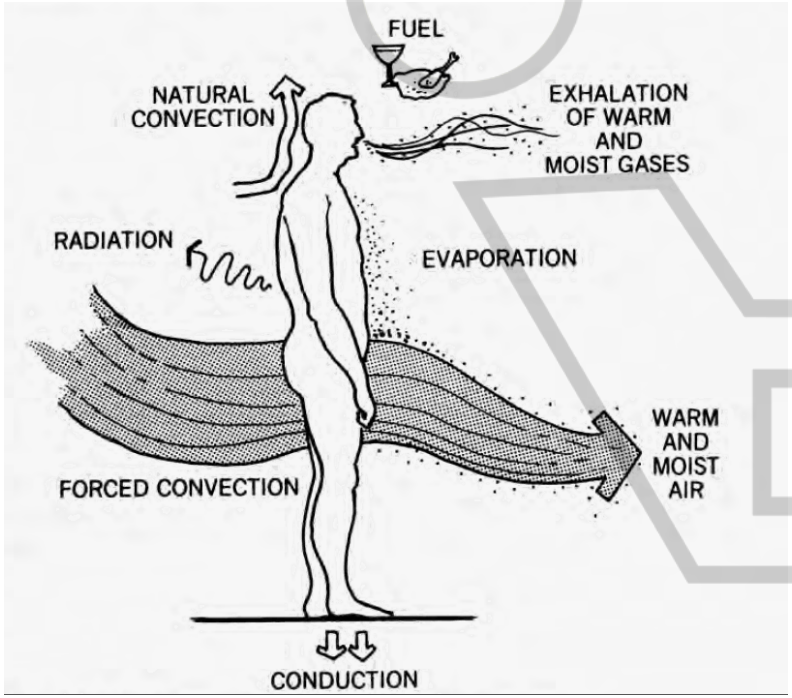
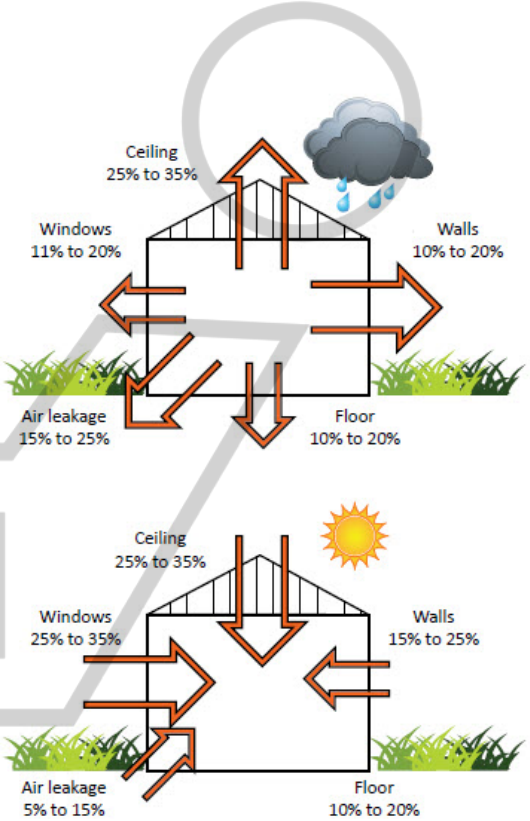
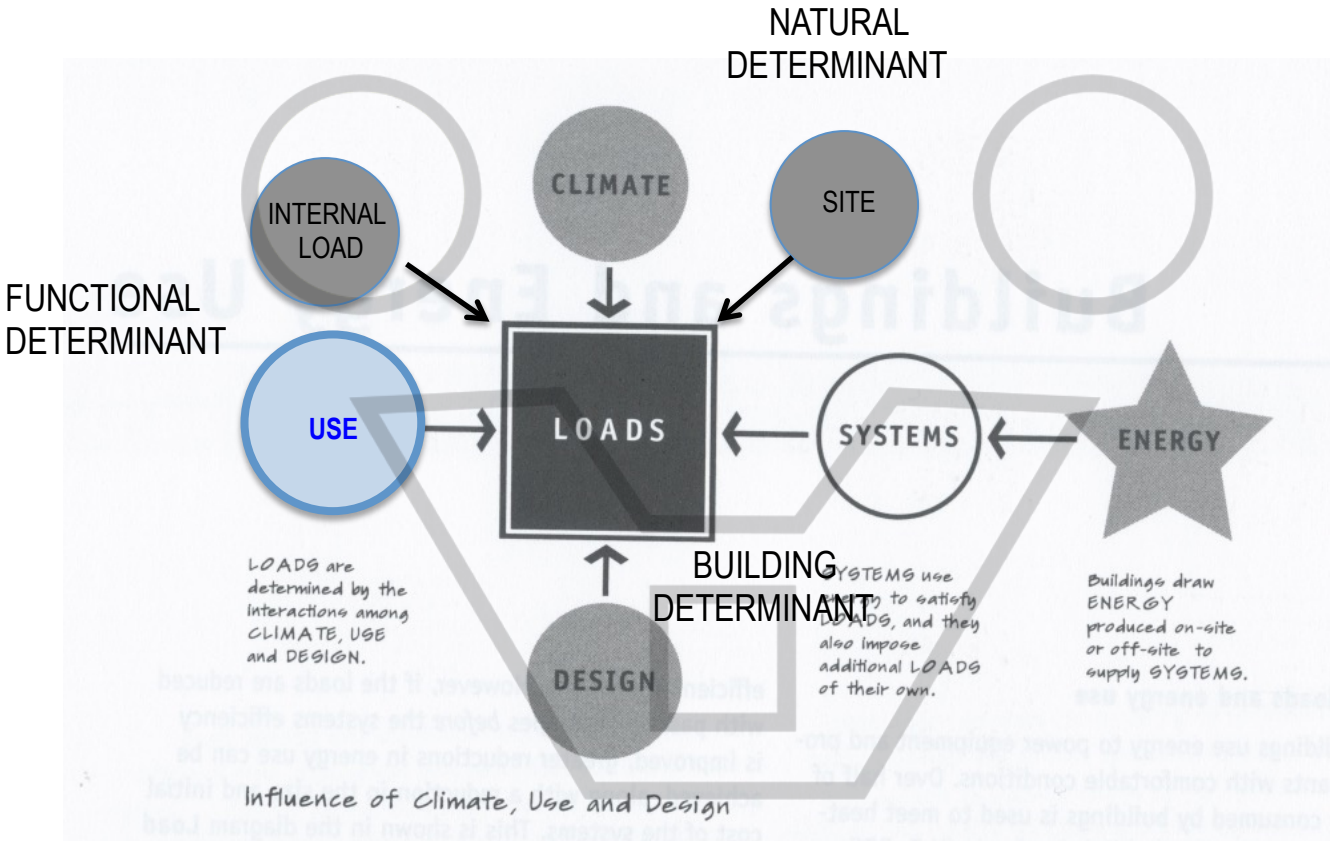
MODELING HUMAN BEHAVIORS AND COMPUTING COMFORT CONDITIONS

Energy mediator devices= Human skin & Building skin





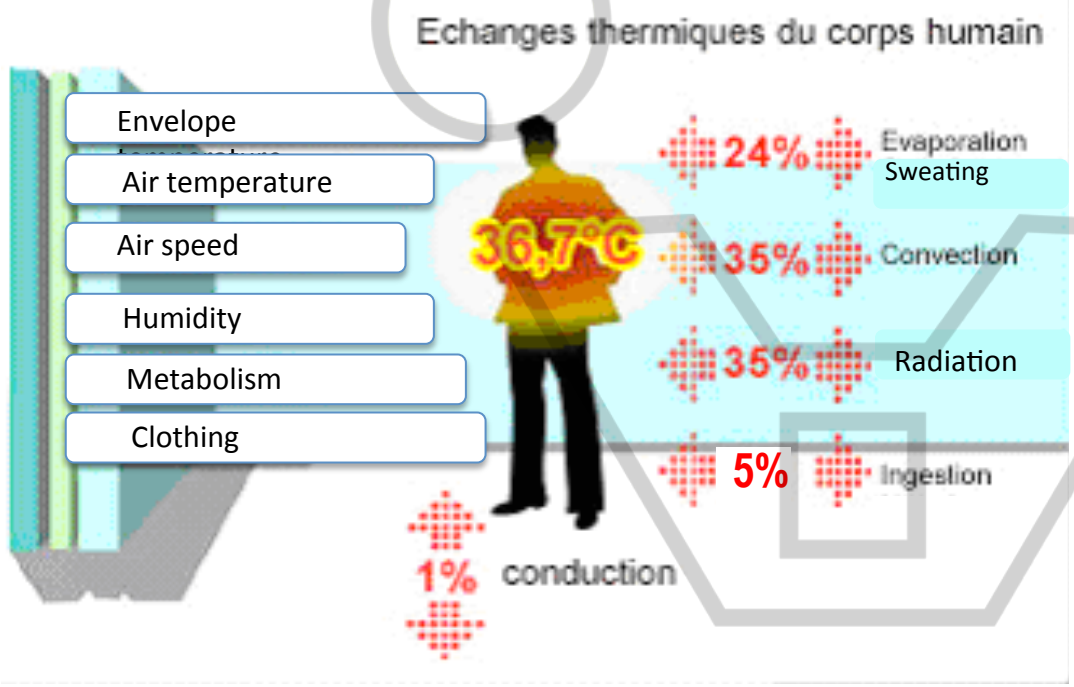
Environmental elements that affect people's comfort

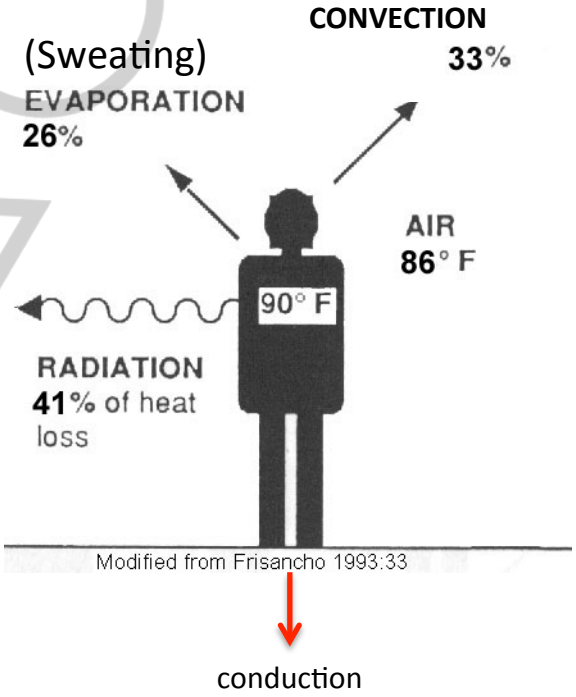


Environmental elements that affect people's comfort

Thermal comfort= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)

HOW THE BODY EXCHANGE THERMAL ENERGY





Environmental elements that affect people's comfort

Thermal comfort= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)

HOW THE BODY EXCHANGE THERMAL ENERGY

Environmental Temperature

Thermal comfort exists when a body's heat loss equals its heat gain or *vice versa*.
The body exchanges:
·62% of this heat via radiation,
·15% by evaporation,
·10% by convection,
·10% by respiration and
·3% by conduction.

http://www2.ecospecifier.org/

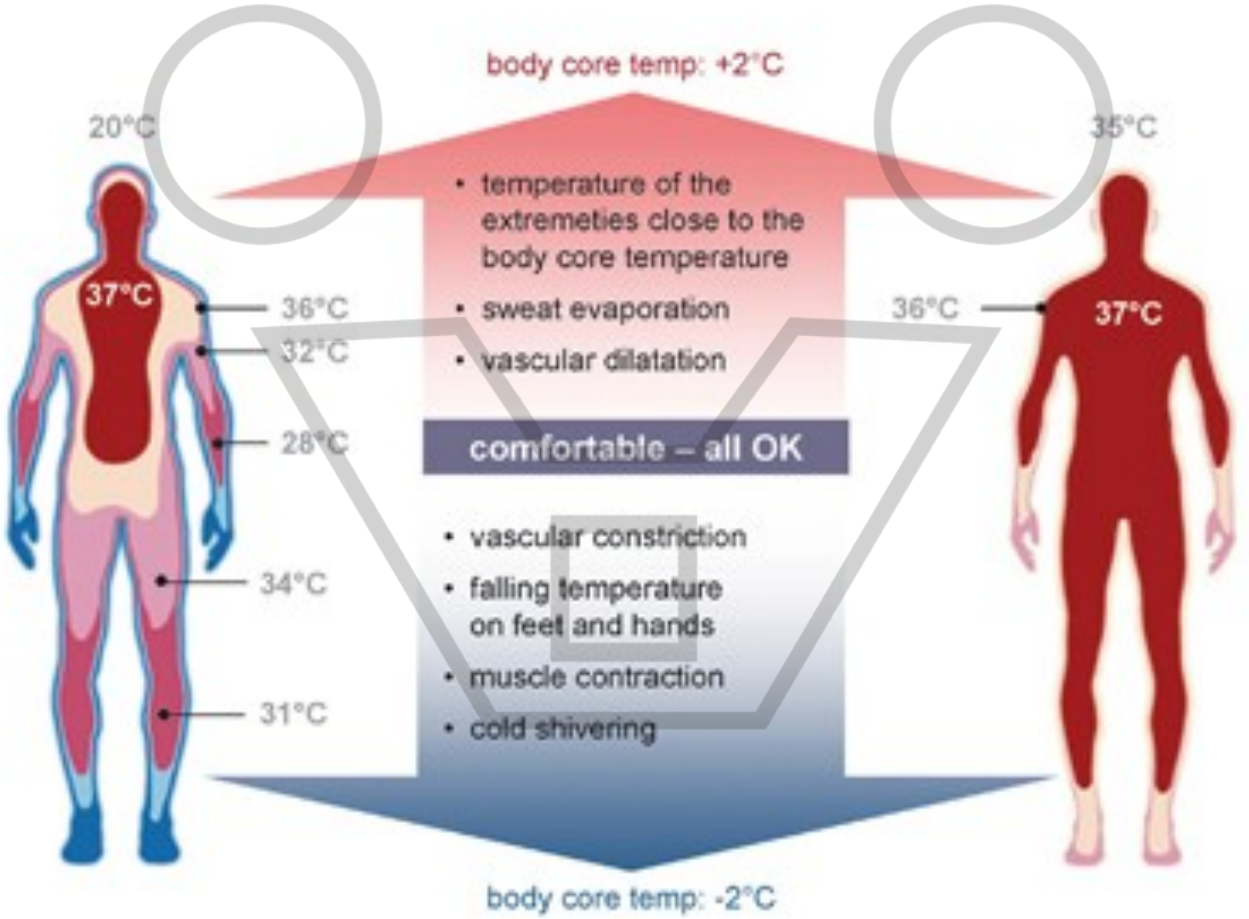
Relatively small changes in mean radiant temperature have a far greater effect than similar changes in air temperatures (Ballinger 1992).
This gives rise to the importance of recognising the overall Environmental Temperature [T(env)]*, as opposed to just the dry bulb temperature.*

T(env) = 2/3 Mean radiant surface temperature + 1/3 Air temperature

Environmental elements that affect people's comfort

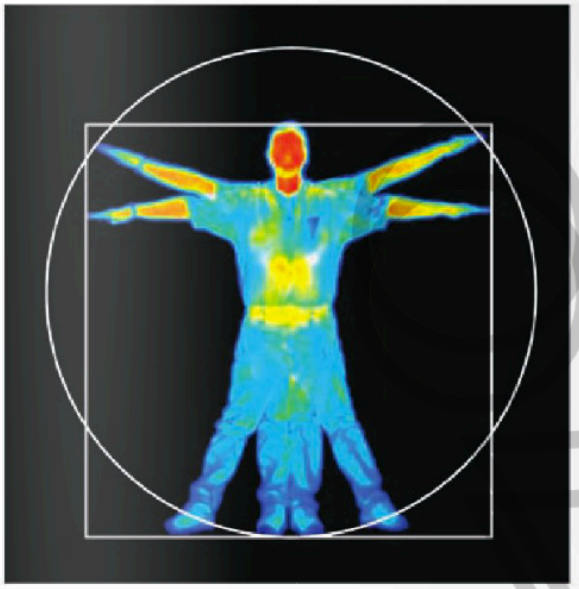
<u>Thermal comfort</u>= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)

Body actions to mantain thermal equilibrium

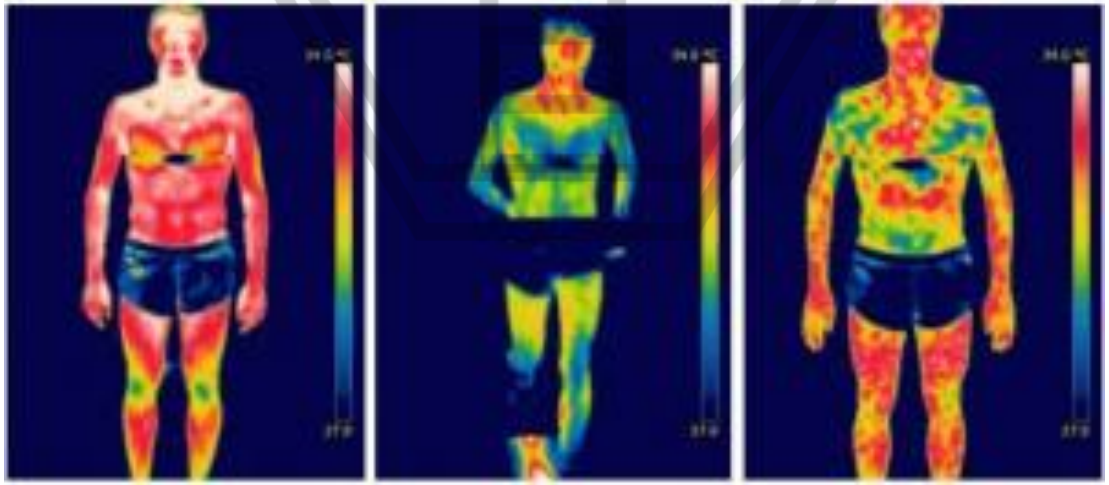


Environmental elements that affect people's comfort

<u>Thermal comfort</u>= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)



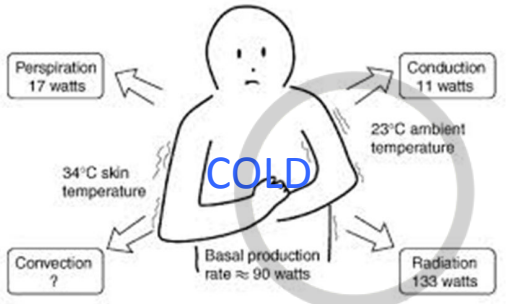
DIFFERENT HUMAN THERMAL ZONES

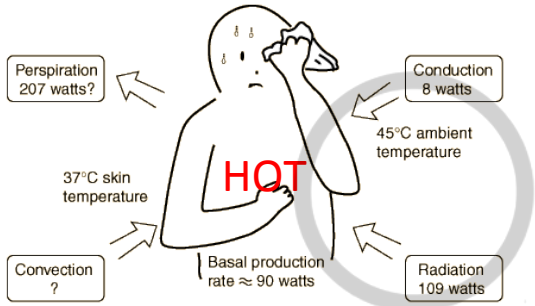


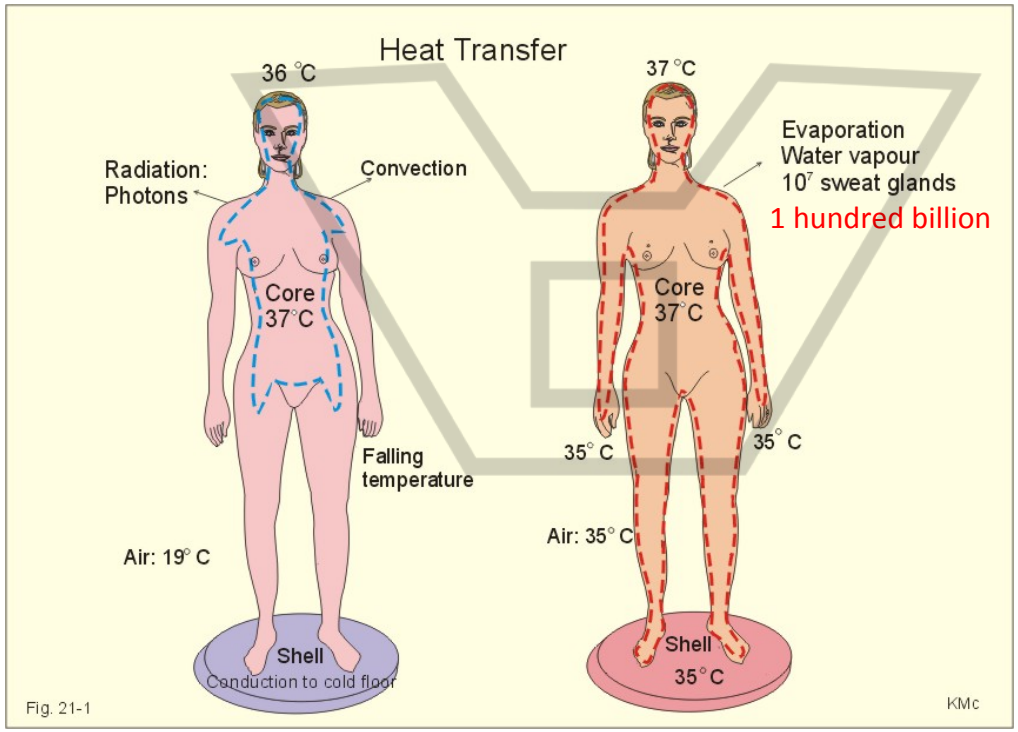
Environmental elements that affect people's comfort

Thermal comfort= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)

Body actions to mantain thermal equilibrium







Thermal comfort= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)

EFFECT OF WIND ON TEMPERATURE (Apparent Temperature)

	Wind Speed (mph)					
Temp (˚C)	10	20	30	40	50	60
20	17	15	14	13	12	11
15	12	9	7	6	5	4
10	7	3	1	0	-2	-3
5	2	-3	-5	-7	-9	-10
0	-4	-9	-11	-14	-16	-17
-5	-9	-15	-18	-21	-23	-24
-10	-15	-21	-25	-28	-30	-32
-15	-21	-27	-32	-35	-37	-39
-20	-27	-33	-38	-42	-45	-47
		Significant	Severe	Extreme		

Wind chill equivalent temperatures from Steadman

Environmental elements that affect people's comfort

<u>Thermal comfort</u>= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)

Apparent temperature (AT) as a Wind Chill - after Steadman 1994

Temperature (°C)

Wind Speed (km/h)	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	-8	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	8	9	10	11	12	14	15	16	17	19	20	21
2	-9	-8	-6	-5	-4	-3	-2	-1	0	1	2	4	5	6	7	8	10	11	12	13	15	16	17	18	20	21
4	-9	-8	-7	-6	-5	-4	-2	-1	0	1	2	3	4	6	7	8	9	10	12	13	14	15	17	18	19	21
6	-9	-8	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	8	9	10	11	12	14	15	16	18	19	20
8	-10	-9	-8	-7	-5	-4	-3	-2	-1	0	1	2	4	5	6	7	8	10	11	12	13	15	16	17	19	20
10	-10	-9	-8	-7	-6	-5	-4	-2	-1	0	1	2	3	4	6	7	8	9	10	12	13	14	16	17	18	20
12	-11	-9	-8	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	8	9	10	11	13	14	15	16	18	19
14	-11	-10	-9	-8	-7	-5	-4	-3	-2	-1	0	1	2	4	5	6	7	8	10	11	12	13	15	16	17	19
16	-11	-10	-9	-8	-7	-6	-5	-4	-3	-1	0	1	2	3	4	6	7	8	9	11	12	13	14	16	17	18
18	-12	-11	-10	-8	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	8	9	10	11	13	14	15	17	18
20	-12	-11	-10	-9	-8	-7	-6	-4	-3	-2	-1	0	1	2	4	5	6	7	9	10	11	12	14	15	16	18
22	-13	-11	-10	-9	-8	-7	-6	-5	-4	-3	-1	0	1	2	3	4	6	7	8	9	11	12	13	15	16	17
24	-13	-12	-11	-10	-9	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	8	9	10	12	13	14	15	17
26	-13	-12	-11	-10	-9	-8	-7	-6	-4	-3	-2	-1	0	1	2	4	5	6	7	9	10	11	12	14	15	16
28	-14	-13	-12	-10	-9	-8	-7	-6	-5	-4	-3	-1	0	1	2	3	5	6	7	8	9	11	12	13	15	16
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Apparent temperature with no radiational heating and relative humidity fixed at 70%

Formula from *Norms of apparent temperature in Australia* , **Aust. Met. Mag**, Vol 43, 1994, 1-16.

Environmental elements that affect people's comfort

<u>Thermal comfort</u>= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)

WIND CHILL- Siple e Passel del 1945 reviewed in 2001

Wind Speed (km/hr)	Air Temperature (Celsius)																
	0	-1	-2	-3	-4	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50	-55	-60
6	-2	-3	-4	-5	-7	-8	-14	-19	-25	-31	-37	-42	-48	-54	-60	-65	-71
8	-3	-4	-5	-6	-7	-9	-14	-20	-26	-32	-38	-44	-50	-56	-61	-67	-73
10	-3	-5	-6	-7	-8	-9	-15	-21	-27	-33	-39	-45	-51	-57	-63	-69	-75
15	-4	-6	-7	-8	-9	-11	-17	-23	-29	-35	-41	-48	-54	-60	-66	-72	-78
20	-5	-7	-8	-9	-10	-12	-18	-24	-30	-37	-43	-49	-56	-62	-68	-75	-81
25	-6	-7	-8	-10	-11	-12	-19	-25	-32	-38	-44	-51	-57	-64	-70	-77	-83
30	-6	-8	-9	-10	-12	-13	-20	-26	-33	-39	-46	-52	-59	-65	-72	-78	-85
35	-7	-8	-10	-11	-12	-14	-20	-27	-33	-40	-47	-53	-60	-66	-73	-80	-86
40	-7	-9	-10	-11	-13	-14	-21	-27	-34	-41	-48	-54	-61	-68	-74	-81	-88
45	-8	-9	-10	-12	-13	-15	-21	-28	-35	-42	-48	-55	-62	-69	-75	-82	-89
50	-8	-10	-11	-12	-14	-15	-22	-29	-35	-42	-49	-56	-63	-69	-76	-83	-90
55	-8	-10	-11	-13	-14	-15	-22	-29	-36	-43	-50	-57	-63	-70	-77	-84	-91
60	-9	-10	-12	-13	-14	-16	-23	-30	-36	-43	-50	-57	-64	-71	-78	-85	-92
65	-9	-10	-12	-13	-15	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
70	-9	-11	-12	-14	-15	-16	-23	-30	-37	-44	-51	-58	-65	-72	-80	-87	-94
75	-10	-11	-12	-14	-15	-17	-24	-31	-38	-45	-52	-59	-66	-73	-80	-87	-94
80	-10	-11	-13	-14	-15	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
85	-10	-11	-13	-14	-16	-17	-24	-31	-39	-46	-53	-60	-67	-74	-81	-89	-96
90	-10	-12	-13	-15	-16	-17	-25	-32	-39	-46	-53	-61	-68	-75	-82	-89	-96
95	-10	-12	-13	-15	-16	-18	-25	-32	-39	-47	-54	-61	-68	-75	-83	-90	-97
100	-11	-12	-14	-15	-16	-18	-25	-32	-40	-47	-54	-61	-69	-76	-83	-90	-98
105	-11	-12	-14	-15	-17	-18	-25	-33	-40	-47	-55	-62	-69	-76	-84	-91	-98
110	-11	-12	-14	-15	-17	-18	-26	-33	-40	-48	-55	-62	-70	-77	-84	-91	-99
	0 to -10 Low			-10 to -25 Moderate			-25 to - 45 Cold			-45 to -59 Extreme			-60 Plus very Extreme				

Environmental elements that affect people's comfort

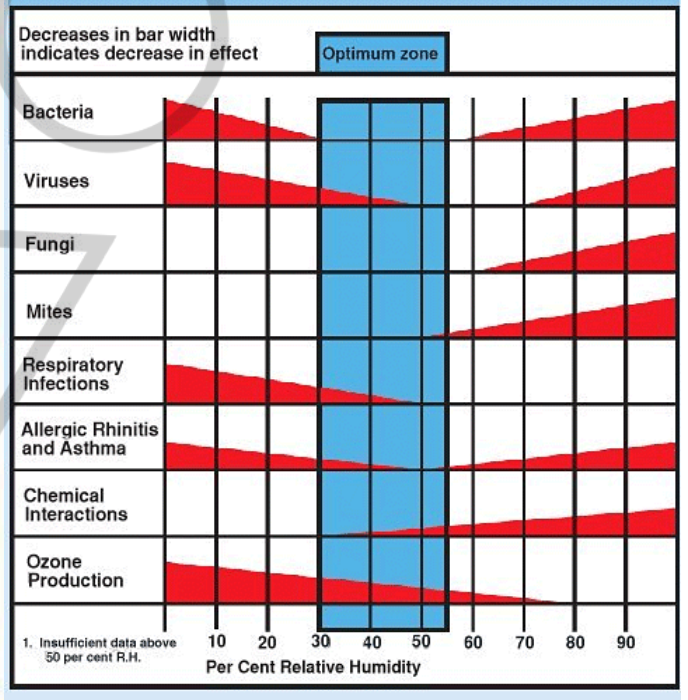
<u>Thermal comfort</u>= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)

HUMIDEX- PERCEIVED TEMPERATURE AND DISCOMFORT INDEX (range 20°C-55°C)

	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
42°	48	50	52	55	57	59	62	64	66	68	71	73	75	77	80	82
41°	46	48	51	53	55	57	59	61	64	66	68	70	72	74	76	79
40°	45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75
39°	43	45	47	49	51	53	55	57	59	61	63	65	66	68	70	72
38°	42	44	45	47	49	51	53	55	56	58	60	62	64	66	67	69
37°	40	42	44	45	47	49	51	52	54	56	58	59	61	63	65	66
36°	39	40	42	44	45	47	49	50	52	54	55	57	59	60	62	63
35°	37	39	40	42	44	45	47	48	50	51	53	54	56	58	59	61
34°	36	37	39	40	42	43	45	46	48	49	51	52	54	55	57	58
33°	34	36	37	39	40	41	43	44	46	47	48	50	51	53	54	55
32°	33	34	36	37	38	40	41	42	44	45	46	48	49	50	52	53
31°	32	33	34	35	37	38	39	40	42	43	44	45	47	48	49	50
30°	30	32	33	34	35	36	37	39	40	41	42	43	45	46	47	48
29°	29	30	31	32	33	35	36	37	38	39	40	41	42	43	45	46
28°	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
27°	27	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
26°	26	26	27	28	29	30	31	32	33	34	34	35	36	37	38	39
25°	25	25	26	27	27	28	29	30	31	32	33	34	34	35	36	37
24°	24	24	24	25	26	27	28	28	29	30	31	32	33	33	34	35
23°	23	23	23	24	25	25	26	27	28	28	29	30	31	32	32	33
22°	22	22	22	22	23	24	25	25	26	27	27	28	29	30	30	31

Fino a 29 C°	Nessun disagio
Da 30 a 34 C°	Sensazione di disagio
Da 35 a 39 C°	Intenso disagio. Prudenza: limitare le attività fisiche più pesanti
Da 40 a 45 C°	Forte sensazione di malessere. Pericolo: evitare gli sforzi
Da 46 a 53 C°	Pericolo grave: interrompere tutte le attività fisiche
Oltre 54 C°	Pericolo di morte: colpo di calore imminente

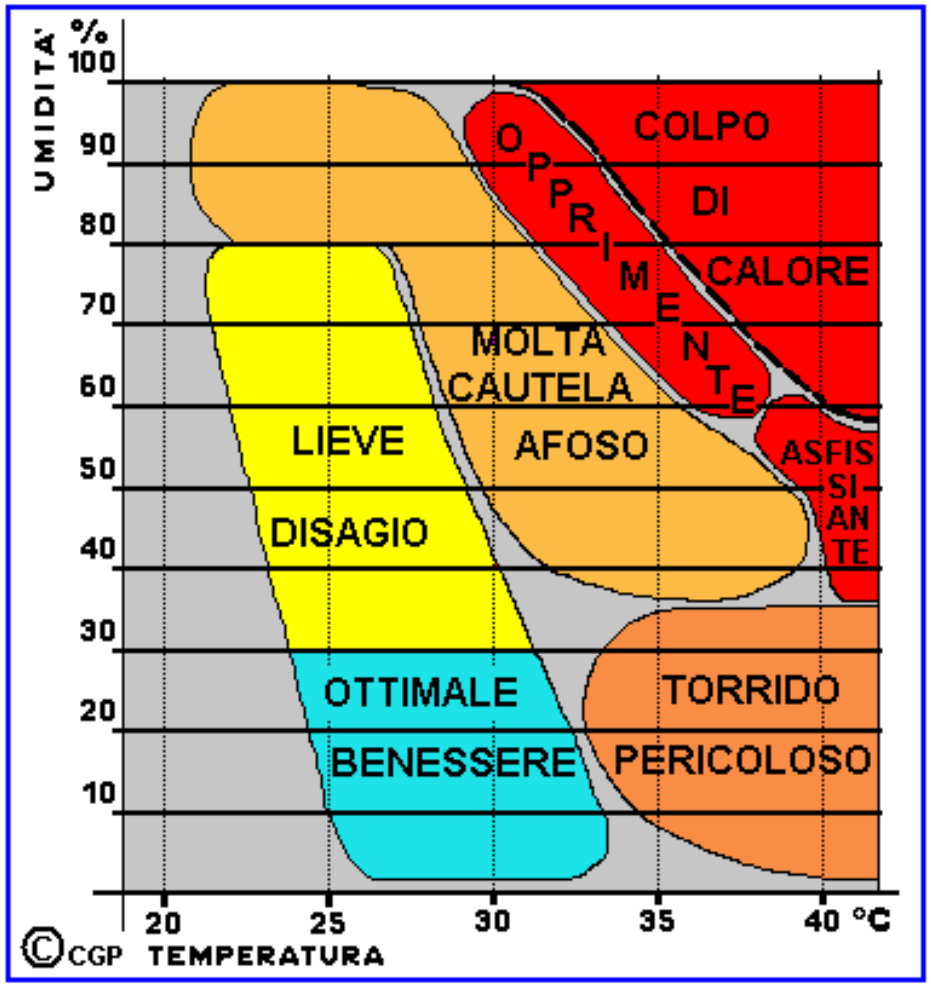
OPTIMUM INDOOR RELATIVE HUMIDITY & AIR QUALITY GUIDE



Environmental elements that affect people's comfort

<u>Thermal comfort</u>= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)

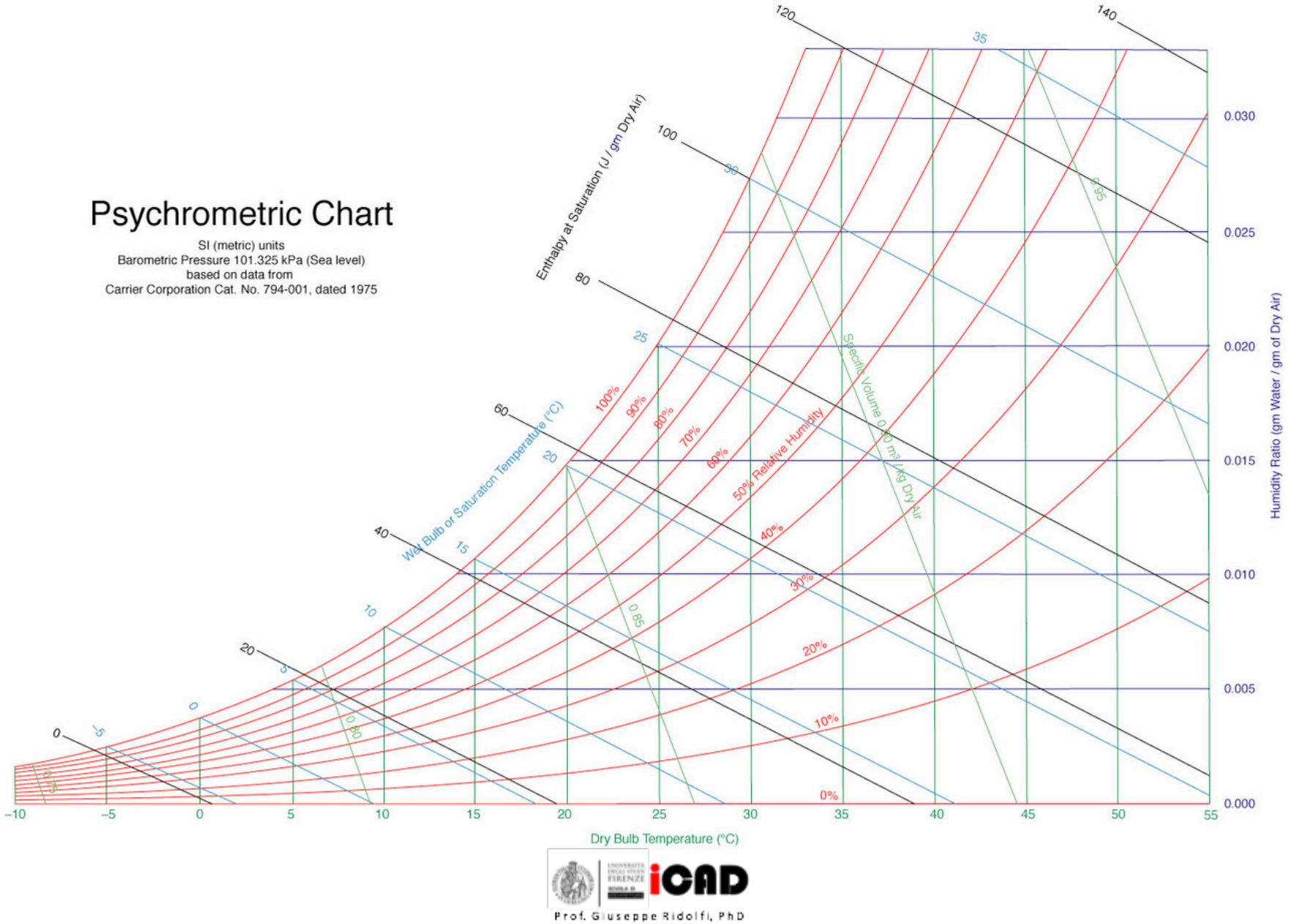
HUMIDEX- PERCEIVED TEMPERATURE AND DISCOMFORT INDEX
(range 20°C-55°C)



Prof. Giuseppe Ridolfi, PhD

Environmental elements that affect people's comfort

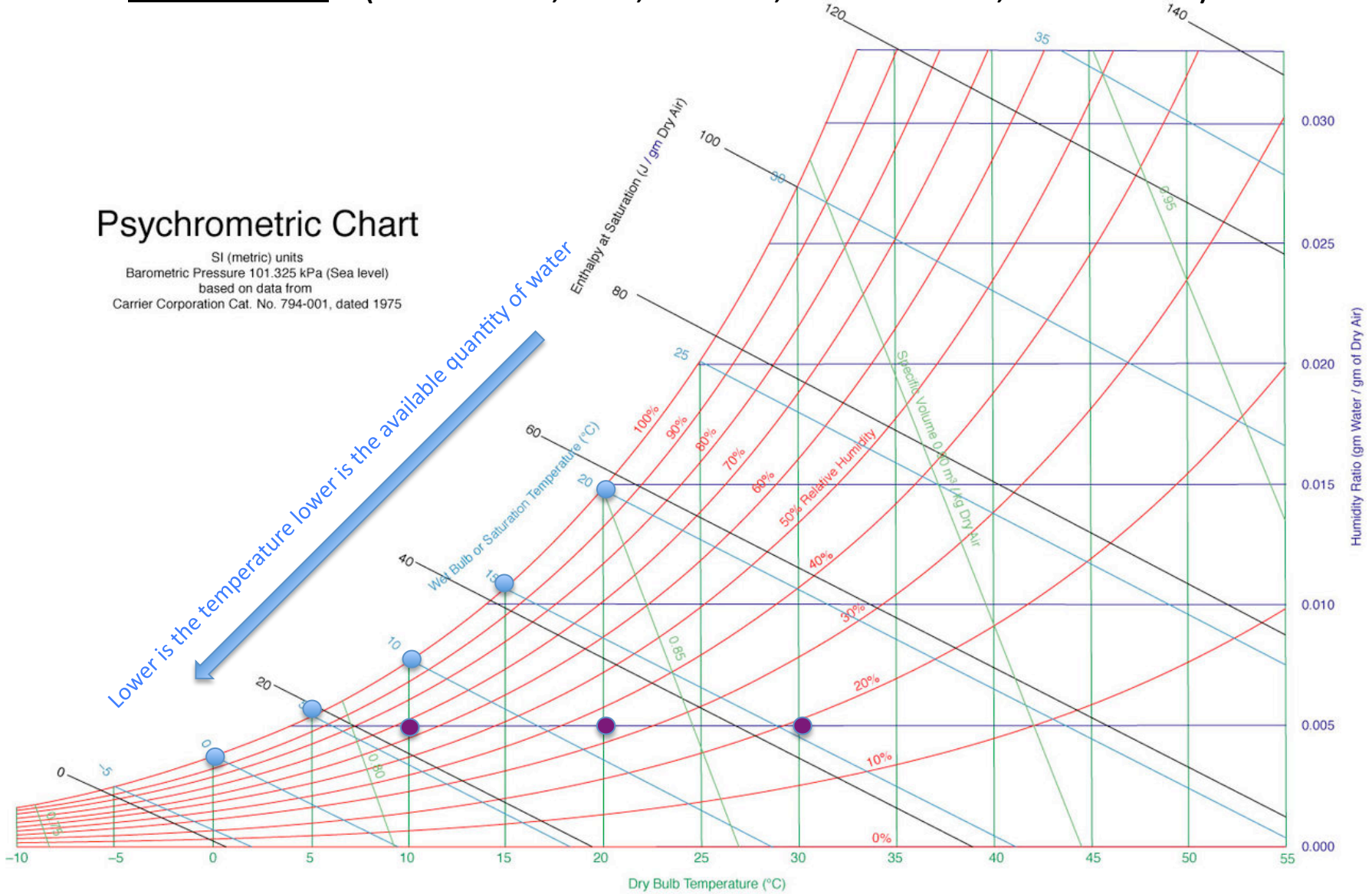
<u>Thermal comfort</u>= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)



Prof. Giuseppe Ridolfi, PhD

Environmental elements that affect people's comfort

Thermal comfort= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)



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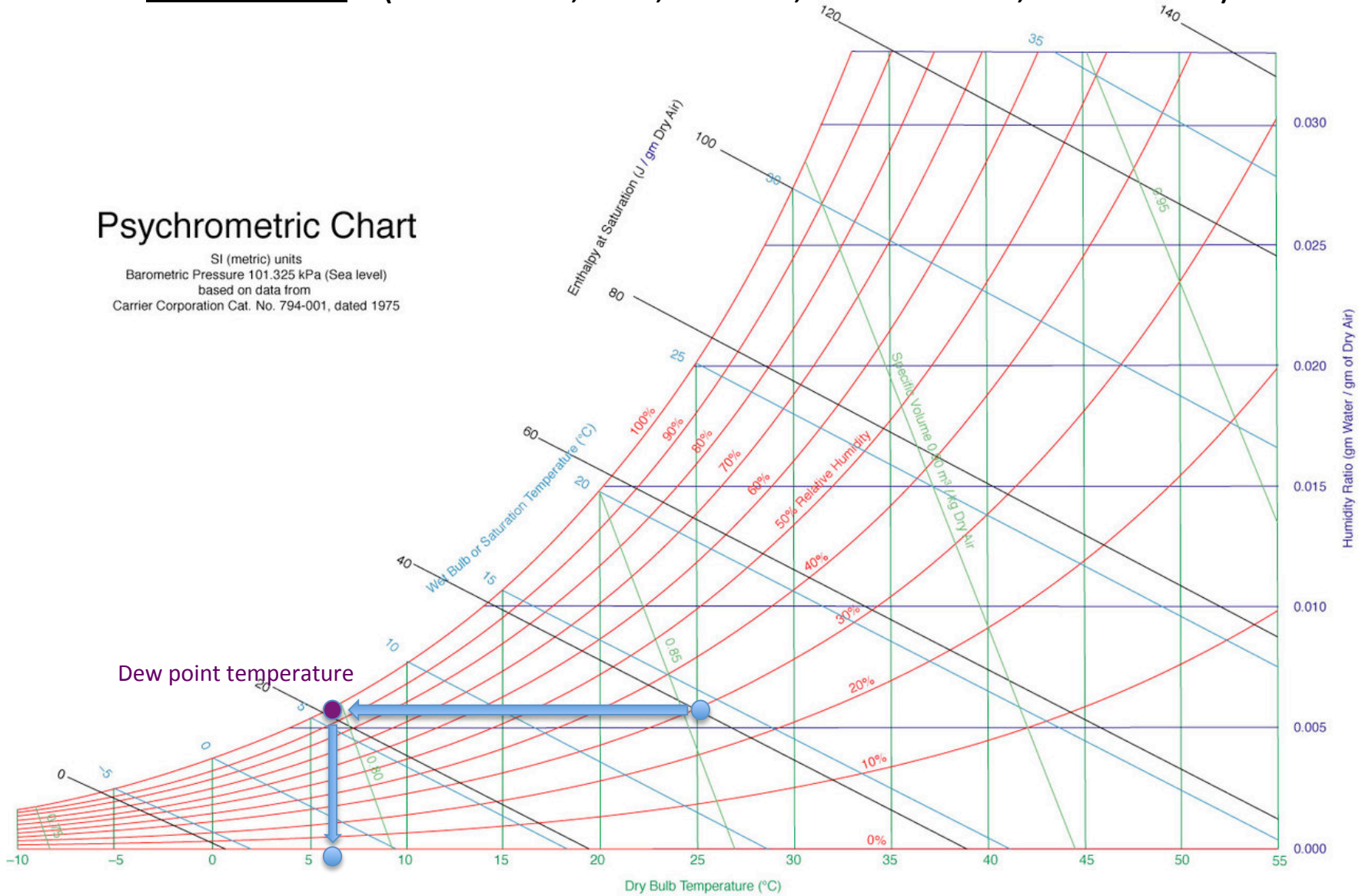

Prof. Giuseppe Ridolfi, PhD

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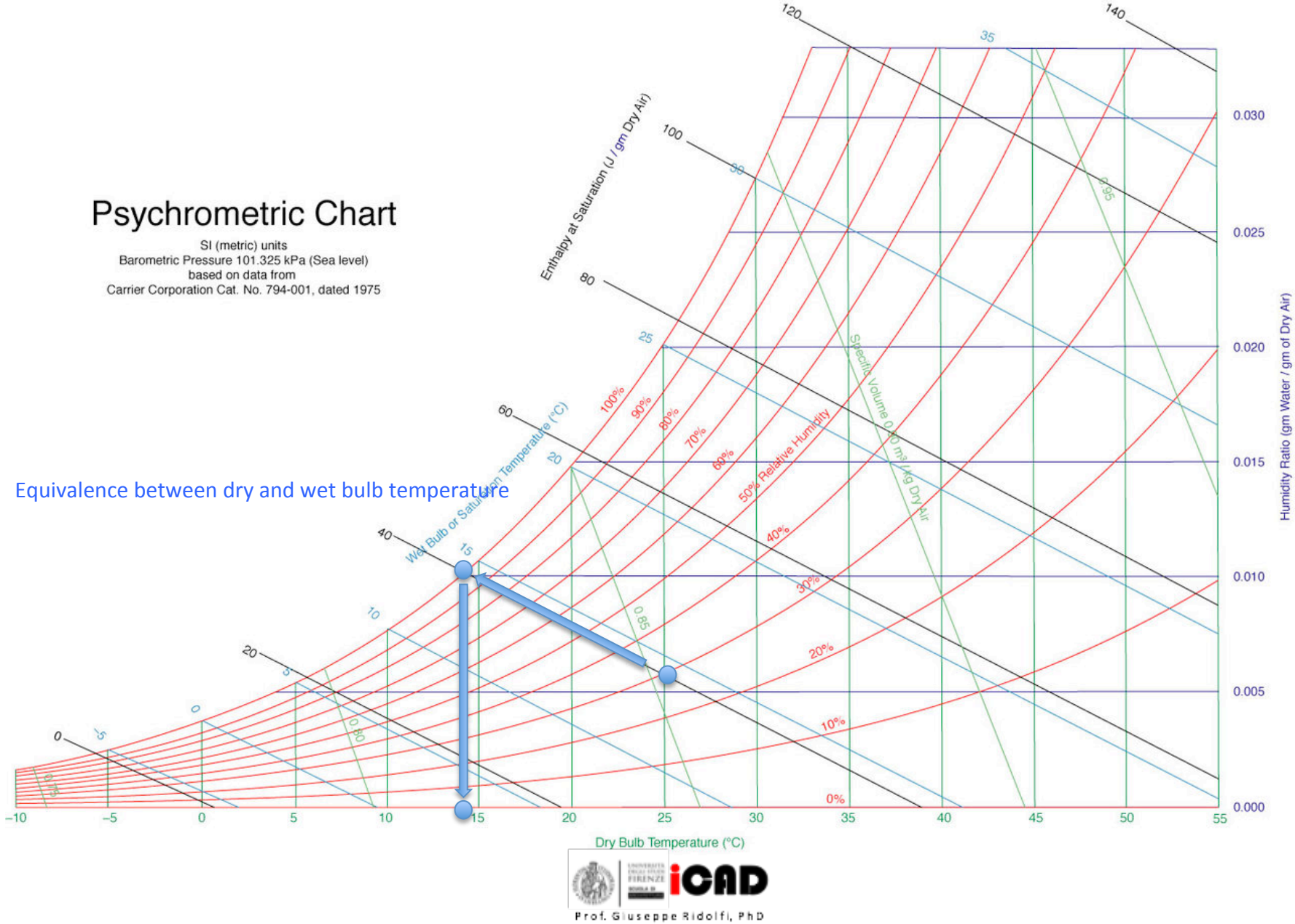


Equivalence between dry and wet bulb temperature

Prof. Giuseppe Ridolfi, PhD

Environmental elements that affect people's comfort

Thermal comfort= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)

EFFECTIVE TEMPERATURE & THERMAL COMFORT ZONE

	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
42°	48	50	52	55	57		62	64	66	68	71	73	75	77	80	82
41°	46	48	51	53	55	57	59	61	64	66	68	70	72	74	76	79
40°	45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75
39°	43	45	47	49	51	53	55	57	59	61	63	65	66	68	70	72
38°	42	44	45	47	49	51	53	55	56	58	60	62	64	66	67	69
37°	40	42	44	45	47	49	51	52	54	56	58	59	61	63	65	66
36°	39	40	42	44	45	47	49	50	52	54	55	57	59	60	62	63
35°	37	39	40	42	44	45	47	48	50	51	53	54	56	58	59	61
34°	36	37	39	40	42	43	45	46	48	49	51	52	54	55	57	58
33°	34	36	37	39	40	41	43	44	46	47	48	50	51	53	54	55
32°	33	34	36	37	38	40	41	42	44	45	46	48	49	50	52	53
31°	32	33	34	35	37	38	39	40	42	43	44	45	47	48	49	50
30°	30	32	33	34	35	36	37	39	40	41	42	43	45	46	47	48
29°	29	30	31	32	33	35	36	37	38	39	40	41	42	43	45	46
28°	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
27°	27	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
26°	26	26	27	28	29	30	31	32	33	34	34	35	36	37	38	39
25°	25	25	26	27	27	28	29	30	31	32	33	34	34	35	36	37
24°	24	24	24	25	26	27	28	28	29	30	31	32	33	33	34	35
23°	23	23	23	24	25	25	26	27	28	28	29	30	31	32	32	33
22°	22	22	22	22	23	24	25	25	26	27	27	28	29	30	30	31

Fino a 29 C°	Nessun disagio
Da 30 a 34 C°	Sensazione di disagio
Da 35 a 39 C°	Intenso disagio. Prudenza: limitare le attività fisiche più pesanti
Da 40 a 45 C°	Forte sensazione di malessere. Pericolo: evitare gli sforzi
Da 46 a 53 C°	Pericolo grave: interrompere tutte le attività fisiche
Oltre 54 C°	Pericolo di morte: colpo di calore imminente

The humidex is a Canadian creation first used in 1965

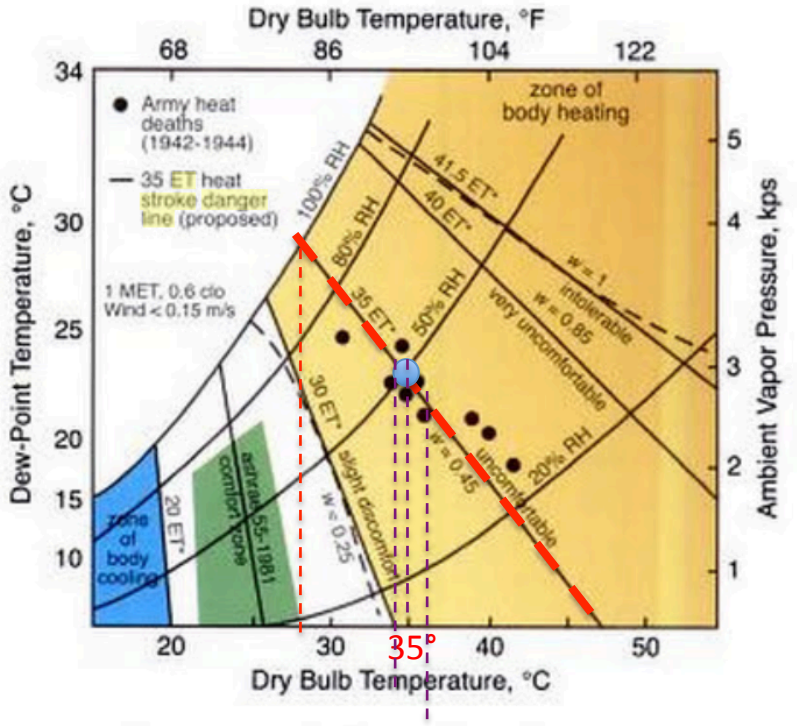
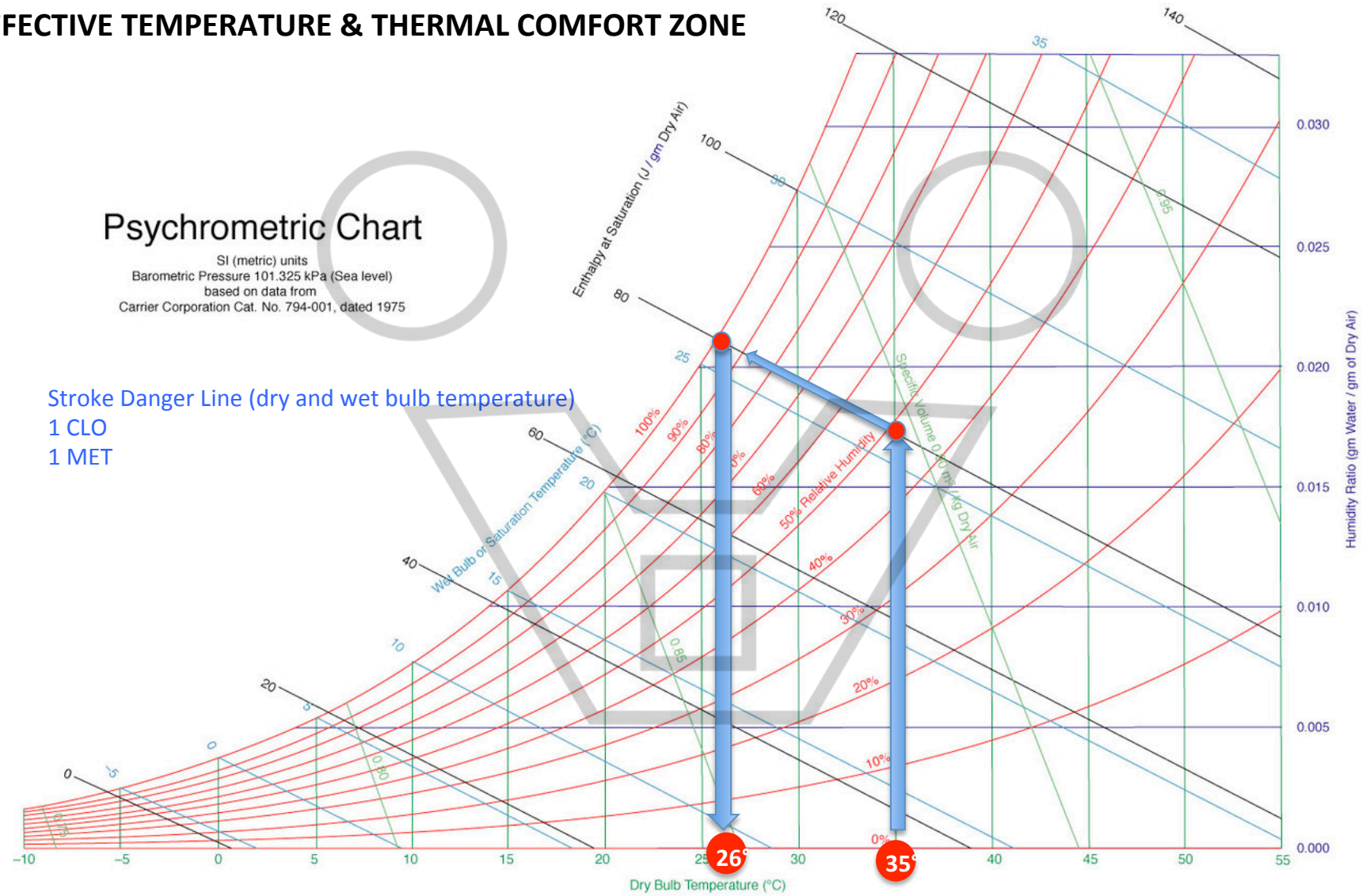


Fig. 8-8. Nomogram for the "new," effective temperature (ET*), including data points for US Army heat deaths provided by Hardy. ashrae: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc; clo: unit of clothing insulation, 1 clo = 0.155 m^2 K/W; MET: unit of metabolism, 1 MET = 58.15 W/m^2. RH: relative humidity. Illustration: Adapted with permission from ASHRAE. Copyright 2005 © American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc (www.ashrae.org). Reprinted with permission from the *2005 ASHRAE Handbook—Fundamentals*. (This text may not be copied nor distributed in either paper or digital form without ASHRAE's permission.) Data source: Hardy JD. Thermal comfort and health. *ASHRAE J.* 1971;13:43.

Environmental elements that affect people's comfort

Thermal comfort= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)

EFFECTIVE TEMPERATURE & THERMAL COMFORT ZONE

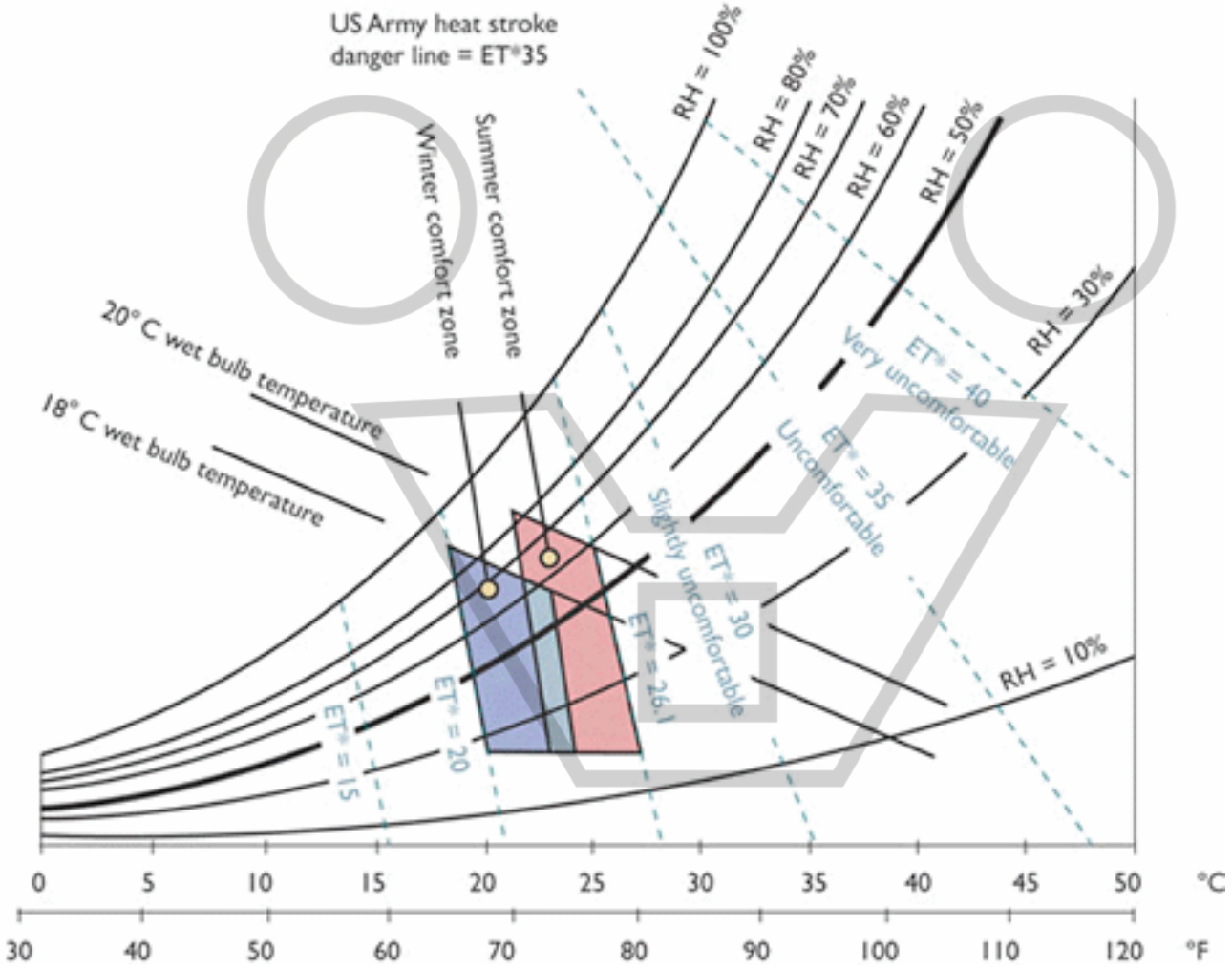


Stroke Danger Line (dry and wet bulb temperature)
1 CLO
1 MET

Environmental elements that affect people's comfort

Thermal comfort= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)

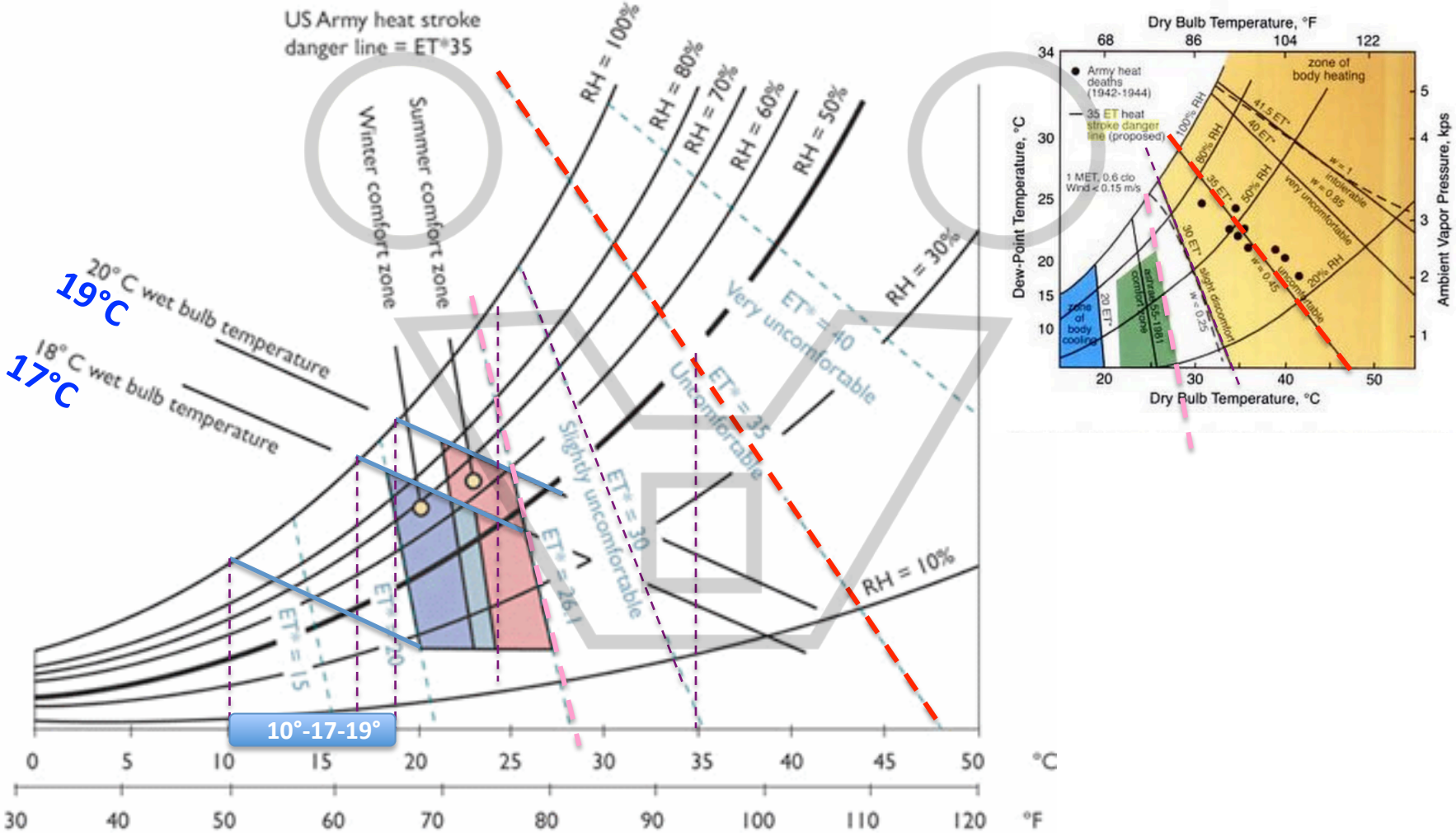
EFFECTIVE TEMPERATURE & THERMAL COMFORT ZONE



Environmental elements that affect people's comfort

Thermal comfort= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)

EFFECTIVE TEMPERATURE & THERMAL COMFORT ZONE _ Using wet bulb temperature



Environmental elements that affect people's comfort

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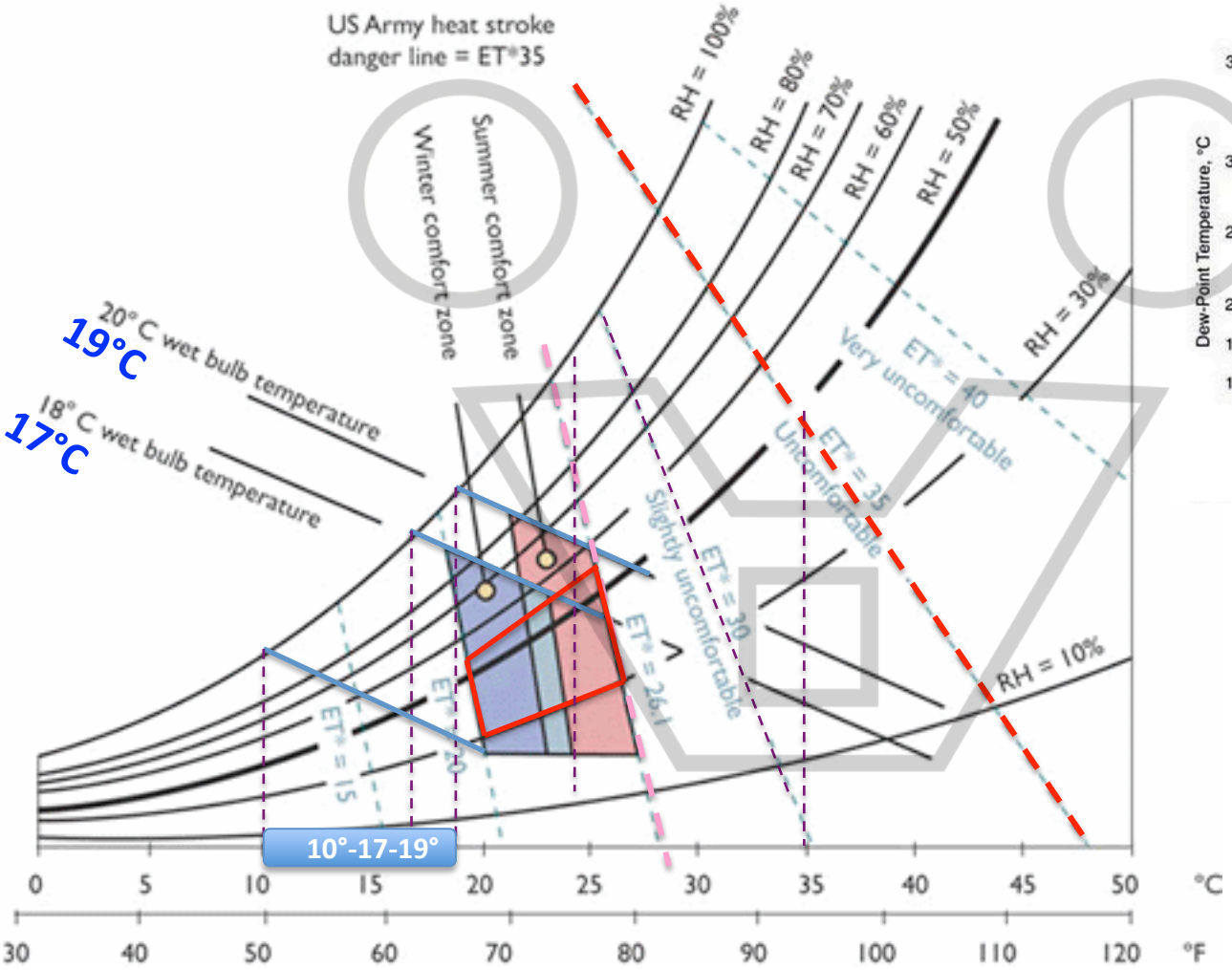
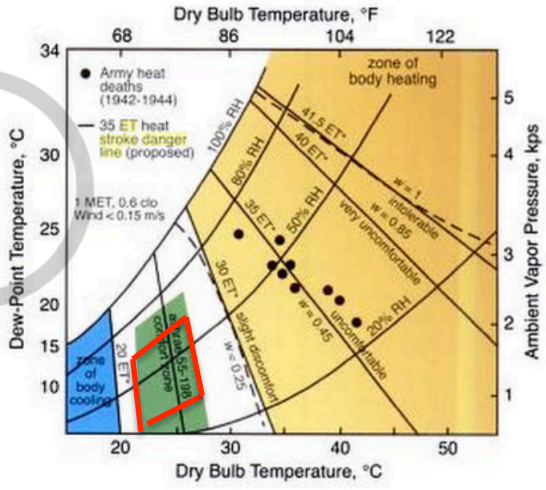
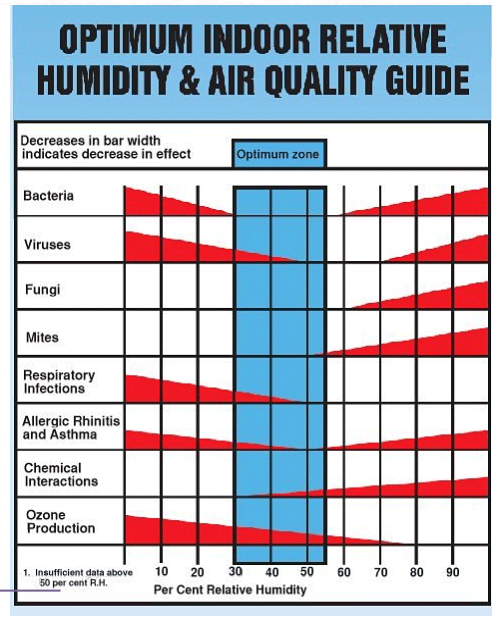
EFFECTIVE TEMPERATURE & THERMAL COMFORT ZONE _ Using wet bulb temperature







Environmental elements that affect people's comfort

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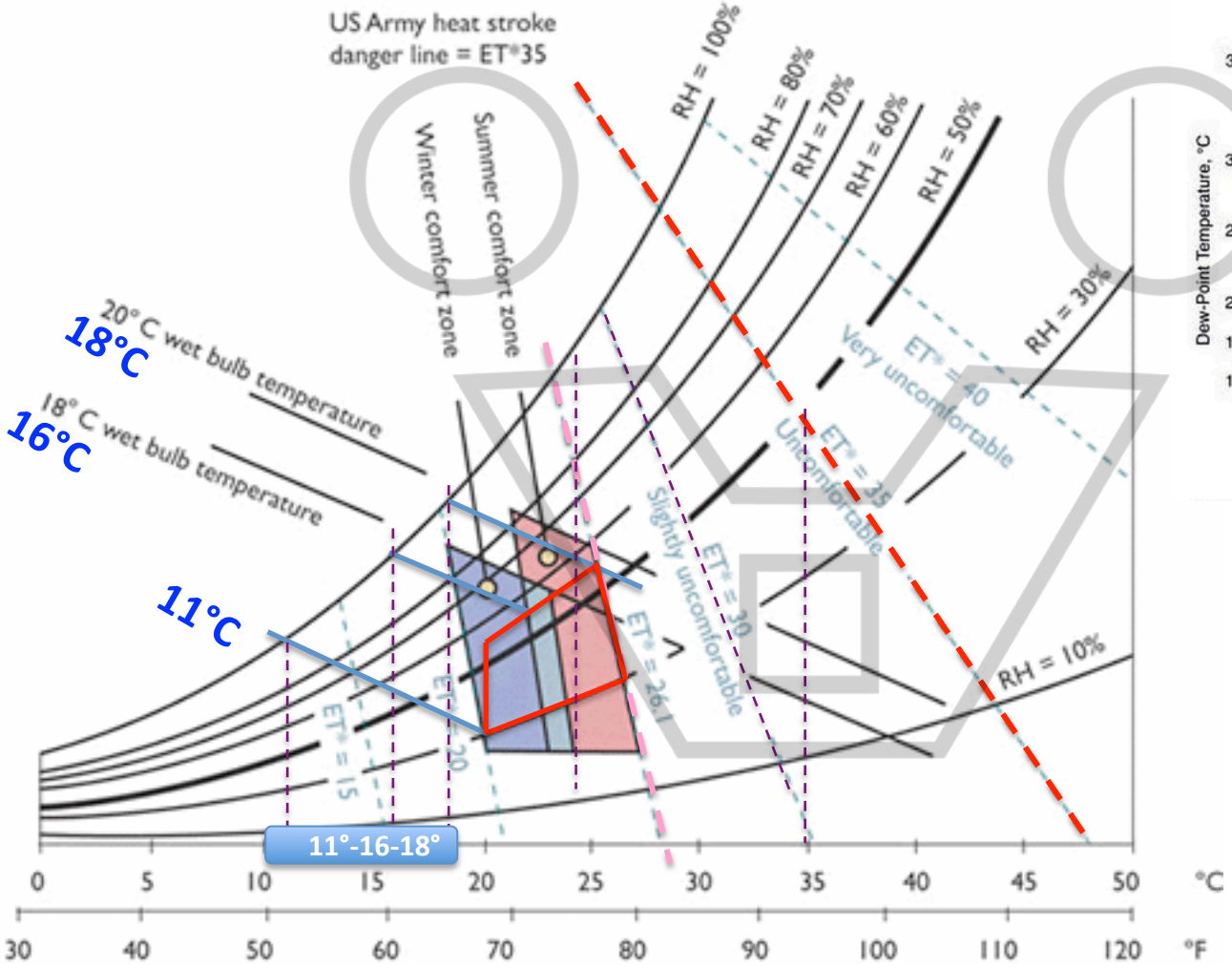
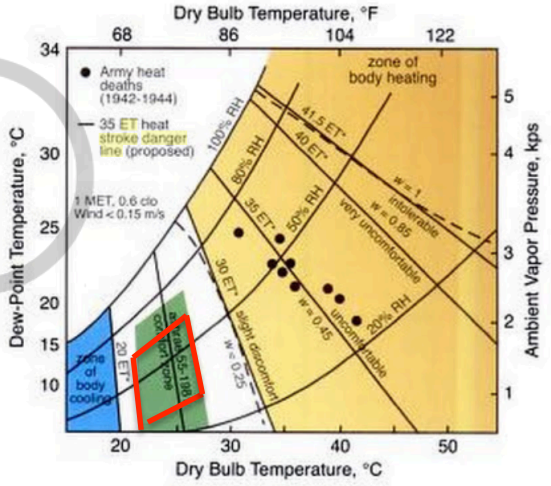
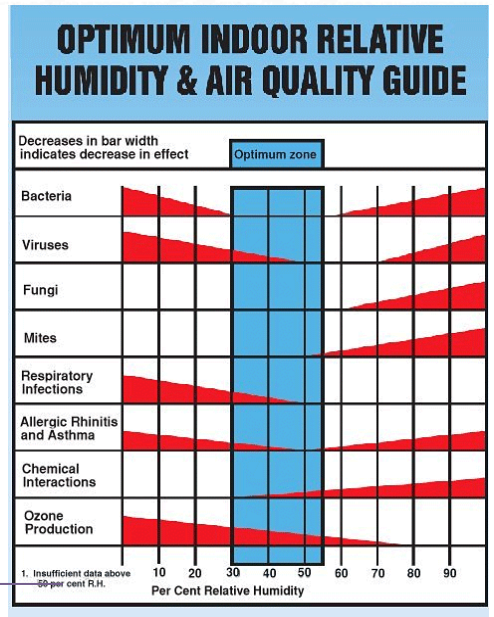
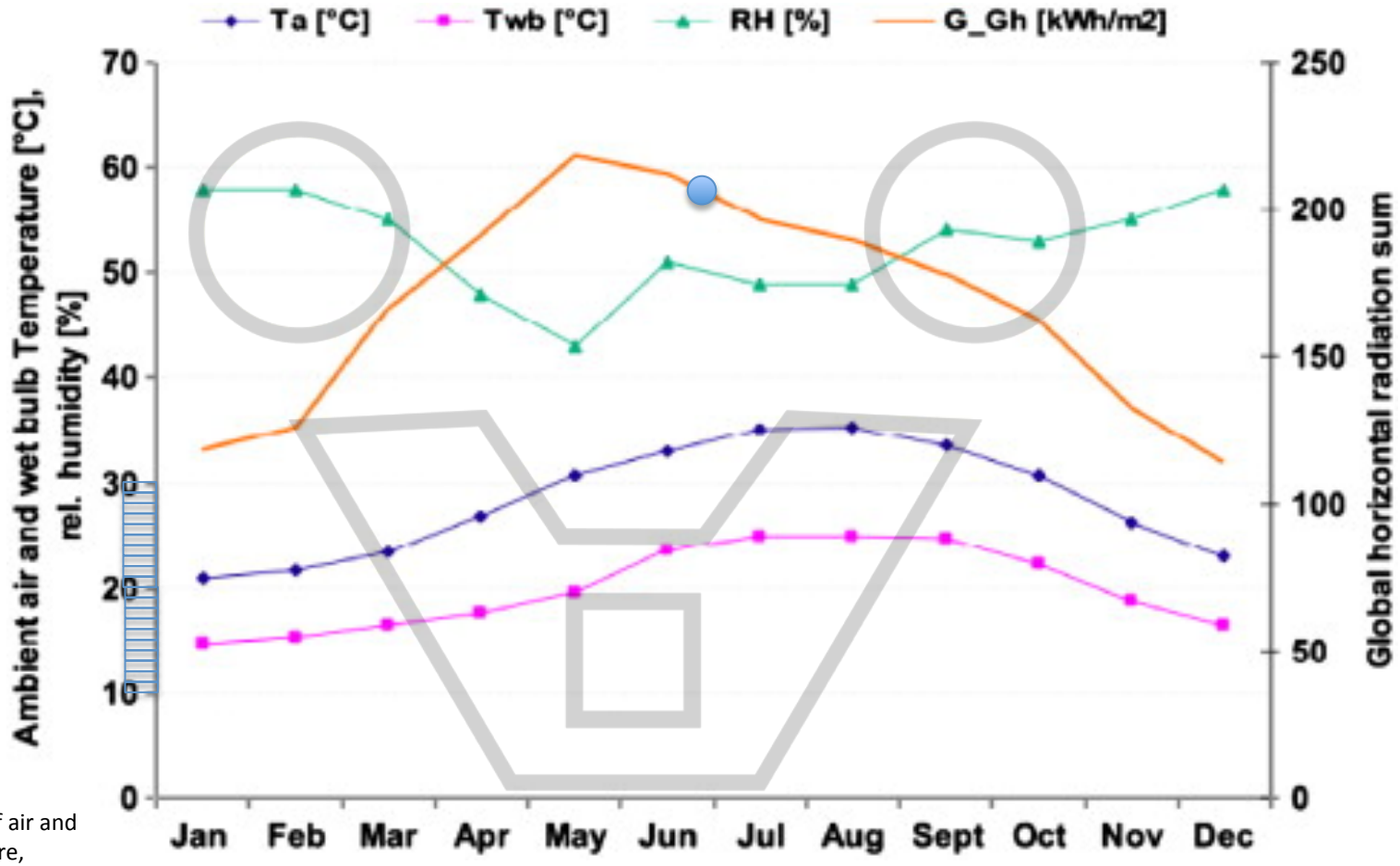
EFFECTIVE TEMPERATURE & THERMAL COMFORT ZONE _ Using wet bulb temperature





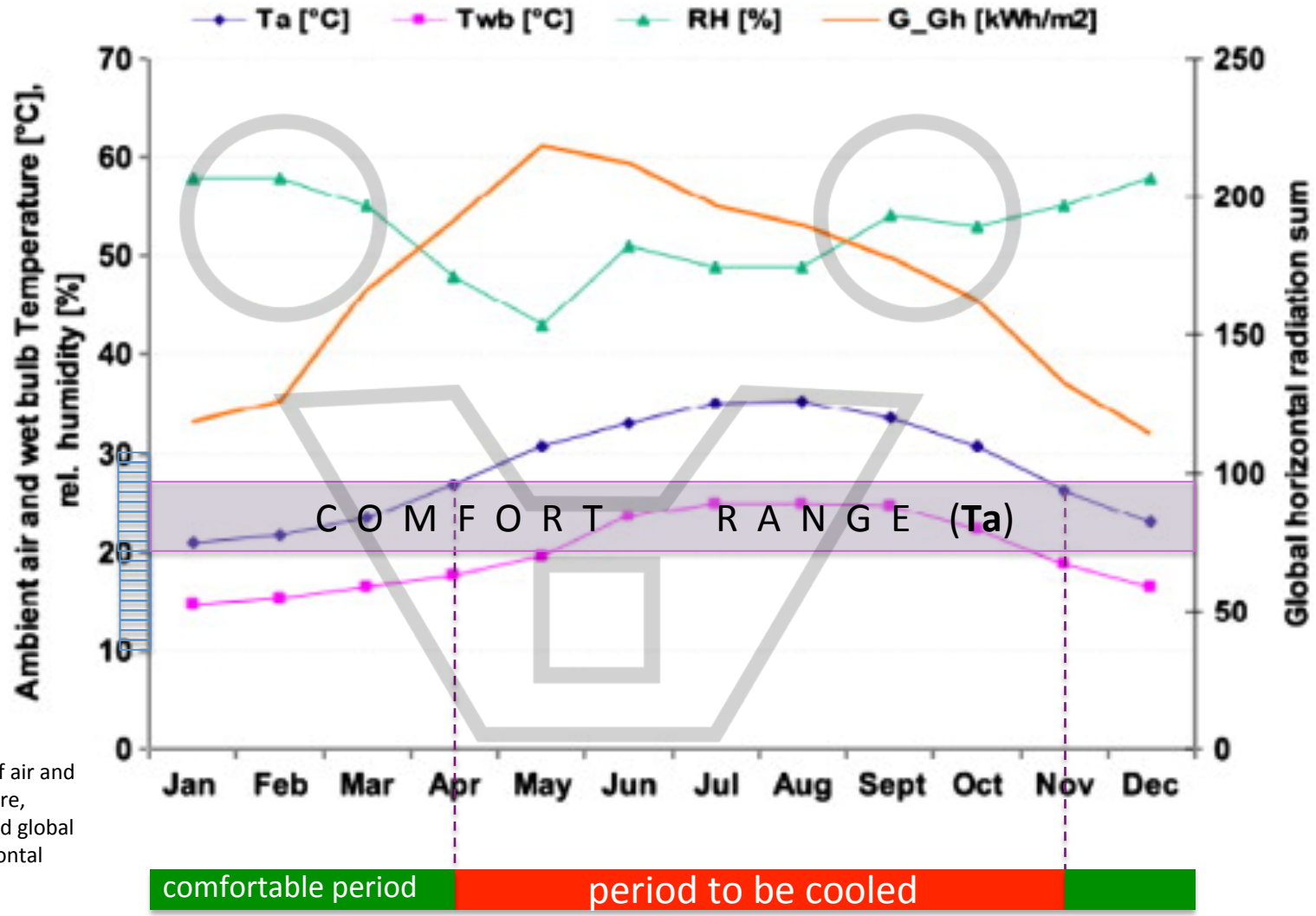


IDENTIFYING THE COMFORT PERIOD



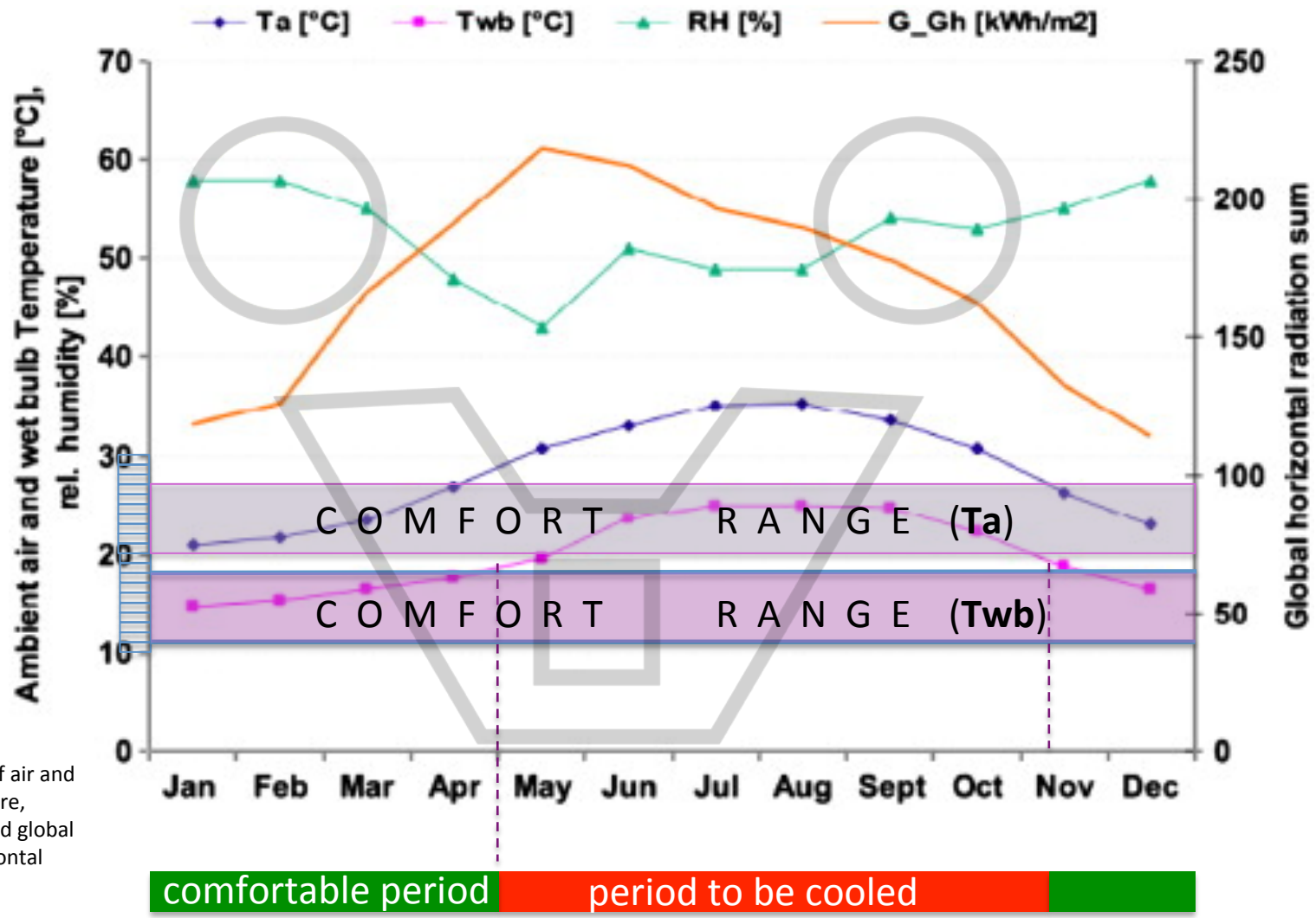
Monthly averages of air and wet bulb temperature, relative humidity and global radiation on a horizontal surface in Dubai.

IDENTIFYING THE COMFORT PERIOD



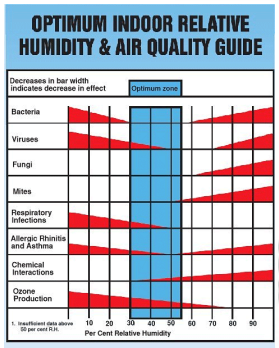
Monthly averages of air and wet bulb temperature, relative humidity and global radiation on a horizontal surface in Dubai.

IDENTIFYING THE COMFORT PERIOD

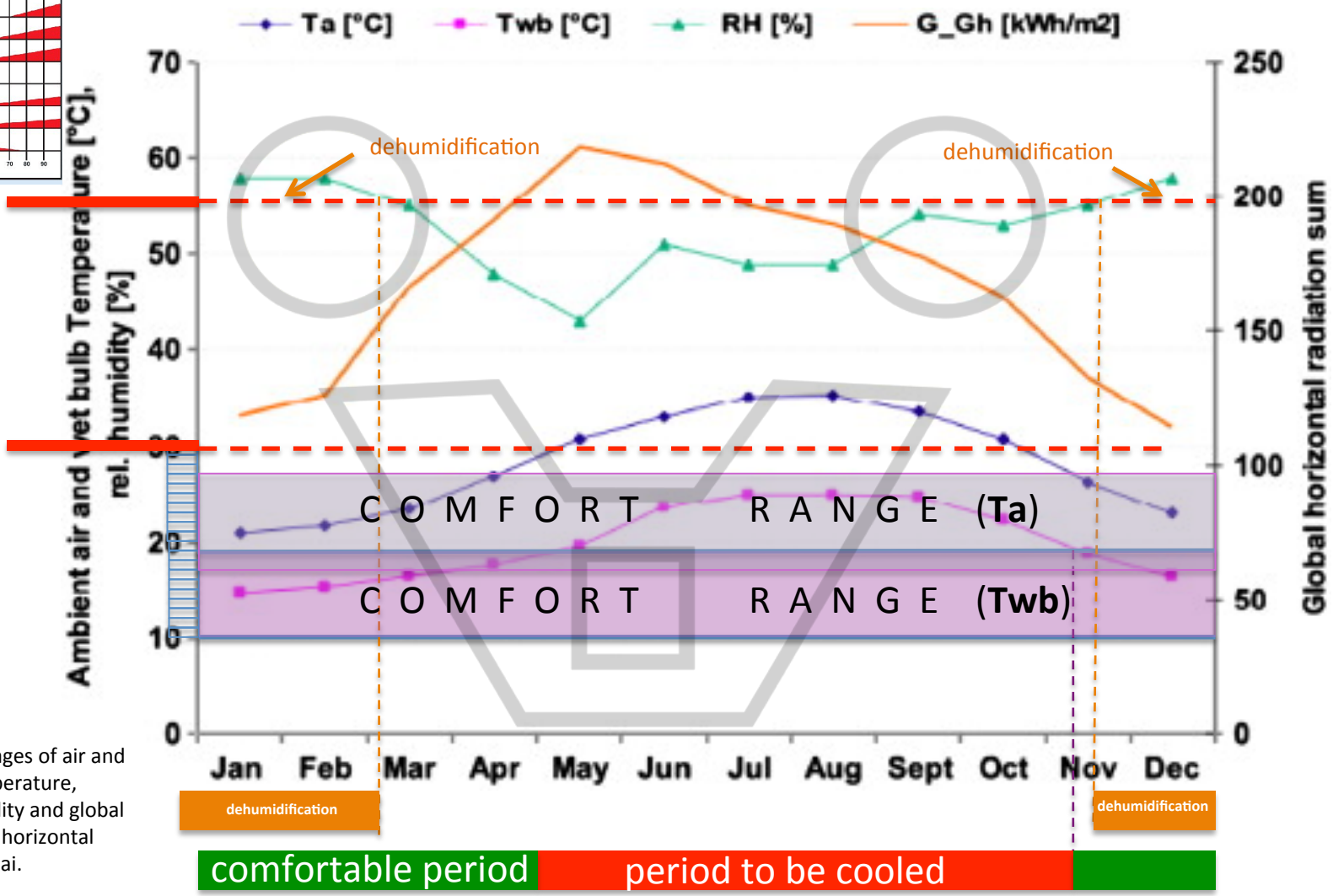


Monthly averages of air and wet bulb temperature, relative humidity and global radiation on a horizontal surface in Dubai.

Environmental elements that affect people's comfort

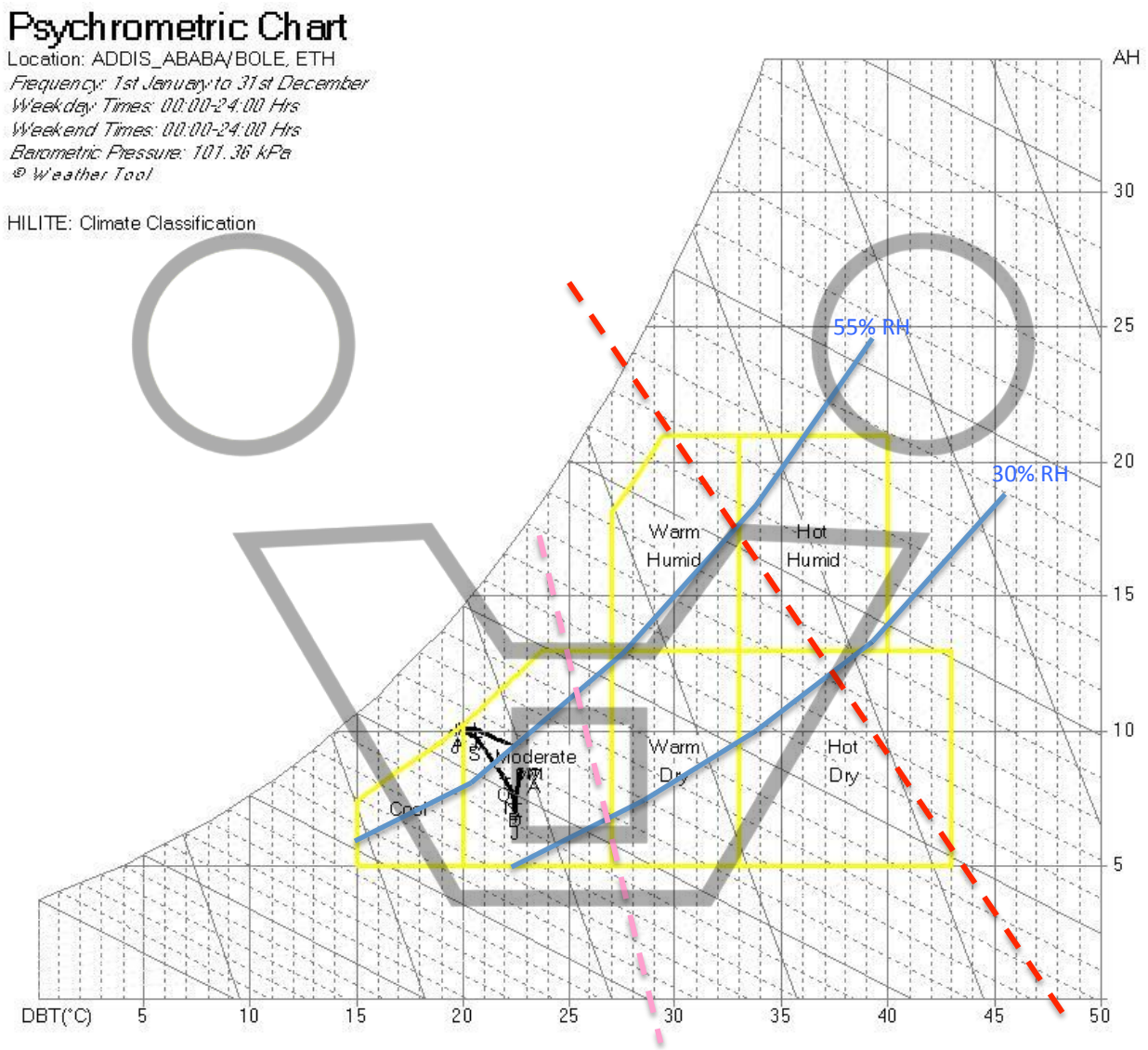


IDENTIFYING THE COMFORT PERIOD



Monthly averages of air and wet bulb temperature, relative humidity and global radiation on a horizontal surface in Dubai.

Environmental elements that affect people's comfort



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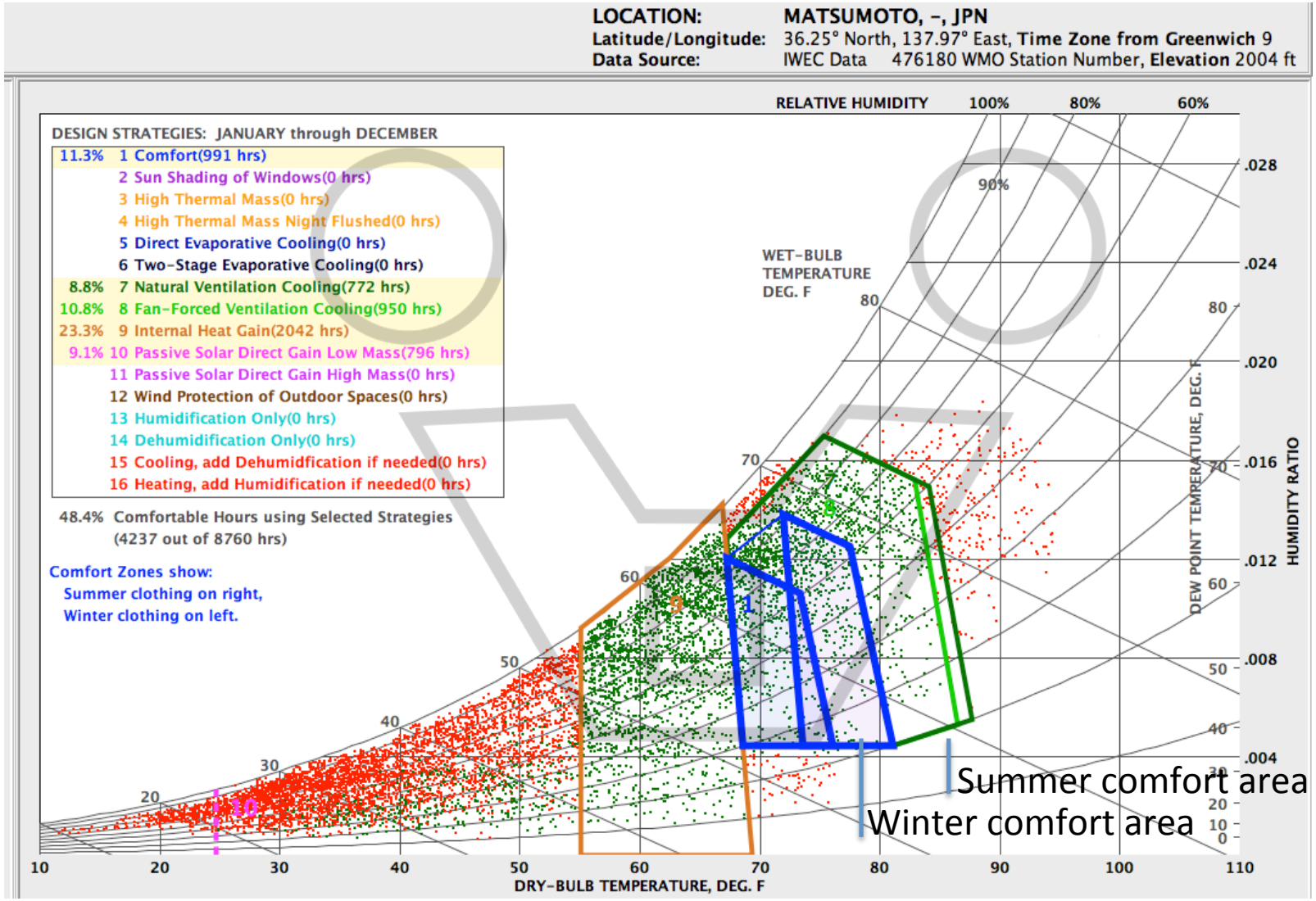
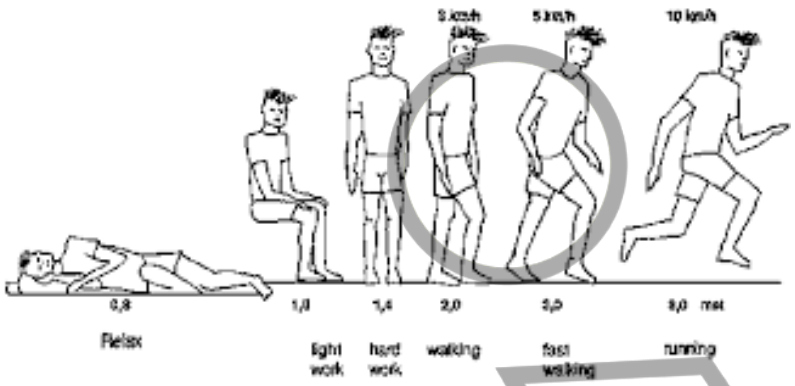


Ecotec output from climate-consultant http://www.energy-design-tools.aud.ucla.edu/

Environmental elements that affect people's comfort

<u>Thermal comfort</u>= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)



1met = 50kcal/hm²=0,05815Kw/hsqm
1 kcal = 4.190 J = 1.164 Wh.

1 BTU/h ft2= 5,6783 w/h mq
1 w/h mq= 0,17610904672173 BTU/h ft2
http://www.the-engineering-page.com/conv/u.html

1 BTU = 252 cal
1 BTU = 1,055056 kJ
1 W= 3,412 BTU/h = 1J/s
1 Kcal= 0,00116 Kw/h
http://www.convertworld.com

Table 4 Typical Metabolic Heat Generation for Various Activities

	Btu/h-ft²	met*
Resting		
Sleeping	13	0.7
Reclining	15	0.8
Seated, quiet	18	1.0
Standing, relaxed	22	1.2
Walking (on level surface)		
2.9 fps (2 mph)	37	2.0
4.4 fps (3 mph)	48	2.6
5.9 fps (4 mph)	70	3.8
Office Activities		
Reading, seated	18	1.0
Writing	18	1.0
Typing	20	1.1
Filing, seated	22	1.2
Filing, standing	26	1.4
Walking about	31	1.7
Lifting/packing	39	2.1
Driving/Flying		
Car	18 to 37	1.0 to 2.0
Aircraft, routine	22	1.2
Aircraft, instrument landing	33	1.8
Aircraft, combat	44	2.4
Heavy vehicle	59	3.2
Miscellaneous Occupational Activities		
Cooking	29 to 37	1.6 to 2.0
Housecleaning	37 to 63	2.0 to 3.4
Seated, heavy limb movement	41	2.2
Machine work		
sawing (table saw)	33	1.8
light (electrical industry)	37 to 44	2.0 to 2.4
heavy	74	4.0
Handling 110 lb bags	74	4.0
Pick and shovel work	74 to 88	4.0 to 4.8
Miscellaneous Leisure Activities		
Dancing, social	44 to 81	2.4 to 4.4
Calisthenics/exercise	55 to 74	3.0 to 4.0
Tennis, singles	66 to 74	3.6 to 4.0
Basketball	90 to 140	5.0 to 7.6
Wrestling, competitive	130 to 160	7.0 to 8.7

Sources: Compiled from various sources. For additional information, see Buskirk (1960), Passmore and Durnin (1967), and Webb (1964).

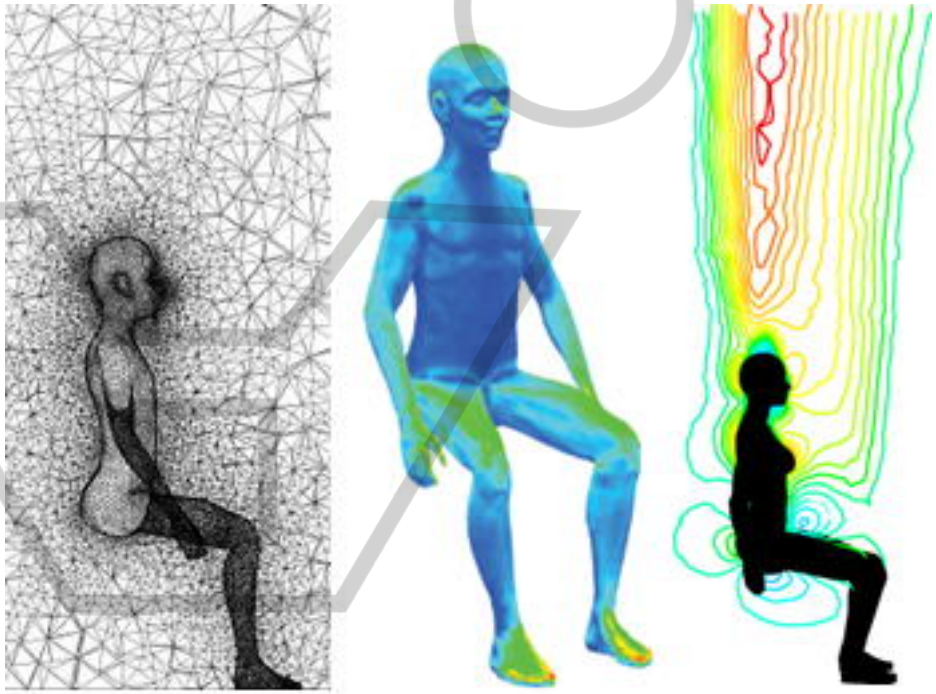
Environmental elements that affect people's comfort

Thermal comfort= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)

Sitting Activity Met = 1
= 50kcal/hsqm=0,05815Kw/hsqm

Average body surface
Male= 2 mq
Female= 1,75

100 watt/h



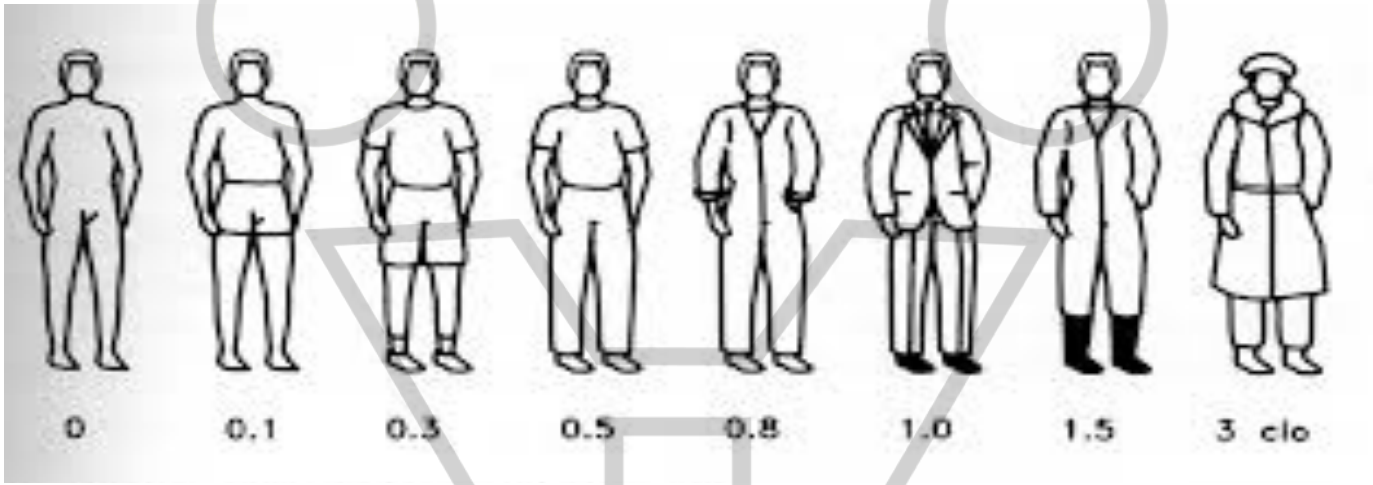
100 watt/h

Environmental elements that affect people's comfort

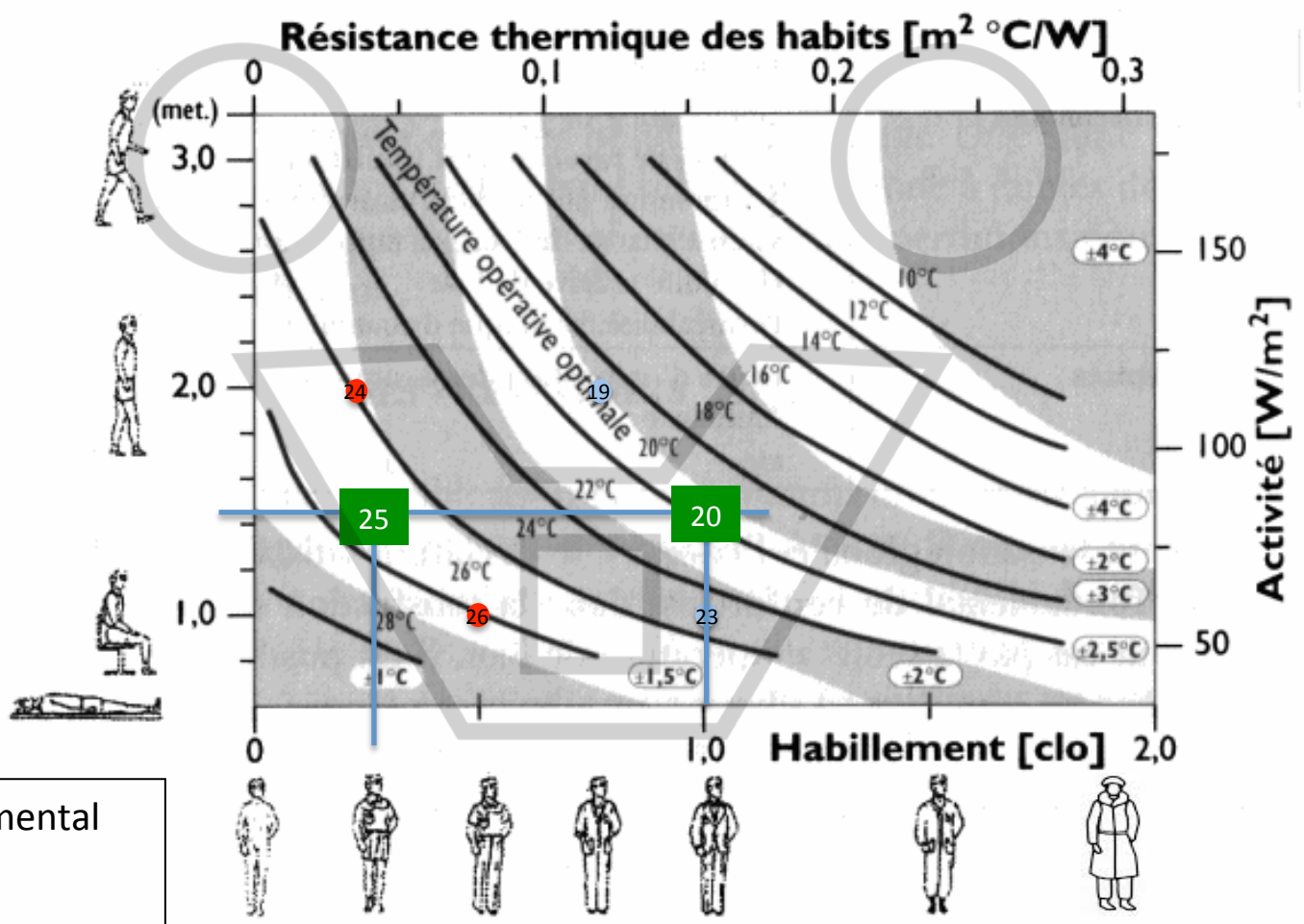
Converting the excess heat generated by the Stockholm Central Station's 2500 daily users to hot water and pump it to the nearby Kungsbrohuset office block.

Environmental elements that affect people's comfort

<u>Thermal comfort</u>= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)



THERMAL COMFORT ZONE

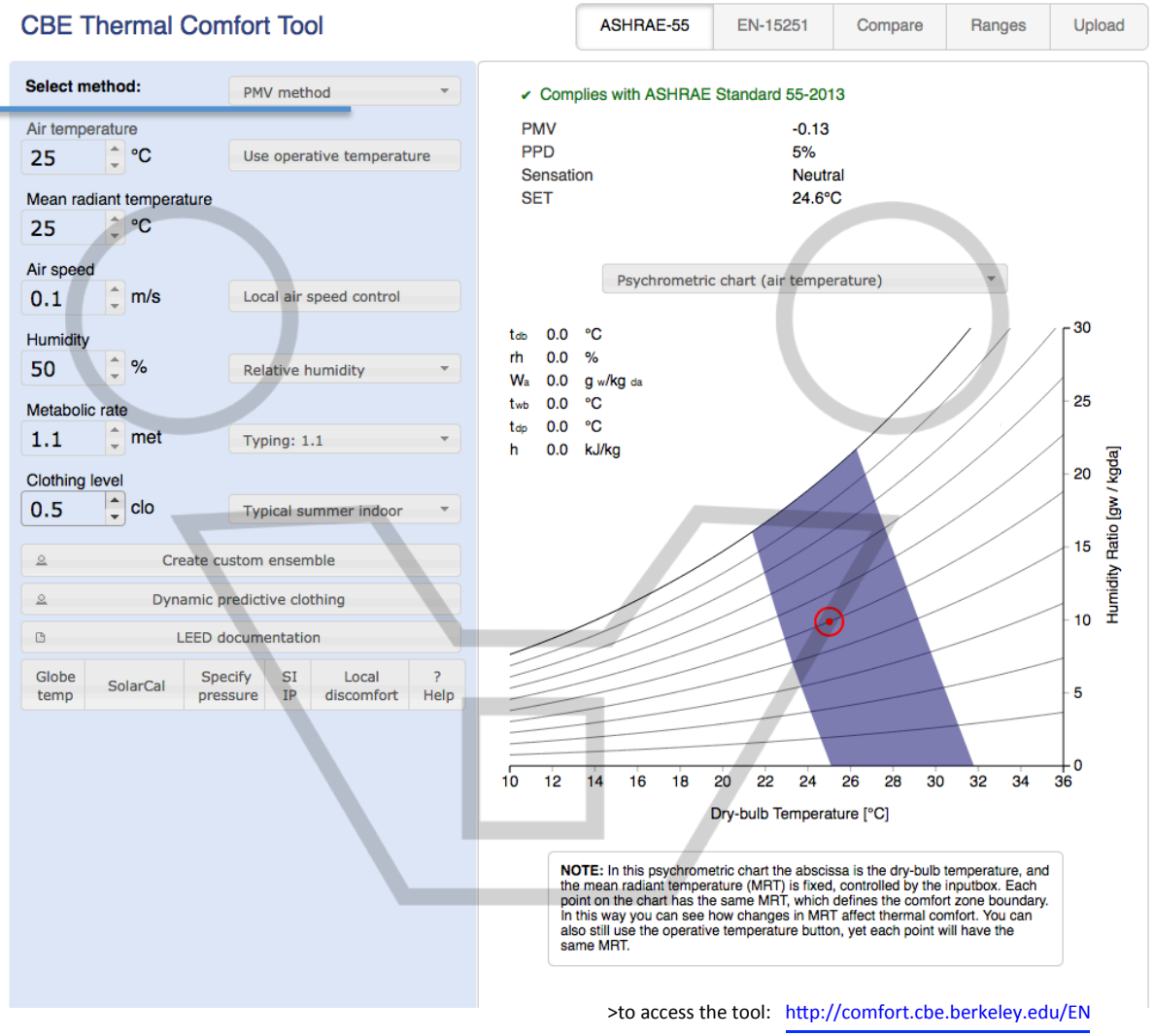


Ideal Environmental temperature

Winter 19°-21°C
Summer 25°-26°C

Environmental elements that affect people's comfort

THERMAL COMFORT ZONE



>to access the tool: http://comfort.cbe.berkeley.edu/EN

The **PMV** model can be applied to air conditioned buildings,
The **Adaptive** model can be generally applied only to buildings where no mechanical systems have been installed