Designing For Comfort:

New Approaches for Detailed Window Modeling

BuildEnergy NYC, October 4, 2018

NESEA
NORTHEAST SUSTAINABLE ENERGY ASSOCIATION

bldgtyp

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(architect, passive house consultant, teacher)

Outline (45 mins)

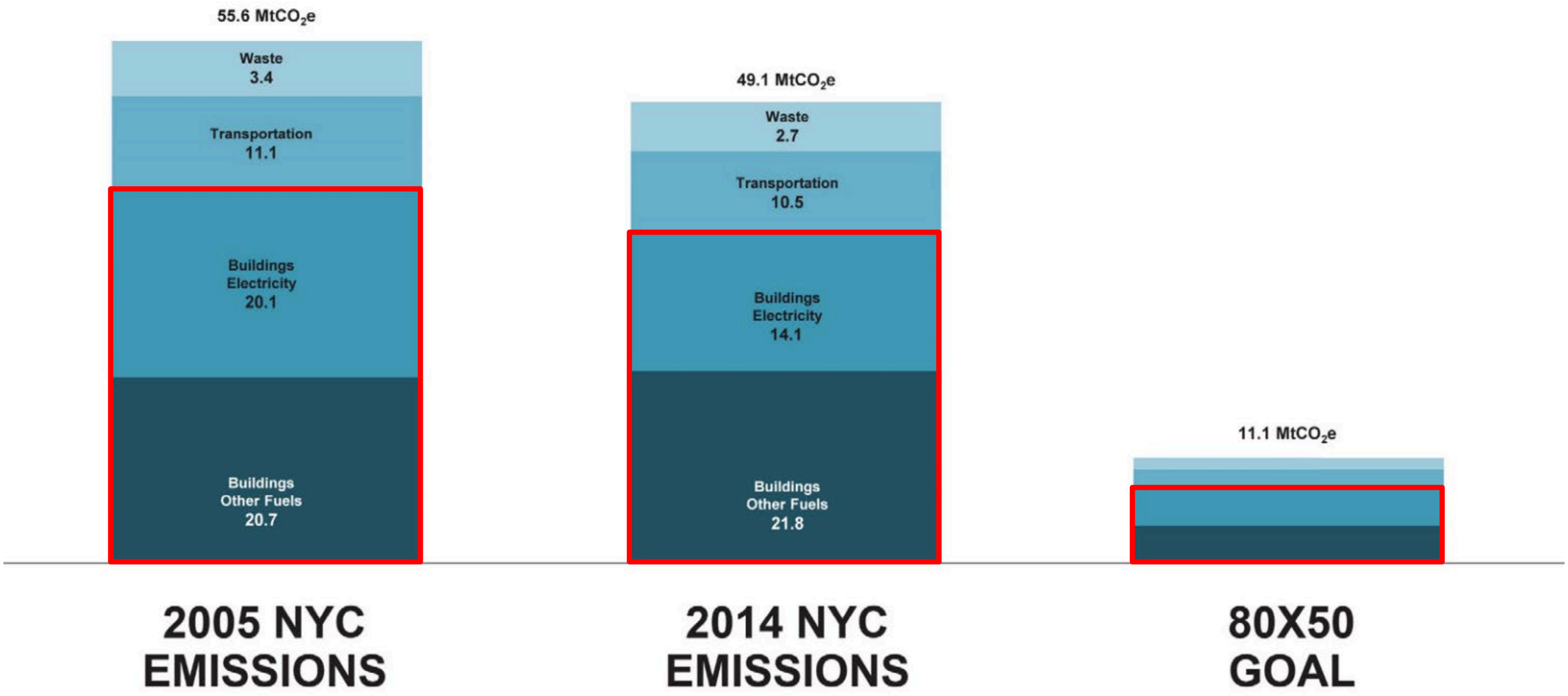
- A Brief Introduction to Thermal Comfort
- Passive House Institute certification and thermal comfort limits
- Applying detailed modeling techniques to windows for Thermal Comfort analysis
- What's next?

A (Brief) Introduction to Thermal Comfort

Perceptions of Thermal Comfort depend on:

- **Air temperature**
- **Humidity level**
- Velocity of air flows
- Surface temperatures
- Clothing level
- Activity Level
- Age, Gender, Body type
- Culture / Expectations
- Control over space

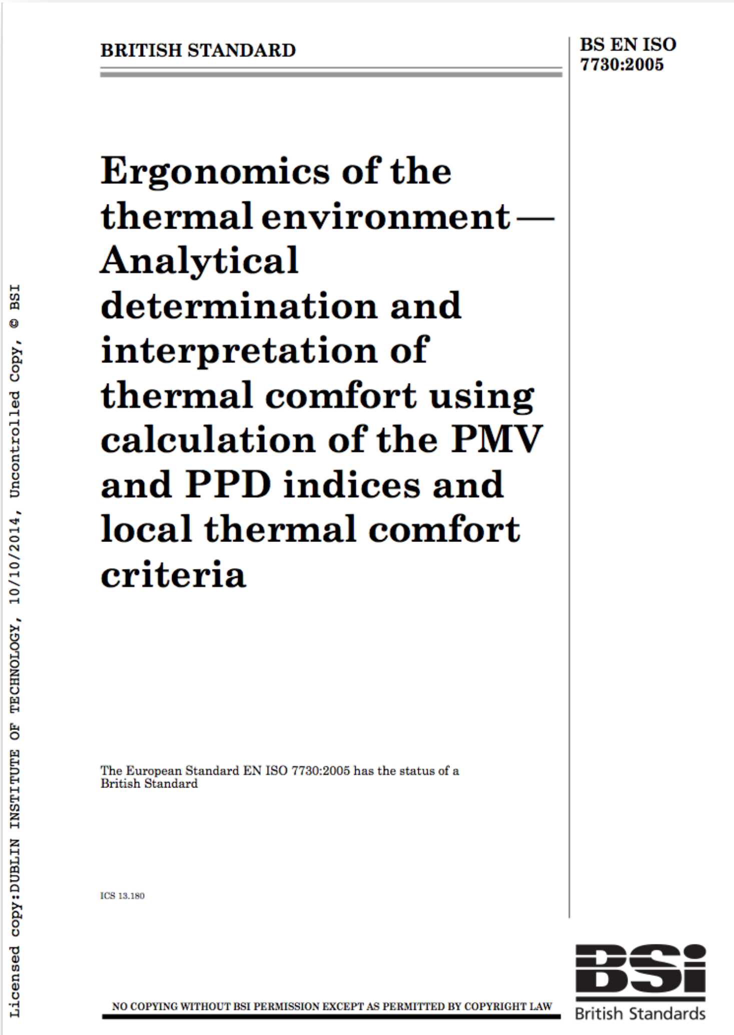

Isn't it just up to the mechanical systems?



How do we improve comfort AND reduce energy consumption?

From: "Advancing Passive House Policy NAPHN 2016 policy session 1 presentations" John Lee. NYC Mayor's Office of Sustainability

Thermal Comfort Standards



BRITISH STANDARD

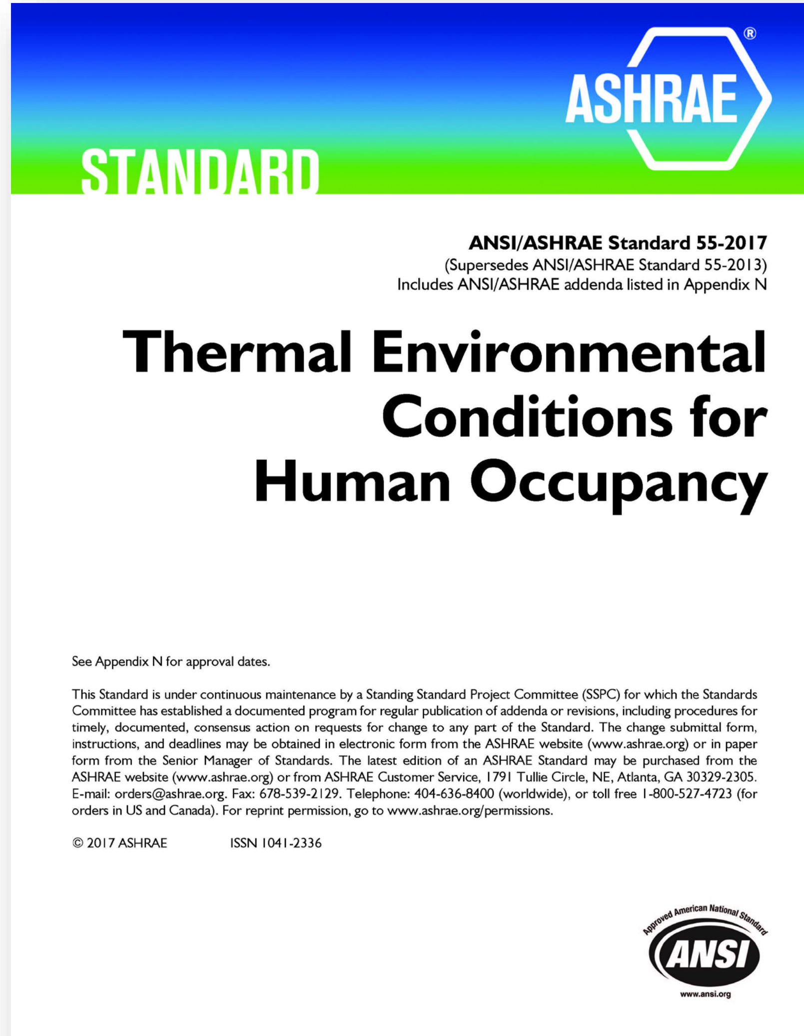
BS EN ISO 7730:2005

Ergonomics of the thermal environment — Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria

The European Standard EN ISO 7730:2005 has the status of a British Standard

ICS 13.180

BSi British Standards



STANDARD

ASHRAE®

ANSI/ASHRAE Standard 55-2017
(Supersedes ANSI/ASHRAE Standard 55-2013)
Includes ANSI/ASHRAE addenda listed in Appendix N

Thermal Environmental Conditions for Human Occupancy

See Appendix N for approval dates.

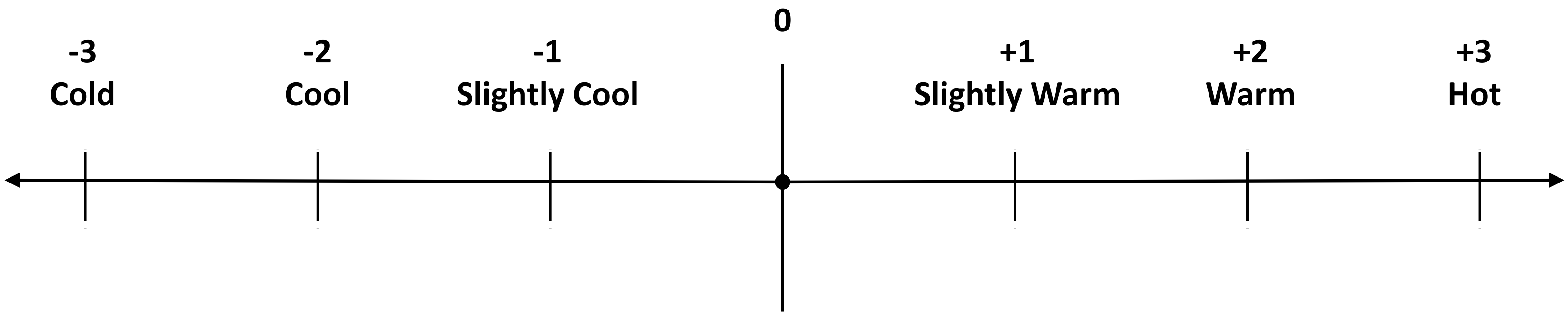
This Standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the Standard. The change submittal form, instructions, and deadlines may be obtained in electronic form from the ASHRAE website (www.ashrae.org) or in paper form from the Senior Manager of Standards. The latest edition of an ASHRAE Standard may be purchased from the ASHRAE website (www.ashrae.org) or from ASHRAE Customer Service, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: orders@ashrae.org. Fax: 678-539-2129. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to www.ashrae.org/permissions.

 ISSN 1041-2336

Approved American National Standard ANSI www.ansi.org

Predicted Mean Vote [PMV]

"The predicted mean vote (PMV) model uses heat balance principles to relate the ***six key factors*** *for thermal comfort to the average response of people on the … scale."*



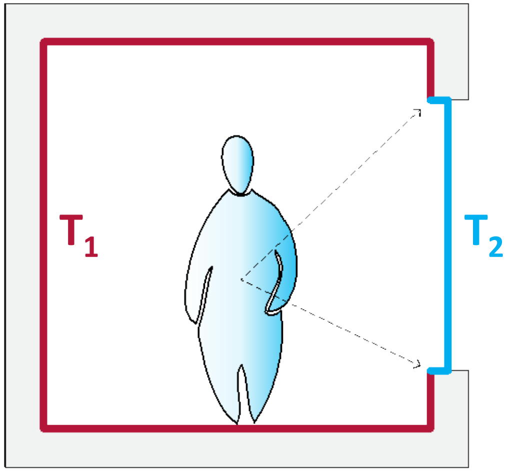
1. *Air temp*
2. *Air Relative Humidity*
3. *Air Speed*
4. *Occupant Metabolic Rate*
5. *Occupant Clothing Level*
6. *Mean Radiant Temperature*

From: ASHRAE 55, 2017. Appendix H3

Radiant Temperature?

ISO 7730: 2005

ISO 7730:2005 Table A.1			ISO 7730: 2005 Table A.4		
Category	Thermal State of the Body as a Whole				
			Radiant Temp. Asymmetry °C		
	Percent Persons Dissatisfied [PPD]	Predicted Mean Vote [PMV]	Warm Ceiling	Cool Wall	Cool Ceiling
A	< 6%	-0.2 <> +0.2	< 2	< 10	< 14
B	< 10%	-0.5 <> +0.5	< 3	< 10	< 14
C	< 15%	-0.7 <> +0.7	< 4	< 13	< 18



ASHRAE 55, 2017

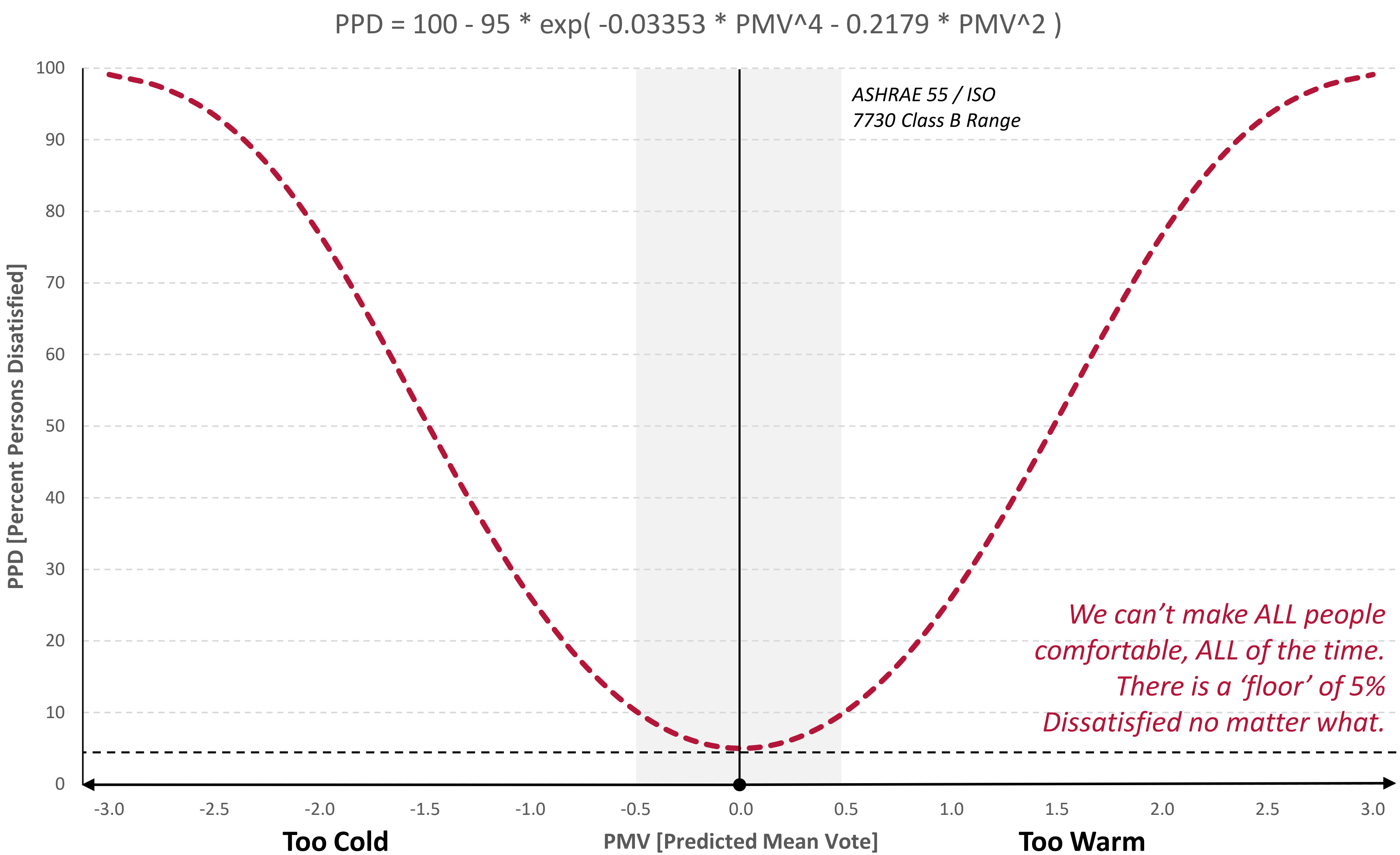
<u>Mechanically Conditioned Spaces</u>
Section 5.3
Any conditioned space

Compliance is achieved by demonstrating:
-0.5 < PMV < +0.5
(same as ’Class B’ in ISO 7730)

<u>‘Naturally’ Conditioned Spaces</u>
Section 5.4 but only IF…

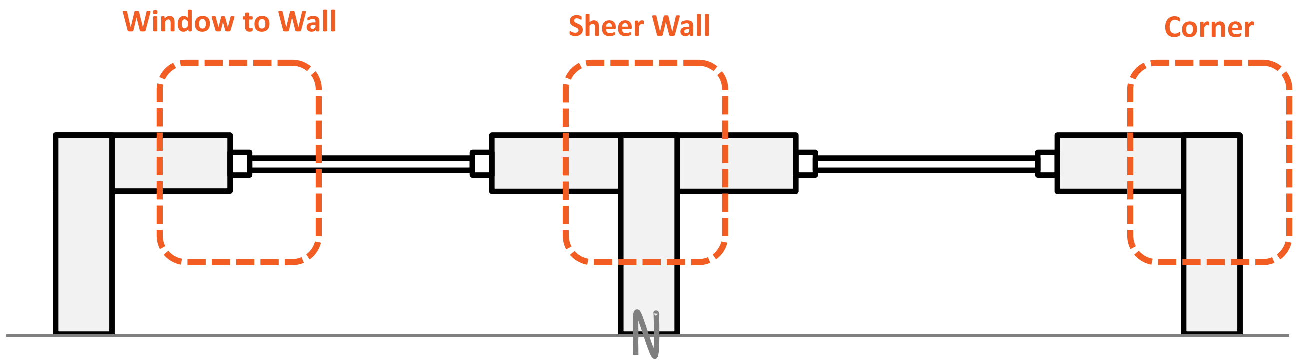
- No mechanical cooling in the space
- 1.0 - 1.3 Met.
- Occupants can control clothing level (0.5 – 1.0 Clo.)
- Outdoor temp is > 50-F and < 92.3-F

Overall PMV and Occupant Dissatisfaction

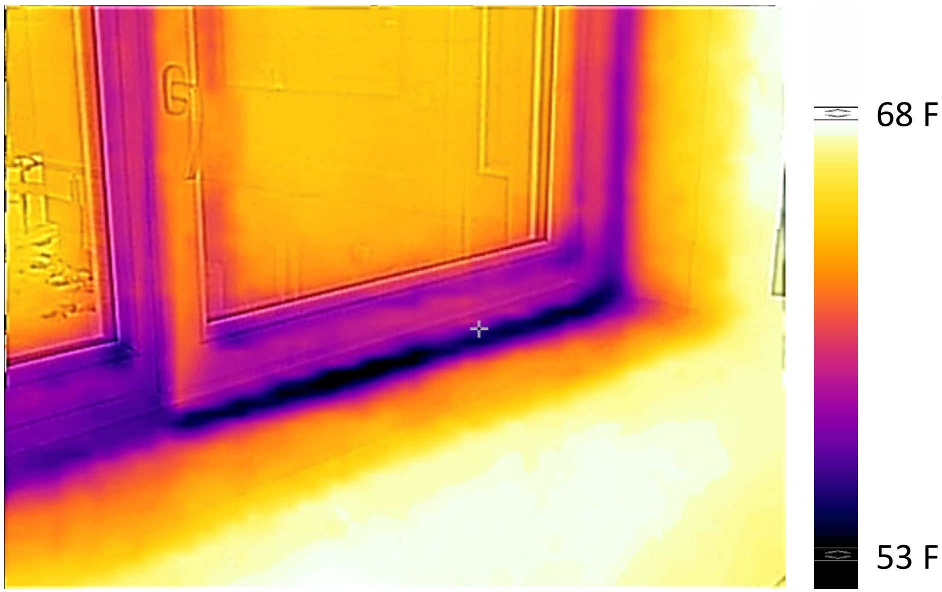


From: ASHRAE 55, 2017. Appendix H, Figure H3

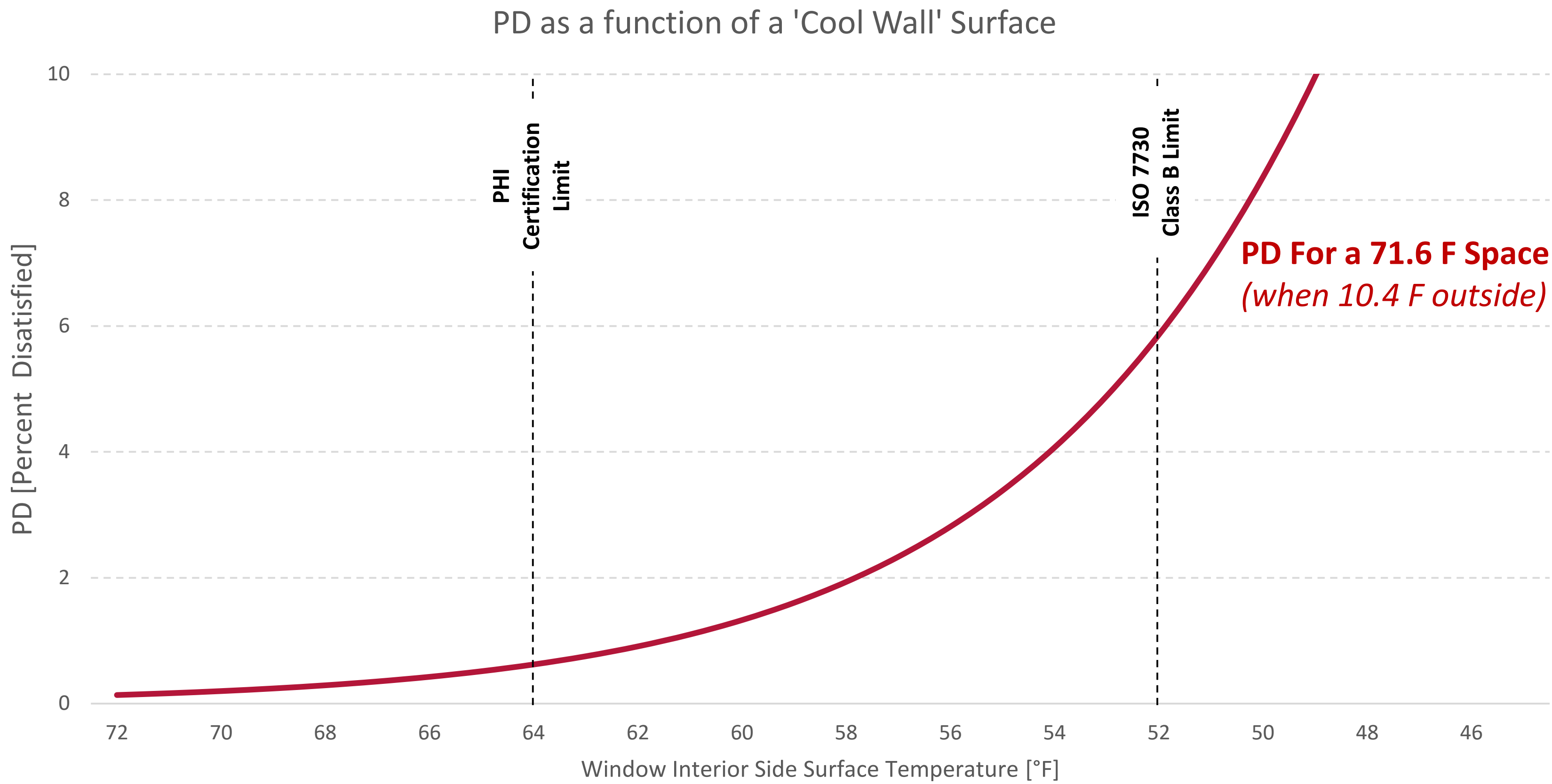
Localized thermal discomfort



Source: Justin Downey. RWDI



Window Surface Temperature Effect



Window U-Value (Btu/hr-sf-F):	**U-value: 0.167 (64 F)**	**U-value: 0.3 (58 F)**	**U-value: 0.4 (54 F)**	**U-value: 0.5 (49 F)**

*From: ISO 7730 Section 6.5, Equation 10: PD = 100 / 1+ exp(6.61 – 0.345 * ΔT [C])*

Thermal Comfort Problems from Windows

Entire industries of products have developed in order to fix the comfort problems caused by poor quality windows

The Passive House Institute Certification

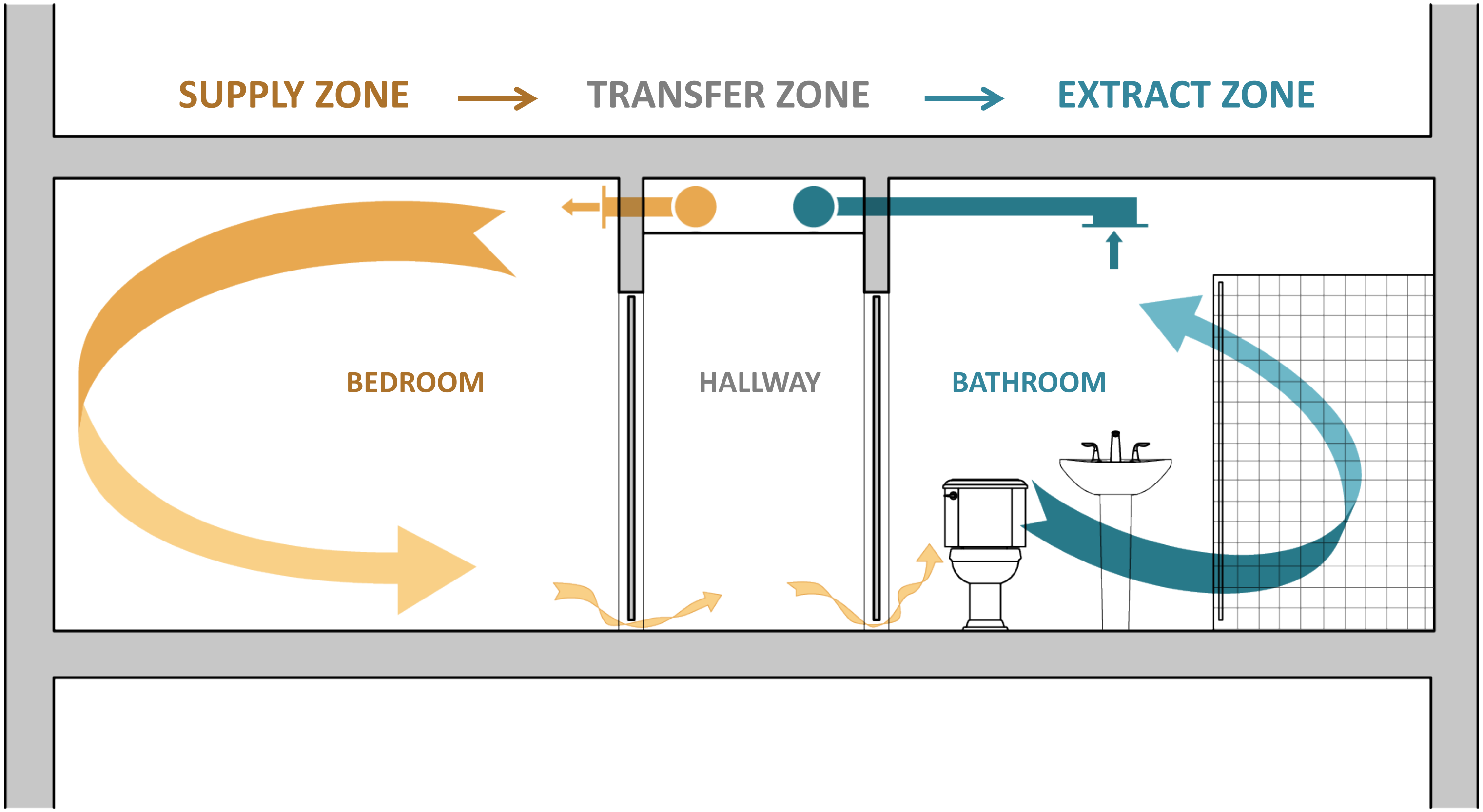
"A **Passive House** is a building, for which thermal comfort . . . **can be achieved solely by post-heating or post-cooling** of the fresh air mass [supply air], which is required to fulfill sufficient indoor air quality conditions . . . without a need for additional recirculated air."

- Dr. Wolfgang Feist. 2006

Passive House Institute

Eliminate Perimeter Supply?

Often supply air (and therefor heating) is restricted to the 'core' of the building for reasons of economy. This is only possible if the exterior surfaces have surface temperatures within the comfort zone.



PHI Certification Requirement

Minimum Thermal Protection:

"For the arctic to warm-temperate climate zones interior surface temperatures of the standard cross-sections of walls and ceilings as well as the **average interior surface temperatures of windows may not be more than 7.6 F *[4.2 K]* below the operative indoor temperature 71.6 F *[22 C]*.**

The 'operative' temperature is a simplified combination temp that results from the air temp, mean radiant temp and air speed.

…The requirements will be checked in the PHPP with an indoor temperature of 71.6 F *[22 C]* and a **minimum outdoor temperature** taken from the climate data set for the building's location."

For PHI certification this is the mean temp over the coldest 12 hour period for the building's climate. For PHI certification projects in NYC this is +10.4F [-12C]

From: "Criteria for the Passive House, EnerPHit and PHI Low Energy Building Standard, version 9f, revised 15.08.2016"

7.6 F Radiant Temp. Asymmetry?

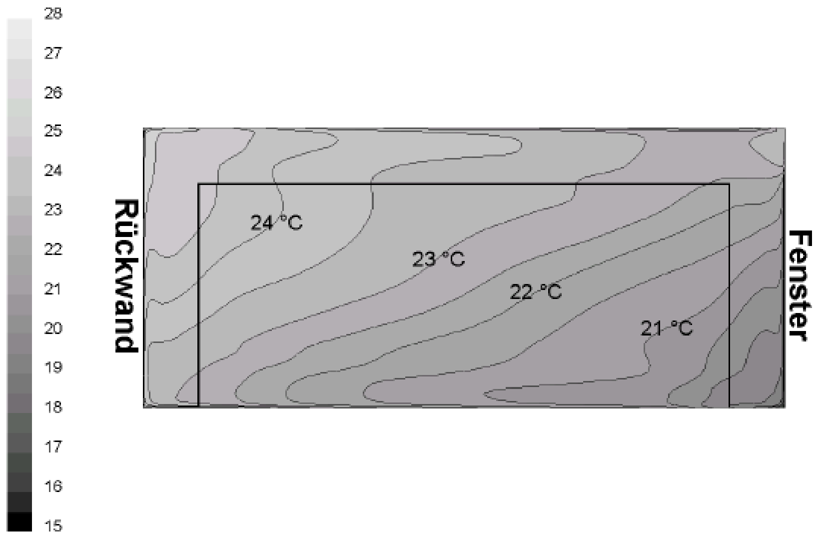
Ventilation and Air Conditioning: Technical Health Req. 1994-2001

*"Radiation temperature asymmetry: In **DIN 1946 Part 2** a limit value of 14.4 F [8 k] (10 K in ISO 7730) is given for radiation temperature asymmetry (ΔT_{si}) value for cold wall surfaces. The wording of the standard indicates some uncertainty around this value; **due to practical experience with the comfort in residential areas, a lower limit must be required [for Passive House certification]. As a benchmark, half of the limit value of DIN 1946 could be used**: in the designated spaces, the radiation temperature asymmetry should be below 7.2 F [4 K]."*

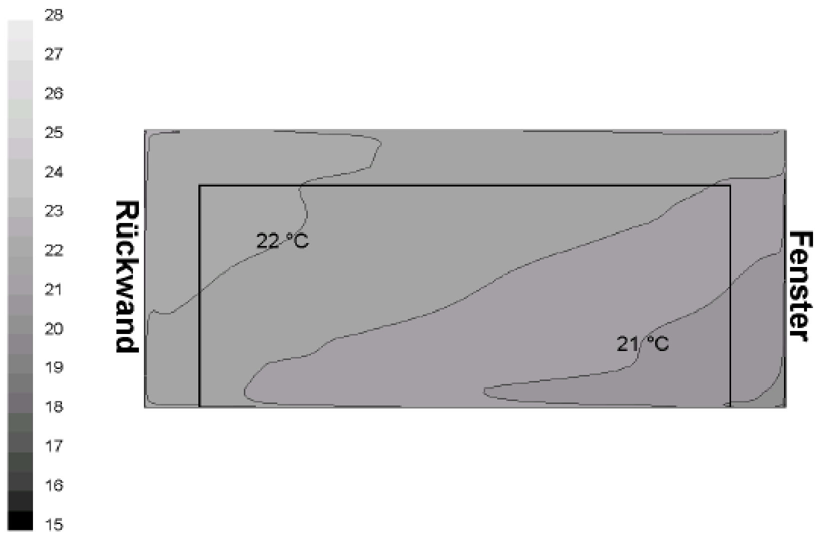
From: "Highly insulating window systems: examination and optimization in the installed state" Dr. Rainer Pfluger, Dipl.-Phys. Jürgen, Schnieders, Dr. Berthold Kaufmann, Dr. Wolfgang Feist. Passivhaus Institut 2003

4.2 K Radiant Temperature Asymmetry?

In [Pfluger 2003] numerous further variants for the placement of cold structural elements were calculated. As long as the criterion ΔT_{si} < 7.6 F [4.2 K] was met, ***no inadmissibly high temperature stratifications resulted****, even when the ceiling and window heights were increased.*



U_W = 1,6 W/(m²K)

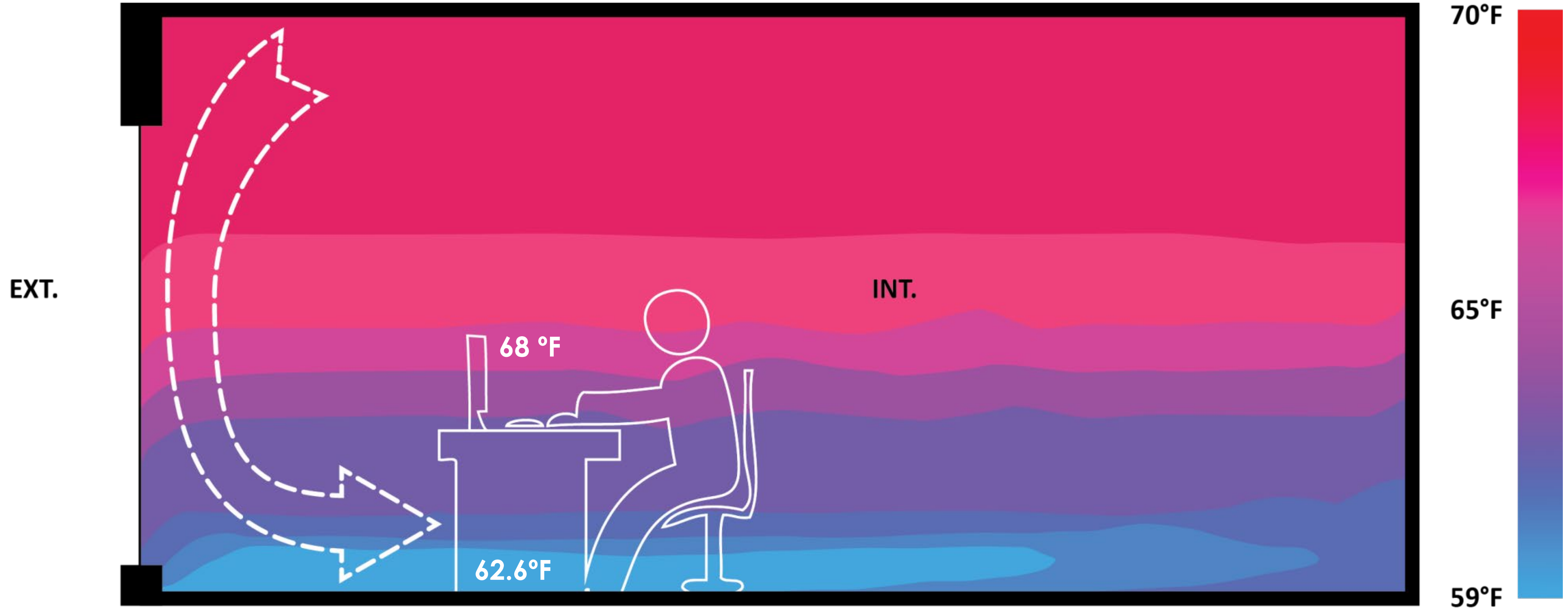


U_W = 0,5 W/(m²K)

From: "Comfort standards for passive-house windows." Jürgen Schnieders, Dr. Wolfgang Feist, Passivhaus Institut 2007

Air Temperature Stratification?

TYPICAL WINDOW ($R_w \approx 3.6$ (hr-ft^2-F)/Btu)



Source: PHI

PHI Max Allowable Window $U_{W\text{-Installed}}$ (NYC)

Recommendation for $U_{W,installed}$ [W/(m²K)]

0.95	1.10	1.20	0.52

	Vertical	Sloped	Horizontal Roof	Horizontal Floor
W/m²-k	*0.950*	*1.100*	*1.200*	*0.520*
Btu/hr-ft²-F	**0.167**	0.194	0.211	0.092

The following exemptions from the thermal comfort requirements apply in addition:

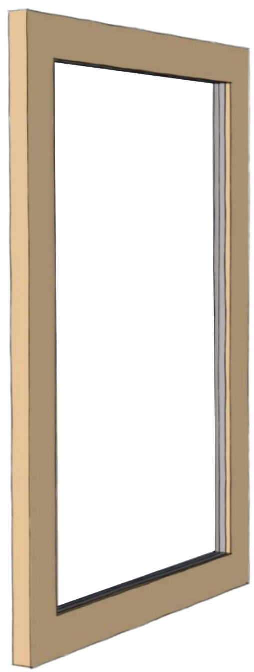
- ☐ The requirements do not apply for areas which are not adjacent to rooms with prolonged occupancy or for separate isolated areas which are smaller than 1 m².
- ☐ For windows and doors, exceeding the limit value is permissible if low temperatures arising on the inside are compensated by means of heating surfaces or if, for other reasons, there are no concerns relating to thermal comfort.
- ☐ Alternatively, the criteria for thermal comfort will be deemed to have been fulfilled if evidence of the comfort conditions is provided in accordance with DIN EN ISO 7730.

From: "Criteria for the Passive House, EnerPHit and PHI Low Energy Building Standard, version 9f, revised 15.08.2016"

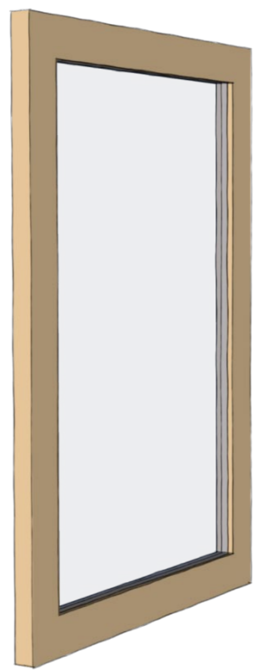
$U_{W\text{-Installed}}$?

U_g
U-Value of
the Glass

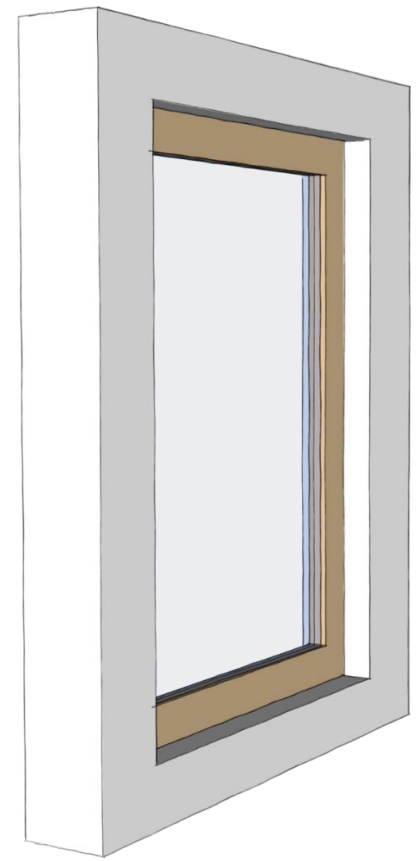
U_f
U-Value of
the Frame



U_w
U-Value of
the Window



$U_{w\text{-installed}}$
U-Value of the Window
<u>in the specific wall type</u>

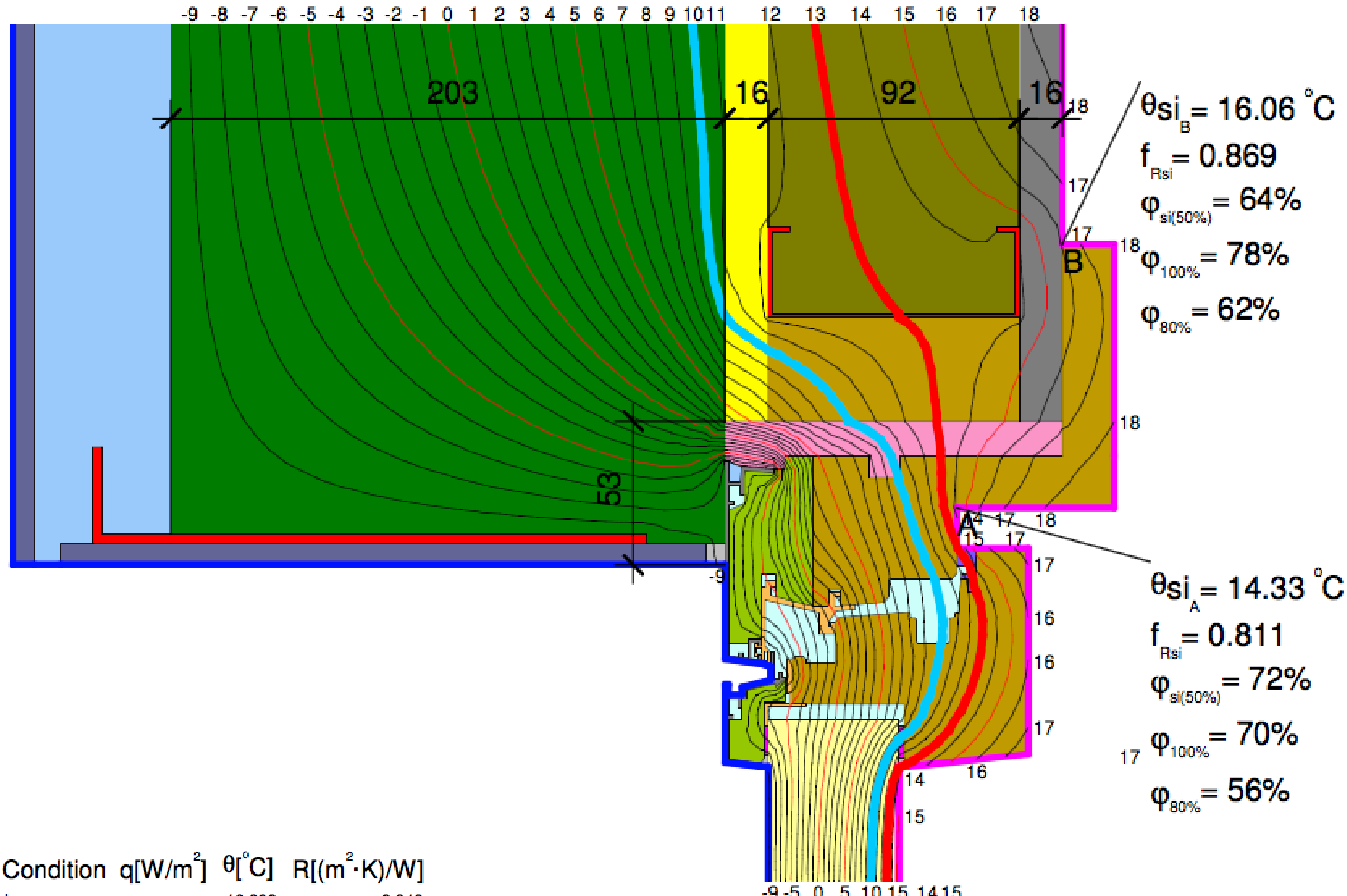


$U_{W\text{-Installed}}$: Calculation

$$U_{w\text{-installed}} = \frac{(U_g \times A_{glass}) + (U_f \times A_{frame}) + (\Psi_{spacer} \times L_{spacer}) + (\Psi_{install} \times L_{install})}{A_{window}}$$

The addition of the Psi-Install (calculated separately) is used to calculate the $U_{w\text{-INSTALLED}}$

$U_{W\text{-}Installed}$: Window $Psi_{Install}$



Boundary Condition	q[W/m²]	θ[°C]	R[(m²·K)/W]
Exterior, normal		-10.000	0.040
Interior, without window/door		20.000	0.250
Symmetry/Model section	0.000		

Psi-Install: +0.043 W/mk

$U_{W\text{-}Installed}$: Calculation in the PHPP

Go to glazing list   Go to window frames list

0.167 | 0.194 | 0.211 | 0.092

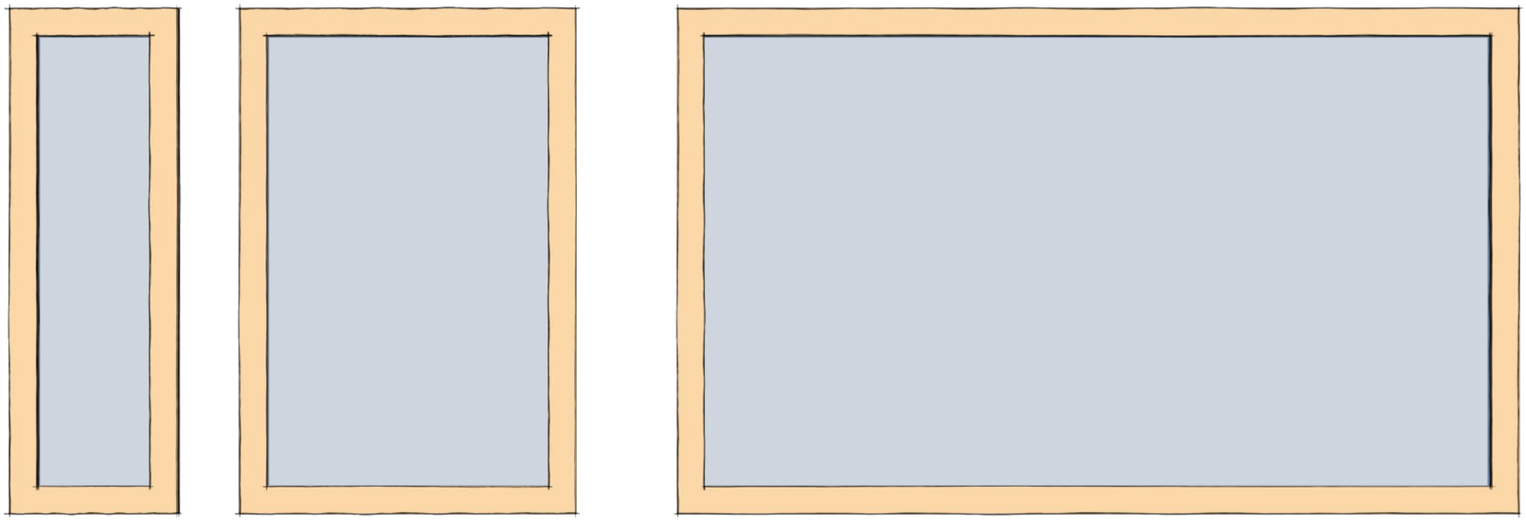
Description	Orien-tation	Window rough openings: Width (ft)	Window rough openings: Height (ft)	Glazing: Selection from 'Components' worksheet (1-Sorting: LIKE LIST)	Frame: Selection from 'Components' worksheet (Sort: AS LIST)	SHGC: Perpen-dicular radiation (-)	U-Value: Glazing (BTU/hr.ft²°F)	U-Value: Frames (avg.) (BTU/hr.ft²°F)	Results: U_w installed (BTU/hr.ft²°F)	Results: Glazed fraction per window (%)	Window surface temperature indicator: Comfort (Exemption)	Energy balance (kBTU/yr)
ND1	North	3.33	7.01	06ud Zola Solid Door Planel	01ud Zola Thermoplus Clad uPVC - Operable	0.00	0.18	0.17	0.217	69%		-627
Win_N2.1	North	4.87	8.00	01ud Zola Triple (Ar) Lo-g	02ud Zola Thermoplus Clad uPVC - Fixed	0.30	0.09	0.17	0.139	83%		-376
Win_N2.2	North	9.00	3.00	01ud Zola Triple (Ar) Lo-g	02ud Zola Thermoplus Clad uPVC - Fixed	0.30	0.09	0.17	0.151	77%		-322
Win_N2.3	North	3.00	3.00	01ud Zola Triple (Ar) Lo-g	01ud Zola Thermoplus Clad uPVC - Operable	0.30	0.09	0.17	0.175	56%	x	-153
Win_E0.1	East	5.00	2.50	01ud Zola Triple (Ar) Lo-g	01ud Zola Thermoplus Clad uPVC - Operable	0.30	0.09	0.17	0.178	59%		-120
Win_E1.1	East	2.00	4.00	01ud Zola Triple (Ar) Lo-g	02ud Zola Thermoplus Clad uPVC - Fixed	0.30	0.09	0.17	0.192	63%	x	-88
Win_E1.2	East	4.92	5.17	01ud Zola Triple (Ar) Lo-g	02ud Zola Thermoplus Clad uPVC - Fixed	0.30	0.09	0.17	0.147	80%		-4
Win_E2.1	East	2.33	3.85	01ud Zola Triple (Ar) Lo-g	01ud Zola Thermoplus Clad uPVC - Operable	0.30	0.09	0.17	0.188	54%	x	-108
Win_S1.1	South	6.60	8.18	02ud-Zola Triple (Ar) Med-g	02ud Zola Thermoplus Clad uPVC - Fixed	0.53	0.10	0.17	0.129	86%		1445
Win_S1.2	South	3.00	8.18	02ud-Zola Triple (Ar) Med-g	01ud Zola Thermoplus Clad uPVC - Operable	0.53	0.10	0.17	0.151	68%		455
Win_S1.3	South	3.00	8.18	02ud-Zola Triple (Ar) Med-g	01ud Zola Thermoplus Clad uPVC - Operable	0.53	0.10	0.17	0.151	68%		387
Win_S1.4	South	5.58	8.18	02ud-Zola Triple (Ar) Med-g	02ud Zola Thermoplus Clad uPVC - Fixed	0.53	0.10	0.17	0.132	84%		1528
Win_S2.1	South	4.18	6.00	02ud-Zola Triple (Ar) Med-g	02ud Zola Thermoplus Clad uPVC - Fixed	0.53	0.10	0.17	0.144	79%		936
Win_S2.2	South	3.11	6.00	02ud-Zola Triple (Ar) Med-g	01ud Zola Thermoplus Clad uPVC - Operable	0.53	0.10	0.17	0.155	66%		487
Win_S2.3	South	7.08	9.83	02ud-Zola Triple (Ar) Med-g	02ud Zola Thermoplus Clad uPVC - Fixed	0.53	0.10	0.17	0.130	87%		3085
Win_S2.4	South	3.39	9.83	02ud-Zola Triple (Ar) Med-g	01ud Zola Thermoplus Clad uPVC - Operable	0.53	0.10	0.17	0.154	72%		919
Win_S2.5	South	5.62	9.83	02ud-Zola Triple (Ar) Med-g	02ud Zola Thermoplus Clad uPVC - Fixed	0.53	0.10	0.17	0.135	85%		2190
Win_W0.1	West	5.00	2.50	01ud Zola Triple (Ar) Lo-g	01ud Zola Thermoplus Clad uPVC - Operable	0.30	0.09	0.17	0.178	59%		-116
Win_W1.1	West	2.50	2.50	01ud Zola Triple (Ar) Lo-g	02ud Zola Thermoplus Clad uPVC - Fixed	0.30	0.09	0.17	0.197	61%	x	-127

In the Passive House Planning Package (PHPP) the $U_{W\text{-}Install}$ is calculated uniquely for EACH window. These values are used for both energy analysis and a thermal comfort check.

$U_{W\text{-Installed}}$: Window Size

U_f= 0.14 Btu/(hr-ft²-F)

U_g= 0.08 Btu/(hr-ft²-F)



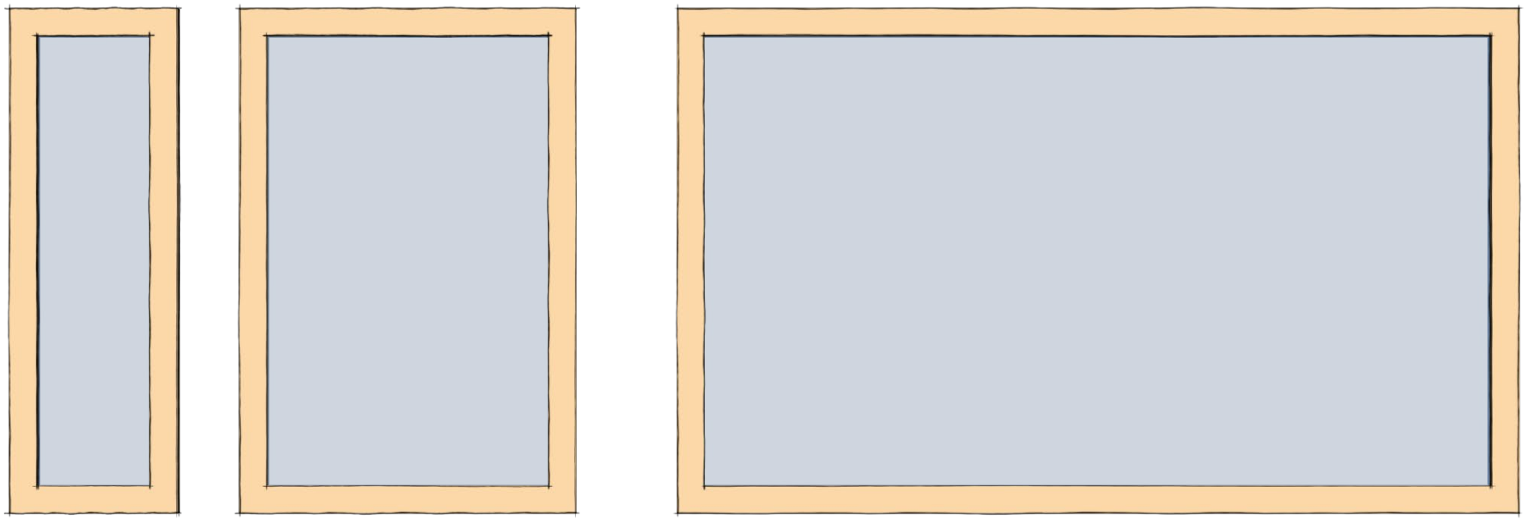
2’ x 6’ | 4’ x 6’ | 10’ x 6’

U_w = 0.185 | **U_w = 0.169** | **U_w = 0.159**

$U_{W\text{-Installed}}$: Average Surface Temp

$$T_{surface\text{-}int} = T_i - (R_{si} \times U_{surface} \times (T_i - T_e))$$

In NYC this is +10.4 F [-12C]



2’ x 6’

4’ x 6’

10’ x 6’

$U_w = 0.185$
$T_{surface} = 63.2$ F

$U_w = 0.169$
$T_{surface} = 64.0$ F

$U_w = 0.159$
$T_{surface} = 64.4$ F

Issues with Simplified Surface Temp. Check

Probably a good conservative solution for the most part. But…

1. Prescriptive: Doesn’t allow for creative solutions

2. Coarse: Doesn’t take all the specific parameters of the actual situation into account:

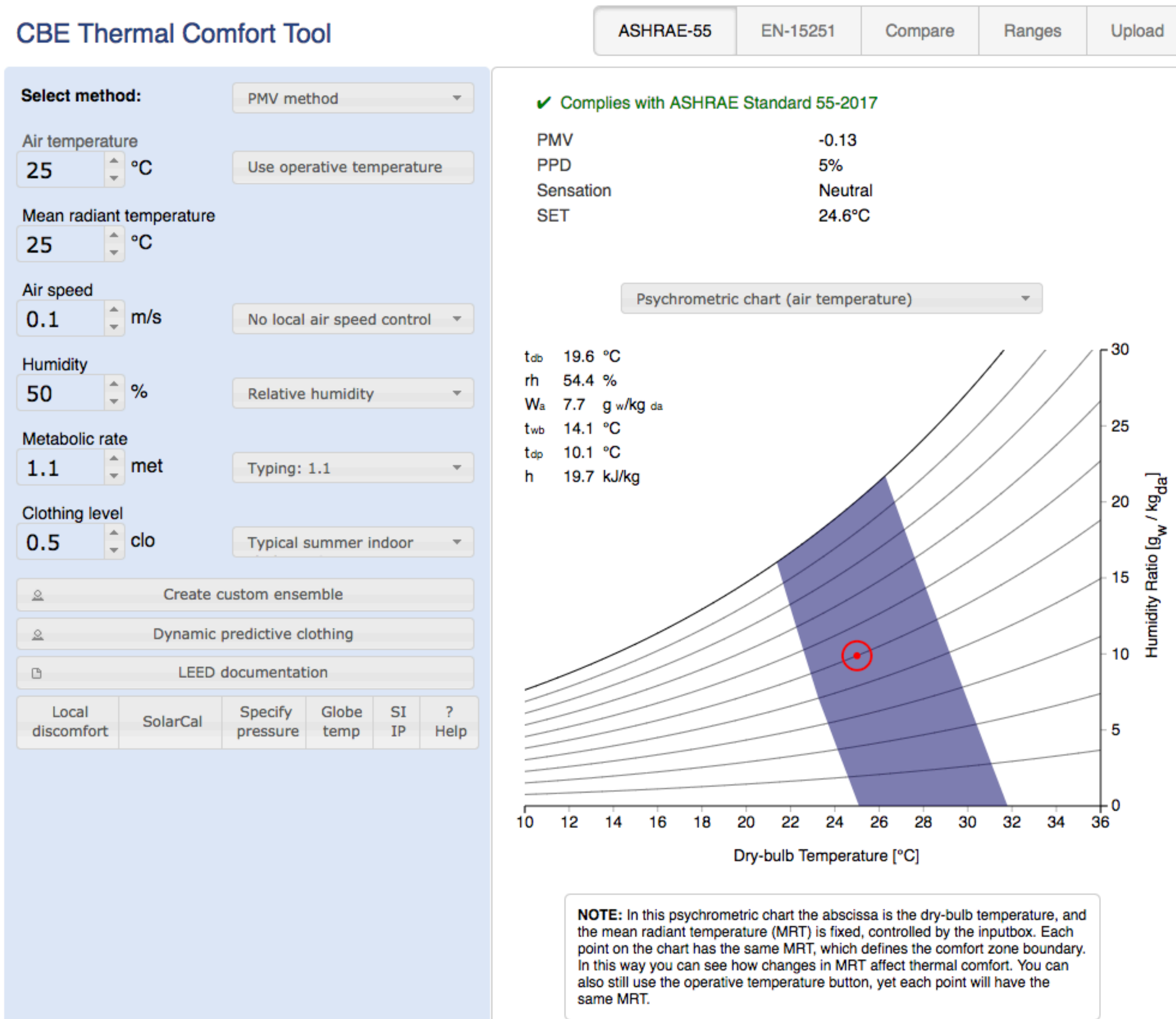
- Window and Room Geometry [View Factors]
- Localized low-temps [Asymmetric Psi-Installs]
- What about complex situations [corner glass, double height]
- Is a single design-day calculation suitable or is annual evaluation better?
- What about summer comfort?

Detailed Window Thermal Comfort Modeling

Goal: Develop a more detailed methodology and tool for Passive House designers to utilize for thermal comfort analysis and design related to windows.

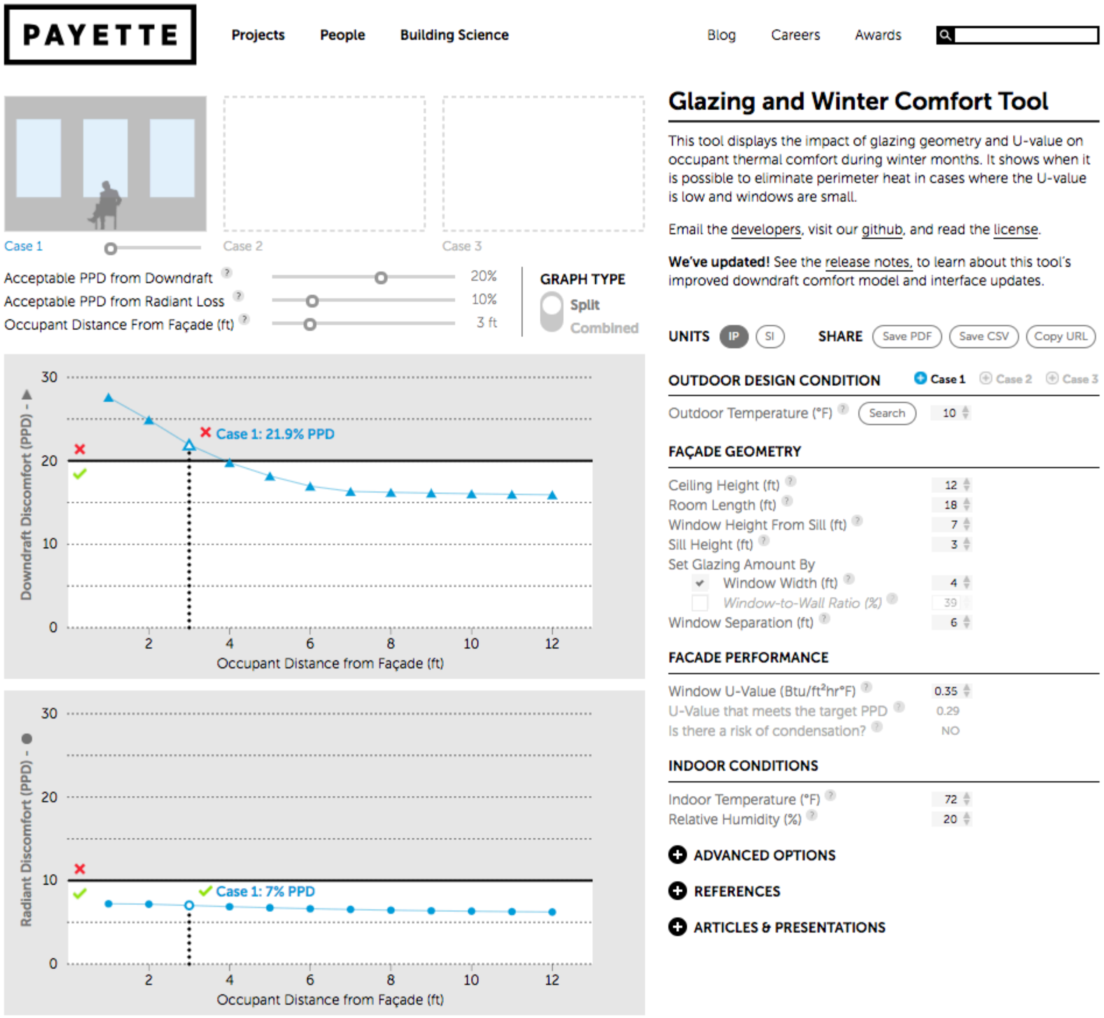
Existing Modeling Tools

http://comfort.cbe.berkeley.edu/



Existing Modeling Tools

https://www.payette.com/building-science/glazing-and-winter-comfort-tool/

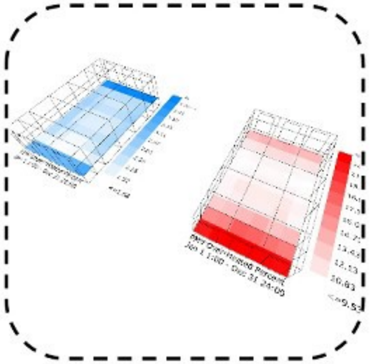


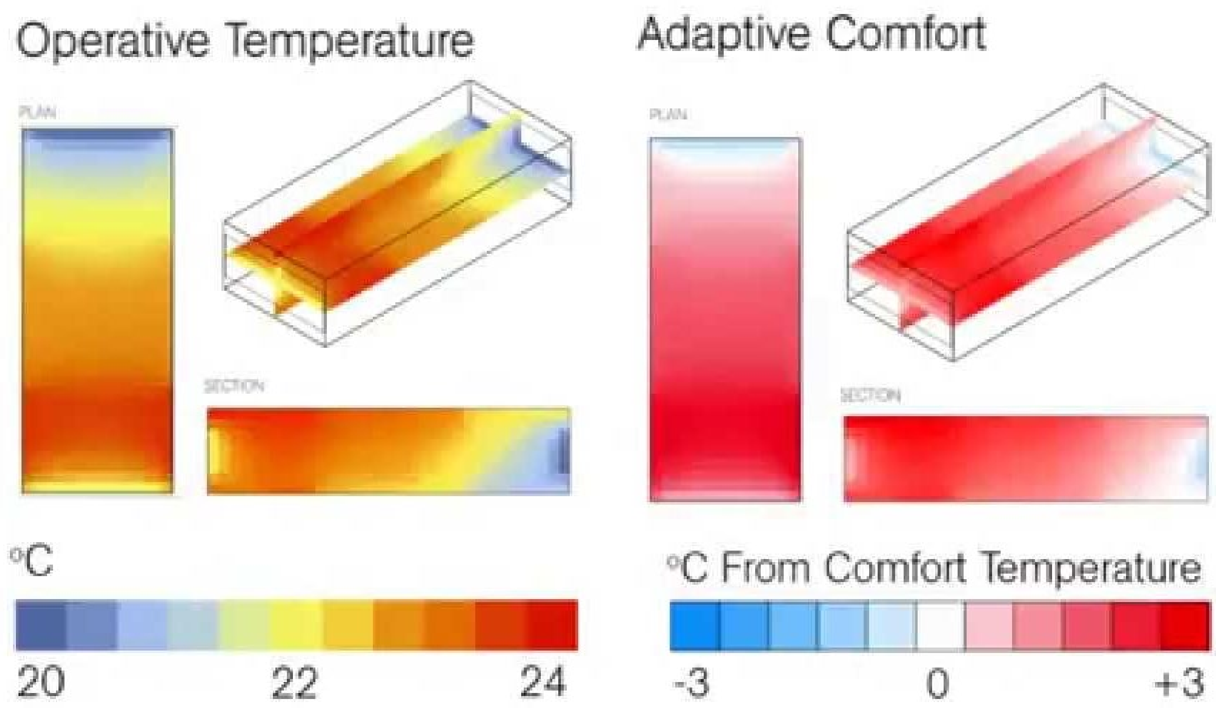
Existing Modeling Tools

Ladybug

Honeybee

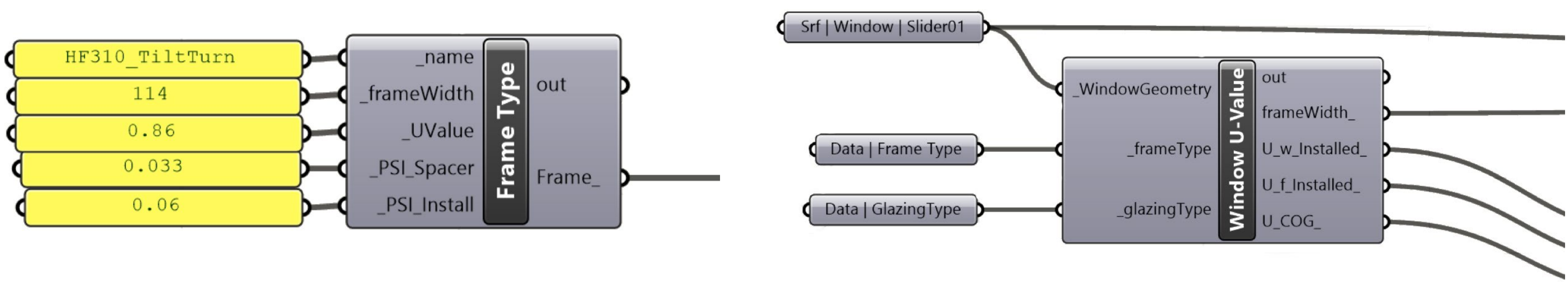
Building Energy, Daylight + Comfort Modelling



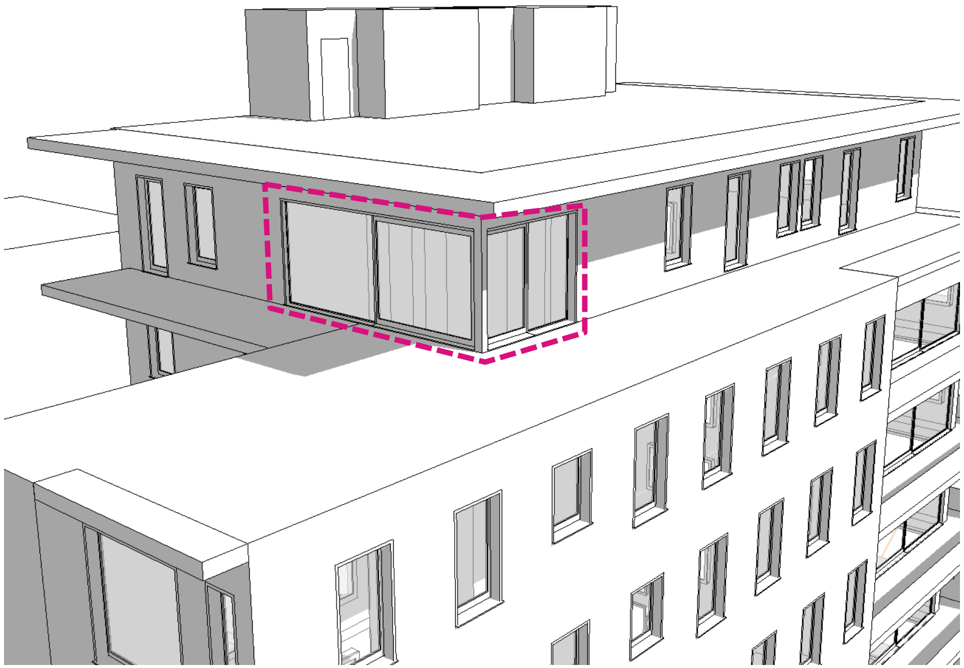


Can it be used for Passive House certification?

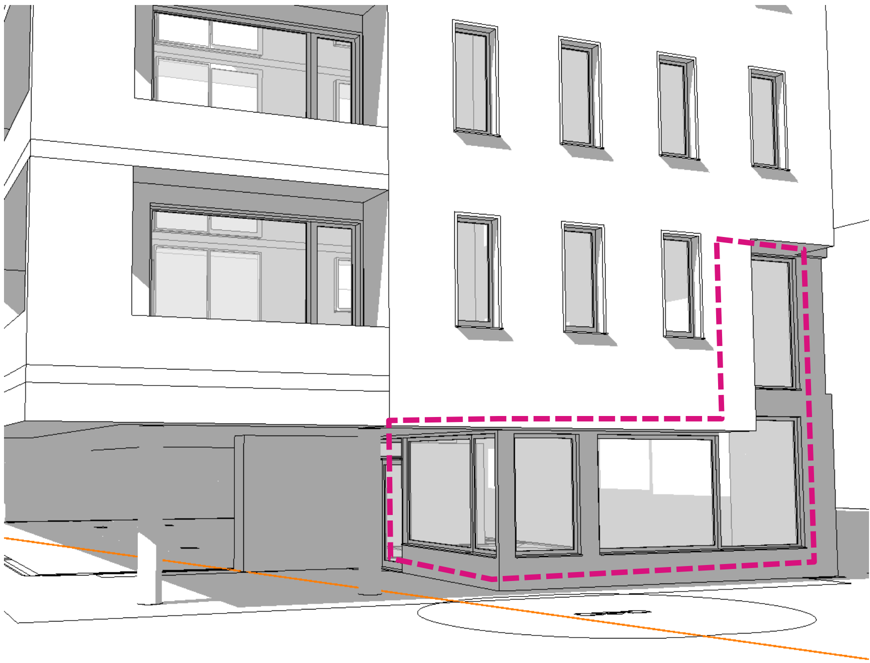
- Relies on surface temps from an hourly (Energy+) model rather than PHI design day Exterior temps
- Uses Energy+ simplified U-Factor method for whole windows (no Psi-Install)
- Doesn’t output asymmetry result by default
- Uses AHSRAE 55 targets not PH thresholds
- Doesn’t calculate bi-directional asymmetry



Example: Candela Lofts Passive House

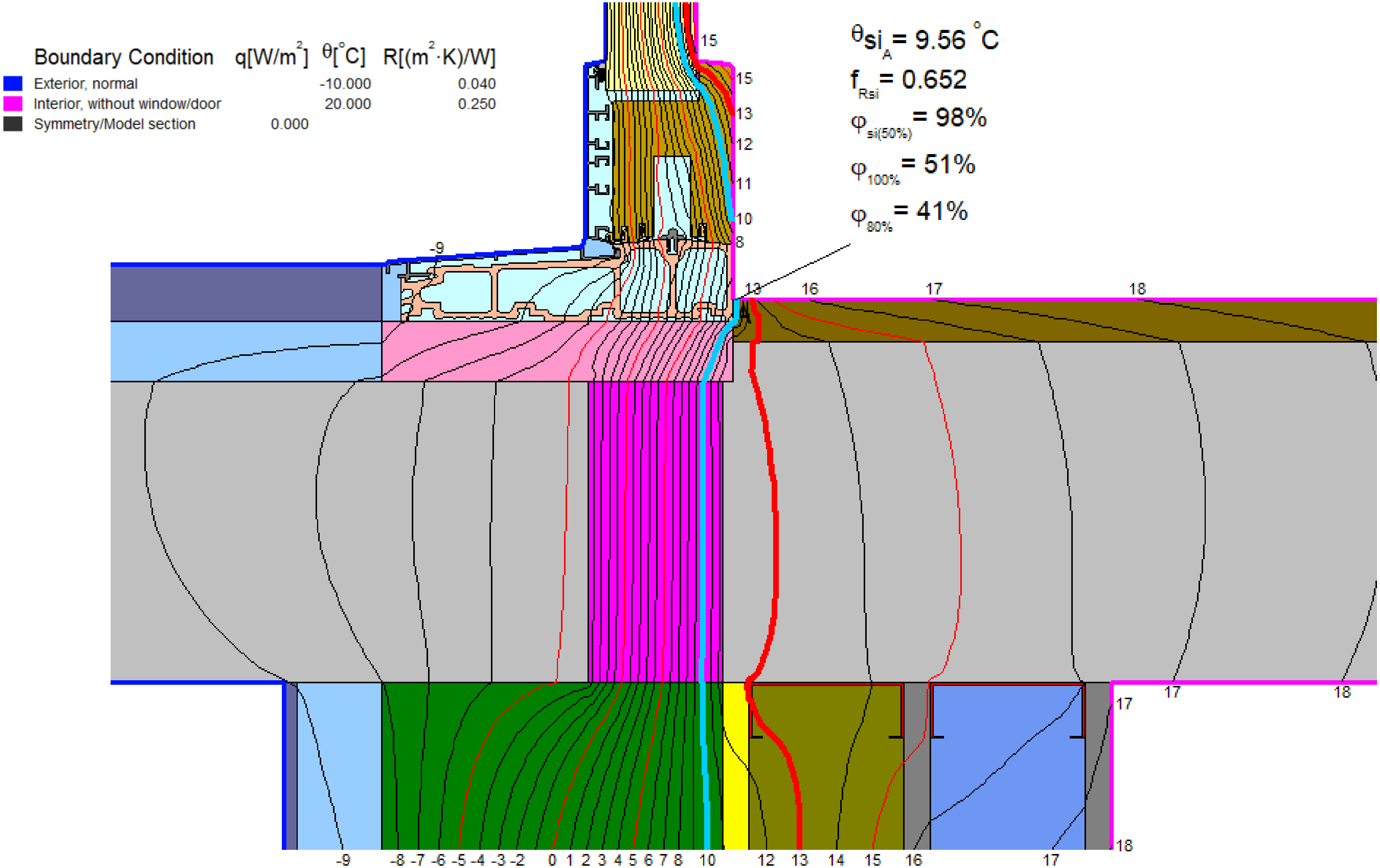


Penthouse Corner Glass

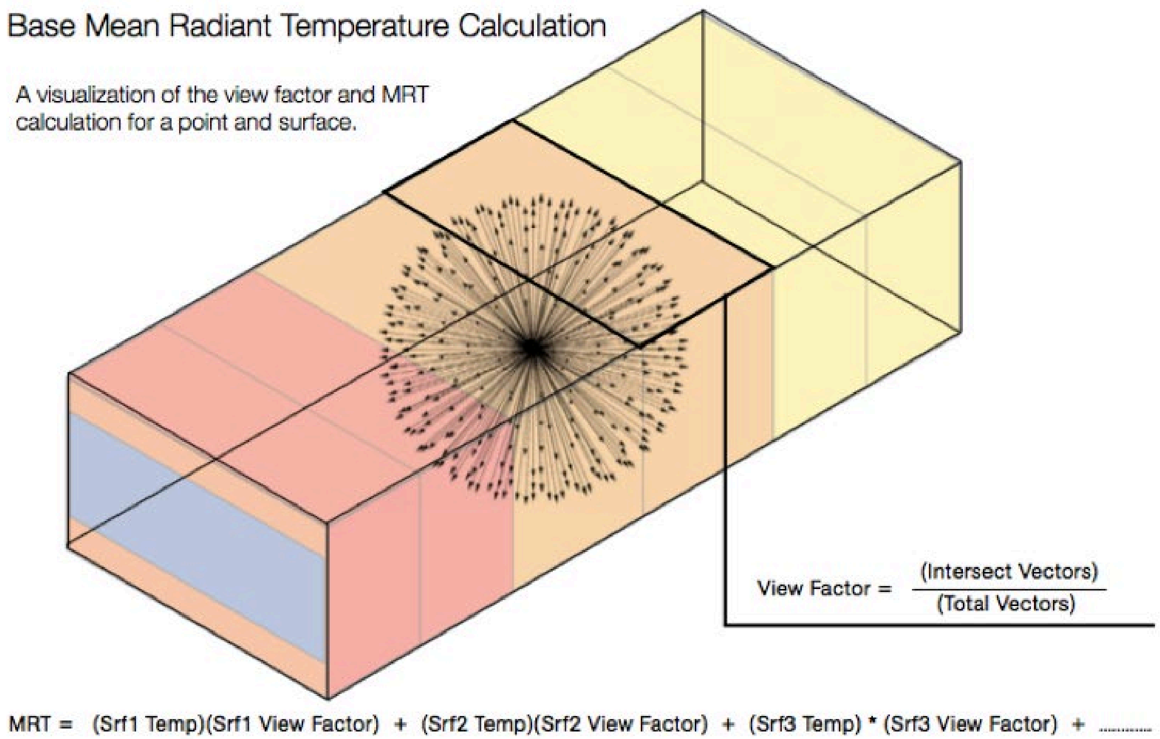


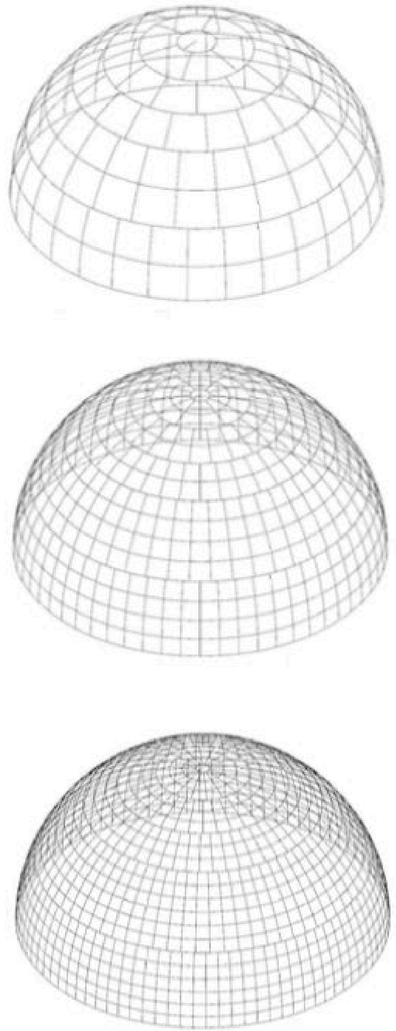
Lobby Double-Height

Example: Localized low temperatures



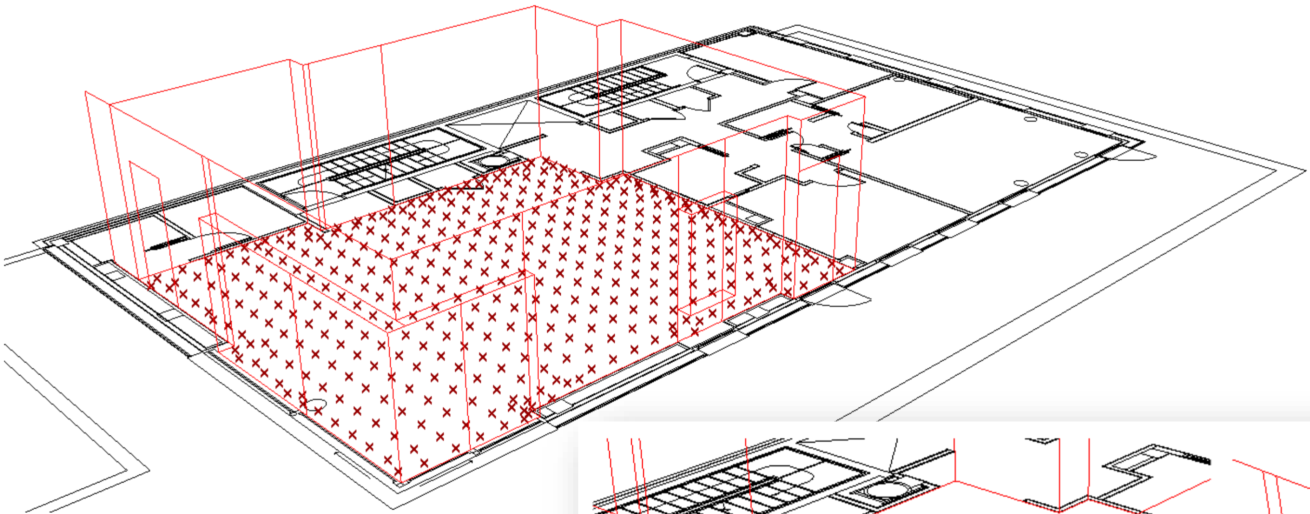
Detailed Radiant Temp Asymmetry Calc.

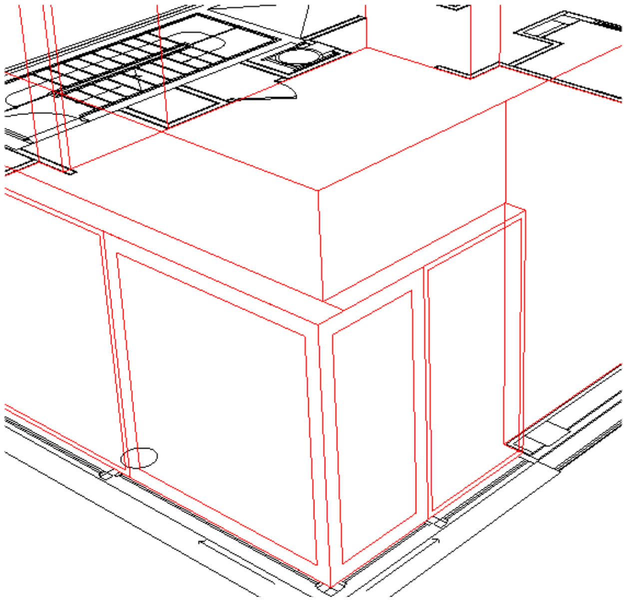




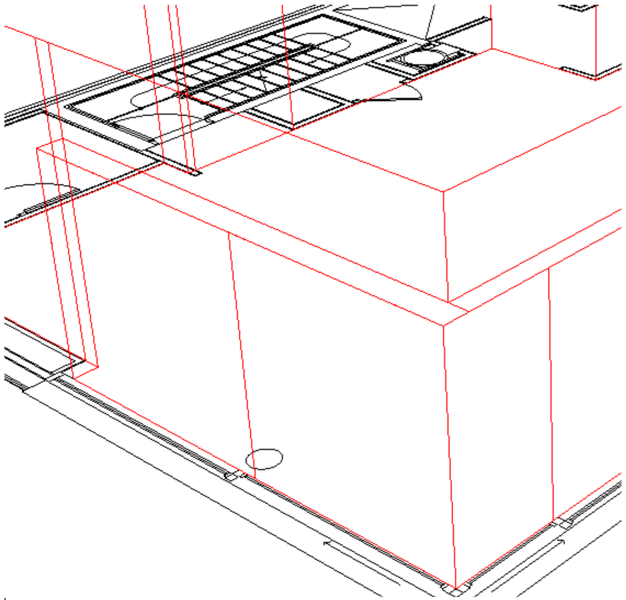
From: "PAN CLIMATIC HUMANS: Shaping Thermal Habits in an Unconditioned Society by Chris Mackey"

Example: Analysis Model



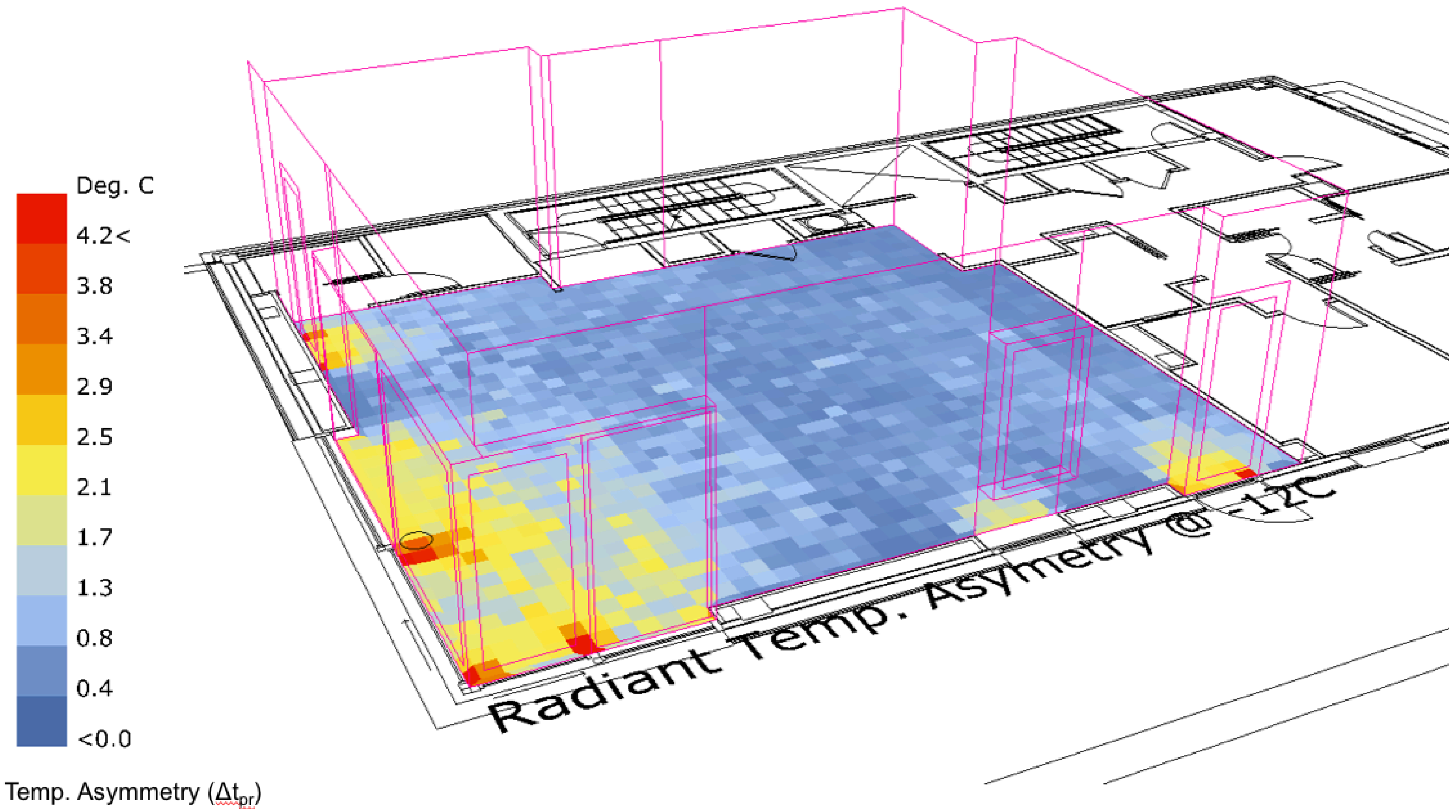


Detailed Window Method

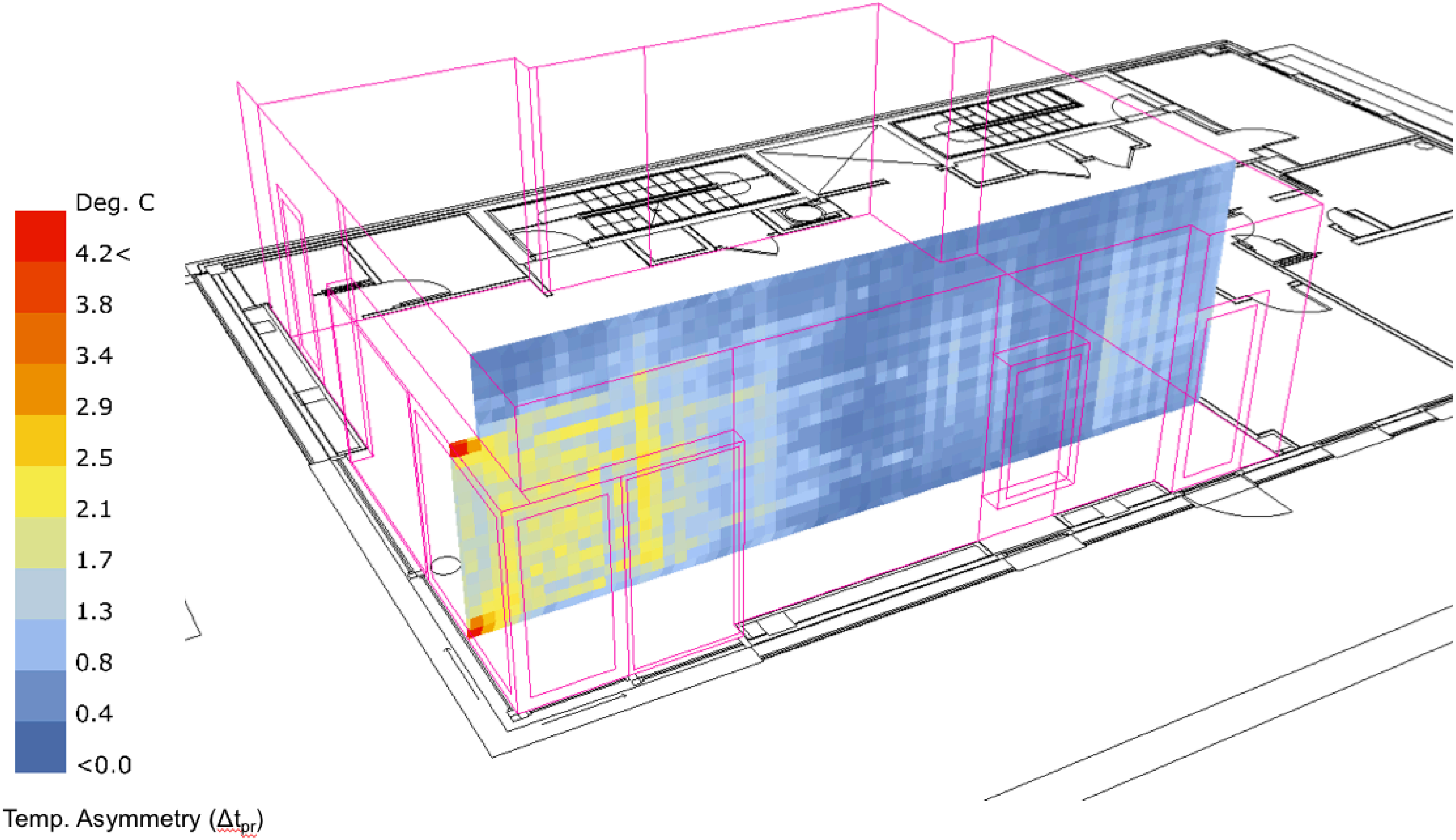


$U_{w\text{-installed}}$ Method

Radiant Temperature Asymmetry Map [-12 C Ext.]



Radiant Temperature Asymmetry Map [-12 C Ext.]



Reporting analysis-point data

EXAMPLE - Excel Reporting Output

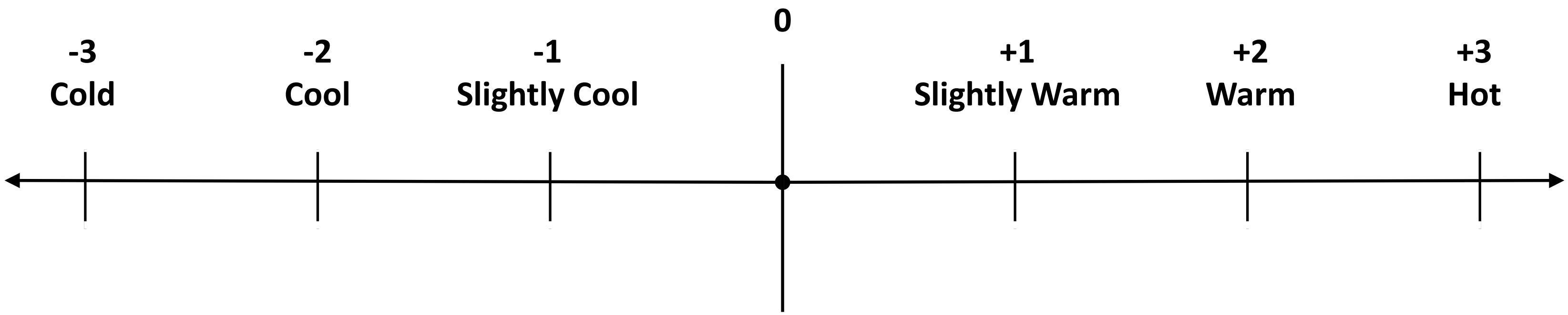
	ISO 7730:2005 Table A.1							Additional		
	Category	Thermal State of the Body as a		Local Discomfort						
		PPD %	PMV	DR%	PD% from...			PD% from...		Radiant Temp Asymmetry Cool Wall [°C]
					Vertical air temp. difference	warm or cool floor	radiant asymmetry (cool wall)	Ankle Draft (0.1m AFF)	Neck Draft	
	A	< 6	-0.2 <> +0.2	< 10	< 3	< 10	< 5			< 10
AHRAE 55--->	B	< 10	-0.5 <> +0.5	< 20	< 5	< 10	< 5	< 20		< 10
	C	< 15	-0.7 <> +0.7	< 30	< 10	< 15	< 10			< 13
	Point 1	5.1	-0.08	4.5	0.6	6.1	0.2	12.1	4.7	1.2
	Point 2	5.3	-0.12	4.6	0.6	6.1	0.3	12.5	4.7	2.0
	Point 3	5.3	-0.12	4.6	0.6	6.1	0.3	12.6	4.7	2.0
	Point 4	5.5	-0.15	4.6	0.7	6.1	0.3	13.3	4.8	2.2
	Point 5	5.7	-0.18	4.7	0.8	6.1	0.3	14.2	4.9	2.1
	Point 6	5.1	-0.07	4.5	0.6	6.1	0.2	10.7	4.7	0.9
	Point 7	5.1	-0.08	4.5	0.6	6.1	0.2	10.8	4.7	1.1
	Point 8	5.2	-0.09	4.5	0.6	6.1	0.2	10.8	4.7	1.4
	Point 9	5.2	-0.11	4.6	0.6	6.1	0.2	11.1	4.7	1.6
	Point 10	5.4	-0.14	4.6	0.7	6.1	0.2	13.0	4.8	1.7
	Point 11	5.1	-0.06	4.5	0.5	6.1	0.2	10.3	4.6	0.6
	Point 12	5.1	-0.06	4.5	0.5	6.1	0.2	10.4	4.6	0.9
	Point 13	5.1	-0.07	4.5	0.5	6.1	0.2	10.4	4.6	0.9
	Point 14	5.1	-0.08	4.5	0.6	6.1	0.2	10.8	4.6	1.0
	Point 15	5.1	-0.08	4.5	0.6	6.1	0.2	10.9	4.6	1.2
	Point 16	5.1	-0.05	4.5	0.5	6.1	0.2	10.3	4.5	0.7
	Point 17	5.1	-0.06	4.5	0.5	6.1	0.2	10.4	4.5	0.7

ISO 7730 Table A.1

Next Steps

Predicted Mean Vote [PMV]

"The predicted mean vote (PMV) model uses heat balance principles to relate the ***<u>six</u> key factors*** *for thermal comfort to the average response of people on the … scale."*



1. *Air temp* = ?
2. *Air Relative Humidity* = ?
3. *Air Speed* = ?
4. *Occupant Metabolic Rate* = ?
5. *Occupant Clothing Level* = ?
6. *Mean Radiant Temperature*

Operative Temp. = 71.6 F [22C]

From: ASHRAE 55, 2017. Appendix H3

- Input boundary conditions for PHI Cert?
- Need an easy way to calculate temp. stratification without complex simulation
- What about summer?
  - ASHRAE 55 2017 now has a “Procedure for Calculating Comfort Impact of Solar Gain on Occupants” – should that be included as a requirement?
- What radiant temp asymmetry values should be used as targets?