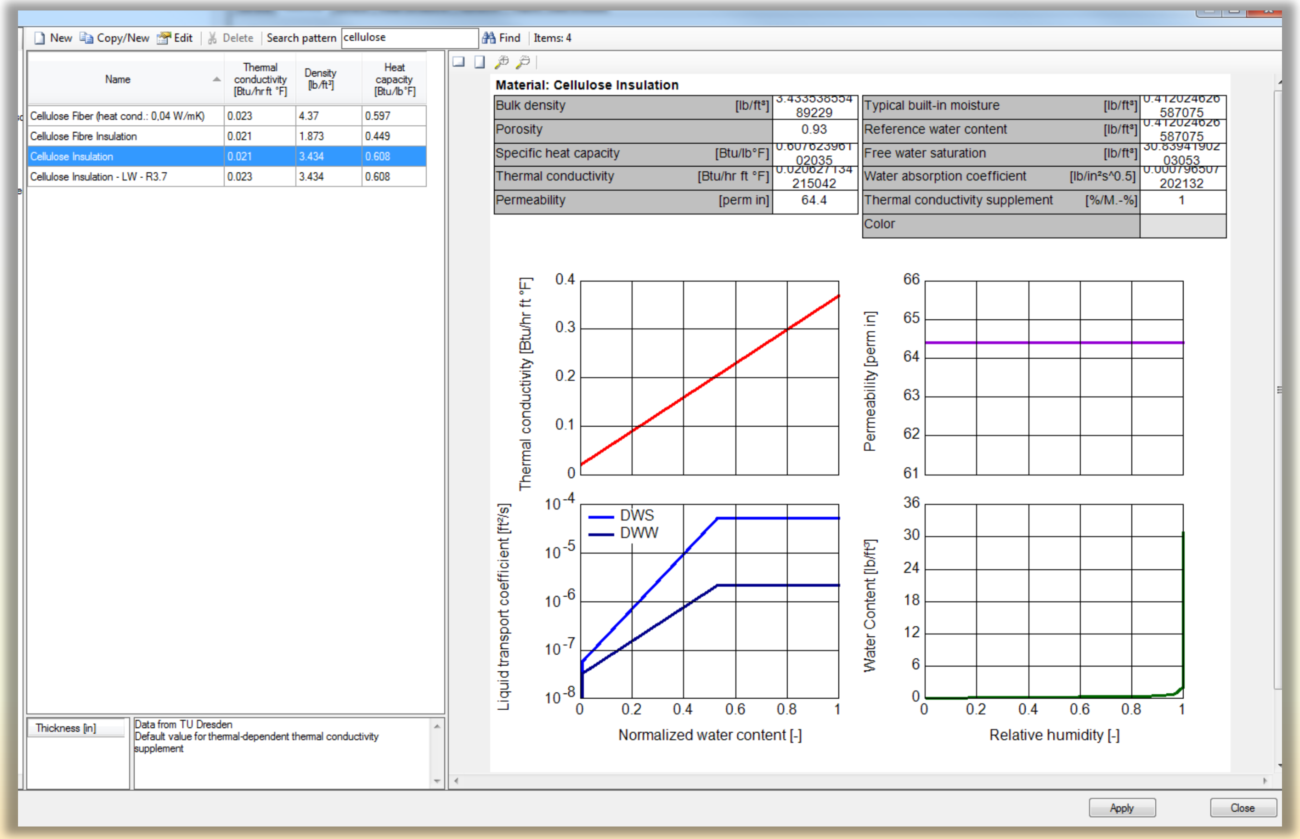
Material properties:

- Porosity
- Specific Heat capacity
- Permeability
- Water absorption coefficient

→ Critical to determine latent loads
- All capabilities of WUFI 1D, but for whole building simulation



Capabilities of WUFI Passive

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Thermal Mass:

- Calculated directly by assemblies input into whole building simulation
- Interior walls modeled and accounted for
    - Zone distribution
        - For all layers, requires:
            - Density
            - Specific heat capacity
            - Temperature dependent enthalpy (for PCM)

- **"Massive" materials:** water, concrete, adobe, rammed earth, stone, PCM's

- Utilizing thermal mass is most challenging in hot humid climates where night temperatures remain elevated.
    - Strategically locate to avoid overheating, no direct solar gain

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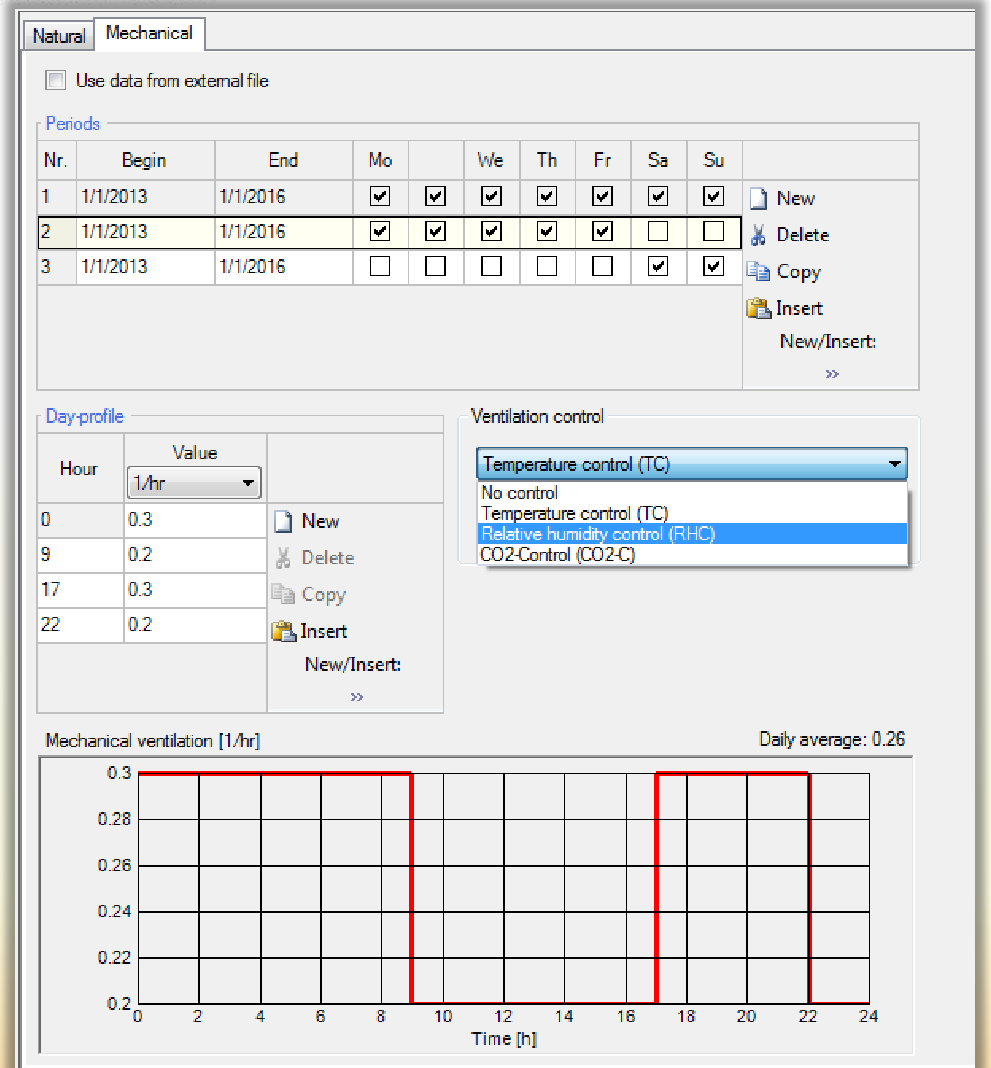
Capabilities of WUFI Passive



Ventilation:

- Daily profiles
- Hourly profiles
- Realistic “schedule” for low rates and boost modes

Capable of modeling demand controlled ventilation by:

- Temperature set points
- Relative Humidity Levels
- CO2 maximums

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Capabilities of WUFI Passive

Internal Heat Gains:

- Hourly & Daily profiles
- Activity & age of occupants
- Convective heat, radiant heat, moisture, and CO_2 entries

Internal loads calculator

Loads

Nr.	Specification	Human	Count	Heat convective [Btu/hr]		Heat radiant [Btu/hr]		Moisture [g/hr]		CO2 [g/hr]	
				Specific	total	Specific	total	Specific	total	Specific	total
1	Adult, sitting person, relaxed	☑	2	221.789	443.58	122.837	245.67	43	86	30.3	60.6
2	Adult, sitting person, working	☑	1	272.971	272.97	139.898	139.9	59	59	36.3	36.3
3	Kid, kindergarden, 3 - 6 years	☑	1	68.243	68.24	40.946	40.95	90	90	32	32
4	Kid, School, 14 - 16 years	☑	1	204.728	204.73	102.364	102.36	50	50	33.8	33.8
				Σ	989.52	Σ	528.882	Σ	285	Σ	162.7

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7. Two Humid Climate Case Studies

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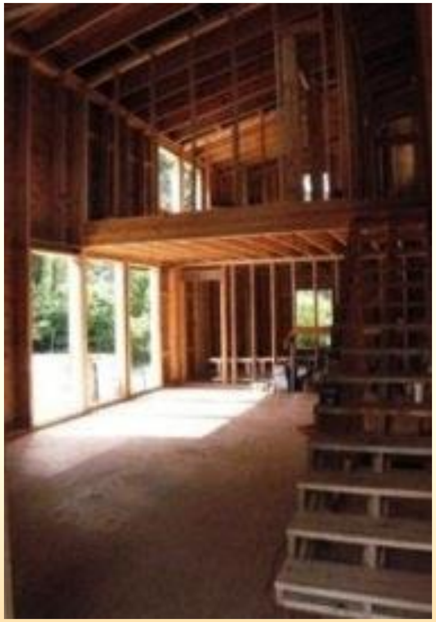
LeBois House – Lafayette, LA

Abbate House – Austin, TX

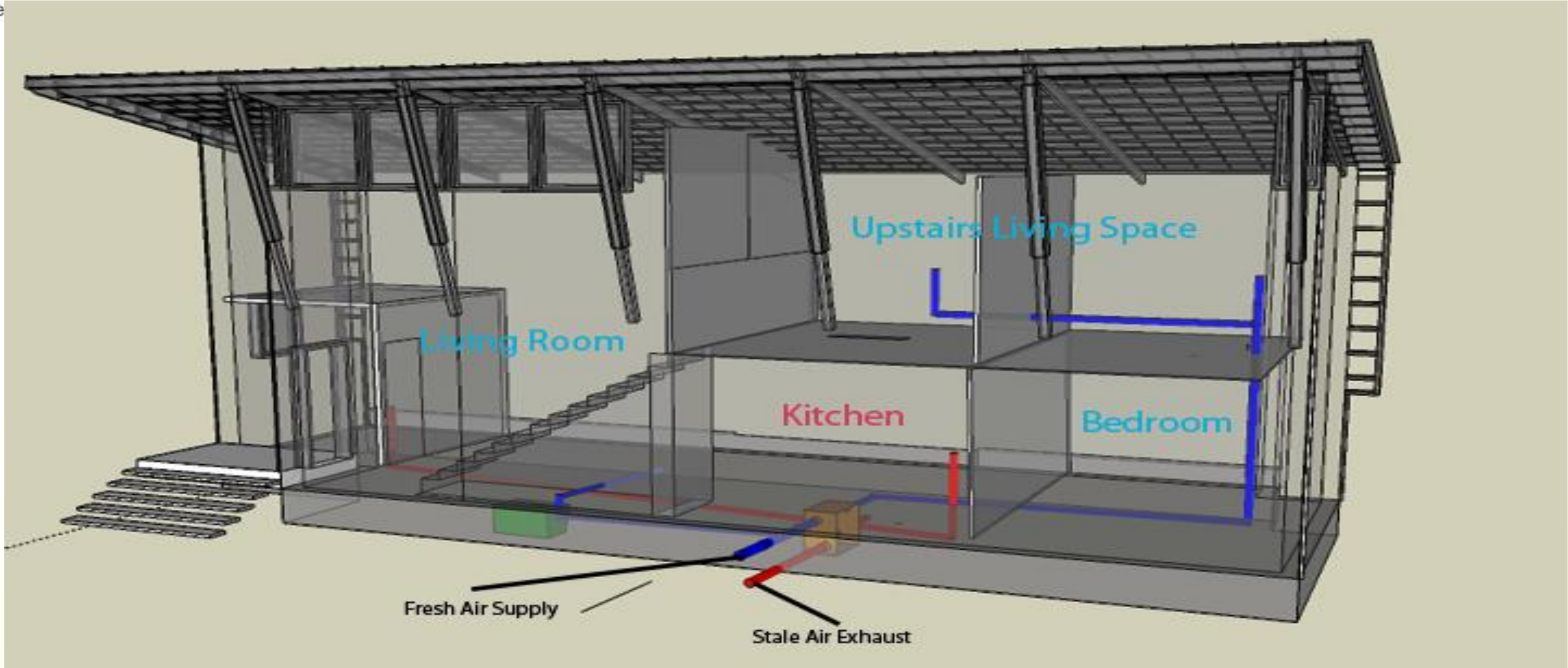
LeBois House (2009)

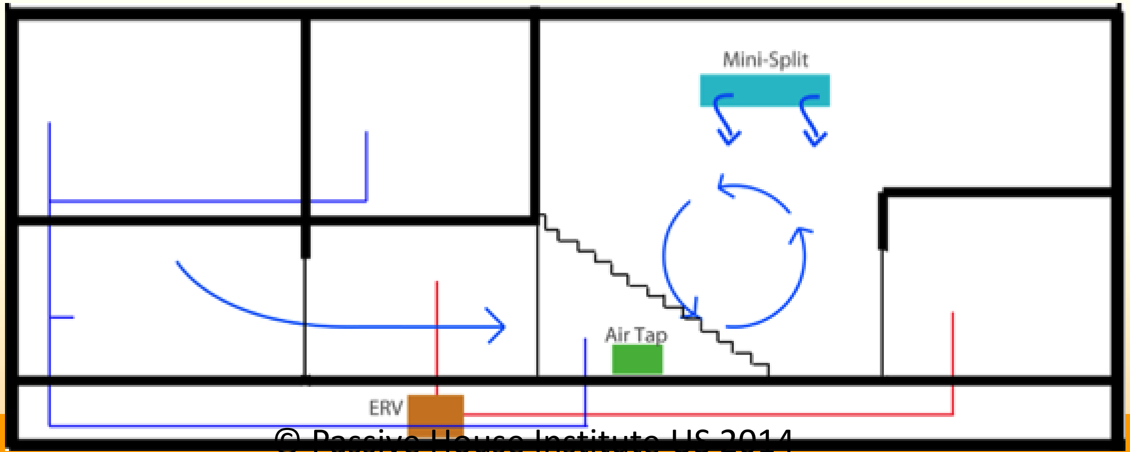
Passive House Institute US

Element	Details
Wall – R 28	2x6" (partial 2x8") stud wall filled with open cell spray foam (Icynene) with 1" of exterior Polyiso Board.
Floor – R 16.5	3" of XPS Board under 4" of Concrete below insulated crawlspace
Roof - R55	12" TJI filled with open cell spray foam (Icynene) with 2" of exterior Polyiso Board.
Windows – R5.2 overall	ThermaProof w/ Alpen Glass SHGC: 0.29, 0.24
Ventilation	Ultimate Air RecopuAerator 200DX ERV
Heating system	Mini Split Heat Pump
Domestic hot water	Heat Pump
Location	Lafayette, LA



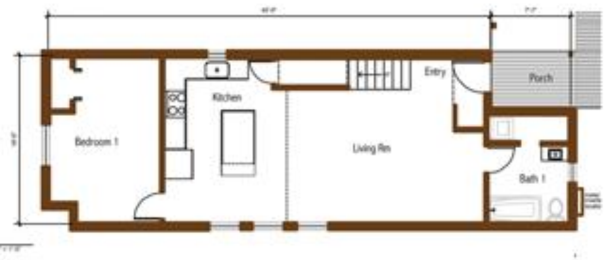
LeBois House: Mechanical Schematic

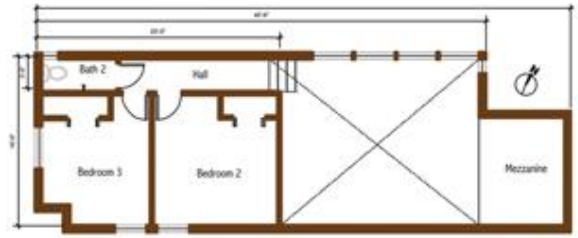




SAFT ARCHITECTURE

SaftArchitecture.com





Map of the first certified Passive Houses's in the United Ststes. LeBois is the greensquare in LA.

LeBois House: PHPP Results

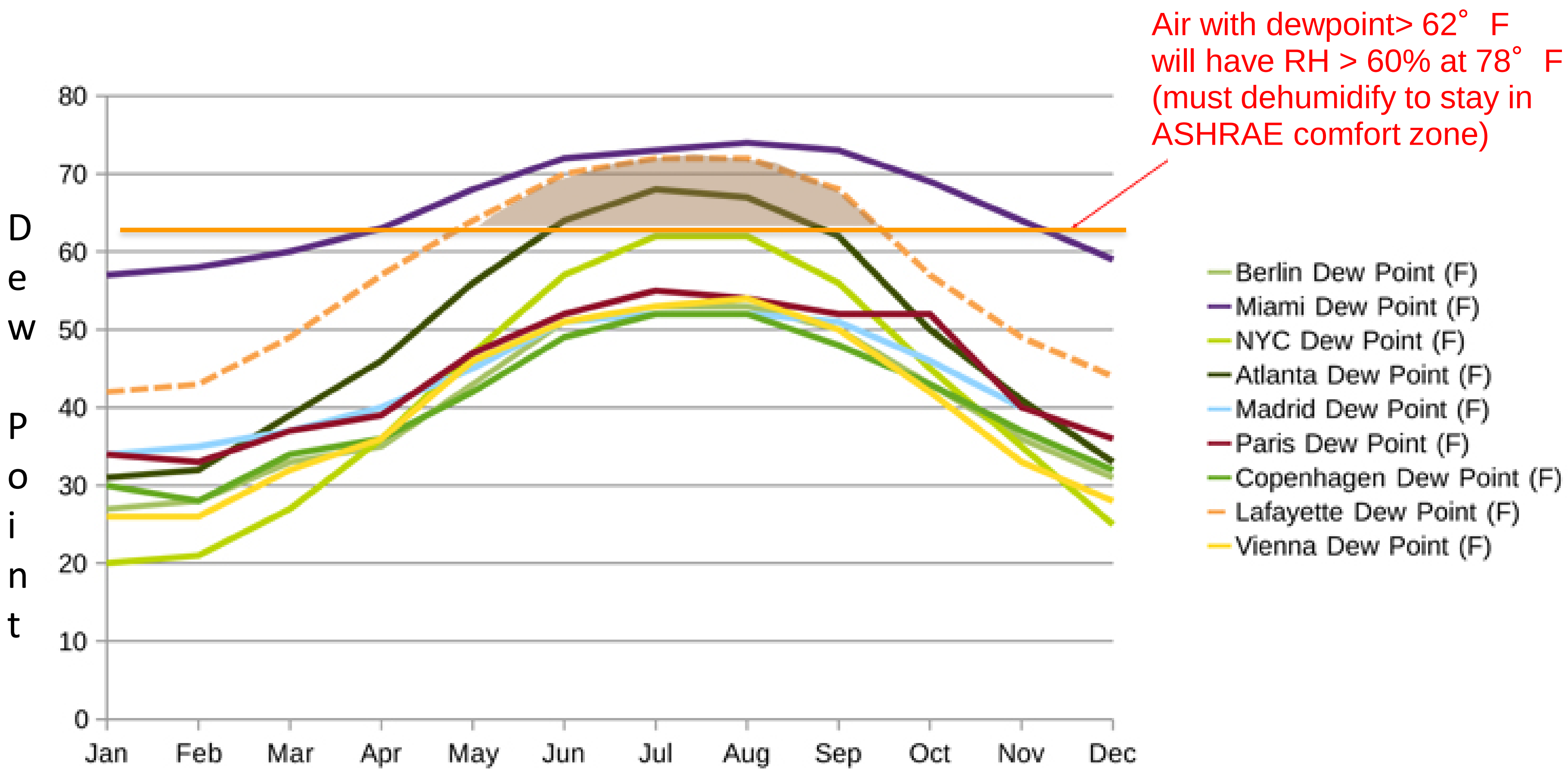
PHIUS
Passive House Institute US

Energy Demands with Reference to the Treated Floor Area

Treated Floor Area: 1290 ft^2

	Applied:	Monthly Method	PH Certificate:	Fulfilled?
Specific Space Heat Demand:	2.52	$kBTU/(ft^2yr)$	4.75 $kBTU/(ft^2yr)$	Yes
Pressurization Test Result:	0.57	ACH_{50}	0.6 ACH_{50}	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	36.8	$kBTU/(ft^2yr)$	38.0 $kBTU/(ft^2yr)$	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	17.4	$kBTU/(ft^2yr)$		
Specific Primary Energy Demand Energy Conservation by Solar Electricity:	15.9	$kBTU/(ft^2yr)$		
Heating Load:	4.65	$BTU/(ft^2hr)$		
Frequency of Overheating:	40.4	%	over 77.0 °F	
Specific Useful Cooling Energy Demand:	4.69	$kBTU/(ft^2yr)$	4.75 $kBTU/(ft^2yr)$	Yes
Cooling Load:	3.83	$BTU/(ft^2hr)$		

LeBois House: Latent Load



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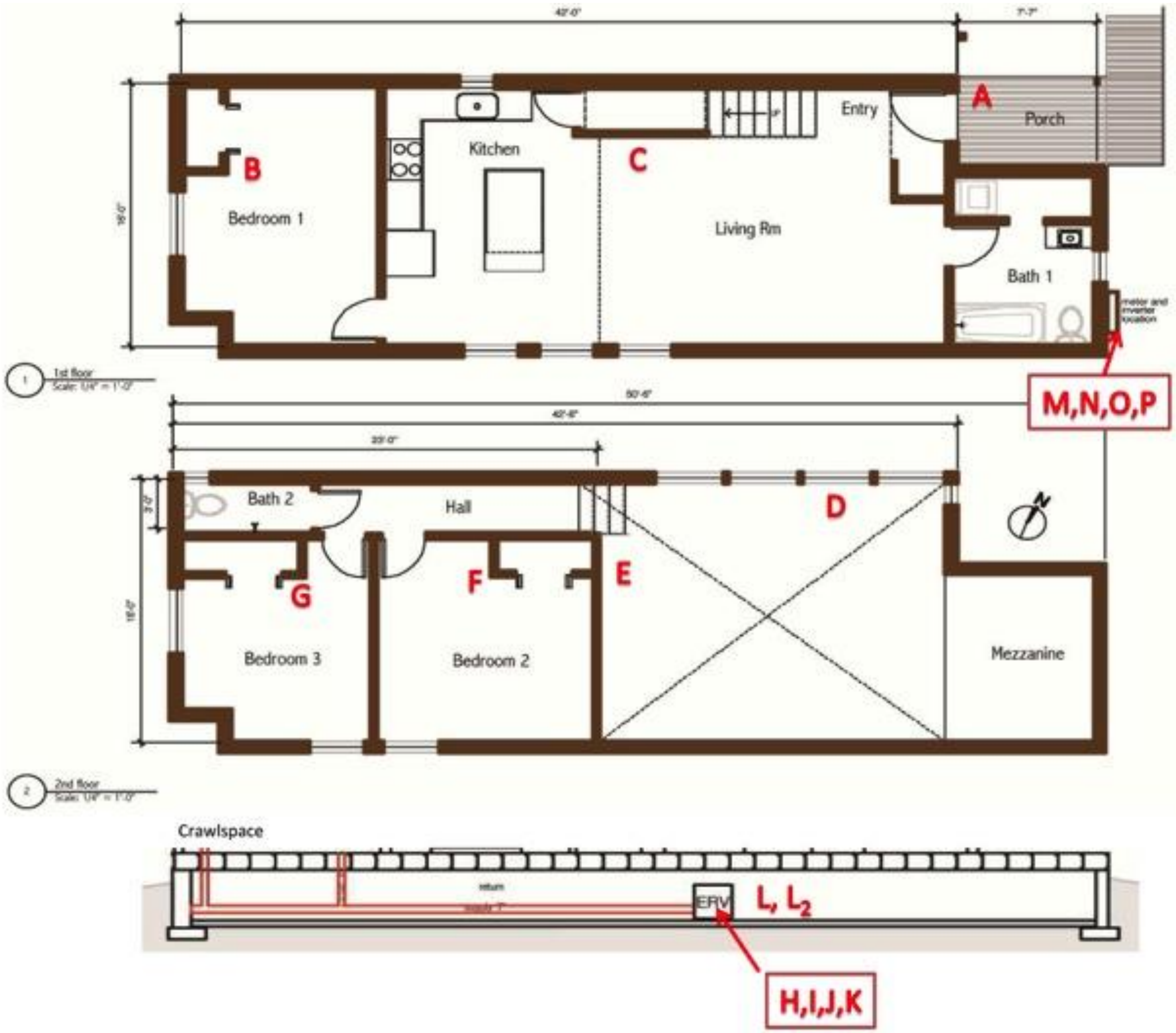
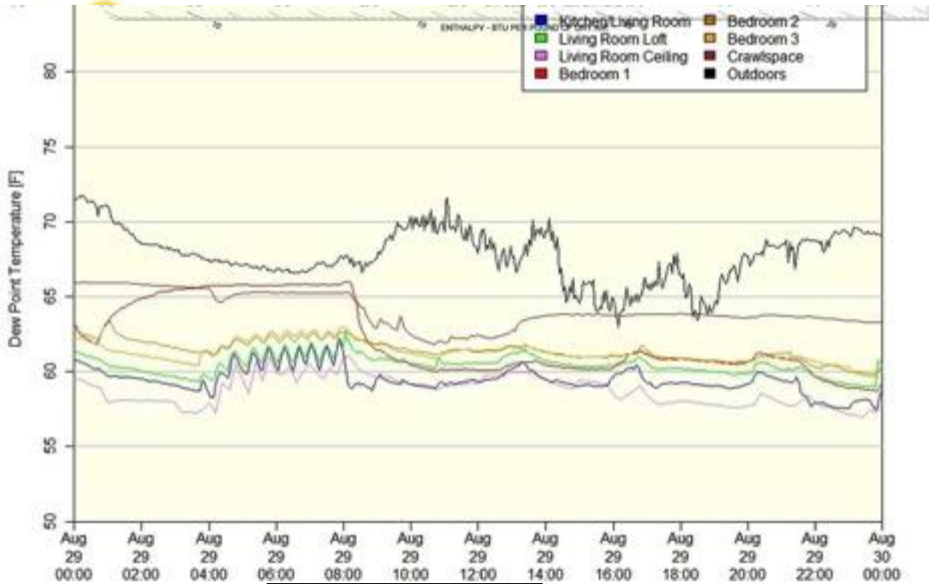
LeBois House: Data Collection



	Instrument	Location/Description
A	Onset T/RH Logger	Outdoors, Shaded on North Side
B	Onset T/RH Logger	Bedroom 1
C	Onset T/RH Logger	Living Room, User Height
D	Onset T/RH Logger	Living Room, Near MS
E	Onset T/RH Logger	Living Room, High
F	Onset T/RH Logger	Bedroom 2
G	Onset T/RH Logger	Bedroom 3
H	Onset T/RH Logger	ERV, fresh inlet
I	Onset T/RH Logger	ERV, fresh tempered
J	Onset T/RH Logger	ERV, exhaust inlet
K	Onset T/RH/Ext Logger	ERV, exhaust outlet
L	Onset T/RH Logger	Crawlspace
L2	External CT for amperage	ERV current (calculate energy use)
M	TED5004 MTU/CT #1	House Net Energy
N	TED5004 MTU/CT #2	PV Generation
O	TED5004 MTU/CT #3	Mini-Split
P	TED5004 MTU/CT #4	DHW

LeBois House

ENERGY & COMFORT

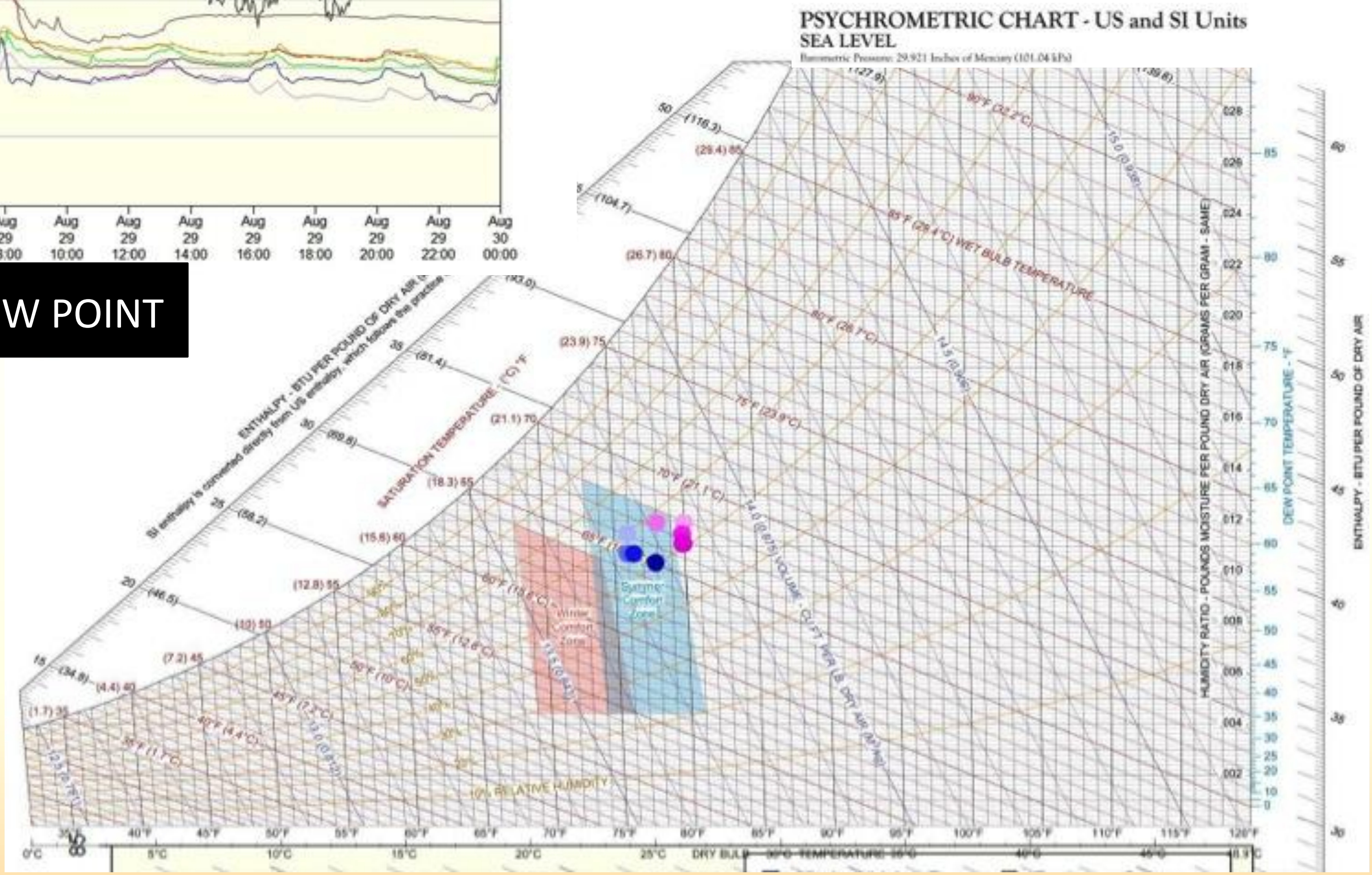


DEW POINT

August 29

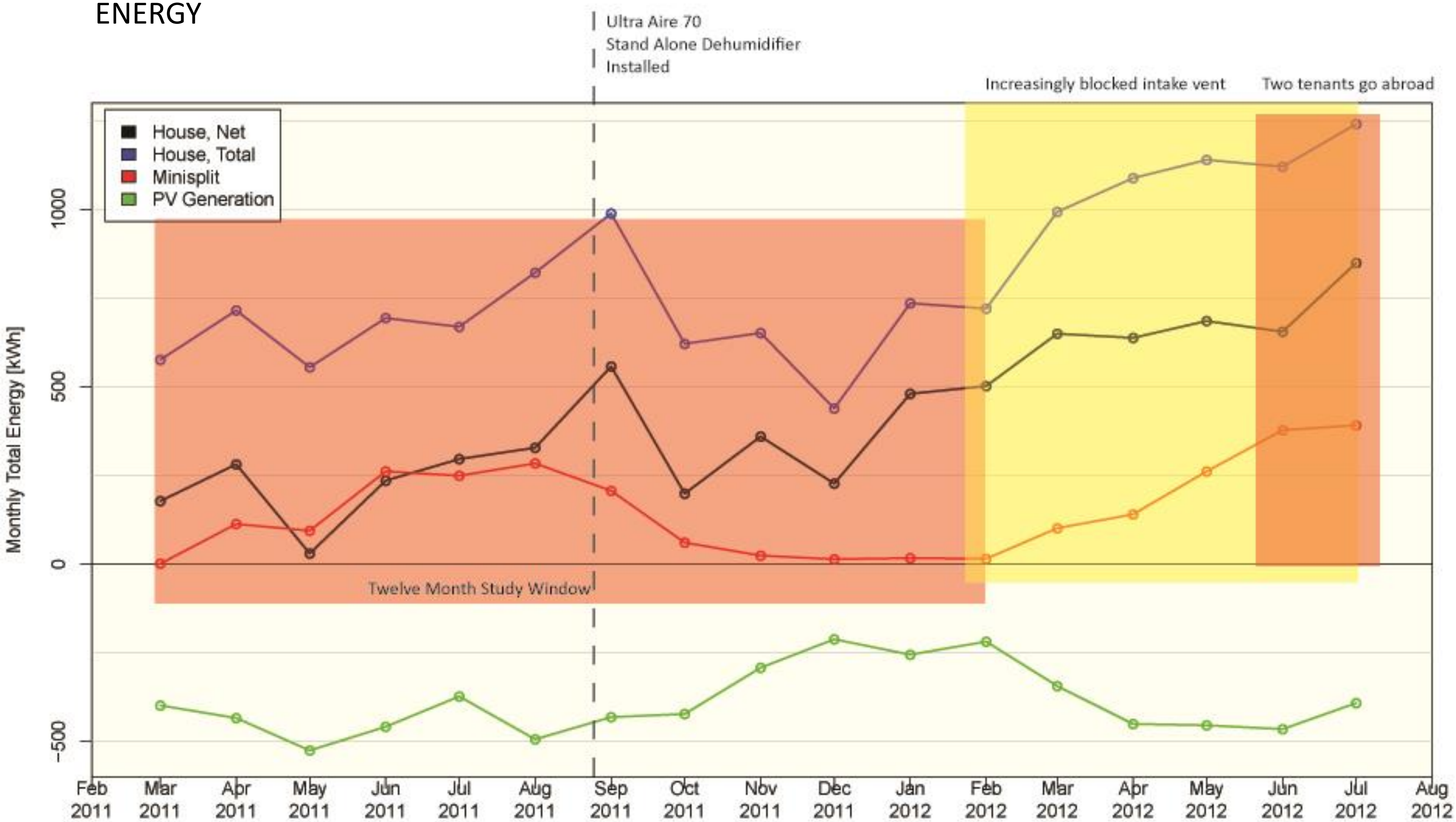
Kitchen/Living
- 6:00am
- Noon
- 6:00pm
- Midnight

Bedroom 2
- 6:00am
- Noon
- 6:00pm
- Midnight



LeBois House

ENERGY



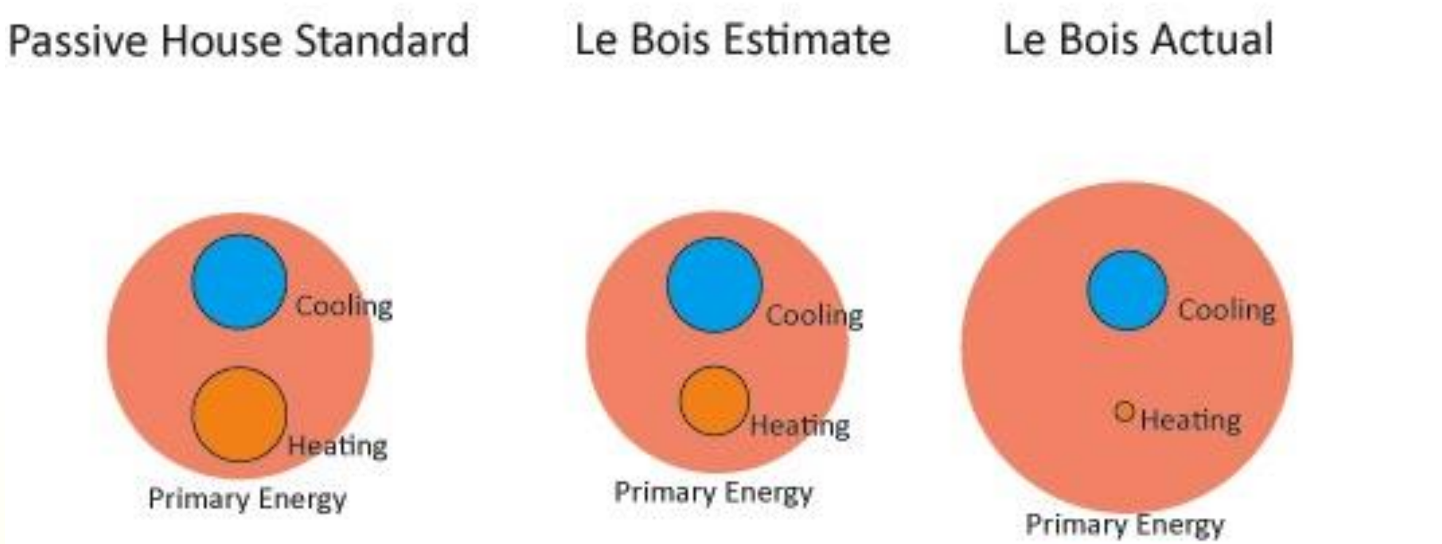
… and the human element …

LeBois House: Actual Energy Usage

	Total Energy Use [kWh]	Mini-Split [kWh]	Net Energy [kWh]	PV Generation [kWh]
Mar 2011	576	1	178	-398
Apr 2011	715	113	281	-434
May 2011	555	94	30	-525
Jun 2011	694	262	235	-458
Jul 2011	669	249	296	-373
Aug 2011	822	284	328	-493
Sep 2011	988	207	557	-431
Oct 2011	621	61	199	-422
Nov 2011	652	24	360	-292
Dec 2011	439	14	227	-212
Jan 2012	735	17	480	-255
Feb 2012	720	15	502	-218
12-Month Total [kWh/a]	**8,185**	**1,342 (cool=1,271 heat=71)**	**3,674**	**-4,511**
Specific 12-Month Total [kWh/m²a]	**68.3**	**11.2 (cool=10.6 heat=0.59)**	**30.7**	**-37.7**

Table 1. Monthly total electrical energy use and generation.

LeBois House: Results Comparison



	PHPP Specific Energy Use [kWh/m^{2}a]	Measured Specific Energy Use (Mar 2011 - Feb 2012) [kWh/m^{2}a]
Primary Energy	116	184
Cooling	15	10.6
Heating	8	0.6

LeBois House: Performance Overview

-Heating rarely required … actual use about 7% of predicted PHPP.

-Cooling more significant … still only 70% of the predicted need

(Only sensible, doesn’t include latent demand or energy use due to the dehumidifier)

-Primary energy approximately 50% greater than PHPP predicted.

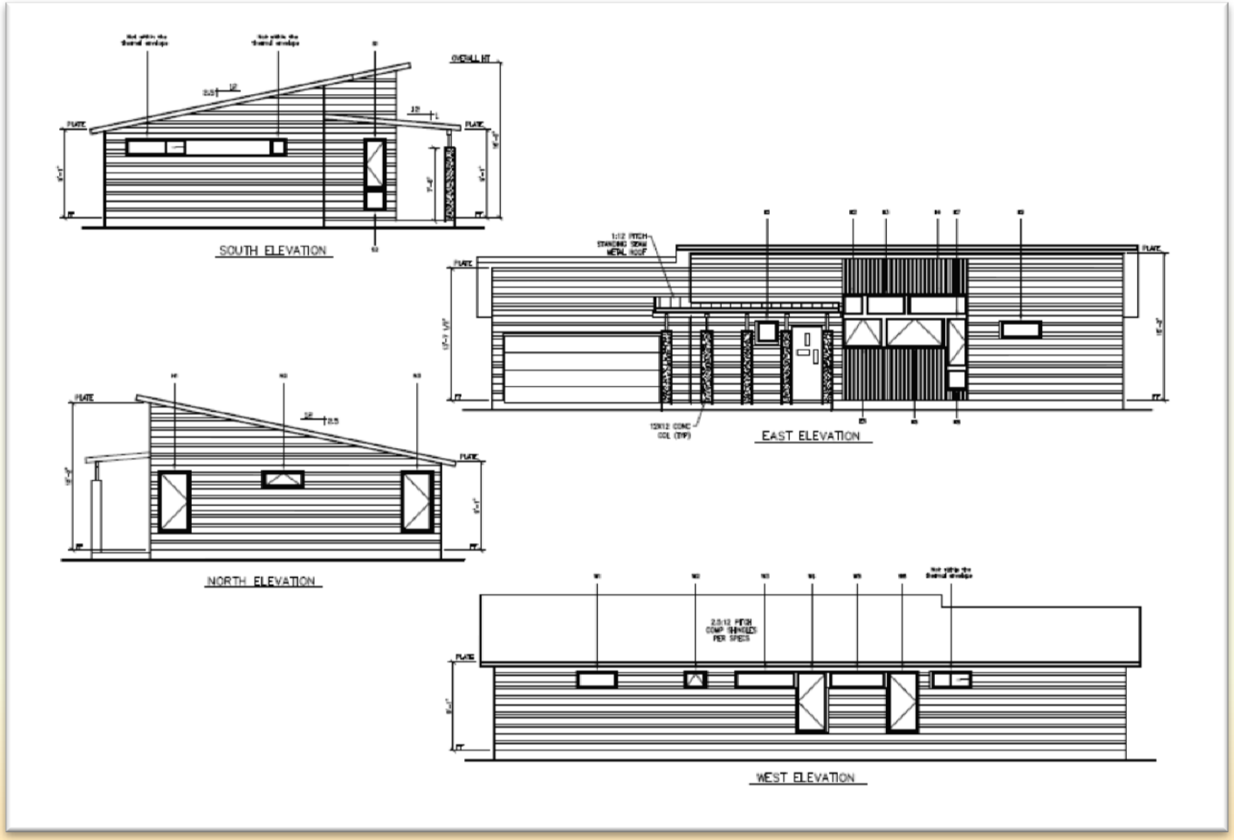
-Annual latent is estimated to be 15 kWh/m2/yr (4.75 kBTU/ft2.yr)(to no quota).

Circumstances:

- 83% spec’d for heat recovery efficiency, only 35% measured. Probably should have modeled with summer efficiency value
- Student life & plug loads

Abbate Case Study

- PHIUS+ Pre-Certified Project
- Austin, TX



Abbate: Modeled Results

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PHPP

Energy Demands with Reference to the Treated Floor Area

Treated Floor Area:	1130	ft²
	Applied:	Monthly Method
Specific Space Heat Demand:	2.22	kBTU/(ft²yr)
Pressurization Test Result:	0.60	ACH_{50}
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	35.9	kBTU/(ft²yr)
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	15.7	kBTU/(ft²yr)
Specific Primary Energy Demand Energy Conservation by Solar Electricity:		kBTU/(ft²yr)
Heating Load:	4.00	BTU/(ft²hr)
Frequency of Overheating:		% over
Specific Useful Cooling Energy Demand:	4.56	kBTU/(ft²yr)
Cooling Load:	2.71	BTU/(ft²hr)

WUFI Passive - Static

PASSIVEHOUSE REQUIREMENTS

Certificate criteria: European

Heating demand

Specific:	2.1	kBtu/ft²yr
total:	2348.7	kBtu/yr
peak (month):	0.9	kBtu/ft²

Cooling demand

Specific:	9.6	kBtu/ft²yr
total:	10808	kBtu/yr
peak (month) - sensible:	1.6	kBtu/ft²
latent:	5	kBtu/ft²yr

Heating load

Specific:	3.8	Btu/hr ft²
total:	4316.3	Btu/hr

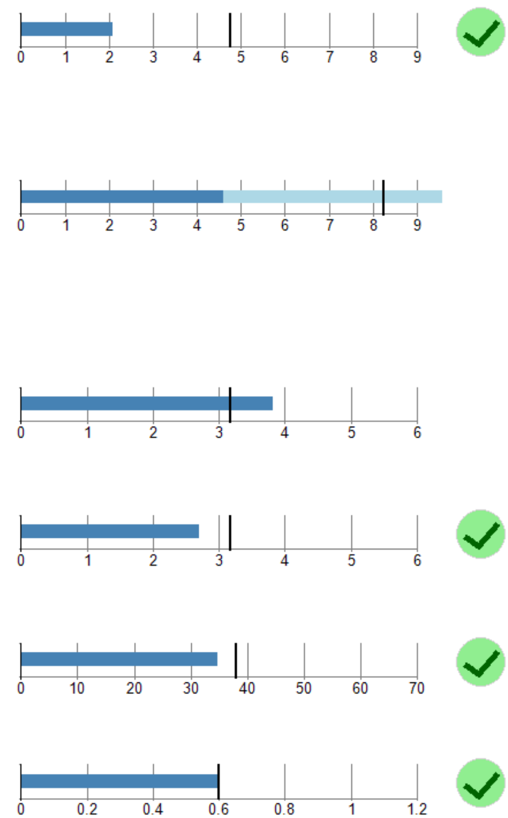
Cooling load

Specific:	2.7	Btu/hr ft²
total:	3059	Btu/hr

Primary energy

Specific:	34.7	kBtu/ft²yr
total:	39232.3	kBtu/yr

Air tightness ACH50 0.6 1/hr



Abbate: Slab Assembly

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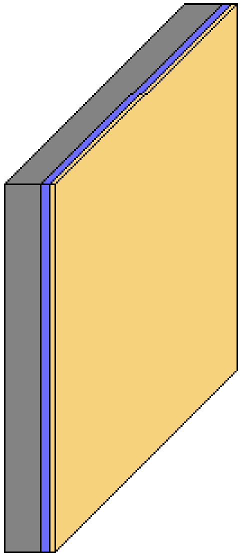
Assembly (Id.3): Slab on Grade w/interior Rigid

Homogenous layers

Thermal resistance: 6.683 hr ft² °F/Btu

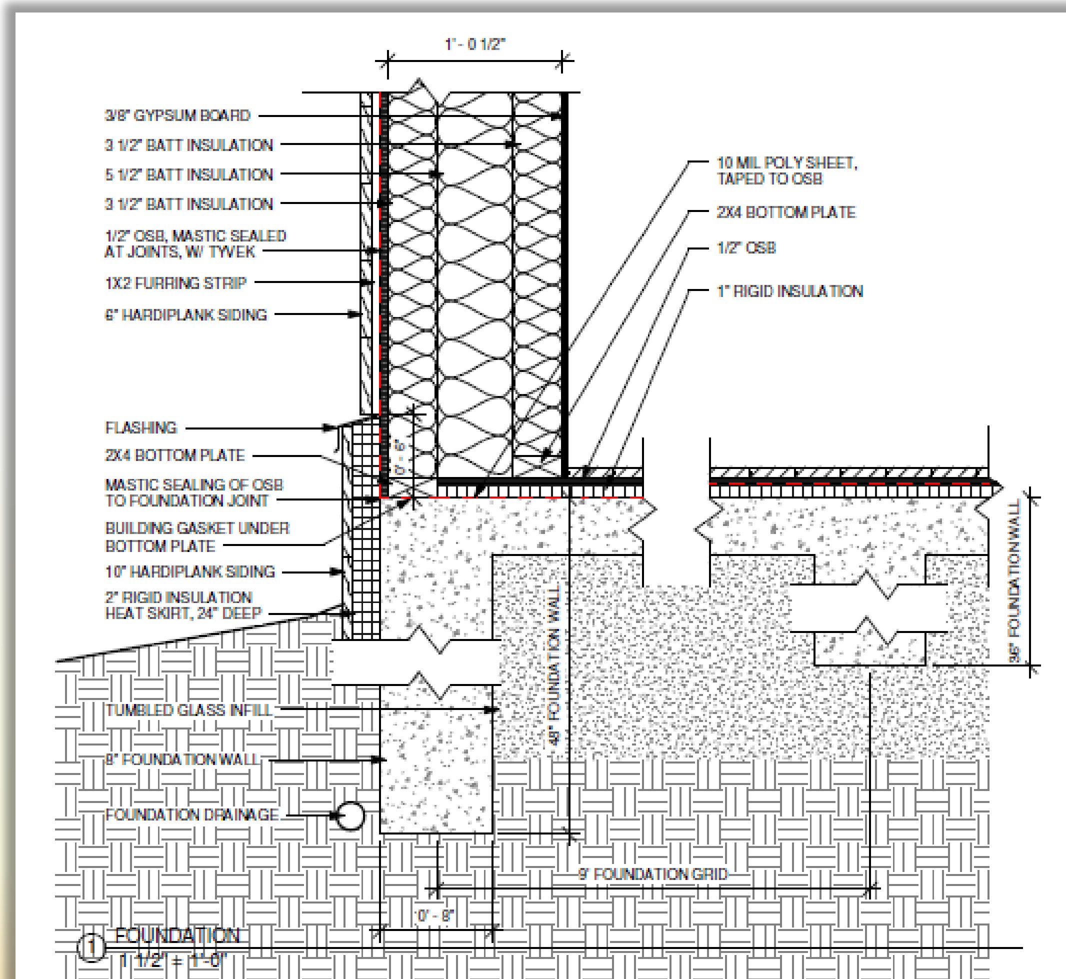
Heat transfer coefficient(U-Value): 0.13 Btu/hr ft² °F

Thickness: 5.5 in



Nr.	Material/Layer (from outside to inside)	ρ [lb/ft³]	c [Btu/lb°F]	λ [Btu/hr ft °F]	Thickness [in]	Color
1	Concrete	131.35	0.19	1.1558	4	
2	Extruded Polystyrene Insulation	1.79	0.35	0.0146	1	
3	OSB 3 (oriented strand board)	37.14	0.41	0.0613	0.5	

Abbate: Foundation Detail



Abbate: Wall Assembly

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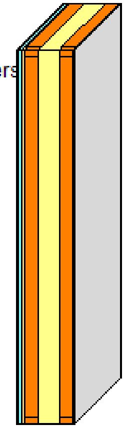
Assembly (Id.6): Double Stud Wall w/ 3/4" rainscreen & 1" SIS

Inhomogenous layers

Thermal resistance: 41.486 / 43.916 hr ft^2 °F/Btu (EN ISO 6946 / homogenous layers

Heat transfer coefficient(U-Value): 0.02 Btu/hr ft^2 °F

Thickness: 14.682 in



Nr.	Material/Layer (from outside to inside)	ρ [lb/ft^3]	c [Btu/lb°F]	λ [Btu/hr ft °F]	Thickness [in]	Color
1	Fibrecementboard	100.51	0.2	0.0751	0.315	
2	Air Layer 25 mm	0.08	0.24	0.0896	0.984	
3	Spun Bonded Polyolefin Membrane (SBP)	27.97	0.36	1.3867	0.008	
4	OSB 3 (oriented strand board)	37.14	0.41	0.0606	0.5	
5	Low Density Glass Fibre Batt Insulation	5.49	0.2	0.025	3.5	
6	Low Density Glass Fibre Batt Insulation	5.49	0.2	0.025	5.5	
7	Low Density Glass Fibre Batt Insulation	5.49	0.2	0.025	3.5	
8	Interior Gypsum Board	39.02	0.21	0.0924	0.375	
	Exchange materials					
9	Softwood	24.97	0.36	0.0651	---	

Abbate: Vented Roof Assembly

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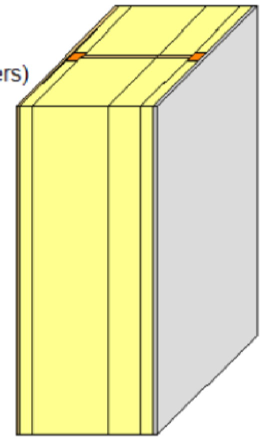
Assembly (Id.2): 16" TJI w/batt insulation

Inhomogenous layers

Thermal resistance: 51.898 / 54.418 hr ft² °F/Btu (EN ISO 6946 / homogenous layers)

Heat transfer coefficient(U-Value): 0.02 Btu/hr ft² °F

Thickness: 17 in



Nr.	Material/Layer (from outside to inside)	ρ [lb/ft³]	c [Btu/lb°F]	λ [Btu/hr ft °F]	Thickness [in]	Color
1	OSB 3 (oriented strand board)	37.14	0.41	0.0606	0.5	
2	Low Density Glass Fibre Batt Insulation	5.49	0.2	0.025	1.5	
3	Low Density Glass Fibre Batt Insulation	5.49	0.2	0.025	9	
4	Low Density Glass Fibre Batt Insulation	5.49	0.2	0.025	4	
5	Low Density Glass Fibre Batt Insulation	5.49	0.2	0.025	1.5	
6	Interior Gypsum Board	39.02	0.21	0.0924	0.5	
	Exchange materials					
7	Softwood	24.97	0.36	0.052	---	
8	OSB 3 (oriented strand board)	37.14	0.41	0.0606	---	

Abbate: Mechanical Schematic

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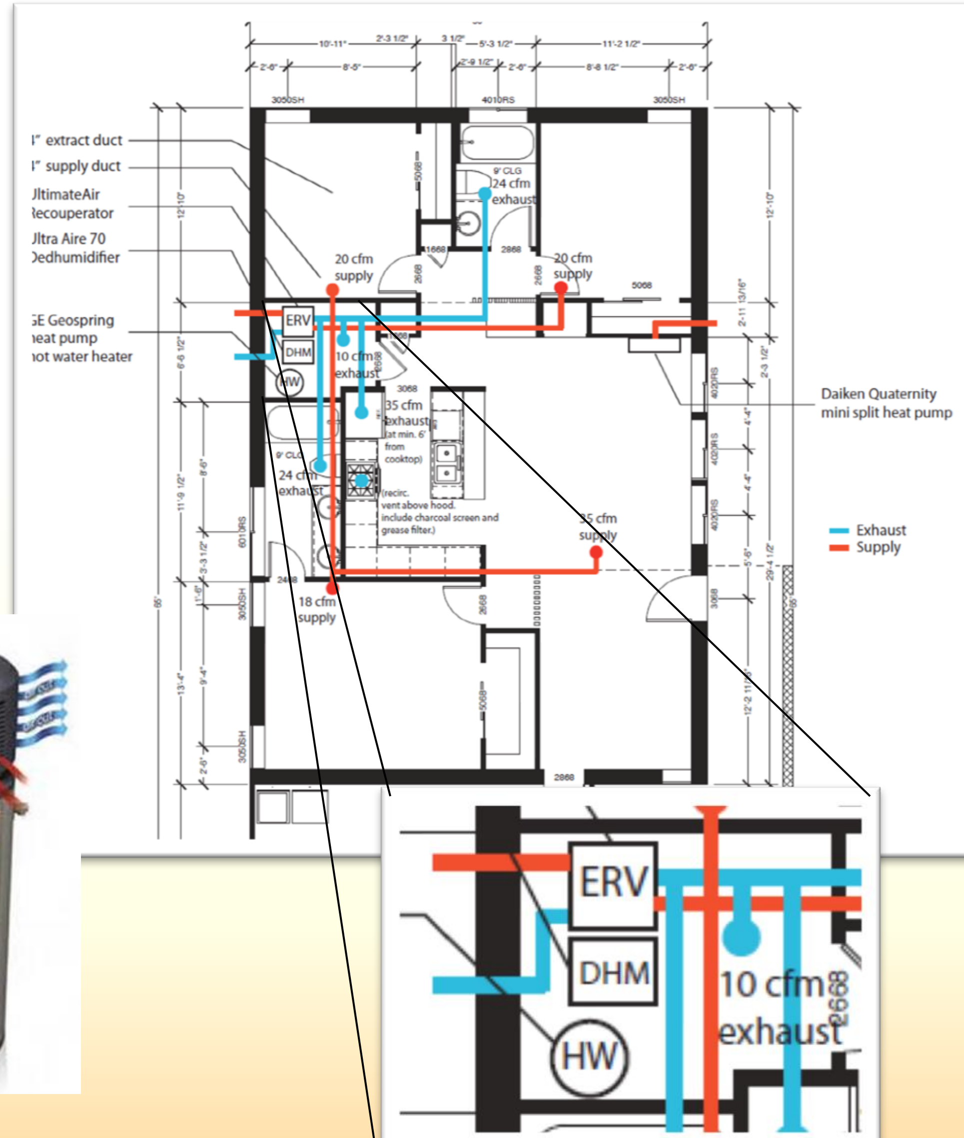
Mini-split Heat Pump:

- Daikin Quaternity
- Single head, centrally located

Dehumidifier:

- Feeds directly into main living space

GE GeoSpring Heat Pump Water Heater



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8. Dynamic Modeled Results

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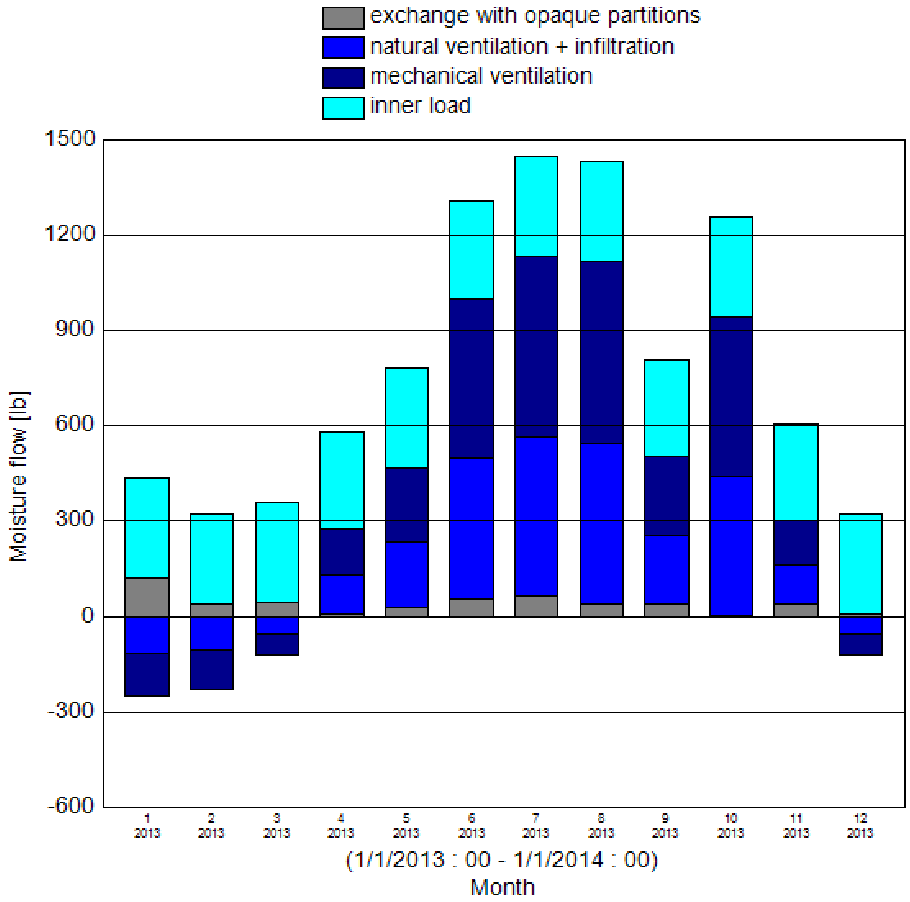
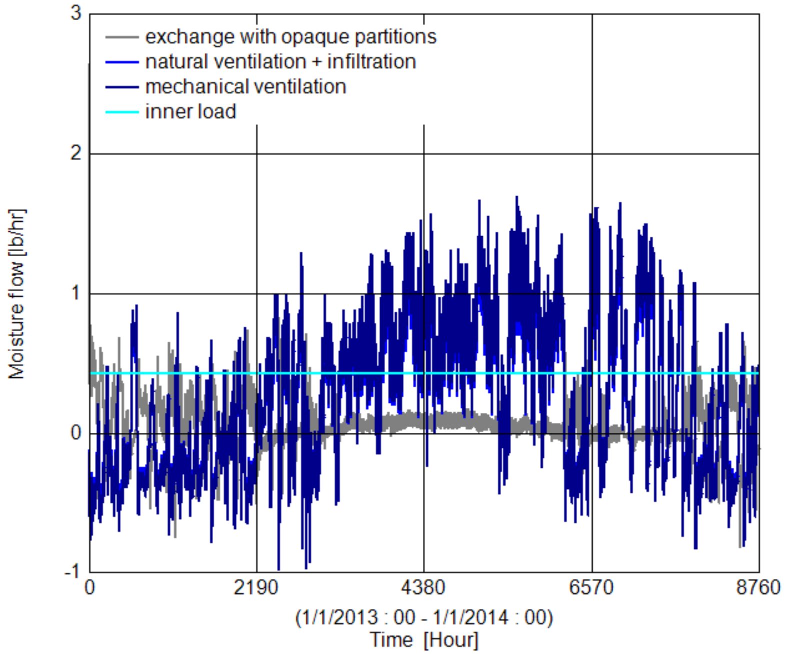
WUFI Passive Dynamic Setup

- Design Conditions:
  - Interior temperatures 68-77F
  - Relative Humidity 40-60%
  - Infiltration: 0.6ACH @ 50 Pascal (PH Level)
  - Ventilation:
    - Natural – 0.05 ACH
    - Mechanical – 0.3 ACH
  - Internal Sources
    - 2 adults, mild activity
    - 1 child 3-6yrs old

Abbate: Moisture Flows

WUFI® PASSIVE





Abbate: Moisture Flows

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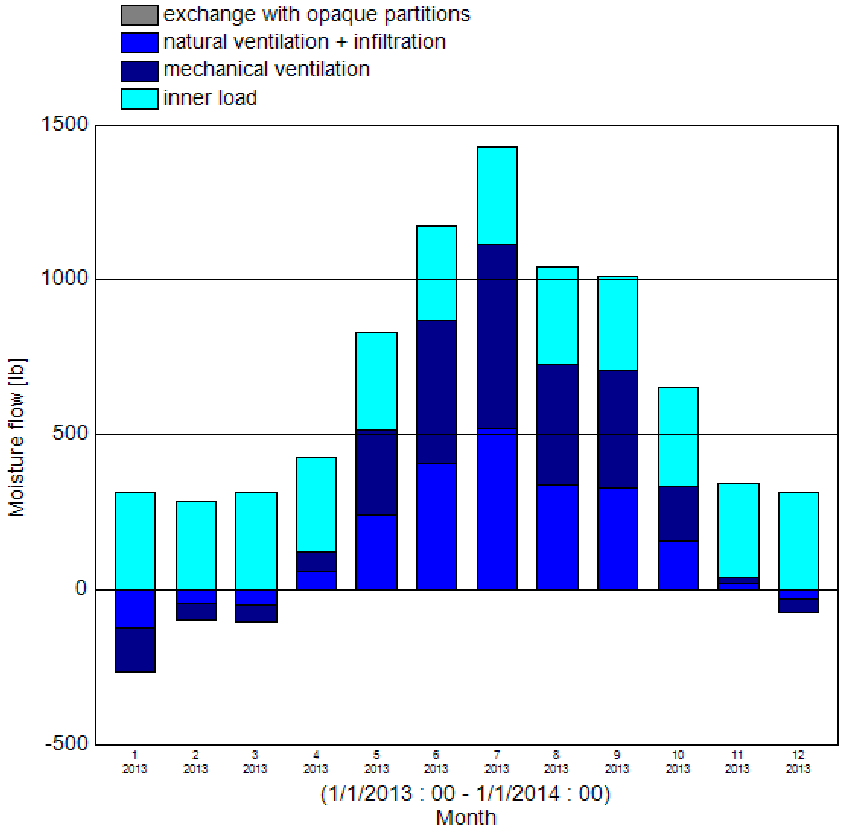
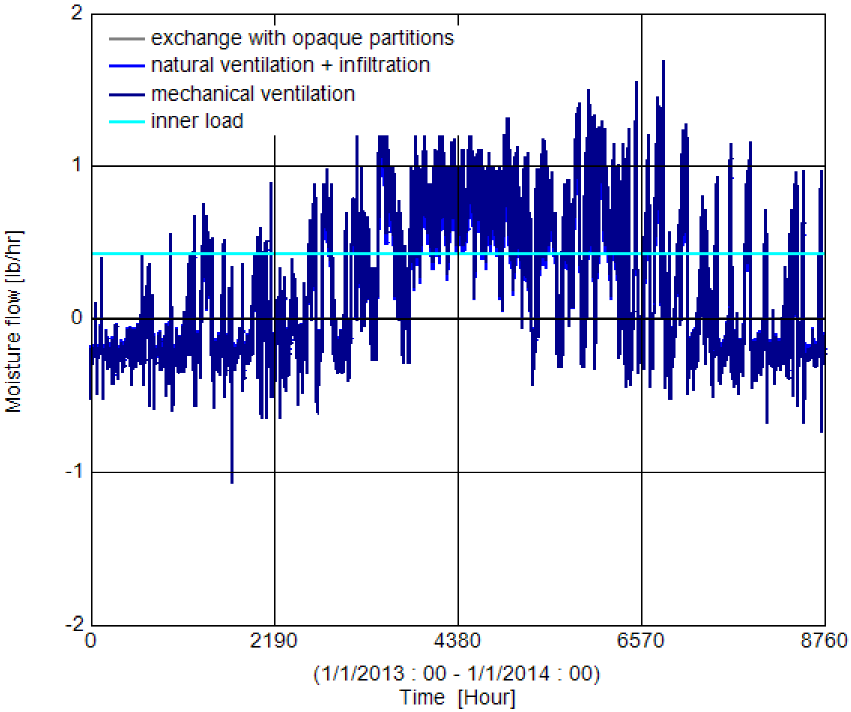
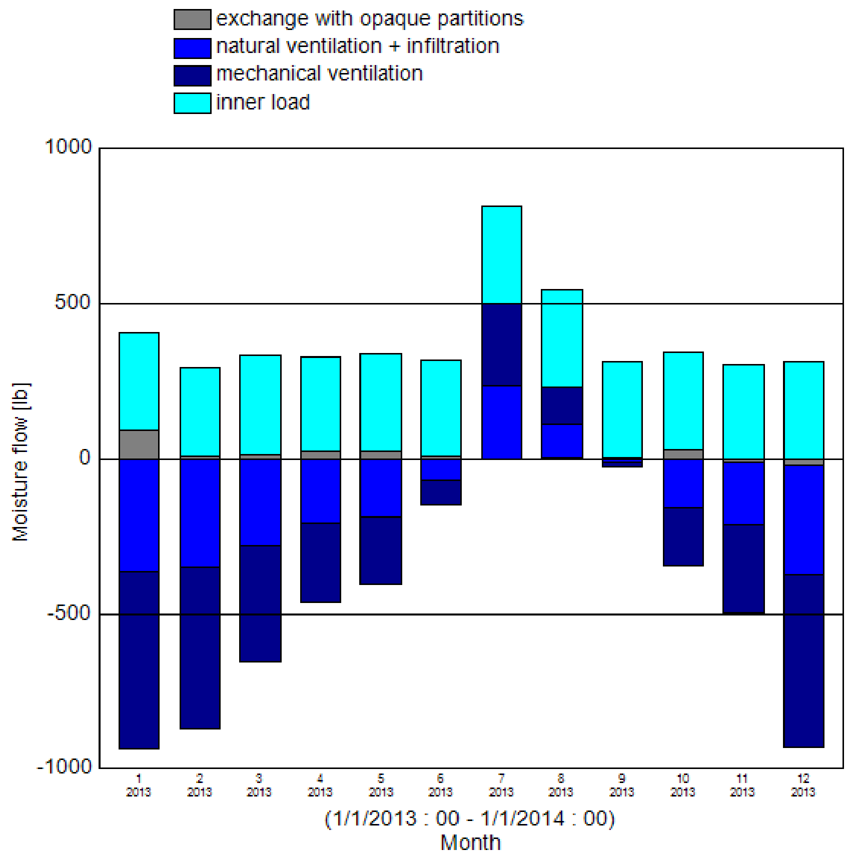
- Completely vapor closed all assemblies

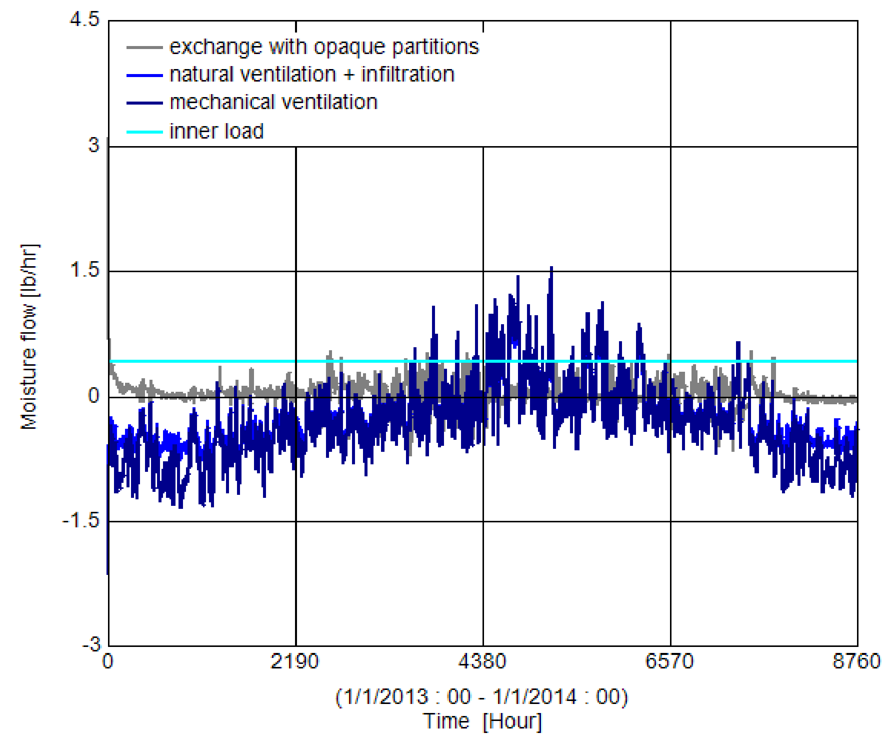




Abbate: In Chicago

- Same house, moved to Chicago





24 Hour Moisture Flows

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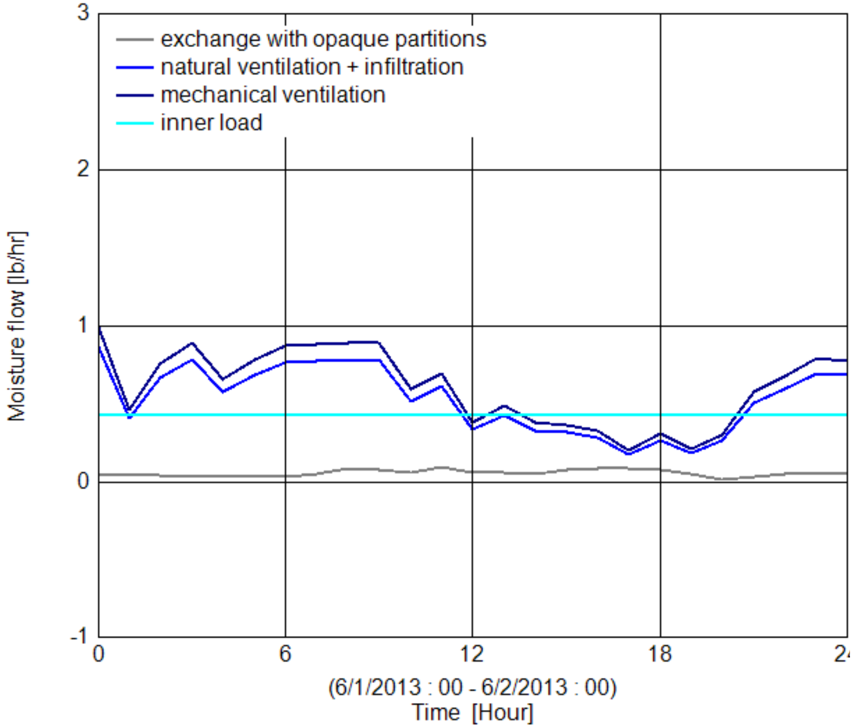
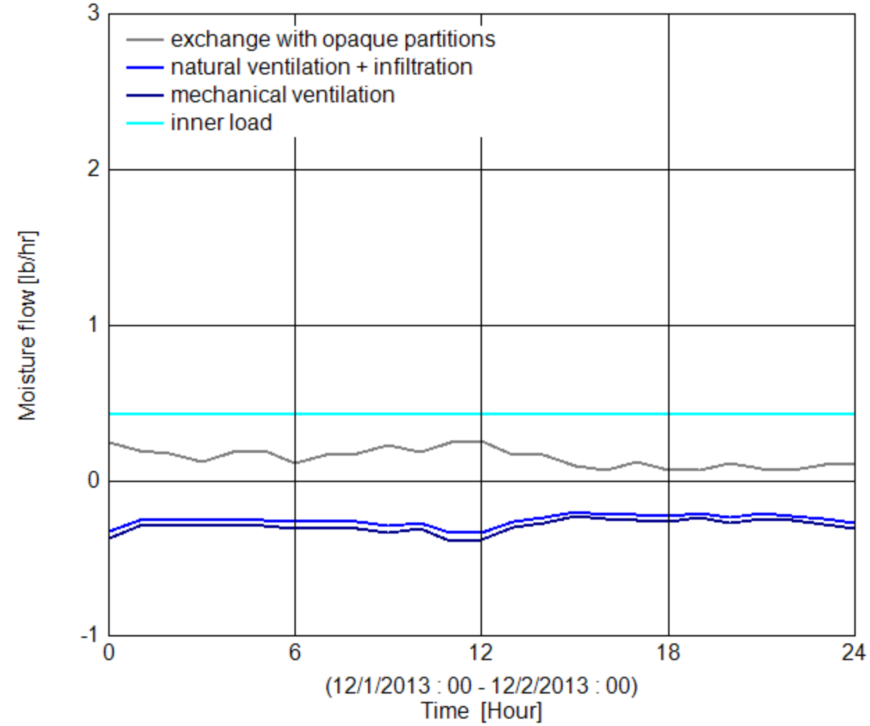


June 1



December 1

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Comfort: Air temperature and Relative Humidity

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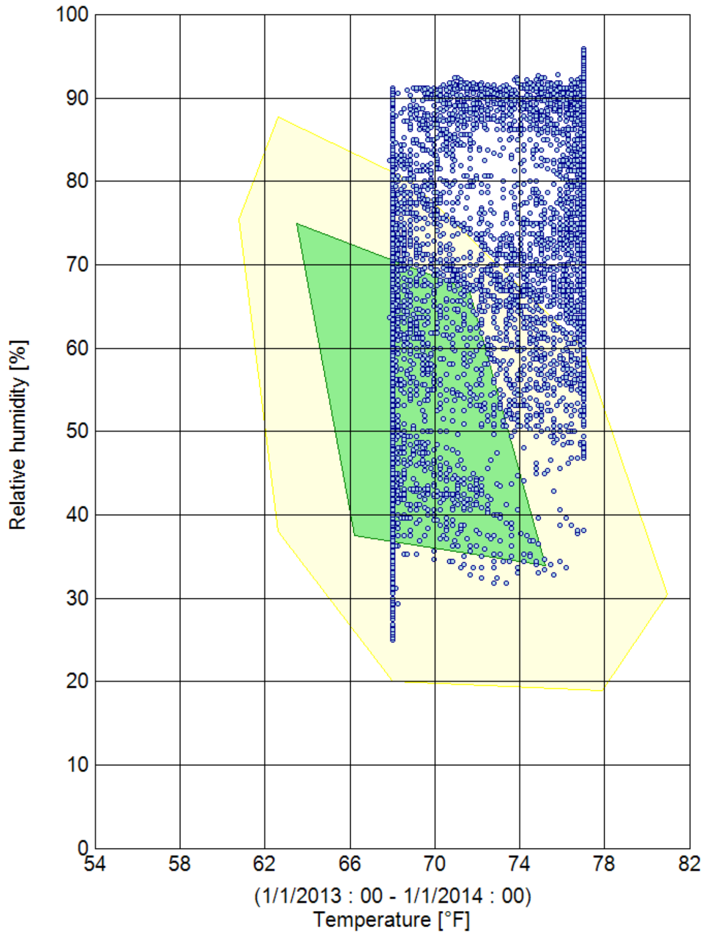
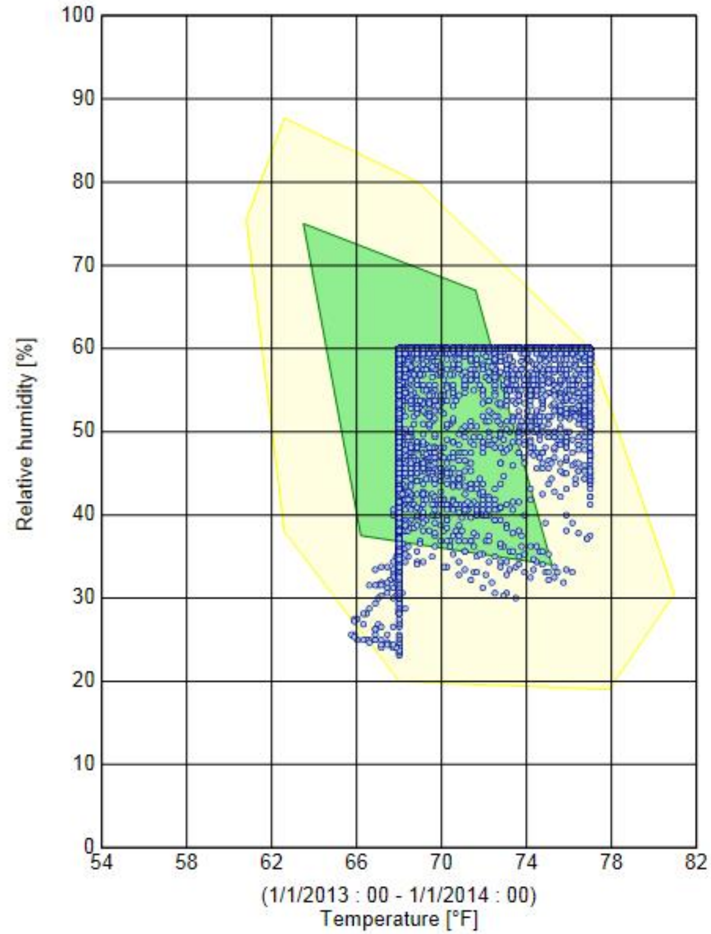
Case with no dehumidification



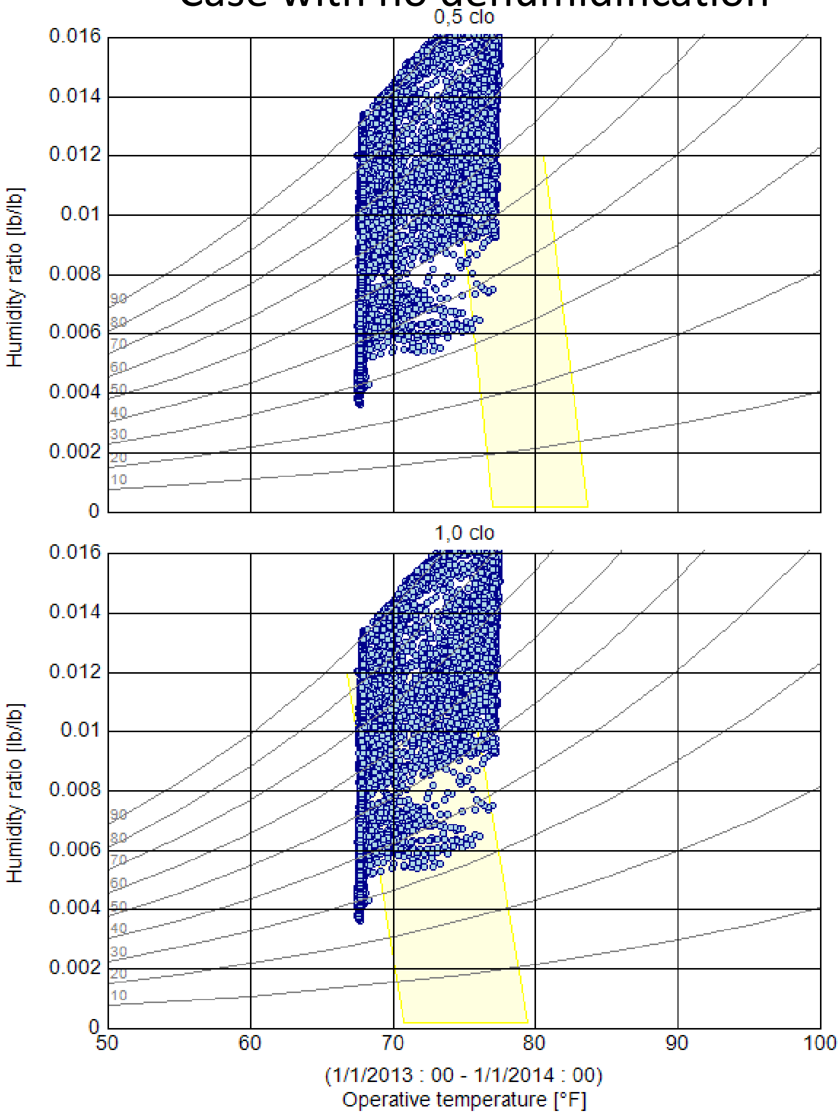
Case with dehumidification



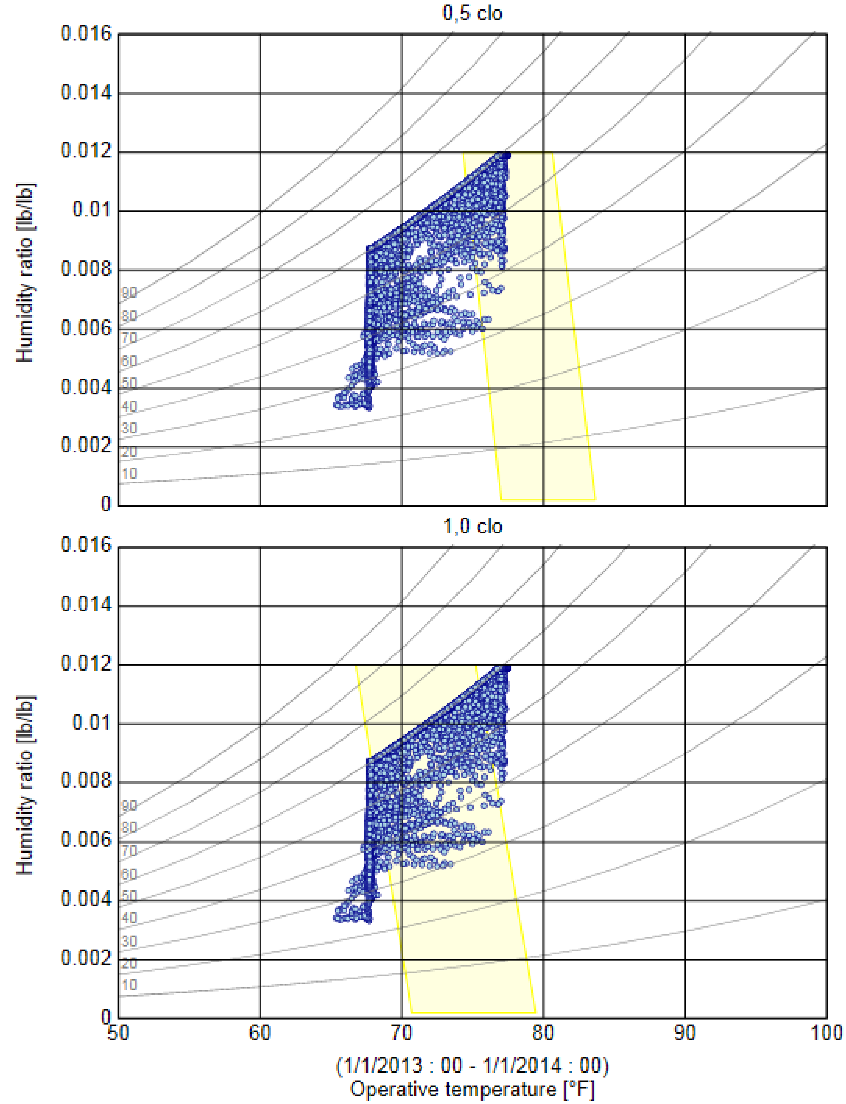
Operative Temperature and Humidity Ratio:

Plotted on ASHRAE comfort chart

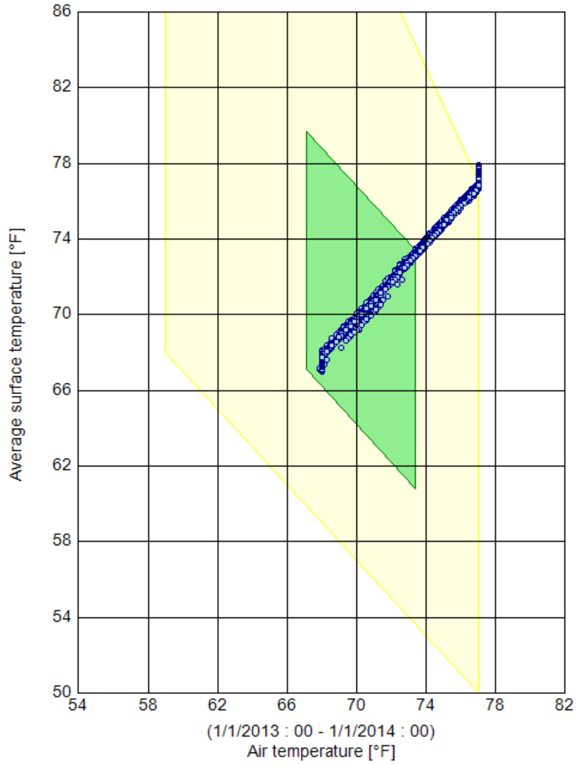
Case with no dehumidification



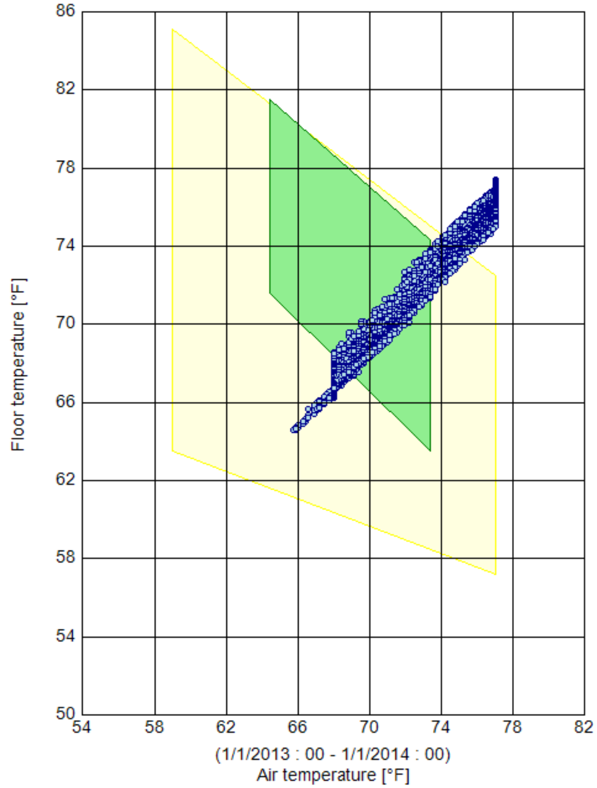
Case with dehumidification



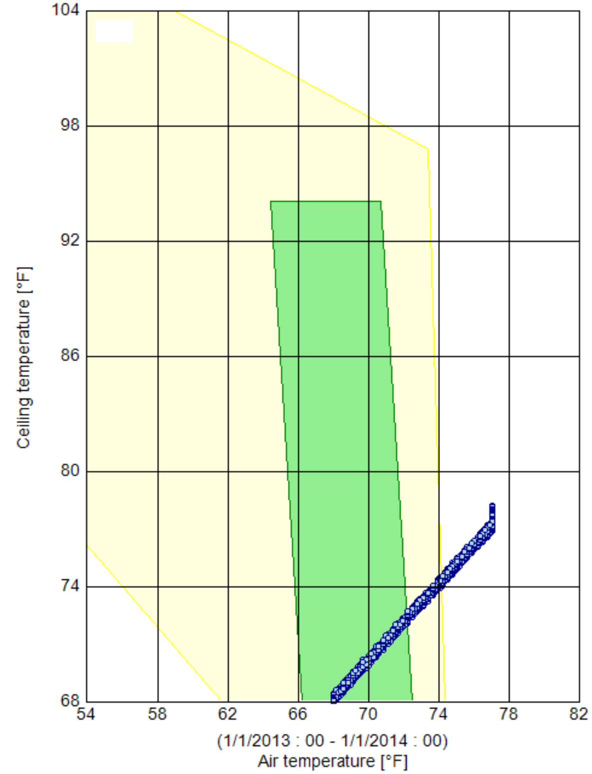
Comfort: Radiant Conditions



Average Surface Temperature

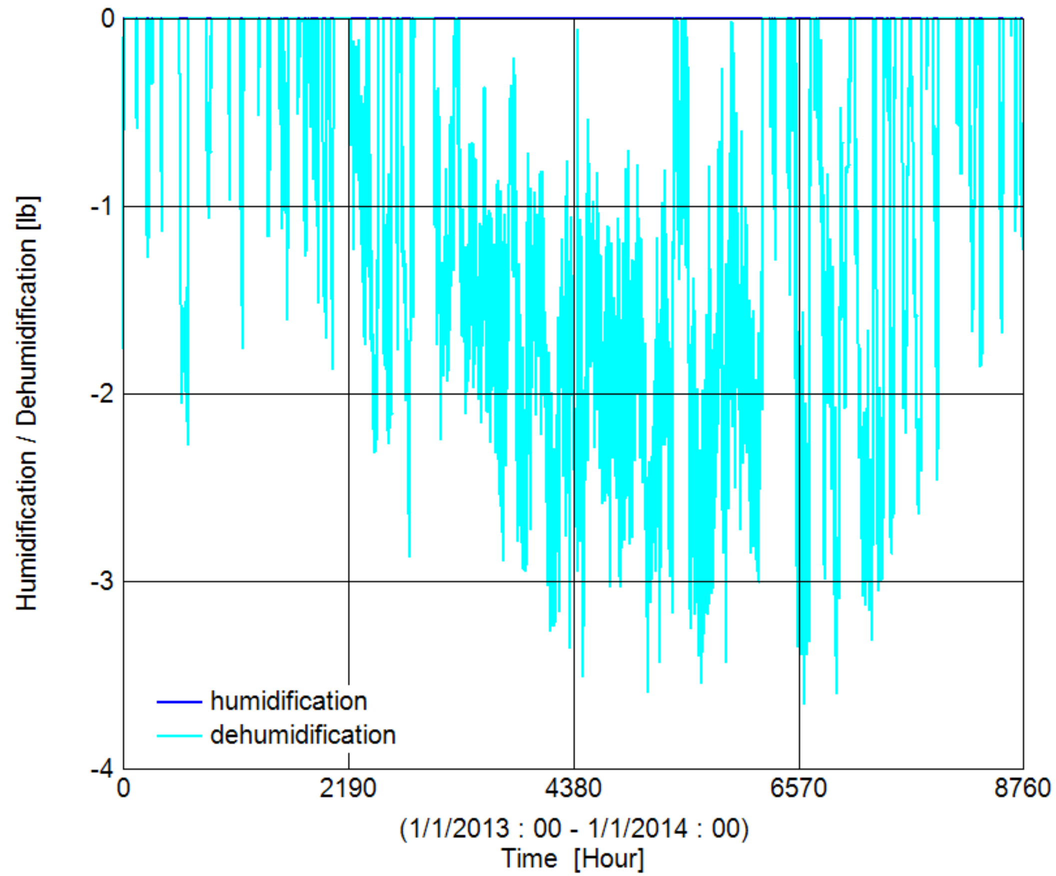


Floor Temperature



Ceiling Temperature

Dehumidification [lb/hr]



Heating/Cooling, Latent Heat [kBTU/hr]

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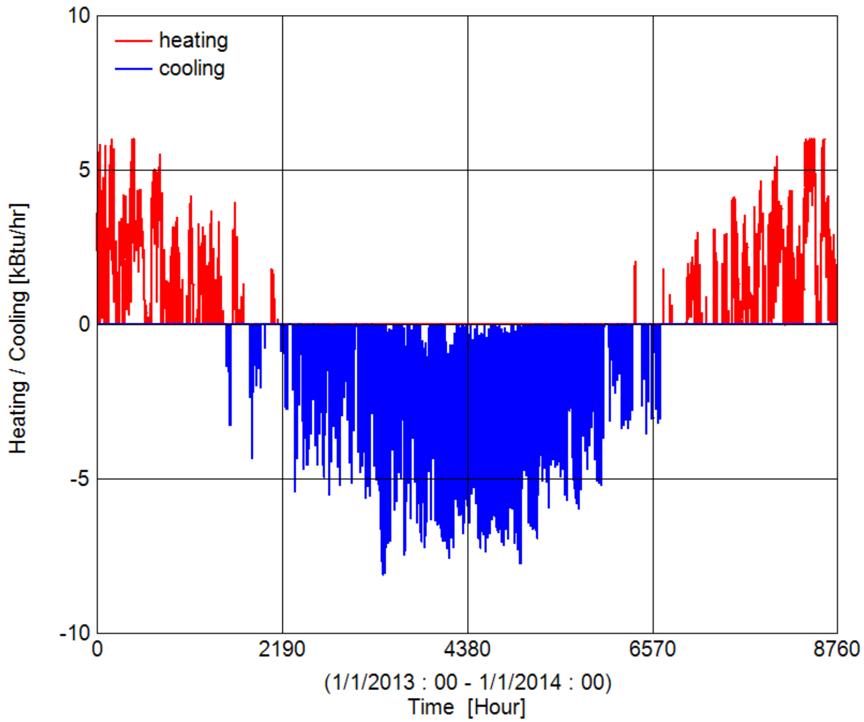
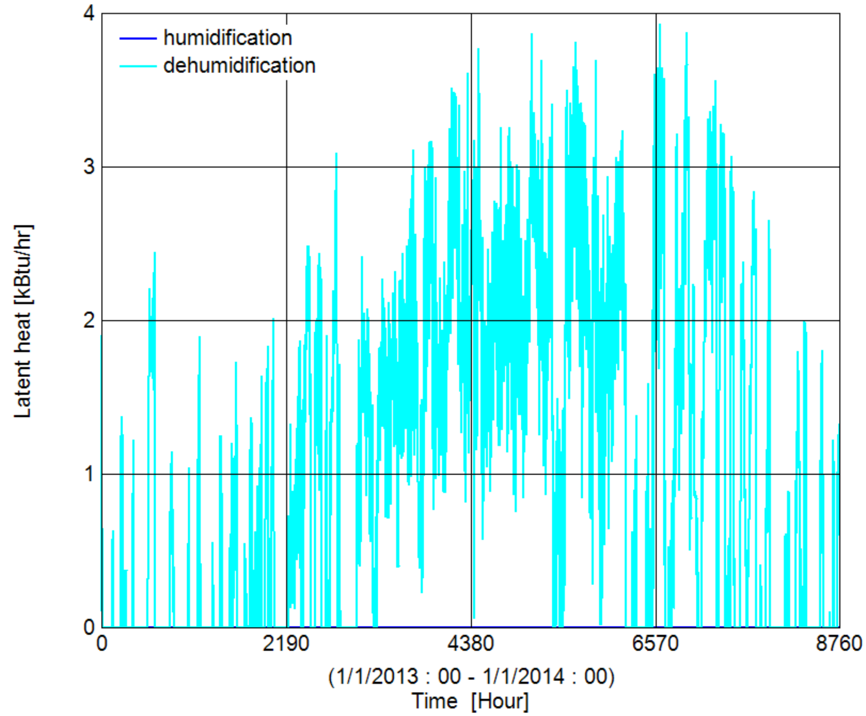
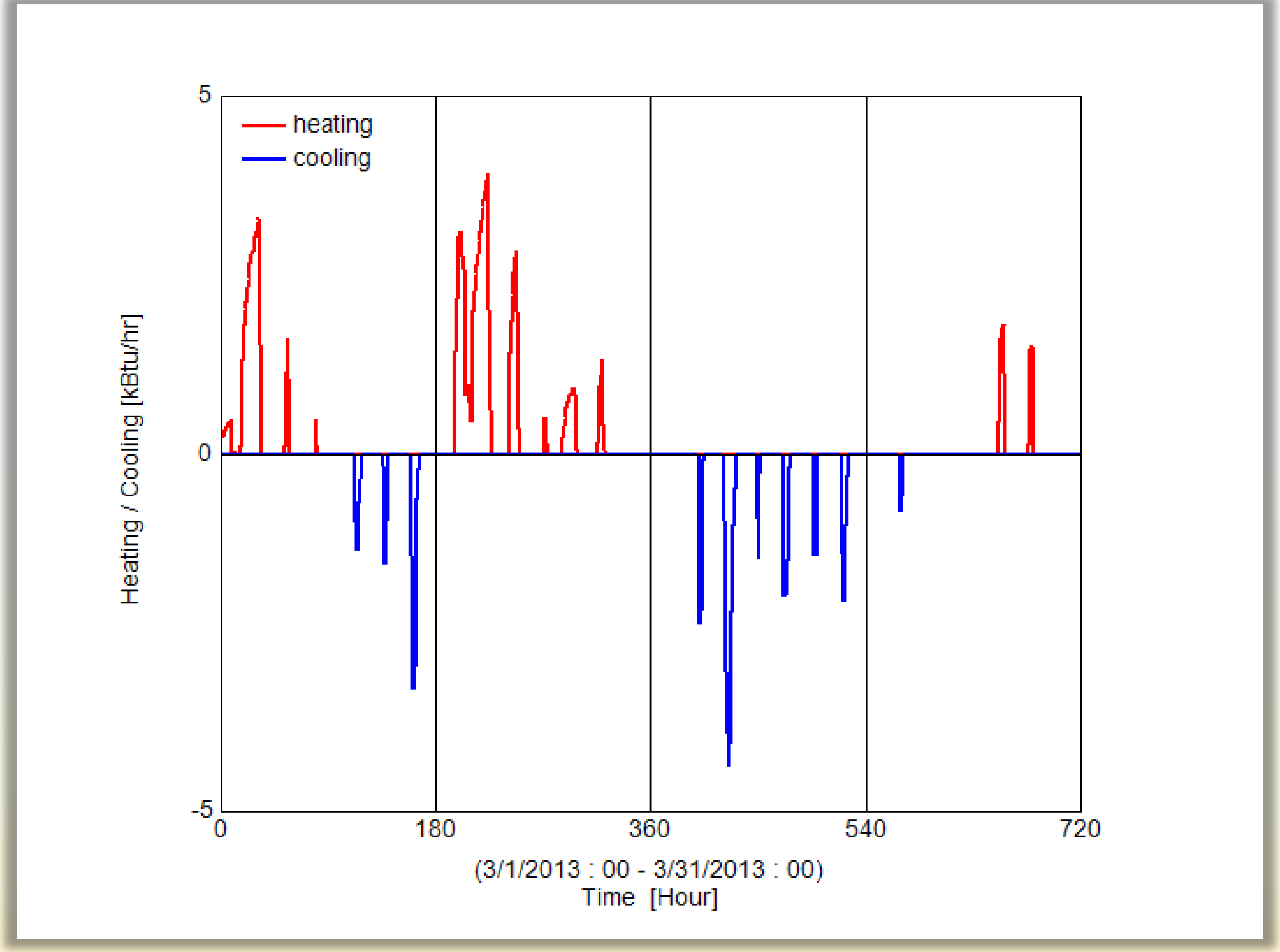




Static Results:
Heating Load: 4.316 kBTU/hr
Cooling Load: 3.059 kBtu/hr

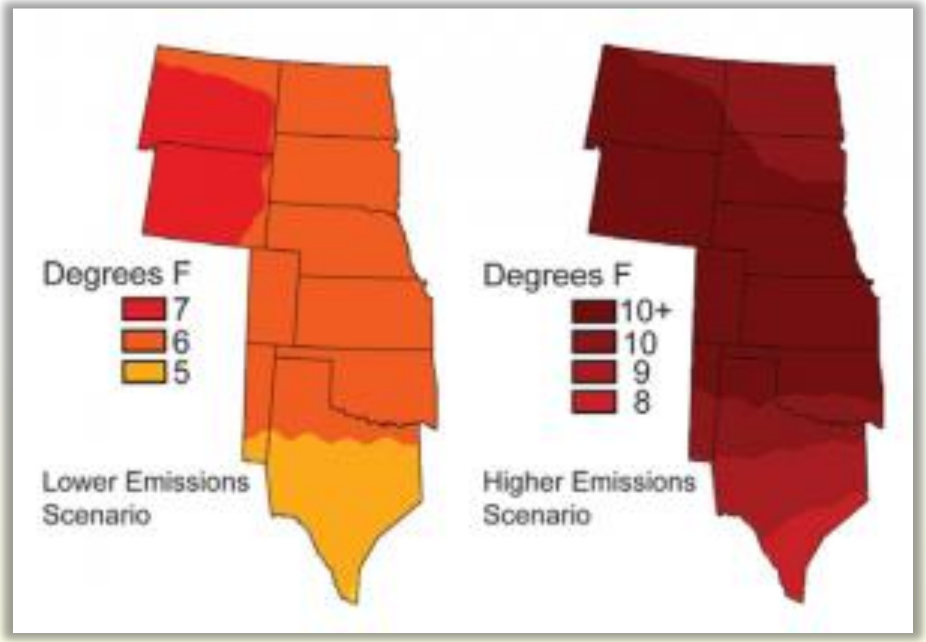
Static Model incapable of calculating latent load
Latent Load: ~4 kBTU/hr

Heating & Cooling: March



Allows you to analyze swing seasons, and optimize glazing conditions. Projects with a lot of large windows will see more dramatic effects in this analysis.

Climate on the Move



Source: www.globalchange.gov

What to take away

- Latent loads are difficult to manage in low load homes
- We may need more efficient mechanical systems to deal with these loads (if we want to meet the current PH standard)
- The majority of the latent cooling demand can be attributed to ventilation and infiltration, there is little (though some) you can do to the envelope
- Dynamic modeling is essential for assessing latent loads because of the complexity of moisture flows, storage, and transport

Thanks!

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Questions?