Design Boundaries: Can I make that a Passive House?

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Wright On Sustainability

Intro & overview

- The question keeps coming up.
- I looked at this one case…
- Check me
  - How I set up this study - 5 min.
    - Insulation levels & component quality high & fixed.
    - Vary size, shape, orientation, window areas, shading.
    - See what % of design space can be Passive Houses.
  - Result statistics, trends & histograms - 10 min.
  - Specific examples of 2, 3, 4 person Passive House configurations - 15 min.

A study of design parameters in PHPP, a computer experiment

- Objective
  - Get a feel for the limits that P/H performance requirements impose on the residential designer, in two Northwest climates (Portland & Bend.)
- Responses
  - Annual heat demand (kBtu/ft2/yr)
    - Concentrate on clearing the first hurdle.
      - Also keep an eye on Daily Temperature Swing.
        - » Bottom of Cooling Load sheet in PHPP.

Study factors (variables) & ranges

- Factors were chosen based on intuition as to what was most important in this region - "top ten list" of important PHPP inputs.
  - If I was doing this for the hot desert I would have included basement as a factor.
  - Study includes both categorical and continuous factors.
- Categorical factors
  - Climate (Portland, Bend/Redmond)
  - Shape/orientation

    Rectangle (LongSouth, ShortSouth)

    L-shaped (LongSouth, ShortSouth, EndLsouth, EndWsouth)
  - Number of storys (1,2,3,4)

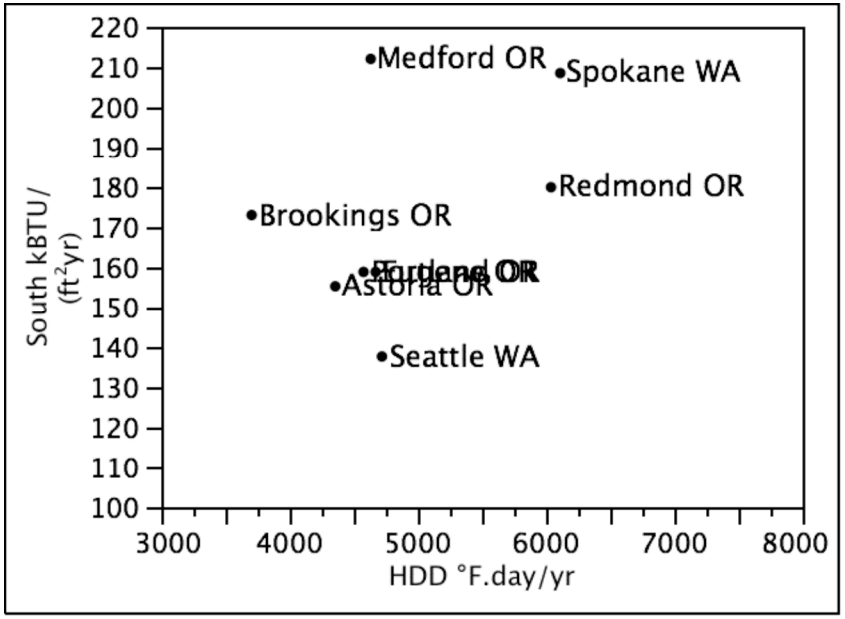
Fully crossed:

16 combinations for rectangular houses.

32 combinations for L-shaped houses.

Climates compared

South kBTU/(ft_yr) By HDD °F.day/yr

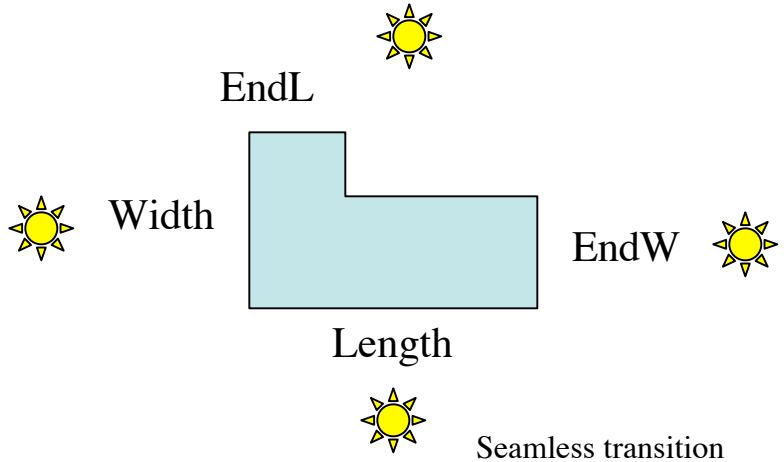


Climate	*HDD °F.day/yr*	*North*	*East*	*South*	*West*	*Horizontal kBTU/(ft_yr)*
Portland OR	4577	36.7	82.4	158.9	87.8	131.6
Seattle WA	4720	35.0	74.3	137.6	77.0	117.1
Astoria OR	4356	42.3	83.2	155.3	88.5	130.5
Brookings OR	3704	46.4	95.4	173.0	99.2	150.7
Eugene OR	4671	45.3	87.7	158.9	93.3	138.3
Medford OR	4633	49.6	114.3	212.0	115.2	172.6
Redmond OR	6038	50.6	99.5	179.9	105.9	147.2
Spokane WA	6110	48.4	109.9	208.5	109.7	149.9

- Seattle slightly colder and 20% darker than Portland.
- Spokane 16% brighter than Redmond OR, about as cold.

Study factors and ranges

- Continuous factors
  - Rectangle shape, outside dimensions
    - Length 13 to 70 feet
    - Width 13 to 70 feet
  - L-shape, outside dimensions
    - Length 13 to 70 feet
    - Width 13 to 70 feet
    - EndL 10 feet plus 0 to 100% of the remaining Length
    - EndW 10 feet plus 0 to 100% of the remaining Width
  - Windows: rough opening % of wall area (above grade)
    - North: 0 to 25%
    - East/West: 0 to 45%
    - South: 0 to 65%
  - Overall additional shading reduction factor 0.25 to 1.00 (75 to 0 % shaded.)
    - Applied year-round to both windows and opaque surfaces.



Seamless transition to rectangles, no ridiculous shapes.

Experiment design

- Rectangular houses
  - 6 continuous factors, 256 runs.
    - Latin hypercube space-filling design.
      - Recommended by NIST for computer experiments*.
  - Fully cross with 16 runs orientation/climate/storys, total 4096 cases.
- L-shaped houses
  - 8 continuous factors, 1024 runs.
  - Fully cross with 32 runs orientation, climate, storys, total 32768 cases.
- Total 36864 cases computed.
  - Automated using Excel table functions.

A six dimensional box has 64 corners.

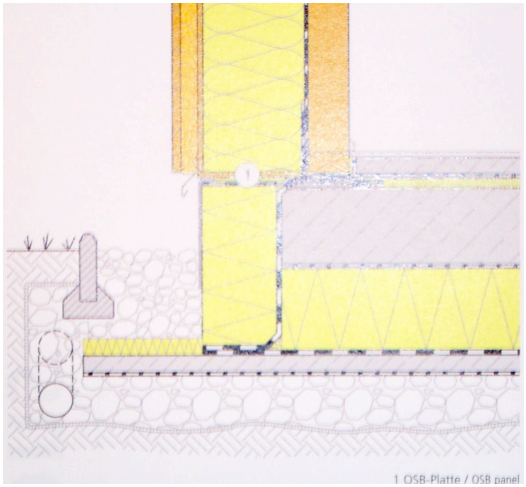
An eight dimensional box has 256 corners.

Taking up the Irwin challenge of iteration & automation.

* http://www.itl.nist.gov/div898/handbook

Constant factors

- Max out the goodness of the envelope & mechanicals, mostly.
- Insulation
  - 18-inch double-stud wall, cellulose & polyiso, R 65.8 hr*ft2*F/Btu.
  - 27-inch ceiling, cellulose, R 89.3.
  - 20-inch foundation, slab on expanded ps, R 71.2.
  - Two entry doors, Vacupor, R 60.5.
- Foundation connection like AWI 05-Efu 01 from *Details for Passive Houses*, perimeter thermal bridge -0.008 Btu/hr-ft-F.



Constant factors

- Treated floor area (TFA) subtractions:
  - 49 ft2 of stairs per story, for multistory.
  - 40% of 40 ft2 mechanical space = 16 ft2.
  - 5% interior partitions.
- Windows
  - Standard window: Serious Casement (max) 36w 60h.
    - Installation coefficients as if all in a single bank.
  - Remainder area window: Serious lo-profile fixed.
  - Serious R-9 heat-gain glass.
- Shading
  - Windows outboard: 2-inch reveals, plus fin shading for L-shapes.
  - 36-inch overhangs 18 in away, South only.
  - 50% temporary summer shading East, South, and West.

Constant factors

- Summer / window ventilation
  - Light construction.
  - Ventilate with 50% of south windows.
  - Cross ventilate with 50% of N, E, W windows.
  - Height difference for multi-story.
  - 13% of Day time.
  - 25% of Night time.

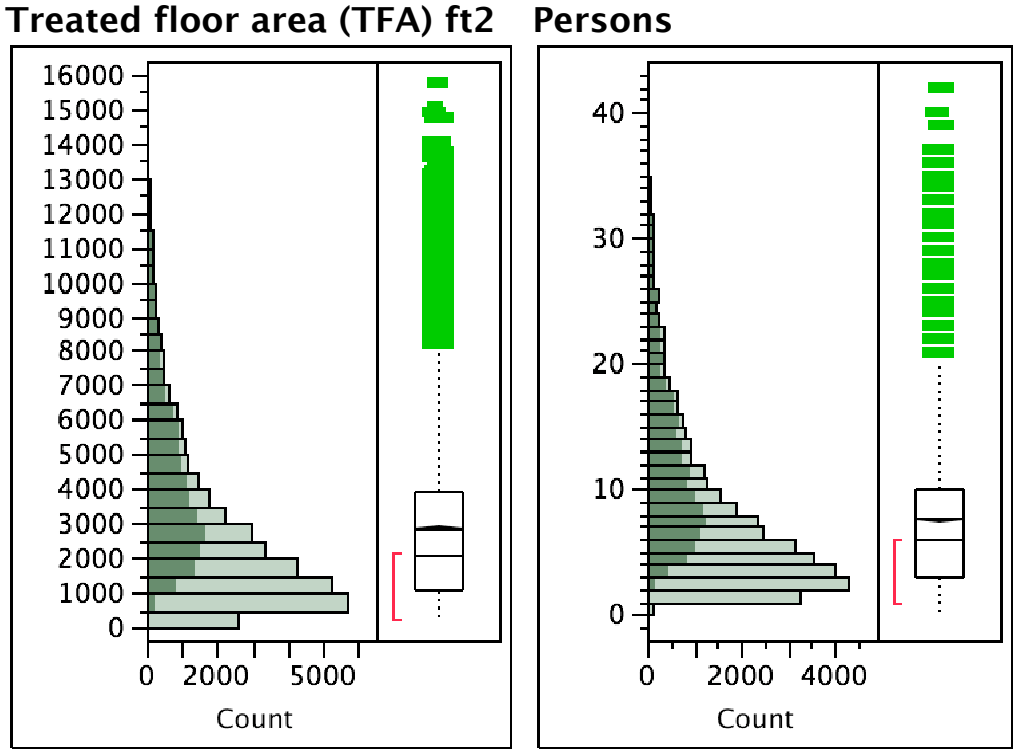
Constant factors

- Ventilation & air-tightness
  - Air change rate at pressure test = 0.5 ACH50.
  - Zehnder Comfoair like performance.
  - 1 kitchen, 1 laundry.
  - 1 full bath + 1 half bath per story.
- No cooling units.
- DHW, primary energy, etc.
  - Gas for all heat (space, DHW, cooking, clothes drying.)
  - Aux elec might need more attention, focus here is on annual heat demand.
  - Monthly-method calculations (as opposed to annual-method.)

My Panaceas

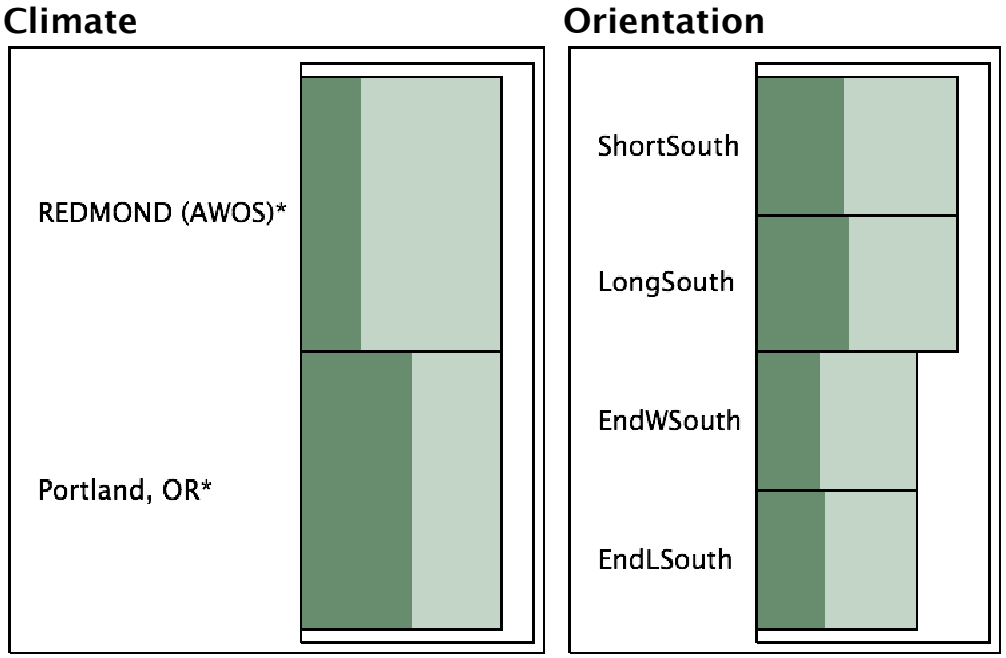
- At least in this region.
  - % overheating? -> window night ventilation.
  - Daily temp swing? -> summer temp shading.
    - I suspect it's cheaper than adding thermal mass.
  - Primary energy? -> use gas.
    - Site energy / net zero? -> heat pumps.

Result statistics - broad view



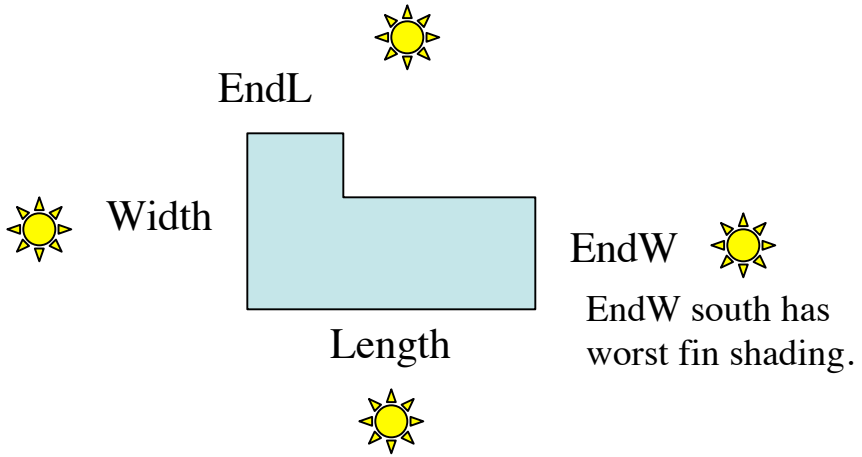
- Distribution of Treated Floor Area.
  - Most cases in the 1000-2000 ft2 range.
  - **Dark portion is Passive Houses.**
  - Finding them becomes more difficult below 2500 ft2.

Result statistics - broad view

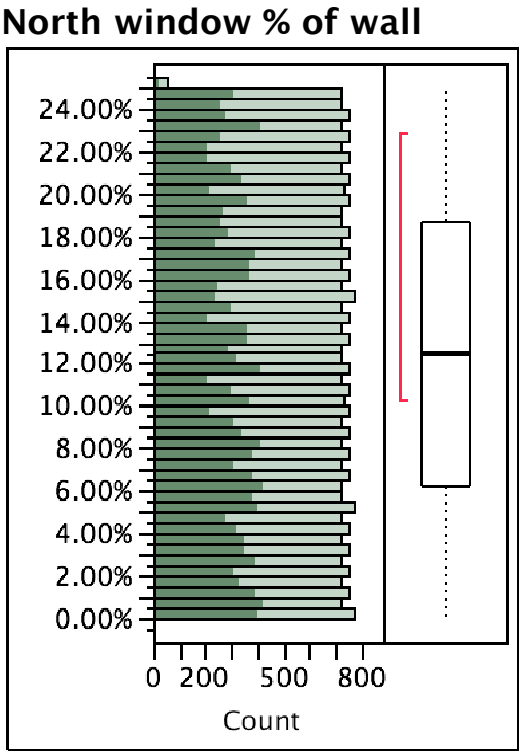


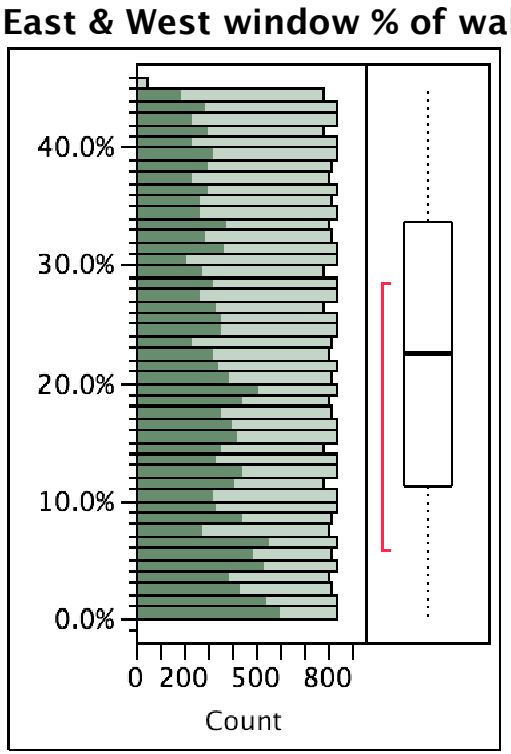
- Long side south orientation only slightly favored overall.
- Made more of a difference in the most difficult cases.

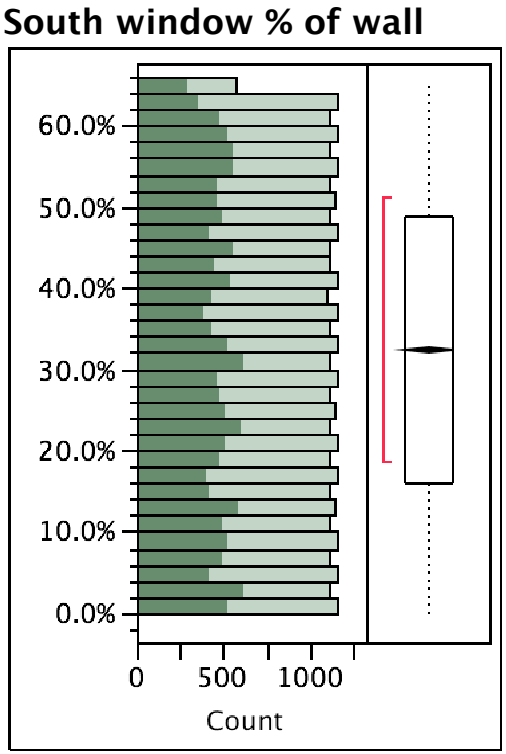
- Half as many Passive Houses in Redmond OR (Bend), as in Portland climate.



Result statistics - broad view

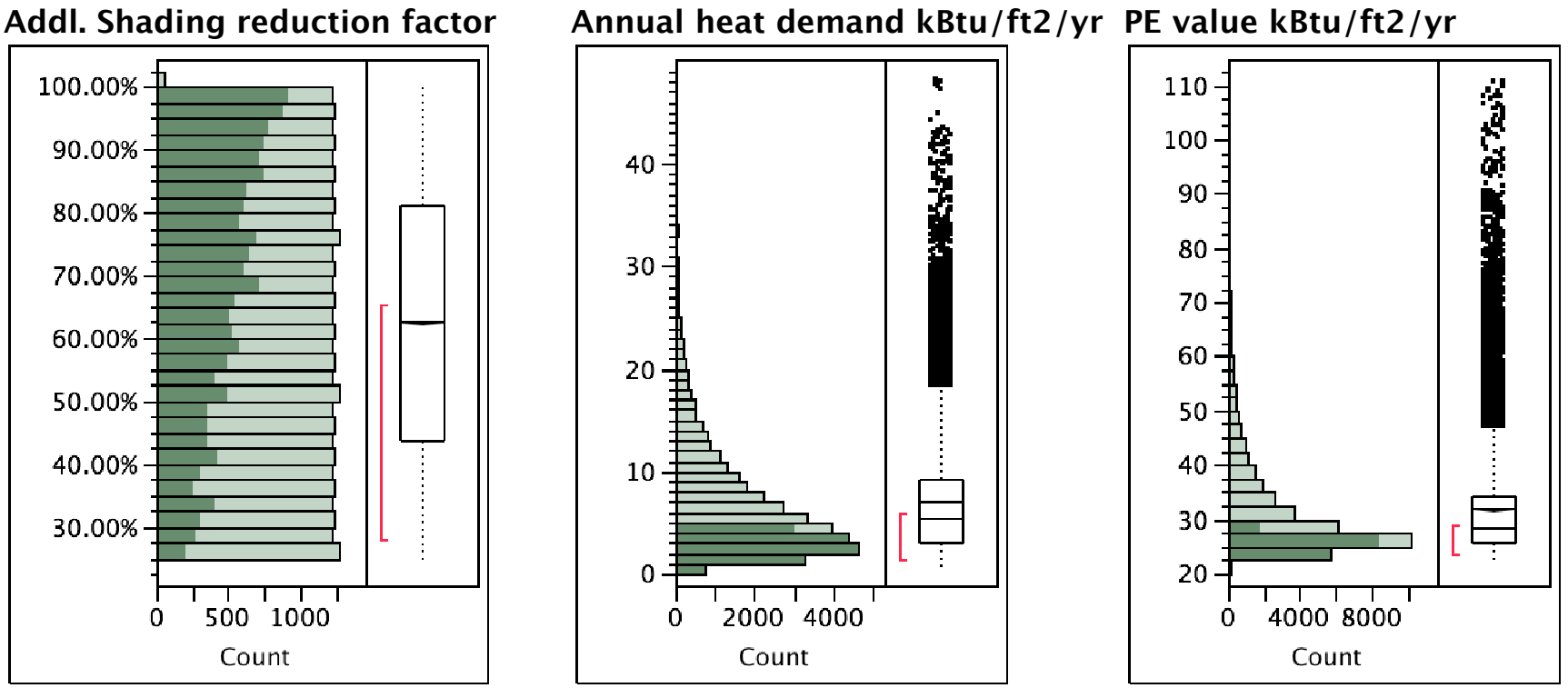






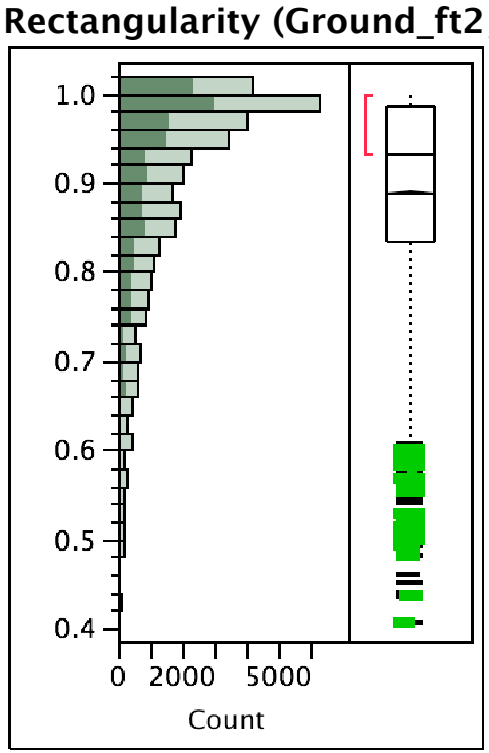
- North, East, West windows disfavored but tolerable. For South windows, it depends on shading.

Result statistics - broad view



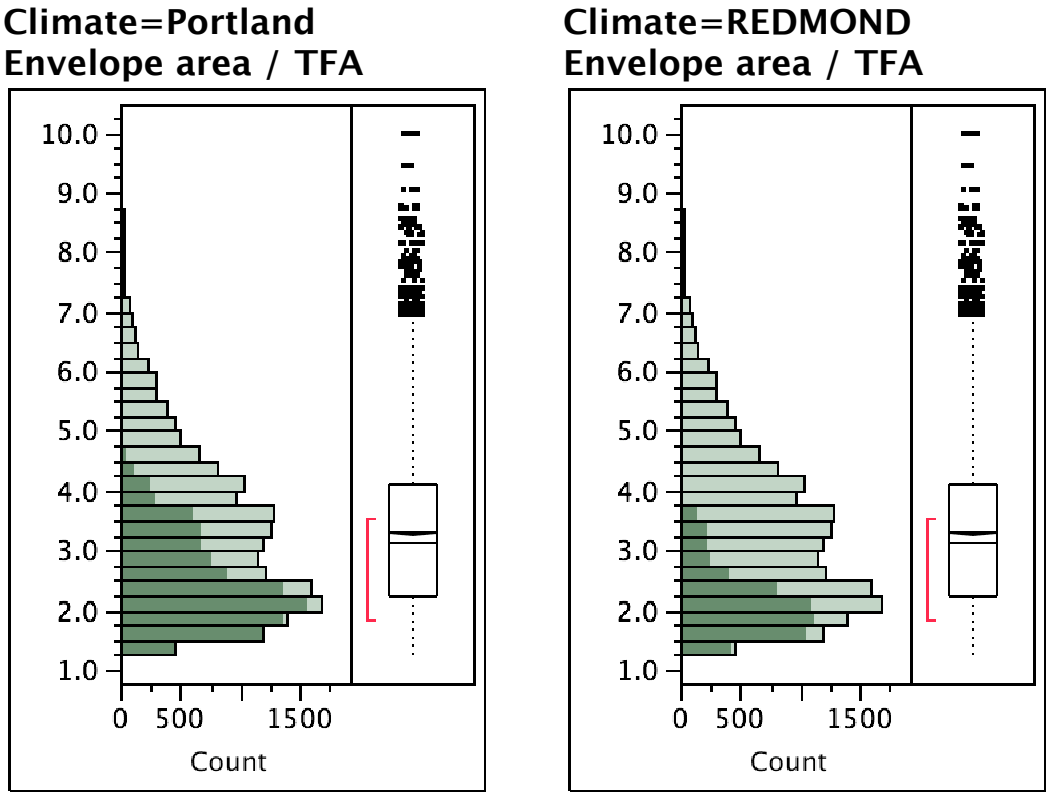
- Shading is bad, but tolerable in many cases. (100%=clear.)

Result statistics - broad view



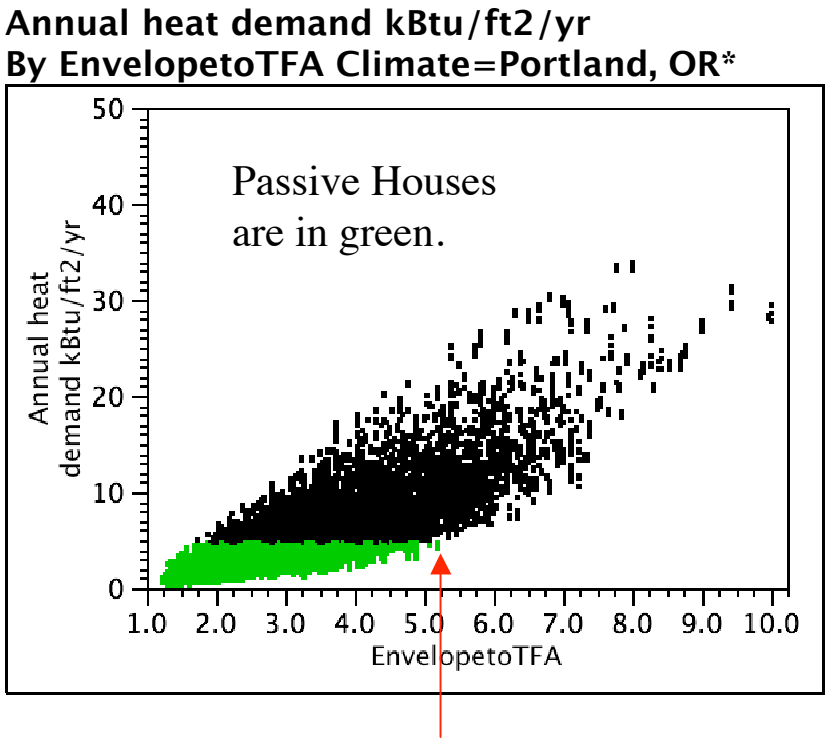
- Setup did not generate a lot of super-L-ish houses, which is probably realistic ? Rectangles with notched corners or shaved sides.

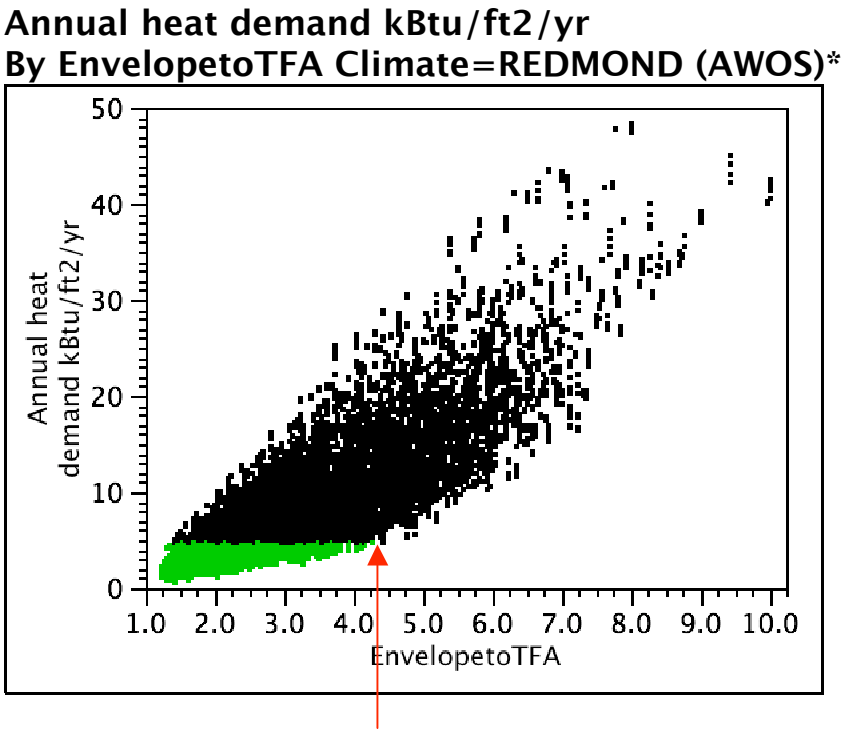
Result statistics - envelope area to TFA ratio



- There's a hard limit on Envelope area to TFA ratio for a Passive House. Lower in Redmond than Portland.

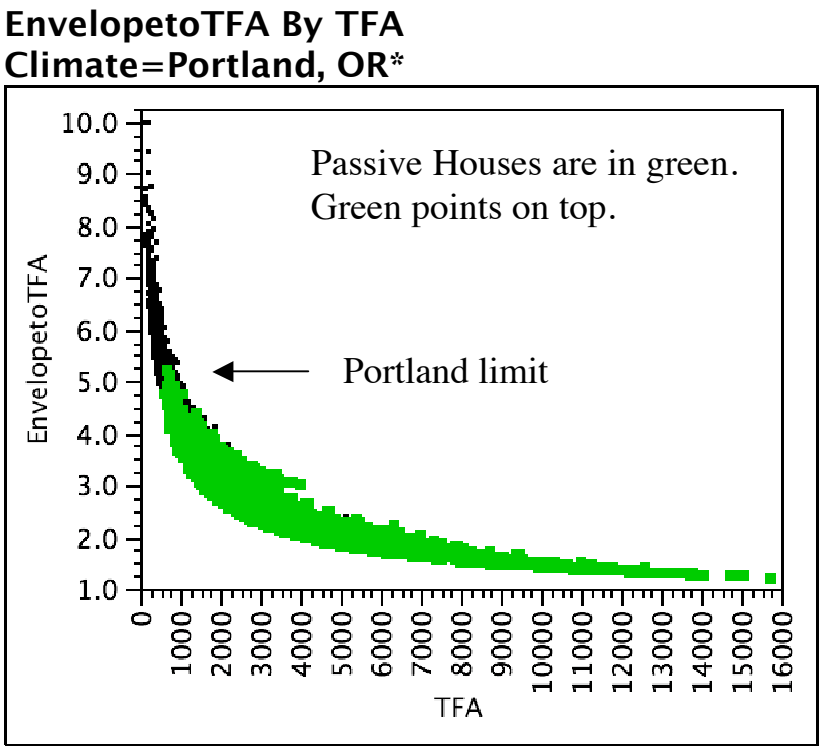
Result statistics - envelope area to TFA ratio

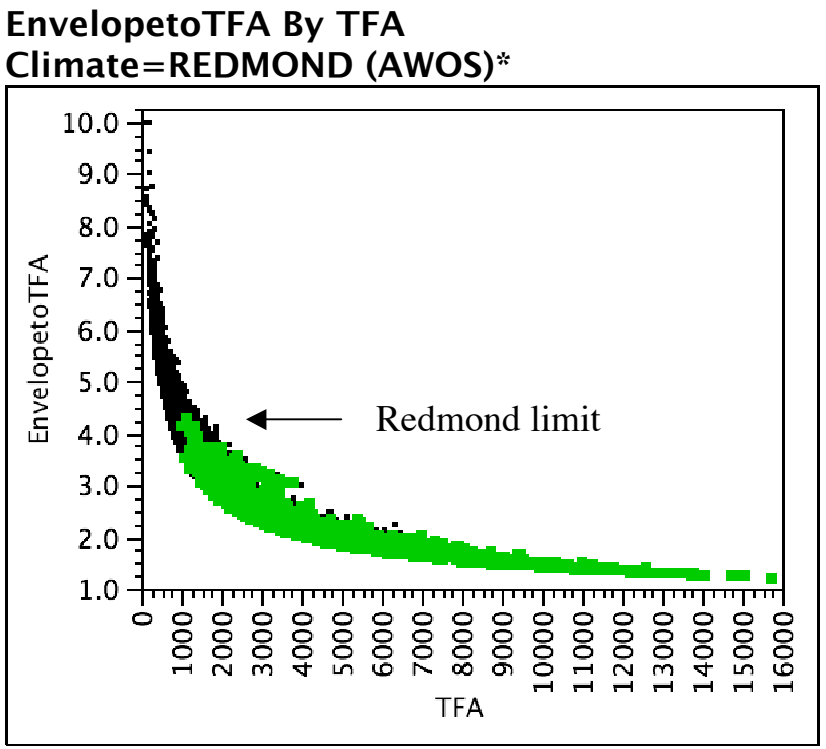




- It's the single most controlling factor of Annual Heat Demand and there's a fundamental reason for that. Heat/TFA ~ Env/TFA.
- Probability of Passive House decreases with rising Envelope/TFA.
- Limit of about 5.2 in Portland, 4.3 in Bend.

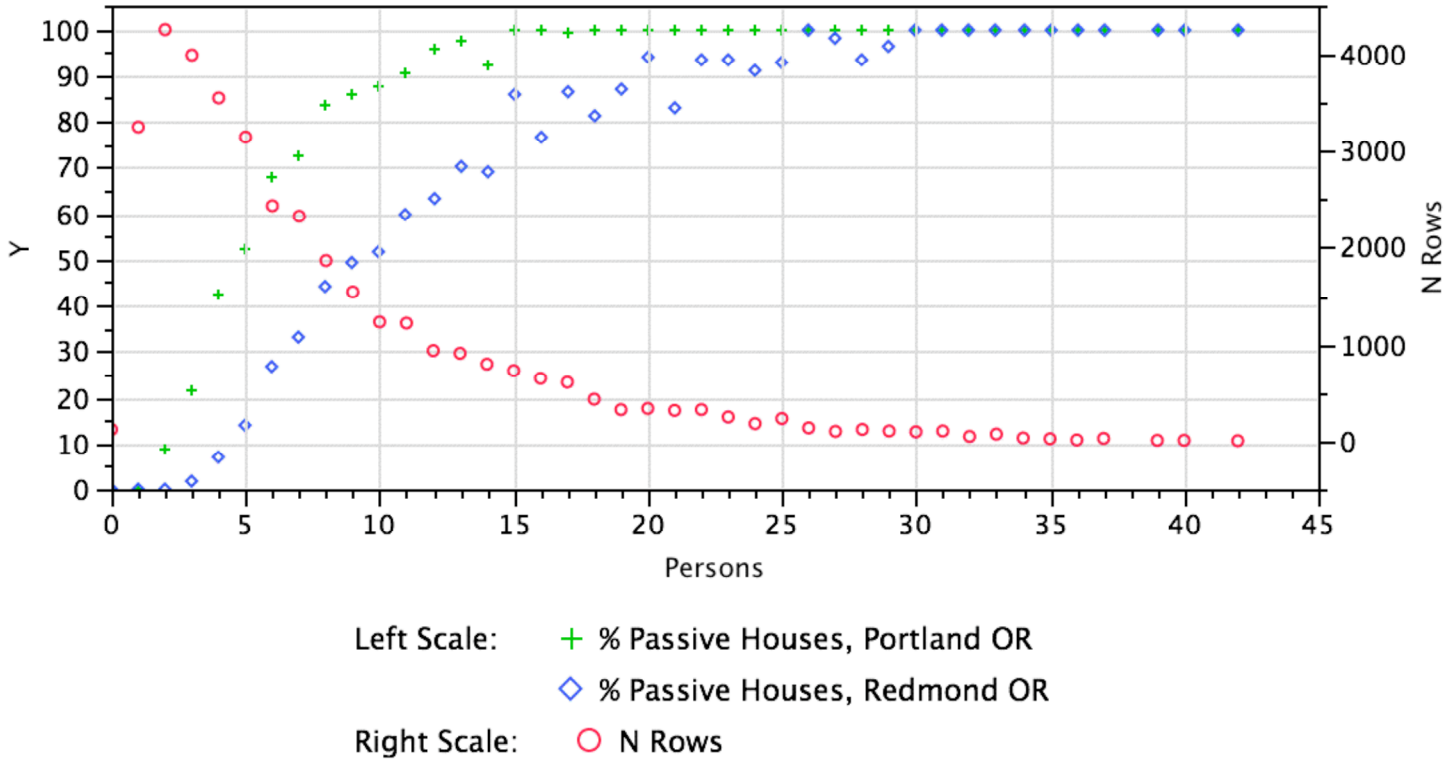
Result statistics - size of house





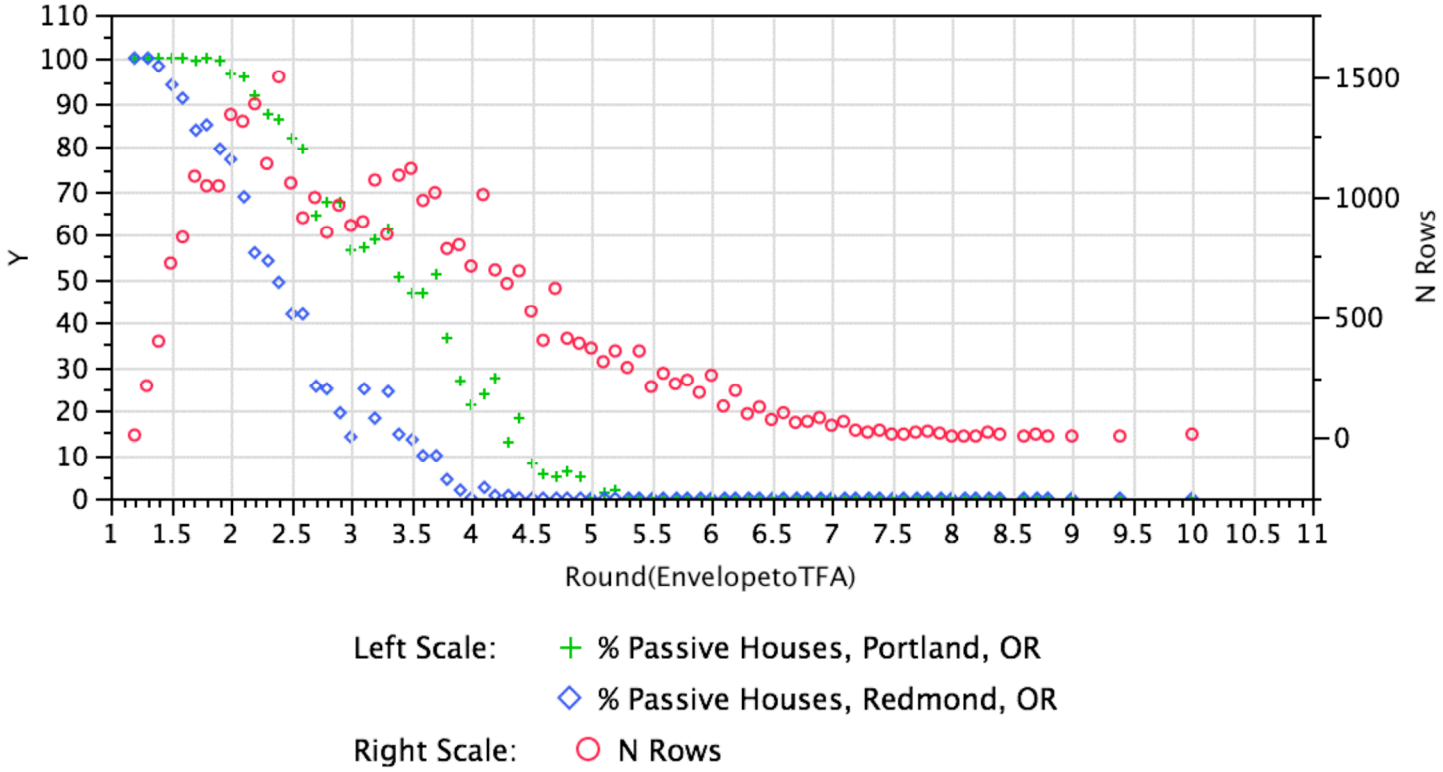
- Envelope/TFA is in turn, rather controlled by the TFA. Small is bad.

Result statistics - size of house



- Despite heavy drilling for desirable 2-3 person Passive Houses, low percentage shot.

Result statistics - envelope to TFA ratio

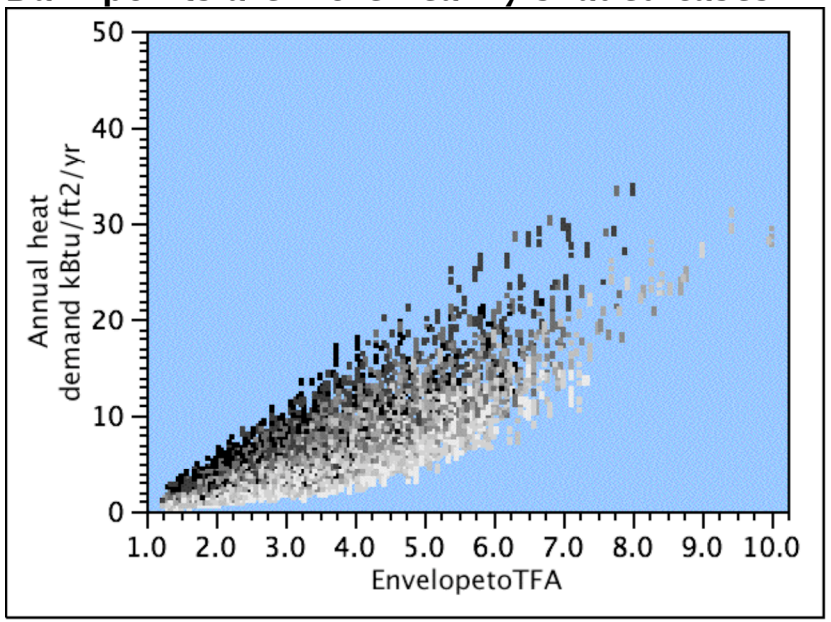


- Estimate Envelope/TFA -> find probability of Passive House.

Result statistics - Shading & Envelope/TFA

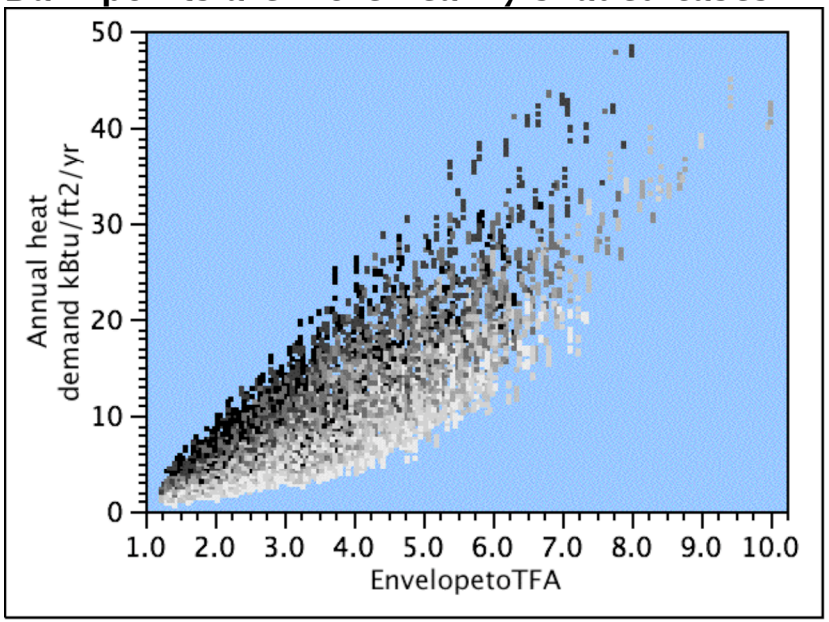
Annual heat demand kBtu/ft2/yr
By EnvelopetoTFA Climate=Portland, OR*

Dark points are more heavily shaded cases.



Annual heat demand kBtu/ft2/yr
By EnvelopetoTFA Climate=REDMOND (AWOS)*

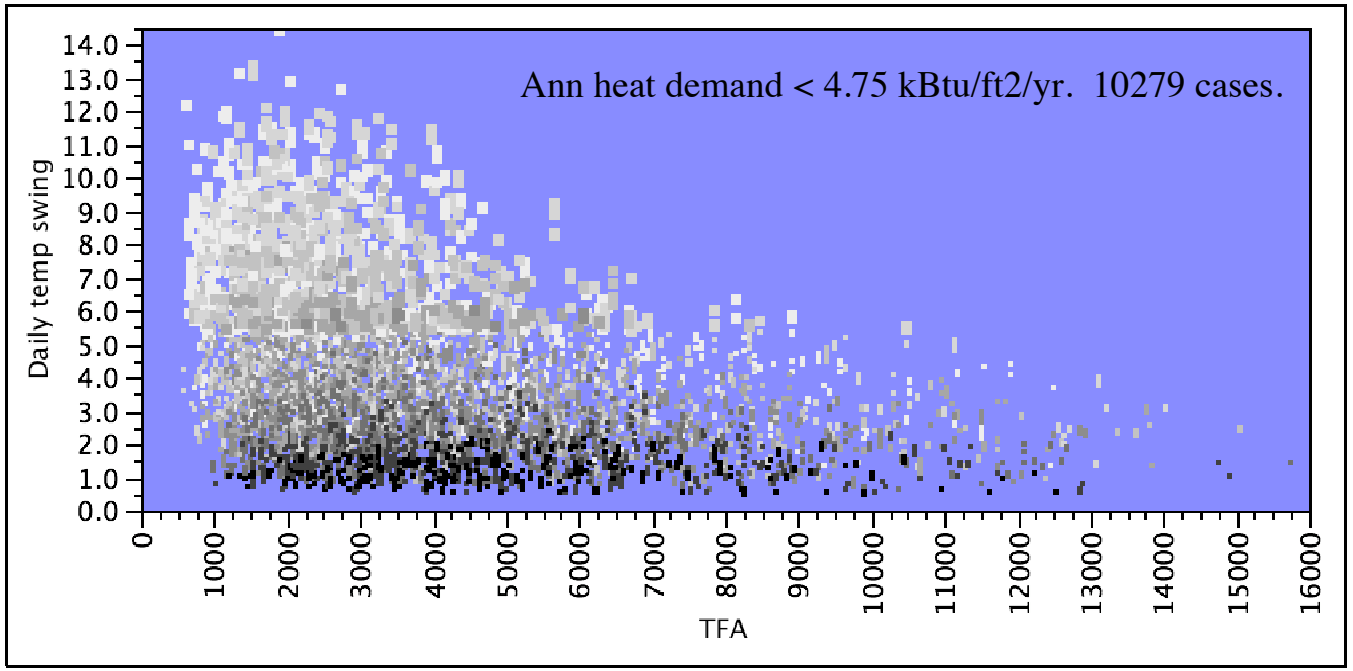
Dark points are more heavily shaded cases.



- To tolerate high envelope/TFA, need sunny site. (An interaction.)
- Shading is the second most defining factor for Annual Heat Demand.

Result statistics - Daily Temperature Swing

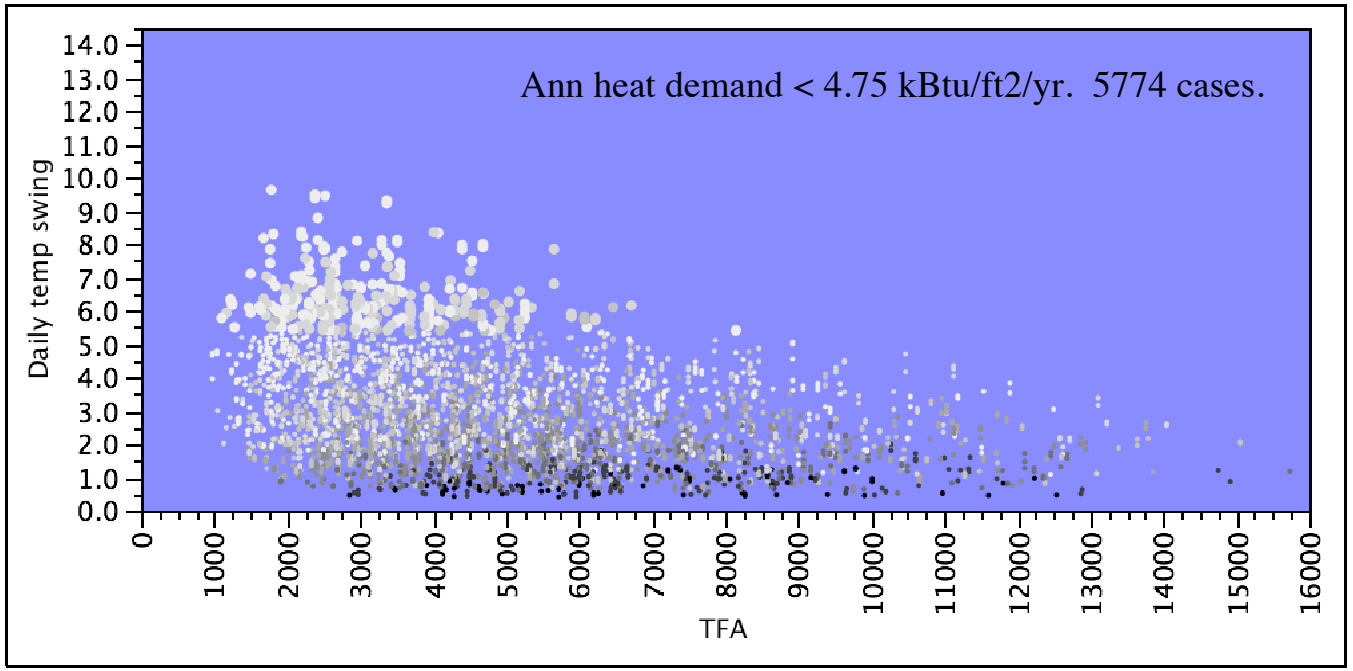
Daily temp swing By TFA, Climate=Portland, OR*



- Many houses pass Annual Heat Demand criterion by finding sunny sites and overglazing, leading to high daily temperature swing. Limit is 3 C (5.4 F). Spec external blinds.

Result statistics - Daily Temperature Swing

Daily temp swing By TFA, Climate=REDMOND (AWOS)*



- Not quite as bad in Redmond.

Sensitivity analysis

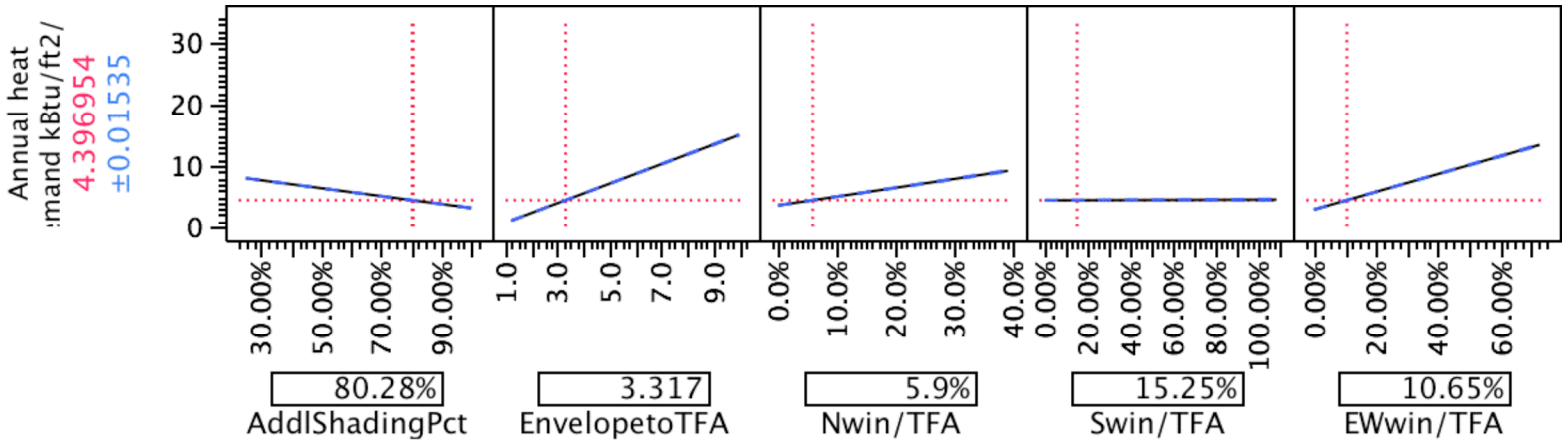
Annual heat demand kBtu/ft2/yr Climate=Portland, OR*

Every 1% of North Window/TFA costs 0.16 kBtu/ft2/yr, depending on shading.

Term	Estimate	Std Error
Intercept	0.5458374	0.023836
AddlShadingPct	-6.475637	0.027956
EnvelopetoTFA	1.7211611	0.005994
Nwin/TFA	15.927565	0.135103
Swin/TFA	2.9565942	0.052501
EWwin/TFA	18.314765	0.071523
(AddlShadingPct-0.625)*(EnvelopetoTFA-3.31695)	-0.720382	0.028725
(AddlShadingPct-0.625)*(Nwin/TFA-0.059)	-8.834494	0.657209
(AddlShadingPct-0.625)*(Swin/TFA-0.15254)	-16.07105	0.256506
(AddlShadingPct-0.625)*(EWwin/TFA-0.10647)	-21.44857	0.346493

Like fitting a line through points and looking at the slope.

Scaled window areas as % of TFA instead of wall, more relevant to energy/TFA, better fit.

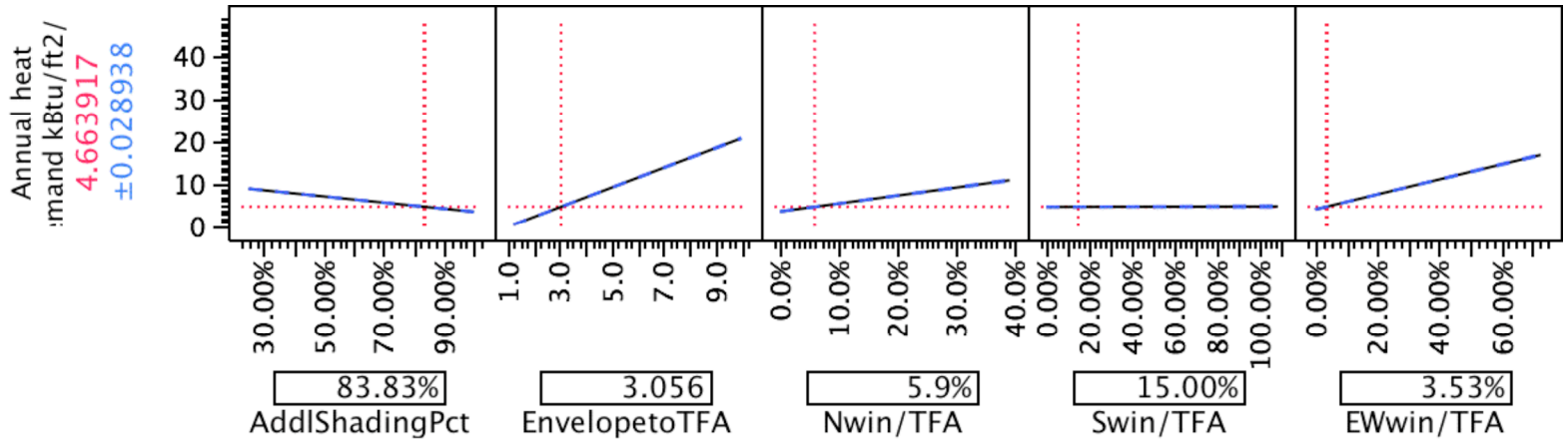


- Interaction: If shading factor is lower than about 0.8, South windows hurt instead of help.

Sensitivity analysis

Annual heat demand kBtu/ft2/yr Climate=REDMOND (AWOS)*

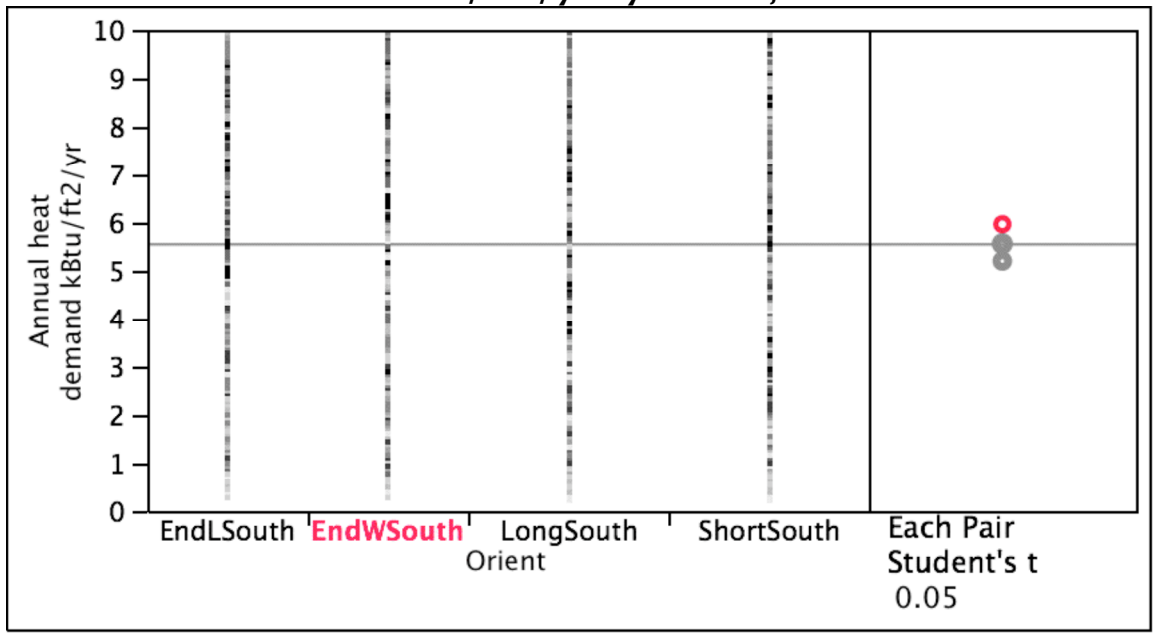
Term		Estimate	Std Error
Intercept		1.7213432	0.03294
AddlShadingPct		-9.730224	0.038633
EnvelopetoTFA		2.5201423	0.008284
Nwin/TFA		21.436498	0.1867
Swin/TFA		5.0060042	0.072552
EWwin/TFA		24.157026	0.098839
(AddlShadingPct-0.625)*(EnvelopetoTFA-3.31695)		-0.932782	0.039696
(AddlShadingPct-0.625)*(Nwin/TFA-0.059)		-12.49363	0.908207
(AddlShadingPct-0.625)*(Swin/TFA-0.15254)		-23.02537	0.354469
(AddlShadingPct-0.625)*(EWwin/TFA-0.10647)		-30.63859	0.478824



- If shading factor is lower than about 0.85, South windows hurt instead of help.

What about orientation

Annual heat demand kBtu/ft2/yr By Orient, Climate=Portland

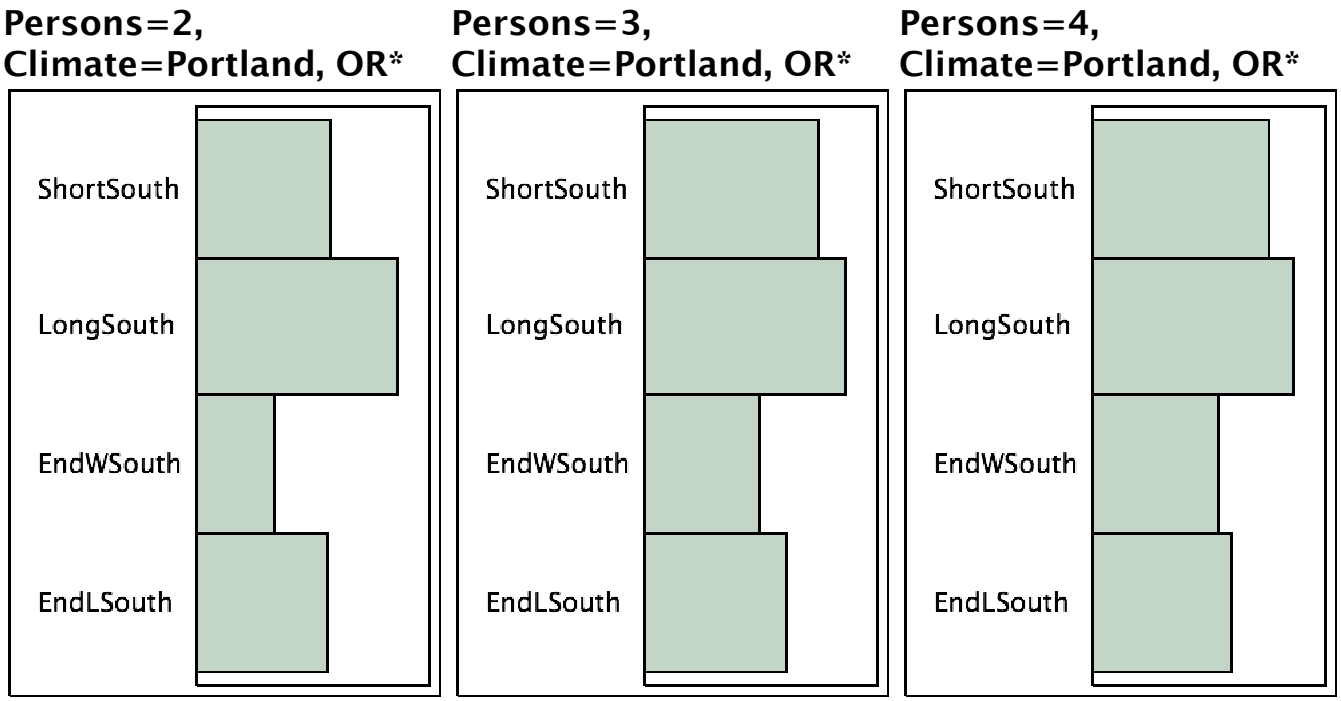


Level				Mean
EndWSouth	A			5.9663324
EndLSouth		B		5.5609647
ShortSouth		B		5.5508706
LongSouth			C	5.2016744

Levels not connected by same letter are significantly different.

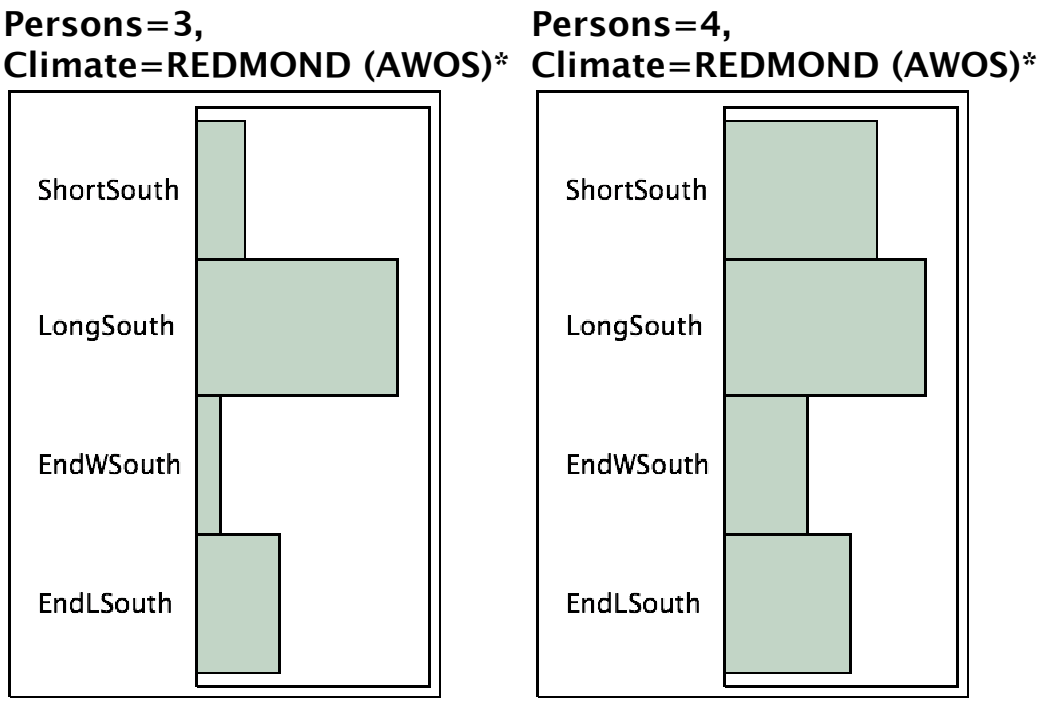
- On average the worst orientation (EndW South), caused 0.76 kBtu/ft2/yr more annual heat demand than the best (Long South). 0.95 in Redmond.
- However, when orientation was added to the sensitivity analysis, it only attributed 0.3-0.4 kBtu/ft2/yr difference to orientation.
- In this study the windows resize to the walls when the building is turned.

What about orientation



- Distribution of Passive Houses by orientation. More critical in small houses.

What about orientation



- Distribution of Passive Houses by orientation. Most critical in small houses in harsh climate.

Case studies

- Focus where design is most constrained. For 2, 3, and 4 person Passive Houses pick a couple of cases in each climate:
  A. Near the low end of the range for annual heat demand - good setups, candidates for cost reduction.
  B. Near the high end of the range (inflexible client situations.)

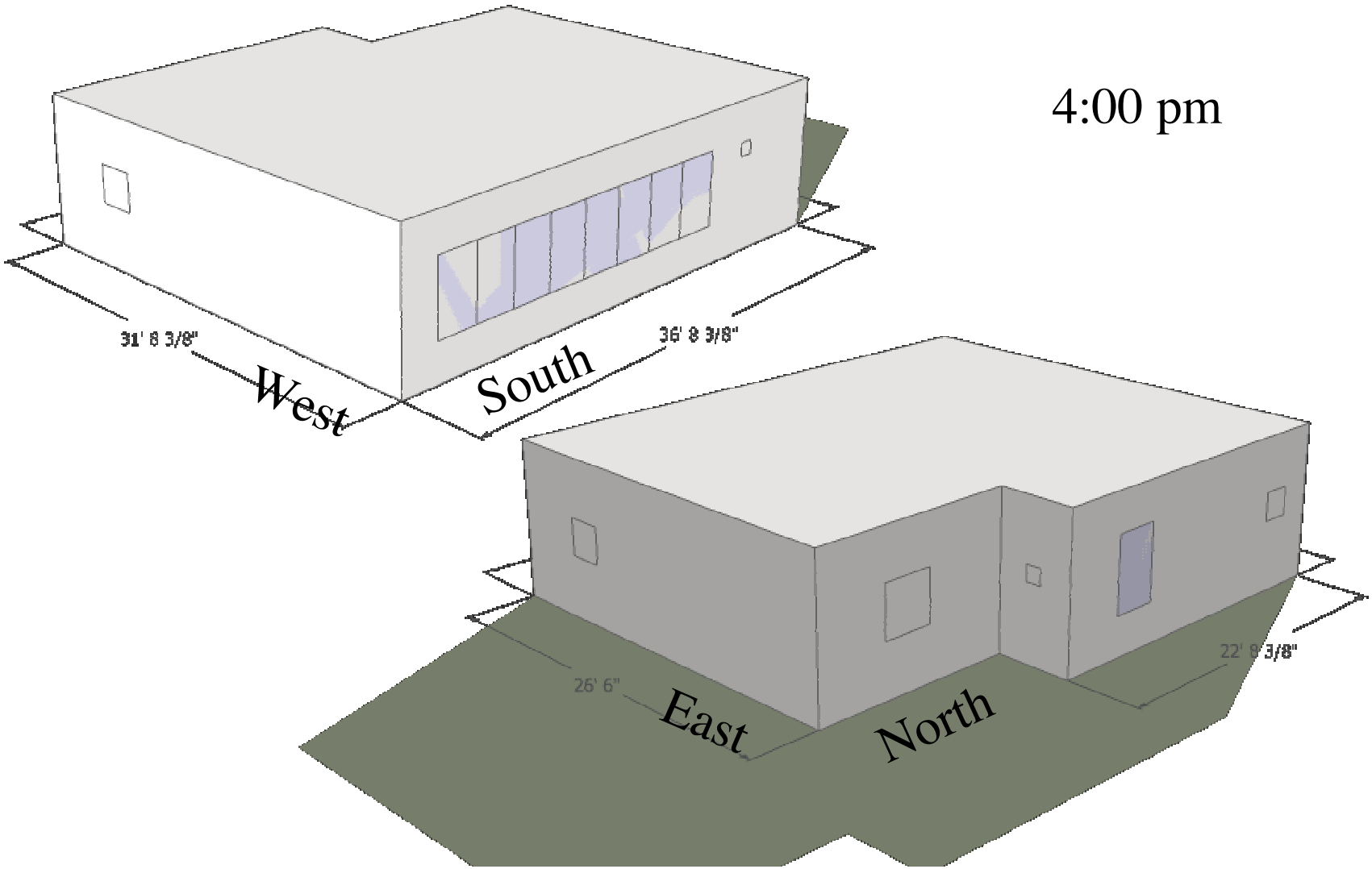
Portland, 2-person houses

Case	278	157	1201	2146
Climate	Portland, OR*	Portland, OR*	Portland, OR*	Portland, OR*
Persons	2	2	2	2
TFA	880	839	808	826
Stories	**1**	**1**	**1**	**1**
Shape	L	L	L	L
Orient	LongSouth	LongSouth	ShortSouth	EndLSouth
Length_ft	51.5	36.7	64.8	39.9
Width_ft	25.1	31.7	17.1	29.0
EndL	41.2	22.7	41.0	35.3
EndW	12.1	26.5	16.6	11.3
Ground_ft2	1157	1089	1097	1077
Aspect	2.1	1.2	3.8	1.4
Rectangularity (Ground/LxW)	90%	94%	99%	93%
EnvelopetoTFA	4.4	4.3	4.8	4.3
NwinPct	2.2%	8.0%	8.7%	12.0%
EWwinPct	13.5%	2.1%	10.7%	2.5%
SwinPct	52.2%	32.2%	49.8%	39.8%
AddlShadingPct	95%	99%	87%	66%
Glazing/TFA	24%	12%	17%	16%
Annual heat demand kBtu/ft2/yr	2.74	2.91	4.58	4.74
Spc Heat Load	3.8	2.9	3.7	3.5
Daily temp swing	6.2	3.8	5.8	3.1
PE value	27.1	27.2	28.8	29.0

- Can I have:
- An 808 sf Passive House with a 3.8 aspect ratio oriented short side south? Yes!
- An 826 sf Passive House with 40% south windows even though its 34% shady here? Likely!

157

4:00 pm



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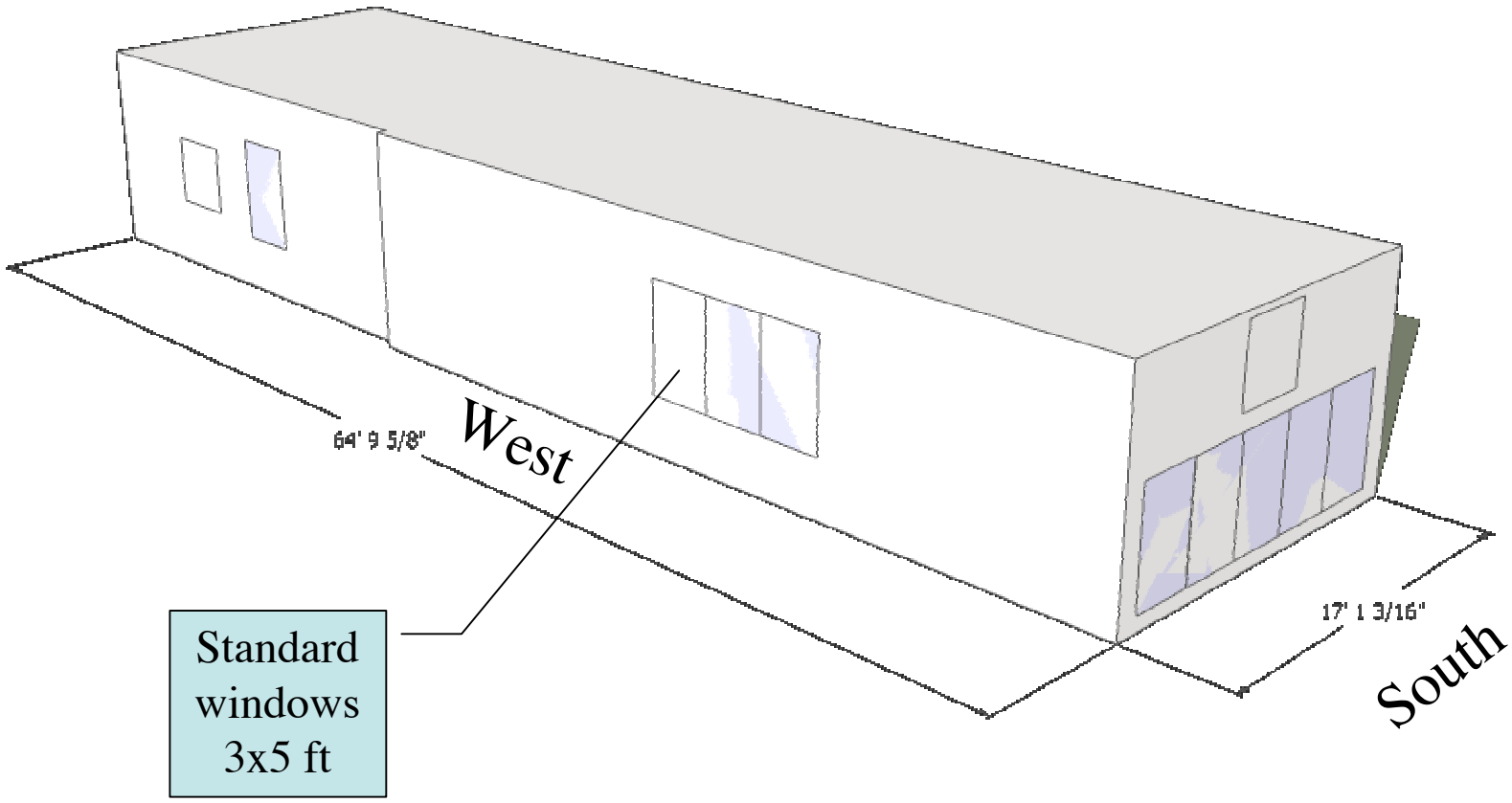
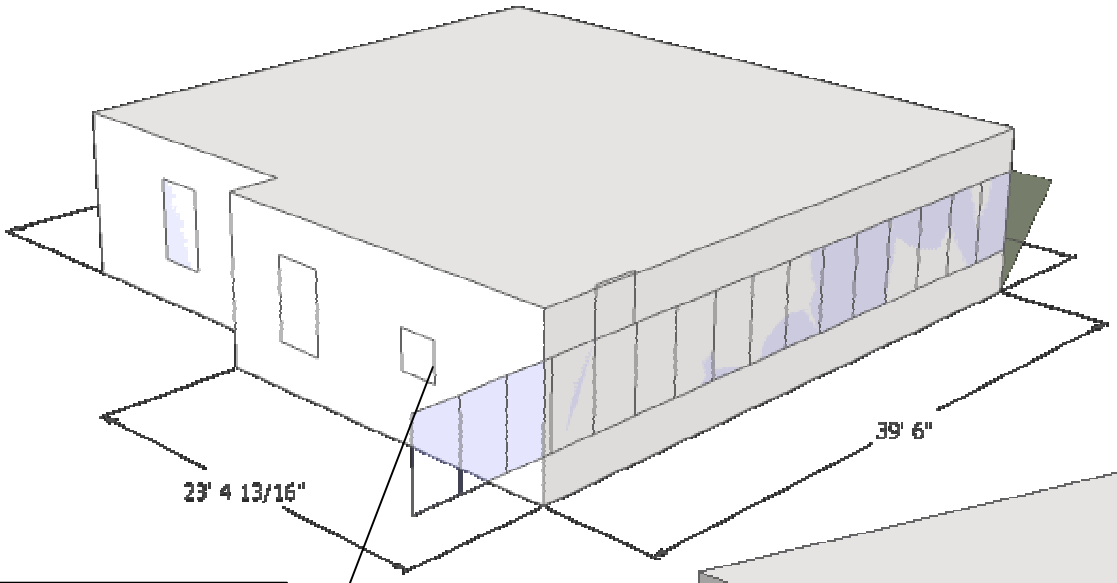


Portland, 3-person houses

Case	1525	965	2226	2895
Climate	Portland, OR*	Portland, OR*	Portland, OR*	Portland, OR*
Persons	3	3	3	3
TFA	1240	1132	1085	1239
Stories	**1**	**1**	**1**	**1**
Shape	L	L	L	L
Orient	ShortSouth	LongSouth	EndLSouth	EndLSouth
Length_ft	40.6	58.3	66.7	49.7
Width_ft	39.5	27.4	21.6	45.4
EndL	23.4	23.2	56.3	24.6
EndW	36.2	23.2	18.5	18.9
Ground_ft2	1546	1450	1408	1591
Aspect	1.0	2.1	3.1	1.1
Rectangularity (Ground/LxW)	96%	91%	98%	71%
EnvelopetoTFA	3.8	4.1	4.3	4.1
NwinPct	18.5%	0.8%	22.0%	11.0%
EWwinPct	8.6%	1.3%	9.8%	0.5%
SwinPct	61.3%	35.5%	9.4%	15.2%
AddlShadingPct	95%	84%	88%	45%
Glazing/TFA	20%	12%	14%	7%
Annual heat demand kBtu/ft2/yr	2.30	2.34	4.62	4.63
Spc Heat Load	3.0	2.7	3.1	2.5
Daily temp swing	5.4	2.8	4.7	1.2
PE value	25.1	24.8	27.0	26.7

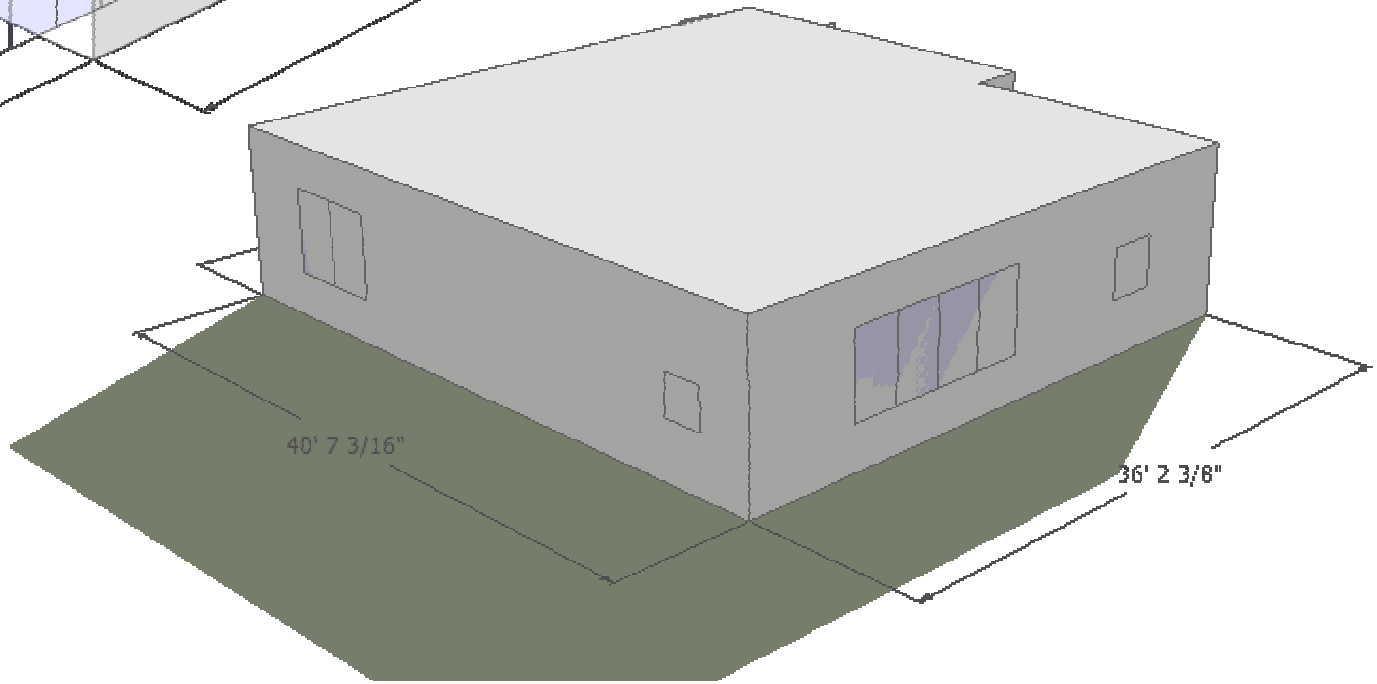
- Can I have:
- An 1085 sf Passive House with a 3.1 aspect ratio and 22% north windows? Yes!
- An 1239 sf L-shaped Passive House in the trees? Yes!

1525

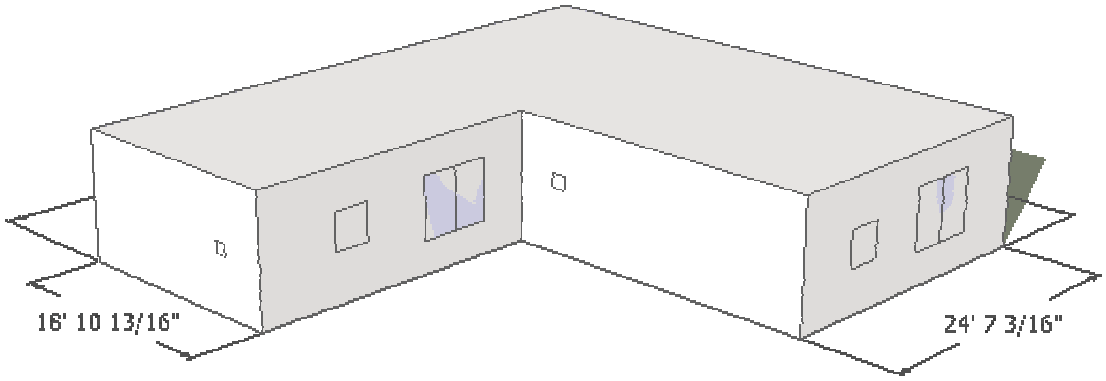


Would need different sized windows to make this fit.

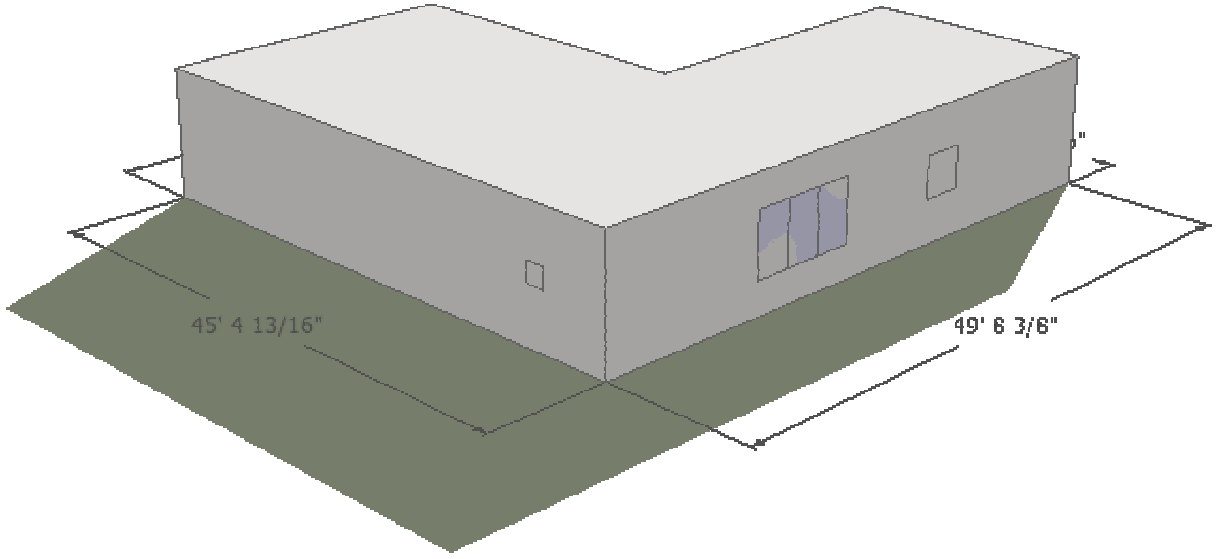
Overperforming, so windows could be cut.



2895



About as L-ish as a Passive House can get.

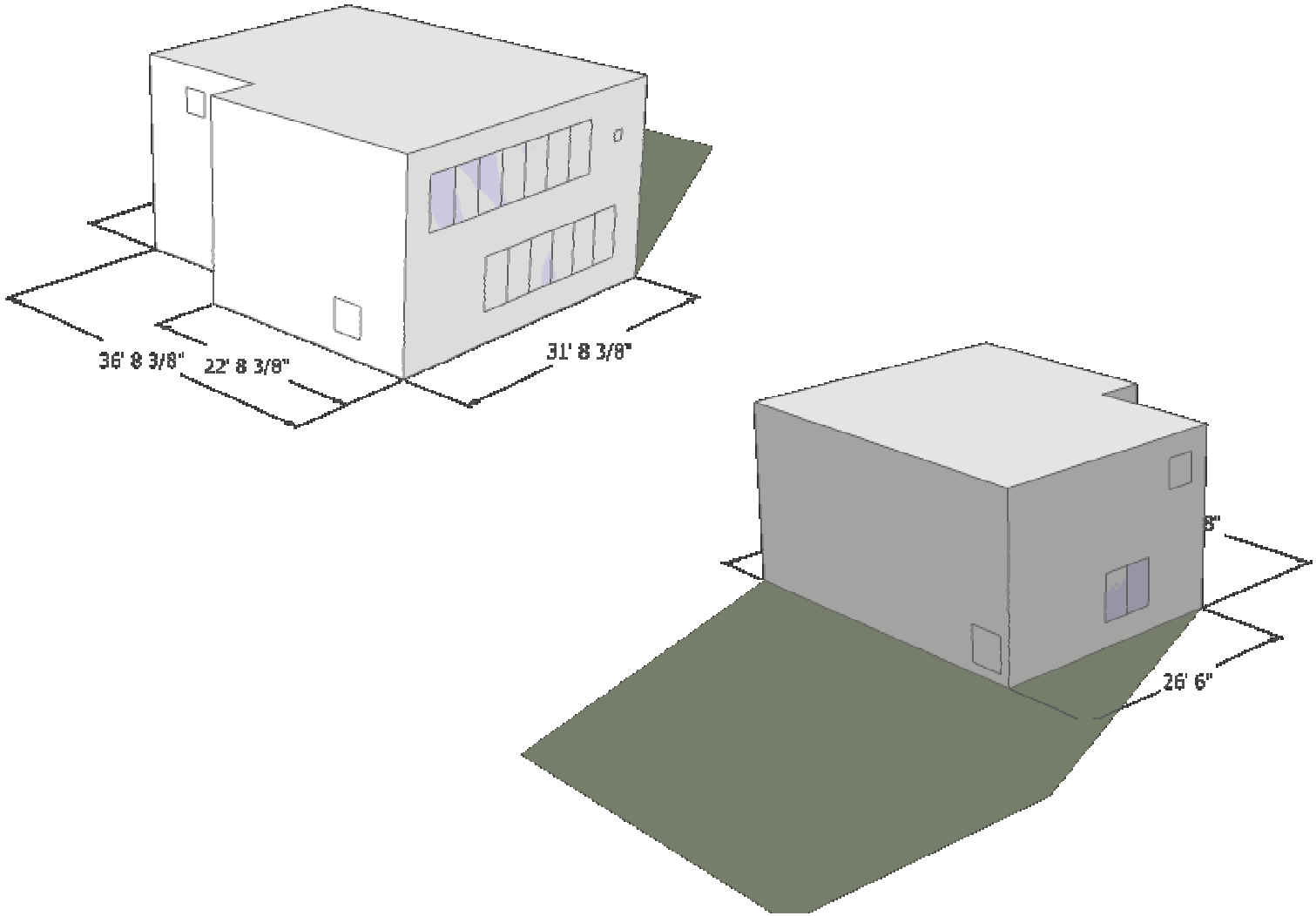


Portland, 4-person houses

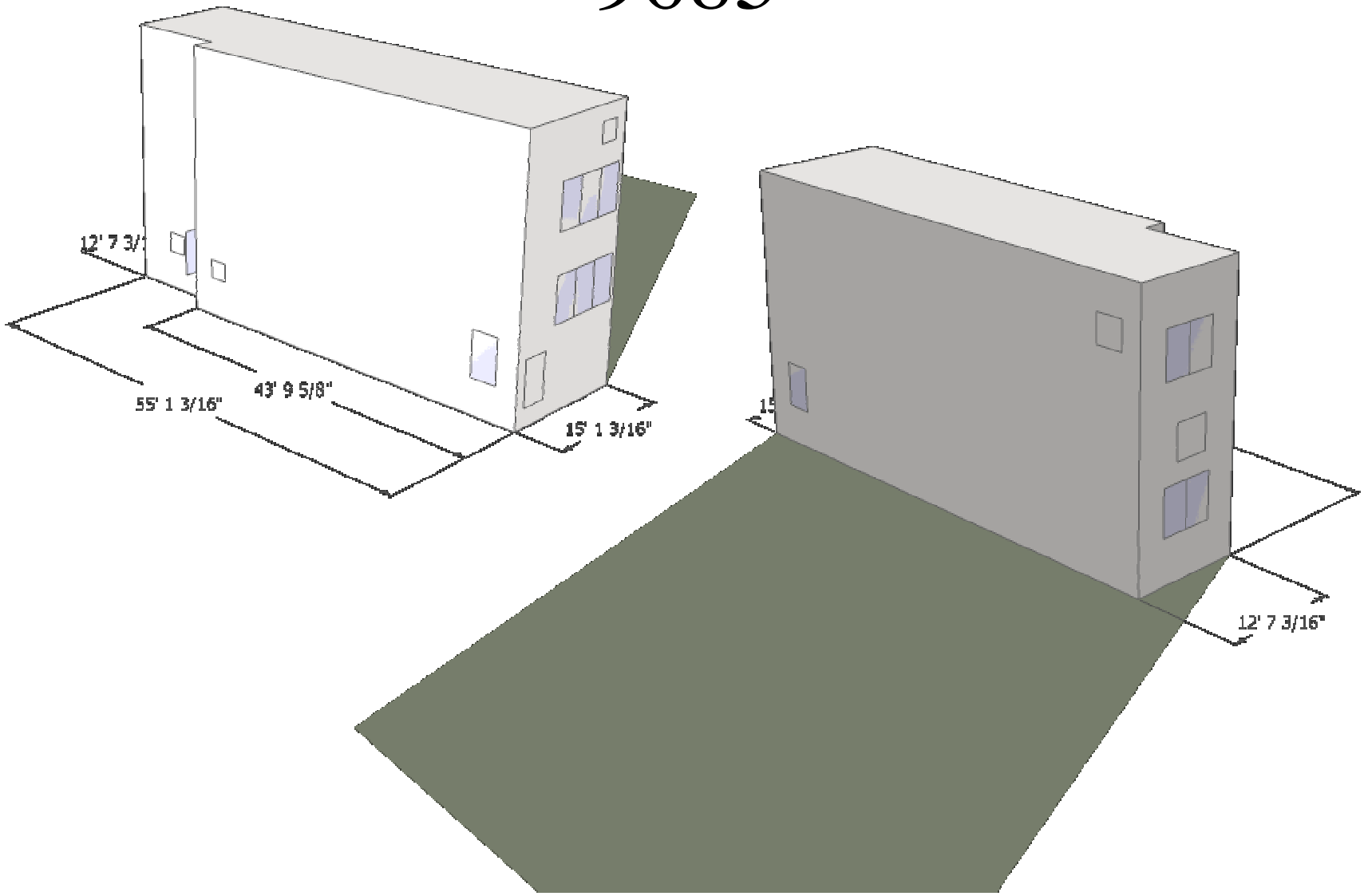
Case	4374	5277	7474	9685
Climate	Portland, OR*	Portland, OR*	Portland, OR*	Portland, OR*
Persons	4	4	4	4
TFA	1672	1589	1413	1562
Stories	**2**	**2**	**2**	**3**
Shape	L	L	L	L
Orient	LongSouth	ShortSouth	EndWSouth	ShortSouth
Length_ft	51.5	36.7	36.6	55.1
Width_ft	25.1	31.7	31.7	15.1
EndL	41.2	22.7	12.6	43.8
EndW	12.1	26.5	24.9	12.6
Ground_ft2	1157	1089	996	805
Aspect	2.1	1.2	1.2	3.6
Rectangularity (Ground/LxW)	90%	94%	86%	97%
EnvelopetoTFA	3.1	3.0	3.3	3.6
NwinPct	2.2%	8.0%	22.6%	20.9%
EWwinPct	13.5%	2.1%	13.2%	1.6%
SwinPct	52.2%	32.2%	2.4%	24.5%
AddlShadingPct	95%	99%	79%	57%
Glazing/TFA	44%	20%	26%	24%
Annual heat demand kBtu/ft2/yr	1.64	1.67	4.38	4.74
Spc Heat Load	3.2	2.3	2.9	2.9
Daily temp swing	5.8	3.2	4.5	2.1
PE value	24.3	24.5	27.2	26.9

- Can I have:
- A 1413 sf L with 23% north windows? Yes!
- A 55x15 foot 3-story with 21% North windows oriented short side south in 43% shade? If you insist.

5277



9685

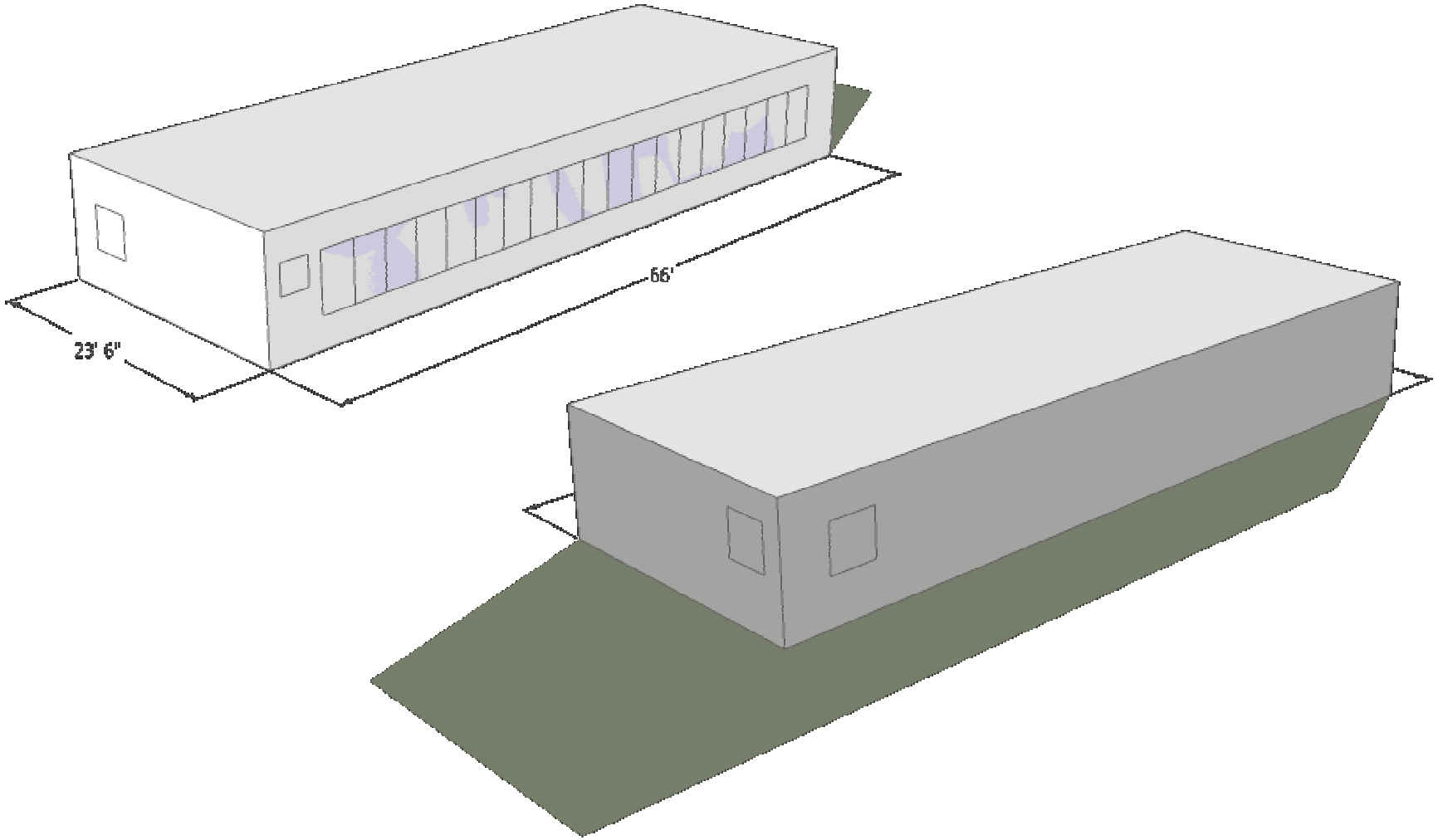


Bend, 3-person houses

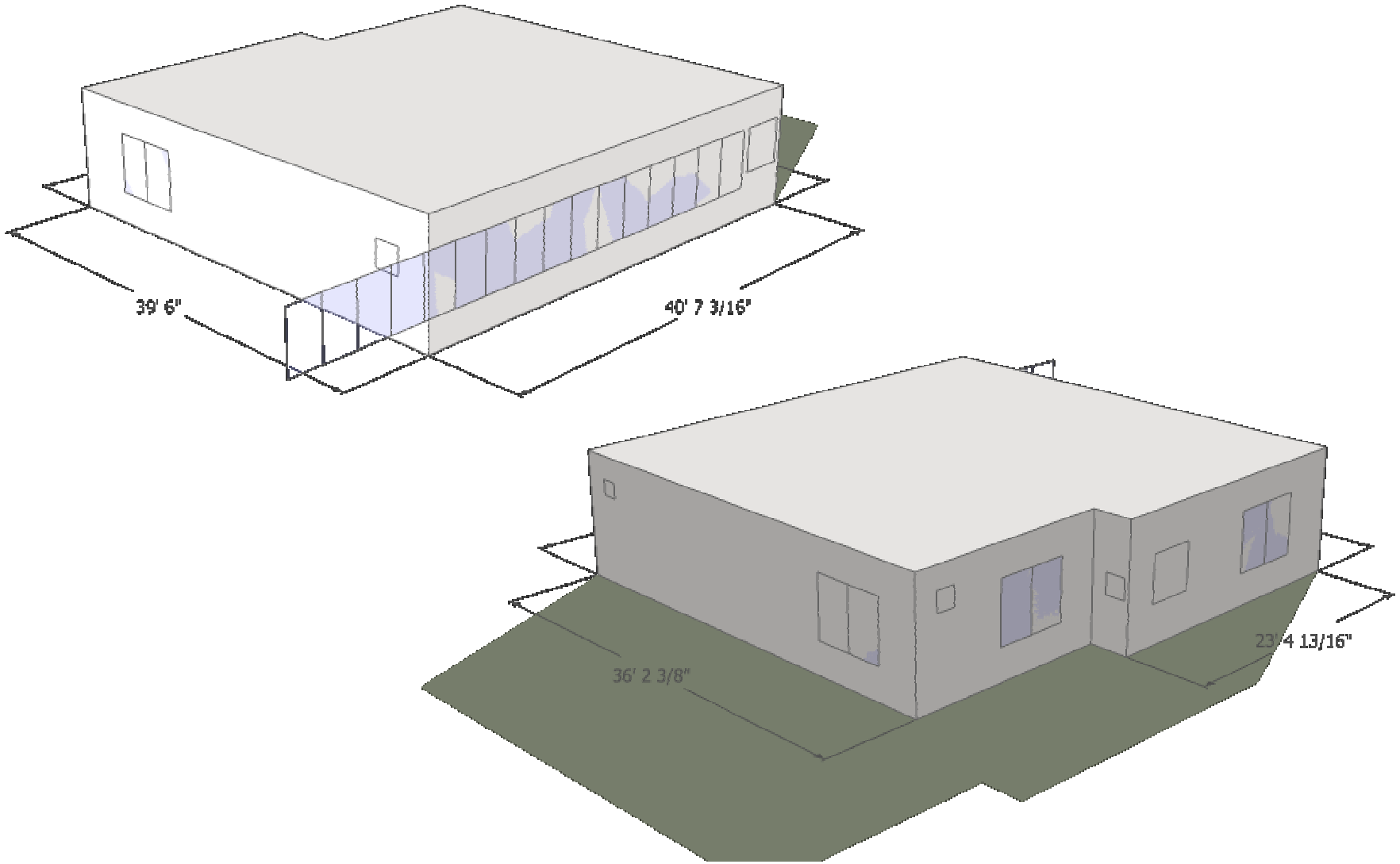
Case	16565	501	2592	2984
Climate	EDMOND (AWOS	EDMOND (AWOS	EDMOND (AWOS	EDMOND (AWOS
Persons	3	3	3	3
TFA	1217	1240	1306	978
Stories	**1**	**1**	**1**	**1**
Shape	R	L	L	L
Orient	LongSouth	LongSouth	EndLSouth	EndLSouth
Length_ft	66.0	40.6	47.3	47.4
Width_ft	23.5	39.5	36.8	27.0
EndL	66.0	23.4	26.1	41.6
EndW	23.5	36.2	31.4	22.3
Ground_ft2	1551	1546	1628	1254
Aspect	2.8	1.0	1.3	1.8
Rectangularity (Ground/LxW)	100%	96%	93%	98%
EnvelopetoTFA	4.1	3.8	3.8	4.1
NwinPct	2.2%	18.5%	3.2%	13.3%
EWwinPct	5.5%	8.6%	22.3%	6.9%
SwinPct	43.1%	61.3%	18.3%	57.6%
AddlShadingPct	86%	95%	99%	98%
Glazing/TFA	17%	20%	13%	23%
Annual heat demand kBtu/ft2/yr	3.89	3.98	4.43	4.52
Spc Heat Load	3.6	3.7	3.5	4.2
Daily temp swing	2.8	4.2	3.8	4.7
PE value	26.1	26.8	26.6	28.3

- Can I have:
- An 1306 sf house with 22% east and west windows and only 18% south windows? Yes!
- A 978 sf Passive House? Yes!

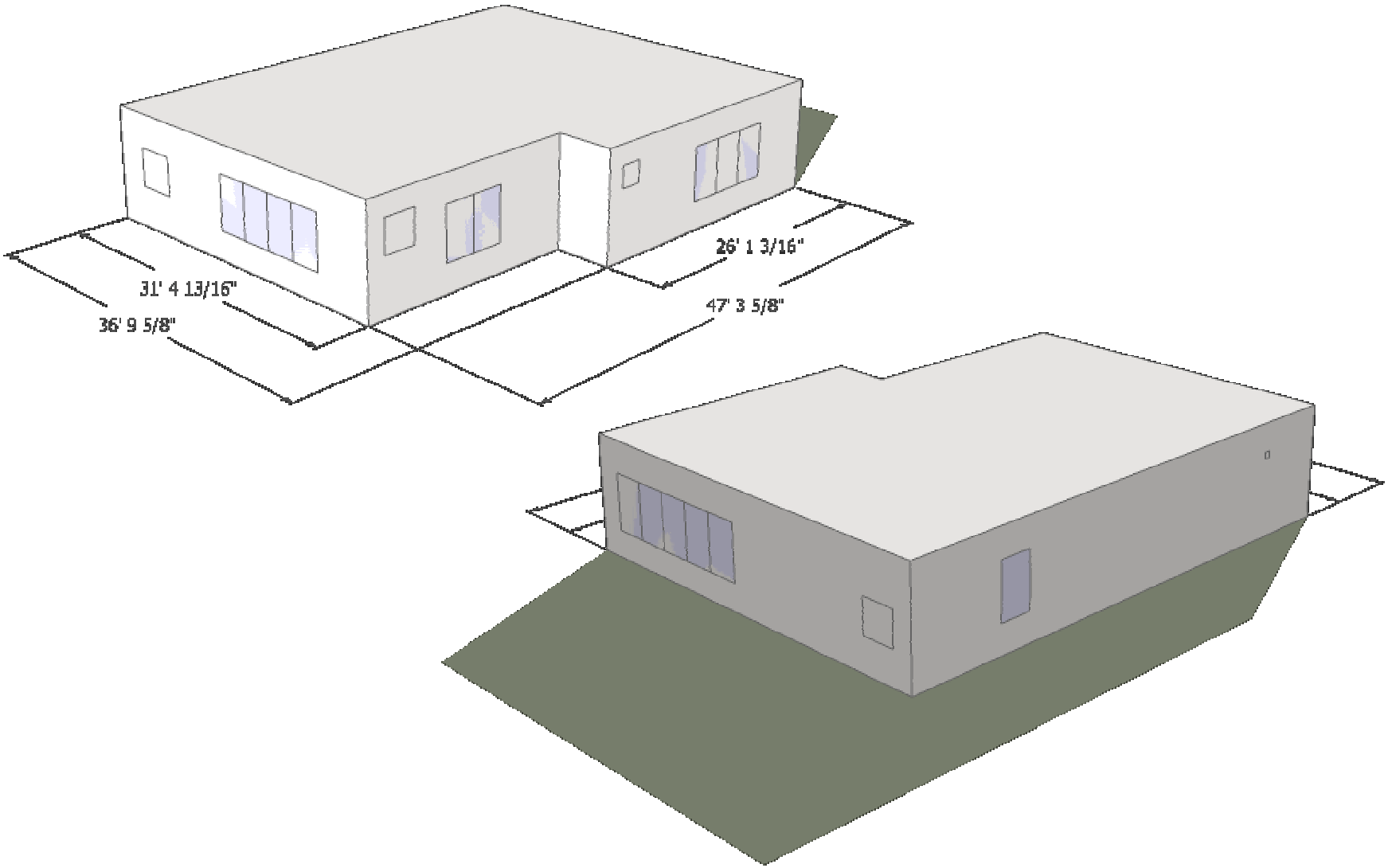
16565



501



2592

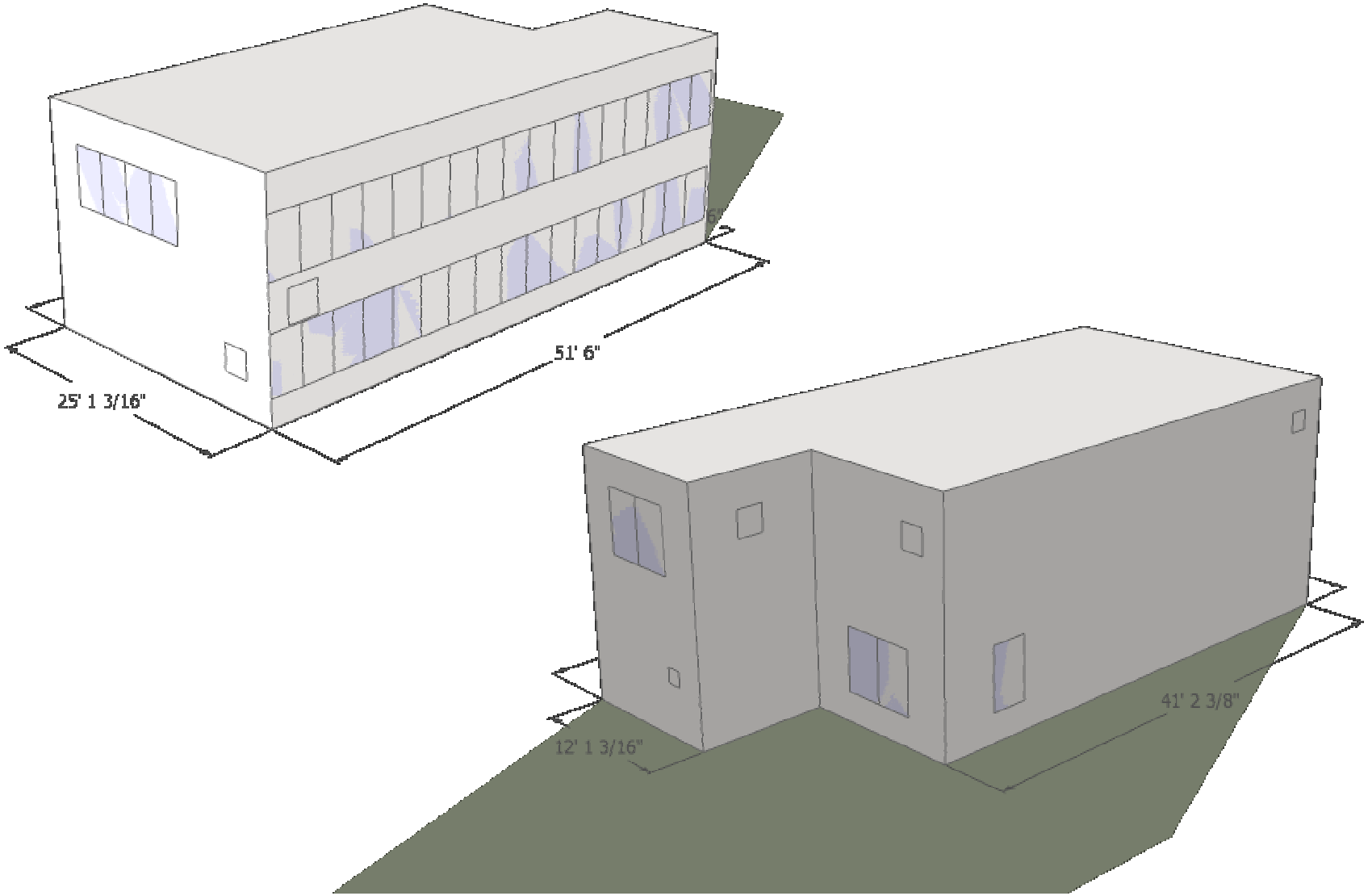


Bend, 4-person houses

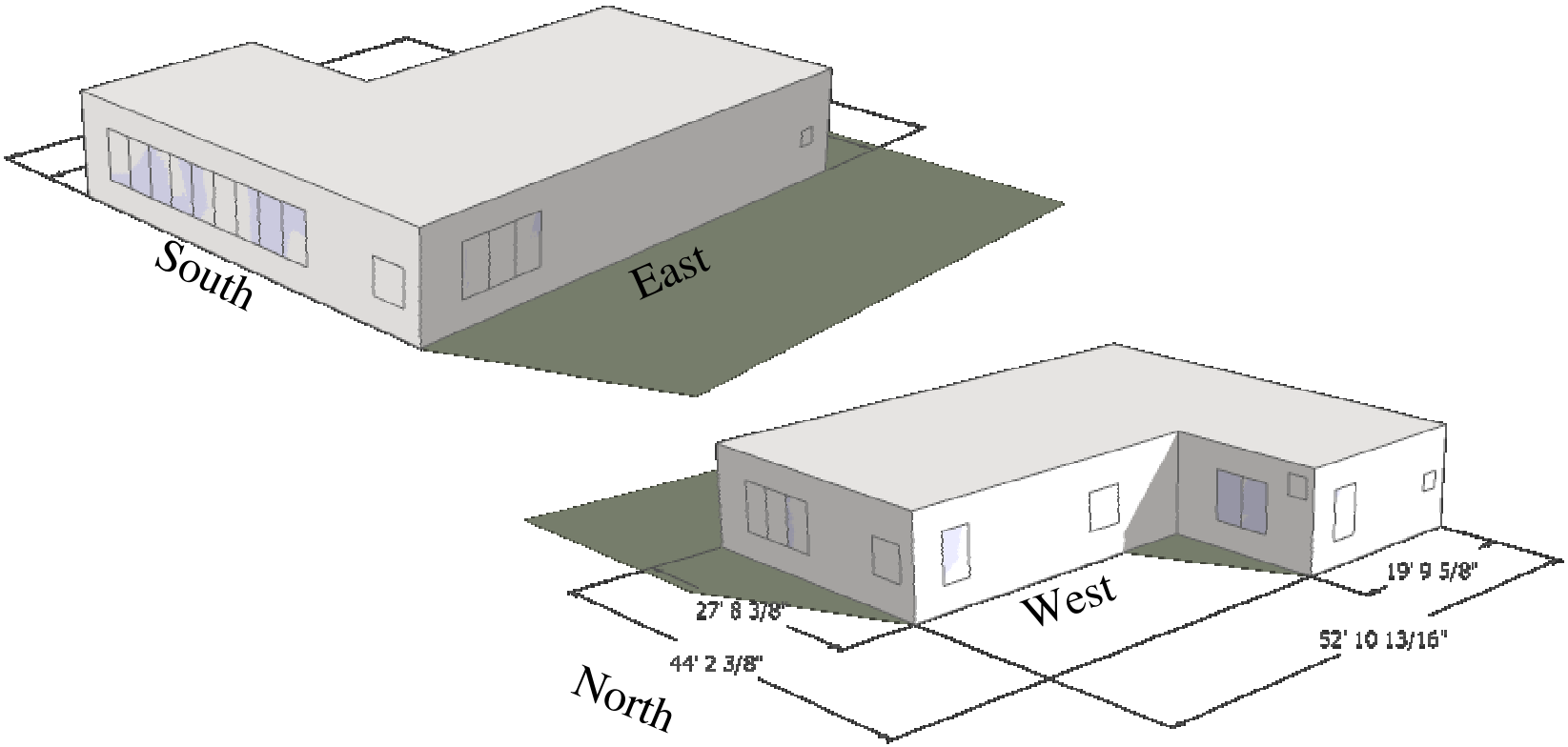
Case	4374	5277	1885	7436
Climate	EDMOND (AWOS	EDMOND (AWOS	EDMOND (AWOS	EDMOND (AWOS
Persons	4	4	4	4
TFA	1672	1589	1425	1664
Stories	**2**	**2**	**1**	**2**
Shape	L	L	L	L
Orient	LongSouth	ShortSouth	ShortSouth	EndWSouth
Length_ft	51.5	36.7	52.9	45.9
Width_ft	25.1	31.7	44.2	28.8
EndL	41.2	22.7	19.8	19.9
EndW	12.1	26.5	27.7	22.1
Ground_ft2	1157	1089	1793	1147
Aspect	2.1	1.2	1.2	1.6
Rectangularity (Ground/LxW)	90%	94%	77%	87%
EnvelopetoTFA	3.1	3.0	3.9	3.1
NwinPct	2.2%	8.0%	20.4%	14.1%
EWwinPct	13.5%	2.1%	8.8%	1.4%
SwinPct	52.2%	32.2%	32.5%	8.0%
AddlShadingPct	95%	99%	99%	96%
Glazing/TFA	44%	20%	14%	10%
Annual heat demand kBtu/ft2/yr	3.03	3.10	4.69	4.72
Spc Heat Load	3.6	3.0	3.6	3.0
Daily temp swing	4.3	2.5	3.8	2.0
PE value	25.6	25.7	26.9	26.6

- Can I have:
- A 1425 sf 1-story L with 20% north windows? Yes!
- A 1664 sf two-story oriented short side south with 14 % north windows and only 8% south? Just barely!

4374



1885



In Conclusion

- Potential further usefulness of this automated PHPP
  - Flash estimates on performance of proposed schematic designs.
  - Screening retrofit candidates.
  - Finding good starting points for P/H design.
    - More fun to start with something that's working and play tradeoffs, than to start with something bad and claw it in.
  - Study could be rerun for different climates or baseline assumptions.
  - Could be extended to T-shapes, U's.

In Conclusion

- I would look first to compact shape.
  - Envelope Area / Treated Floor Area Upper Limit of about 5.2 in Portland, 4.3 in Bend.
  - Annual Heat Demand Sensitivity 1.7 kBtu/ft2/yr per point of Envelope/TFA in Portland, 2.5 in Redmond.
- Small size drives Envelope/TFA up.
  - Small is modest, but small-detached is immodest and there is a price to be paid for getting to the righteous side again.
- Shady sites are an opportunity to save $ on south windows.
  - In this study, if shading factor was lower than about 0.8, South windows hurt instead of help.
- Orientation worth 0.3-1.2 kBtu/ft2/yr on Annual heat demand.
- It's twice as hard east of the mountains.

In Conclusion

- Even in the tough case of small detached houses, there is quite some design space available…
  - …at R-66 prices.
- I underwent a shift in perspective.
  - Of course we're building this design, what is the premium for this crazy Passive House?
  - Of course we're building a Passive House, what is the premium for this crazy design?

In Conclusion

- The Art of Passive House
  - It is a constraint. An art is defined by its constraints.
    - The artist with a stick of charcoal can create beauty, without 3-d, motion, color, sound, or high definition.
      - Compare to James Cameron who spent the price of a house on every frame of *Avatar*.
  - A style is defined by what it leaves out.
    - Modernism packed away the ornamentation. P/H leaves out wasting energy.
    - Haul out the gingerbread.
    - Things to do with East & West walls.
      - Ivy, murals, hedges, porches, decks?
- I expect Passive Houses will stand the test of time.