		Length Heat. Period		Spec. Power q_I		A_{TFA}		
kh/d		d/a		BTU/hr.ft²		ft²		kBTU/yr
0.024	*	157	*	0.67	*	2776	=	6944

Asynchronous Air Circulation:
Simplified Ventilation & Space Conditioning

Ratio of Free Heat to Losses		Q_F / Q_L	=	0.68
$(1 - (Q_F / Q_L)^5) / (1 - (Q_F / Q_L)^6)$			=	95%
				kBTU/yr
		η_G * Q_F	=	18801
				kBTU/yr
		Q_L - Q_G	=	10185

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High Performance Buildings

- Design / Build
- Performance Design / Build
- PH Design Consulting
- Construction

Passive House Projects

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- **Engineering firm focused building energy efficiency for 33 years**
- **Staff of 22, includes 5 P.E.'s with a broad range of experience in:**
  - ❖ Computer modeling (DOE-2, EnergyPlus, BEopt, EnergyPro, TRNSYS, PHPP, etc.)
  - ❖ Monitoring & verification, data acquisition and analysis, technology evaluation
  - ❖ Design: ZNE, passive solar, HVAC, PV systems, controls
  - ❖ Energy efficient products development and commercialization (NightBreeze)
  - ❖ Standards development and energy compliance (CEC)
  - ❖ Green programs admin. (LEED/GPR provider); Sustainable communities
- **Building America**
  - Team lead since 2010
  - Team participation since 2002

Building AMERICA
U.S. Department of Energy

Agenda

5 min **1. Background**

PH context, challenges, experiment

15 min **2. Sunnyvale PH Project**

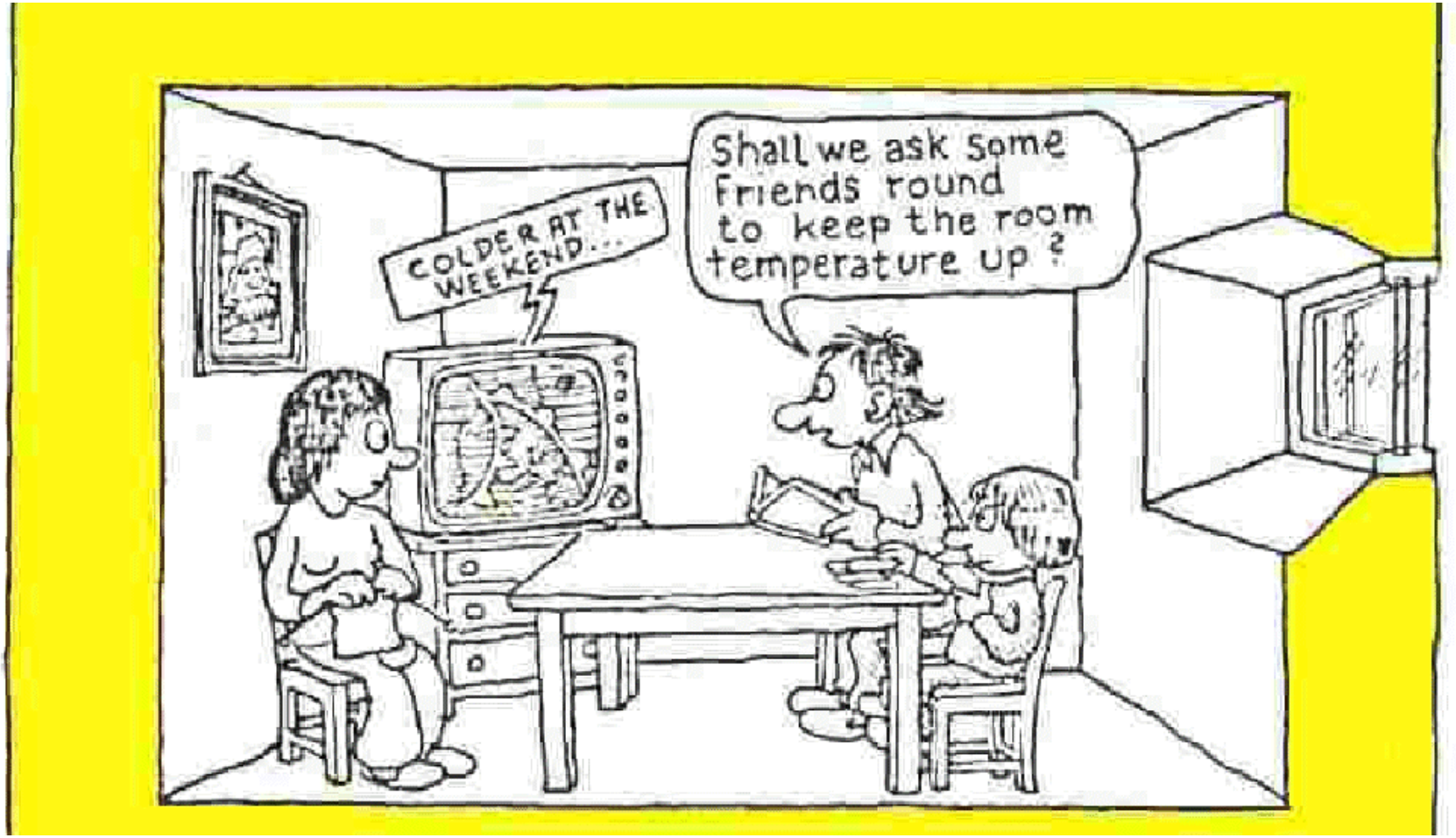
specs, design, performance data

10 min **3. Magic PH Project**

specs, design, performance data…(tour)

5 min **4. Conclusions; Q&A**

Super-insulated buildings are different



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PH Mechanical Systems

- Expectations, goals, behaviors, equipment and **assumptions** have changed …dramatically
- **Same physics**, different behaviors with low loads, high thermal sensitivity & 24/7 ventilation
- Opportunity for "Amazing" or "Dismal" performance
- Caution! Need great energy modeling & mechanical design
- Ventilation systems add significant costs $$$

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PH Mech. Systems Design: Key challenges

- **Cost** - promise of tunneling through cost curve a challenge for SFDs
- **Space** - Lack of conditioned service spaces for ductwork

PH Mech. Systems Design: Research Questions

Simplification

- Combined distribution of ventilation and space conditioning air flows?
- Common areas as plenums and hallways as ducts?
- Cascading airflows room to room OK?
- Temperature differentials? Meet comfort goals?
- What kind of buildings will it work in?
- Reduce total mechanical systems costs? …energy consumption?

Continuous air circulation – the concept

- Origin –European research, Oregon ET MSHP proj., +
- ECM fans - energy efficiency breakthrough (10cfm/w)
- PH buildings the enabler …low aggregate & room loads
- Combined distribution of fresh air and H/C air
  - Min. ductwork; use common areas/hallways
- Continuous operation required to work

Sunnyvale Passive House Retrofit

Before

- 1957 ranch
- No insulation
- Extreme discomfort
- Condensation, mold
- Poor air quality

After

- Passive House
- Extreme comfort
- Sublime IAQ
- Heat w Hair Dryer

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Sunnyvale Passive House Retrofit

Sunnyvale Passive House Retrofit: Airtightness

	CFM_{50}	ACH_{50}
Before	2,985	12.76
After	344	1.47

- **Ann. Heat Demand vs. 0.6 ACH_{50} = + 3.5%**
- **385kBTU / 12 HSPF = 32kWh x 13.6¢ = $4.35**

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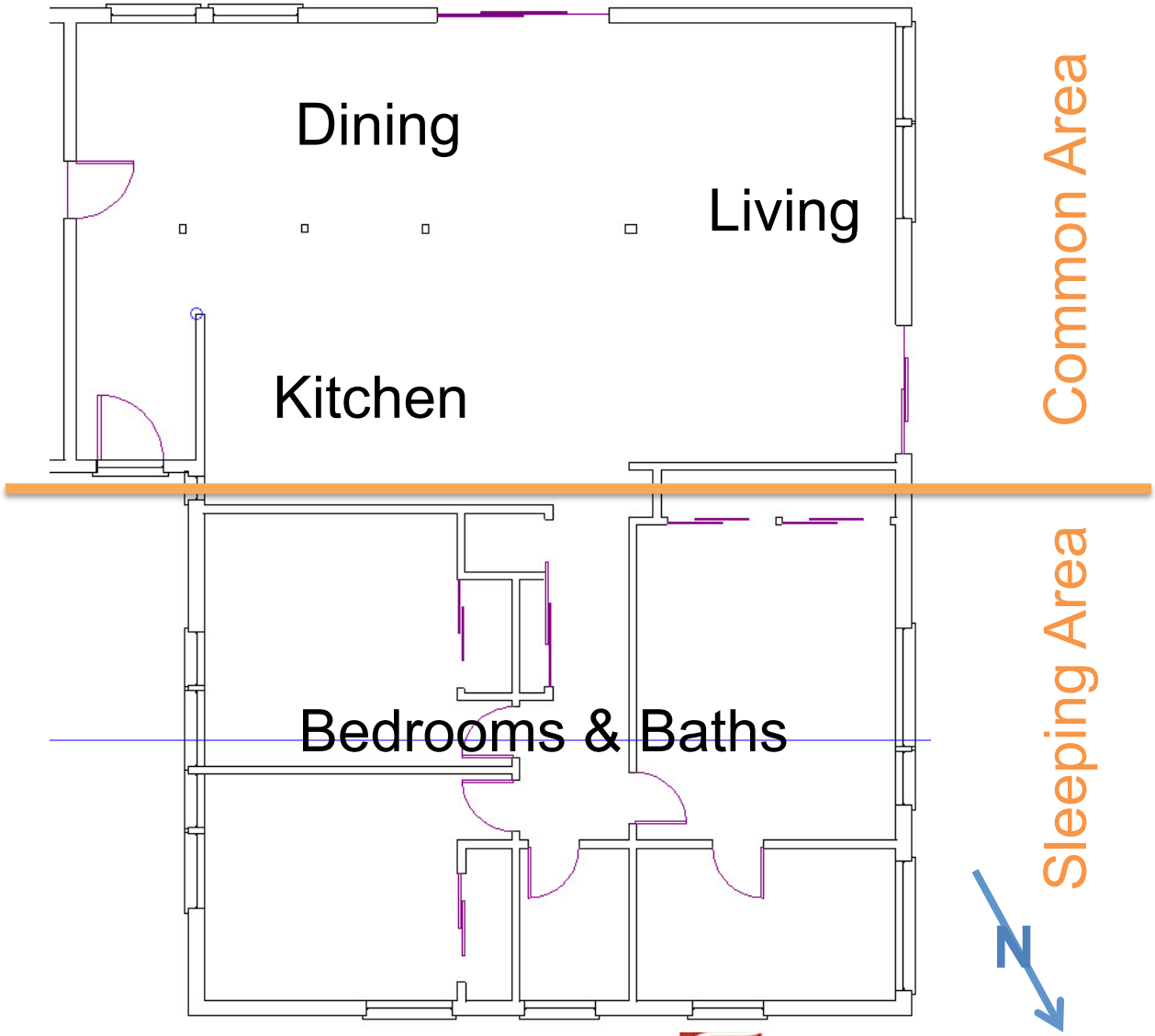
Air Circulation Supply Register

Sunnyvale PH Retrofit: Floor Plan

1,644 sf



Design Drivers:

- HRV system cost
- H/C system cost & performance
- Simplicity

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Energy Balance analysis for master BR

Qt & Qv Losses ("Room Loads")

	Int. Temp 71°- Avg. Daily Winter Temp.51°= 20°ΔT	
Q_t	Q= U(1/R) (btu/hr/sf/°F) x A (sf) x ΔT (°F)	BTU/HR
Q_{floor}	(1/R25) 0.04 btu/hr/sf/°F x 240 sf x 20°F	194
Q_{walls}	(1/R23) 0.043 btu/hr/sf/°F x 160 sf x 20°F	140
$Q_{windows}$	(1/R5) 0.2 btu/hr/sf/°F x 36 sf x 20°F	146
$Q_{ceiling}$	(1/R40) 0.025 btu/hr/sf/°F x 240 sf x 20°F	120
		600
		BTU/day
$Q_{t\ daily}$	24hr x 600 btu/hr	14,400

Qv = 0, no air exchange to exterior …see Qair circ

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Energy Balance analysis for master BR

Qs , Qi, Qac = Gains

Qs	**=0, no direct sun**	
Qi	**Watts x 3.4 btu/watt x hrs/day**	**BTU/day**
Occupants	**2 x 80watts x 3.4 btu/watt x 9 hrs**	**4896**
Lights	**100 watts x 3.4 btu/watt x 2 hrs**	**680**
Electronics	**100 watts x 3.4 btu/watt x 2 hrs**	**680**
		6256
Q_{ac}	**1.1 btu/cfm/^{o}F x 60cfm x 4$^{o}\Delta$T = 264 btu/hr**	
	24hr x 264 btu/hr	**6336**
	Total Gains	**12,592**

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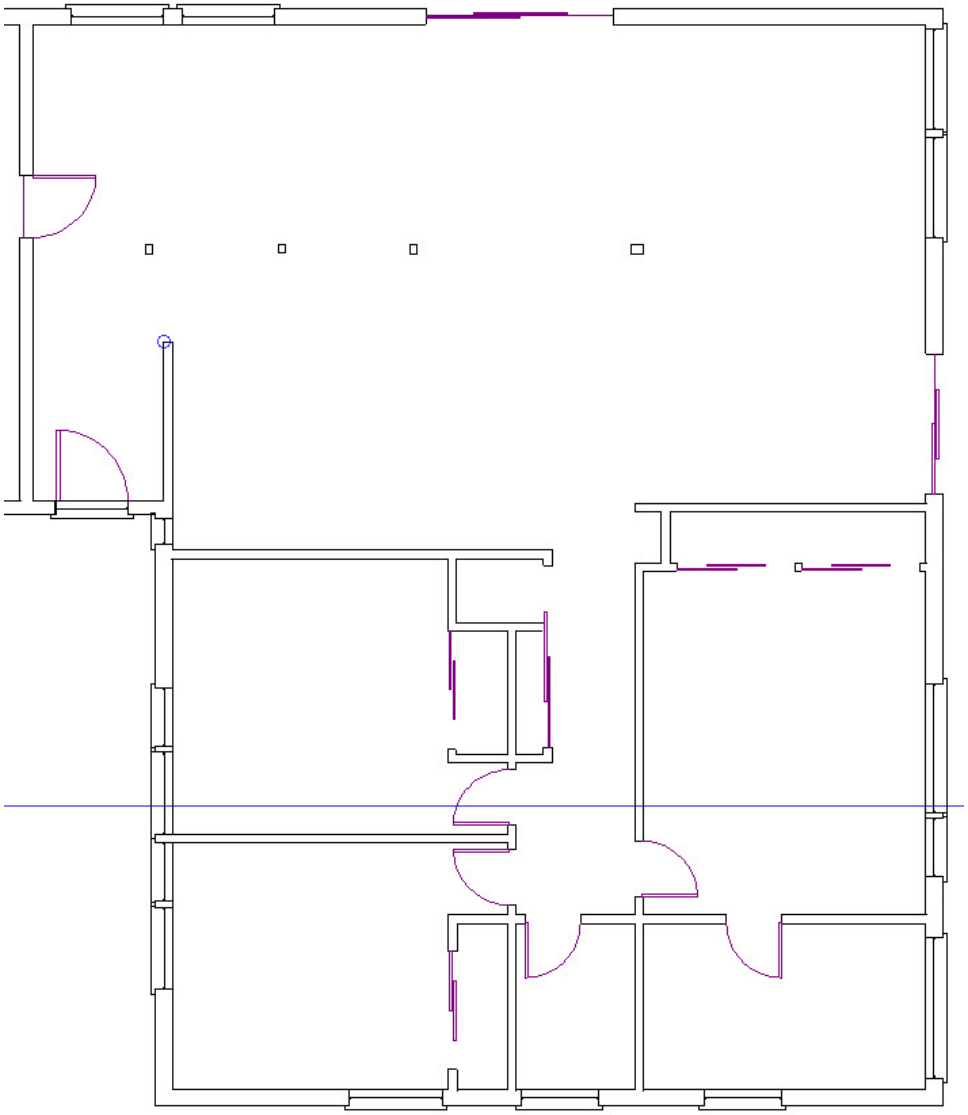
Energy Balance analysis for master BR
Losses-Gains = Supplementary Heat Demand

	BTU/day
Losses ($Q_t + Q_v$)	14,400
Gains ($Qs + Q_i + Q_{ac}$)	12,592
Supplementary Heat Demand	1,808

Can be met easily with periodic resistance heat

Sunnyvale PH Retrofit: Mechanicals

1. Ventilation
2. Heating & Cooling
3. Air Circulation



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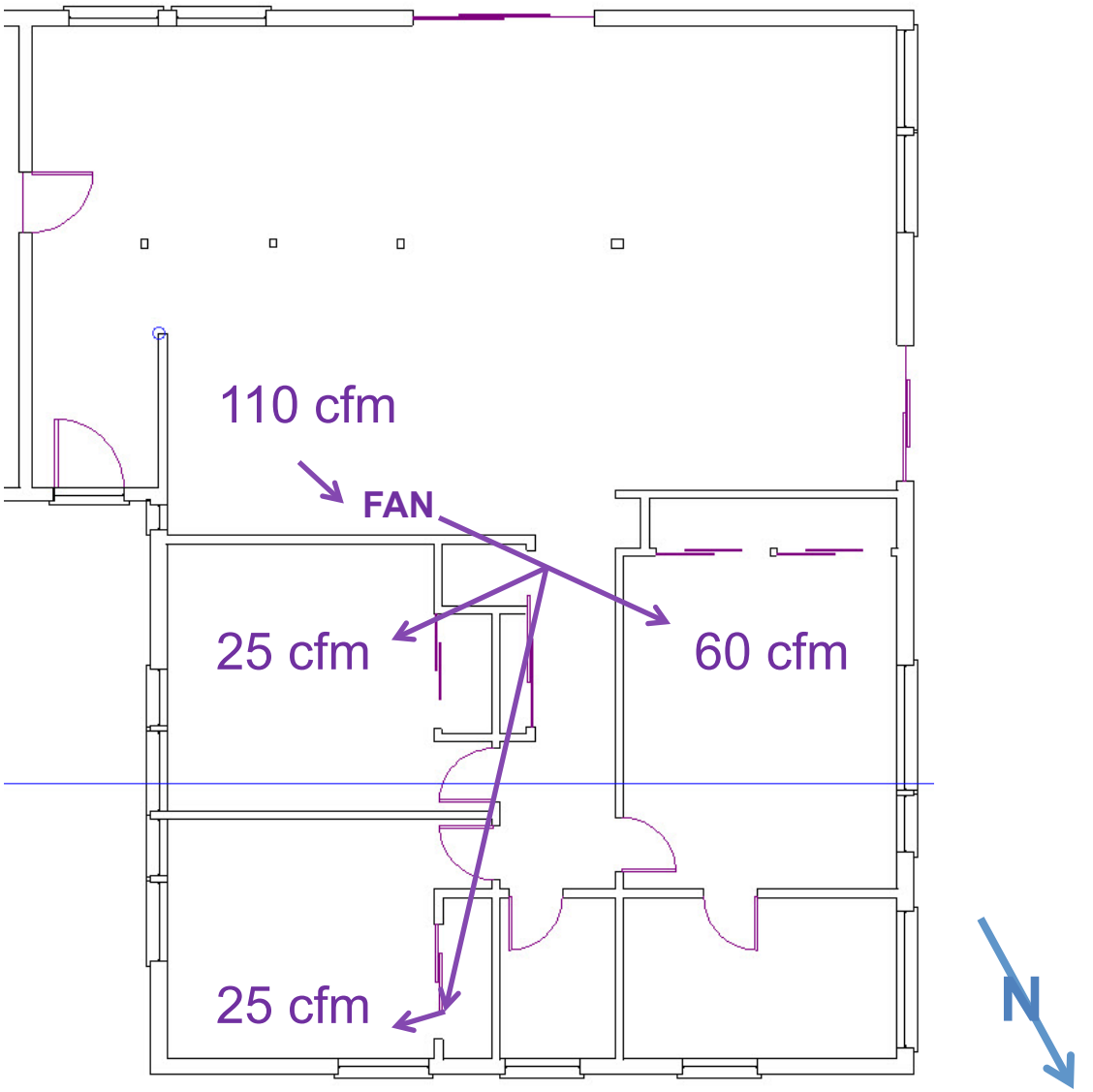
Sunnyvale PH Retrofit: Mechanicals

3. Air Circulation

DC Fan

@13watts



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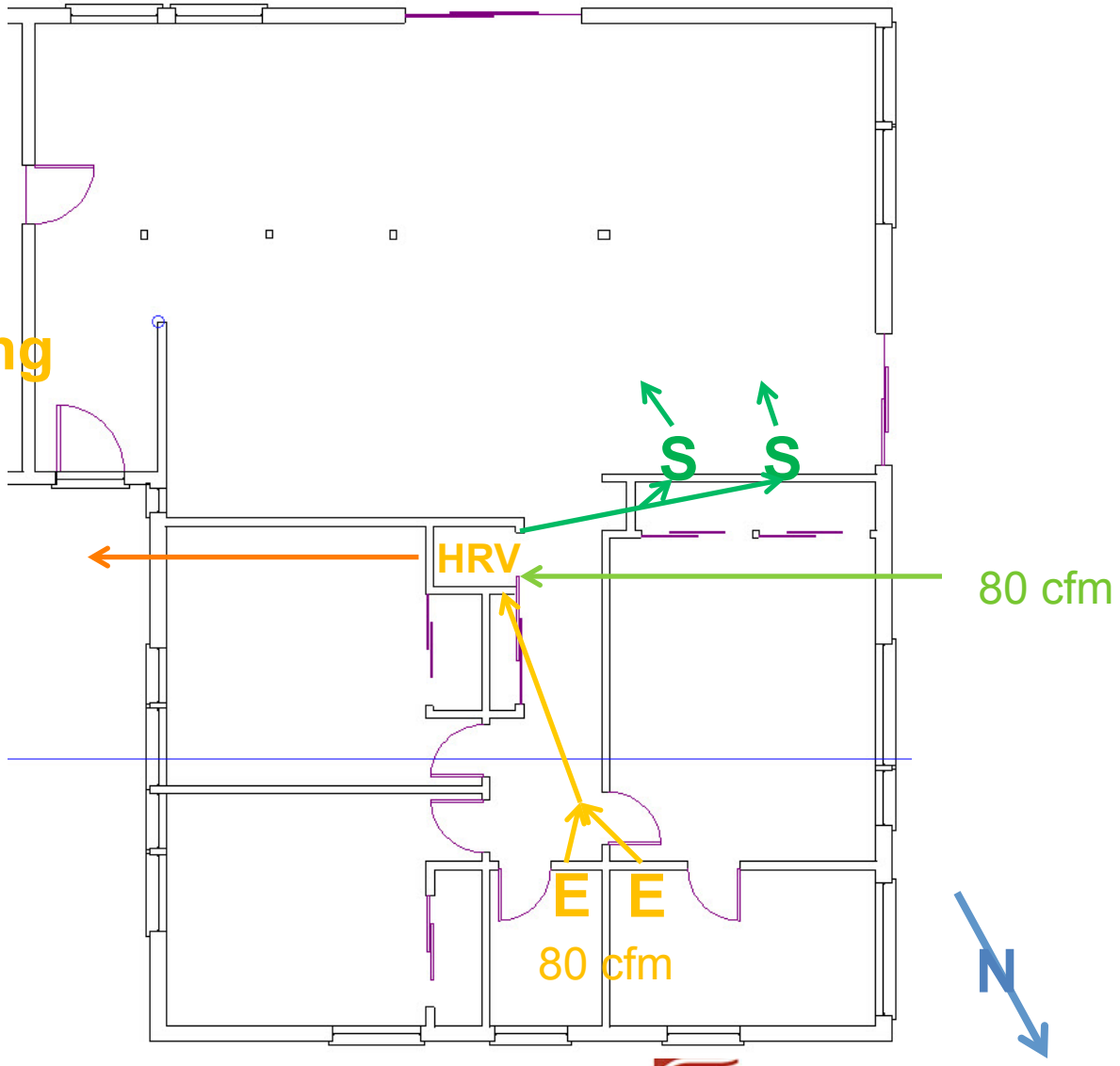
Sunnyvale PH Retrofit: Mechanicals

1. Ventilation – HRV

HR Bypass for cooling



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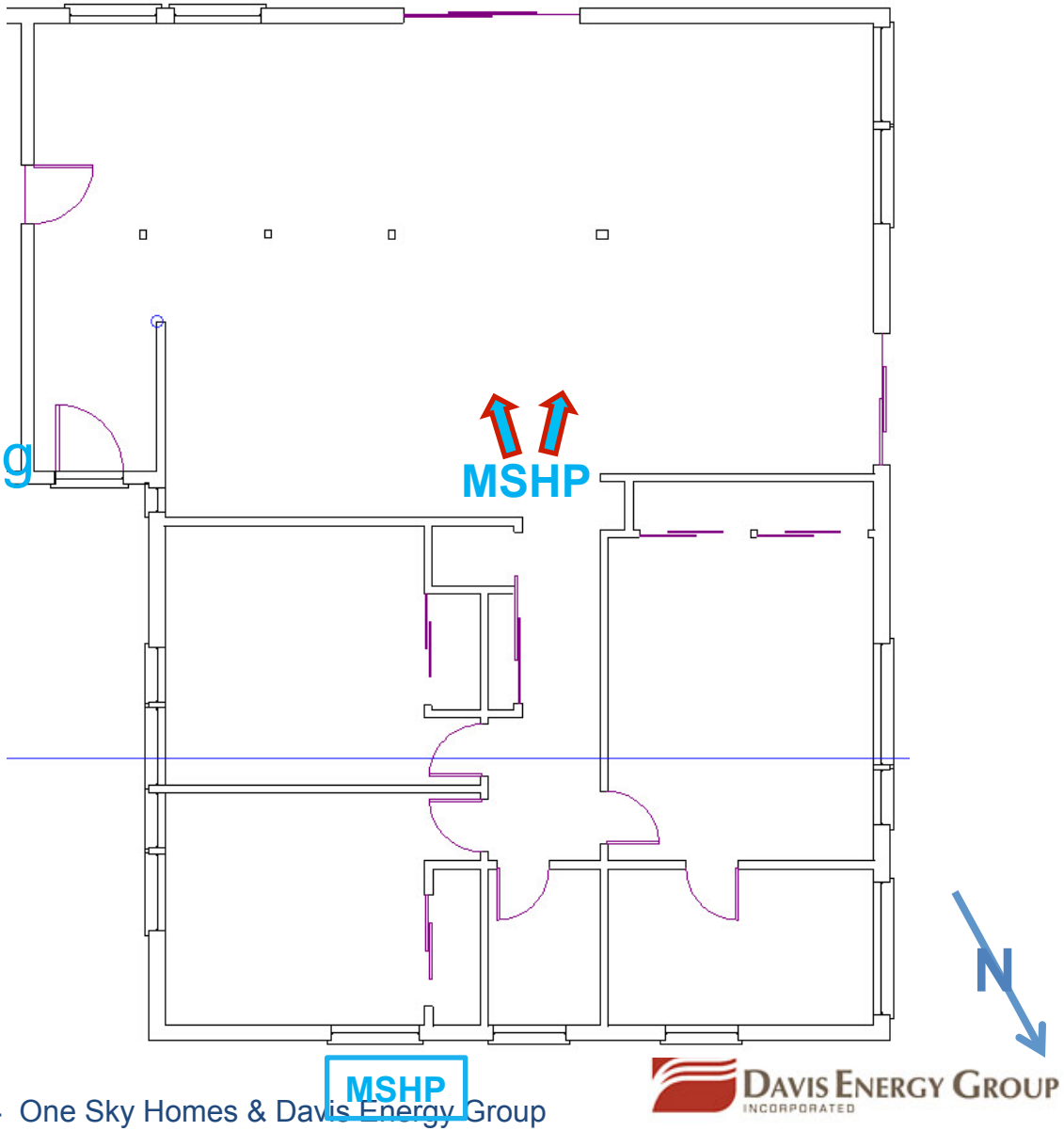
Sunnyvale PH Retrofit: Mechanicals

2. Heating & Cooling

SEER 25, MSHP

3-15kBtu modulating



Sunnyvale PH Retrofit: Mechanical Design Summary

- **Expectations**
  - Temp. differential in winter of 4+ deg?
  - Expected small ΔT in shoulder and summer seasons
- **Client choices**
  - Informed of temp. differentials
  - liked sleeping cool; may need space heater OK
  - Liked simplicity, economy, space saving
  - Set it and forget it

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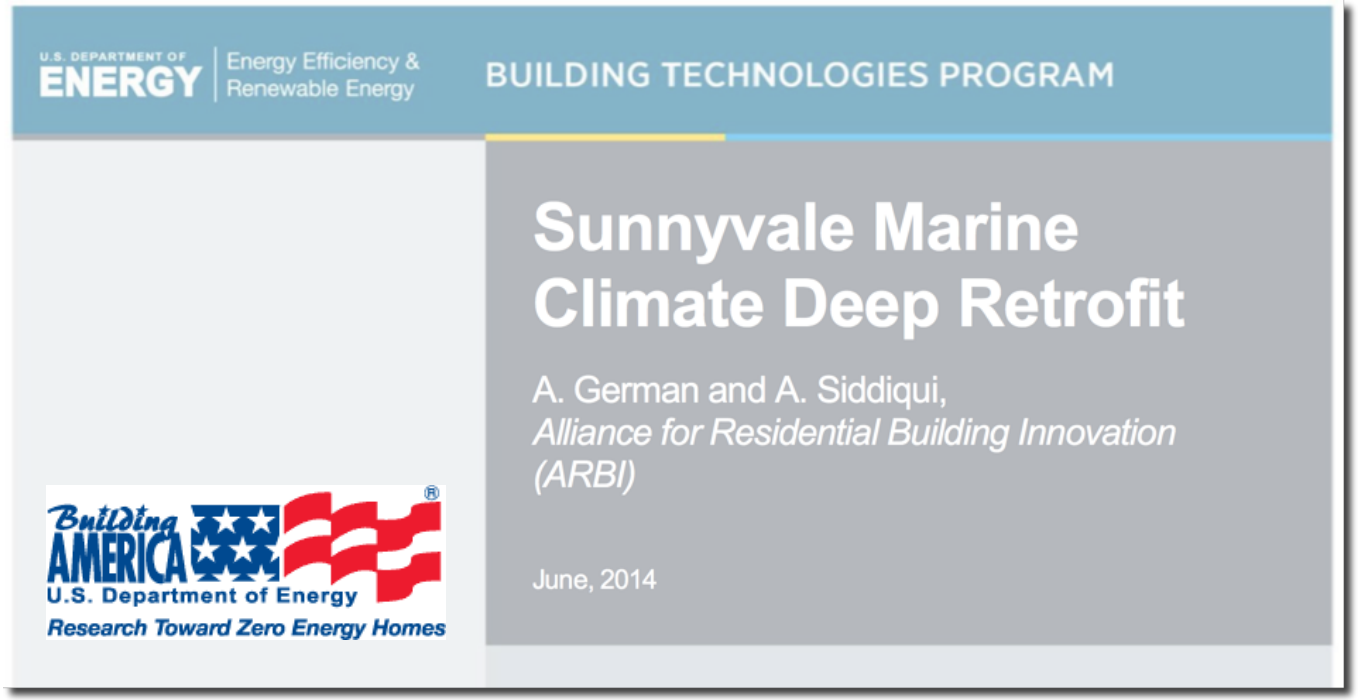
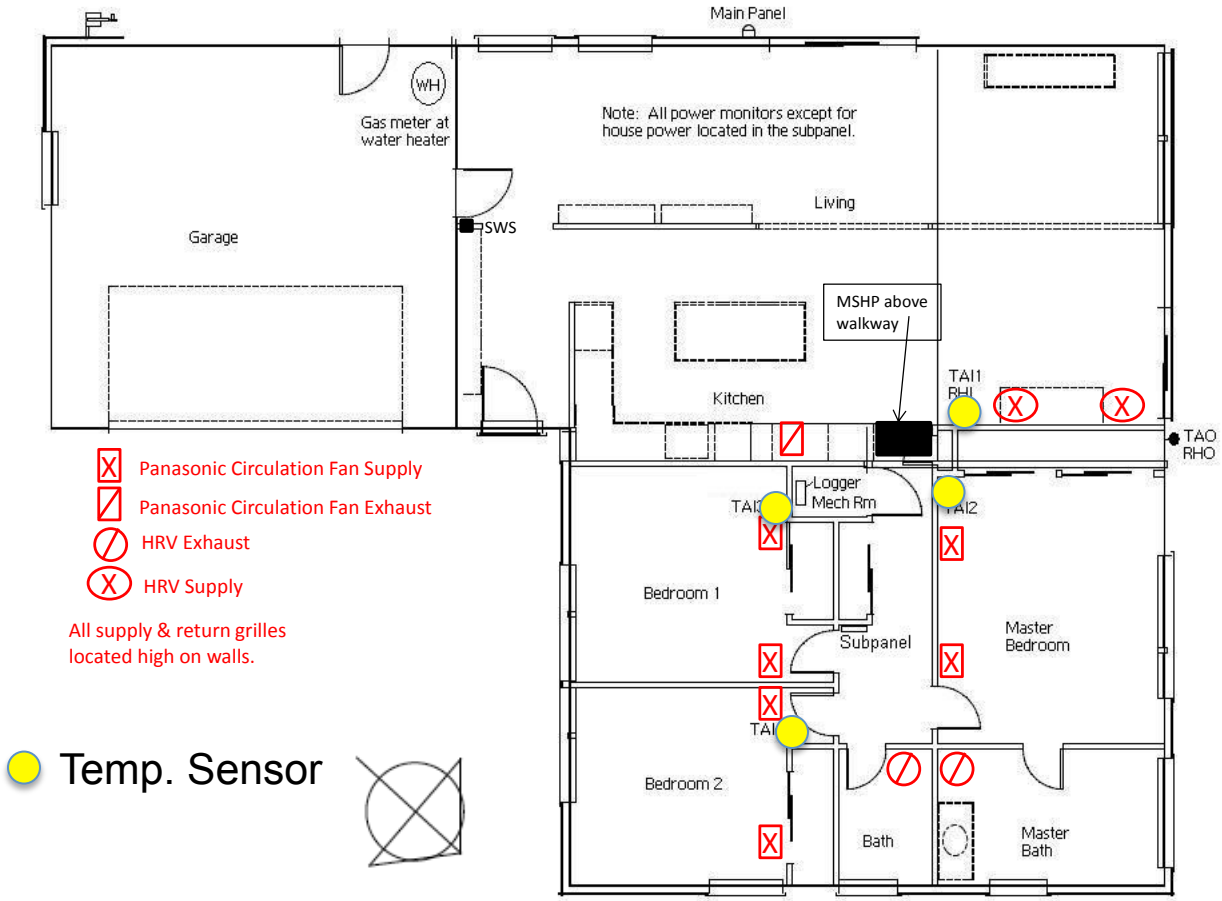
Sunnyvale PH Retrofit: Data Collection & Analysis



- On-site eMonitor – OSH

Sunnyvale PH Retrofit: Data Collection



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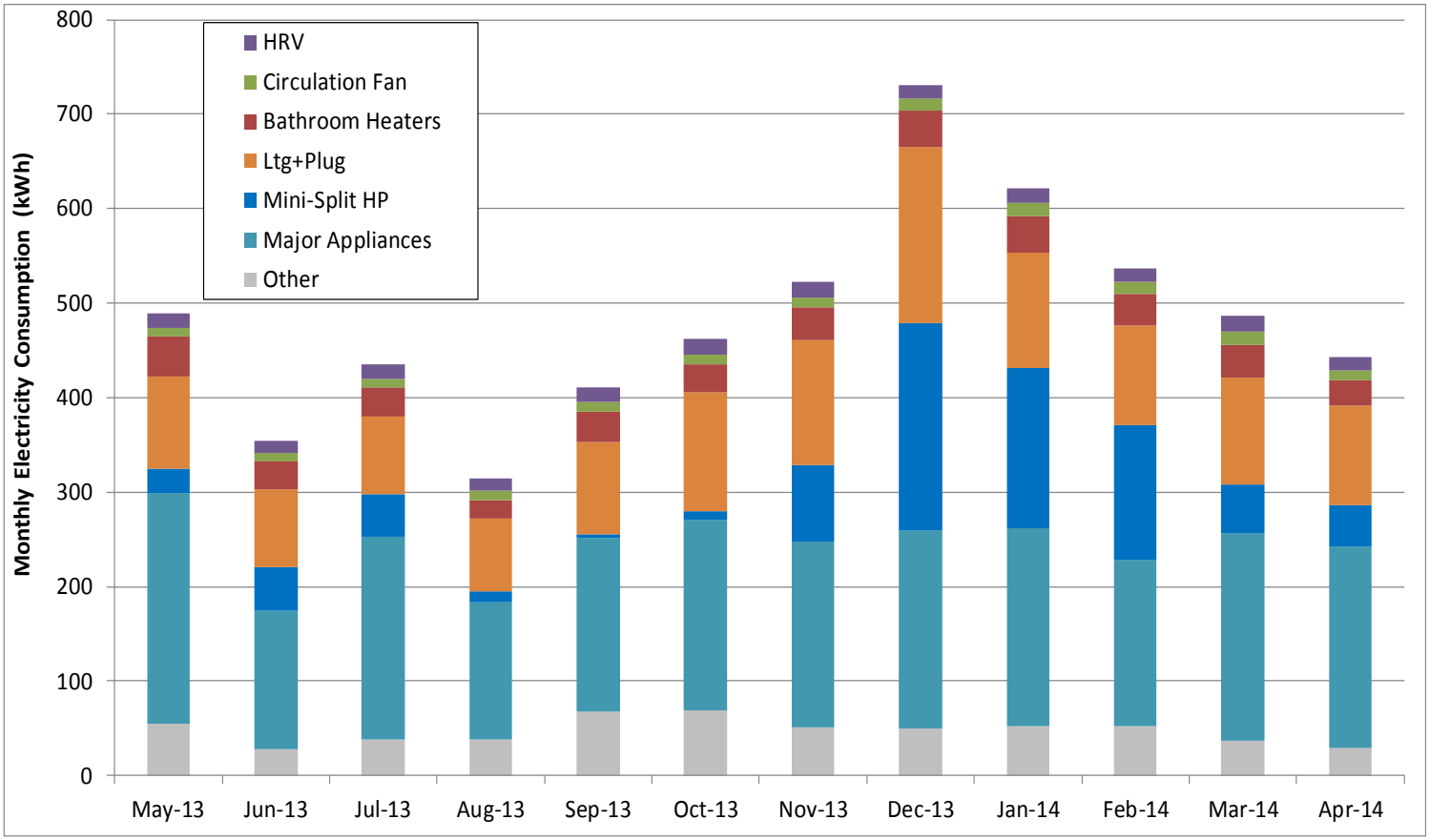
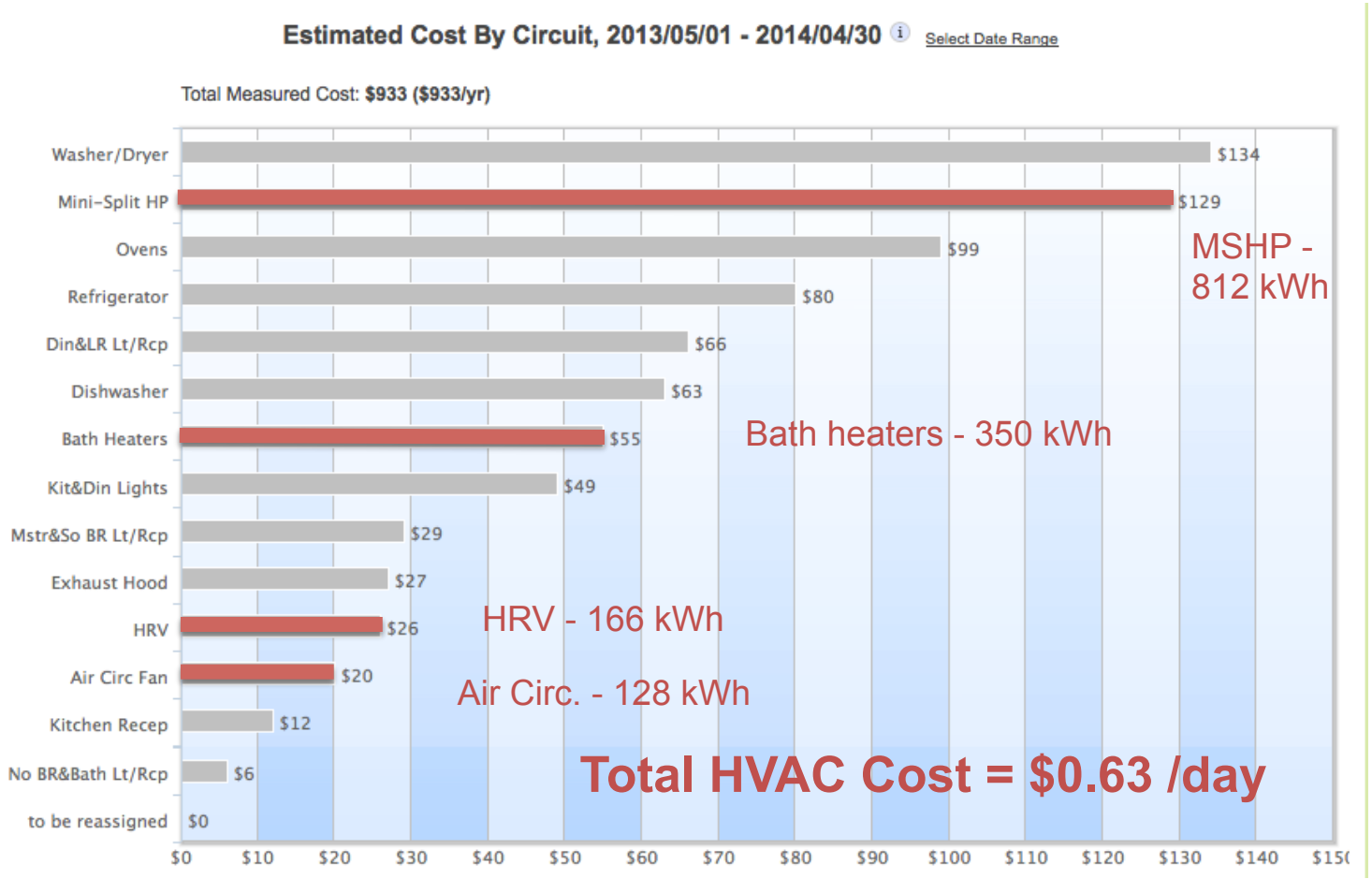
Sunnyvale PH Retrofit: Performance

Monthly Electricity Use

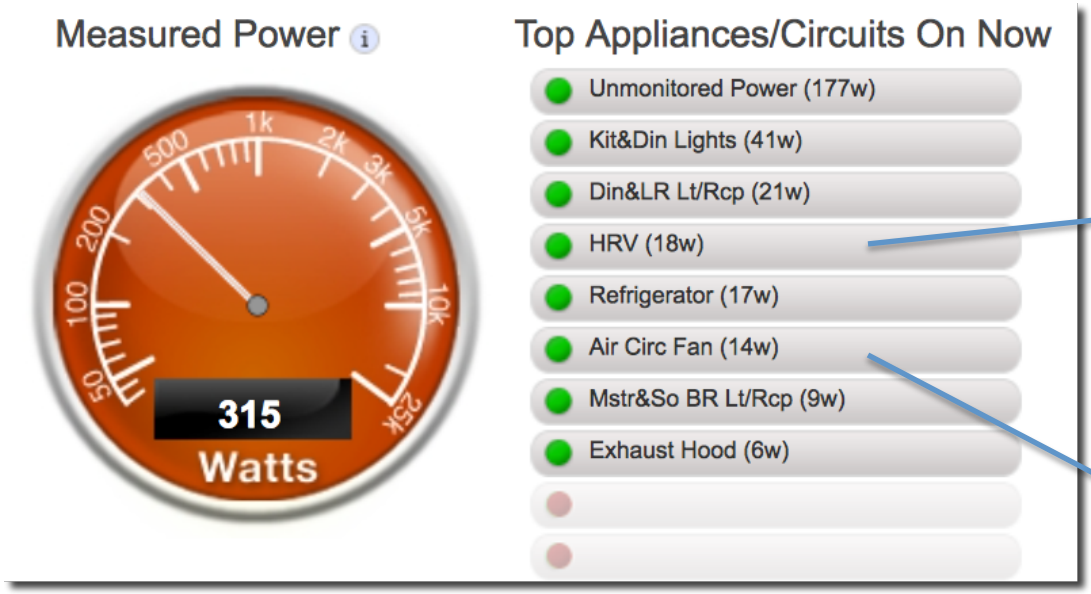


Sunnyvale PH Retrofit: Performance

Annual HVAC Loads



Sunnyvale PH Retrofit: Mechanicals Energy



Typ. Ducted HRV ≈ 40w

HRV = 20w

Avoided Energy (20w)

Air Circ. Fan = 14w

Reduction in static pressure from fully-ducted to minimally-ducted HRV offsets air circ. fan energy!

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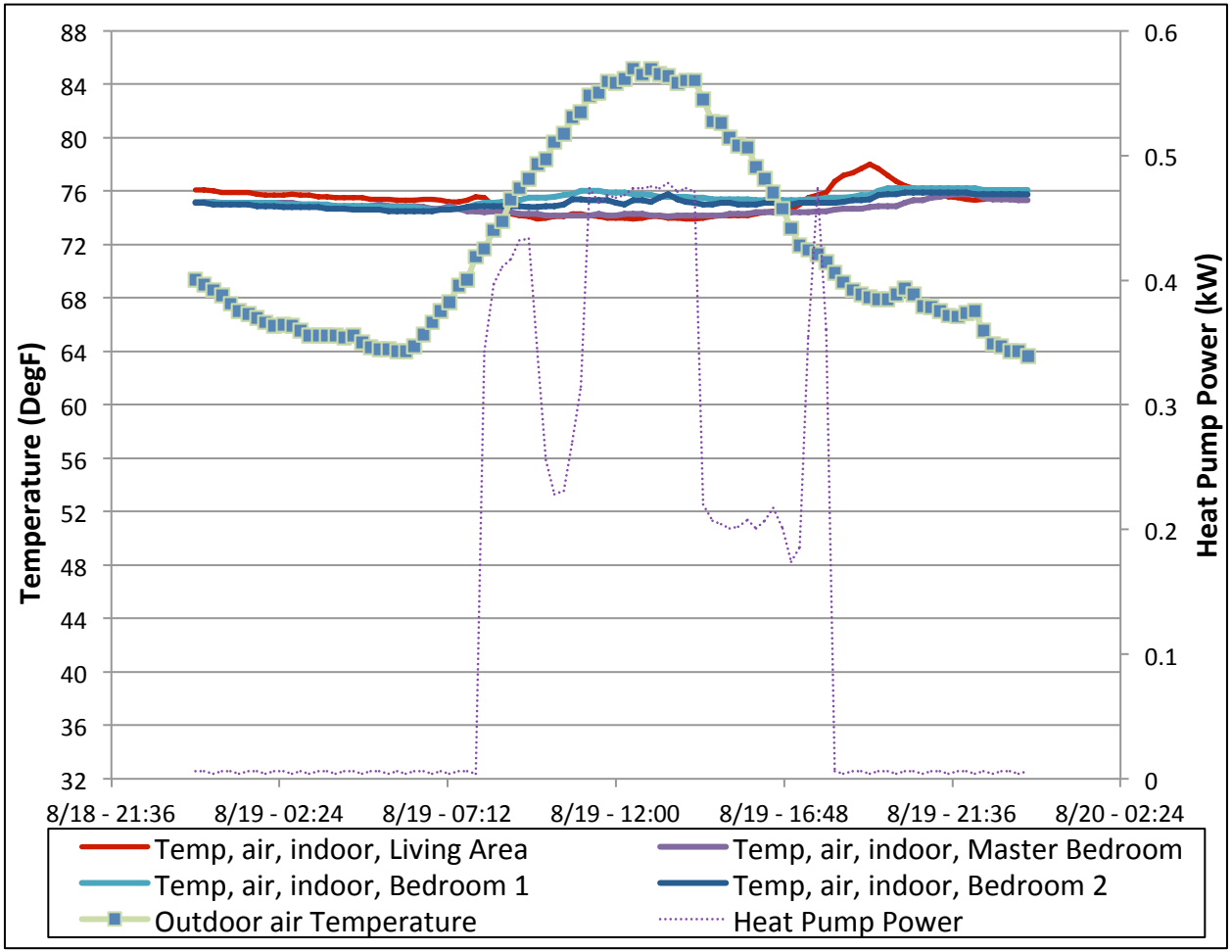
Sunnyvale PH Retrofit: Performance

Space cooling temperature and heat pump operating profile for typical summer day



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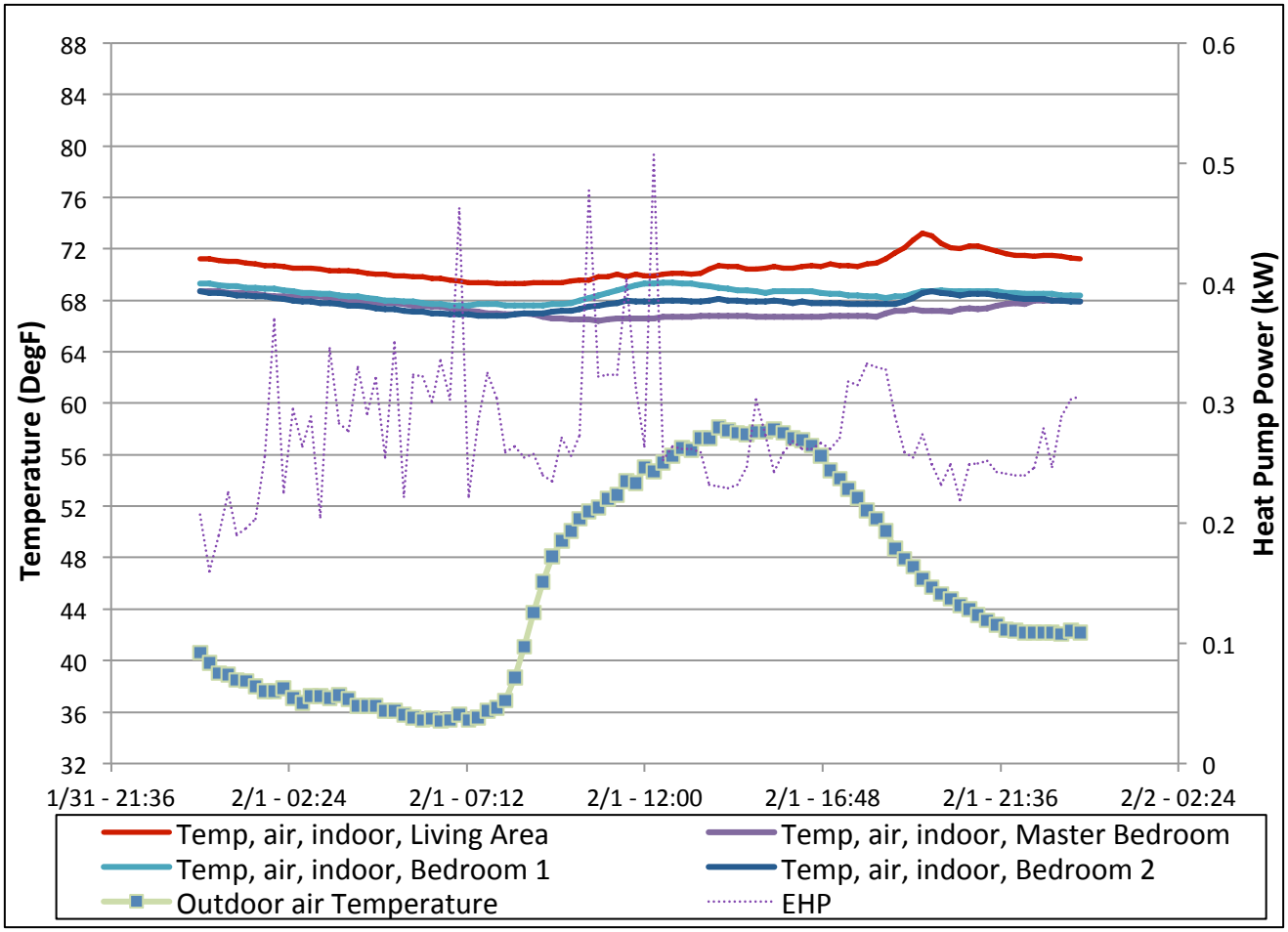
Sunnyvale PH Retrofit: Performance

Space heating temperature and heat pump operating profile for typical winter day



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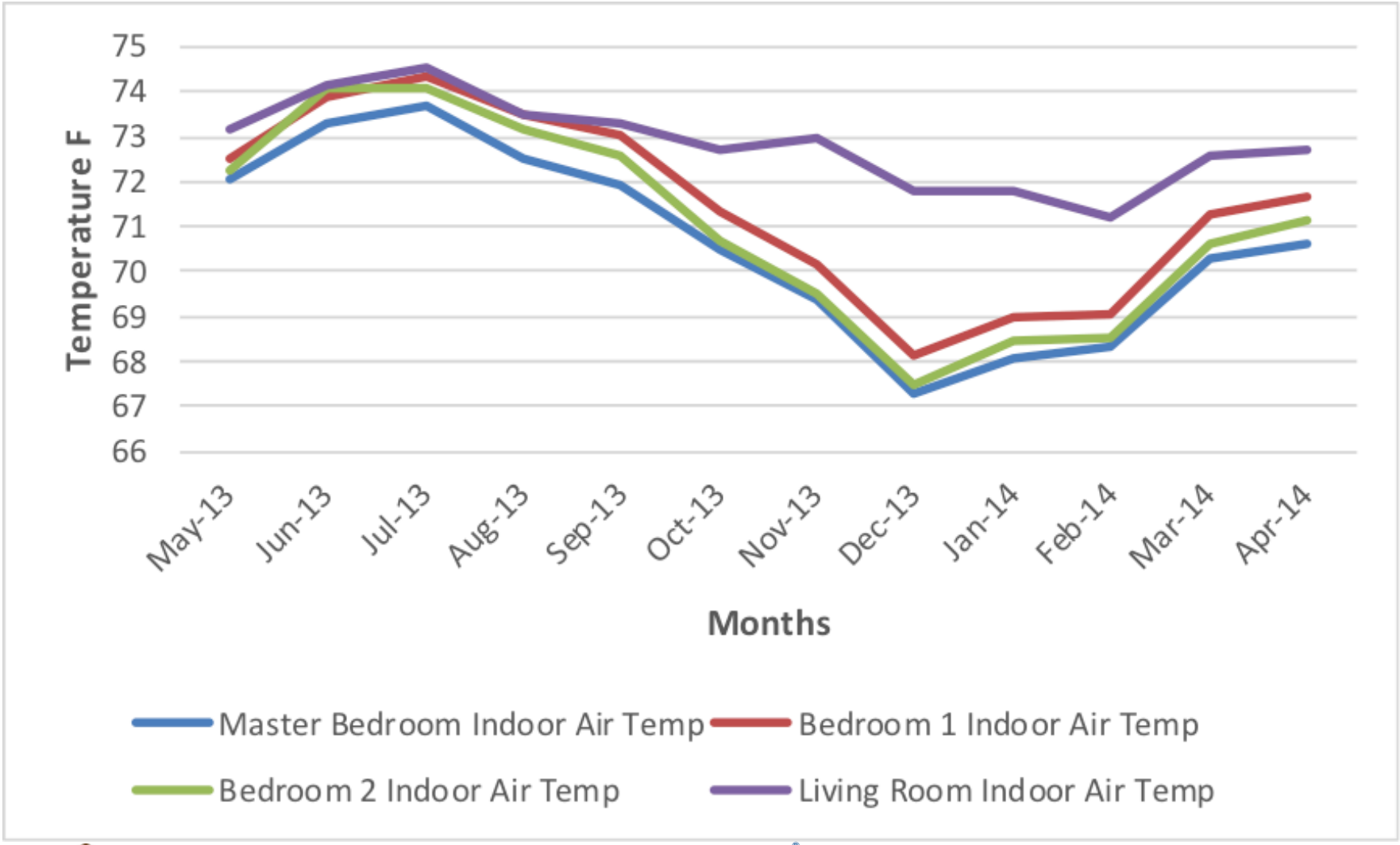
Sunnyvale PH Retrofit: Avg. Temp. Differentials



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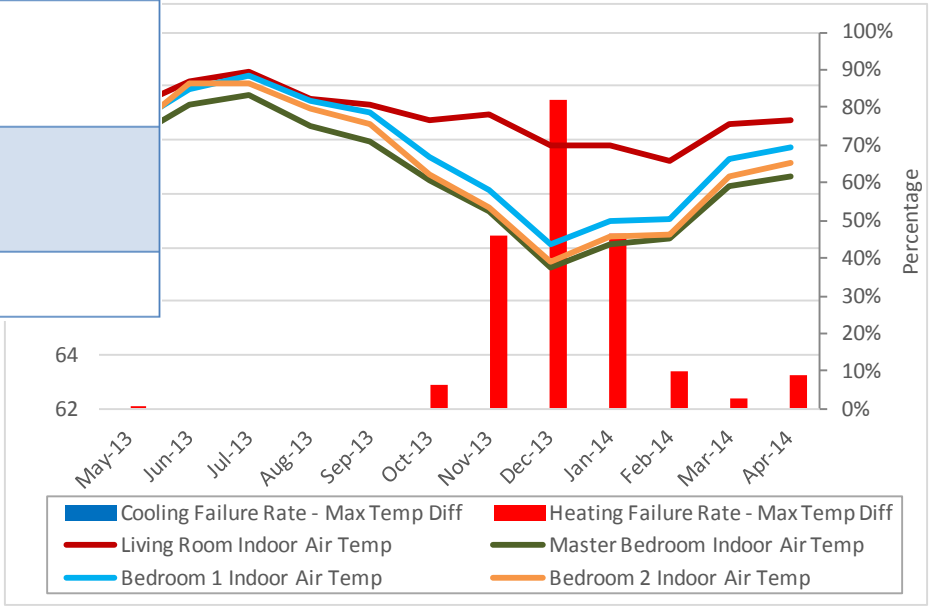
Sunnyvale PH Retrofit: Comfort Performance

Comparison of Observed Room-by-Room Temperature Differences

	Space Cooling	Space Heating
ACCA Manual RS	Max 6°F Avg 3°F	Max 4°F Avg 2°F
Measured Avg. *% Failure - Avg*	0.88 0%	1.73 34%
Measured Max. *% Failure - Max*	5.6 0%	8.2 31%
Measured Min.	0	0



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Sunnyvale PH Retrofit: Performance Summary

- Happy homeowners - mechanical systems exceed their comfort & IAQ expectations
- Very low HVAC energy consumption typical of PH
- Simple; avoided $6k+ in capital cost

Magic PH Project – Palo Alto

- Non-profit community
- 2 story, 5600sf, 22 rm
- 8 BRs, live-in learning center
- “Small institutional”
- ICF walls; 3P win; etc.
- Significant thermal mass

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Magic PH Project

Magic PH Project: Mechanicals

Almost no room for services! Tight budget.

1. **Ventilation**
2. **Heating & Cooling**
3. **Air Circulation**

(15 Fans!)

Panasonic Execs & Engineers from Japan

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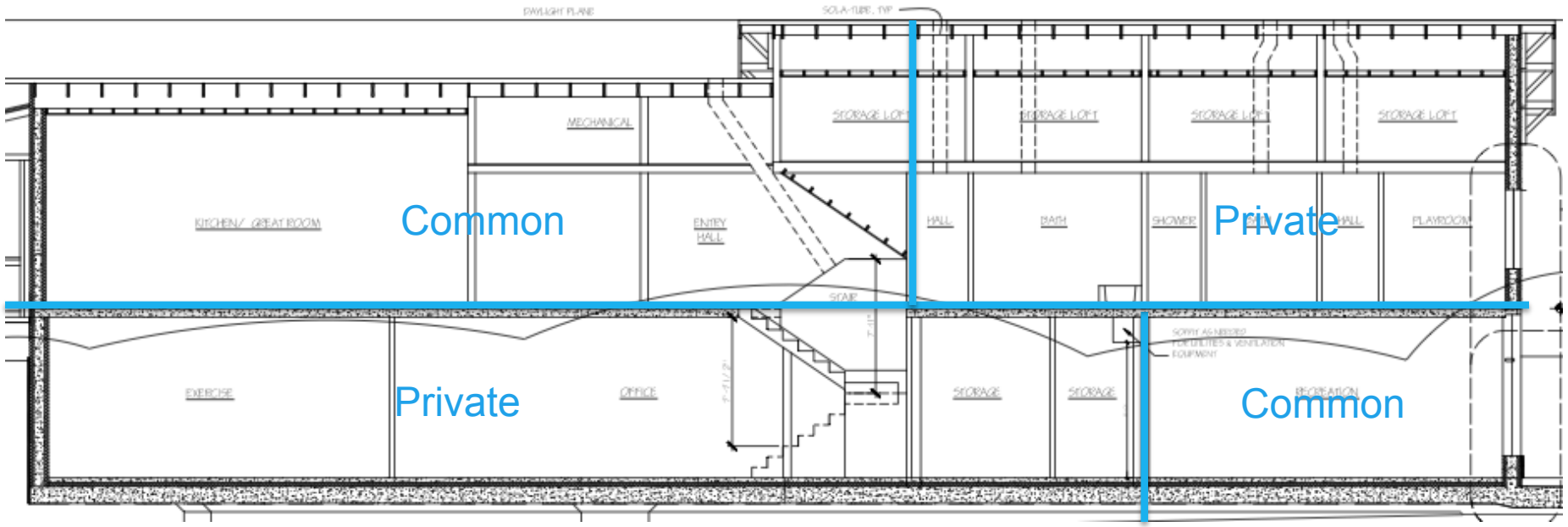
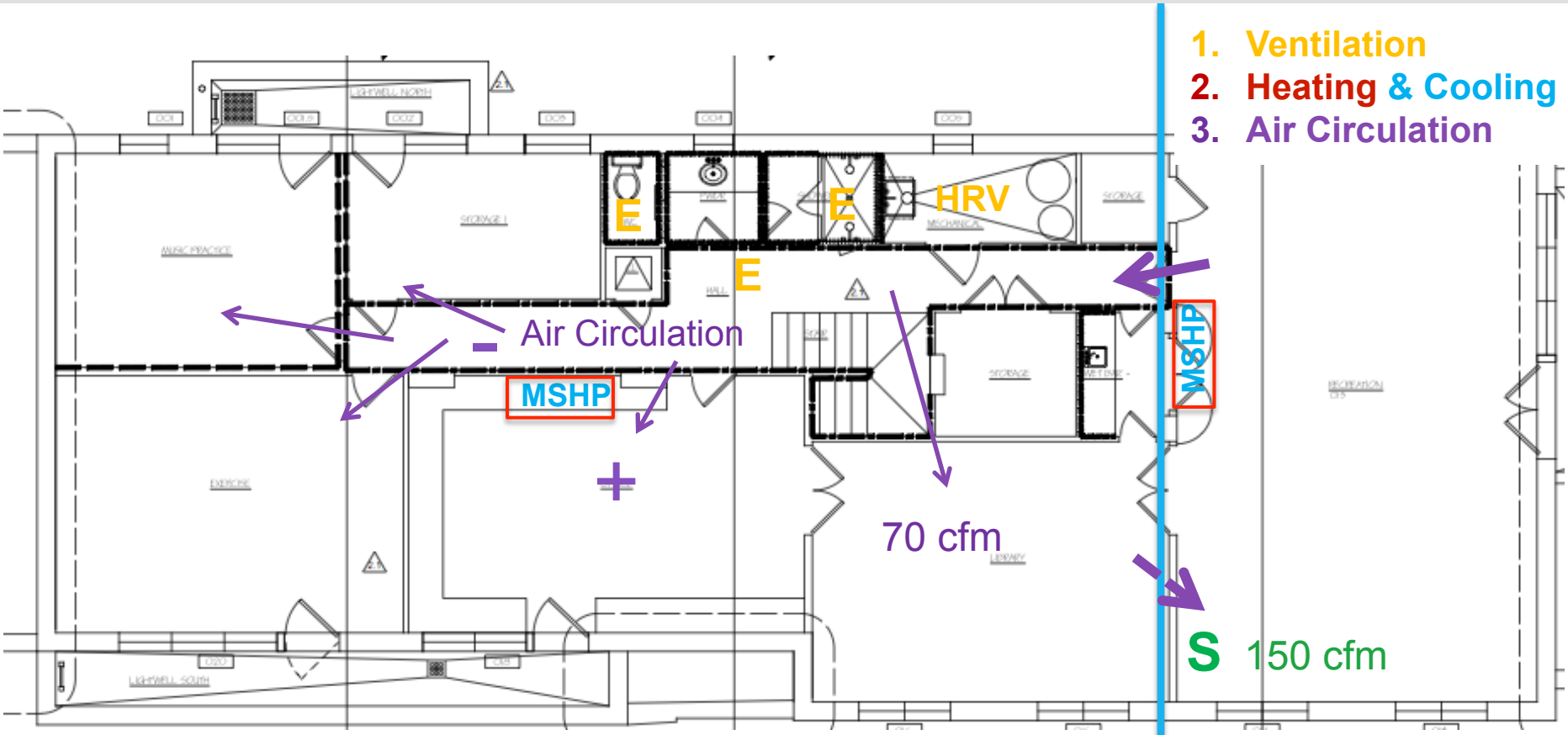
Magic PH Project: Mechanicals

Almost no room for services!



2 Floors, 4 Zones

Magic PH Project: Mechanicals



Basement
2700sf

-

Individual/Small Group
Activities Zone

+

Common
Area Zone

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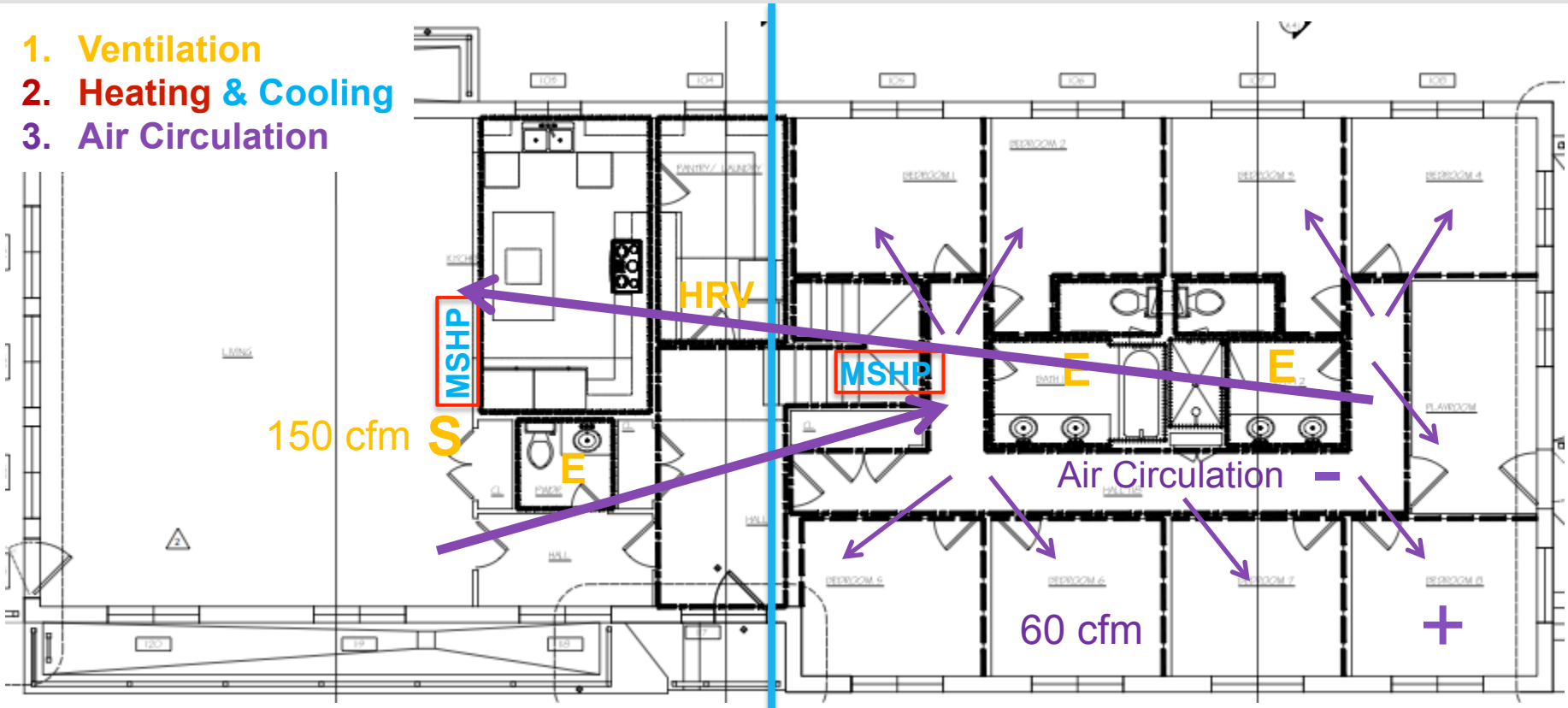
Magic PH Project: Mechanicals

1. Ventilation
2. Heating & Cooling
3. Air Circulation



First Floor
2700sf

\+ Common Area Zone

\- Sleeping/Private Zone

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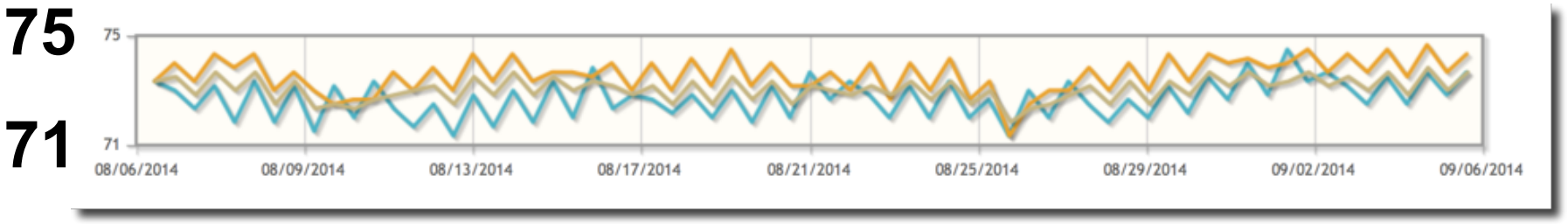
Magic PH Project: Mechanicals

Magic PH Project: Performance Data

- Only temp. & HVAC energy data for August/Sept
- Partial occupancy; No manual window operation
- HRV has bypass mode for some Night Ventilation Cooling
- MSHPs set point = 74

Basement: 30 day temperatures

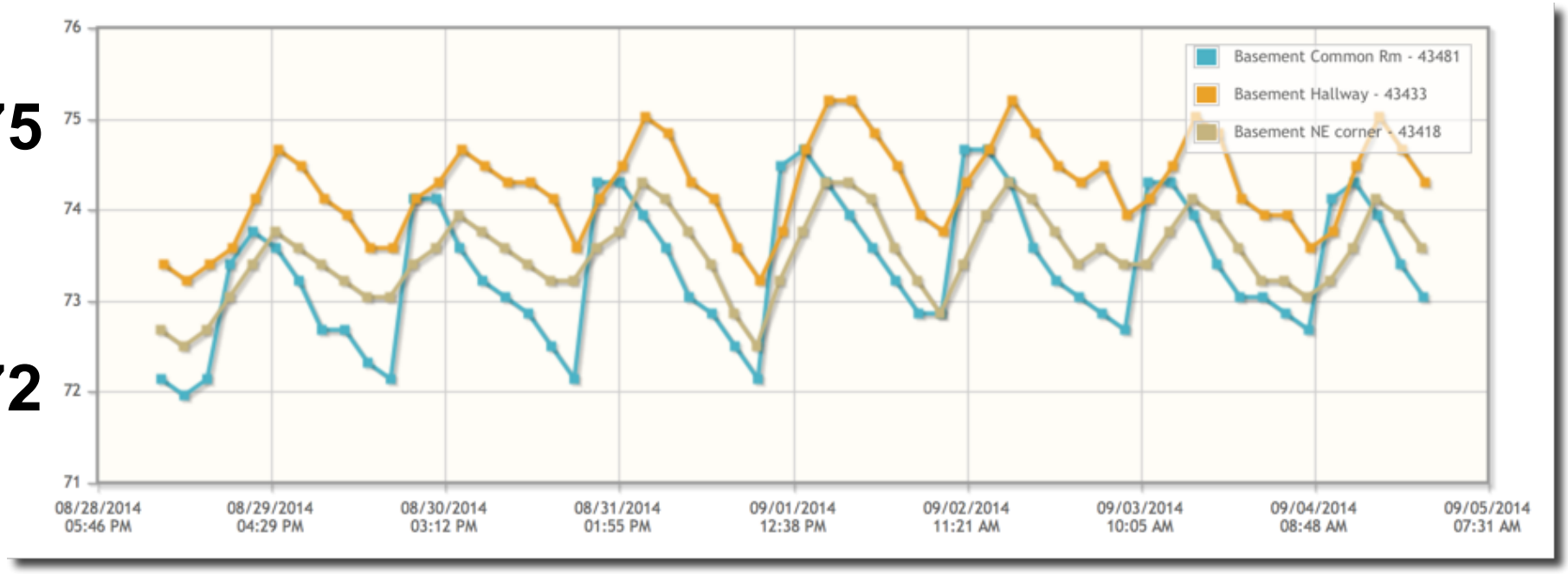


Magic PH Project: Performance Data

Basement: 7 day temperatures

75

72

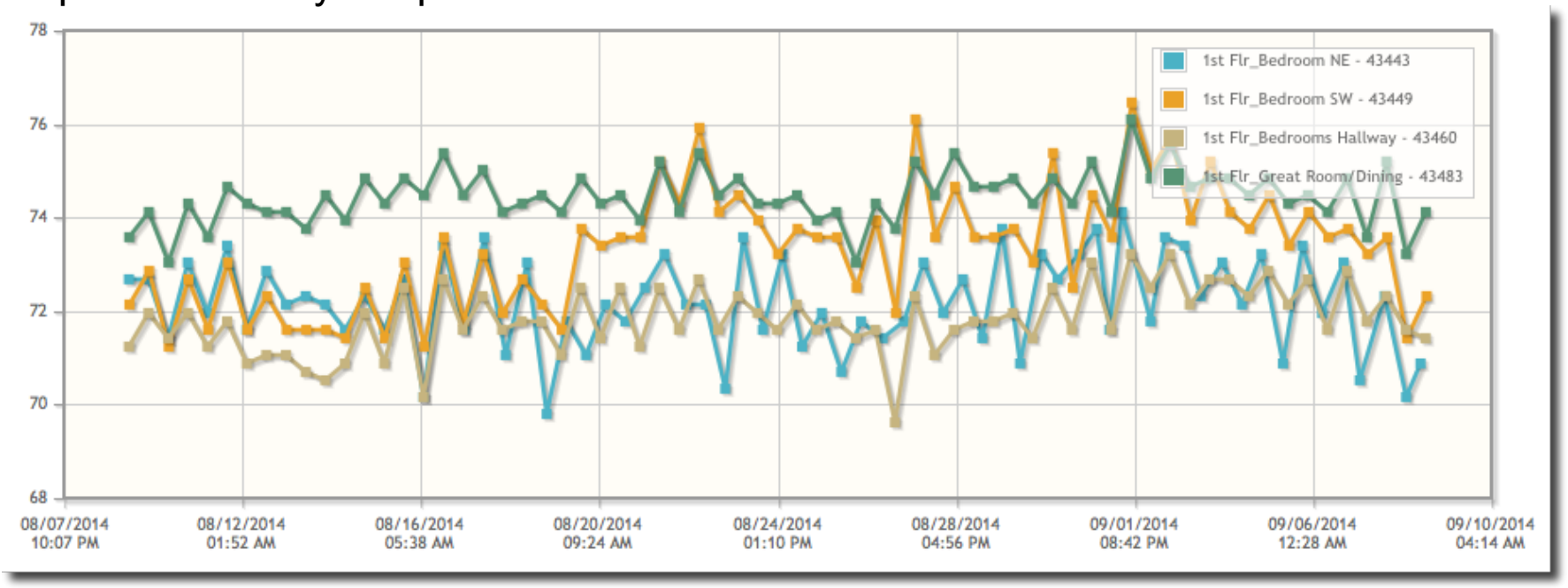


Magic PH Project: Performance Data

Upstairs: 30 day temperatures

76

70



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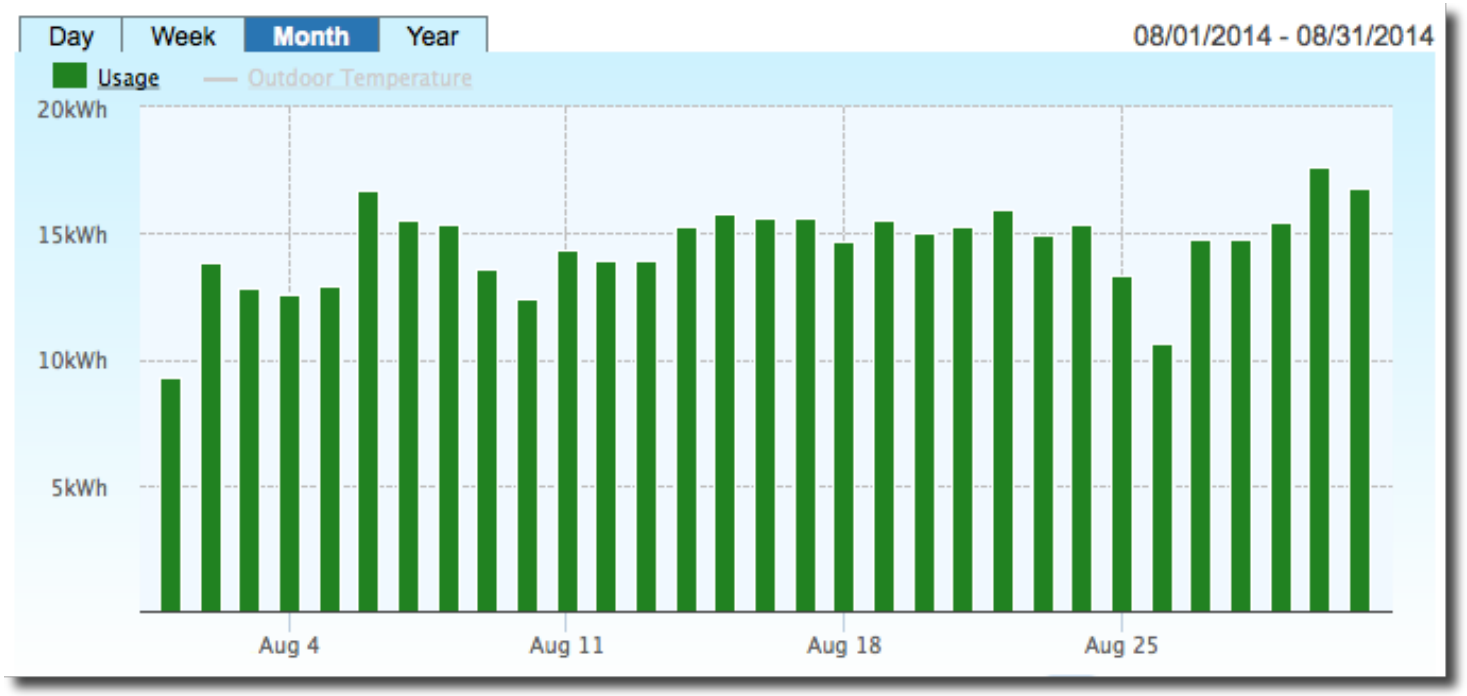
Magic PH Project: MSHP energy

Daily MSHP power consumption

15 kWh

10 – upstairs
5 – basement

($2.25/day)



(2 outdoor, 4 indoor, 74 set point 24/7)

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Magic PH Project: Mechanical Room

Symbiotic water heating & cooling systems

Heat Pump Water Heaters

100gal = 60kBTU daily

HRV w/bypass; Exhaust fan to laundry room

300cfm = 44kBTU daily NVC

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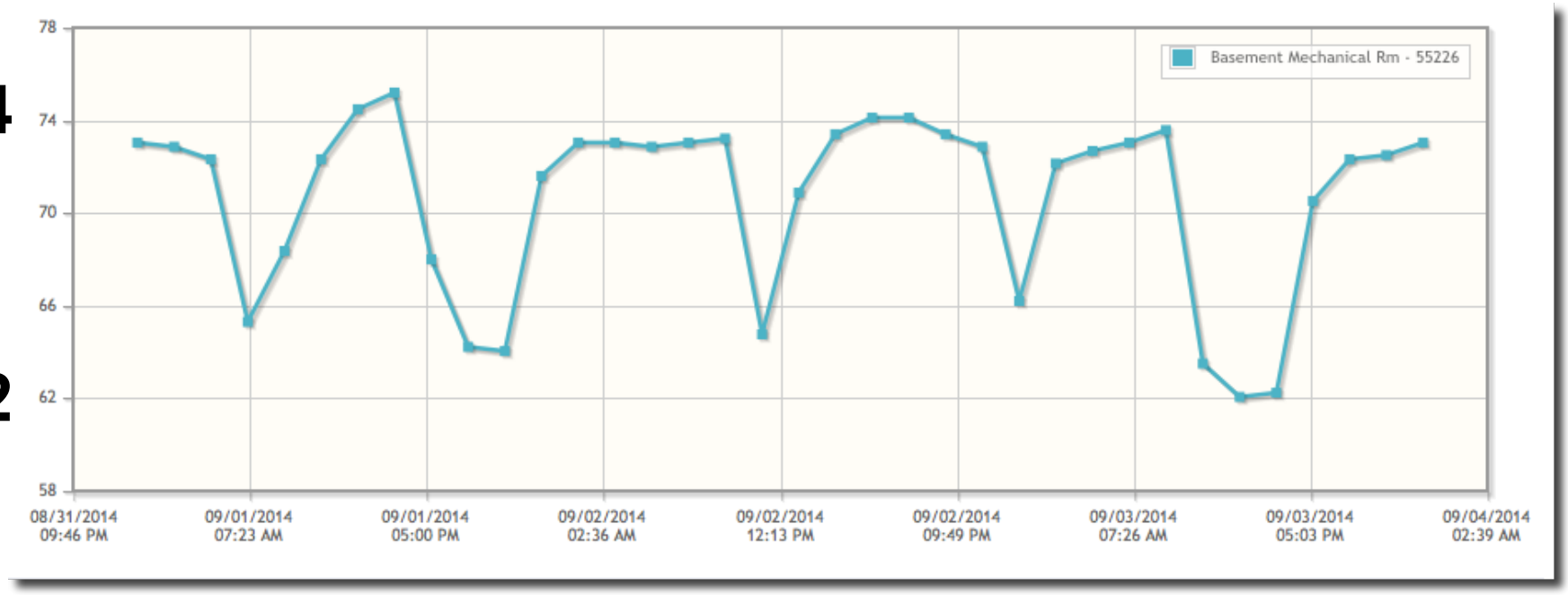
Magic PH Project: Mechanical Room Temps

Mechanical Room: 3 day temperatures – Heat Pump Water heaters working

74

62



Magic PH Project: Summary Results

- Comfort - Promising early data …need heating season data
- Solved lack of service space problem, economically
- HVAC energy – low, as expected; need more data
- Simplified approach cost savings: ≈ $25K+

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Asynchronous Air Circulation: Research Conclusions

- Comfort – satisfactory performance w/limitations. 5°+ avg. temp. variations.
  - Supplementary room heat may be required during peak heating season.
- Direct distribution of heating/cooling to rooms will provide superior comfort.
- Accurate room load calcs required!
- IAQ – no identifiable impact
- Energy use – MSHP vs. std. split = small efficiency gain

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High Performance Living