UNIVERSITÀ DEGLI STUDI FIRENZE
Scuola di Architettura

iCAD

International Course on Architectural Design
Second Level Degree Course

ARCHITECTURE and ENVIRONMENT LAB | ENVIRONMENTAL DESIGN

Computational Materiality for Sustainable Architectures and Comprehensive Skins

MODELING HUMAN BEHAVIORS AND COMPUTING COMFORT CONDITIONS

Prof. Arch. Giuseppe Ridolfi, PhD

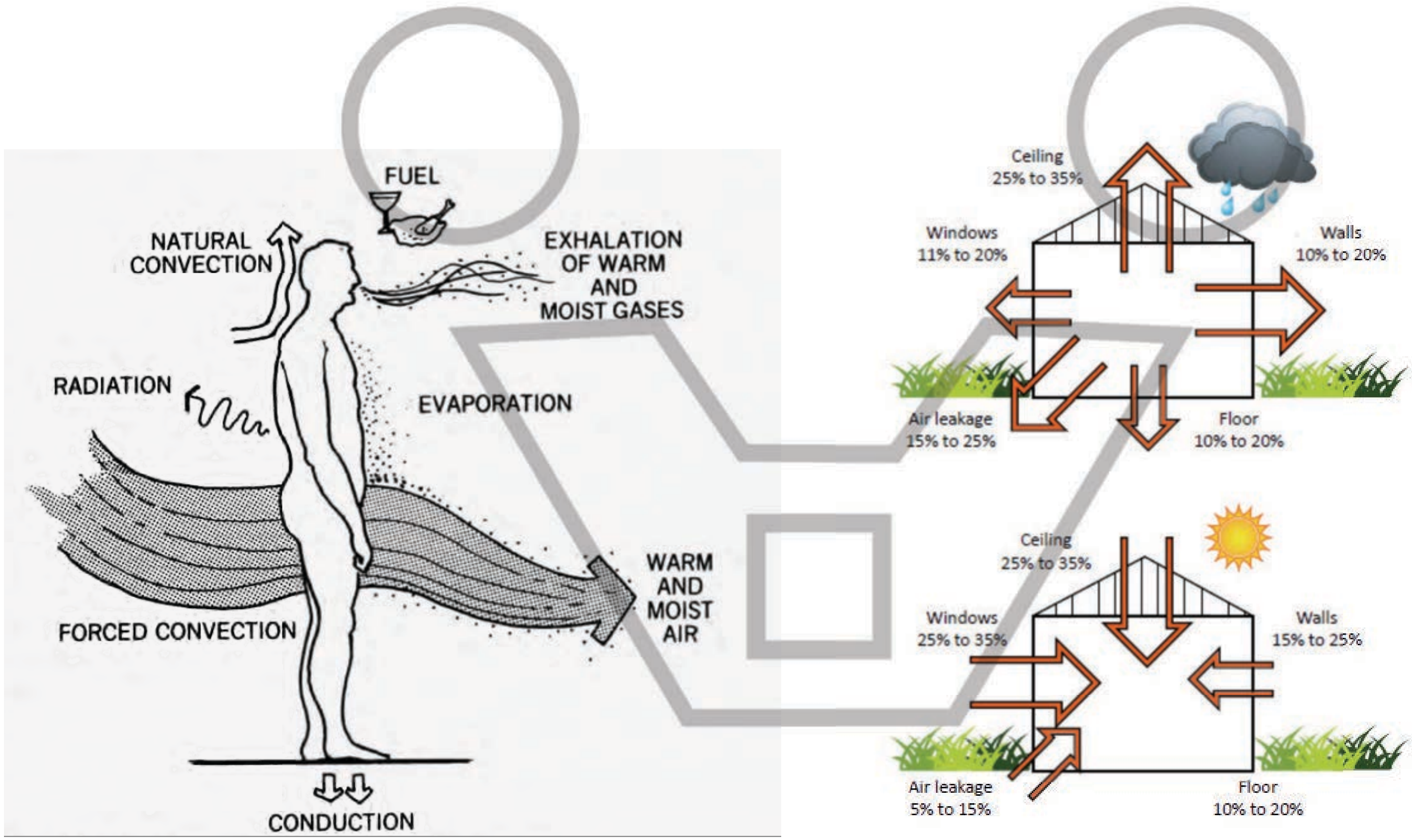
LECTURE #03

MODELING HUMAN BEHAVIORS AND COMPUTING COMFORT CONDITIONS

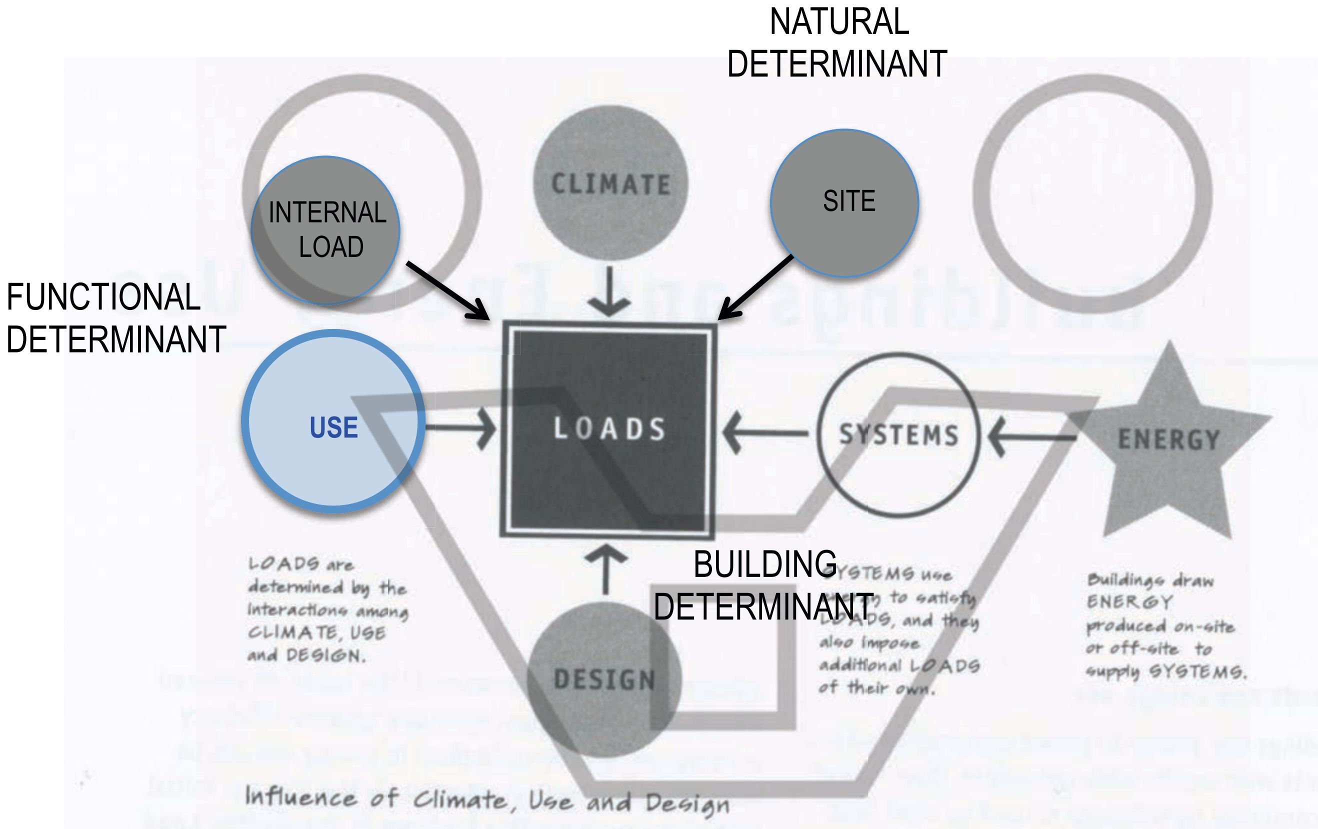
ENVIRONMENTAL ELEMENTS THAT AFFECT PEOPLE'S COMFORT

Prof. Giuseppe Ridolfi, PhD

Energy mediator devices= Human skin & Building skin



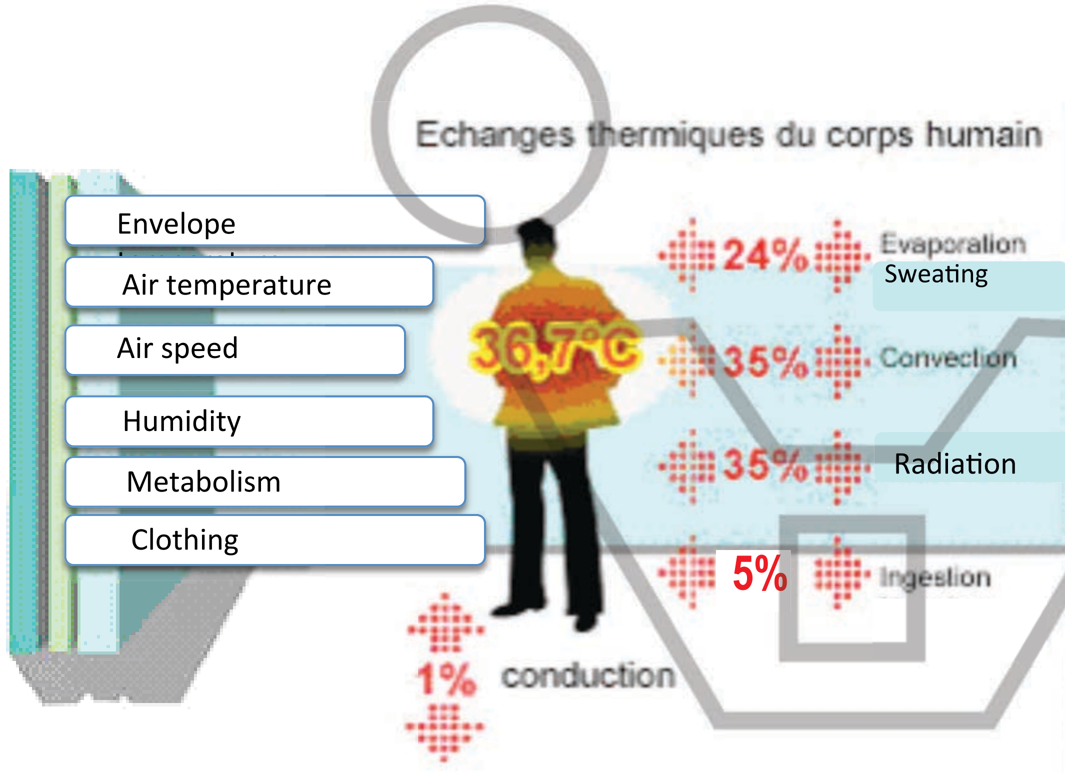
Environmental elements that affect people's comfort

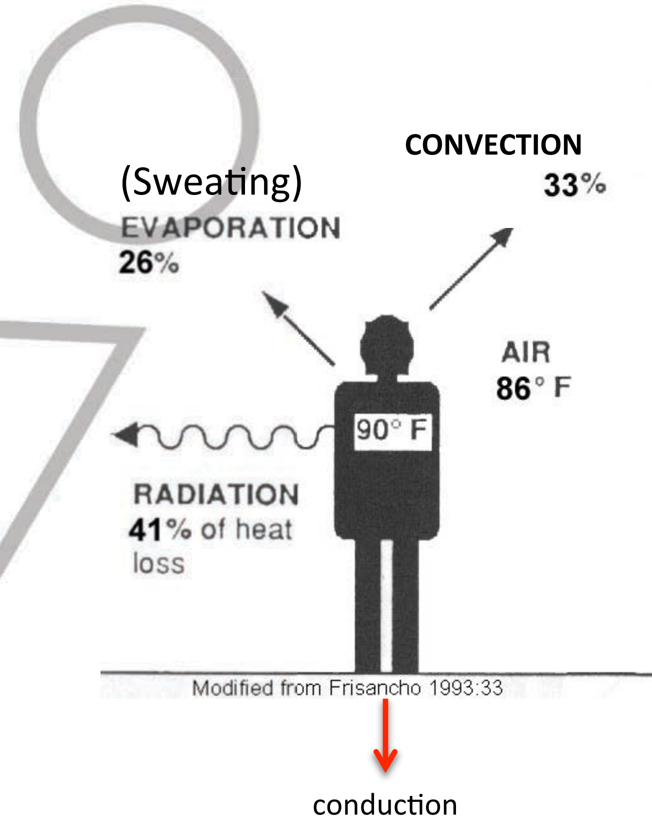


Environmental elements that affect people's comfort

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

HOW THE BODY EXCHANGE THERMAL ENERGY





Environmental elements that affect people's comfort

<u>Thermal comfort</u>= 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/

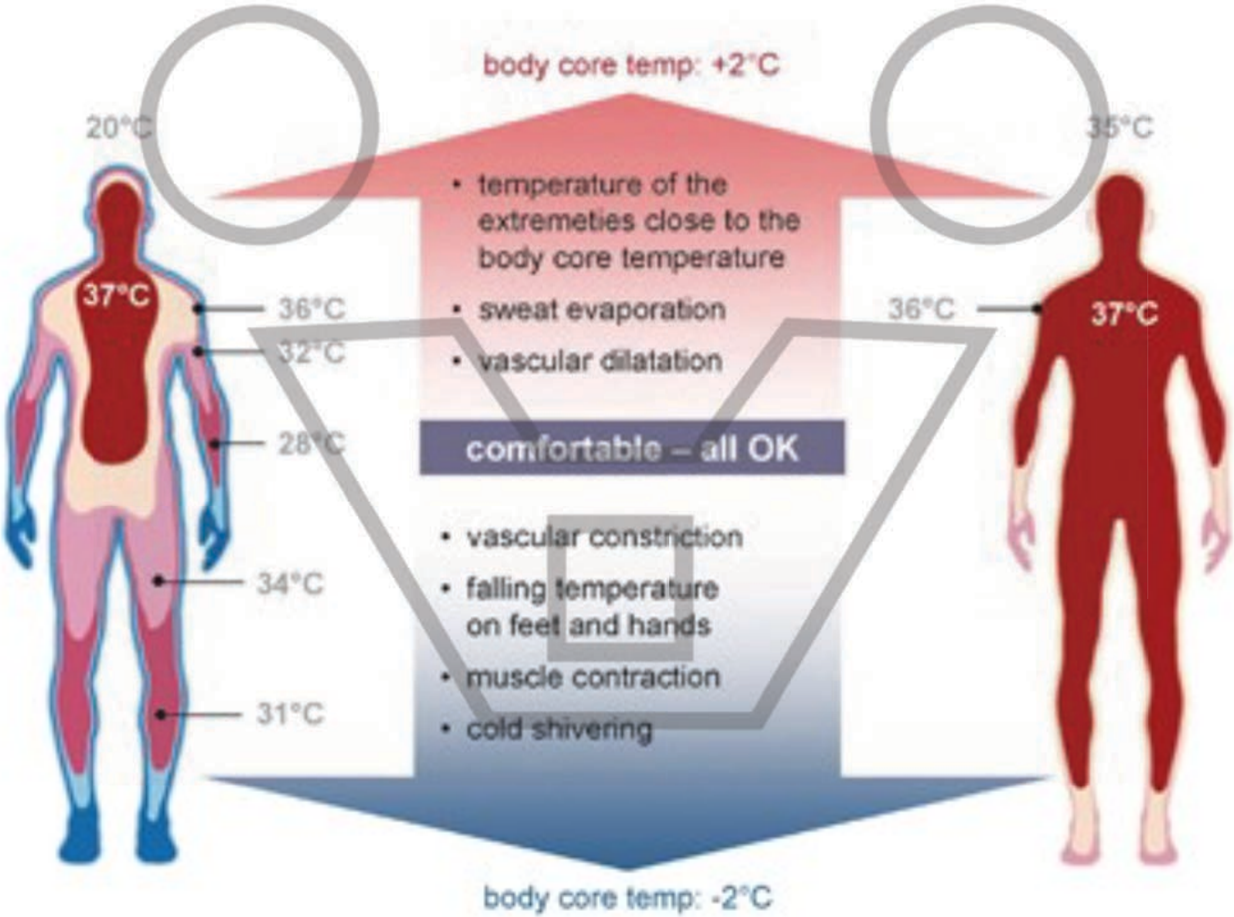
Relatively small changes in mean radiant temperature have a far greater effect than similar changes in air temperatures (Ballinger 1992).
This gives rise to the importance of recognising the overall <u>Environmental Temperature [T(env)]</u>*, as opposed to just the dry bulb temperature.*

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

Environmental elements that affect people's comfort

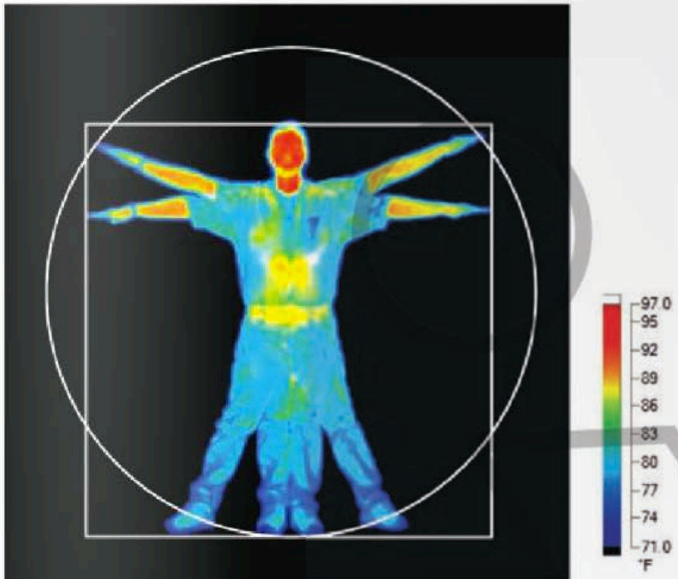
<u>Thermal comfort</u>= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)

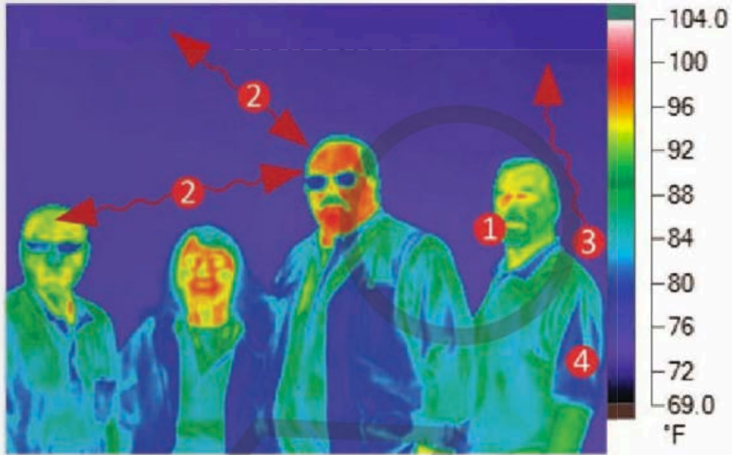
Body actions to mantain thermal equilibrium



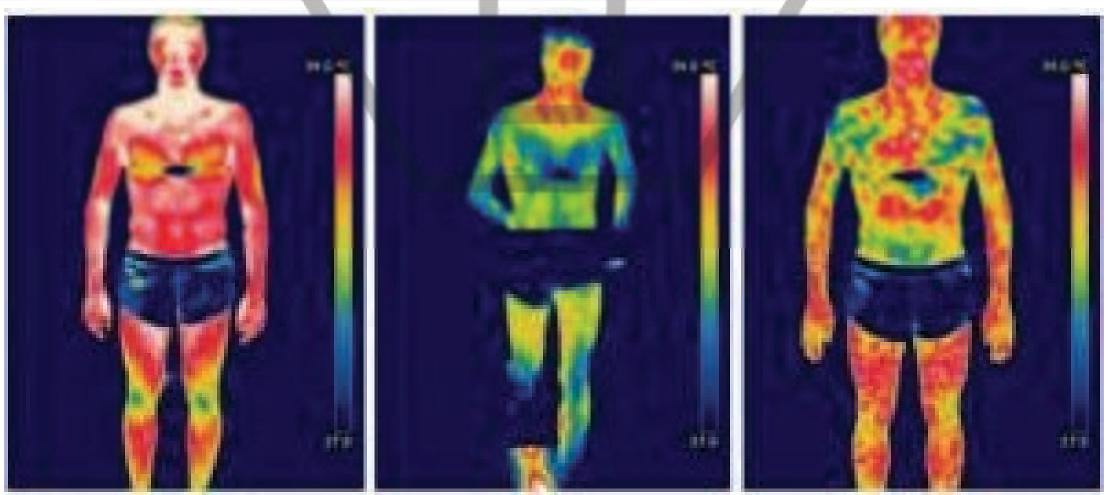
Environmental elements that affect people's comfort

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





DIFFERENT HUMAN THERMAL ZONES



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

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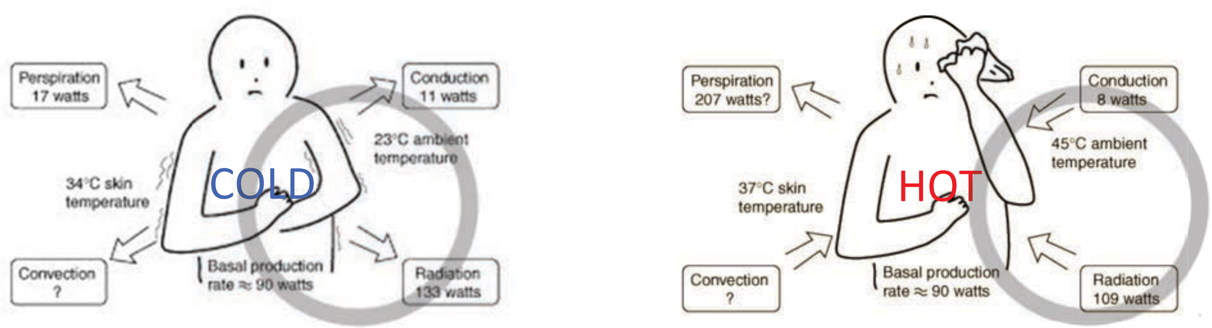

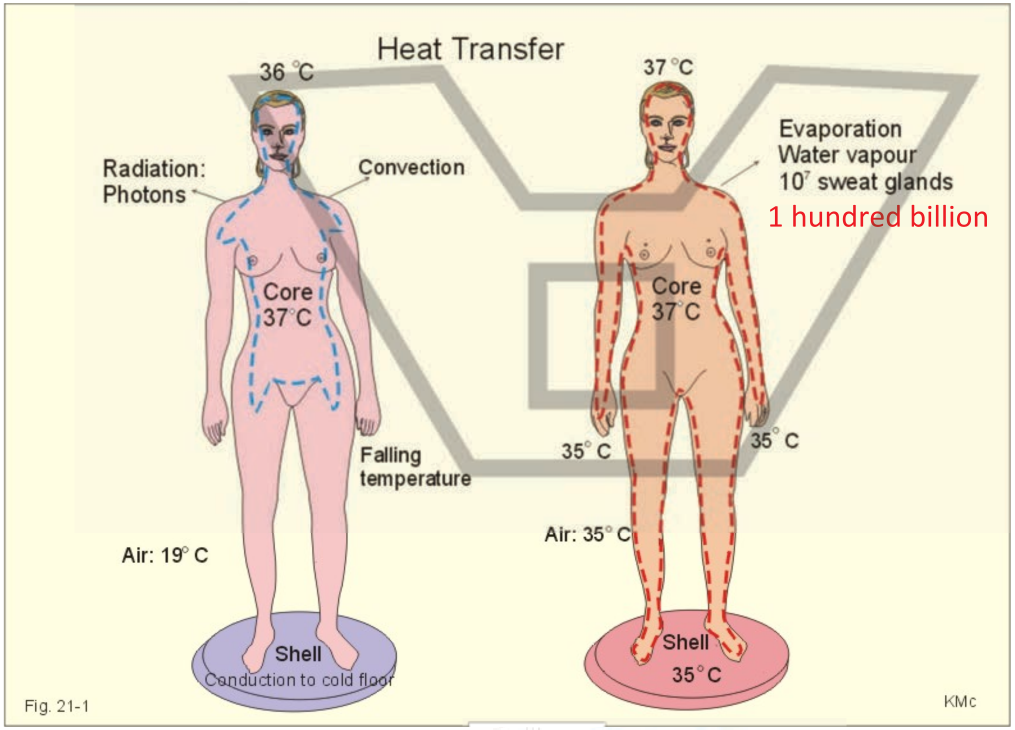

<u>Thermal comfort</u>= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)

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
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80	-24	-23	-22	-21	-19	-18	-17	-16	-15	-14	-13	-12	-10	-9	-8	-7	-6	-4	-3	-2	-1	1	2	3	5	6

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				

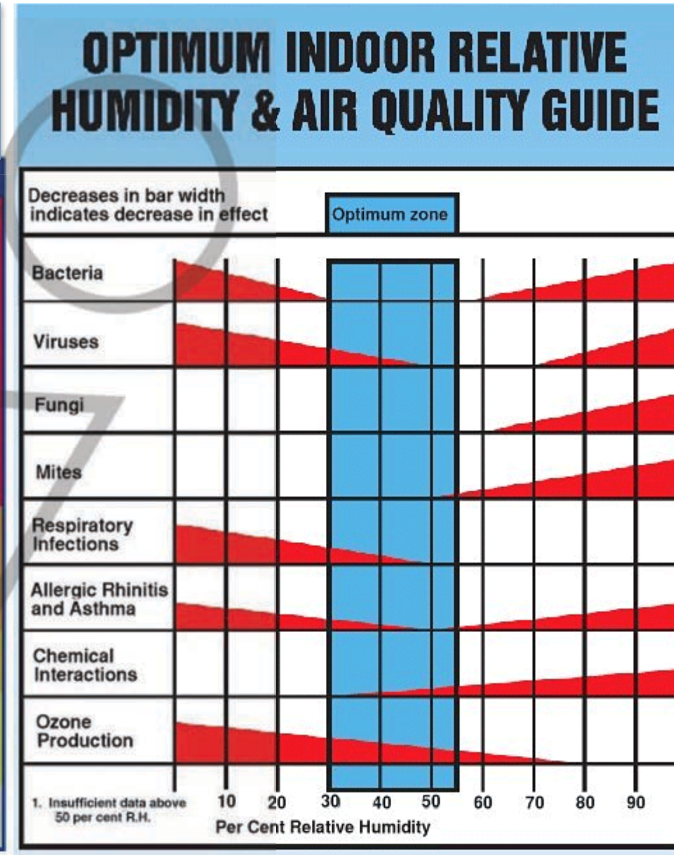
Environmental elements that affect people's comfort

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

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

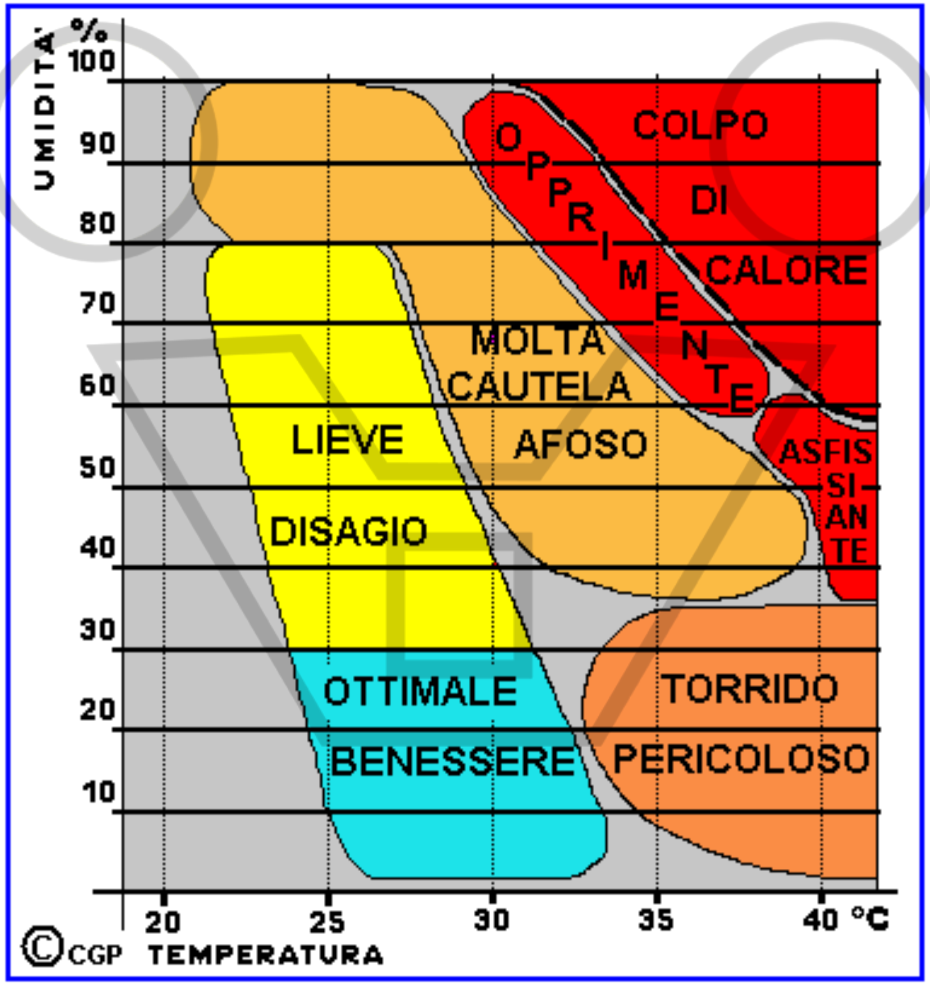
	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
42°	48	50	52	55	57	59	62	64	66	68	71	73	75	77	80	82
41°	46	48	51	53	55	57	59	61	64	66	68	70	72	74	76	79
40°	45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75
39°	43	45	47	49	51	53	55	57	59	61	63	65	66	68	70	72
38°	42	44	45	47	49	51	53	55	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



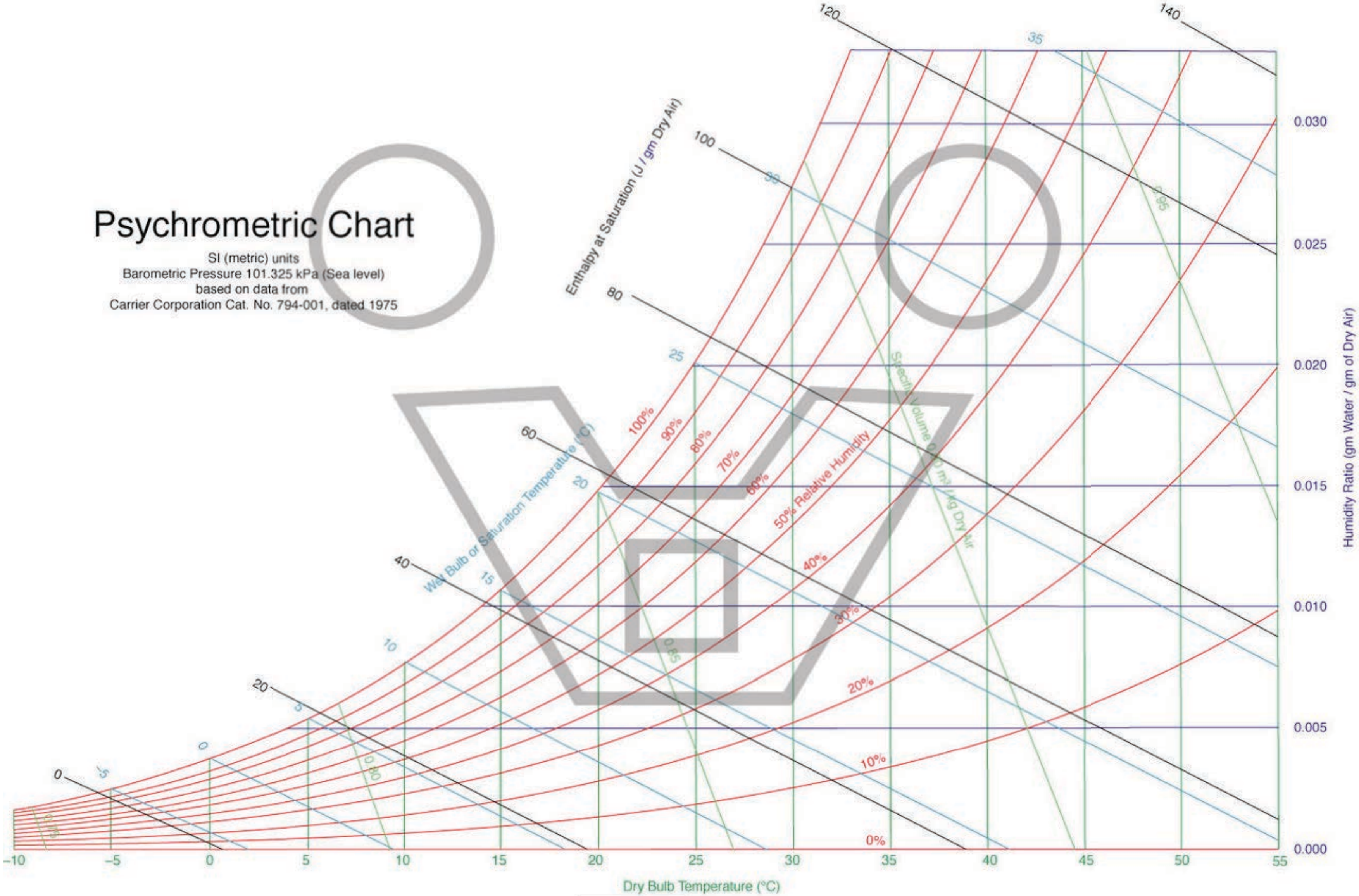
<u>Thermal comfort</u>= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)

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



Environmental elements that affect people's comfort

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



Prof. Giuseppe Ridolfi, PhD

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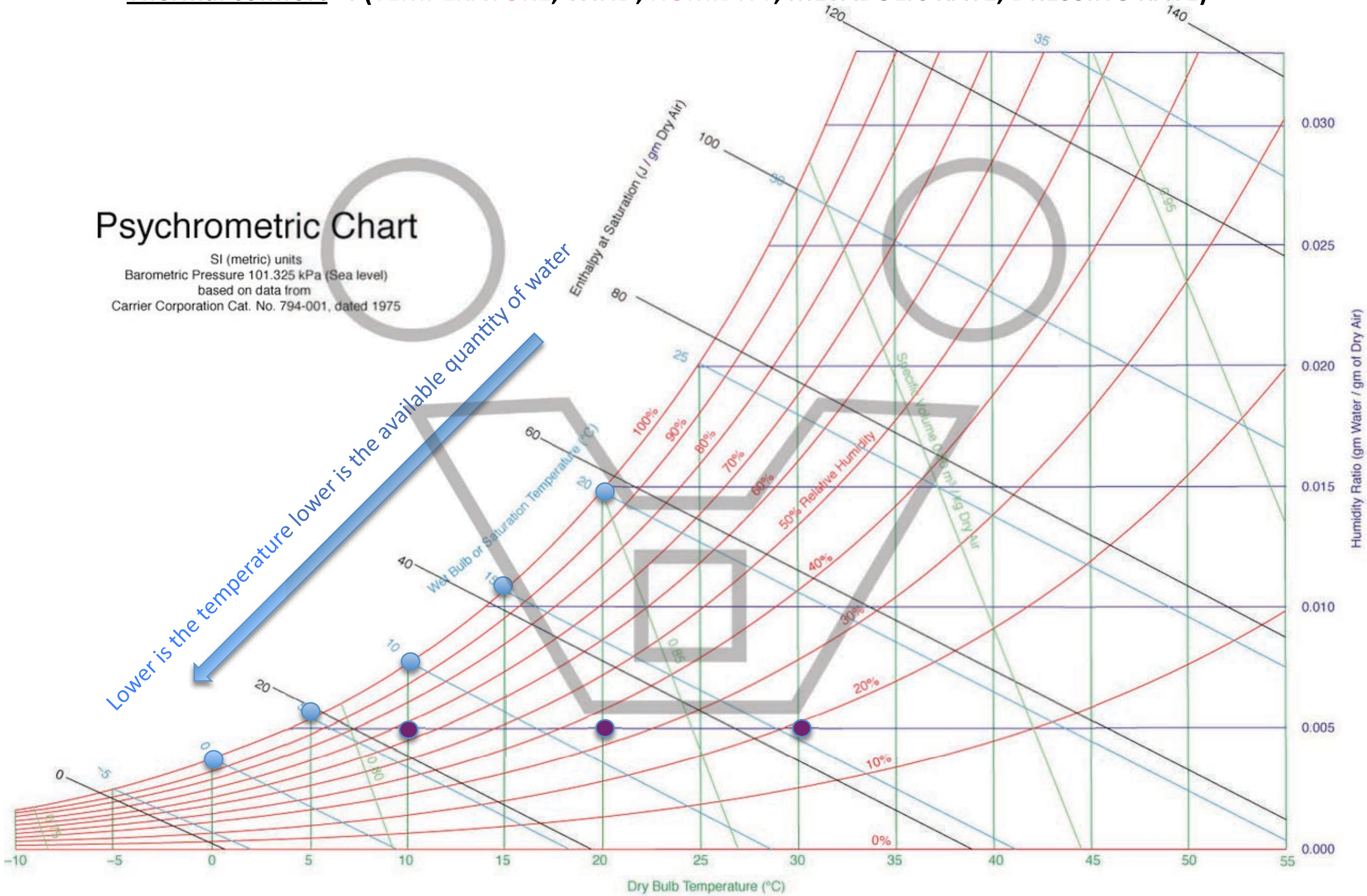
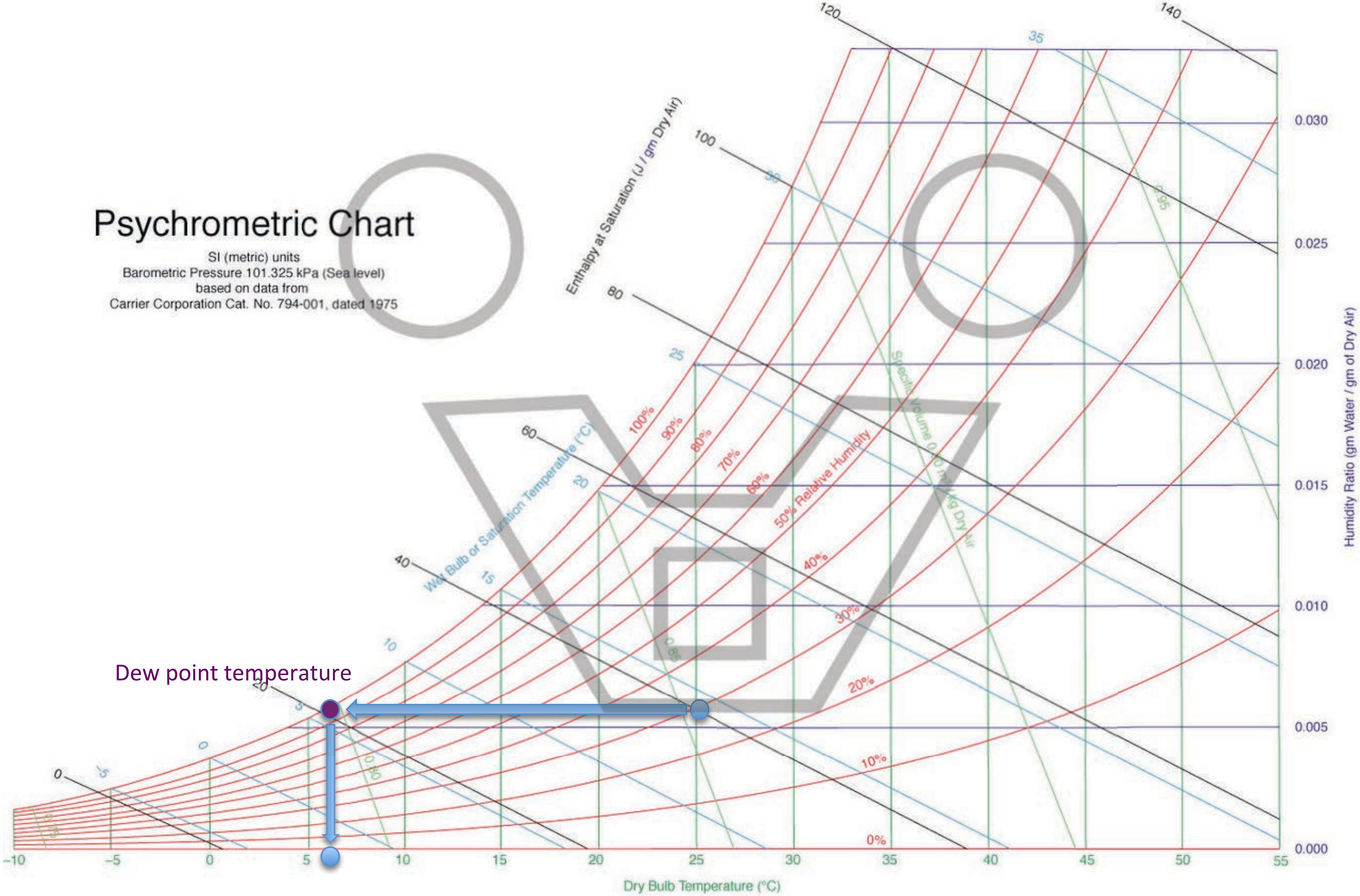


Environmental elements that affect people's comfort

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



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Environmental elements that affect people's comfort

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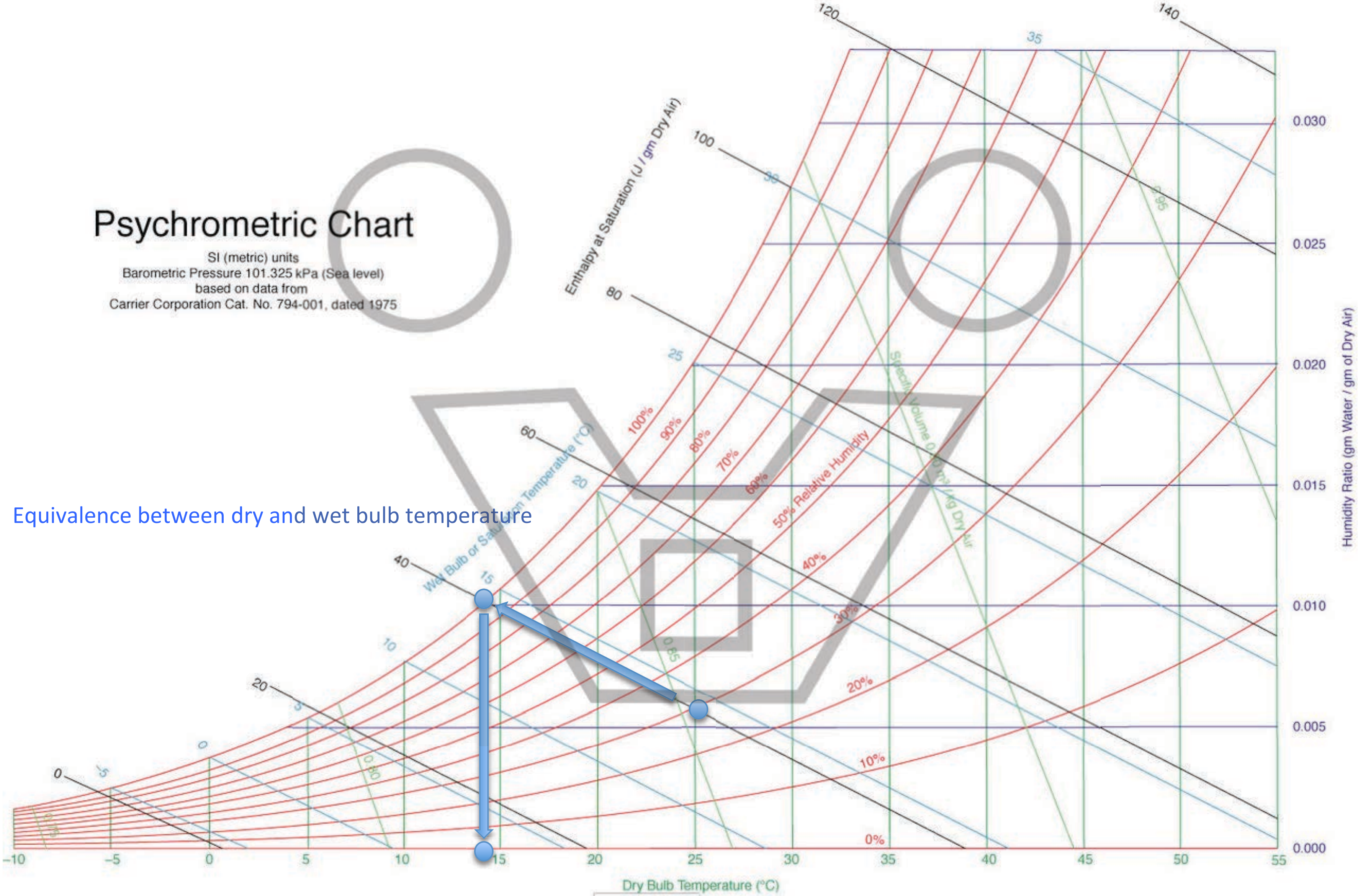

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Thermal comfort= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)

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	[illegible]	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	56	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	[illegible]	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

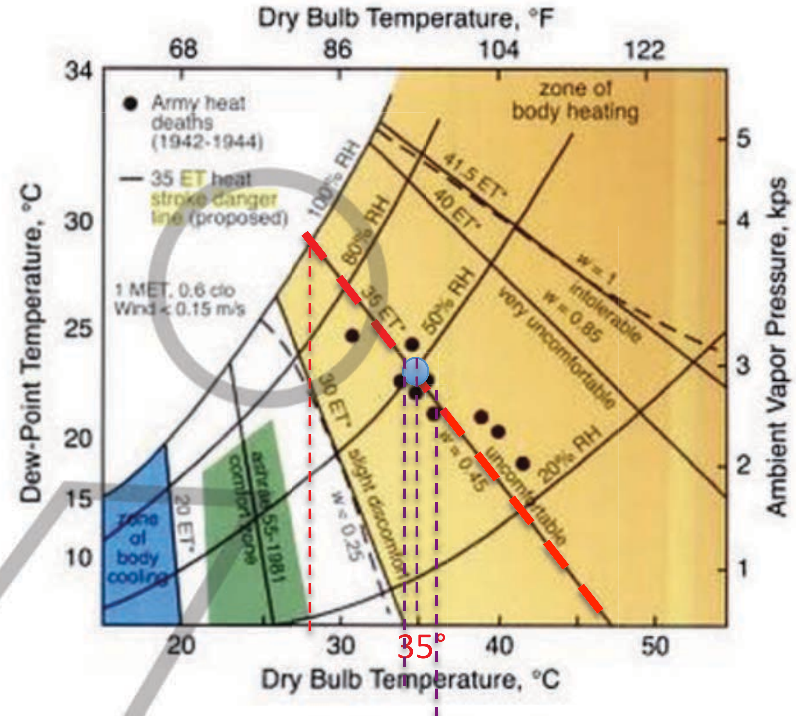


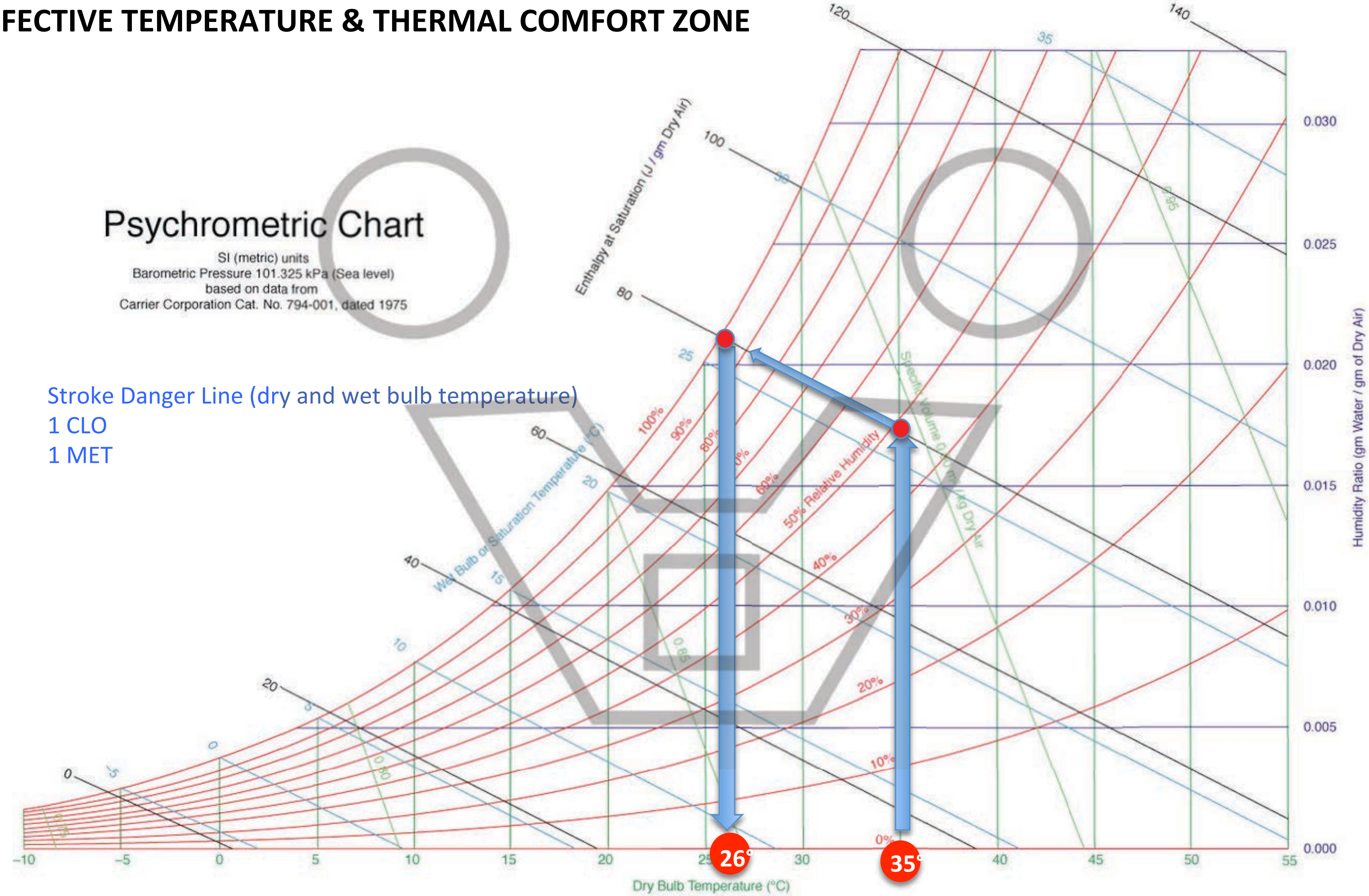
Fig. 8-8. Nomogram for the "new," effective temperature (ET*), including data points for US Army heat deaths provided by Hardy. ashrae: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc; clo: unit of clothing insulation, 1 clo = 0.155 m^2 K/W; MET: unit of metabolism, 1 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

<u>Thermal comfort</u>= 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



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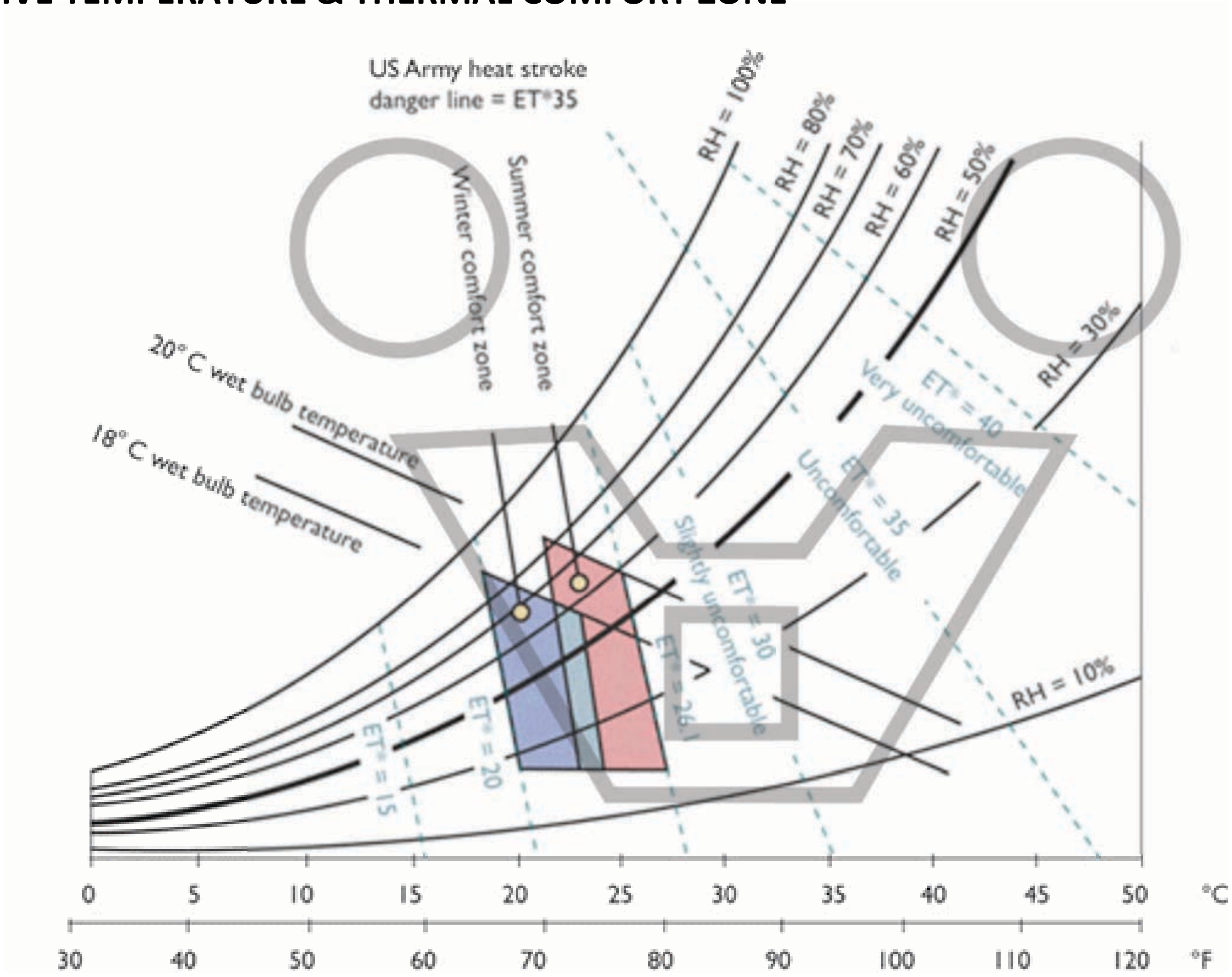
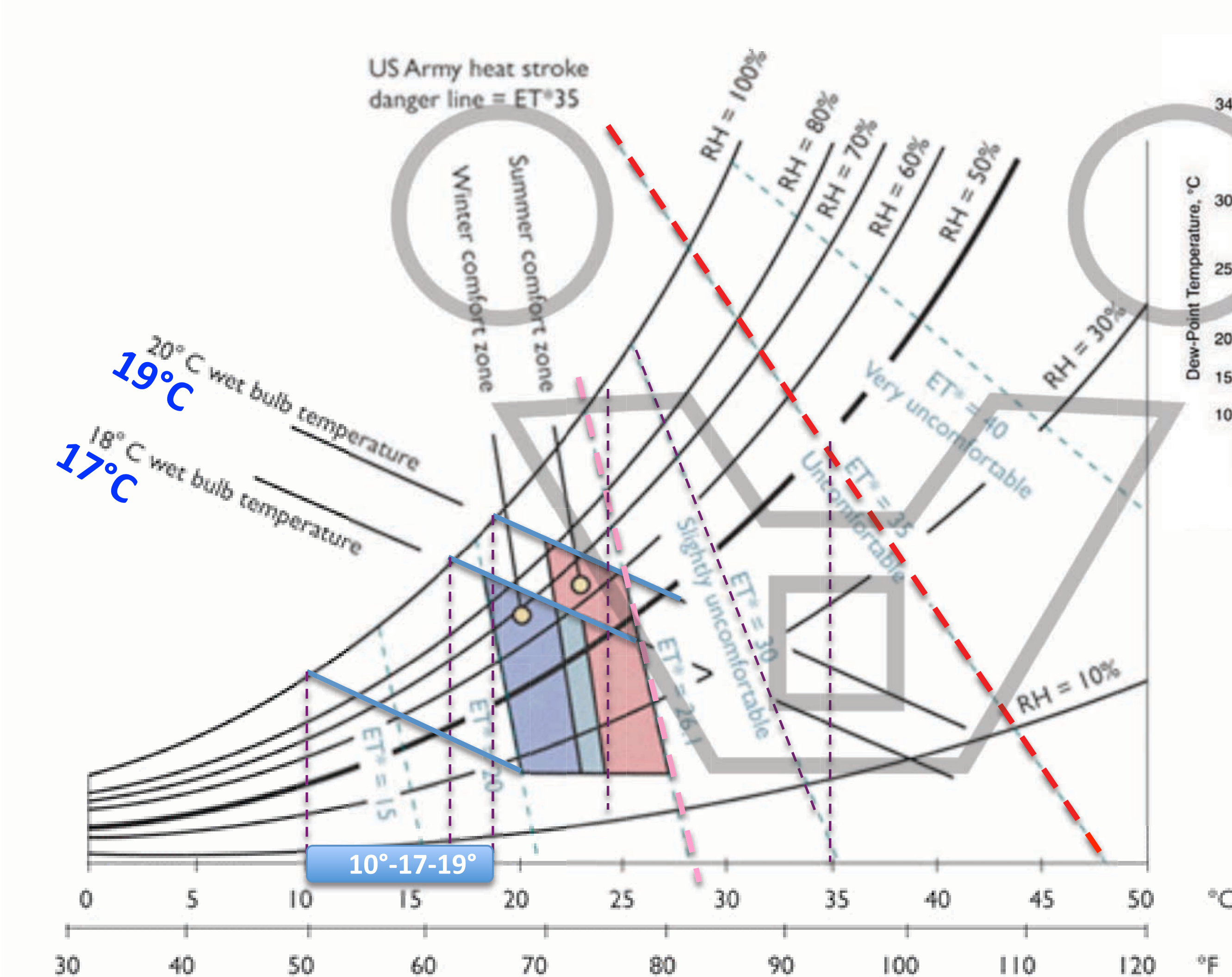
Thermal comfort= f (TEMPERATURE, WIND, HUMIDITY, METABOLIC RATE, DRESSING RATE)

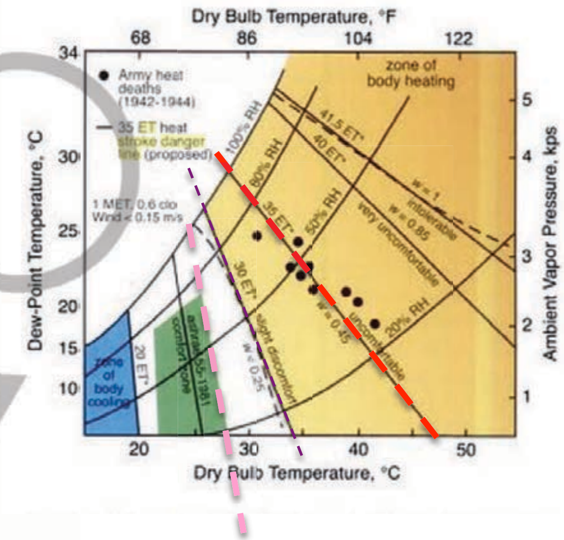
EFFECTIVE TEMPERATURE & THERMAL COMFORT ZONE



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

EFFECTIVE TEMPERATURE & THERMAL COMFORT ZONE _ Using wet bulb temperature

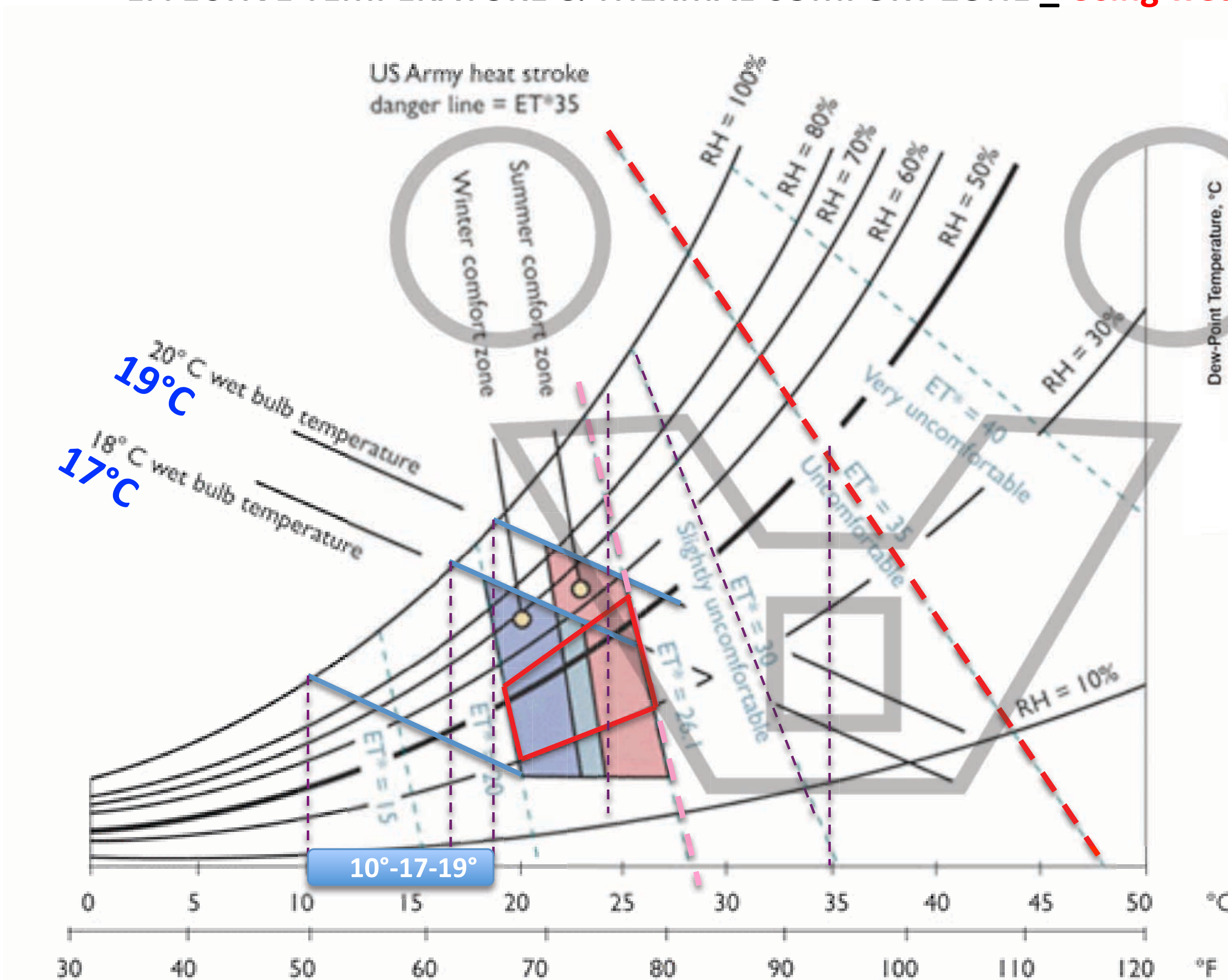


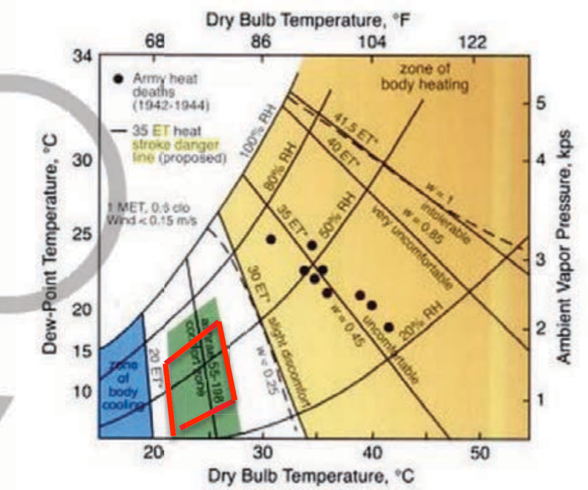


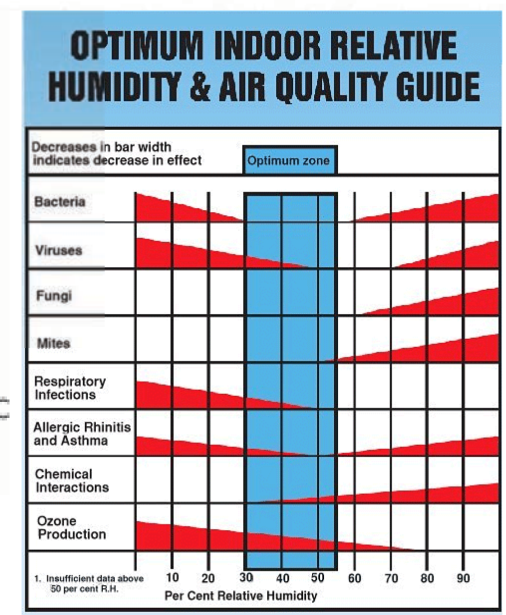
Environmental elements that affect people's comfort

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

EFFECTIVE TEMPERATURE & THERMAL COMFORT ZONE _ Using wet bulb temperature







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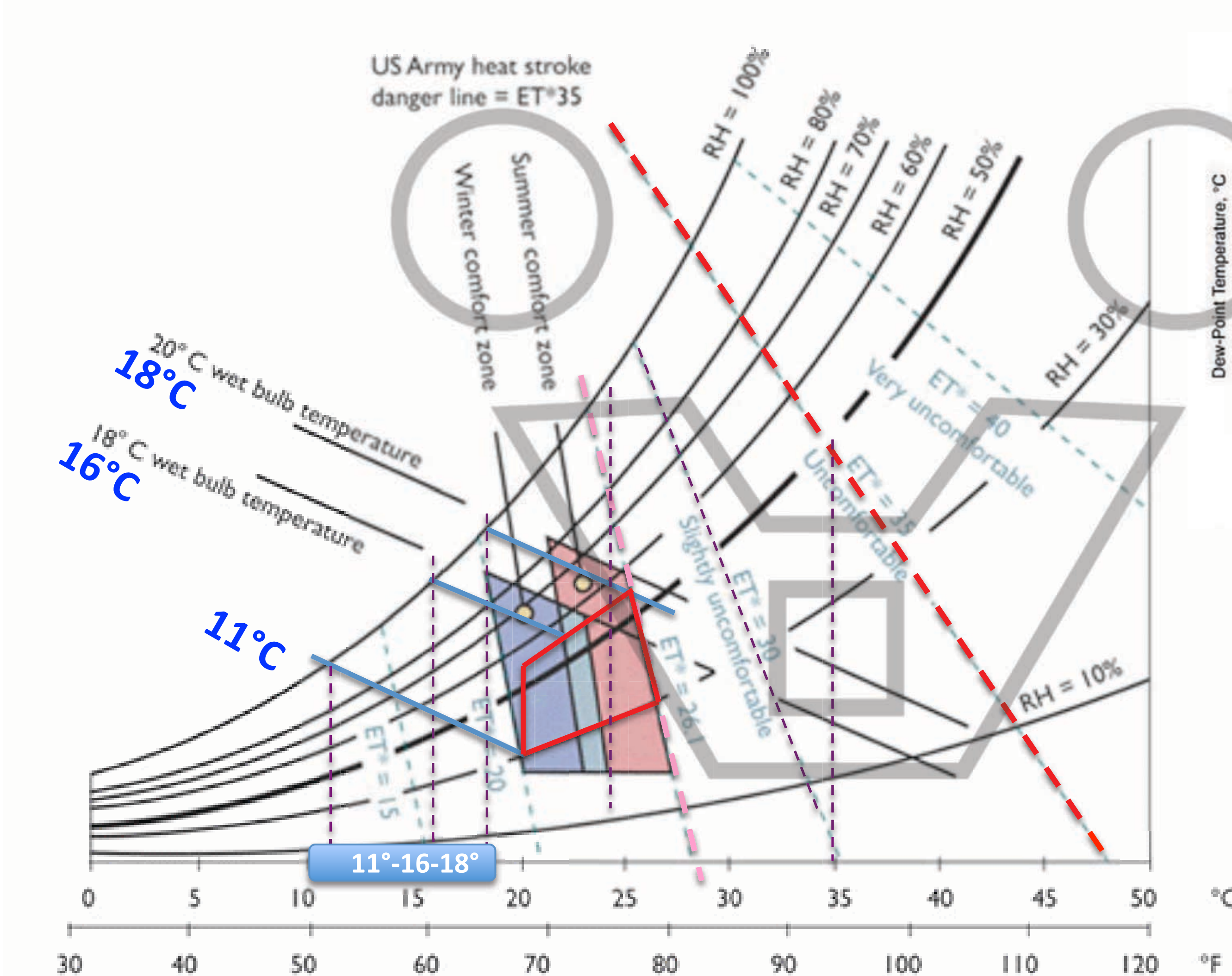
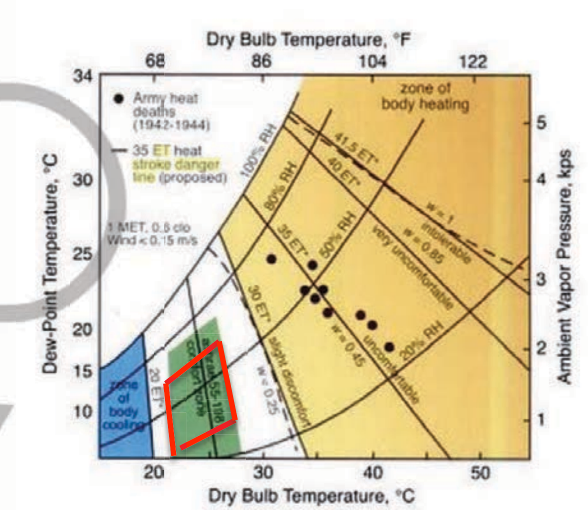
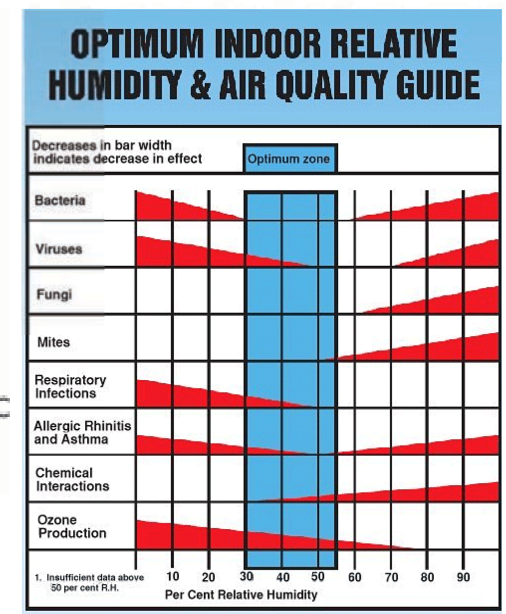
Environmental elements that affect people's comfort

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

EFFECTIVE TEMPERATURE & THERMAL COMFORT ZONE _ Using wet bulb temperature







iCAD

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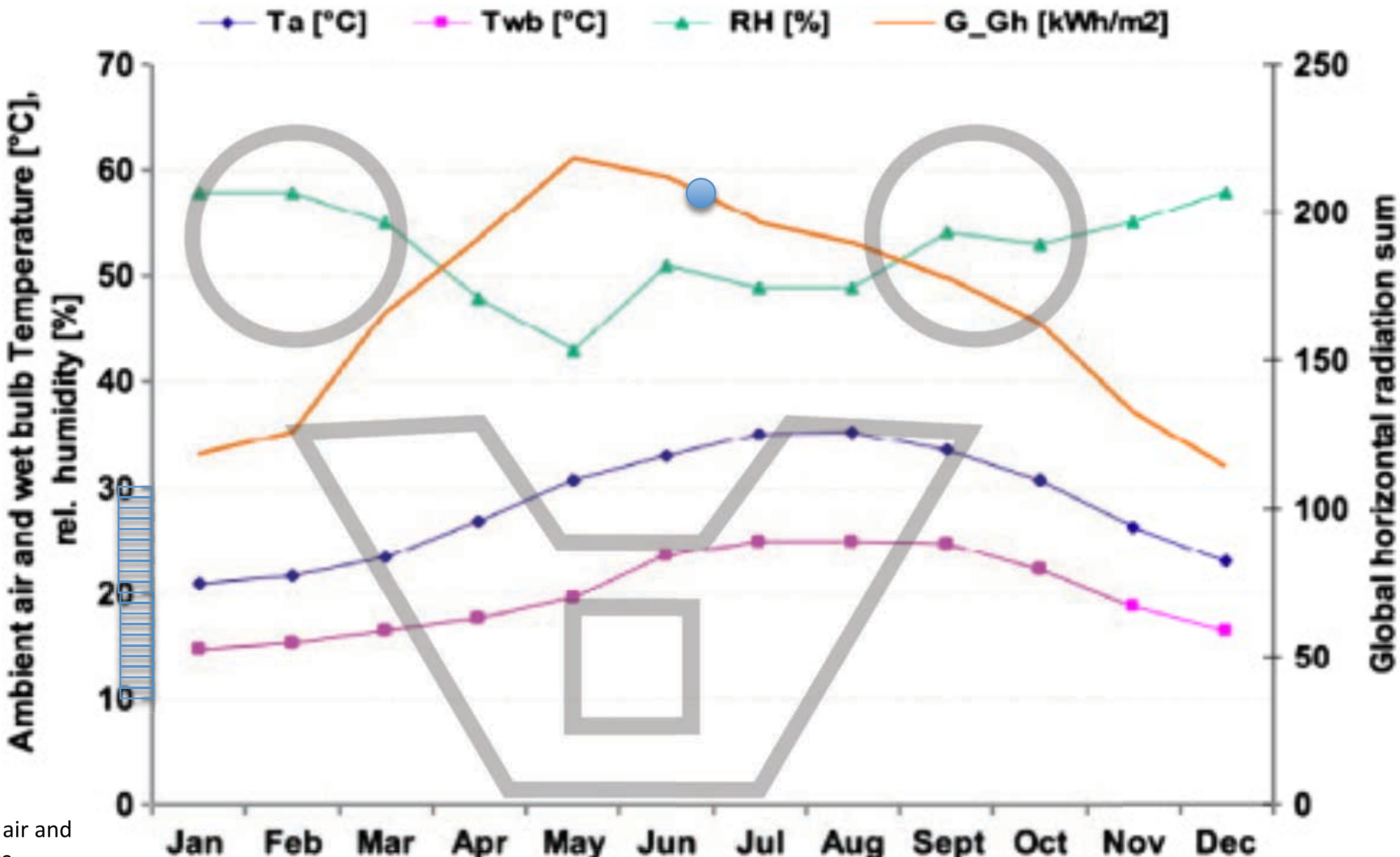
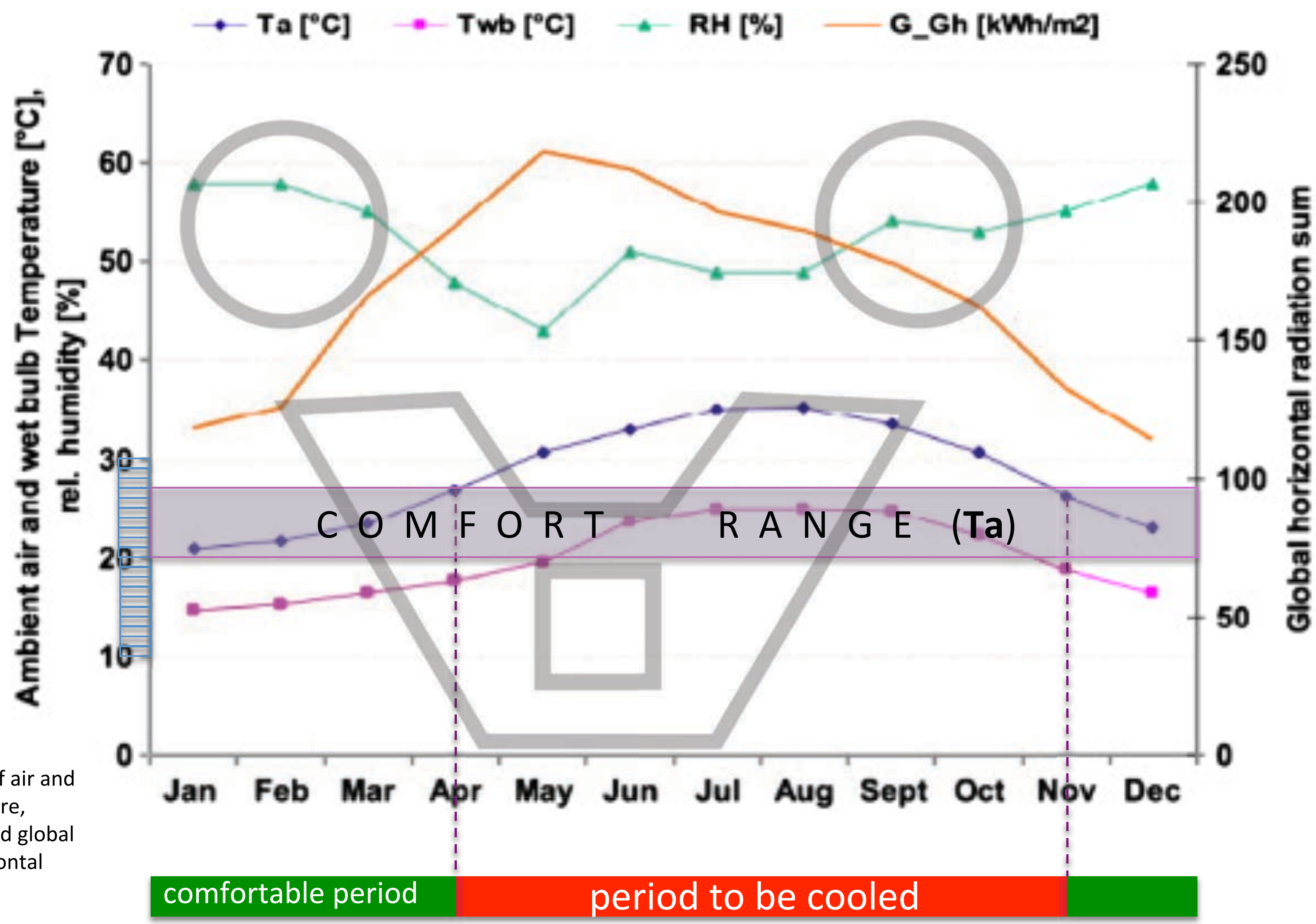
IDENTIFYING THE COMFORT PERIOD



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

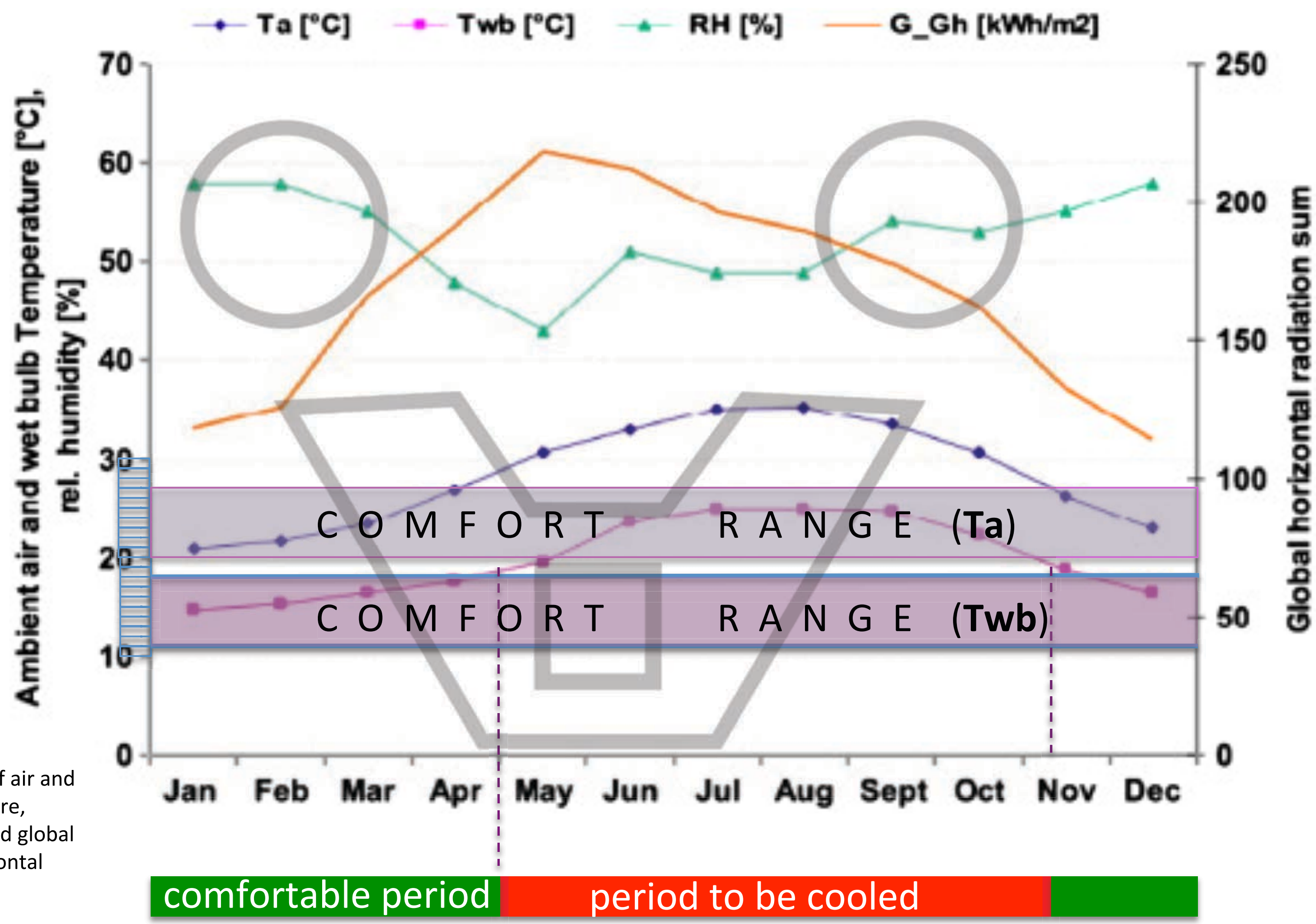
IDENTIFYING THE COMFORT PERIOD



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.

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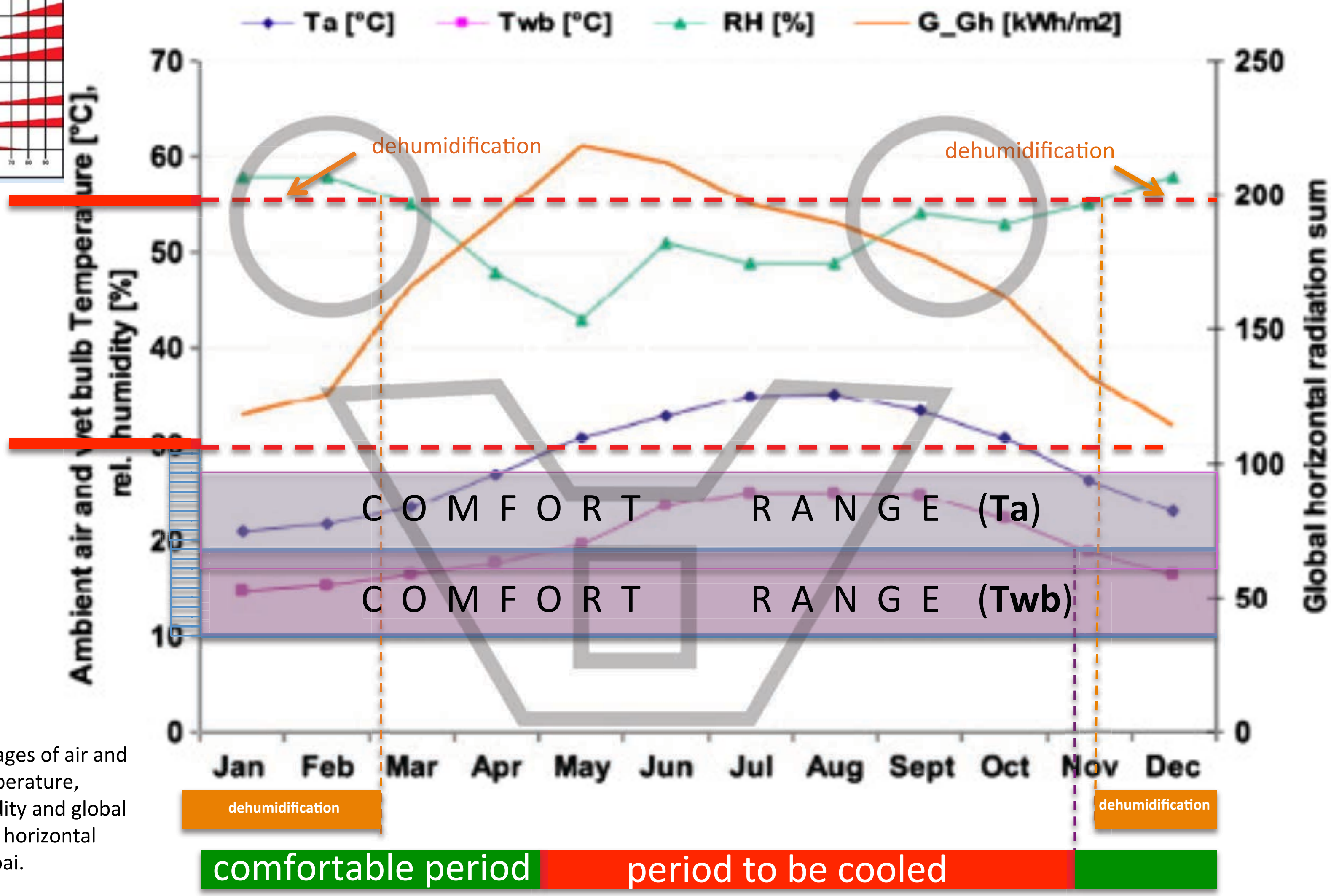
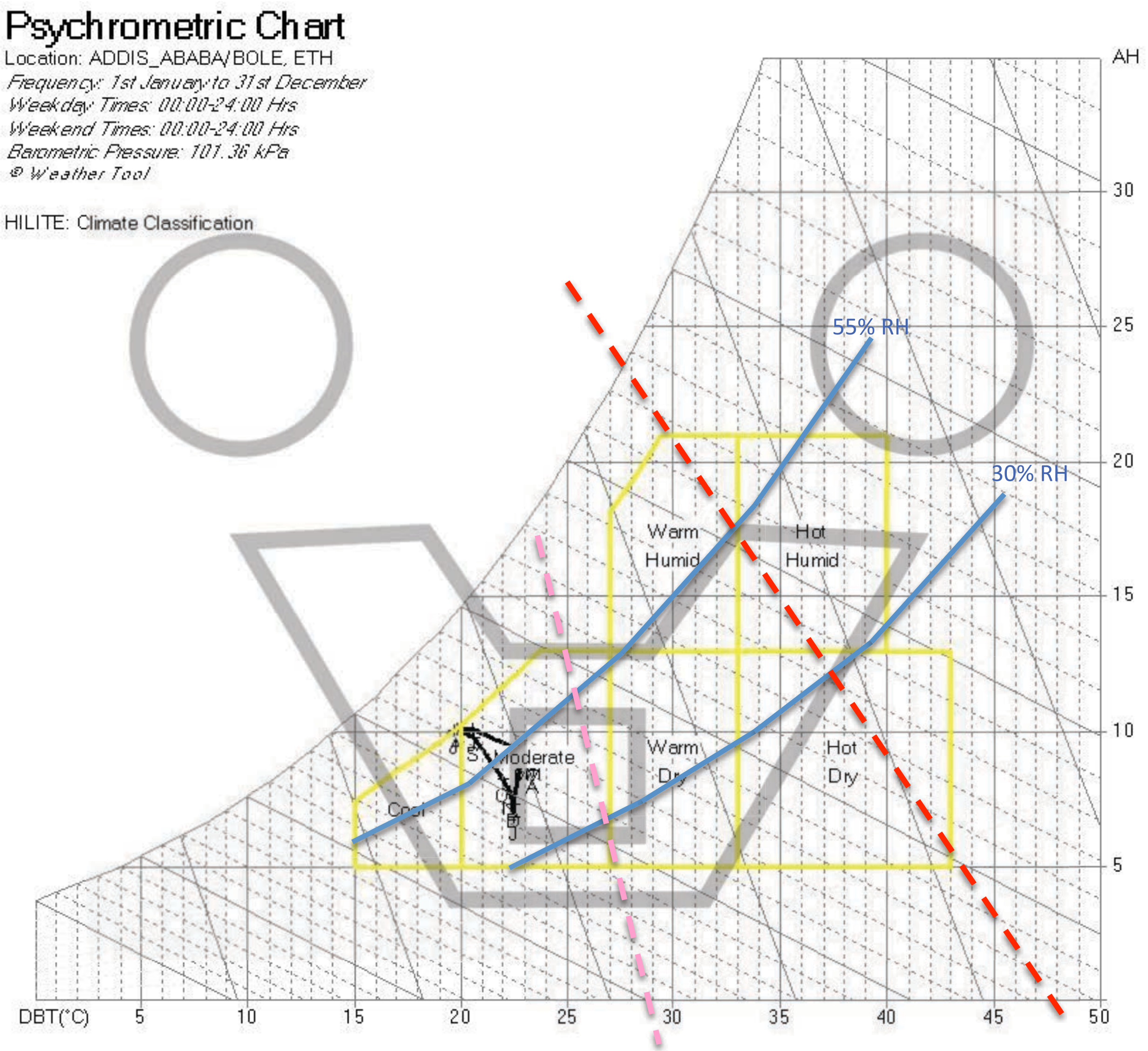
Environmental elements that affect people’s comfort

IDENTIFYING THE COMFORT PERIOD

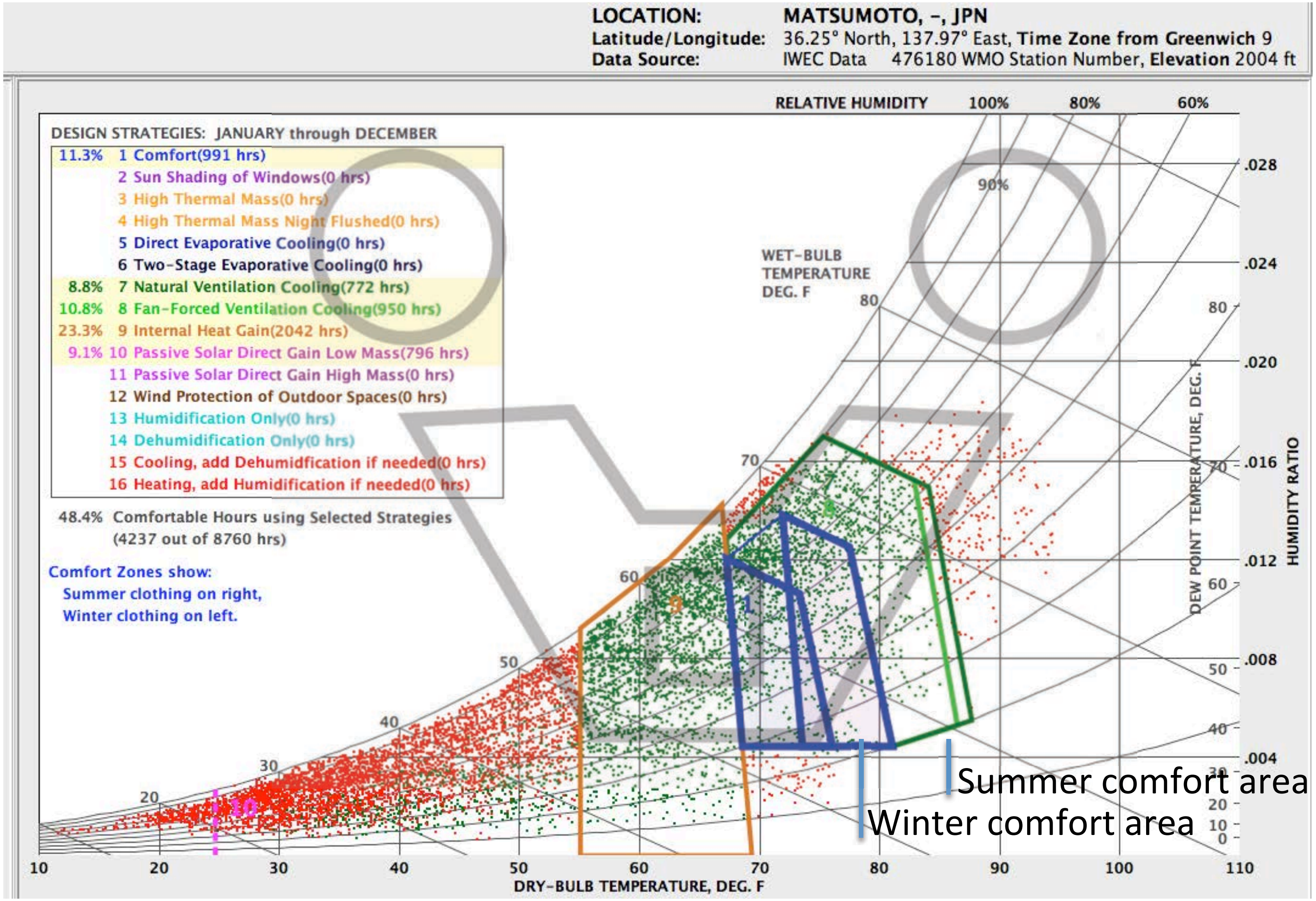


Monthly averages of air and wet bulb temperature, relative humidity and global radiation on a horizontal surface in Dubai.

Environmental elements that affect people's comfort



IDENTIFYING THE COMFORT PERIOD

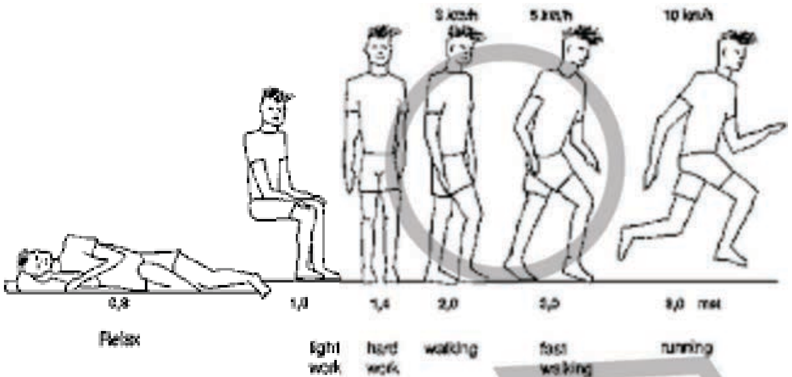


Ecotec output from climate-consultant http://www.energy-design-tools.aud.ucla.edu/

iCAD
Prof. Giuseppe Ridolfi, PhD

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).
*1 met = 18.4 Btu/h·ft²

<u>Thermal comfort</u>= 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

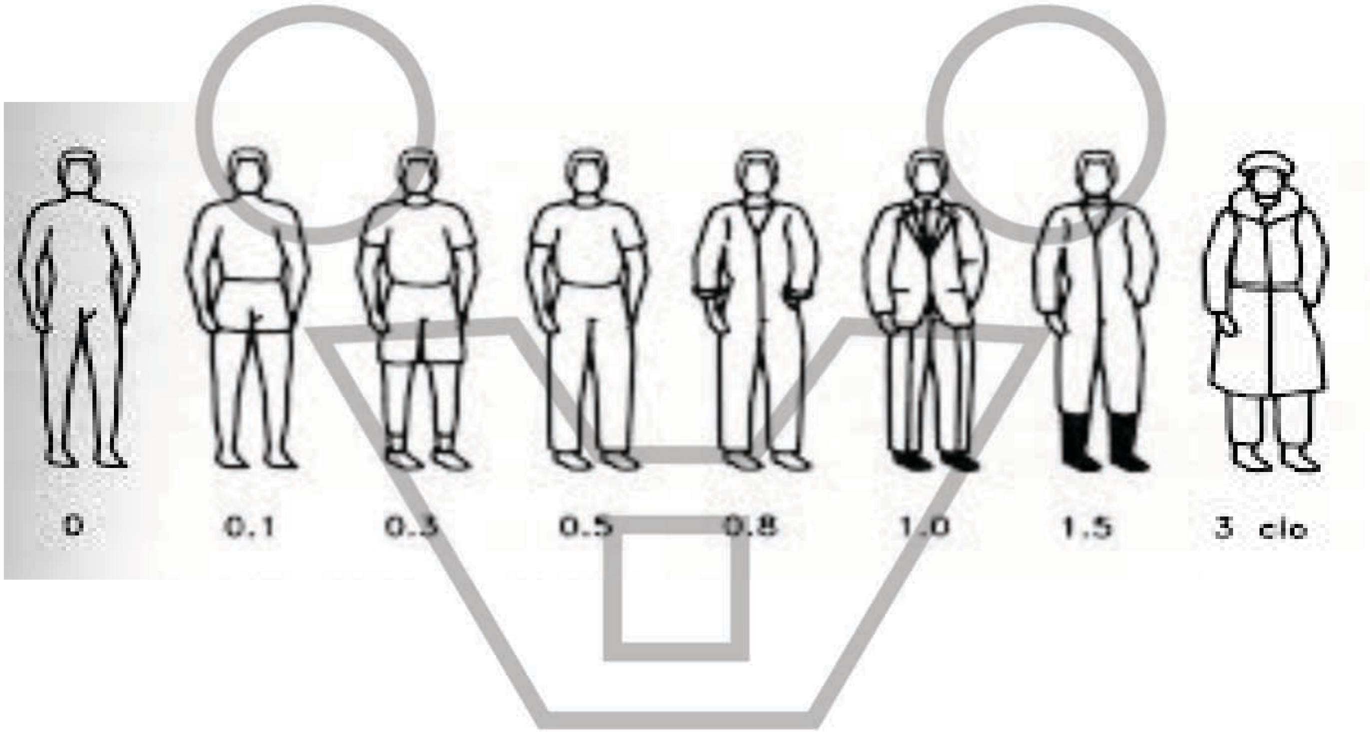
100 watt/h

Environmental elements that affect people's comfort

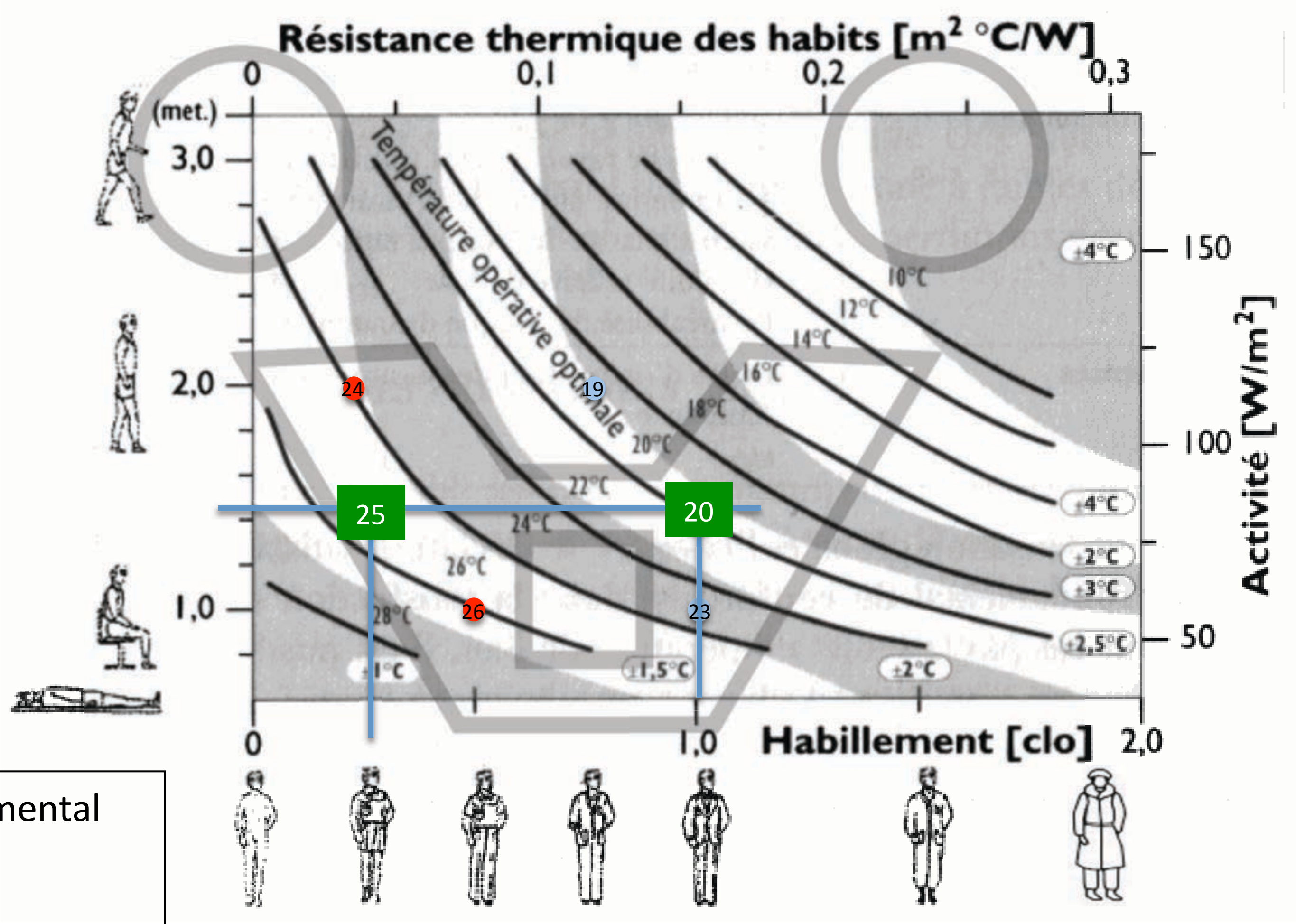
Converting the excess heat generated by the Stockholm Central Station's 2500 daily users to hot water and pump it to the nearby Kungsbrohuset office block.

Environmental elements that affect people's comfort

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



THERMAL COMFORT ZONE

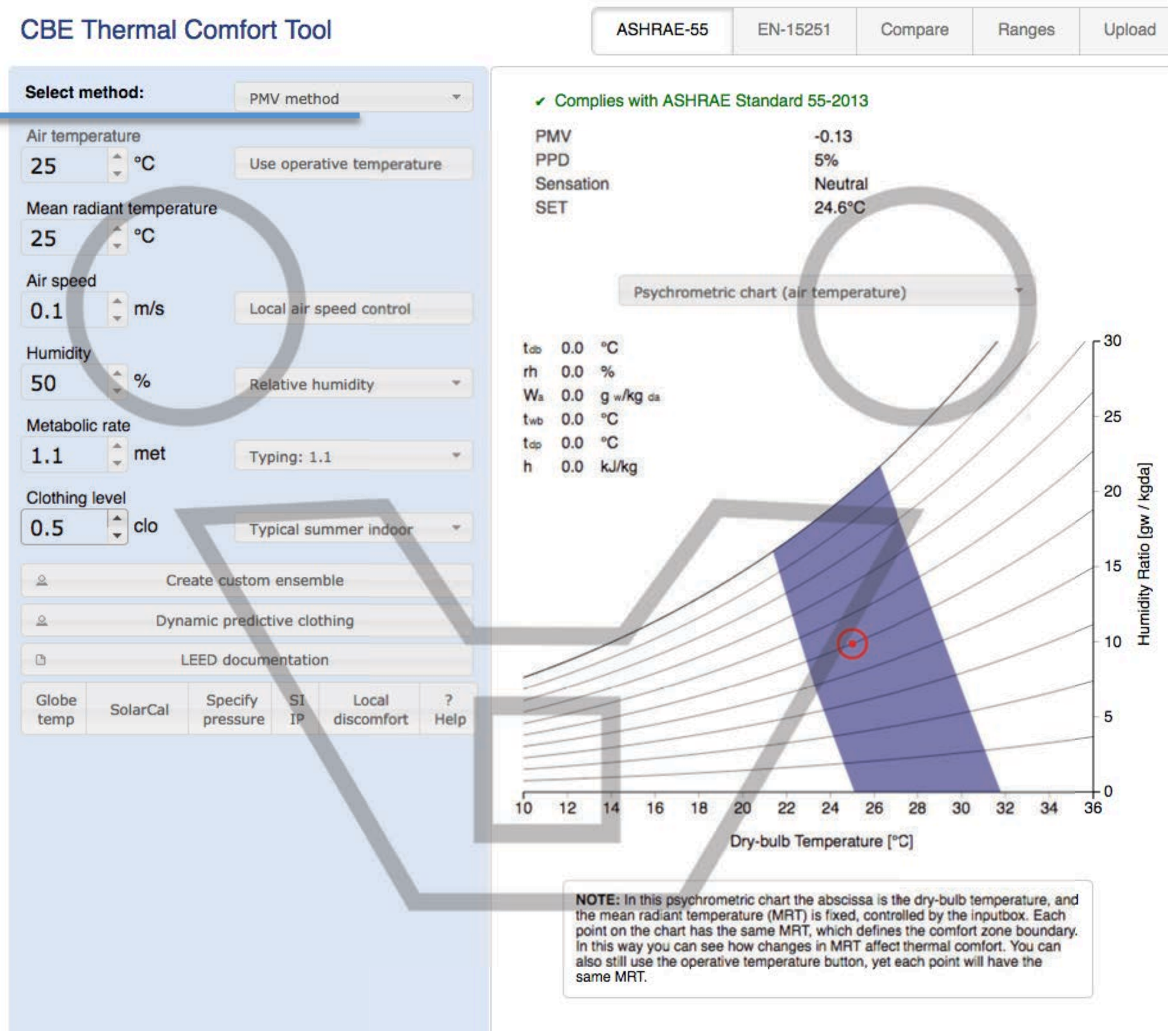


Ideal Environmental temperature

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

Prof. Giuseppe Ridolfi, PhD

MODELING HUMAN BEHAVIOURS AND COMPUTING COMFORT CONDITIONS

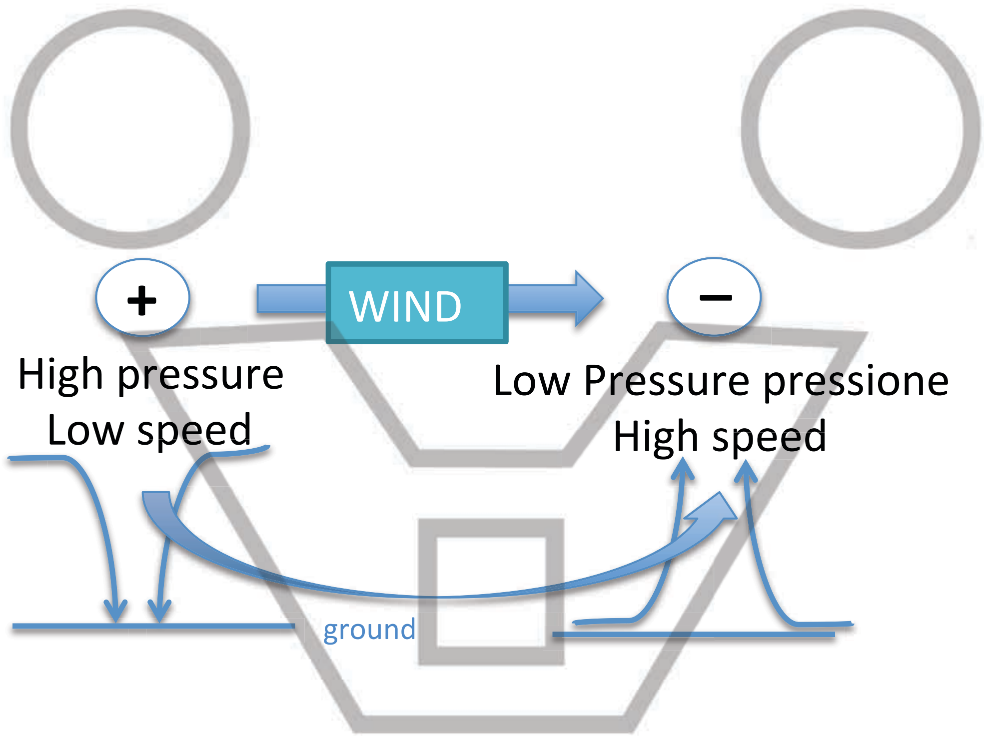
WIND & VENTILATION

Air movement: WIND & CROSS VENTILATION

- Temperature balance
- Quality of indoor air   [Minimal air change = 0,5 vol/h]
- Facilitate human transpiration

Air movement: WIND & CROSS VENTILATION

f *[work done f(pressure), cinetic energy f(velocity)+potential gravitational energy f(high)]*

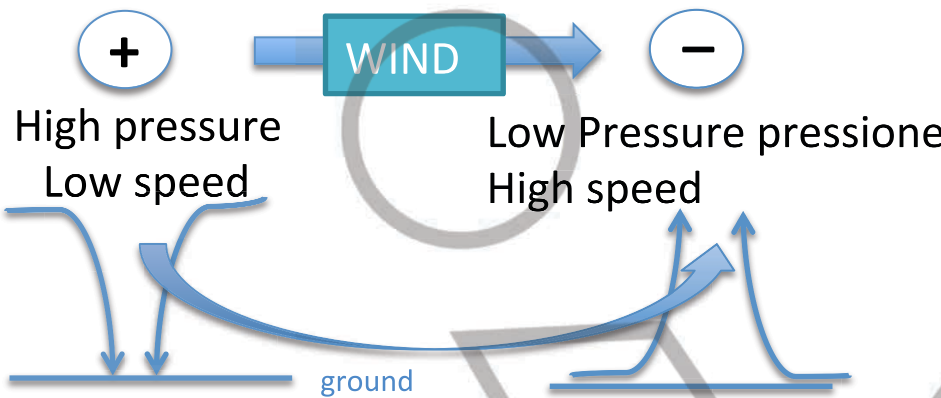


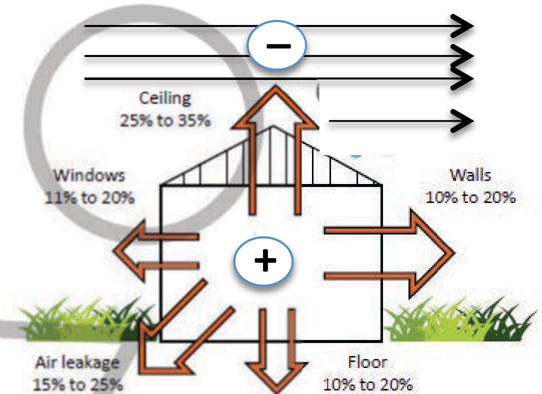
BERNOULLI PRINCIPLE= higher speed lower pressure

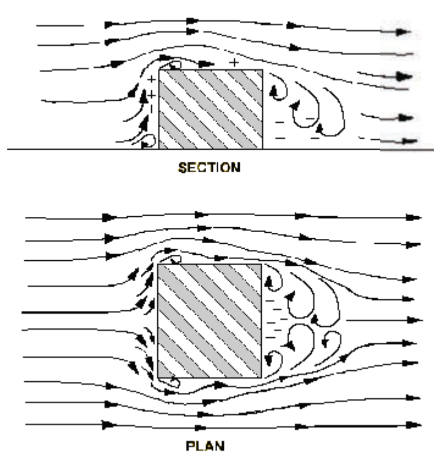
Air movement: WIND & CROSS VENTILATION

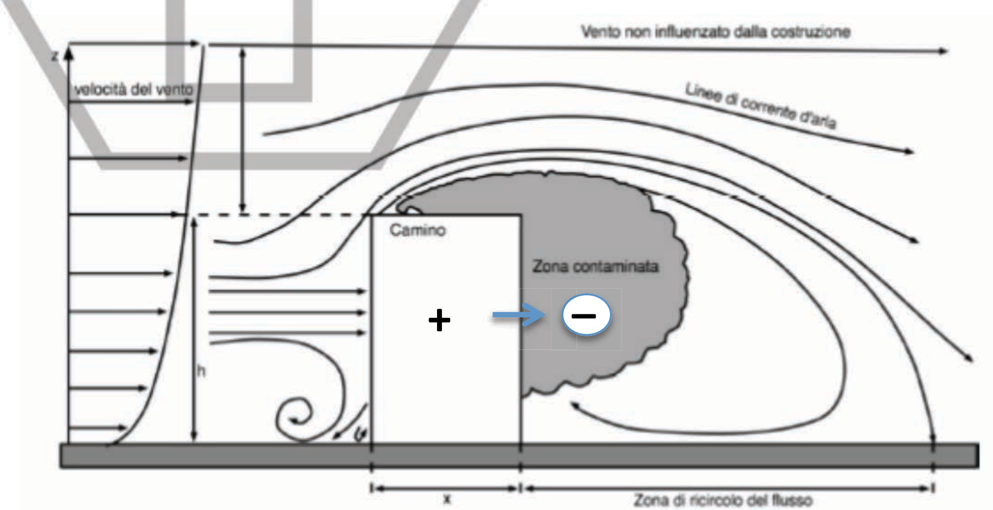
f [work done f(pressure), cinetic energy f(velocity)+potential gravitational energy f(high)]

Bernoulli principle= higher speed lower pressure



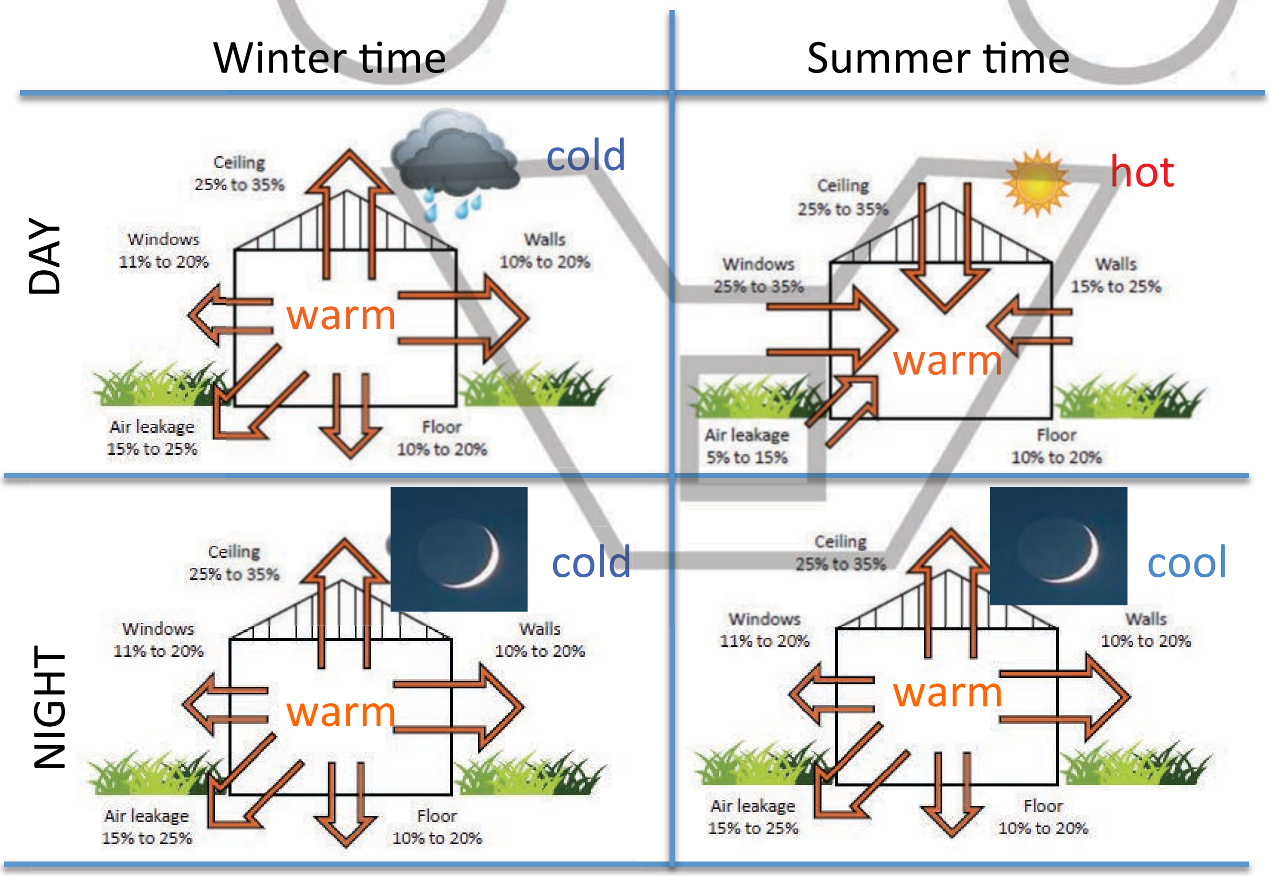




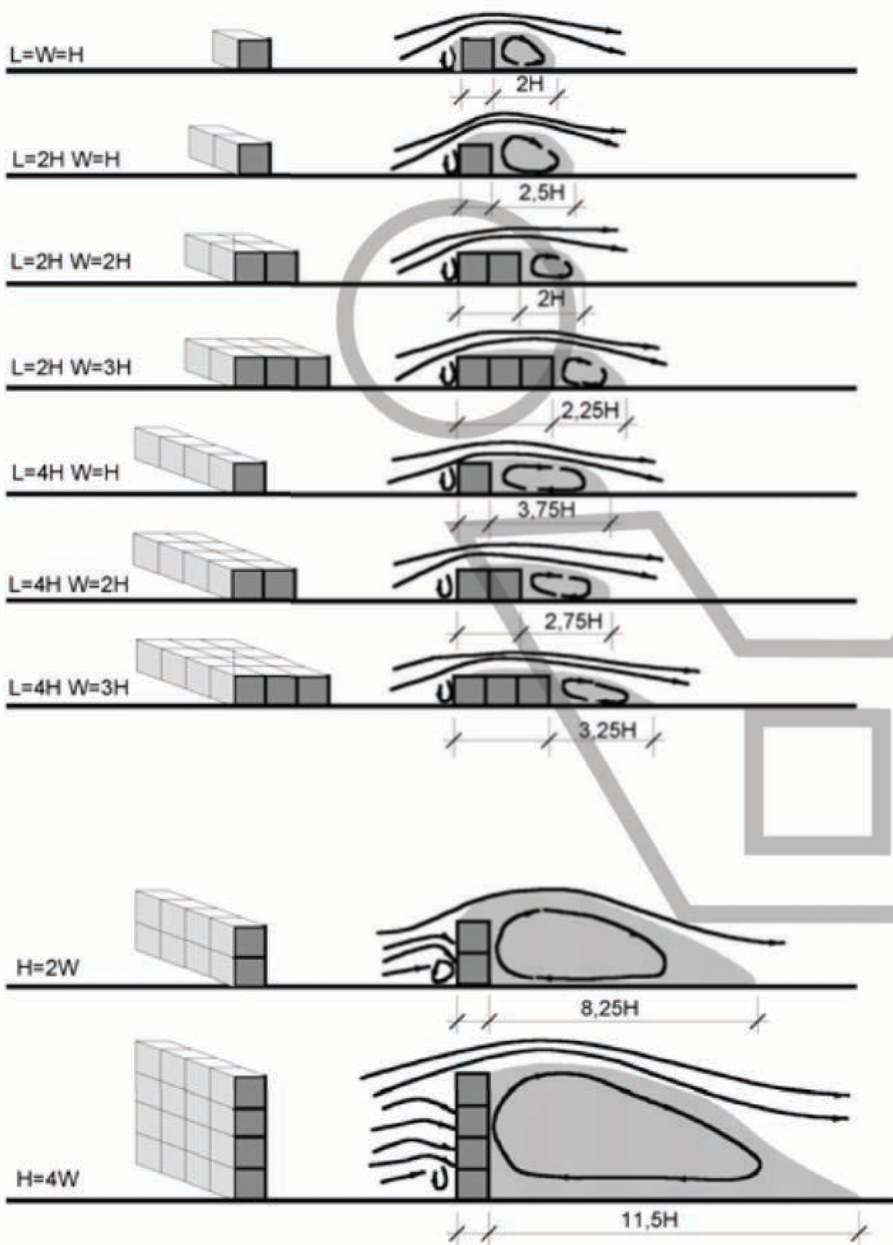


Air movement: WIND & CROSS VENTILATION

<u>From</u> <u>higher temperature</u> (lower density, lower weight, higher pressure)
<u>To</u> <u>lower temperature</u> (higher density, higher weight, lower pressure)

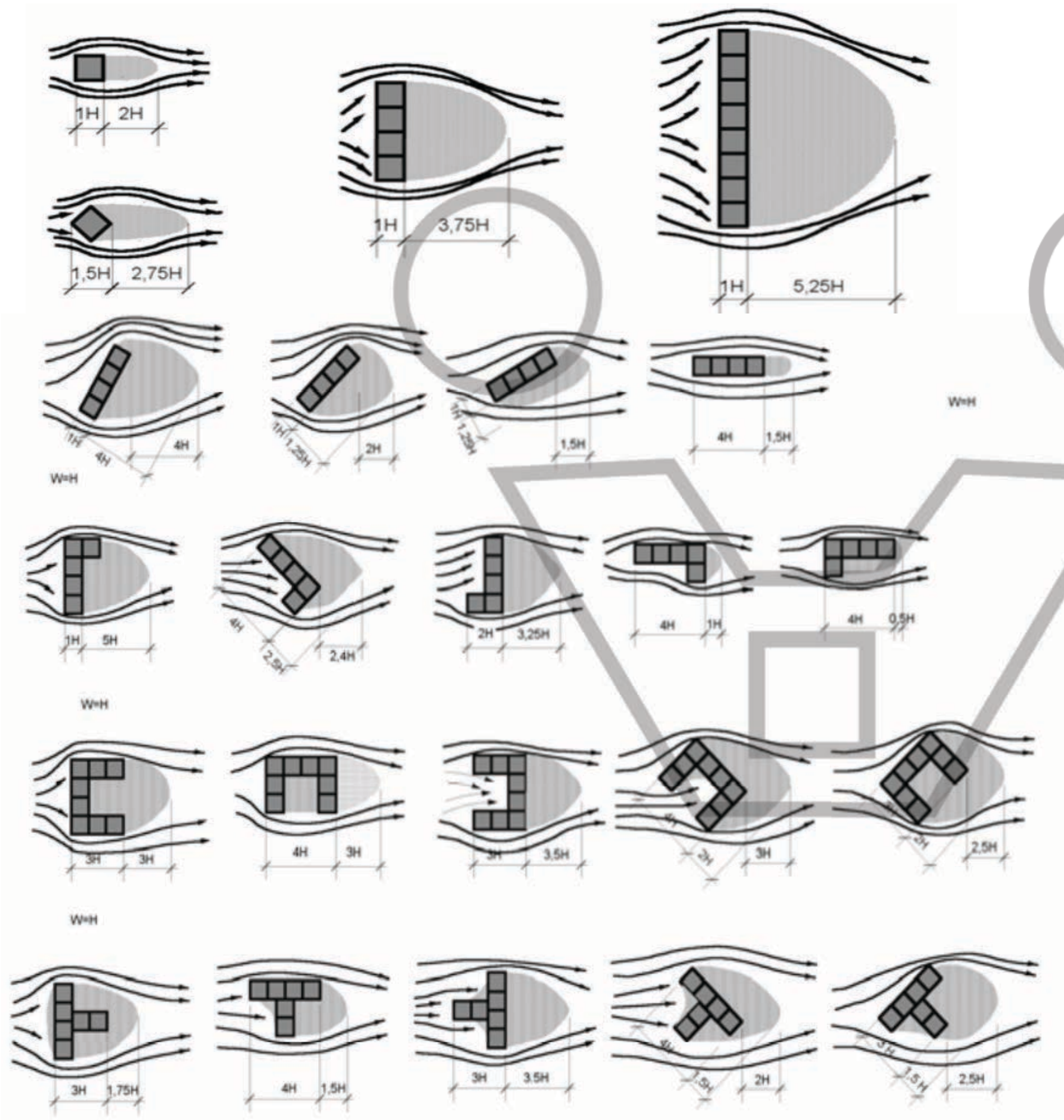


Air movement: WIND ANALYSIS



LOW PRESSURE

Air movement: WIND ANALYSIS



LOW PRESSURE

Air movement: WIND ANALYSIS

HOW TO VISUALIZE WINDS – Airflow Modeling

Understanding the air flow and distribution patterns for buildings.
The building form and shape can affect how air flows through the building and across neighboring developments into the building.
This is an important consideration for natural ventilation and can significantly reduce costs of air-conditioning provisions.
There are Computational Fluid Dynamics (CFD) tools available that can help simulate the air-flow patterns within built-spaces as well as for whole building estates

Basic software tool:
Flow Design http://www.autodesk.com/education/free-software/flow-design (student version available)

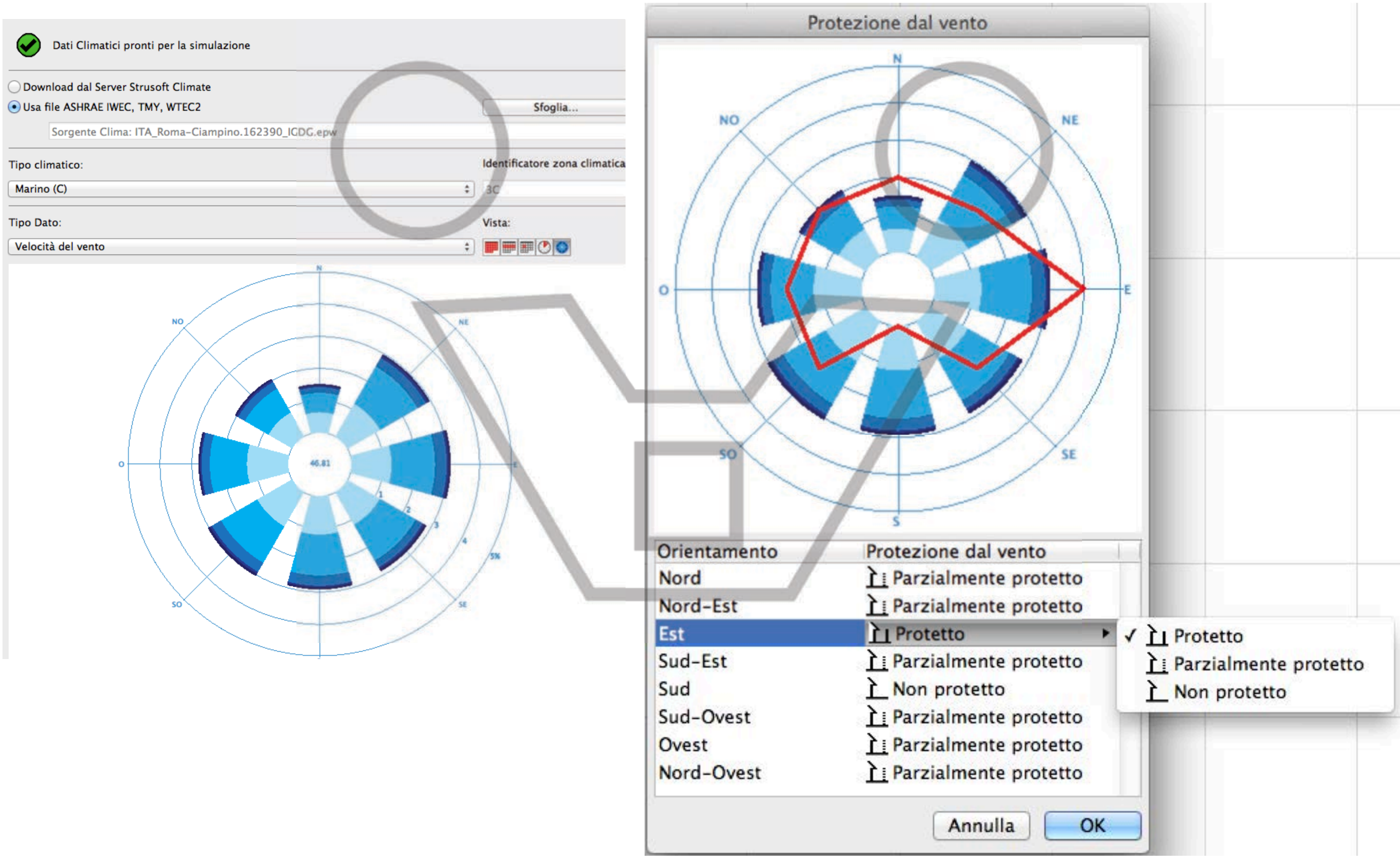
Other popular software tools:
Fluent by Ansys: http://www.ansys.com/. (student version available)
FloVent from Mentor Graphics: http://www.mentor.com/.
Comsol Multiphysics modeling software: https://www.comsol.com/.

References

AIA (The American Institute of Architects) (2012) An Architect's guide to integrating energy modeling in the design process
ERI@N (Energy Research Institute @ NTU) (2013) Nanyang Technological University (NTU), Singapore
NREL (2009) A handbook for planning and conducting charrettes for high-performance projects, National Renewable Energy Laboratory (NREL), Sept 2009

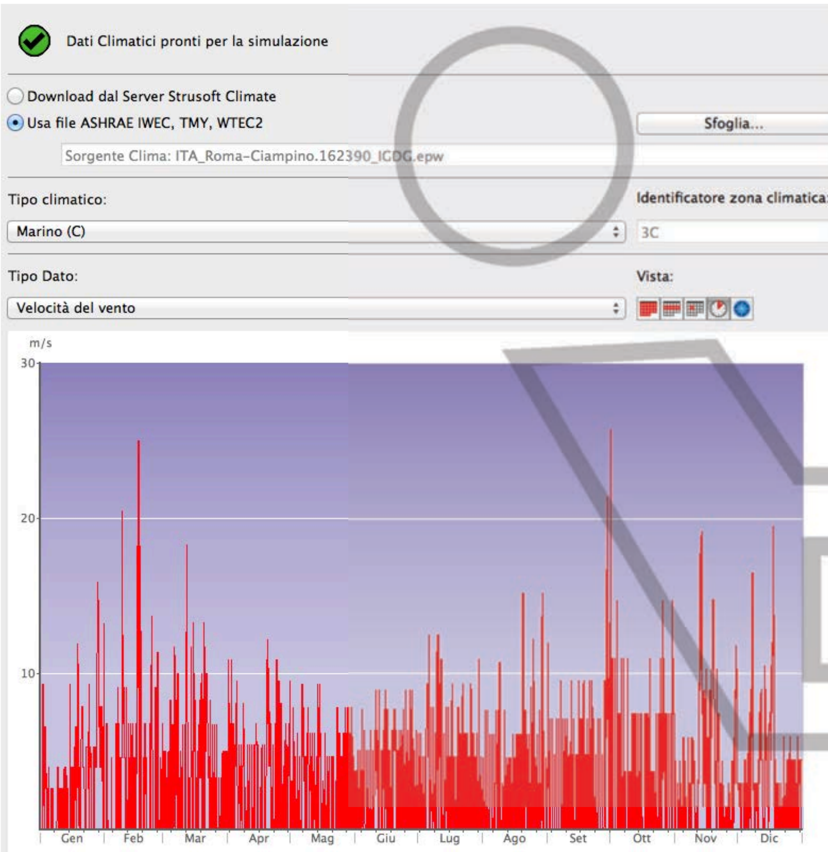
Air movement: WIND ANALYSIS

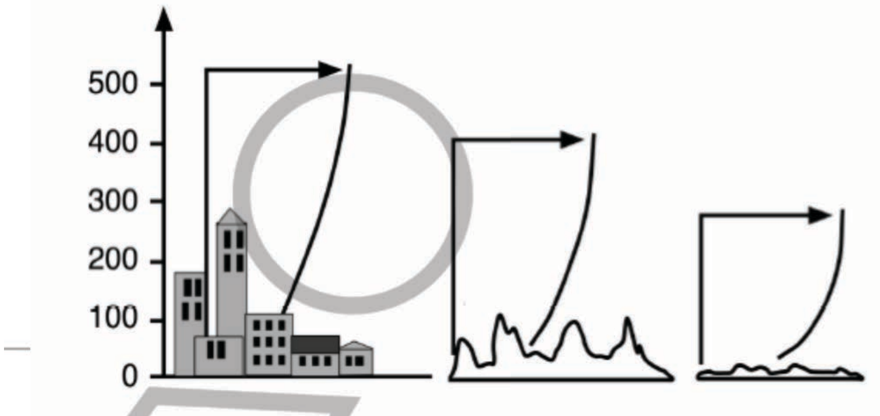
1- determine the coldest and the hottest seasonal period and hours
2- for that periods find the most frequent wind directions



Air movement: WIND ANALYSIS

3- define wind speed for the hottest and coldest periods
4- reduce the speed according to altitude and roughness of the site





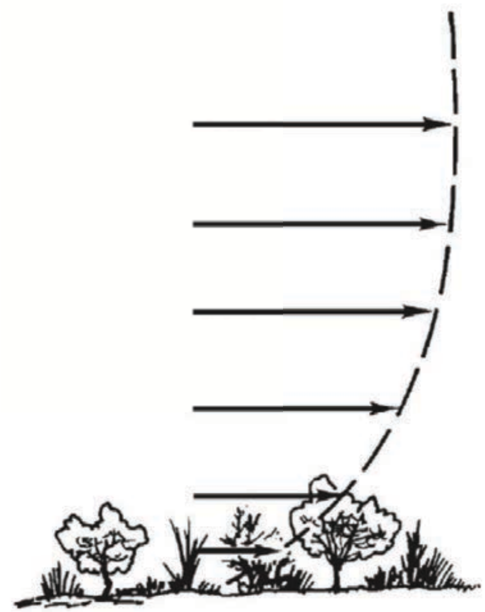
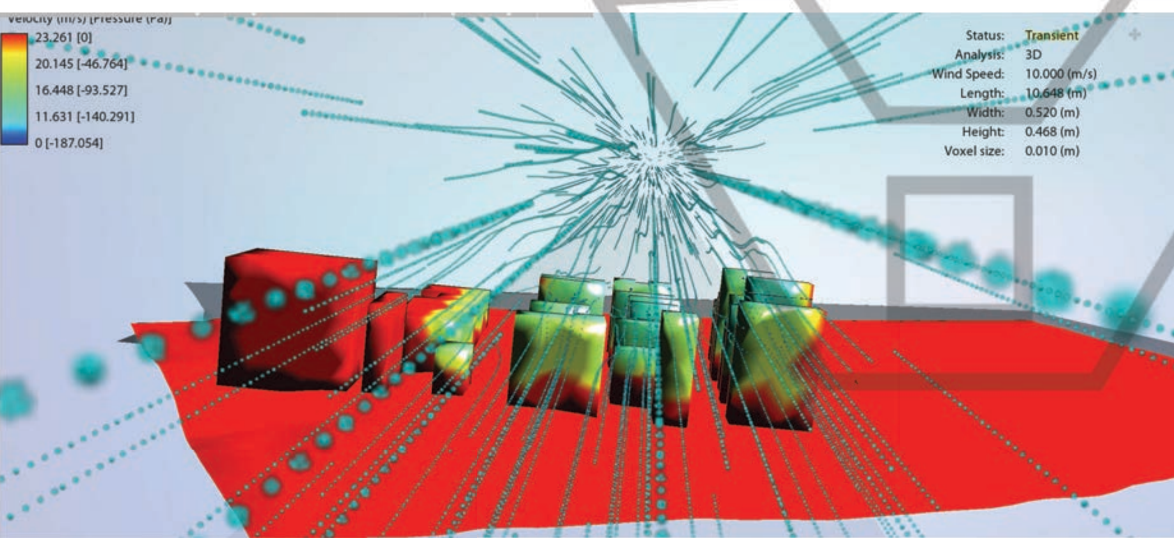
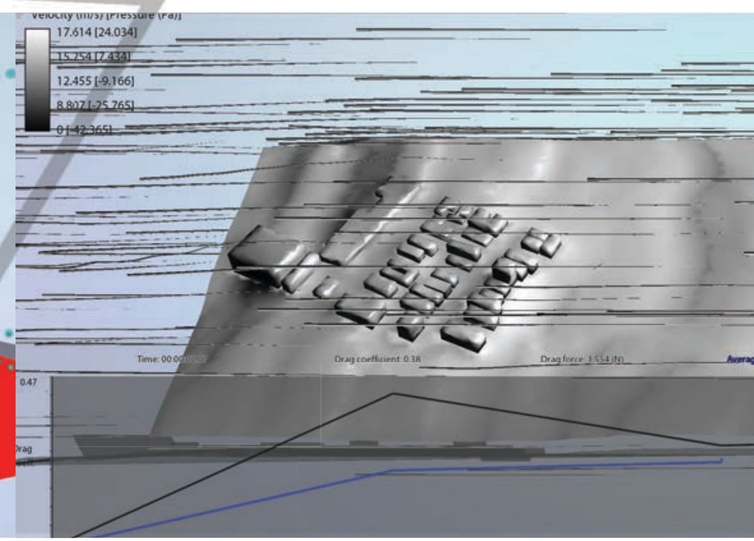


Figure 1—General wind velocity profile near surface (from Rothermel 1983).

Air movement: WIND ANALYSIS

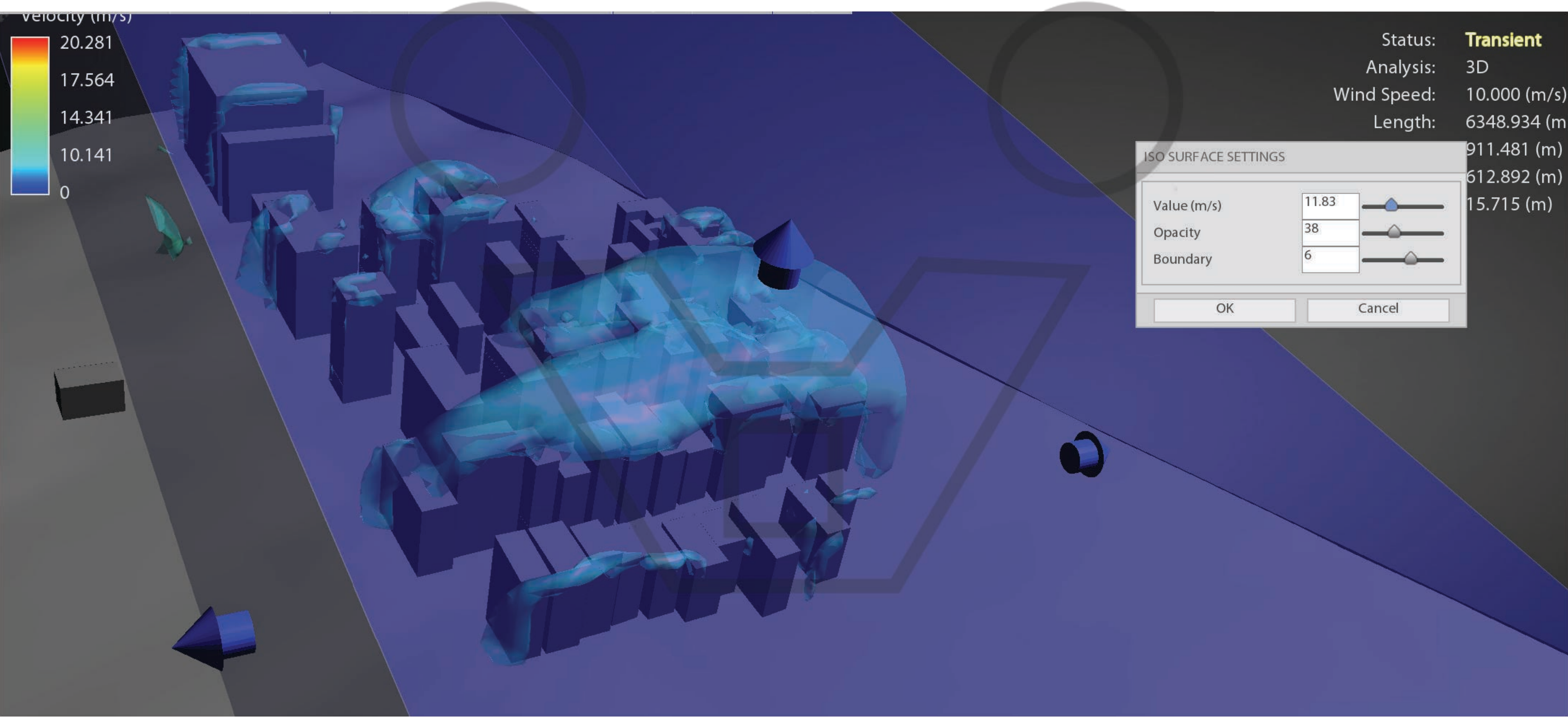
5- Orient the model according to the wind direction



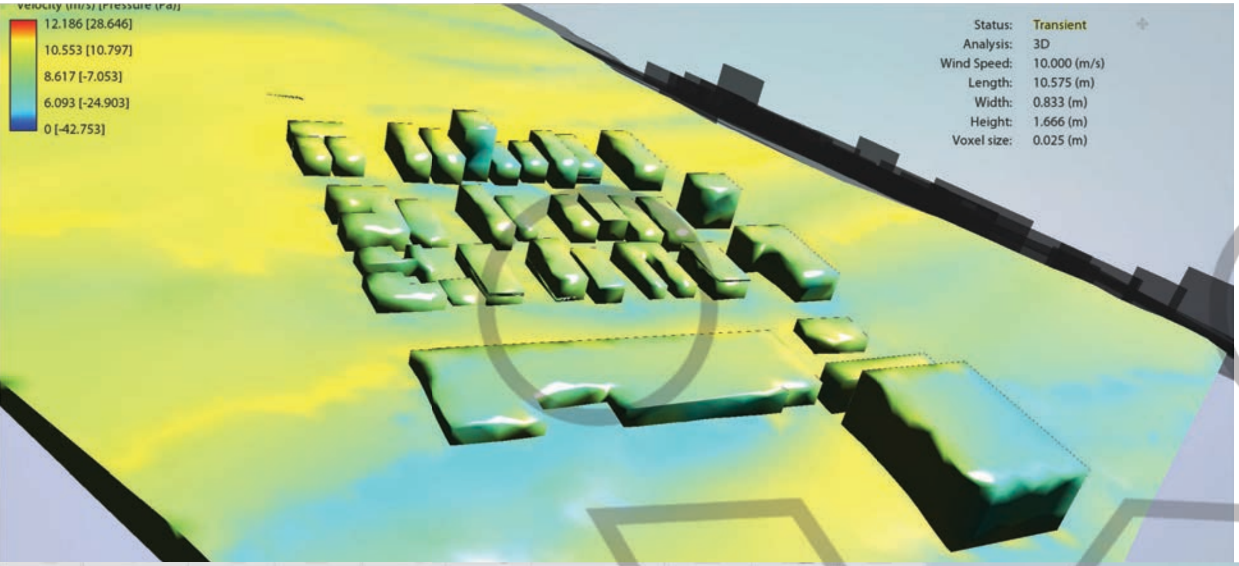


Air movement: WIND ANALYSIS

6- Set the wind velocity & analyze results (low, high pressure zones)

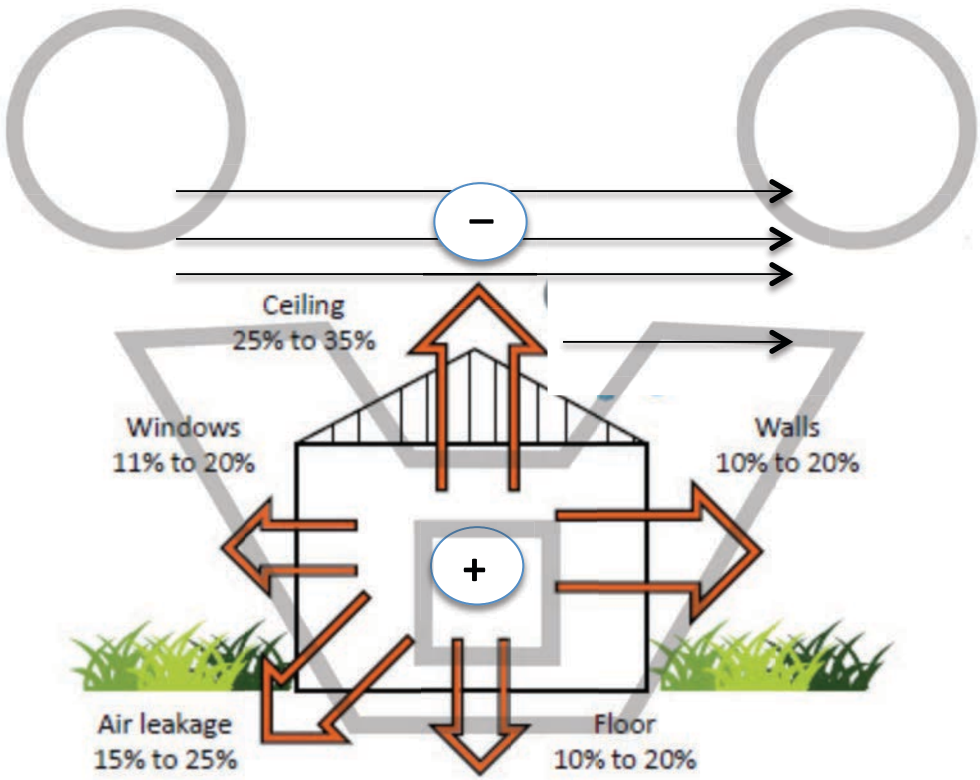


Air movement: WIND ANALYSIS



Air movement: WIND ANALYSIS

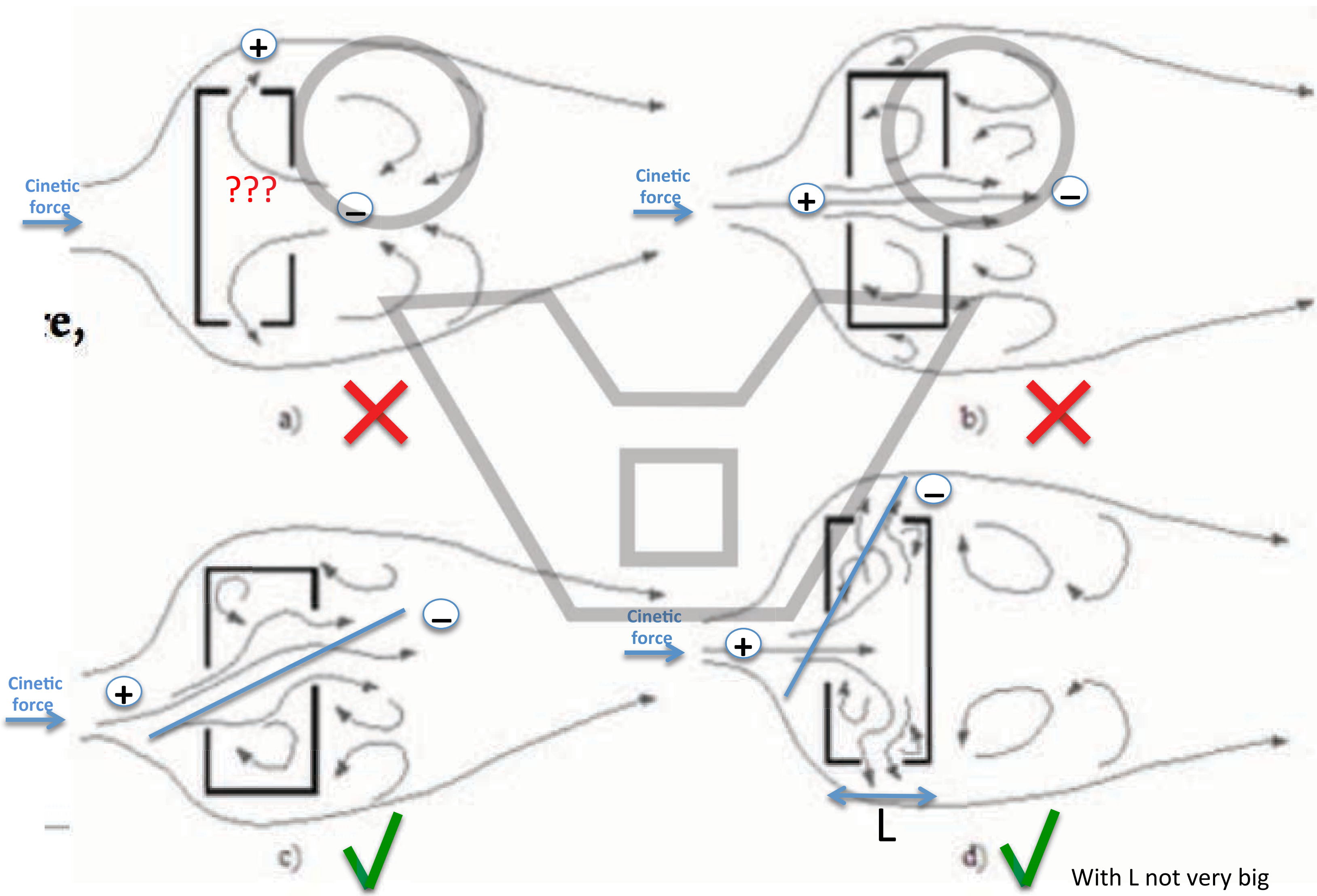
7- Design buildings according the wind pressure zones and cinetic forces



Air movement: WIND ANALYSIS

7- Design buildings according the wind pressure zones and cinetic forces

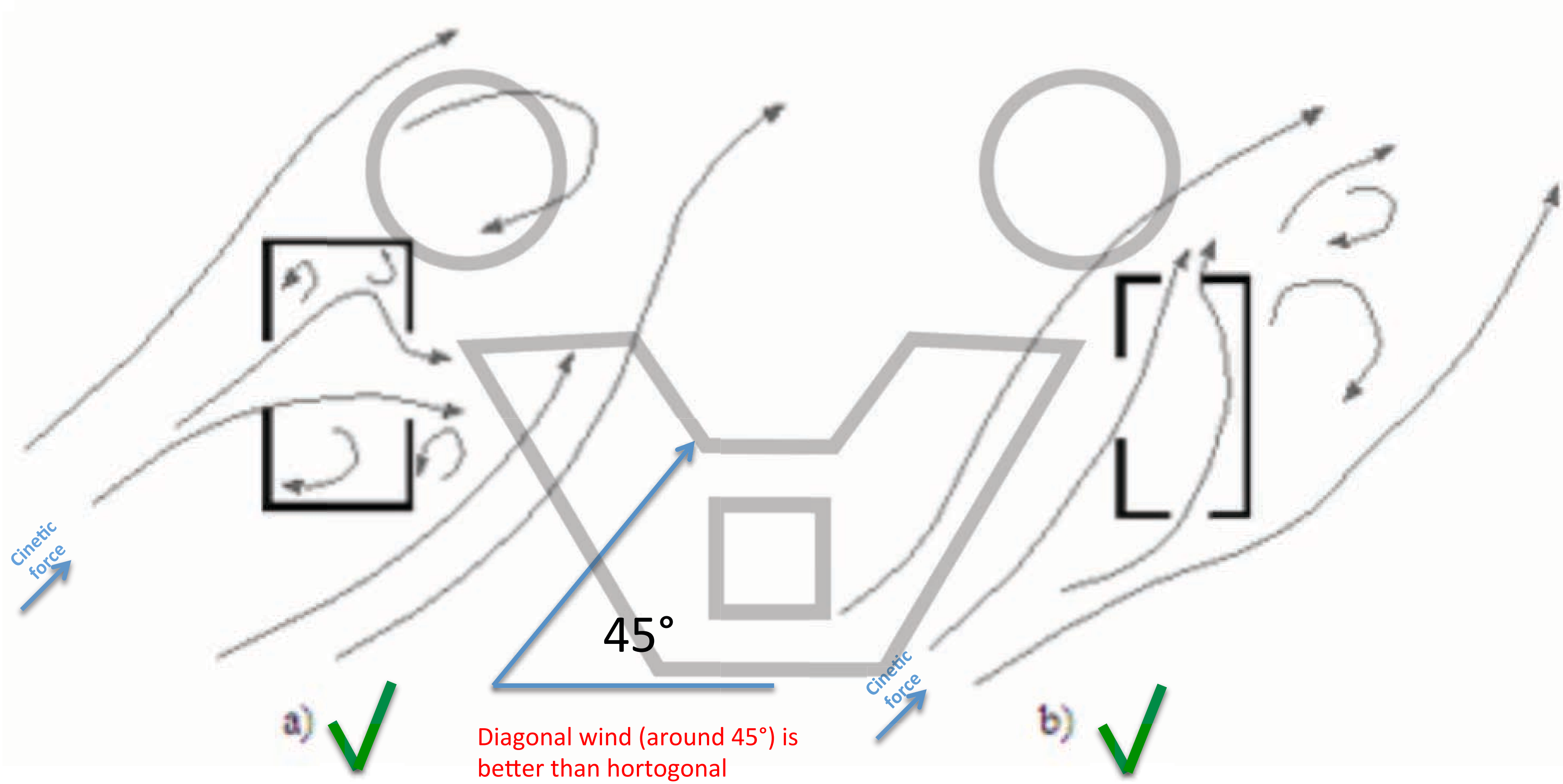
- Designing skin openings for good cross ventilation



Air movement: WIND ANALYSIS

7- Design buildings according the wind pressure zones and cinetic forces

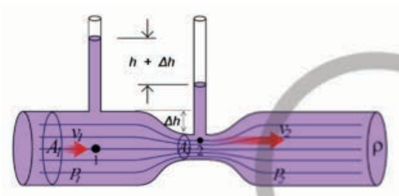
- Designing skin openings for good cross ventilation



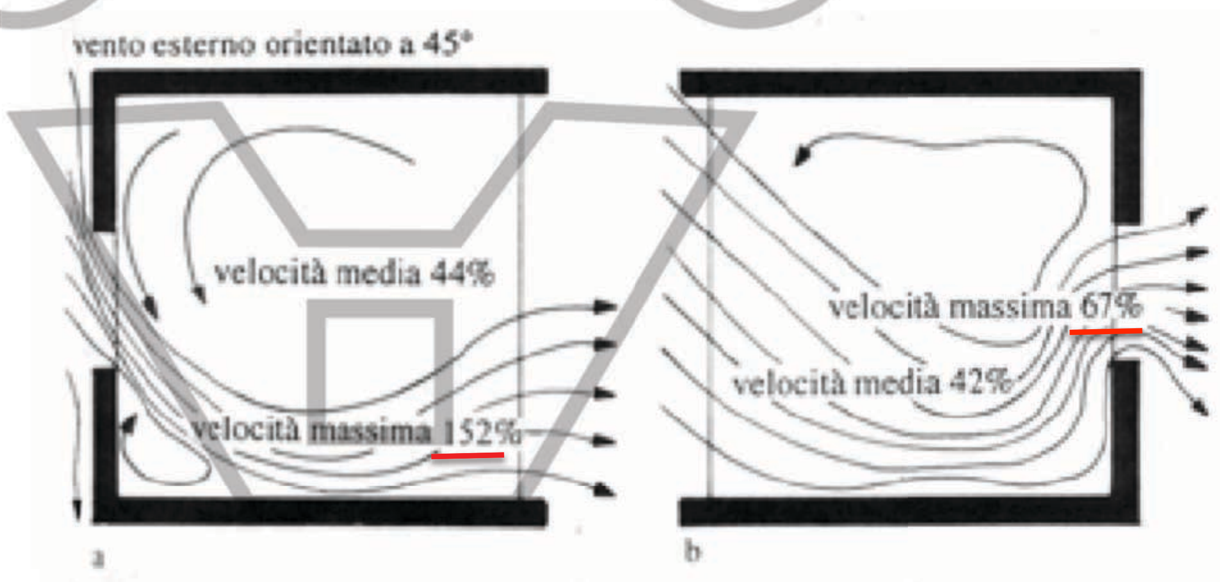
Air movement: WIND ANALYSIS

7- Design buildings according the wind pressure zones and cinetic forces

- Designing skin openings for good cross ventilation



VENTURI EFFECT : Higher speed if the entrance is smaller than the exit



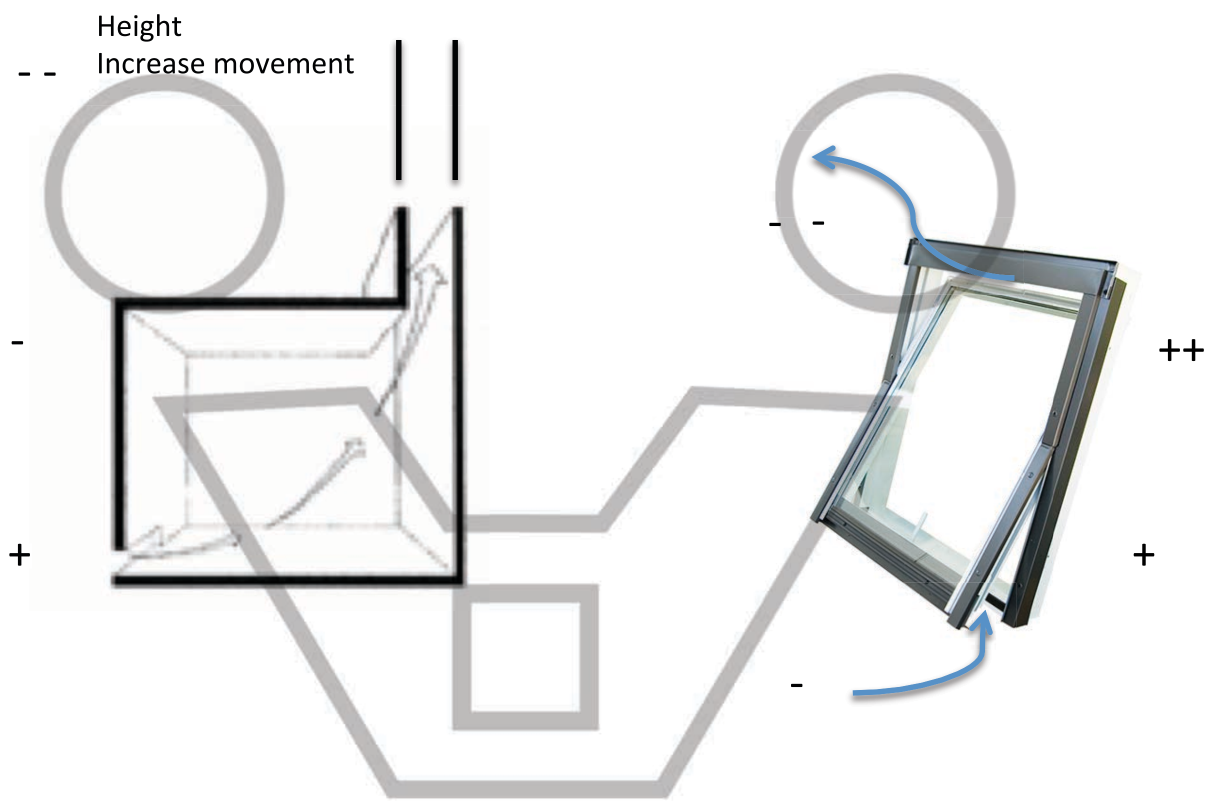
Pairing a large outlet with a small inlet increases incoming wind speed.

MODELING HUMAN BEHAVIOURS AND COMPUTING COMFORT CONDITIONS

STACK EFFECT & VENTILATION

Air movement: VERTICAL VENTILATION

f [work done f(pressure), cinetic energy f(velocity)+potential gravitational energy f(high)]

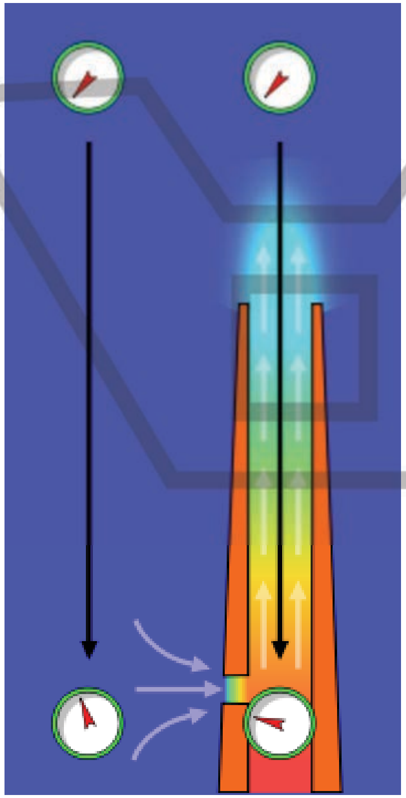


Air movement: VERTICAL VENTILATION

Stack Effect >>> BUOYANCY EFFECT

From higher temperature (lower density, lower weight, higher pressure)
To lower temperature (higher density, higher weight, lower pressure)

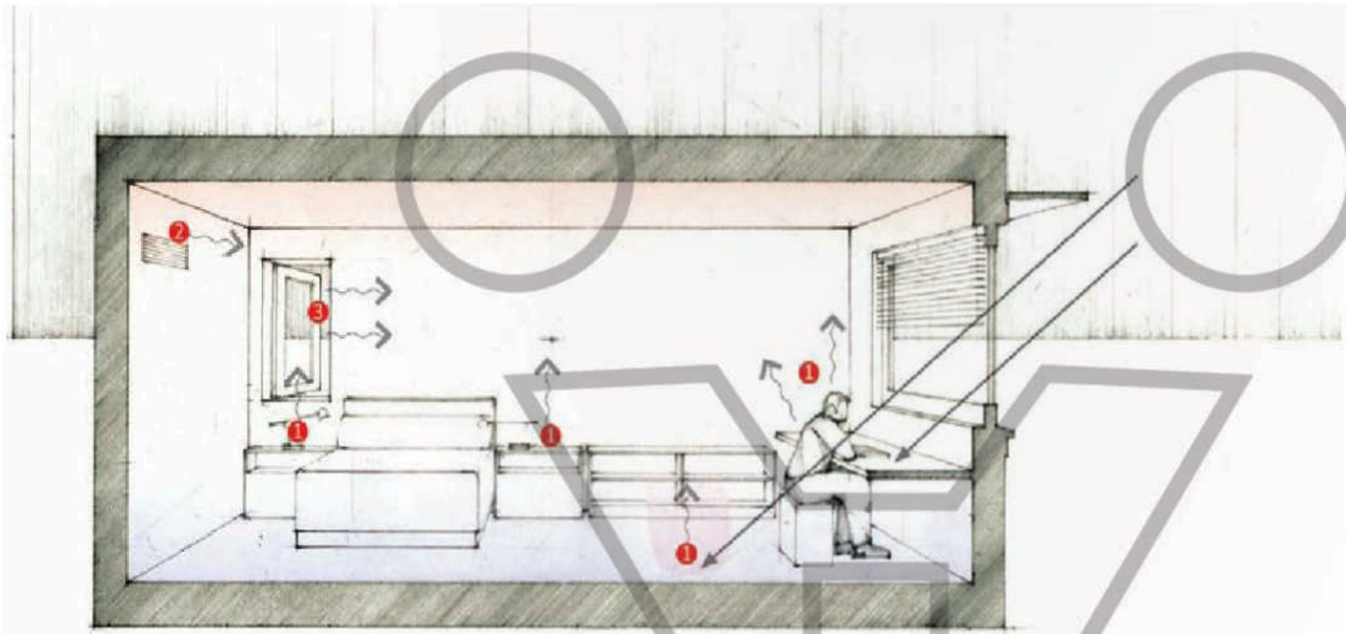
In addition, the stack effect use the difference in altitude (potential gravitational energy)



Typically, at night, wind speeds are slower, so ventilation strategies driven by wind is less effective. Therefore, stack ventilation is an important strategy.

Air movement: VERTICAL VENTILATION

Multiple sources airflow



office and conference room spaces in plan and section. CFD was used to verify the potential for natural ventilation to provide adequate cooling even when outdoor windspeeds are low.

Source: Courtesy of KEMA Energy Analysts.

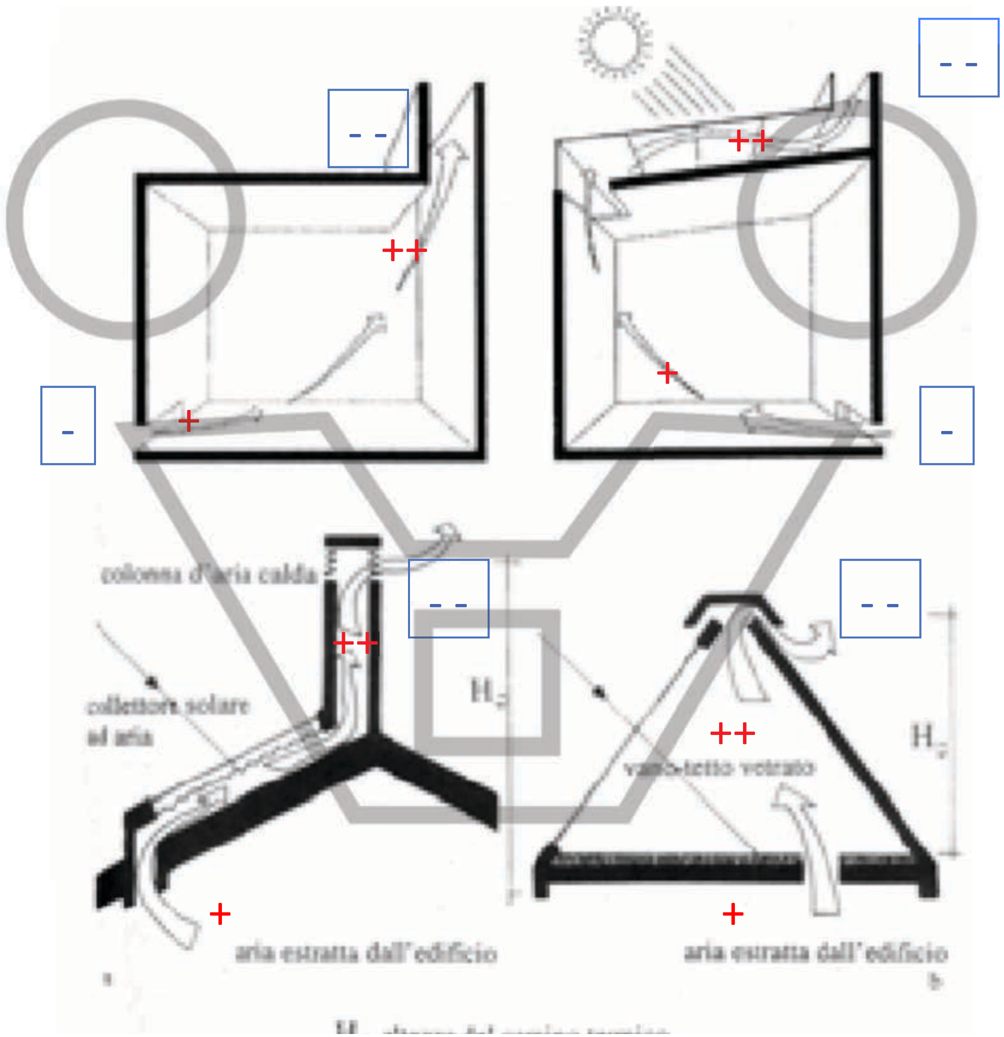
9.2

Airflow within a room is created by multiple sources air rising from (1) heat sources (such as a lamp, person, or a floor warmed by solar irradiation) due to buoyancy creating thermal stratification (red and blue overtones); the interactions of forced air from a (2) fan or a mechanical system and (3) outdoor air speed and direction, channeled by building geometry into and out of a room.

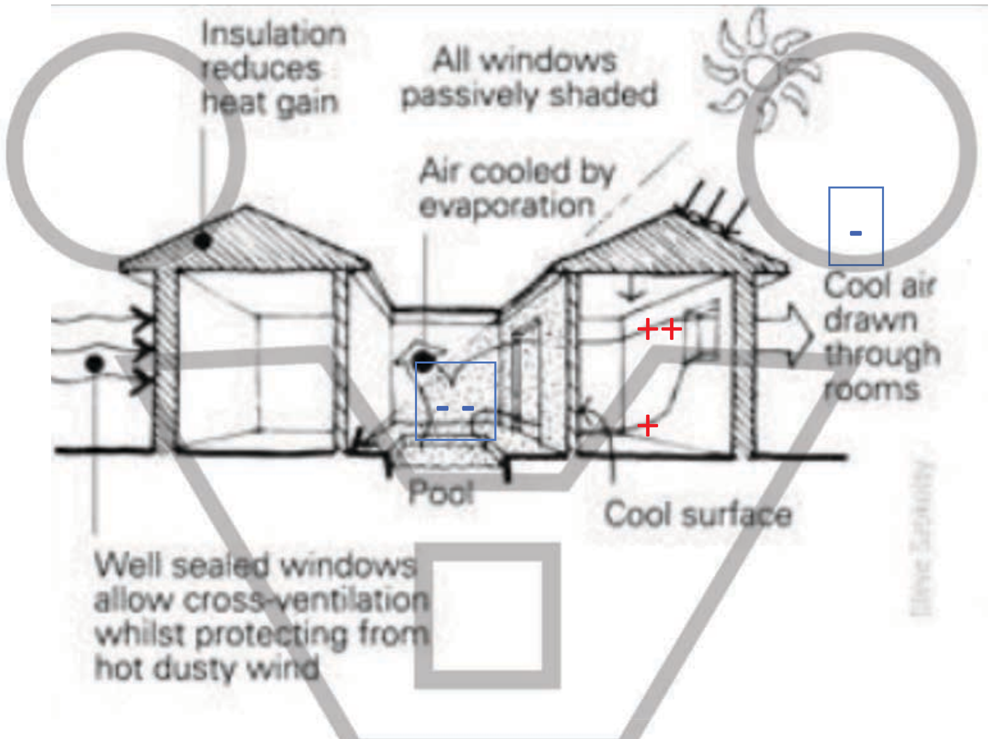
NATURAL VENTILATION AND MIXED-MODE OPERATION

Natural ventilation channels direct outside air to do one or more of the following: provide fresh air, provide cooling, or provide airflow to increase human comfort levels. The ability to use natural ventilation depends climate-wise on peak interior temperatures, and the humidity, solar radiation, and wind

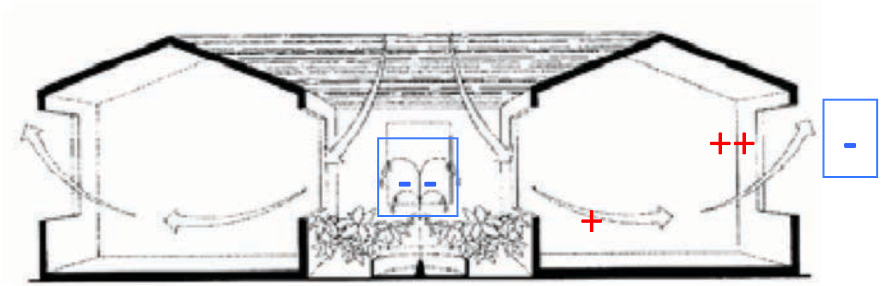
Air movement: VERTICAL VENTILATION



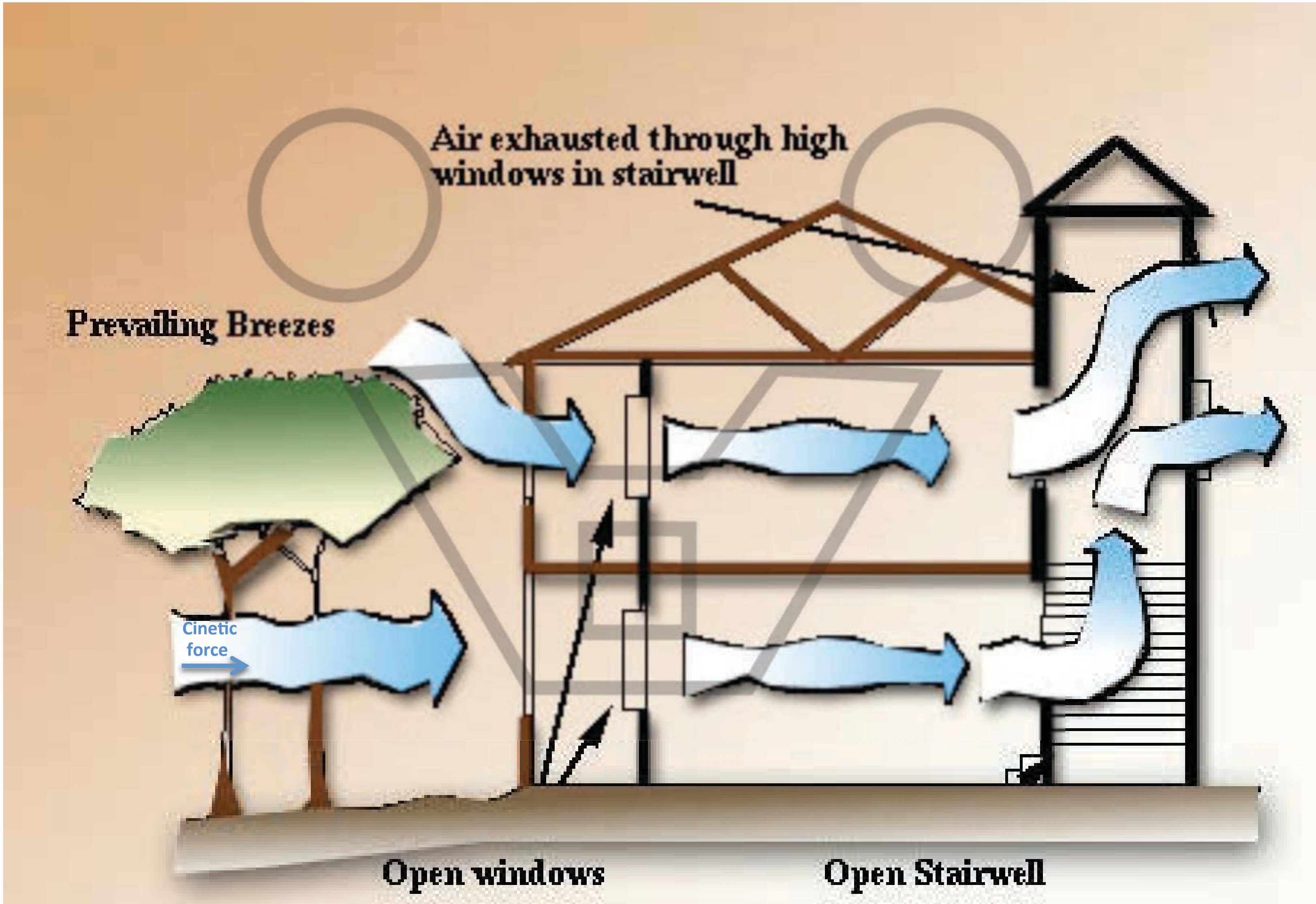
Air movement: VERTICAL VENTILATION



Low Pressure induced by cold zone needs to be carefully checked

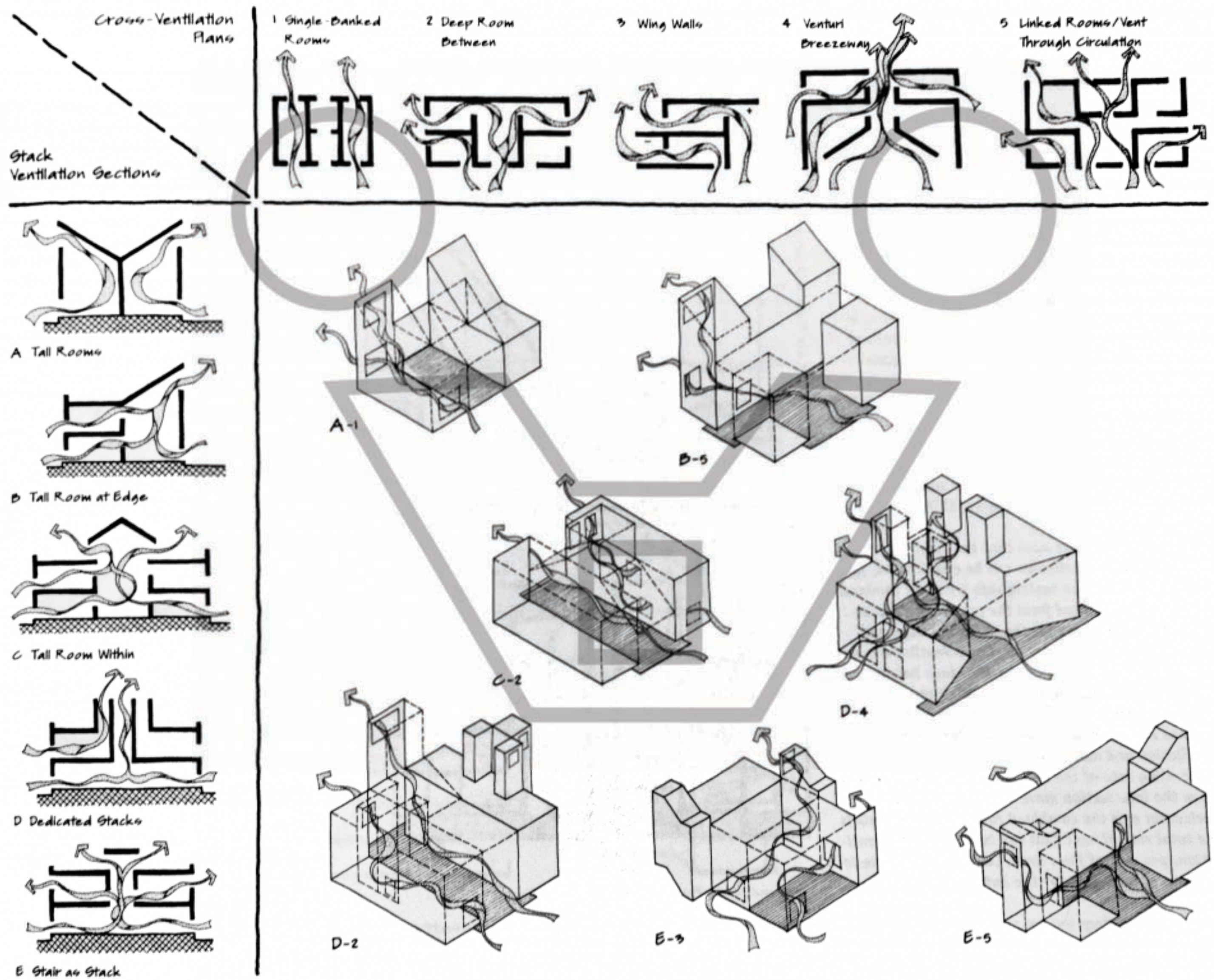


Air movement: VERTICAL VENTILATION



Air movement: VERTICAL VENTILATION

Working with natural ventilation **Air movement: Cross ventilation + Stack effect room diagrams**



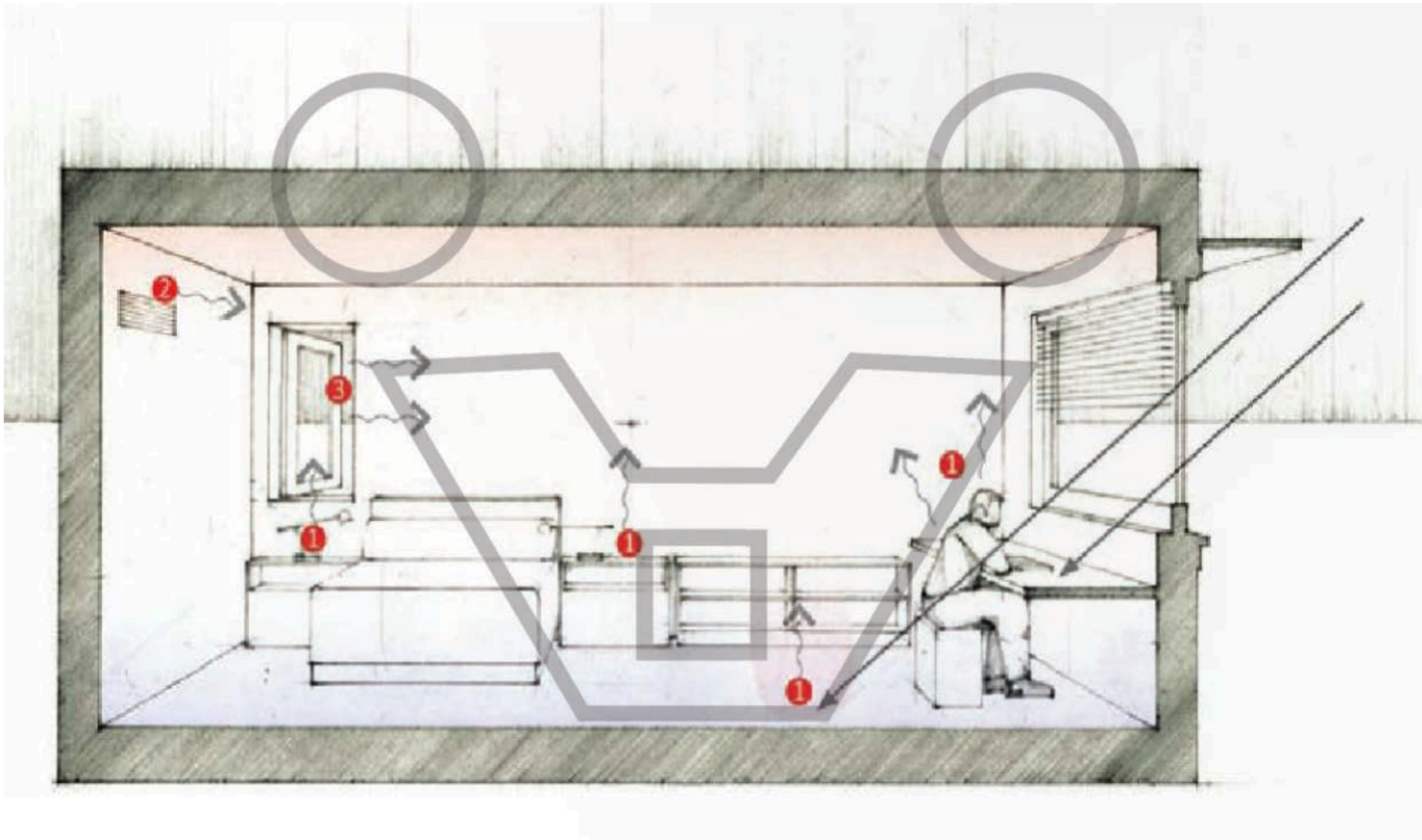
Room Organization Strategies That Facilitate Both Cross and Stack-Ventilation

MODELING HUMAN BEHAVIOURS AND COMPUTING COMFORT CONDITIONS

WORKING WITH NATURAL VENTILATION

- To heat/cool through thermal convection
- to refresh through the sweating acceleration
- to clean exhausted indoor air
- to prevent condensation, moisture, and germs

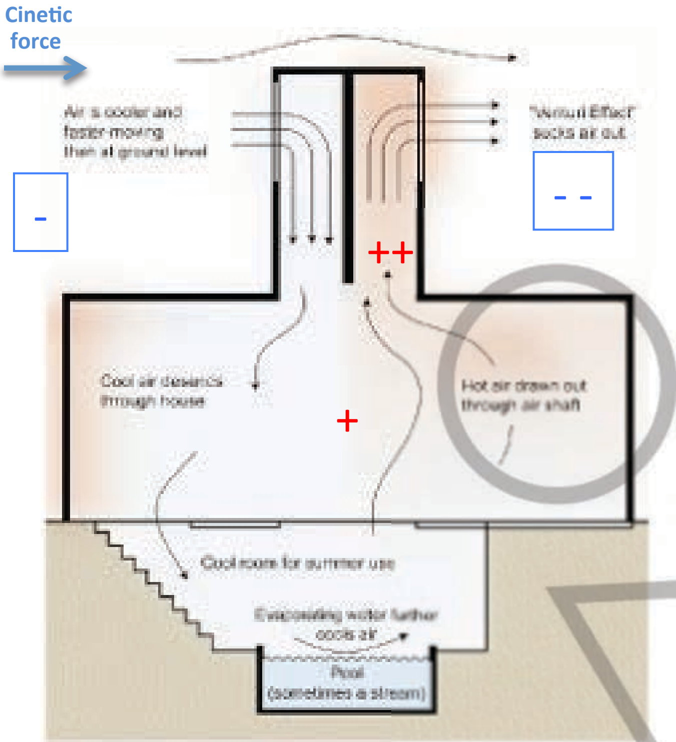
Multiple sources airflow

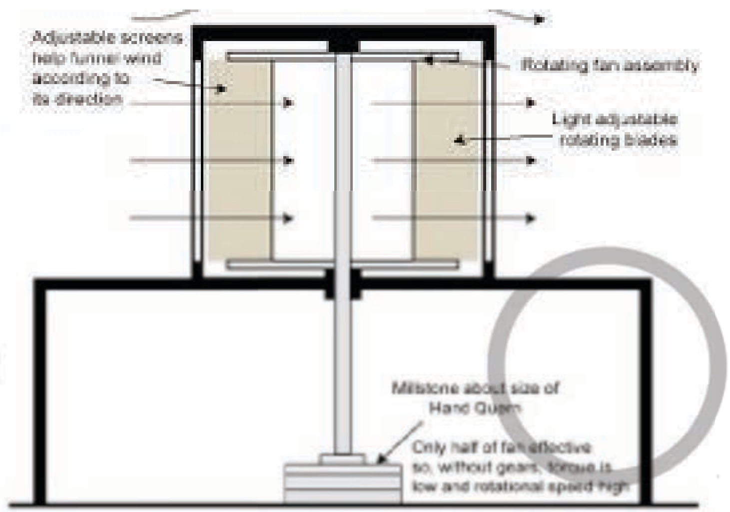


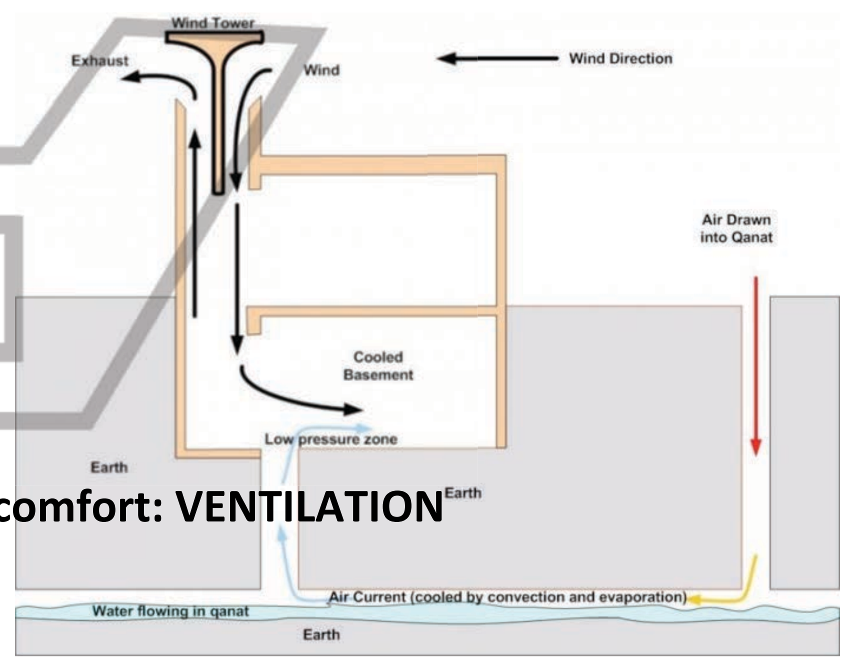
Wind Towers

Working with natural ventilation

Wind Towers

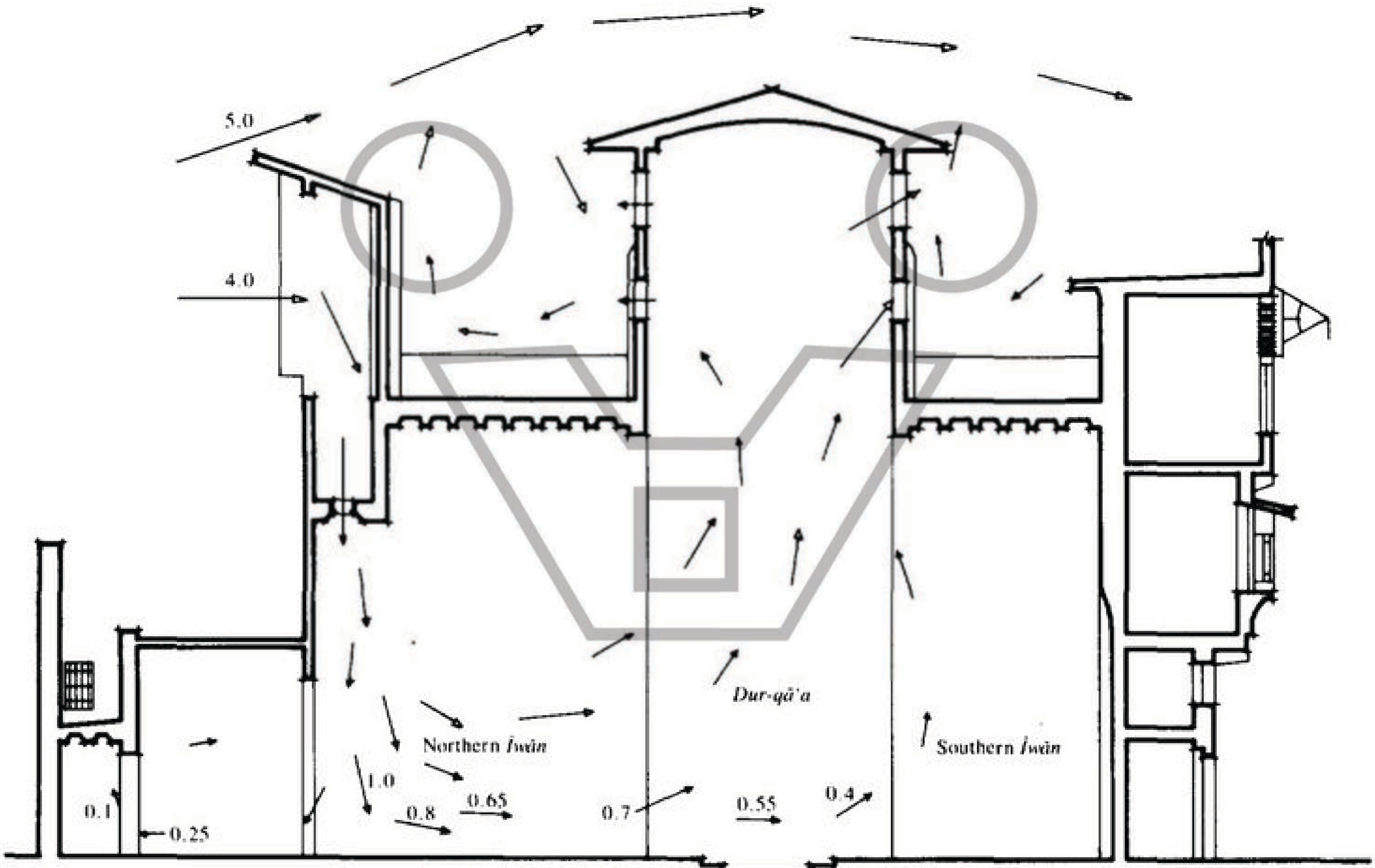






Environmental parameters affecting indoor comfort: VENTILATION

Wind Towers

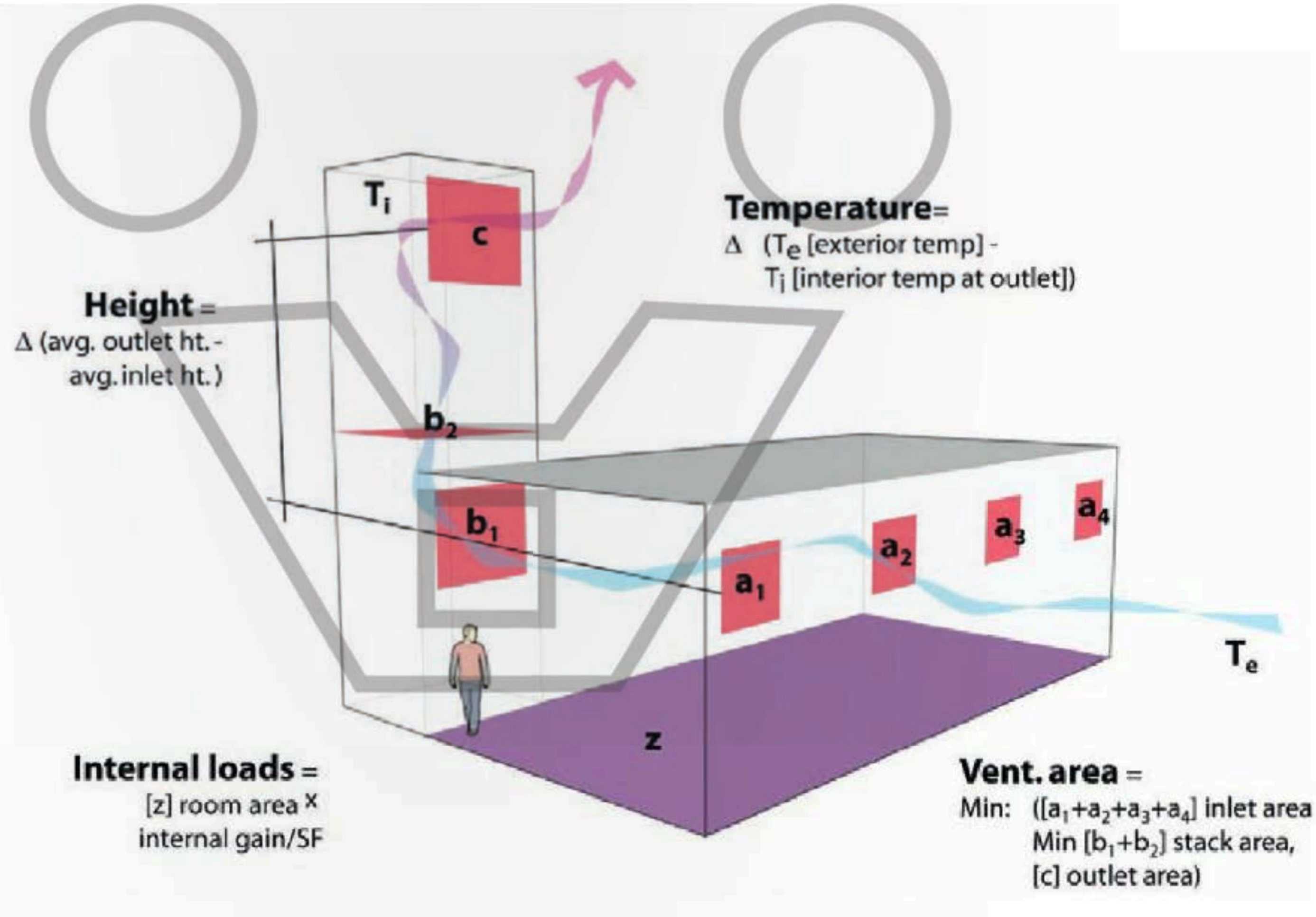


5.0
4.0
Dur-qā'a
Northern Īwān
Southern Īwān
1.0
0.65
0.8
0.7
0.55
0.4
0.1
0.25

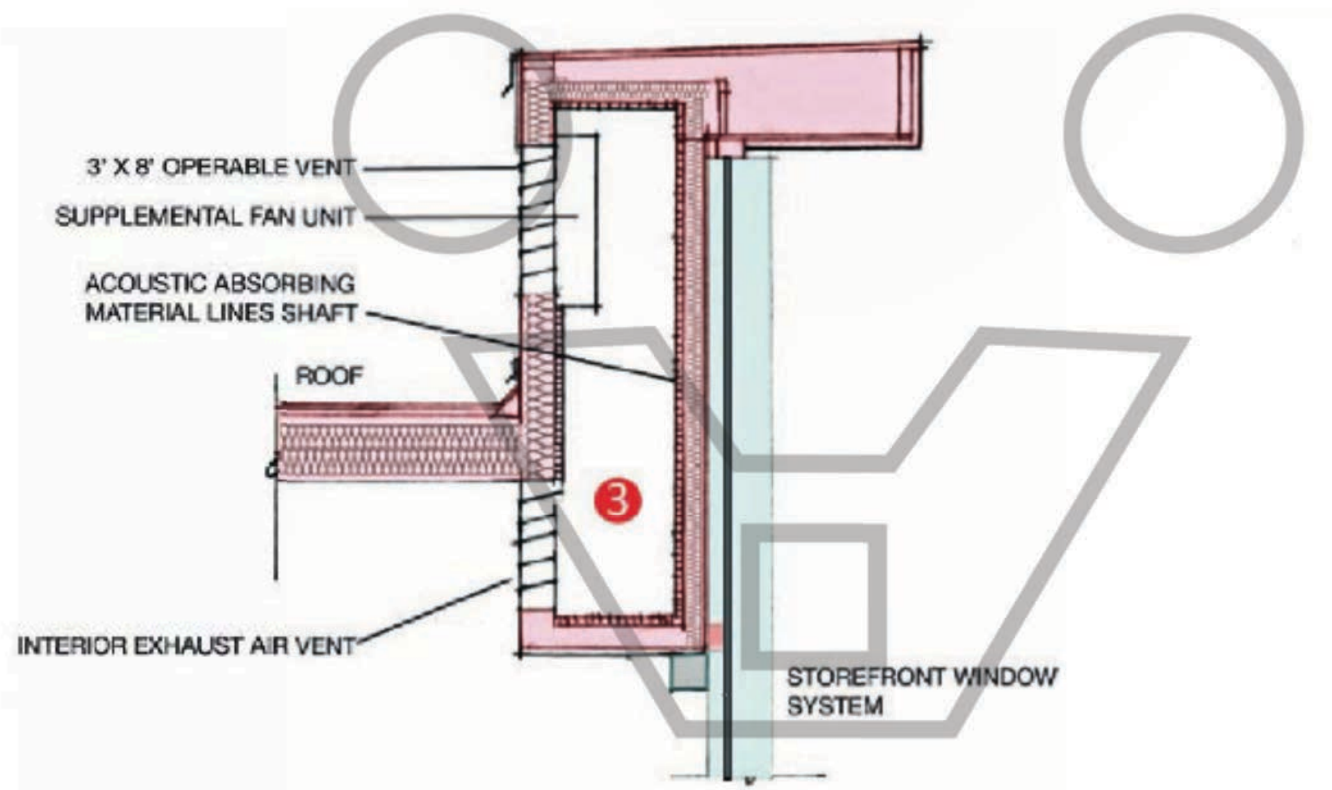
Wind Towers

9.12

Stack diagram showing the important inputs into a natural ventilation model.



Wind Towers

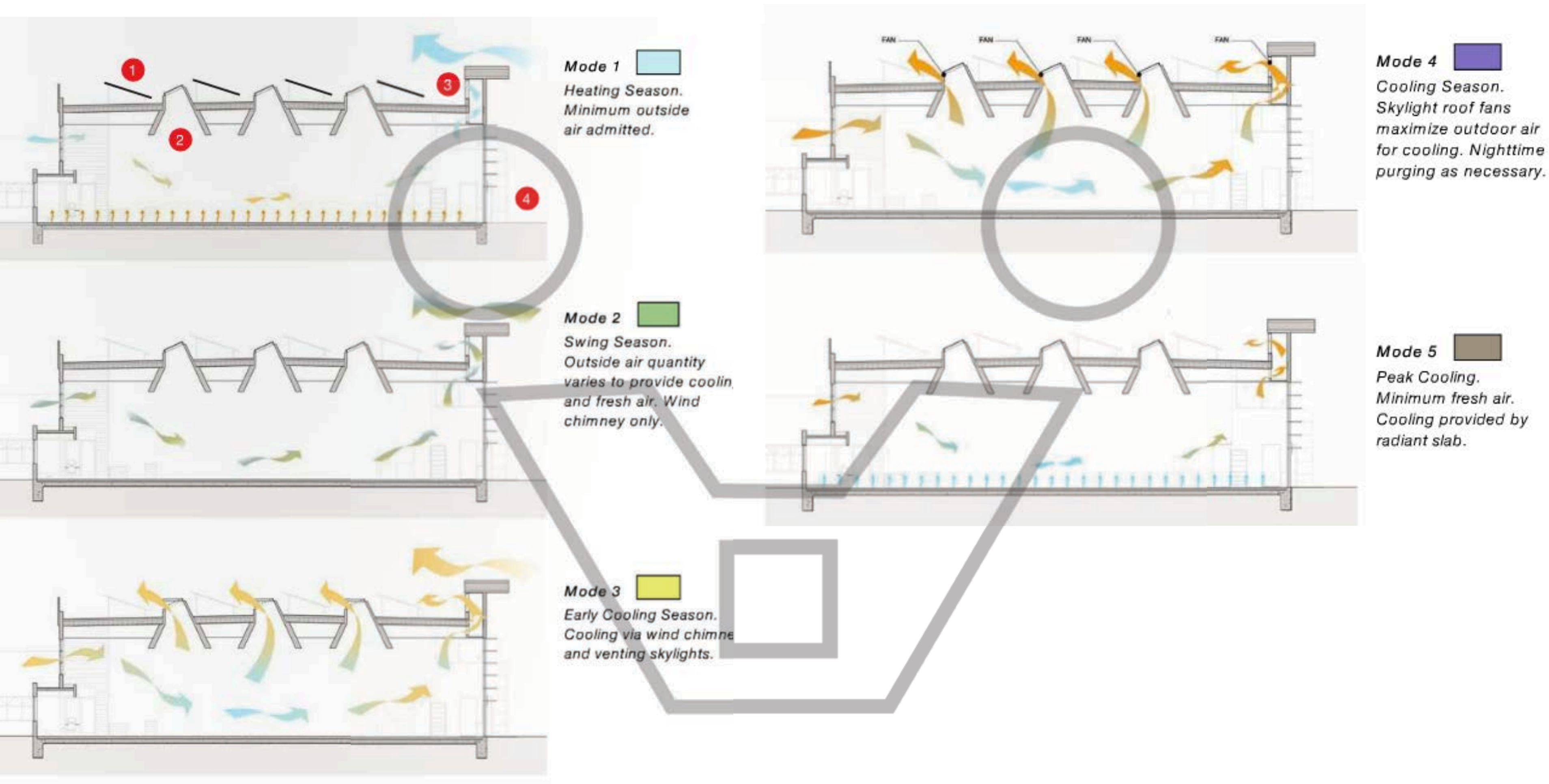


Natural Ventilation Exhaust Vent

9.5

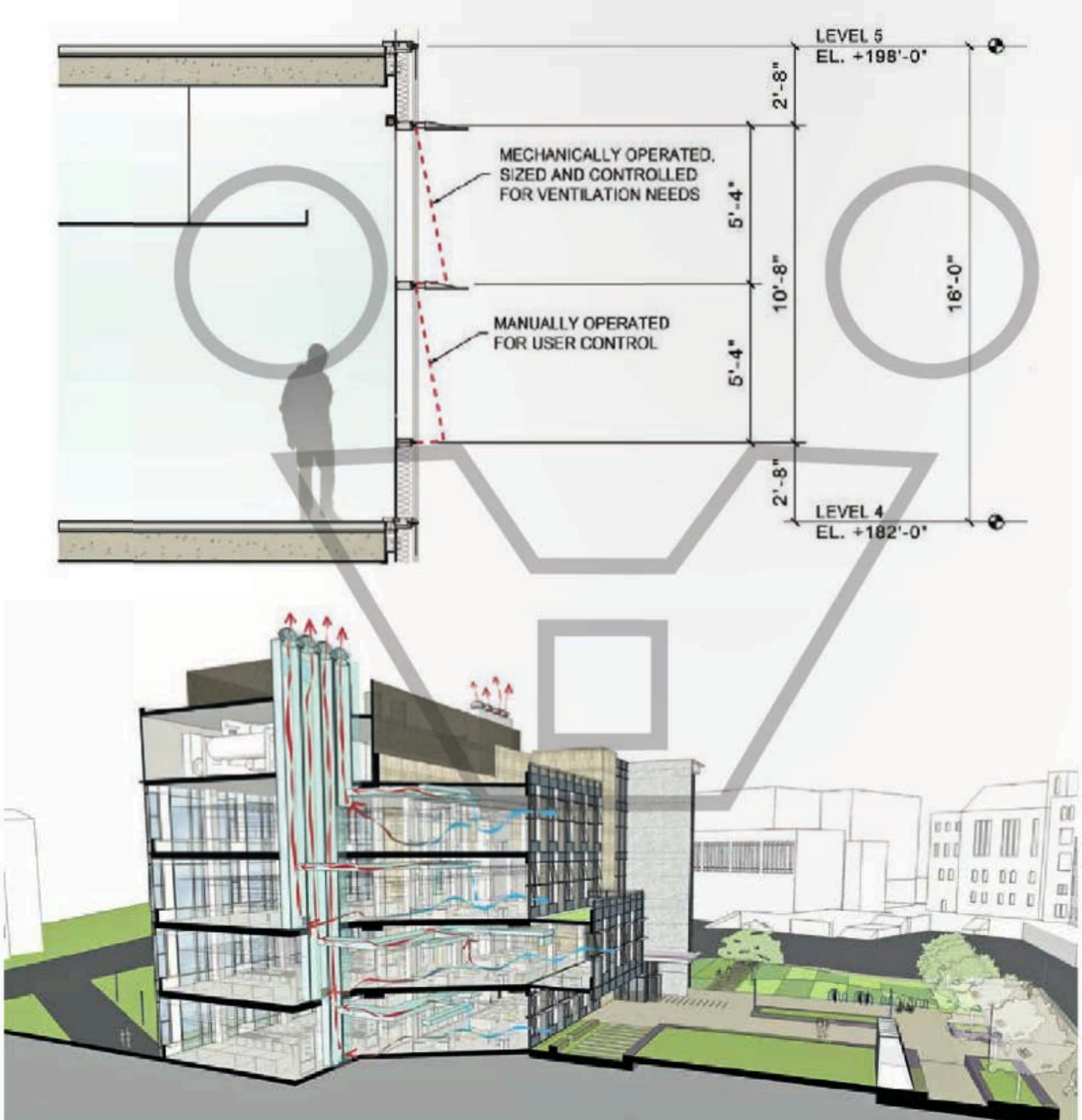
Natural ventilation exhaust vent.

Wind Chimney



Working with natural ventilation

Wind Chimney



9.13

Section through window showing window uses and sizes.

9.14

Natural ventilation diagram showing airflow into the offices and up through each floor's stacks.

Operable Windows

9.16

Photograph of the type of operable windows used at the Bullitt Center. Window diagram shows equal opening size around window's perimeter to reduce wear and provide even, controlled airflow.

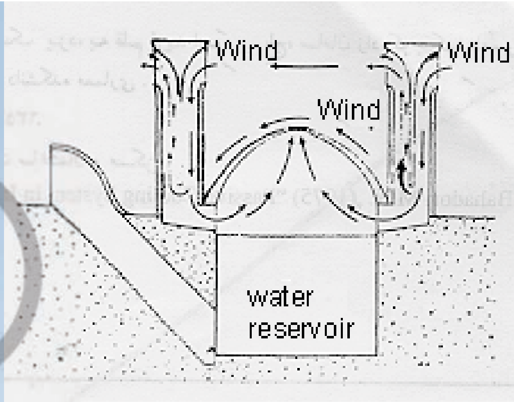
Source: Photo and diagram courtesty Shuco.

MODELING HUMAN BEHAVIOURS AND COMPUTING COMFORT CONDITIONS

WORKING WITH WATER EVAPORATION IN HOT DRY CLIMATE

Working with water evaporation in hot dry climate

Working with water evaporation in hot dry climate



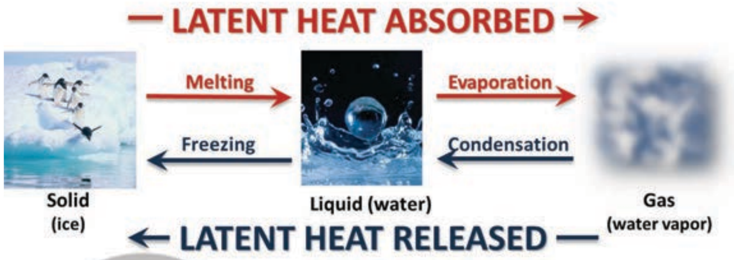
LATENT HEAT vs SENSIBLE HEAT

Latent heat **is the energy absorbed by or released from a substance during a phase change** from a gas to a liquid or a solid or vice versa. If a substance is changing from a solid to a liquid, for example, the substance needs to absorb energy from the surrounding environment in order to spread out the molecules into a larger, more fluid volume. If the substance is changing from something with lower density, like a gas, to a phase with higher density like a liquid, the substance gives off energy as the molecules come closer together and lose energy from motion and vibration.

Sensible heat **is the energy required to change the temperature of a substance with no phase change**. The temperature change can come from the absorption of sunlight by the soil or the air itself. Or it can come from contact with the warmer air caused by release of latent heat (by direct conduction). Energy moves through the atmosphere using both latent and sensible heat acting on the atmosphere to drive the movement of air molecules which create wind and vertical motions.

Working with water evaporation in hot dry climate

How much energy in water state transformation



0,09 W/h
0,079 kcal

Sostanza	Calore latente di fusione (J/g)	Temperatura di fusione (°C)
Acqua	333,5	0
Azoto	25,7	-210
Alcol etilico	108	-114
Ammoniaca	339	-75
Mercurio	11	-39
Zolfo	54	115

0,63 W/gh
0,54 Kcal/g

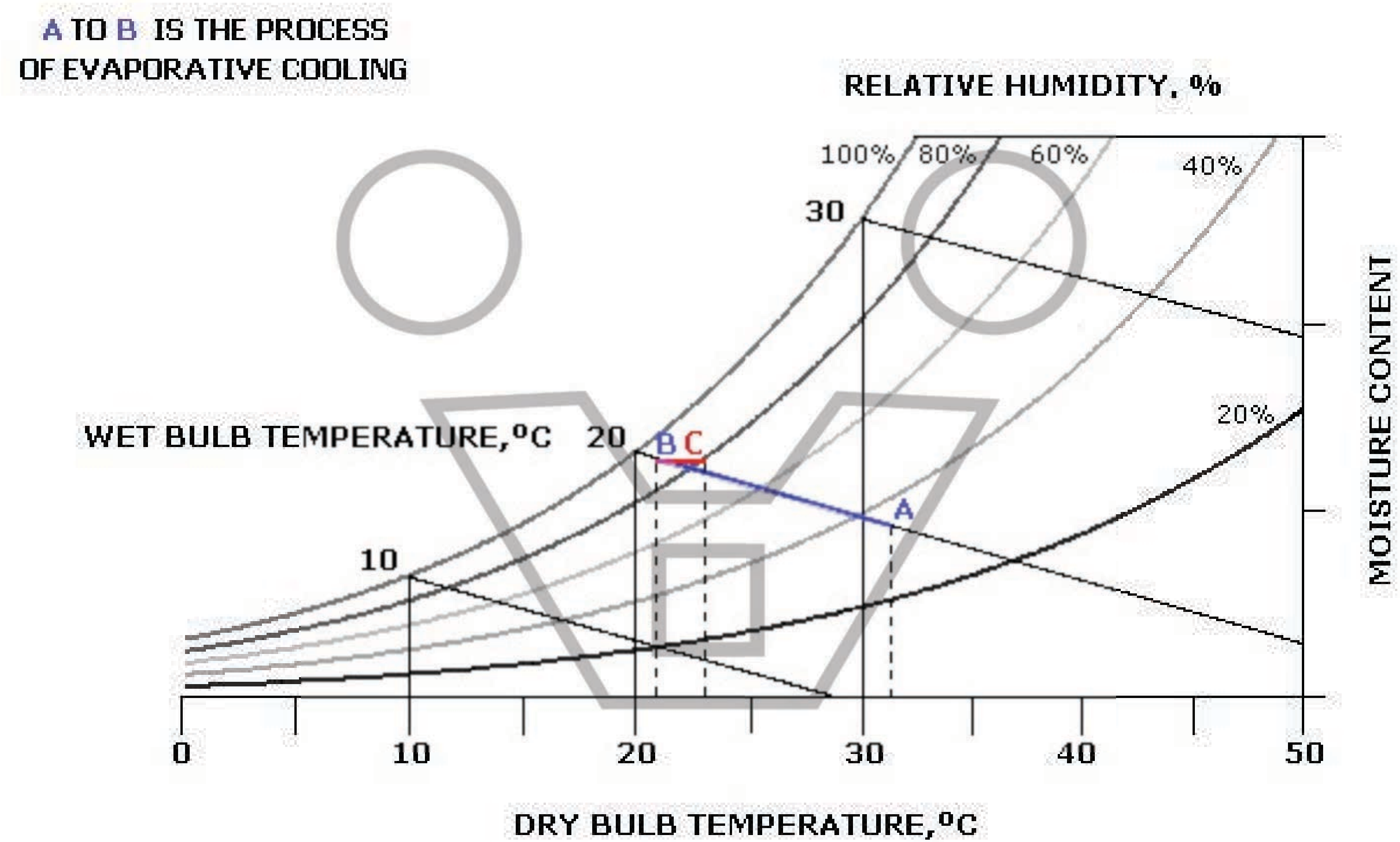
1 litro = 630 W/h

1 litro = 45 W

Tempo medio 15-20’

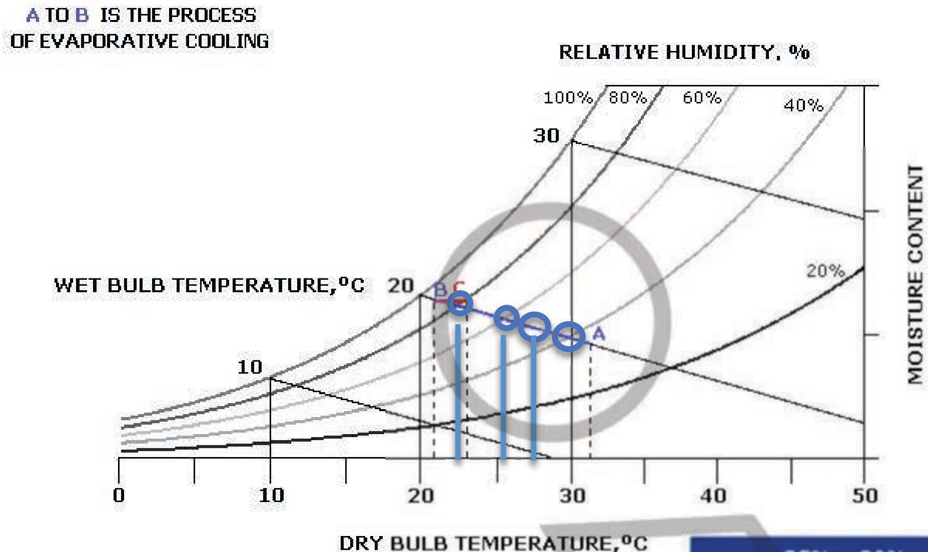
Sostanza	Calore latente di ebollizione (J/g)	Temperatura di ebollizione (°C)
Acqua	2272	100
Azoto	200	-196
Alcol etilico	855	78,3
Ammoniaca	1369	-33
Mercurio	294	357
Zolfo	1406	445

How much is the benefit from evaporative cooling



Working with water evaporation in hot dry climate

How much is the benefit from evaporative cooling



REAL TEMPERATURE:

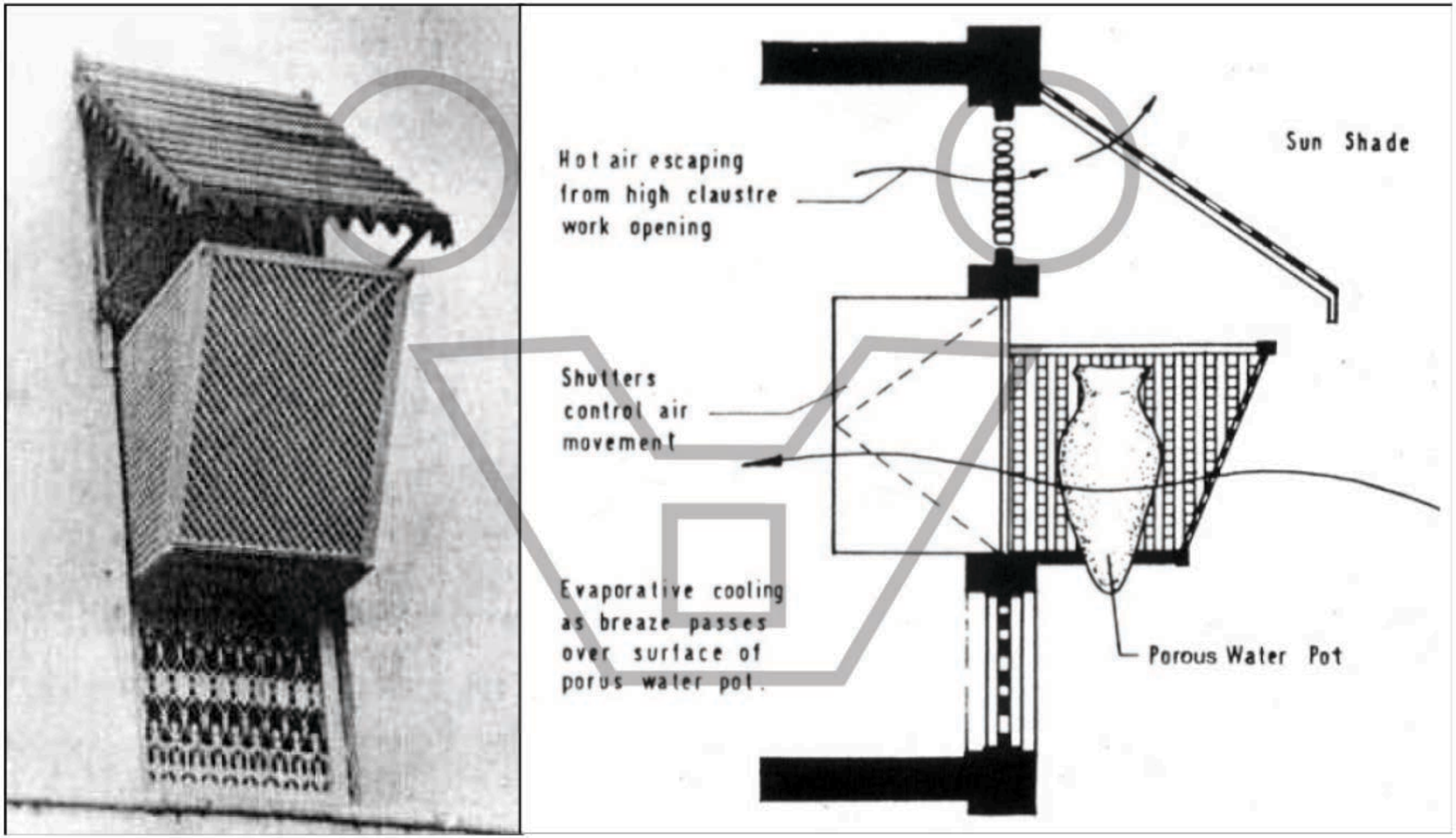
30° (40%) >> 22°(80%) >> diff -8°

APPARENT TEMPERATURE

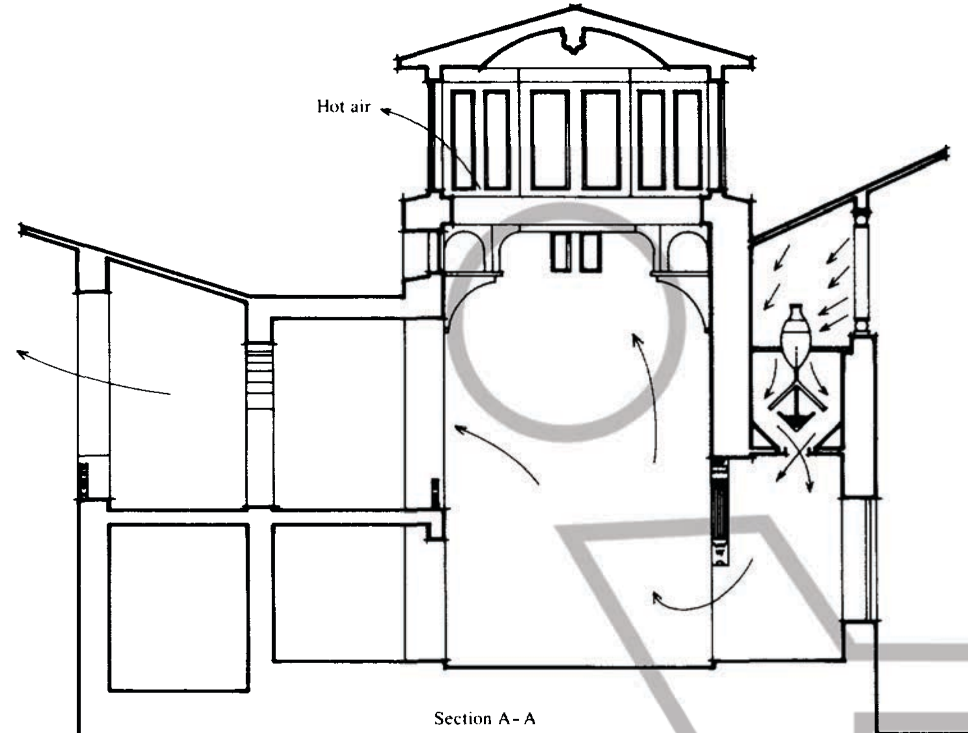
34°	>> 30°	>> diff -4°
34°	>> 28	>> diff -6°
34°	>> 32°	>> diff -8°

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

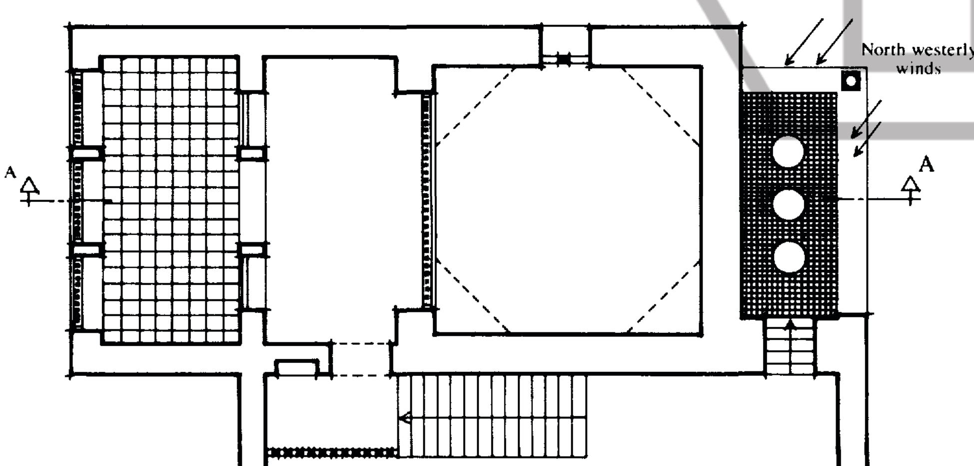
Figure : Muscatese Evaporative cooling window system (Rosa Schiano 2007)



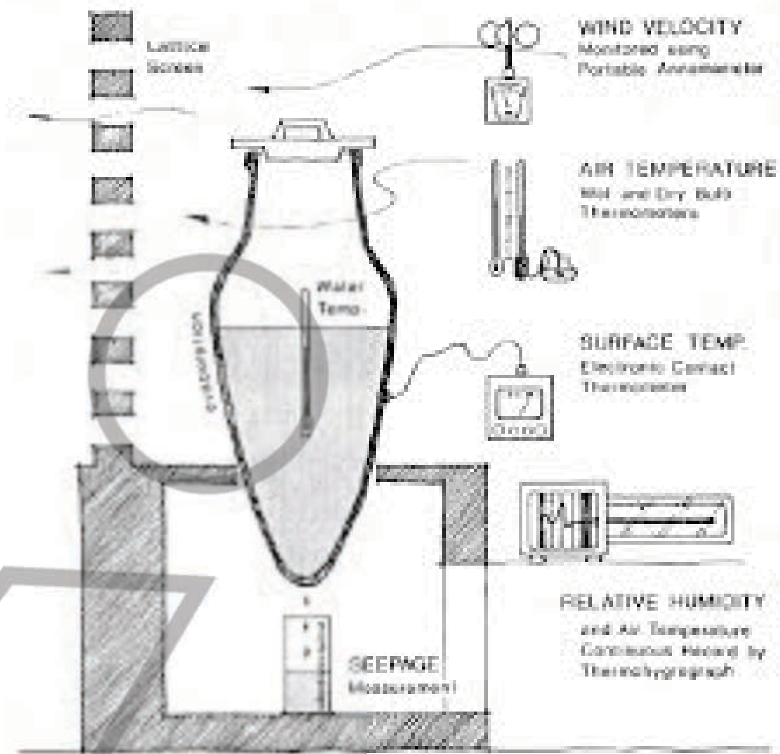
Working with water evaporation in hot dry climate



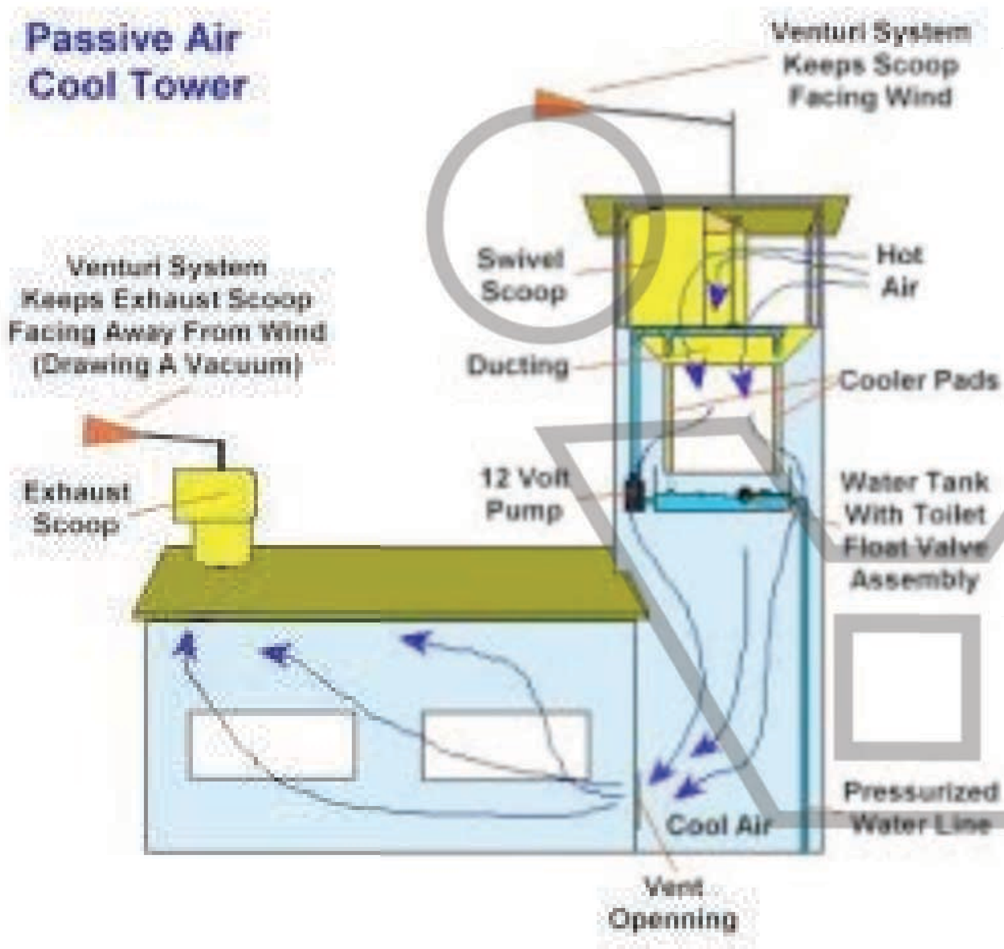
Section A - A

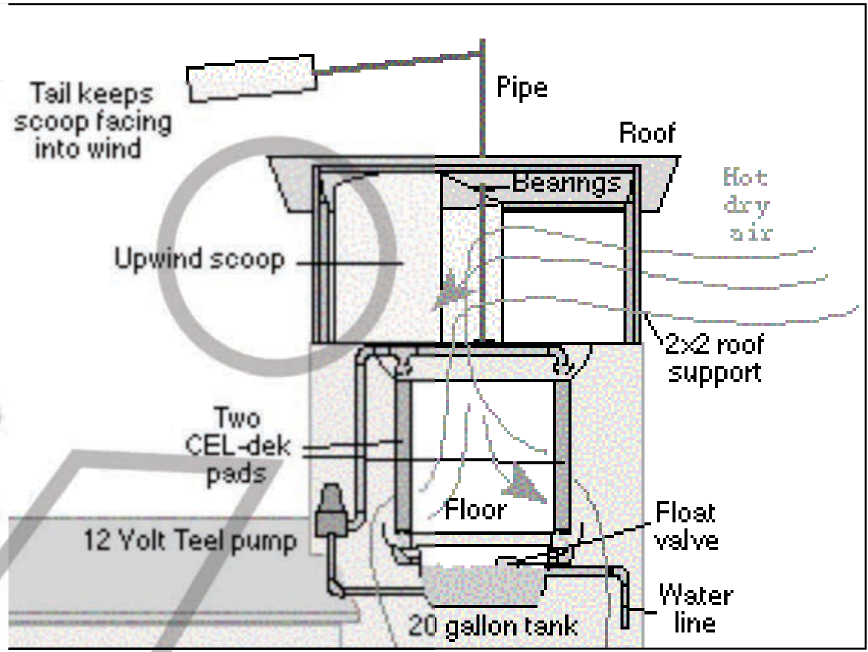


Plan

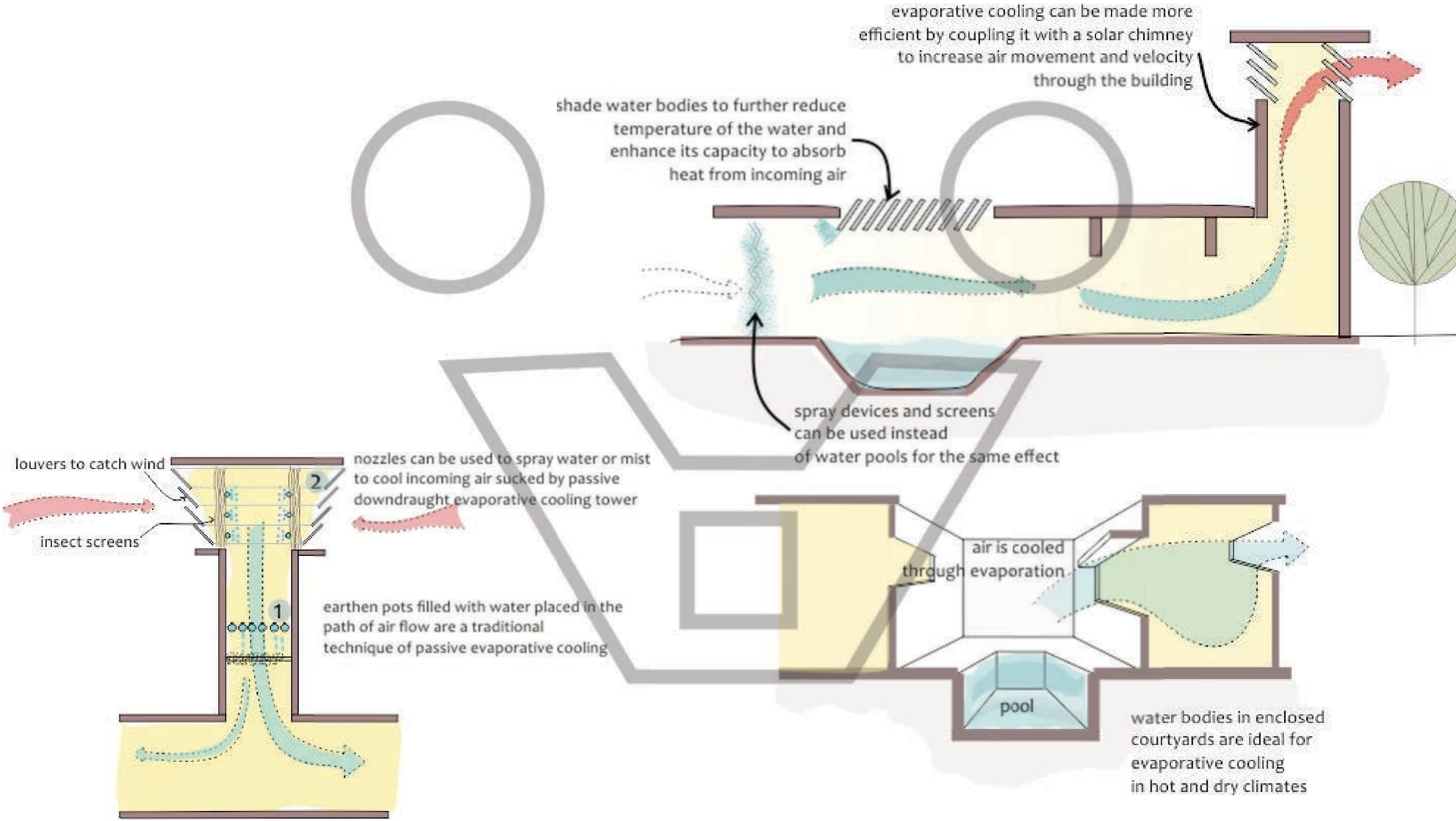


Working with water evaporation in hot dry climate

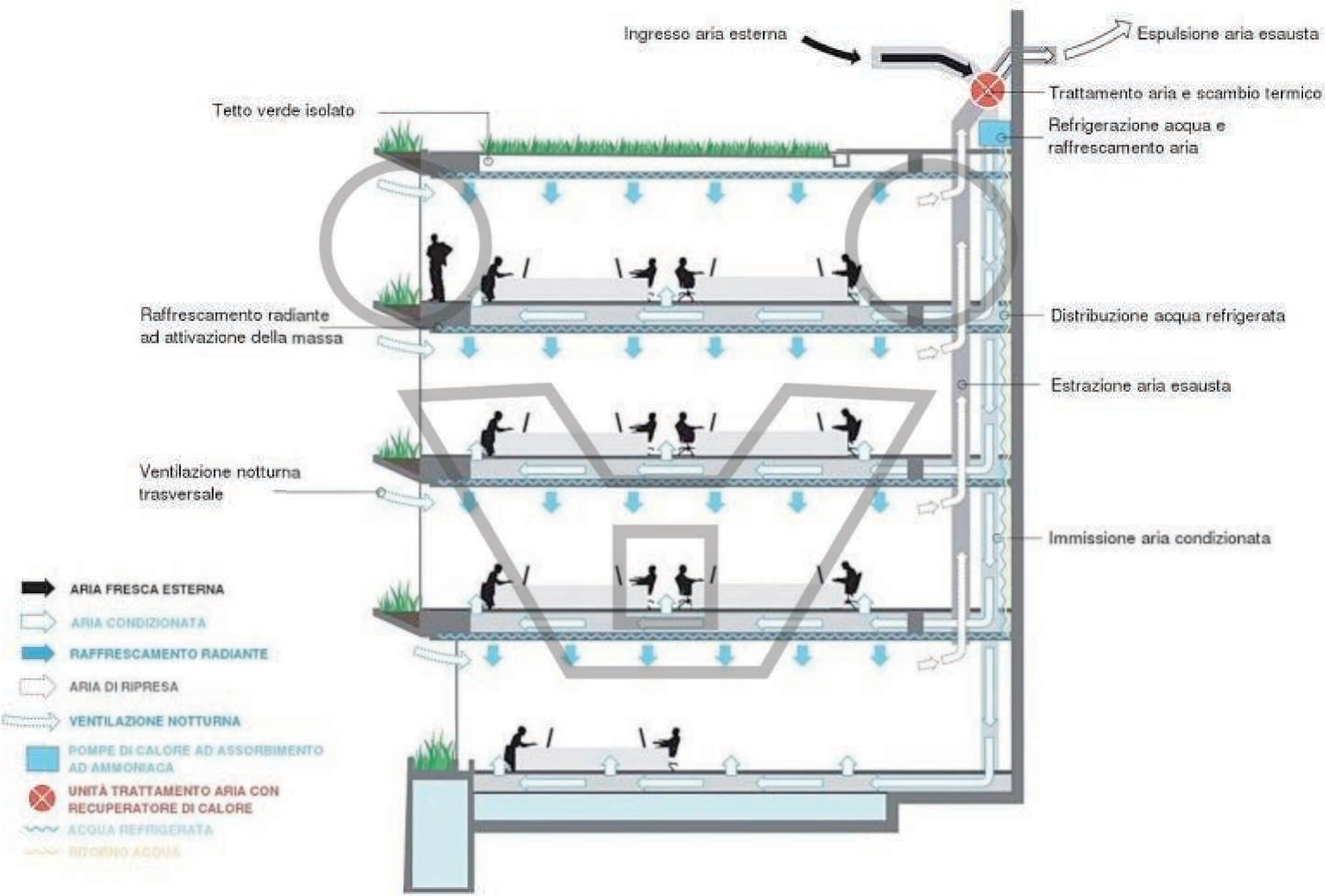




Working with water evaporation in hot dry climate



Working with water evaporation in hot dry climate



MODELING HUMAN BEHAVIOURS AND COMPUTING COMFORT CONDITIONS

WORKING WITH MASS LATENCY
or THERMAL LAG

Working with Mass Latency or Thermal Lag

What is THERMAL LAG?

Thermal Lag describes a body's thermal mass with respect to time. A body with high thermal mass (high heat capacity and low conductivity) will have a large thermal lag.

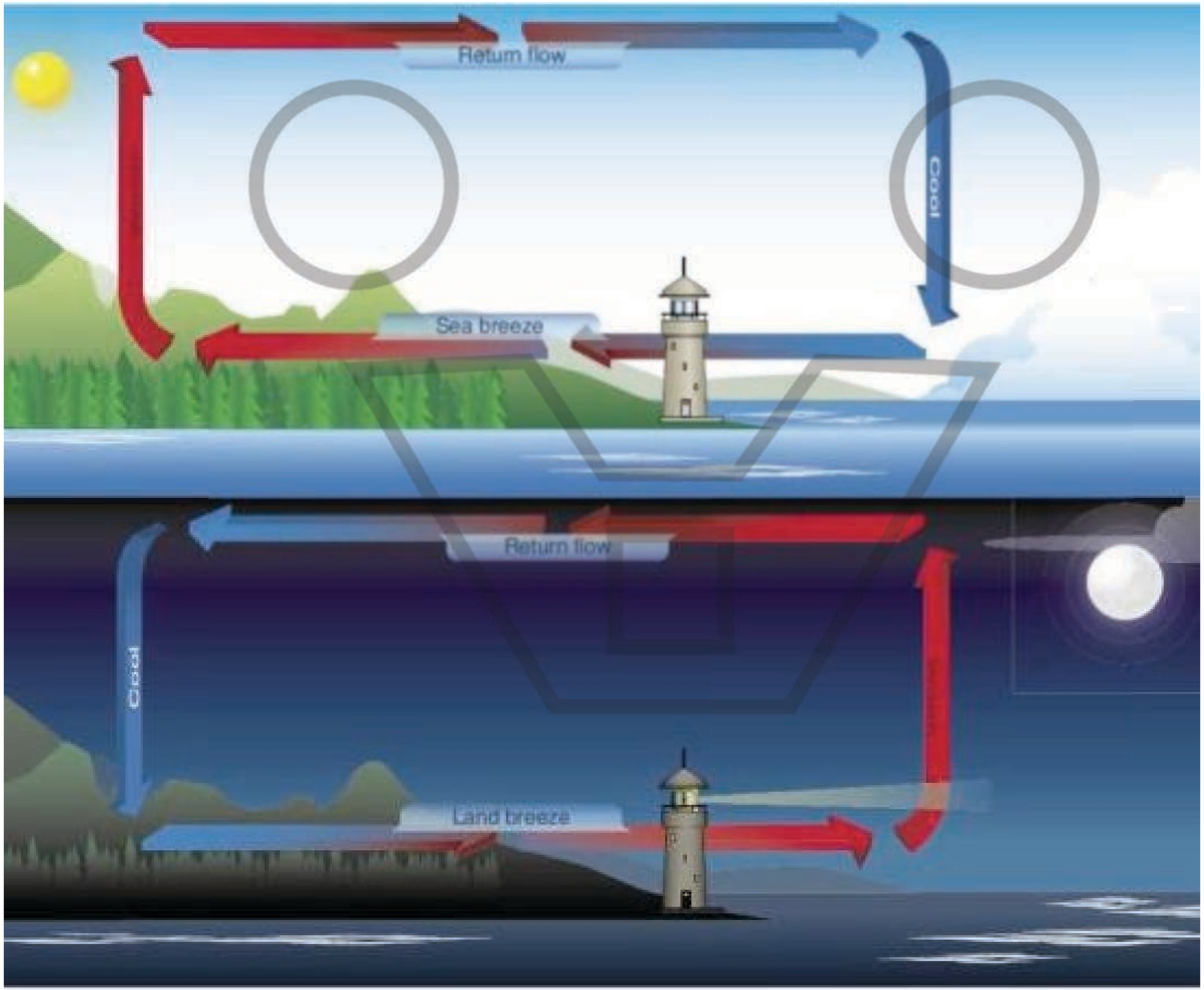
Thermal diffusivity is the thermal conductivity divided by density and specific heat capacity at constant pressure

thermal mass is a property of the mass of a building which enables it to store heat, providing "inertia" against temperature fluctuations. It is sometimes known as the *thermal flywheel effect.*

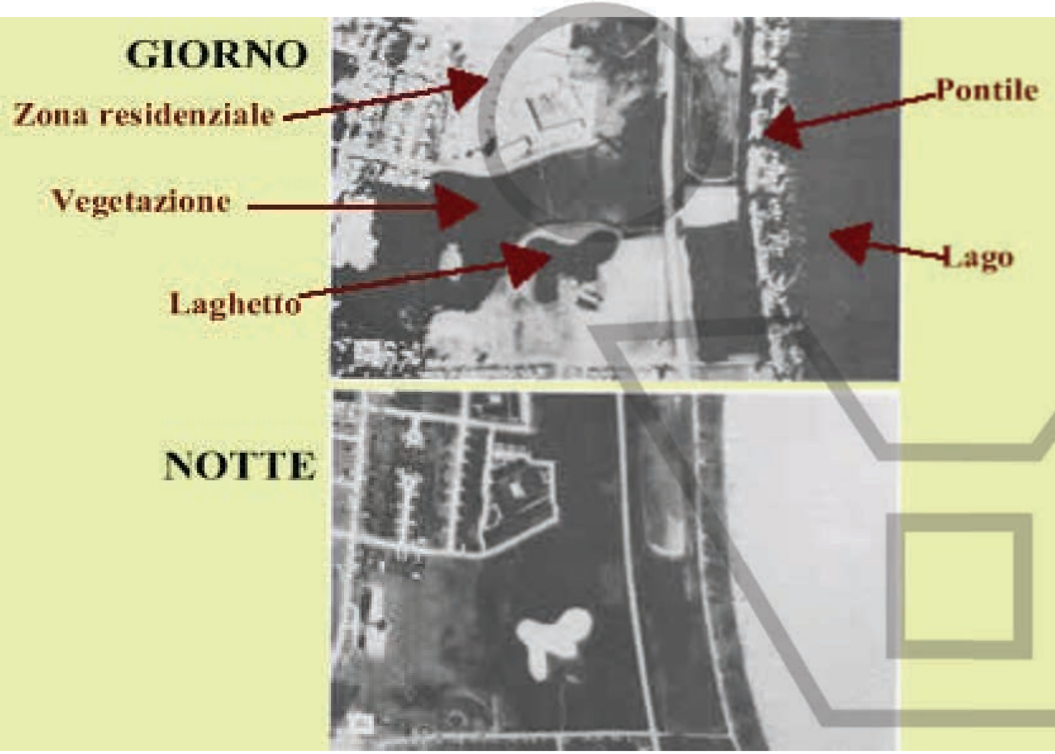
This is distinct from a material's insulative value, which reduces a building's thermal conductivity, allowing it to be heated or cooled relatively separate from the outside,

Working with Mass Latency or Thermal Lag

A thermal flywheel effect from Nature: Marine breezes



Benefit of Thermal Mass



thermography

Thermal mass affects the temperature within a building by stabilising internal temperatures in three ways:

- *stabilising internal temperatures* by providing heat source and heat sink surfaces for radiative, conductive and convective heat exchange processes;
- *providing a time-lag* in the equalisation of external and internal temperatures; and
- *providing a temperature reduction* across an external wall (the decrement factor).

Working with Mass Latency or Thermal Lag

Internal temperatures stabilisation

Thermal mass influences comfort by radiant exchanges with the skin. **In fact radiant exchange with mass surfaces is singularly the most efficient way of maintaining comfort** compared with an other technique as the body is more that twice as sensitive to radiant losses and gains than all other pathways combined (conduction, convection, respiration, evaporation) and more than four times as sensitive than any other single pathway (see 2.3 below).

Thermal comfort exists when a body's heat loss equals its heat gain or *vice versa*.
The body exchanges:

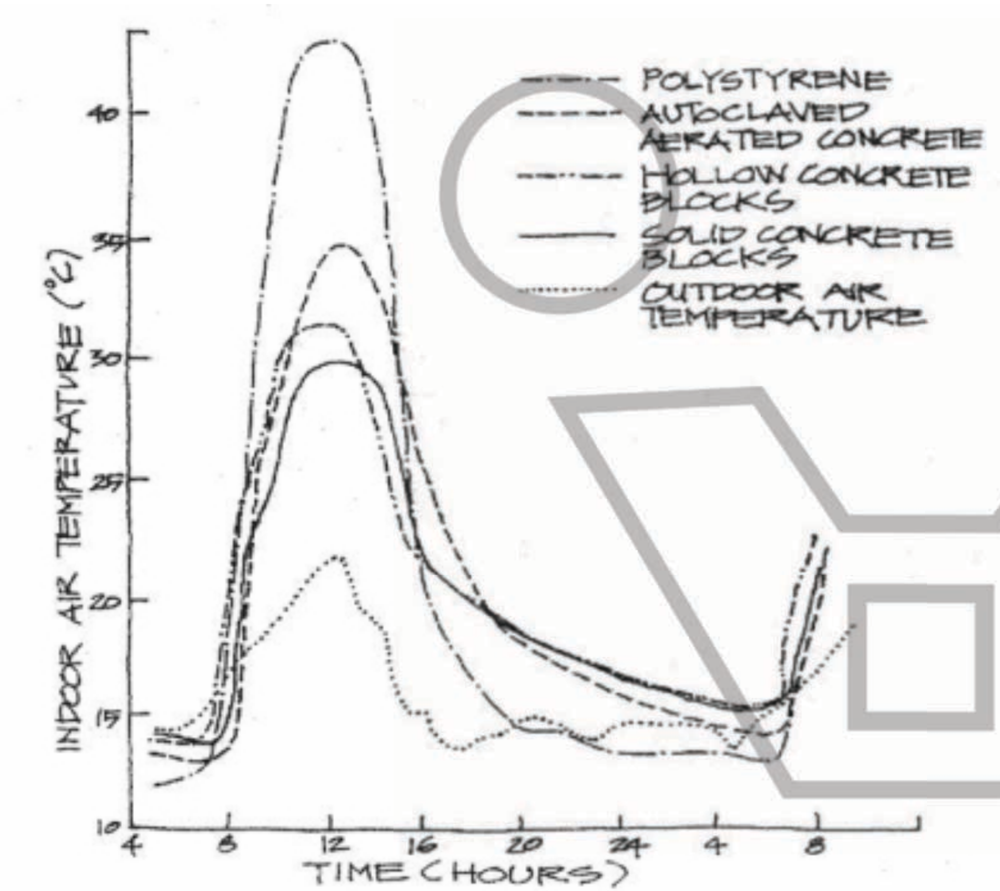
·62% of this heat via radiation,
·15% by evaporation,
·10% by convection,
·10% by respiration and
·3% by conduction.

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

Internal temperatures stabilisation



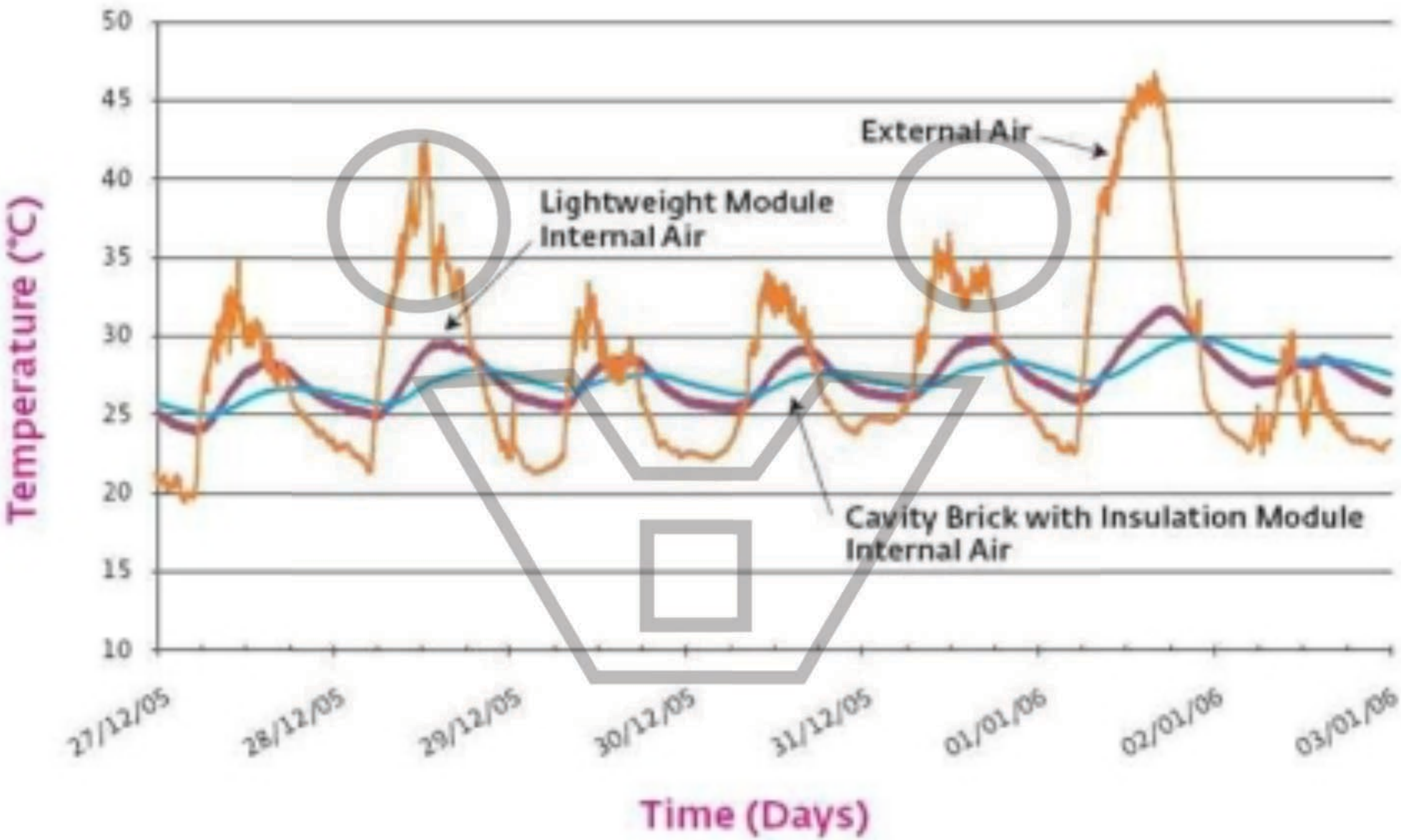
Thermal mass effects on diurnal indoor temperatures of various materials.

When heat enters a space directly by penetration of sunlight, lighting, equipment losses or heating, the temperature rise will be in inverse relationship to the accessible volume of thermal mass. Therefore, the indoor temperature will rise almost immediately if there is little thermal mass in the room. Figure uses an example of a simple box 1150 x 1530 x 1570 mm, with a single window 660 x 1010 mm to demonstrate the effect of thermal mass on internal air temperature using a variety of materials.

This diagram represents unventilated spaces.

Working with Mass Latency or Thermal Lag

Internal temperatures stabilisation using different structural materials



Thermal mass effects on diurnal indoor temperatures of comparative insulated cavity brick & lightweight structures (Think Brick Australia 2006)

Heat capacity by materials

Specific heat is the amount of heat needed to raise the temperature of one kilogram of mass by 1 kelvin.

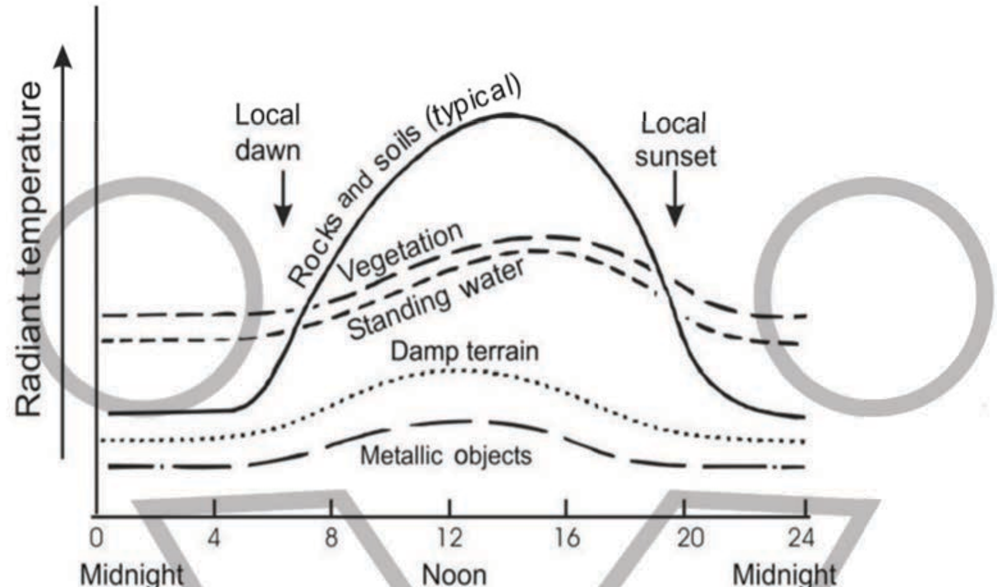
Material	Density (Kg/m3)	Specific heat (kJ/kg.K)	Volumetric heat capacity Thermal mass (kJ/m3.K)
Water	1000	4.186	4186
Concrete	2240	0.920	2060
AAC	500	1.100	550
Brick	1700	0.920	1360
Stone (Sandstone)	2000	0.900	1800
FC Sheet (compressed)	1700	0.900	1530
Earth Wall (Adobe)	1550	0.837	1300
Rammed Earth	2000	0.837	1673
Compressed Earth Blocks	2080	0.837	1740

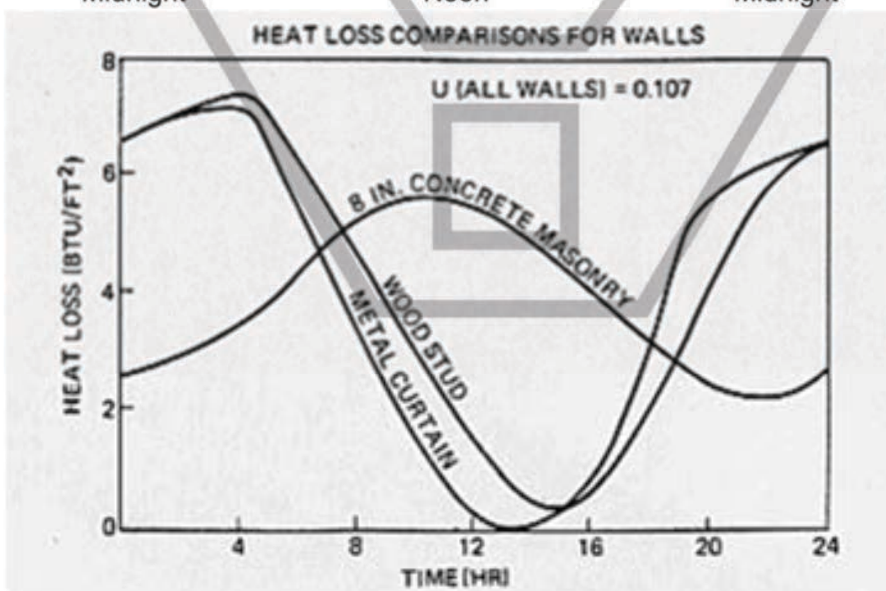
Table 1. Density, specific heat and thermal mass of a range of materials

Note: Figures are based on a number of sources and include estimations and interpolations.

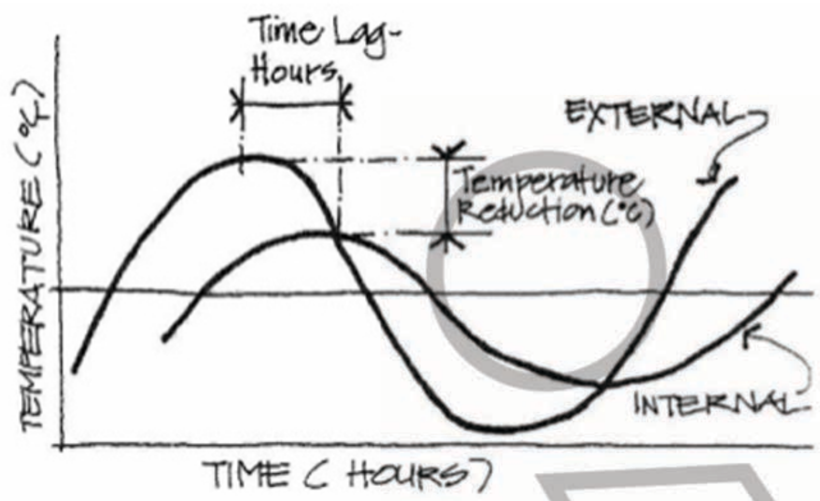
http://www2.ecospecifier.org/knowledge_base/technical_guides/thermal_mass_building_comfort_energy_efficiency

Radiant energy stored by different materials during the 24 hours

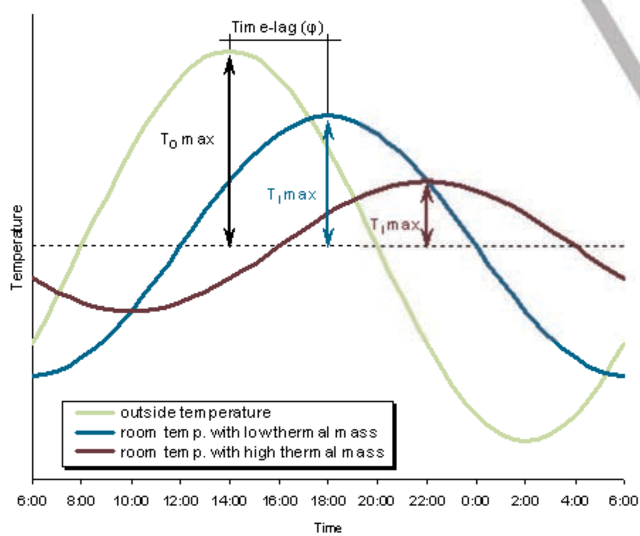




Time lag + temperature reduction



The effect of using heat generated during the day to warm at night in winter and vice versa in summer is known as the 'thermal flywheel' effect. The effectiveness of the flywheel depends on the time lag introduced to a building by an external wall or other boundary element. As can be seen from Figure 3, time 'lag' is the time delay between external maximum or minimum temperatures and internal maximum or minimum temperatures respectively



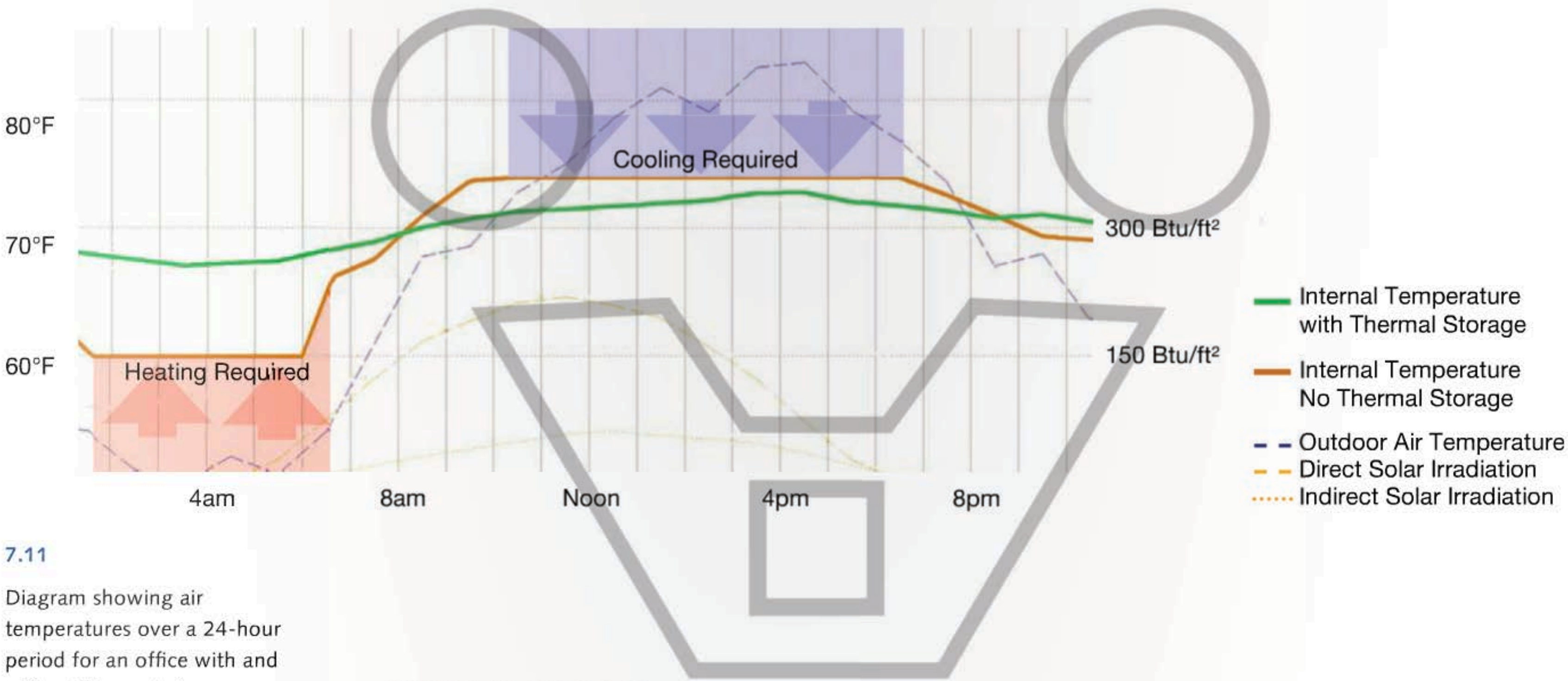
Material (thickness in mm)	**Time lag** (hours)
Insulated Brick Veneer	5.0
Concrete (250)	6.9
Double Brick (250)	7.0
AAC (200)	7.0
Adobe (250)	9.2
Rammed Earth (250)	10.3
Compressed Earth Blocks (250)	10.5
Sandy Loam (1000)	30 days

Table 4: Time lag figures for various materials
(Baggs, SA, JC, DB., 1991) *and* (Think Brick Australia, 2006).

Working with Mass Latency or Thermal Lag

Effect of Thermal mass storage

COOLING vs HEATING: Thermal storage strategy



7.11

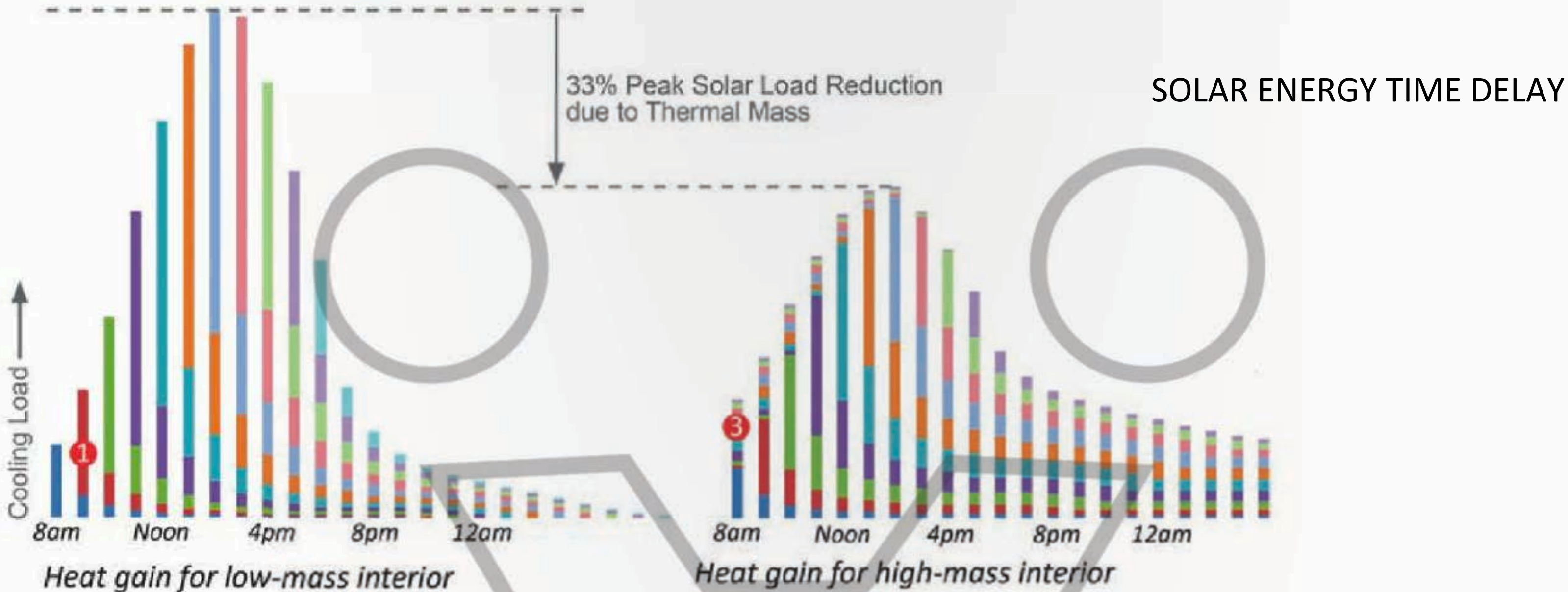
Diagram showing air temperatures over a 24-hour period for an office with and without thermal storage.

Source: Modified output from an Autodesk Ecotect building model. Courtesy of Callison.

THERMAL STORAGE

Although thermal storage can be an important part of maintaining comfort with minimal energy inputs, over the past 200 years construction in much of the First World has tended towards lightweight, insulated buildings. Lightweight buildings are typically less able to use solar energy, since they cannot delay or

Effect of Thermal mass storage



Percentage of Solar Gain released during each hour after being transmitted through glazing

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
High Thermal Mass Example	27%	13%	7%	5%	4%	4%	3%	3%	3%	3%	3%	3%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	1%	1%
2 Low Thermal Mass Example	55%	17%	9%	5%	3%	2%	2%	1%	1%	1%	1%	1%	1%	1%	-	-	-	-	-	-	-	-	-	-	-

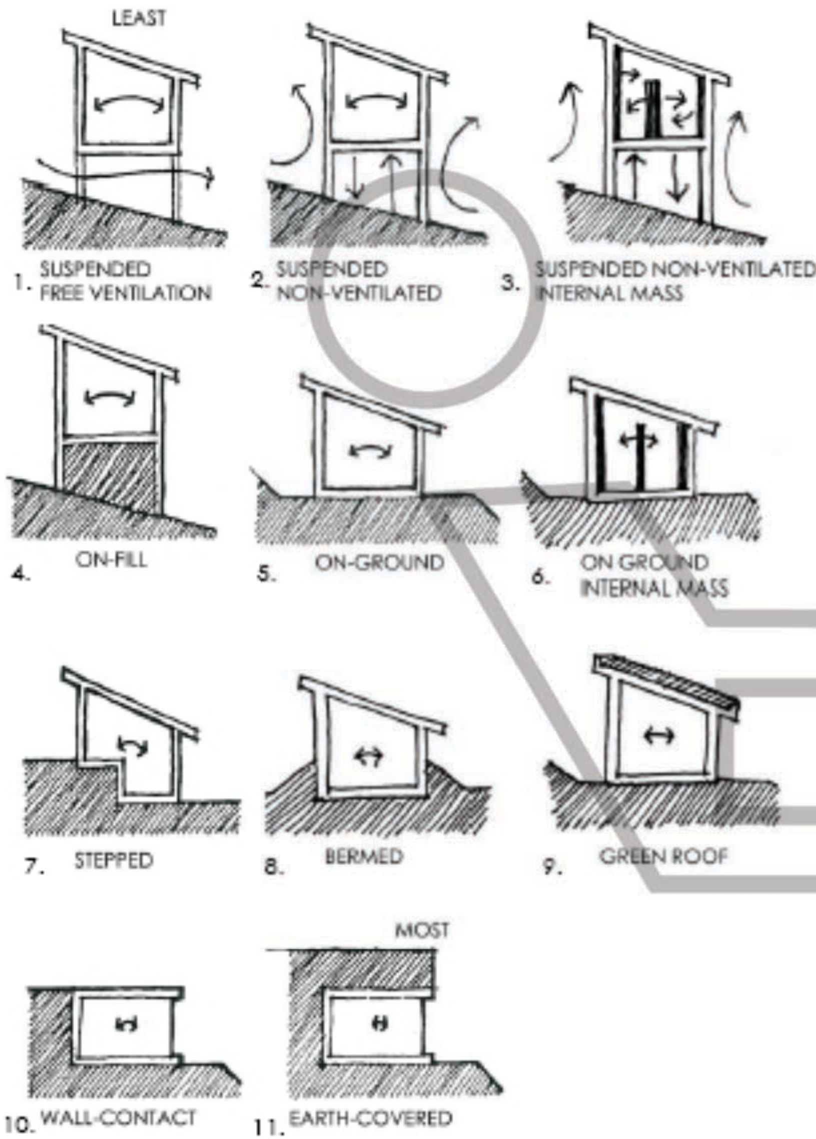
7.12

Solar irradiation values on a south-facing window in Toronto with a .50 glazing to wall ratio were imported onto a spreadsheet to calculate thermal mass effects on peak solar loading using the Radiant Time Series (RTS) method. Each hour's transmitted solar energy becomes a cooling load to the zone over the next 24 hours according to the percentages below for a low-mass and high-mass interior, which are color-coded to show the cumulative effects. At 9am, the solar irradiation that enters is colored red (1), and can be tracked over the next several hours until it becomes nearly negligible. For the low-mass option (2), 55% of the solar energy becomes a cooling load within the same hour it reaches the zone, and 27% is delayed until the second hour, with 9% becoming a cooling load in the third, etc. Each hour has been assigned a color to track it through the day, with the high-mass system including a small remaining solar load from the previous day (3) over the first several hours. The Radiant Time Series method (ASHRAE, 2013) is used to estimating peak cooling loads and contains an accurate but simplified version of estimating the time-delay of solar gain in low-, medium-, and high-mass constructions. The low-mass construction contains carpet, while the high-mass construction exposes concrete floors. The time-delay of other elements, such as exterior walls and solar energy absorbed by the glazing, was not considered. Solar irradiation values calculated in Autodesk Ecotect.

Source: Courtesy of Callison.

Working with Mass Latency or Thermal Lag

Locating mass in a building



HIGH IMPACT on CLIMATE DOMINATED BUILDING

- skinny buildings
- single houses,
- medium density residential,
- low-rise commercial buildings
- small scale educational and industrial buildings.

MEDIUM INTERNAL on LOAD DOMINATED BUILDING

- medium and high-rise commercial and educational structures,

(Baverstock (1994) has shown that mass used in this way can provide 27% of the overall building cooling benefits and 38% of the overall building heating benefits.)

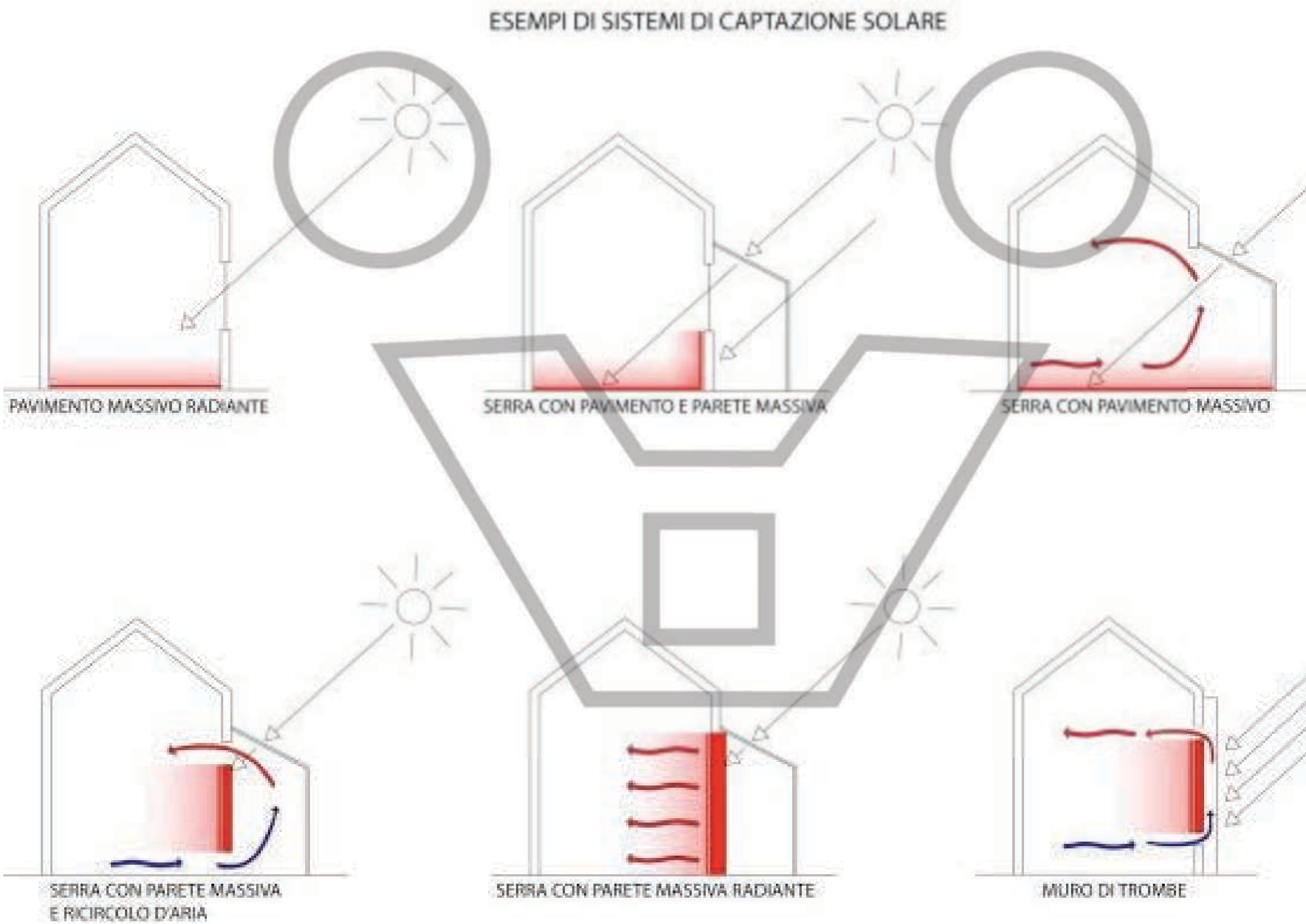
Locating mass in a building and operations in buildings with thermal mass

• External walls require minimum levels of added insulation for wall types under 200kg/m2
In the case of if adequate solar heat various kinds of earth walls such as adobe, rammed earth and compressed earth blocks, with their time lags of 10-11+ hours, is recommended left unsealed or finished with a ‘breathable’ paint.

	Summer		**Winter**	
Device	day	night	day	night
Windows, doors	closed	open	closed	closed
Blinds (external)	closed	open	open	closed
Curtains (internal)	closed	open	open	closed

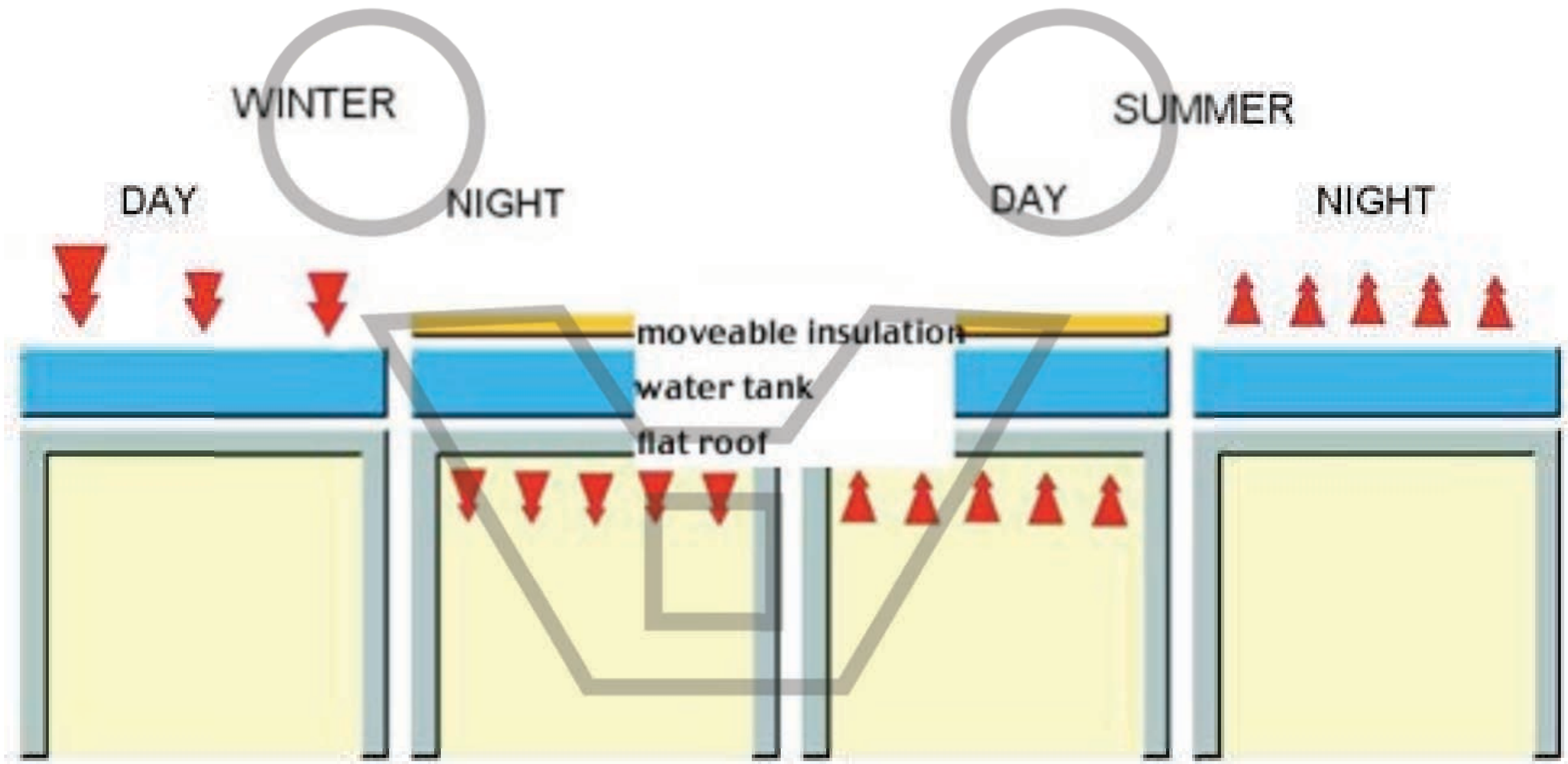
Table 2: User control of shading and ventilation devices

Locating mass in a building

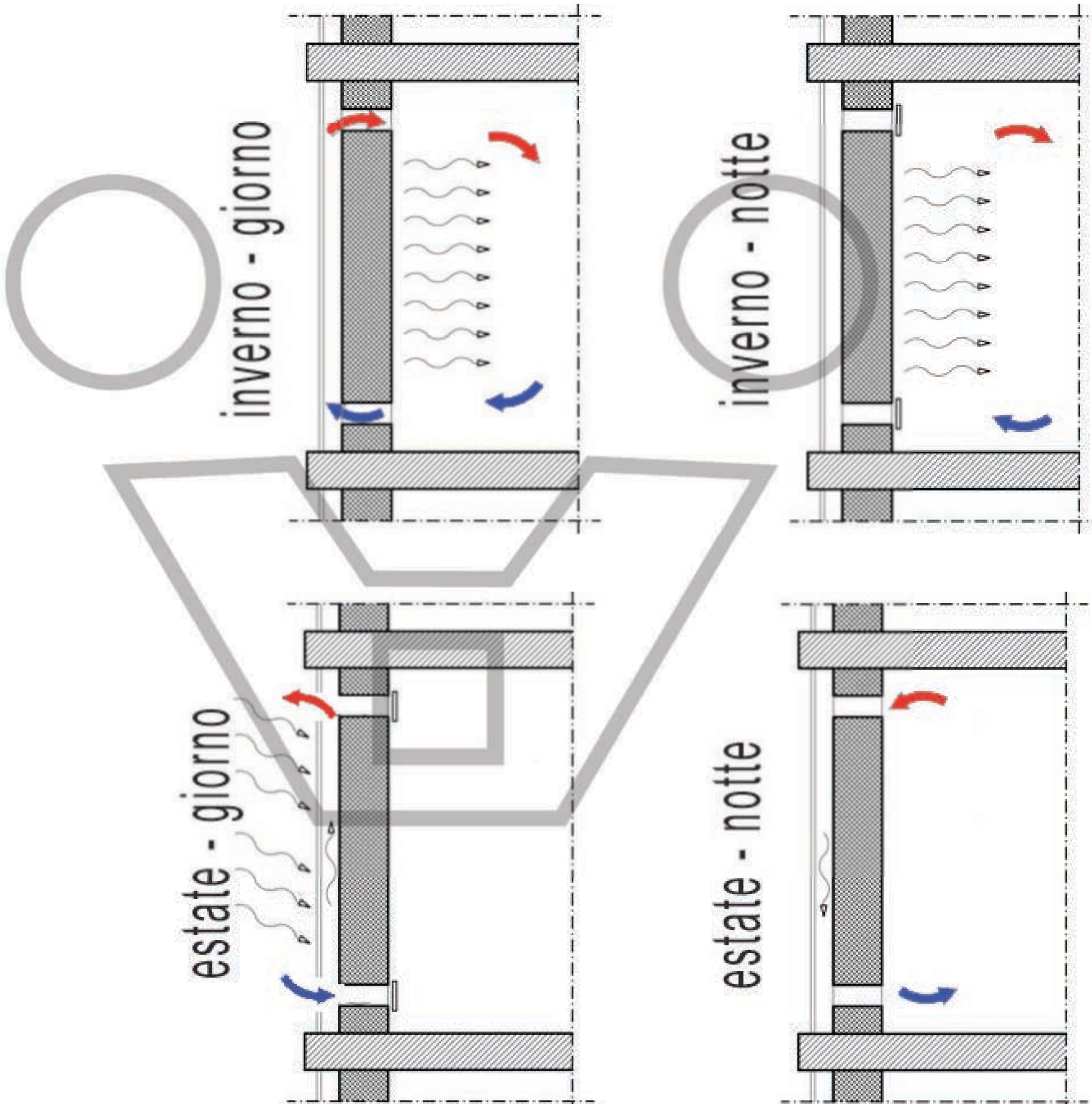


Locating mass in a building

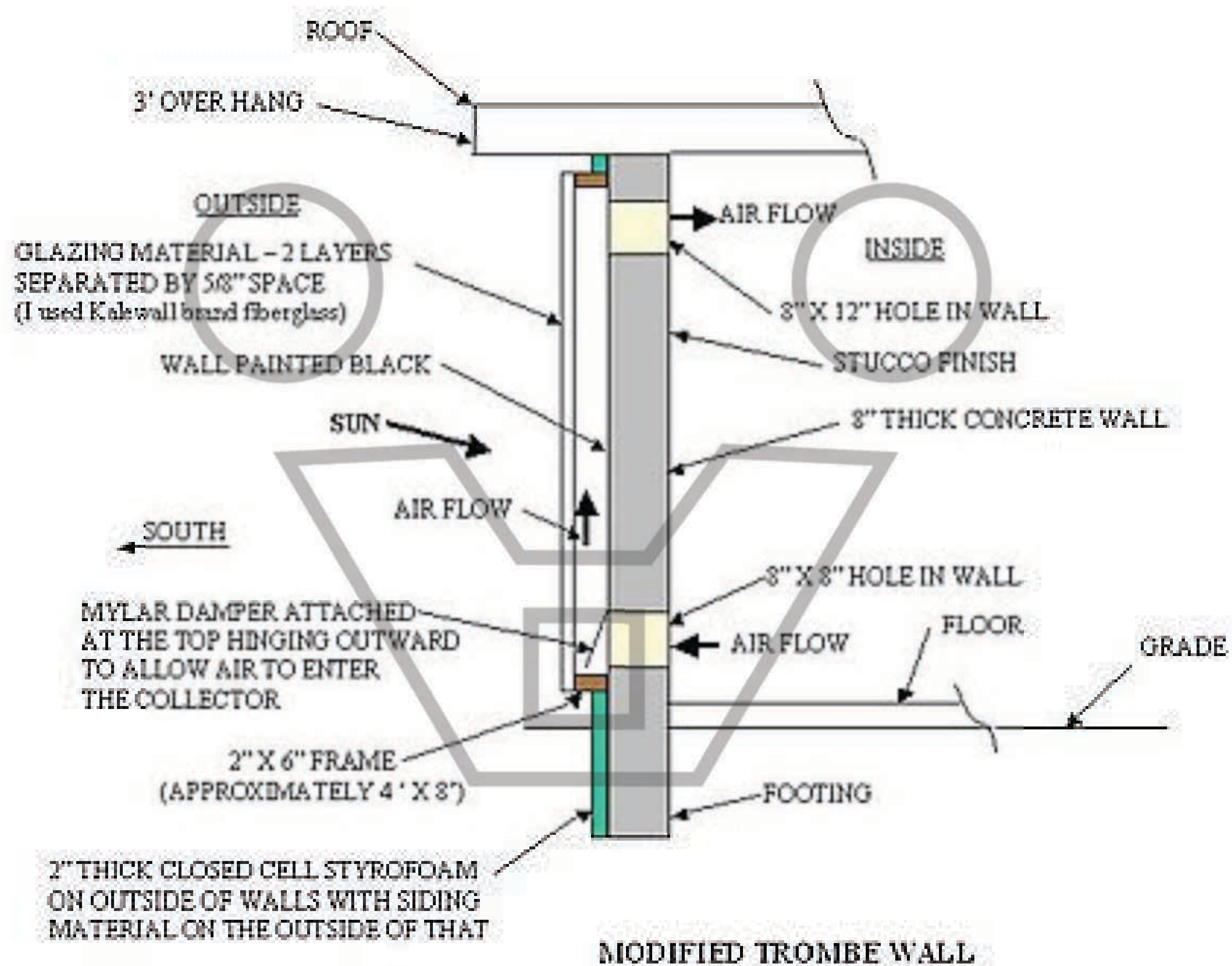
THERMAL STORAGE FOR HOT ARID CLIMATE



Trombe wall



Modified Trombe wall



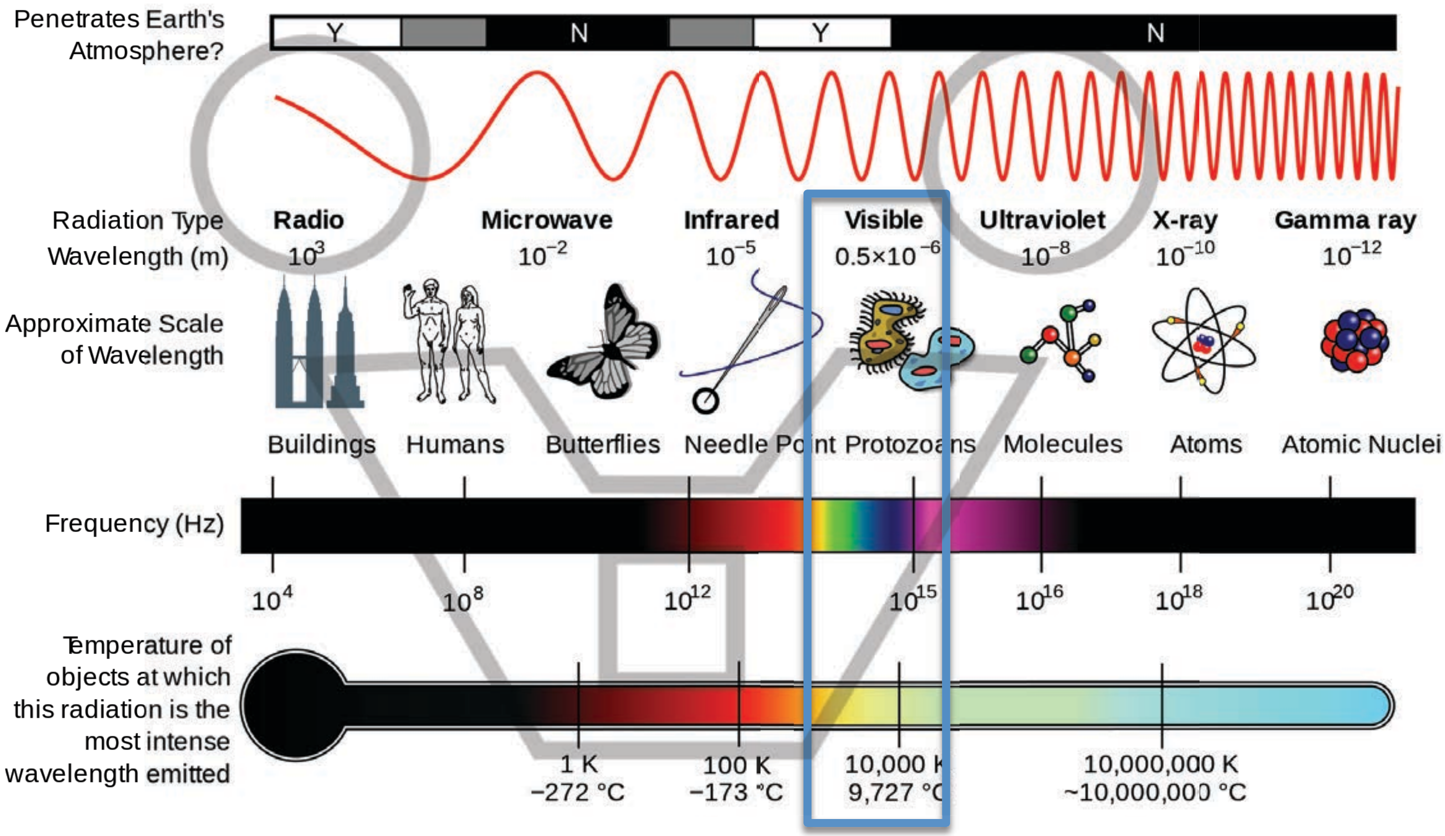
Locating mass in a building

MODELING HUMAN BEHAVIOURS AND COMPUTING COMFORT CONDITIONS

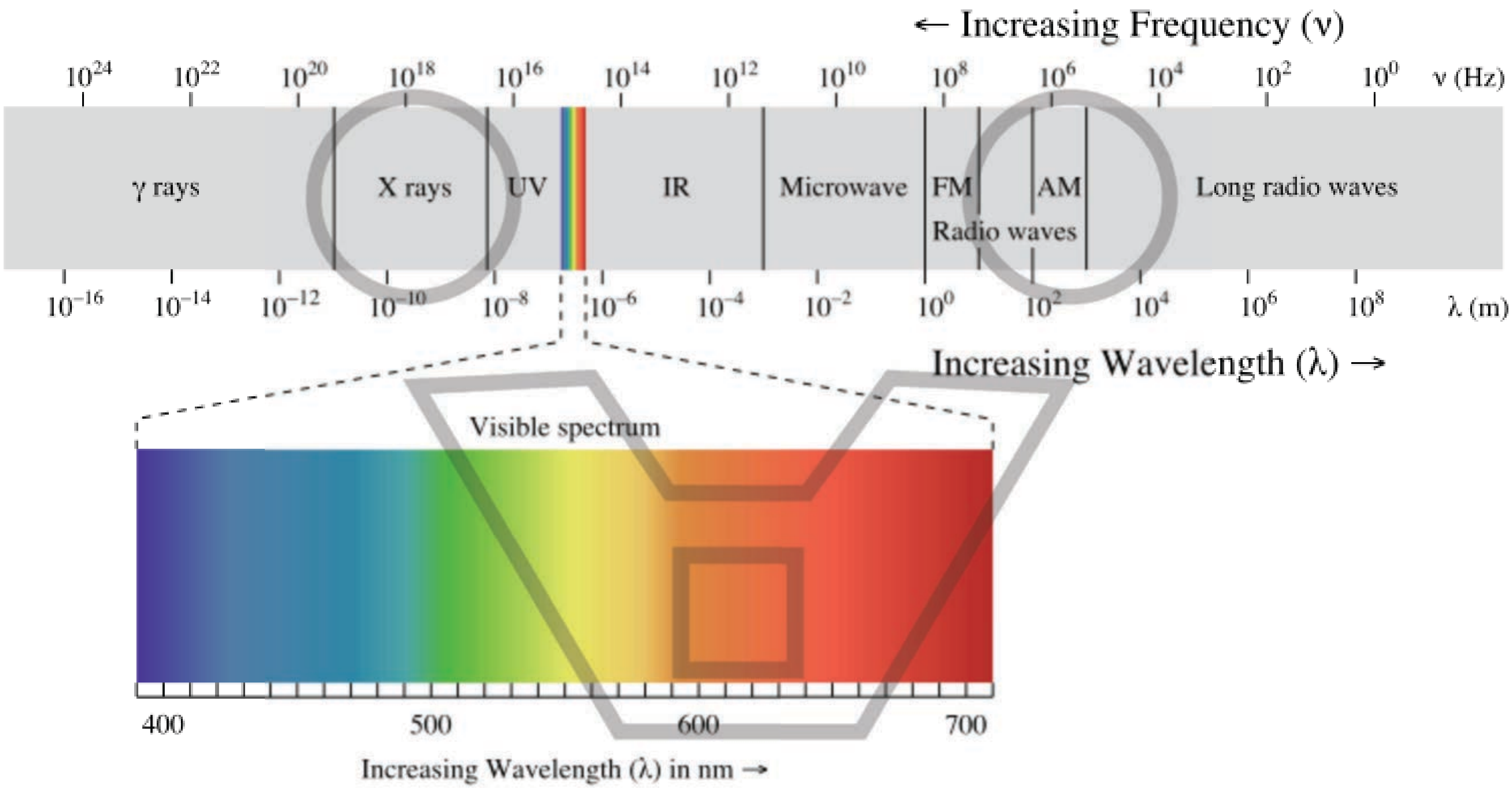
DAYLIGHT

Daylight vs thermal (and visual) comfort
A conflictual relationship

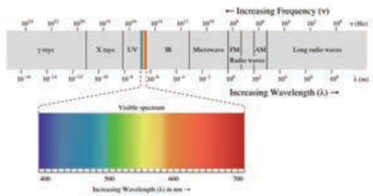
VISIBLE RADIATION

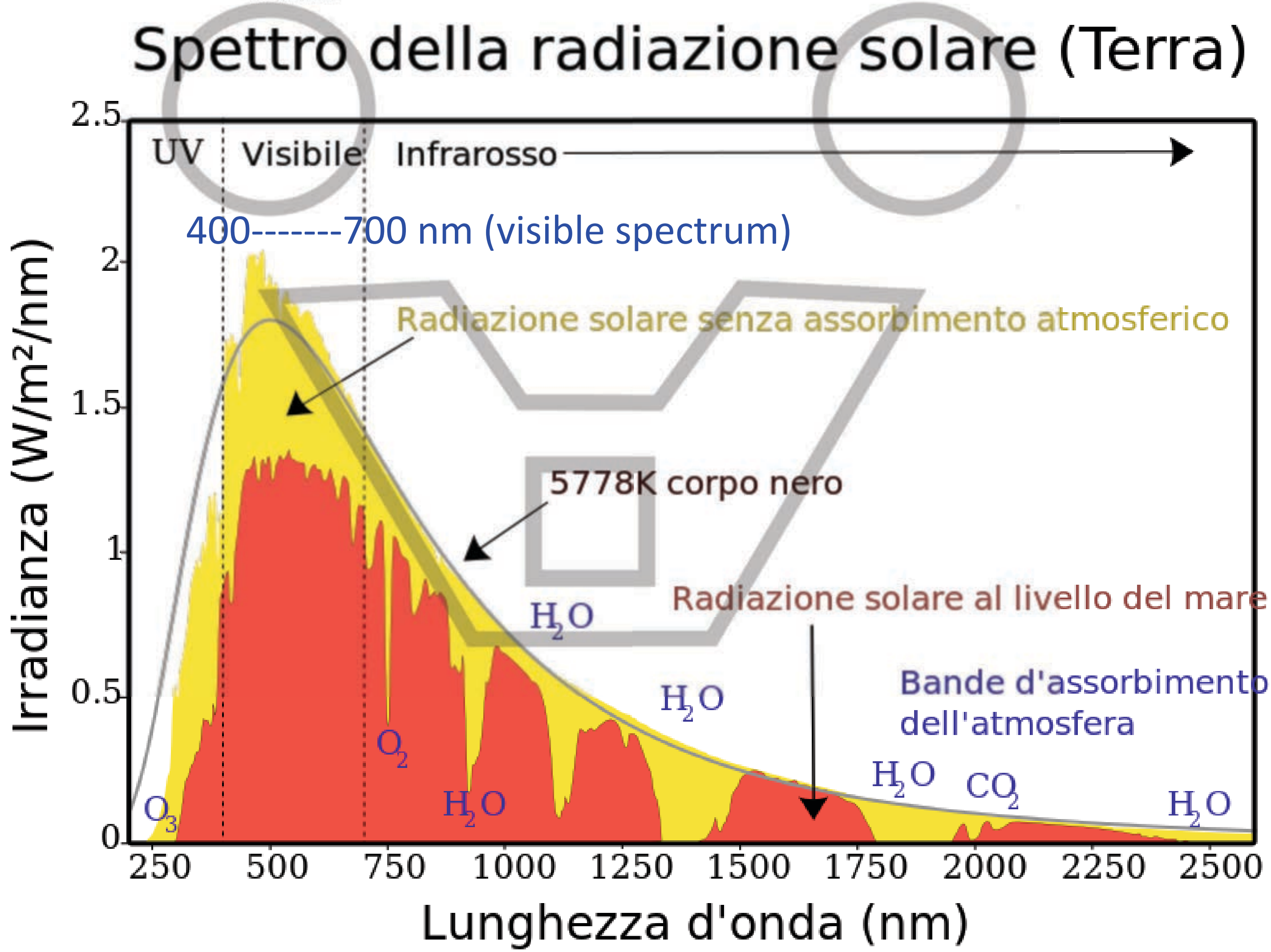


VISIBLE SPECTRUM

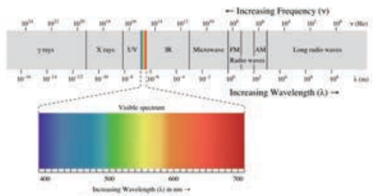


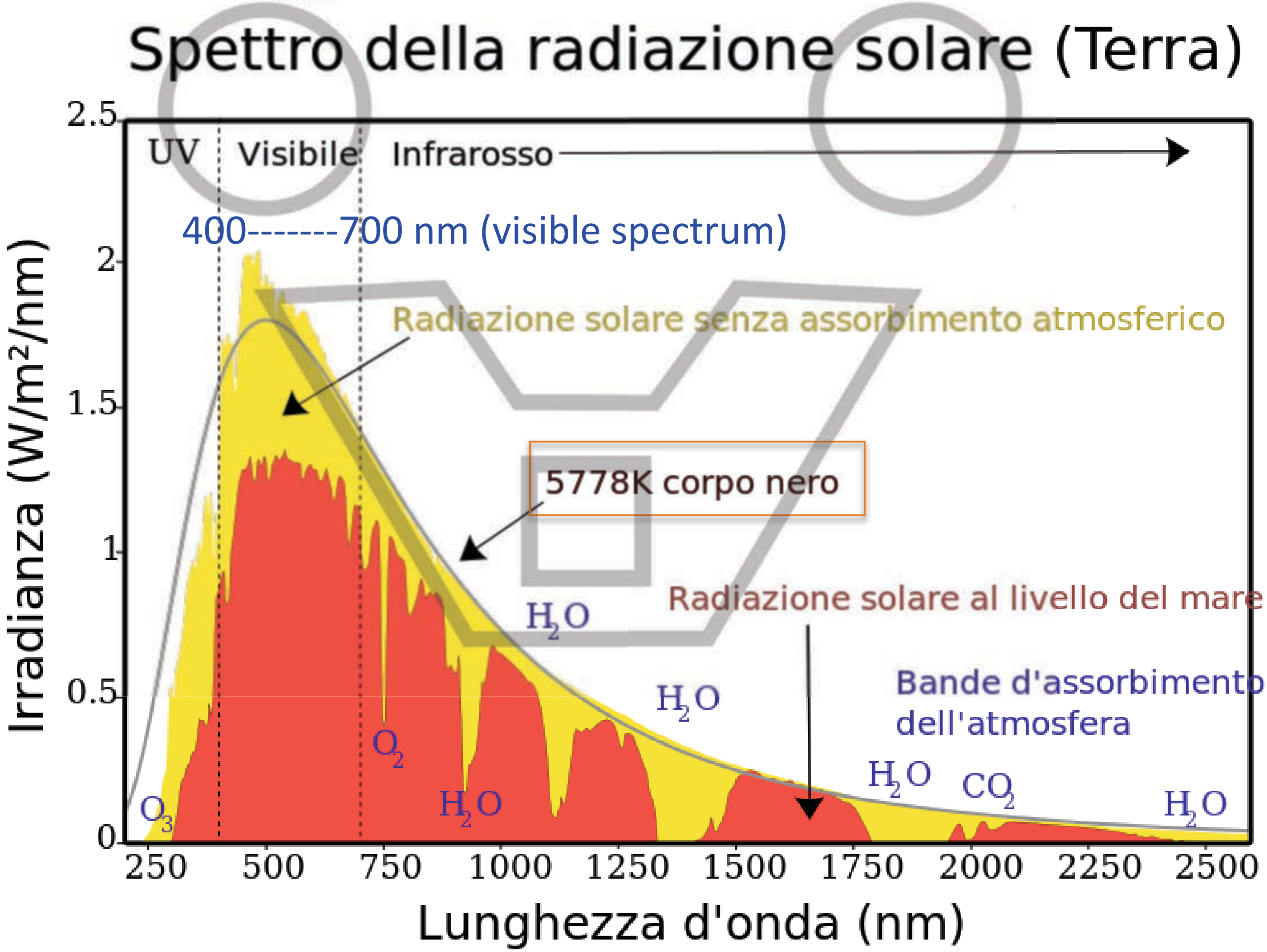
ABSOLUTE ENERGY IN THE VISIBLE SPECTRUM





ABSOLUTE ENERGY IN THE VISIBLE SPECTRUM





RELATIVE ENERGY IN THE VISIBLE SPECTRUM

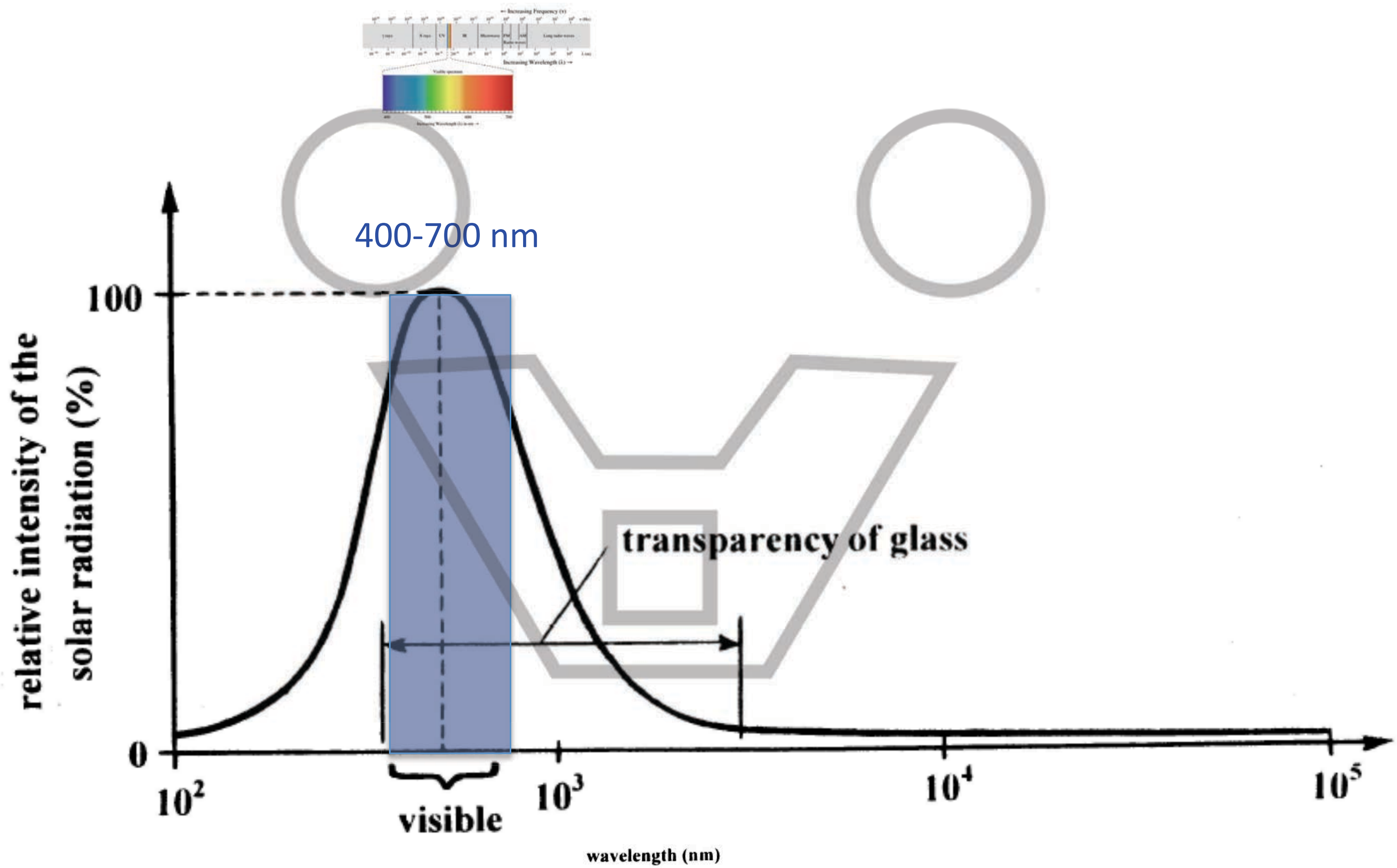


Fig. 7. Range di trasparenza del vetro rappresentato sullo spettro della radiazione solare.
Un confronto con la figura precedente mostra che il vetro non è trasparente nel range di emissione dei corpi a temperatura ambiente o di poco superiore.

TRASPARENCY OF GLASS & % OF RADIATION PASSING THROUGH GLASS

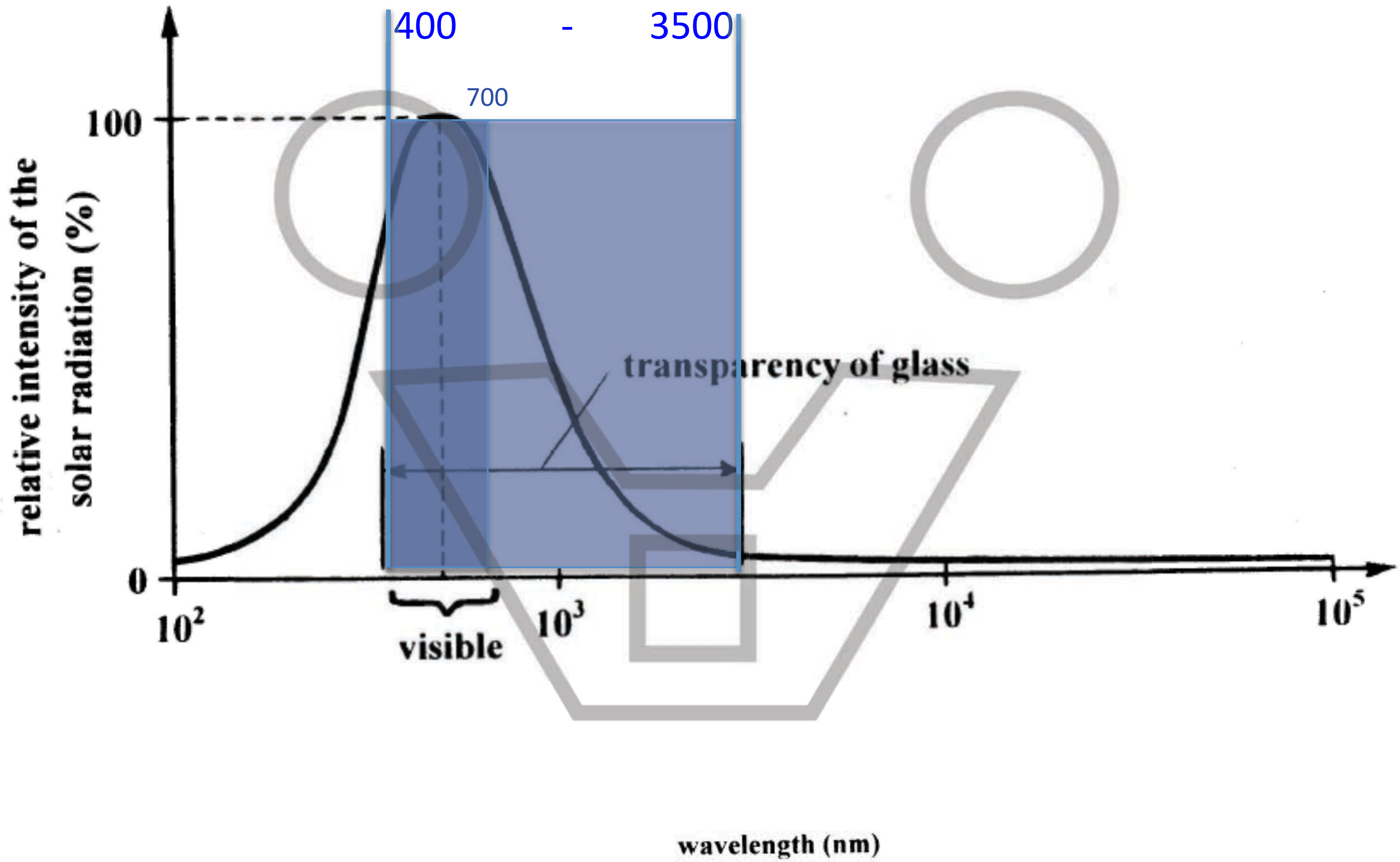
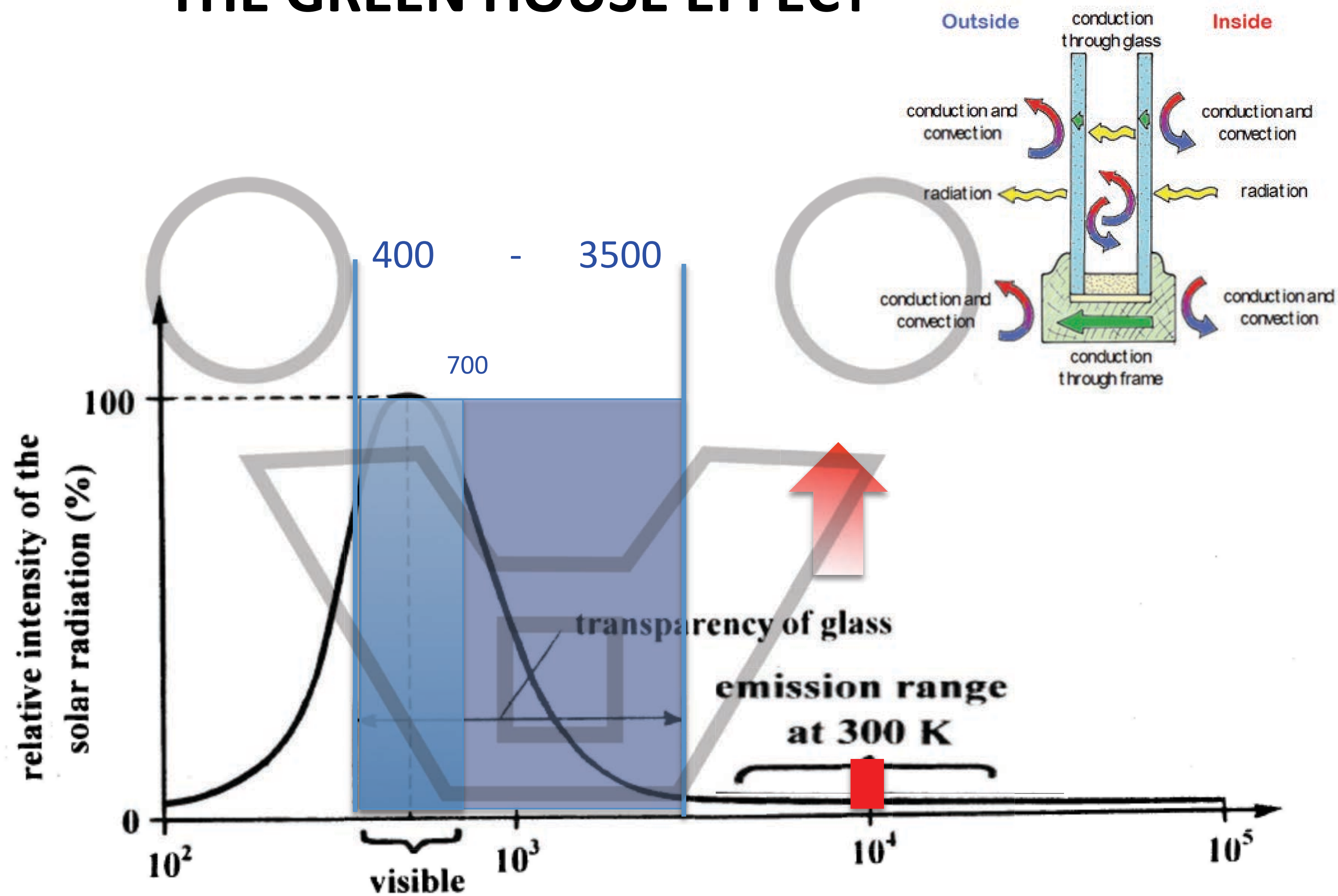


Fig. 6. Spettro della radiazione solare.

Sull'asse orizzontale è indicato il range di emissione relativo ad un corpo a 300 K. Lo spettro di emiss questo corpo non è rappresentato e sarebbe interamente sotto la curva dello spettro solare.

THE GREEN HOUSE EFFECT



400-3500

GLAZING MATERIALS AND GEOMETRY.
Spectrally selective coating

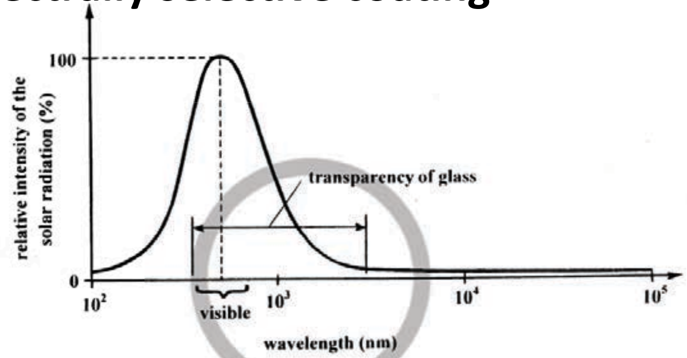
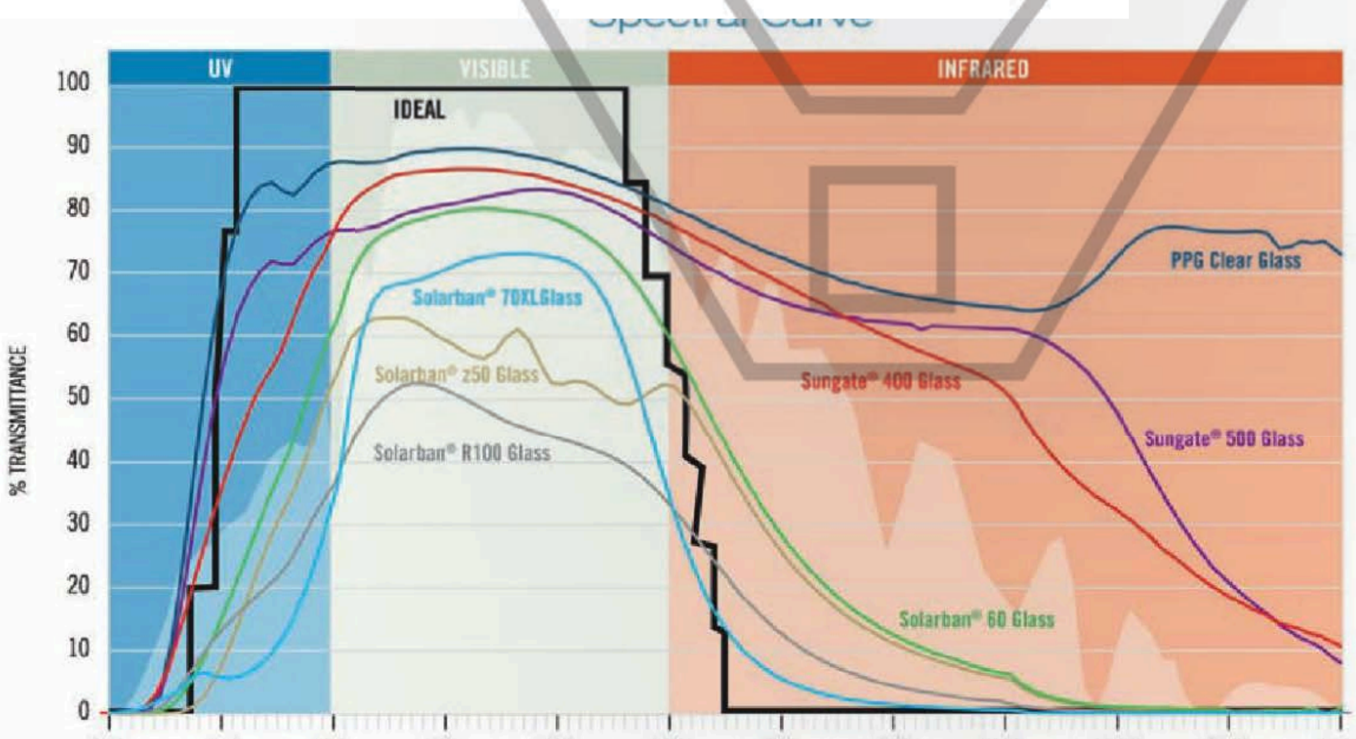


Fig. 7. Range di trasparenza del vetro rappresentato sullo spettro della radiazione solare. Un confronto con la figura precedente mostra che il vetro non è trasparente nel range di emissione dei corpi a temperatura ambiente o di poco superiore.



6.5

Spectrally selective coatings allow glazing products to reflect solar irradiation outside the visible spectrum without significantly reducing visible light transmittance. This allows low-SHGC products with high Tvis.

Source: Courtesy of PPG Industries.

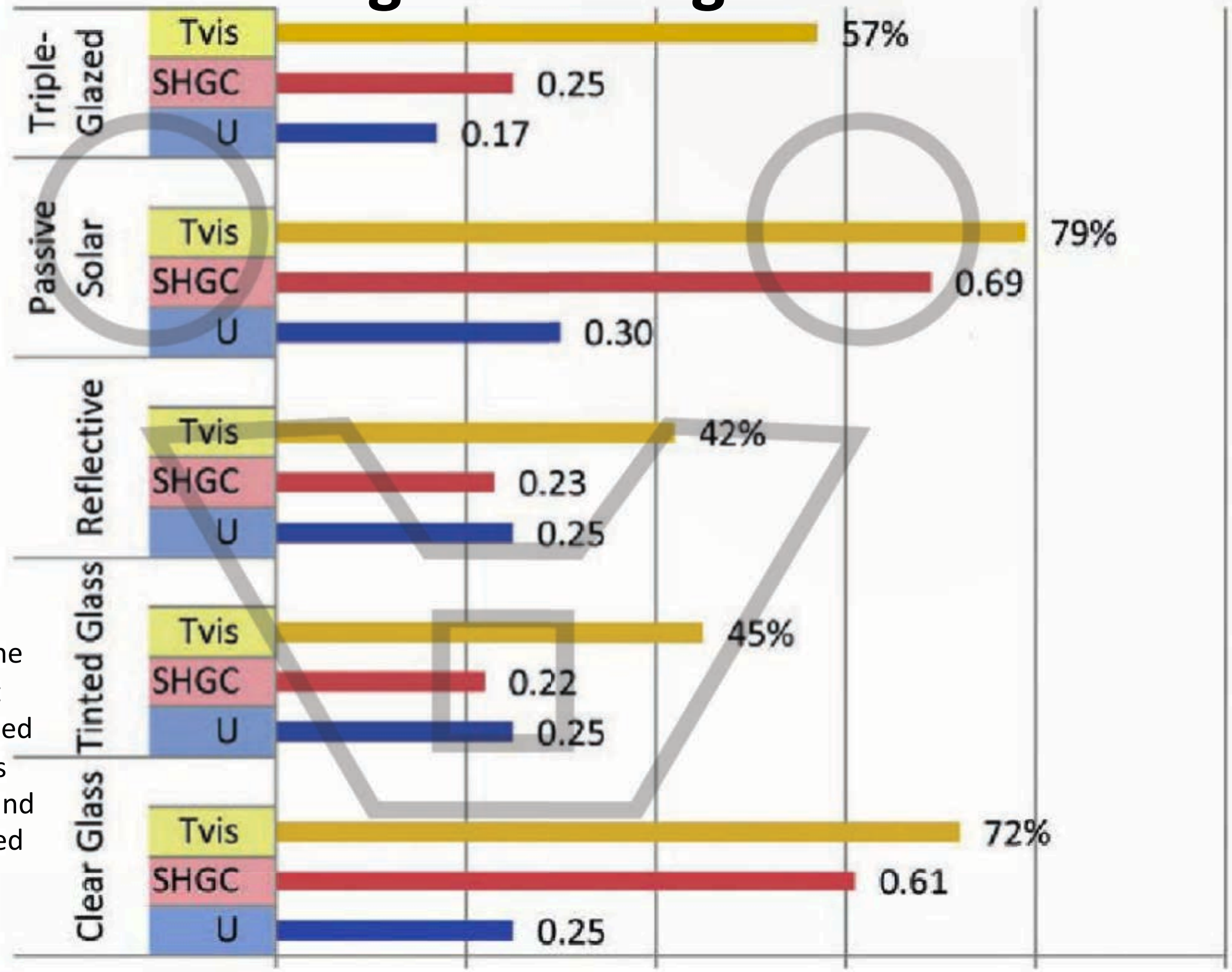
Environmental parameters affecting daylight: GLAZING PROPERTIES

visible Trasmittance (TVis) for daylighting)

Solar Heat Gain Coefficient (SHGC)

Solar Heat Gain COefficient (SHGC) is the fraction of the incident solar radiation trasmitted through a windoes plus the portion absorbed and subsequentially released iward

Glaring & Shading



6.4

Glazing properties from some widely manufactured insulated glazing units (IGUs).

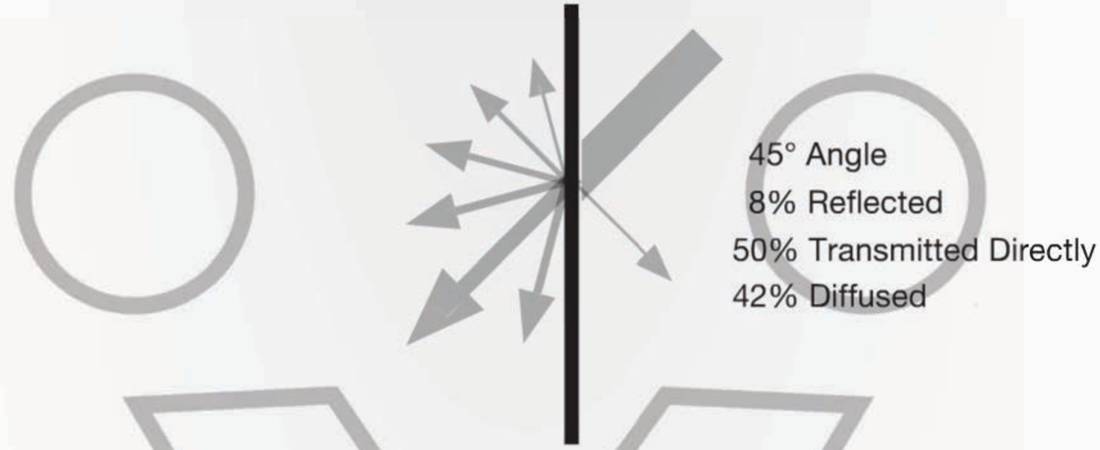
Source: Courtesy of Callison. Chart based on ©ASHRAE Handbook of Fundamentals (2005), 31.20.

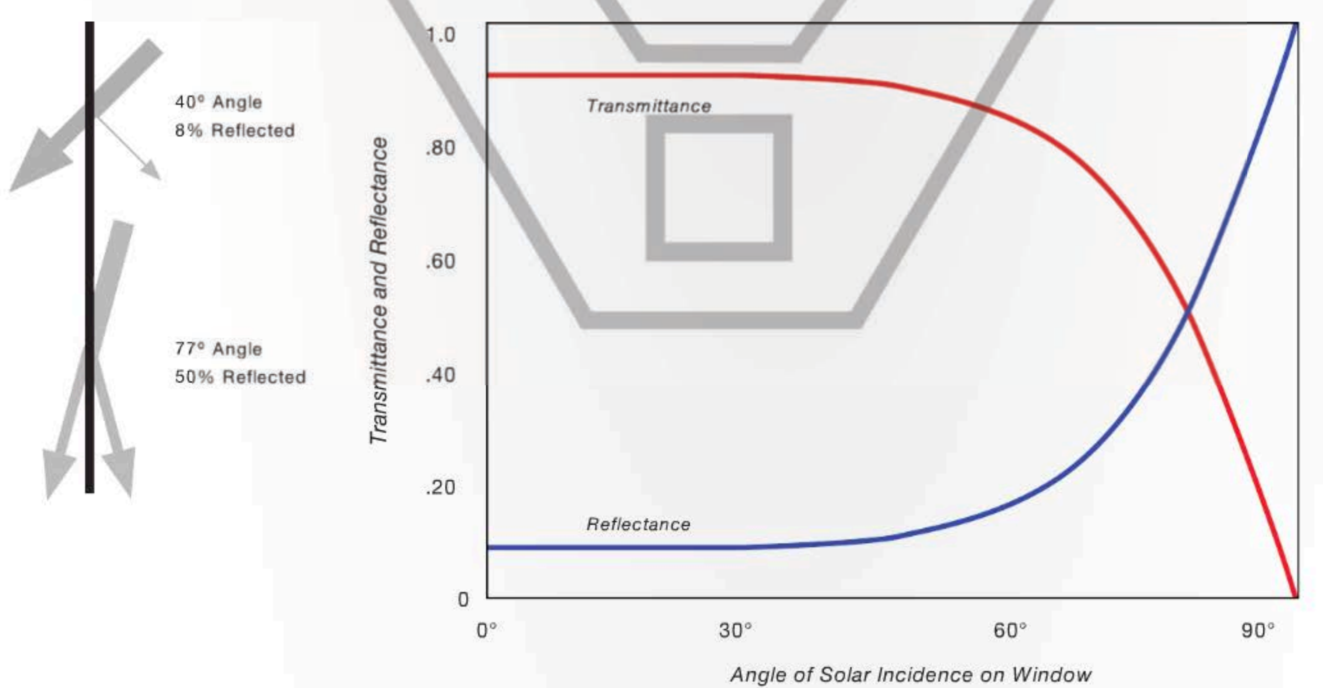
GLAZING MATERIALS AND GEOMETRY.

Reflectance & Trasmittance f(angle of incidence)

6.6

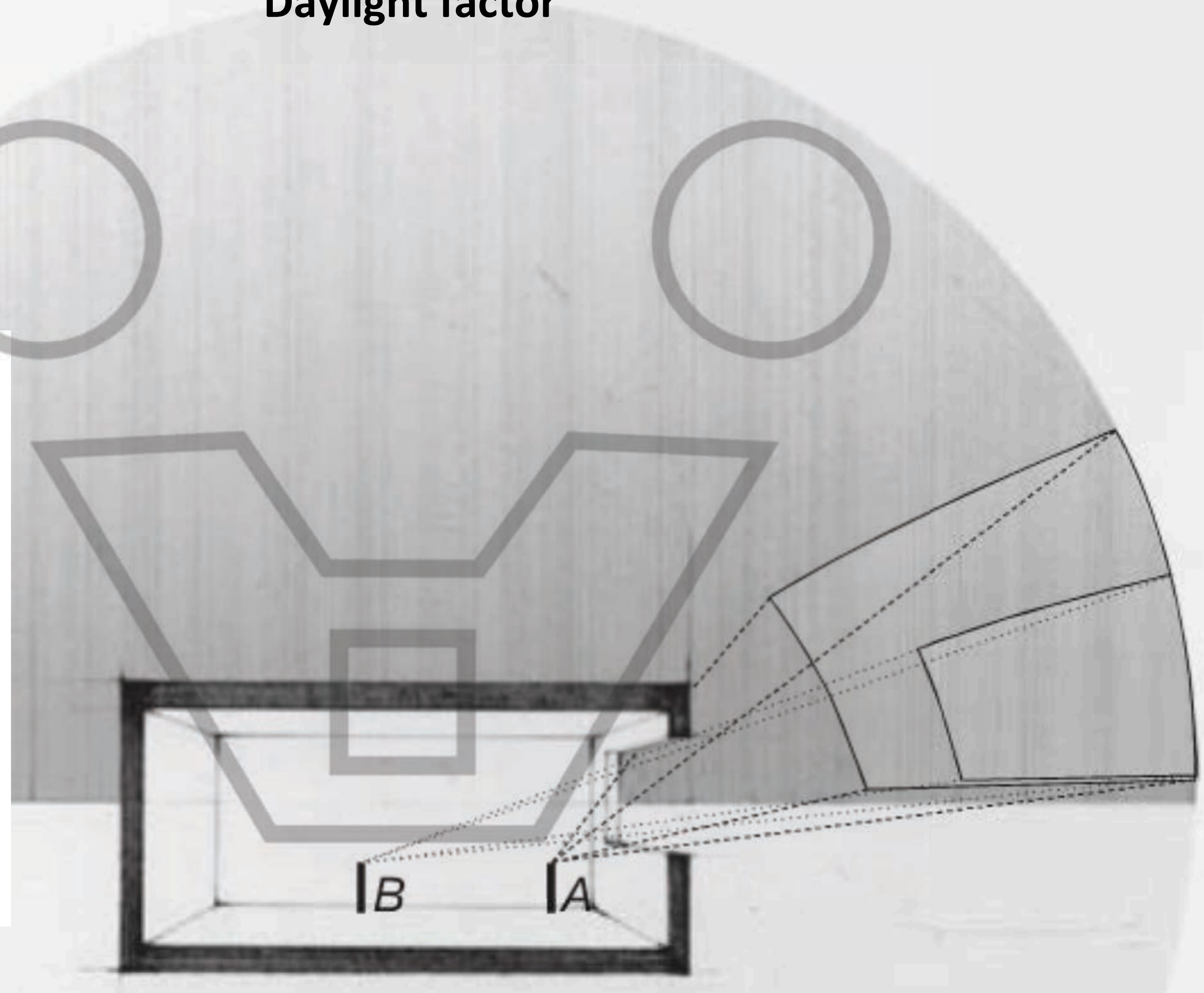
Translucent materials transmit some light and heat directly, and diffuse the rest of the transmitted light. In most cases, the diffused light is more concentrated around the directly transmitted light.





GLAZING GEOMETRY & MATERIALS

Daylight factor

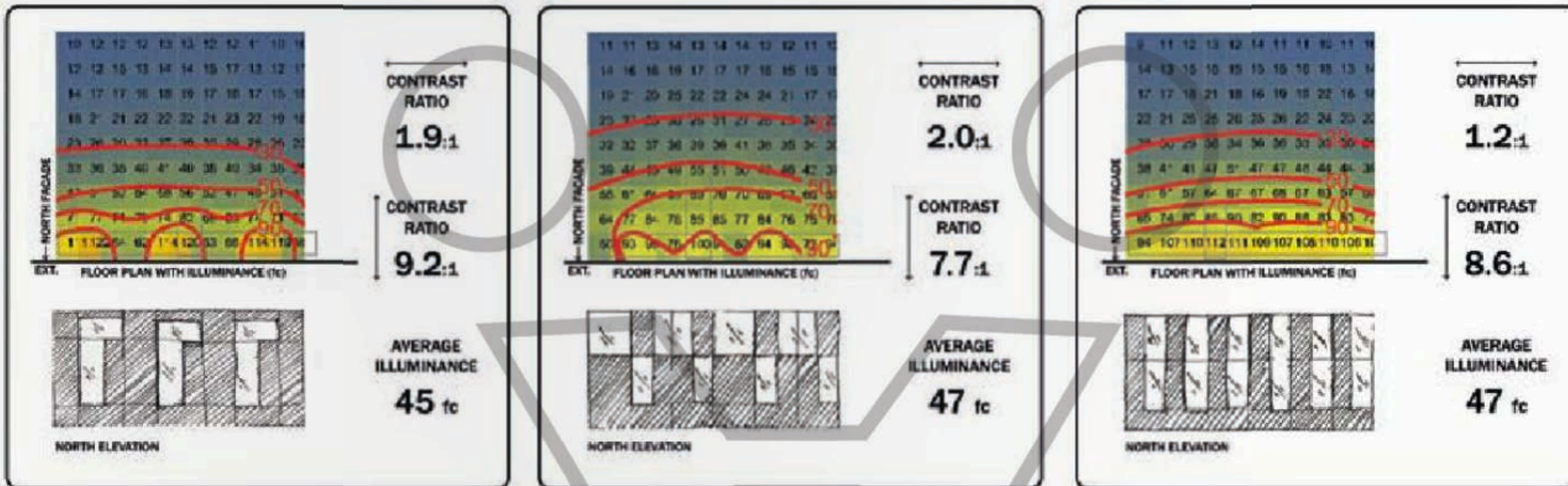


Daylight factor is based on the amount of indoor light as a percentage of outdoor light levels. Using a CIE overcast sky, it reports the percentage of outdoor light that arrives at a given point. Point A has access to significantly more sky than point B, with a proportionally higher daylight factor.

Source: Illustration by Amal Kissoondyal.

GLAZING GEOMETRY & MATERIALS

Illuminance levels

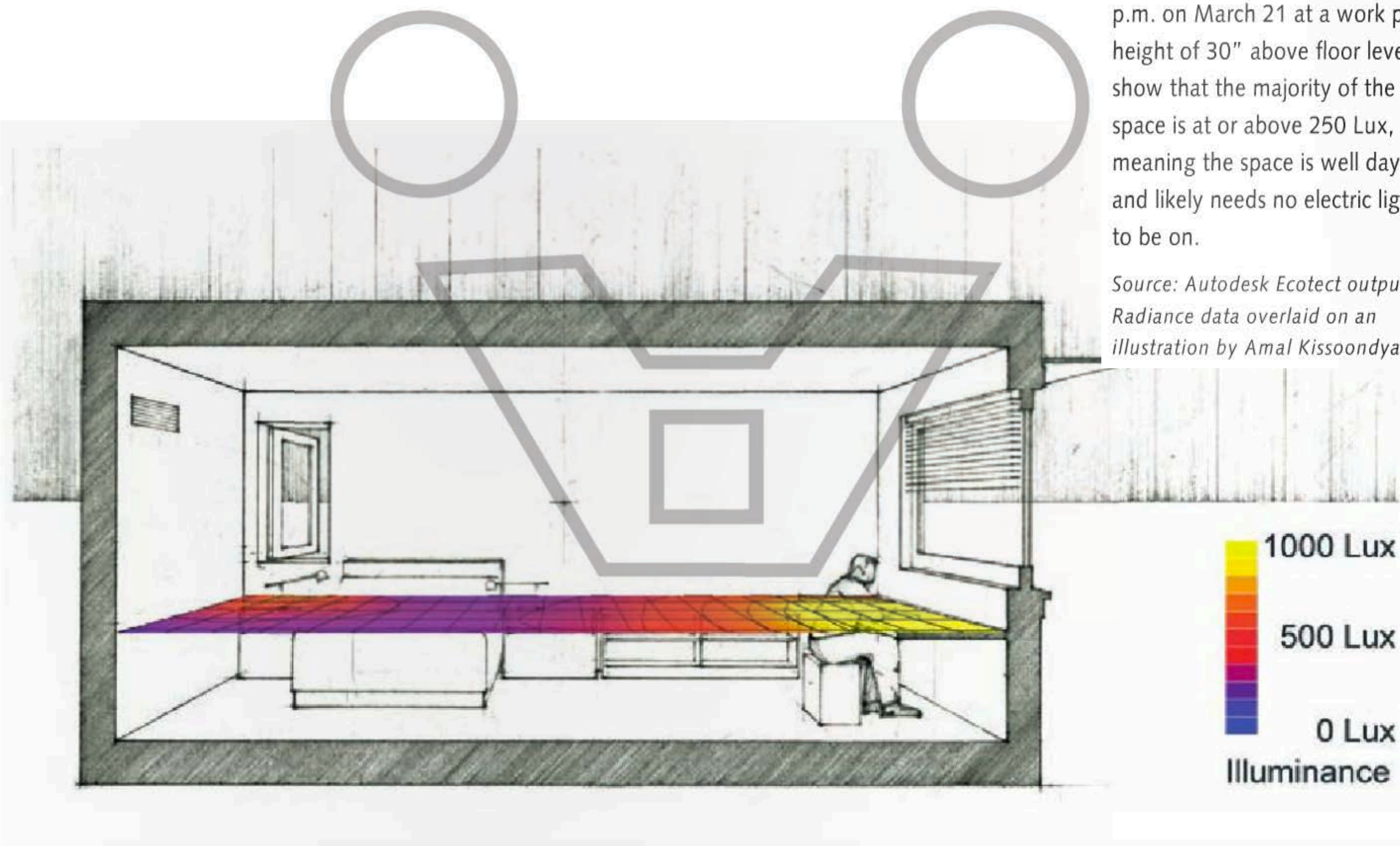


Plan-view studies showing illuminance levels for three window options on a north façade under overcast skies. The room's contrast ratios across width and depth are also shown, with lower contrast being preferable, but difficult to achieve, with side-lighting. Lighting designers typically include a room's contrast ratio in their studies to ensure even lighting throughout a space.

Source: Courtesy SERA Architects.

GLAZING GEOMETRY & MATERIALS

False Color Illuminance levels



False color illuminance levels for 2 p.m. on March 21 at a work plane height of 30" above floor level show that the majority of the space is at or above 250 Lux, meaning the space is well daylit and likely needs no electric lights to be on.

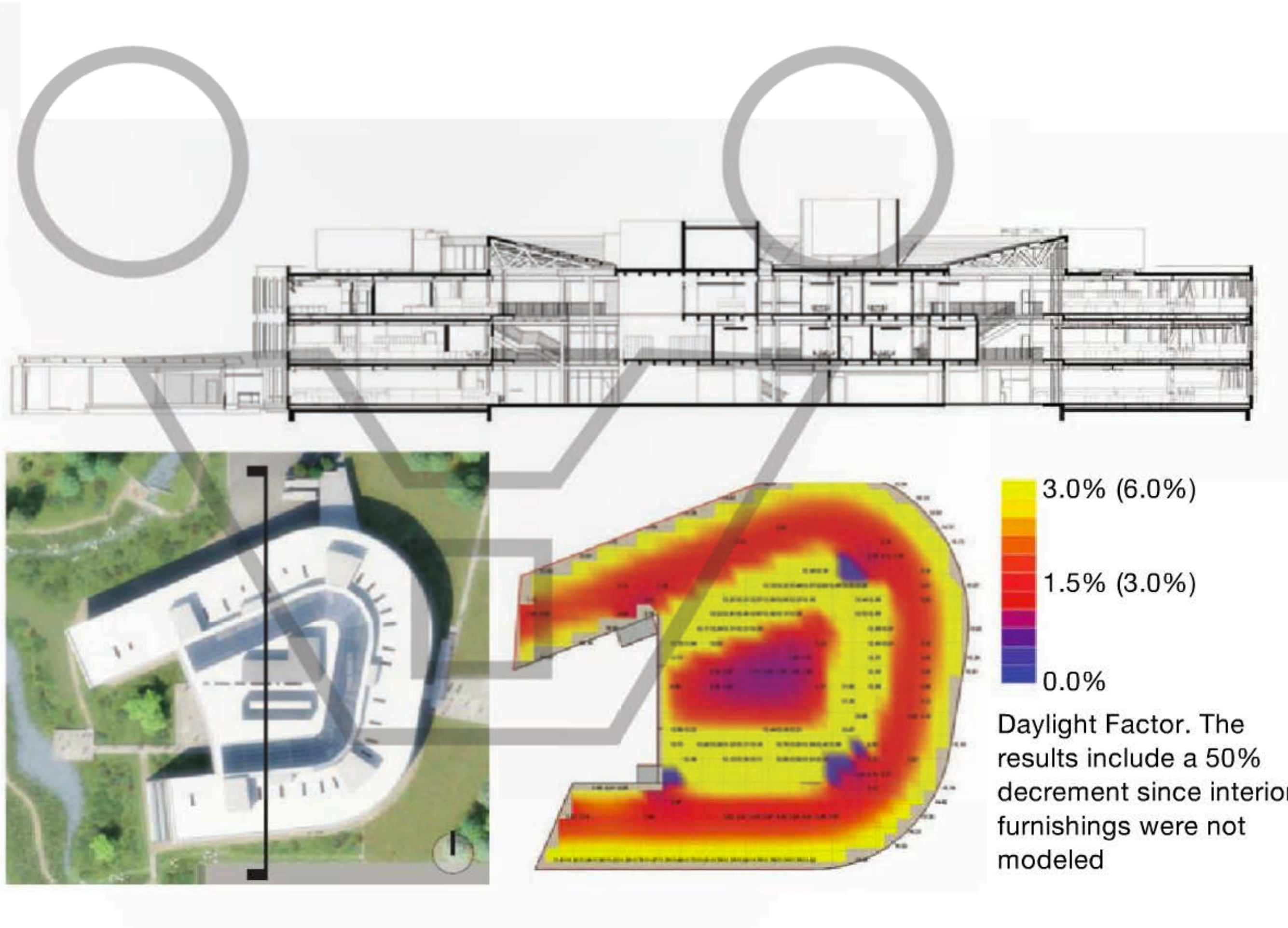
Source: Autodesk Ecotect output of Radiance data overlaid on an illustration by Amal Kissoondyal.

GLAZING GEOMETRY & MATERIALS

Day light false color analysis

Federal Center South, Building 1202, is a 60'-wide office plate in the form of a U-shape around a daylit atrium. The false color results of a daylight factor simulation on the ground floor show good daylight based on sectional properties, including: office plate width, skylight geometry and glazing properties.

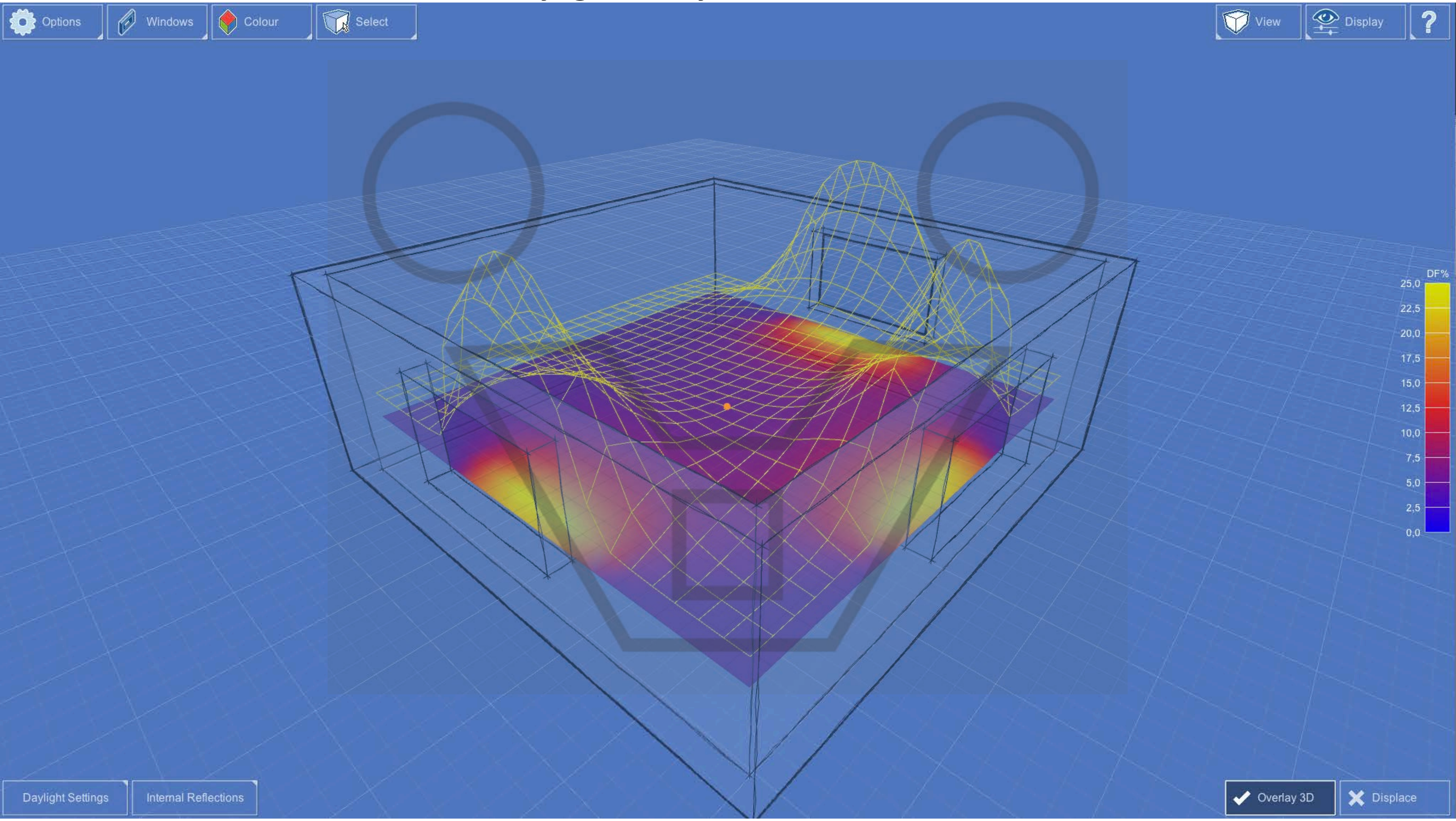
Source: Courtesy of ZGF Architects LLP.



Daylight Factor. The results include a 50% decrement since interior furnishings were not modeled

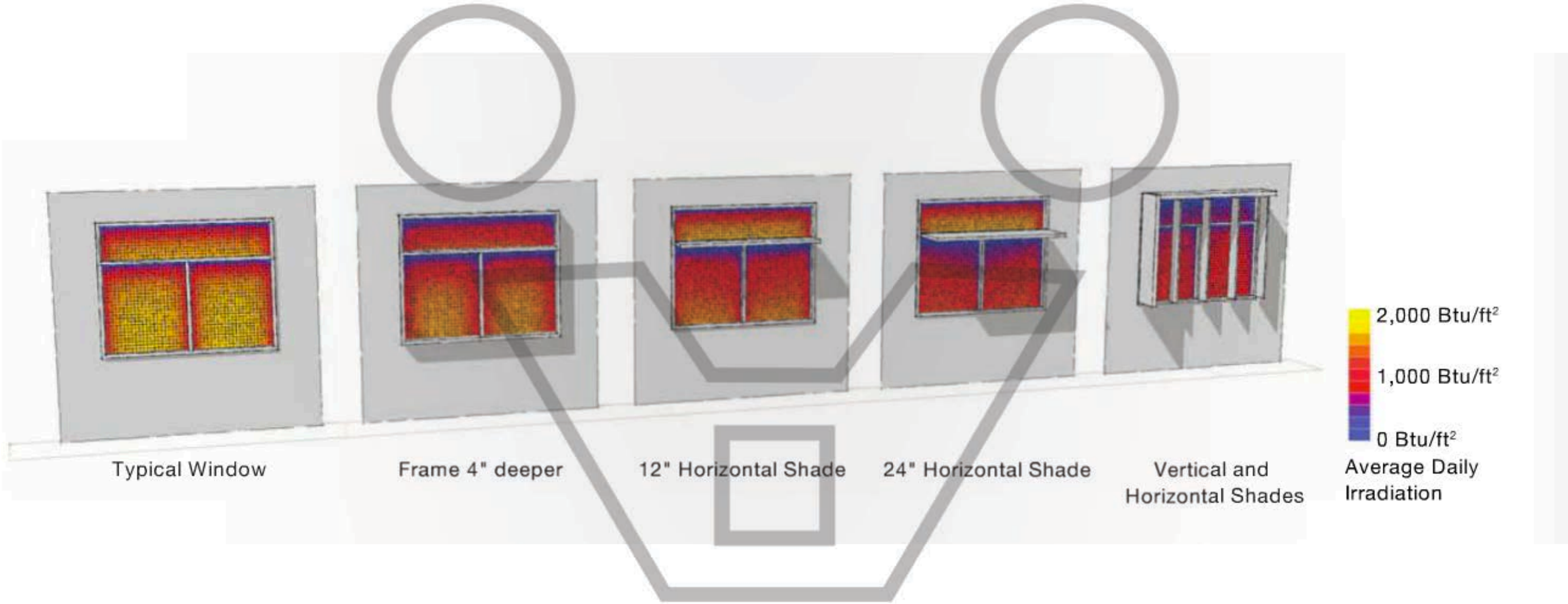
GLAZING GEOMETRY & MATERIALS

Daylight analyis



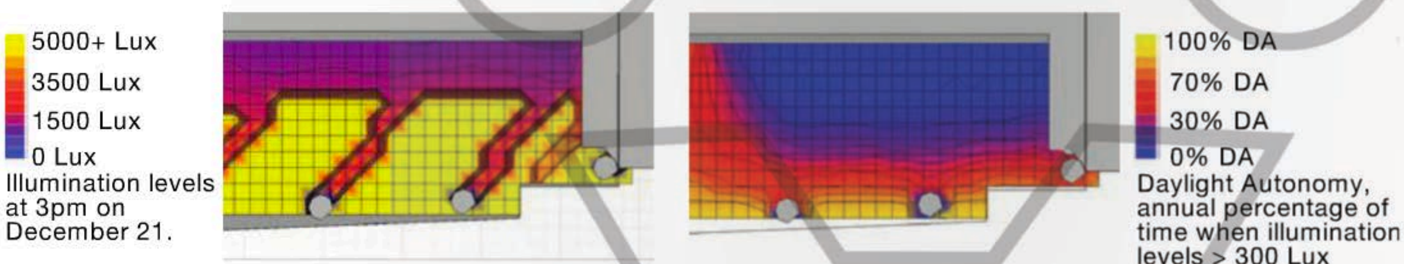
http://andrewmarsh.com/software/app-daylight/

Glaring & Shading



Glaring & Shading

Daylight assessment: Point-in-time vs annual analysis

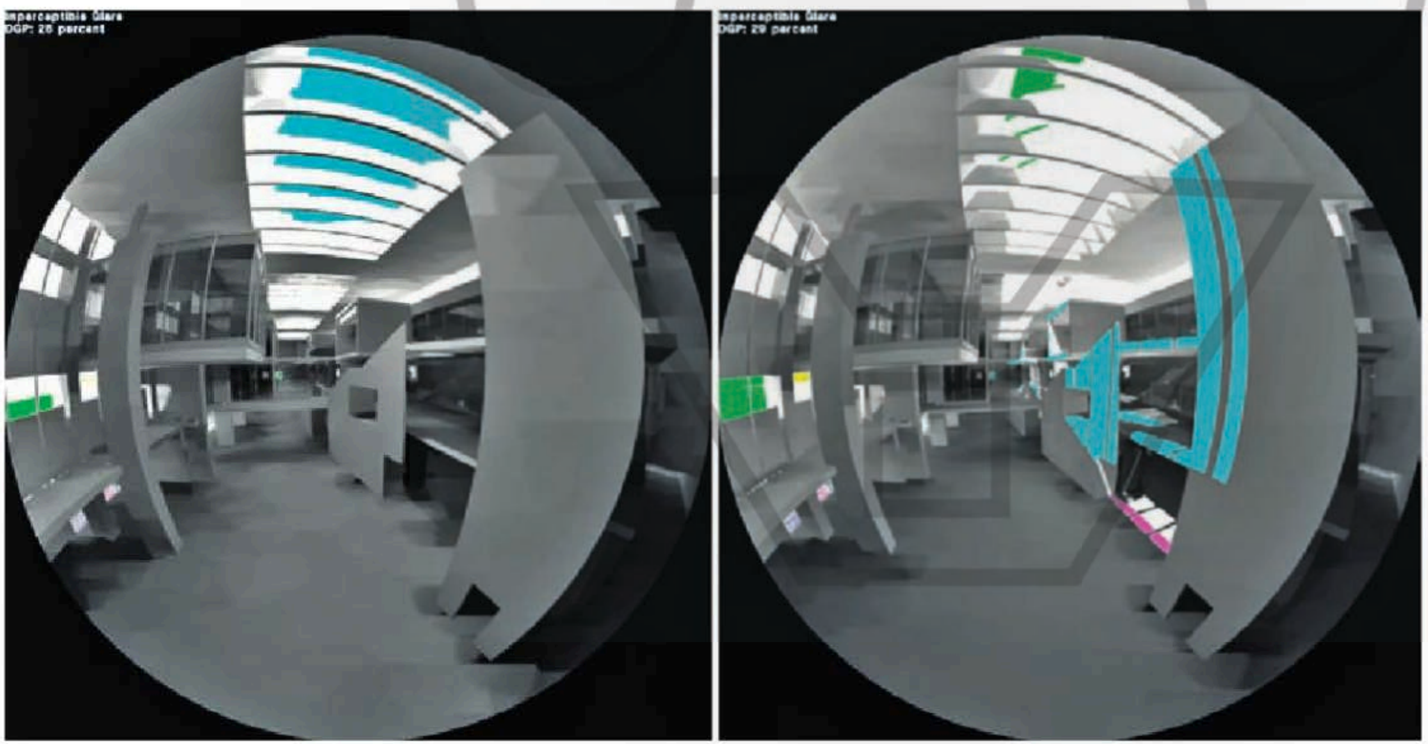


2.6

Plan view of an open office space, showing a façade with columns at the bottom. A point-in-time (PIT) analysis (left) provides information about daylight levels and potential for glare at 3:00 p.m. on the winter solstice, for example. An annual daylight autonomy analysis (right) shows areas that are successfully daylit for a certain percentage of the year. Both use false colors to illustrate lighting levels; they are Autodesk Ecotect outputs of Radiance and Daysim analyses, respectively.

on investment of 3 years. If the project team assumes that occupants will turn off the lights when they leave at night, occupancy sensors may only be projected to reduce lighting energy use by 20%, with a return on investment of 10 years. As a broader example, ASHRAE 90.1's baseline building energy use is unique to every design, leading to industry-wide misunderstanding regarding a building's modeled

Glaring & Shading



8.12

Daylight glare probability studies of atrium skylight options using DIVA software shows .26 and .29, both considered imperceptible glare. Each area within a field of view that contributes to glare is assigned a random color to show its location.

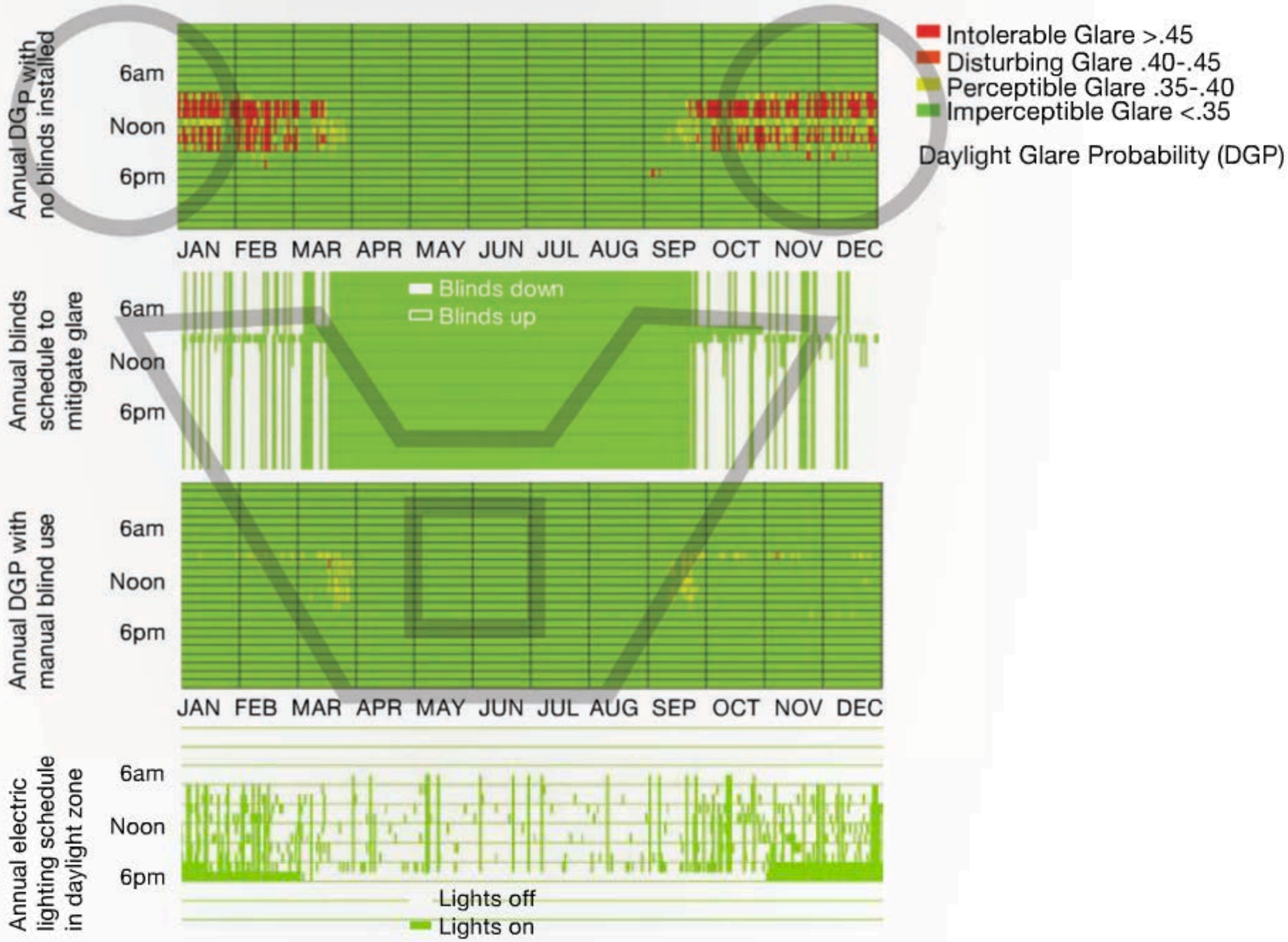
Source: Courtesy of SERA Architects.

Glaring & Shading

8.13

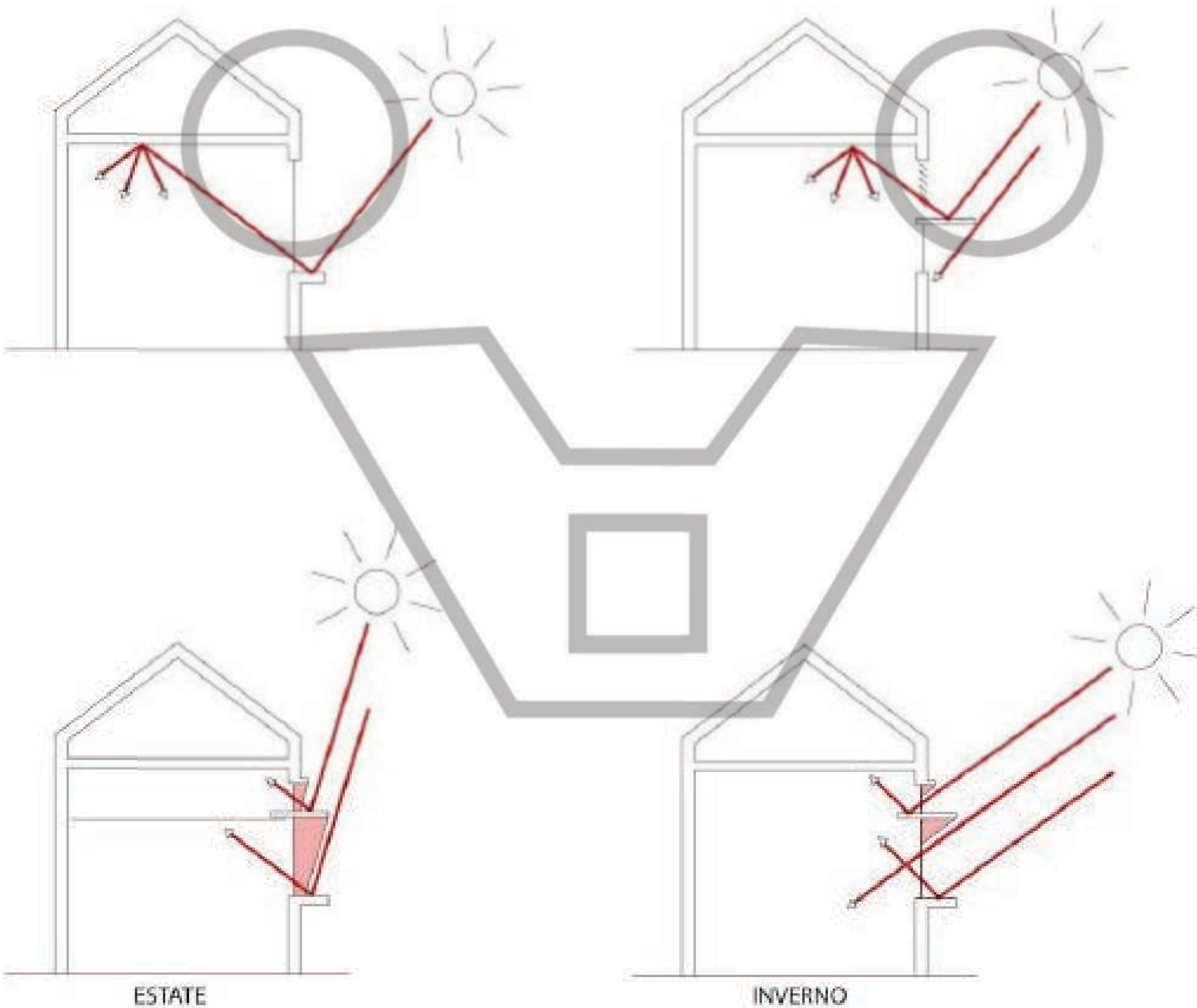
An east-facing viewpoint within a south-facing office space experiences glare primarily during times with low-angle sun in the Fall and Winter. Diva for Rhino software creates a blinds schedule to minimize glare, based on research of building occupants' tendency to lower them based on glare but raise them infrequently, per the Lightswitch model (Reinhart, 2002). The blind schedule helps create a lighting usage schedule that can estimate lighting energy use savings to compare design options.

Source: Courtesy of Jeff Niemasz.



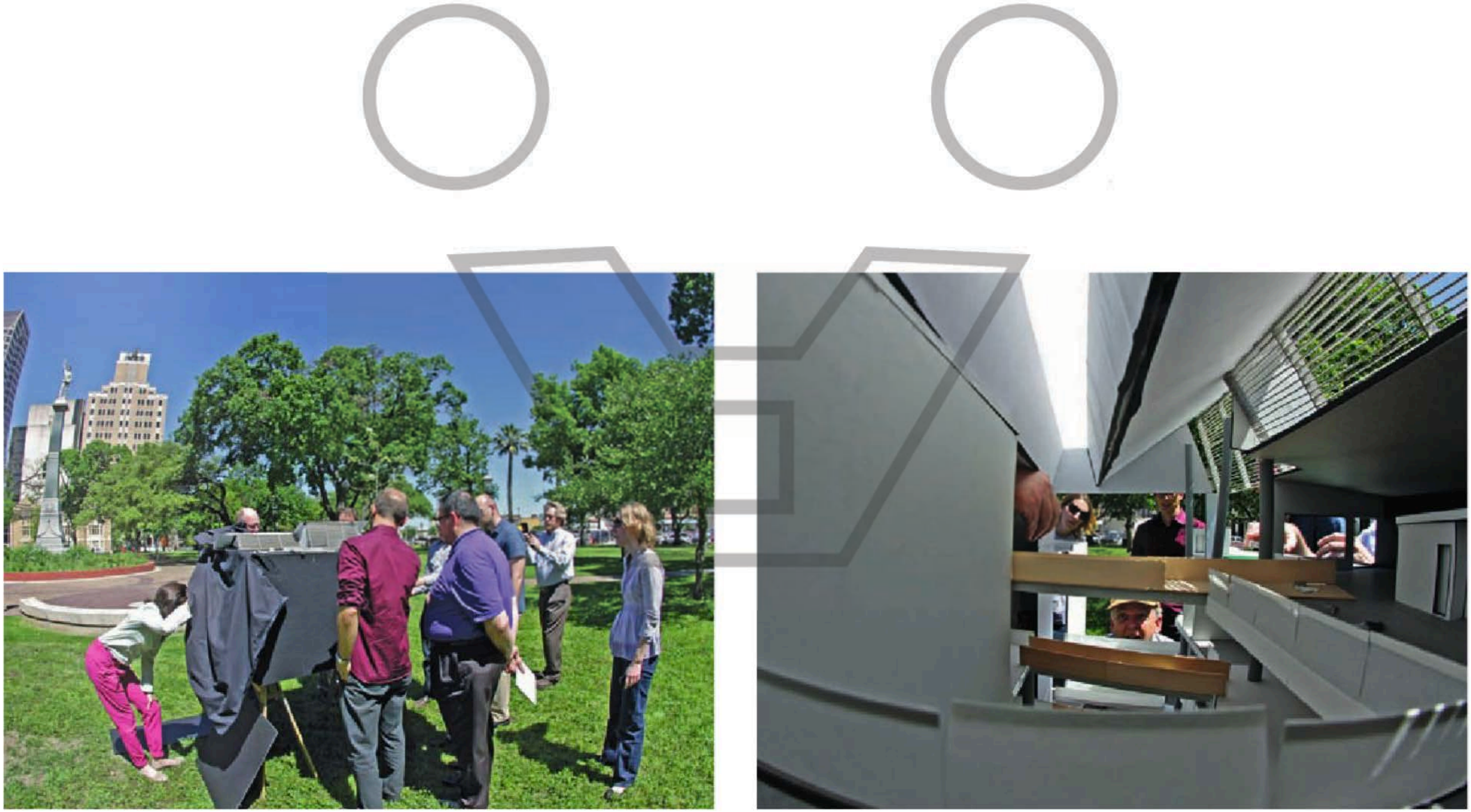
Glaring & Shading

Systems for daylight diffusion



Environmental parameters affecting daylight: WINDOWS GEOMETRY

Physical scale model to evaluate daylight and glare

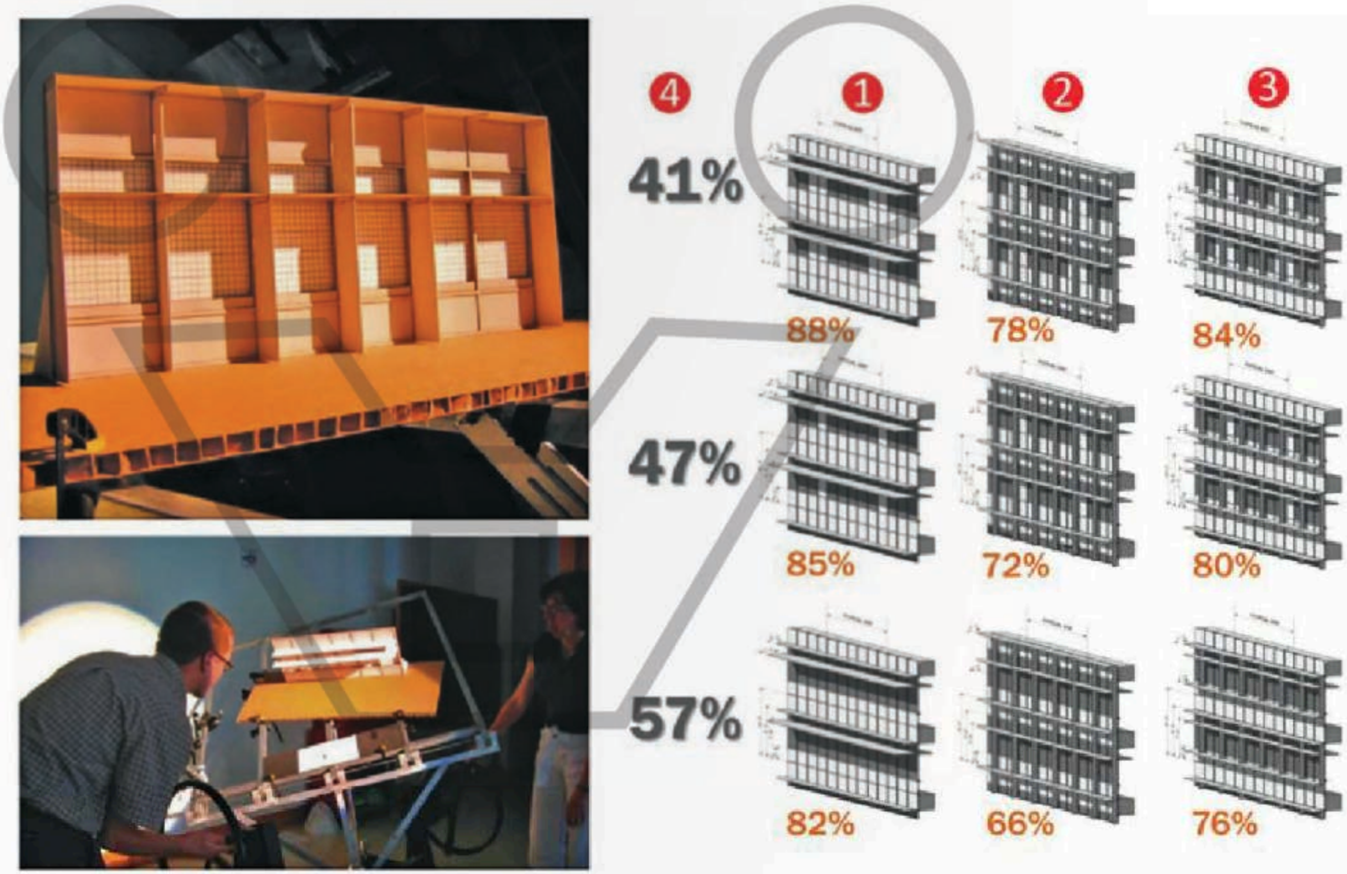


Glaring & Shading

LIGHTING vs GLARING: Shaping windows and shading

7.17

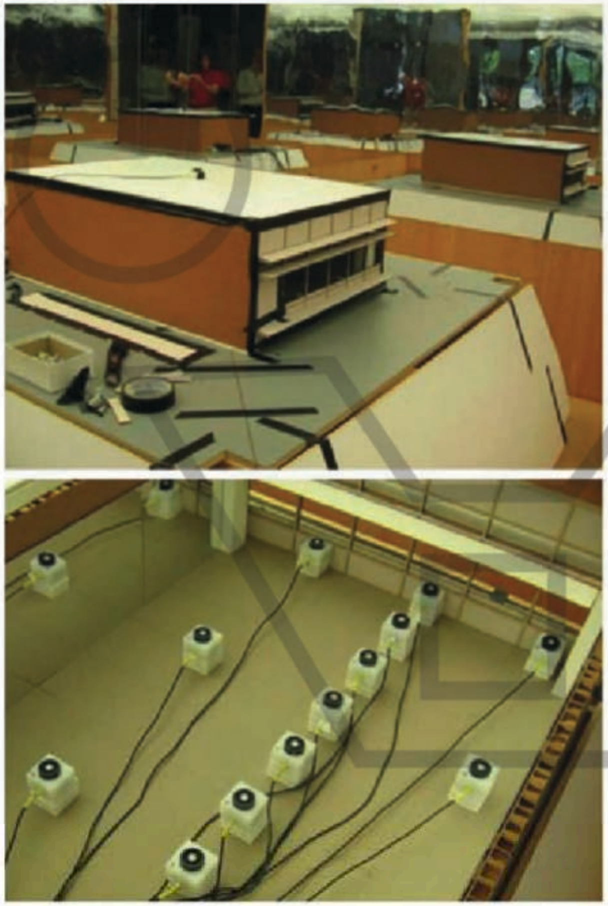
Façade shading studies testing options with (1) horizontal shade only, (2) vertical and horizontal fins with the horizontal element as a light shelf, and (3) vertical and horizontal fins with the horizontal as sill reflector. Each option was tested with 3 glazing percentage options (4). The orange number shows the percentage of the glazing that is shaded in each option.

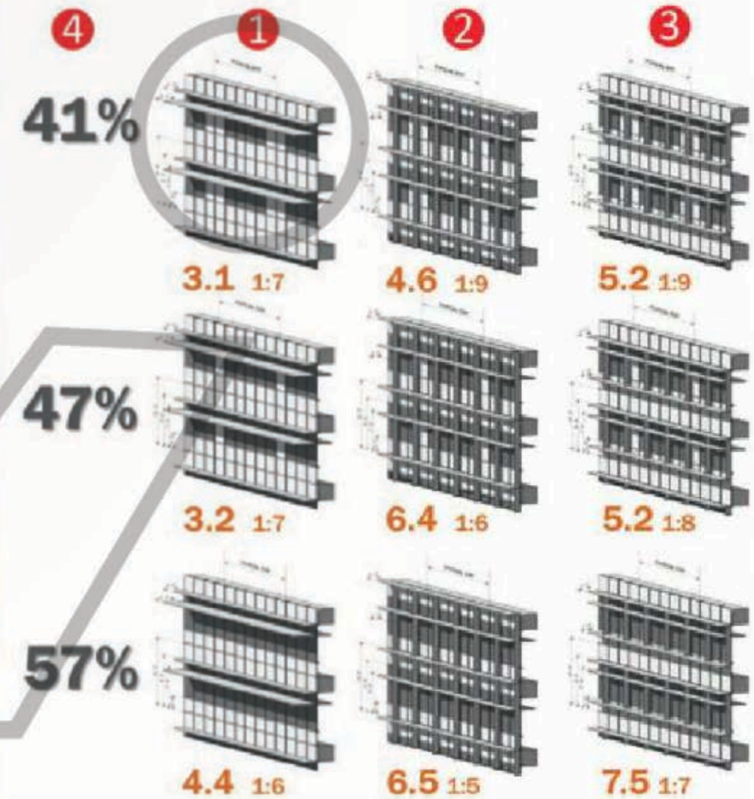


Glaring & Shading

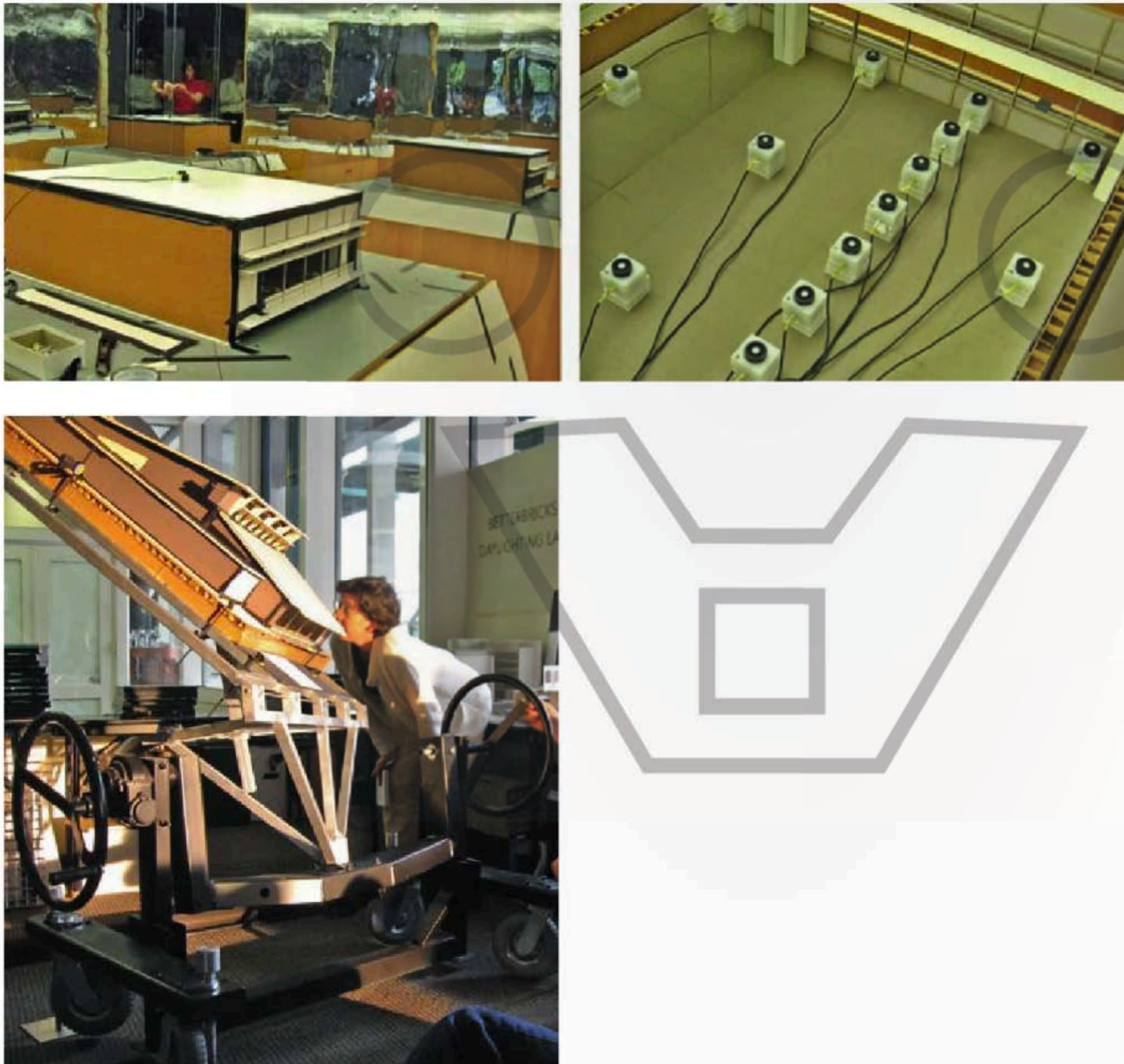
7.18

Daylighting studies testing the same 9 shading options as 7.17. The large orange number shows the average daylight factor in the 16′ perimeter zone, and the small number shows the contrast ratio across this area.





Glaring & Shading



8.14

A physical daylighting model showing use of light meters to calculate the daylight factor. An overcast sky is simulated by the light box, which has highly reflective ceiling and walls to create uniform light levels.

Source: Courtesy of SERA Architects.

And a physical daylighting model showing use of a heliodon at the Energy Studies in Buildings Laboratory in Portland, Oregon, to predict daylighting levels under sunny sky conditions. The large wheels rotate the model through specific solar angles in relation to a bright electric light.

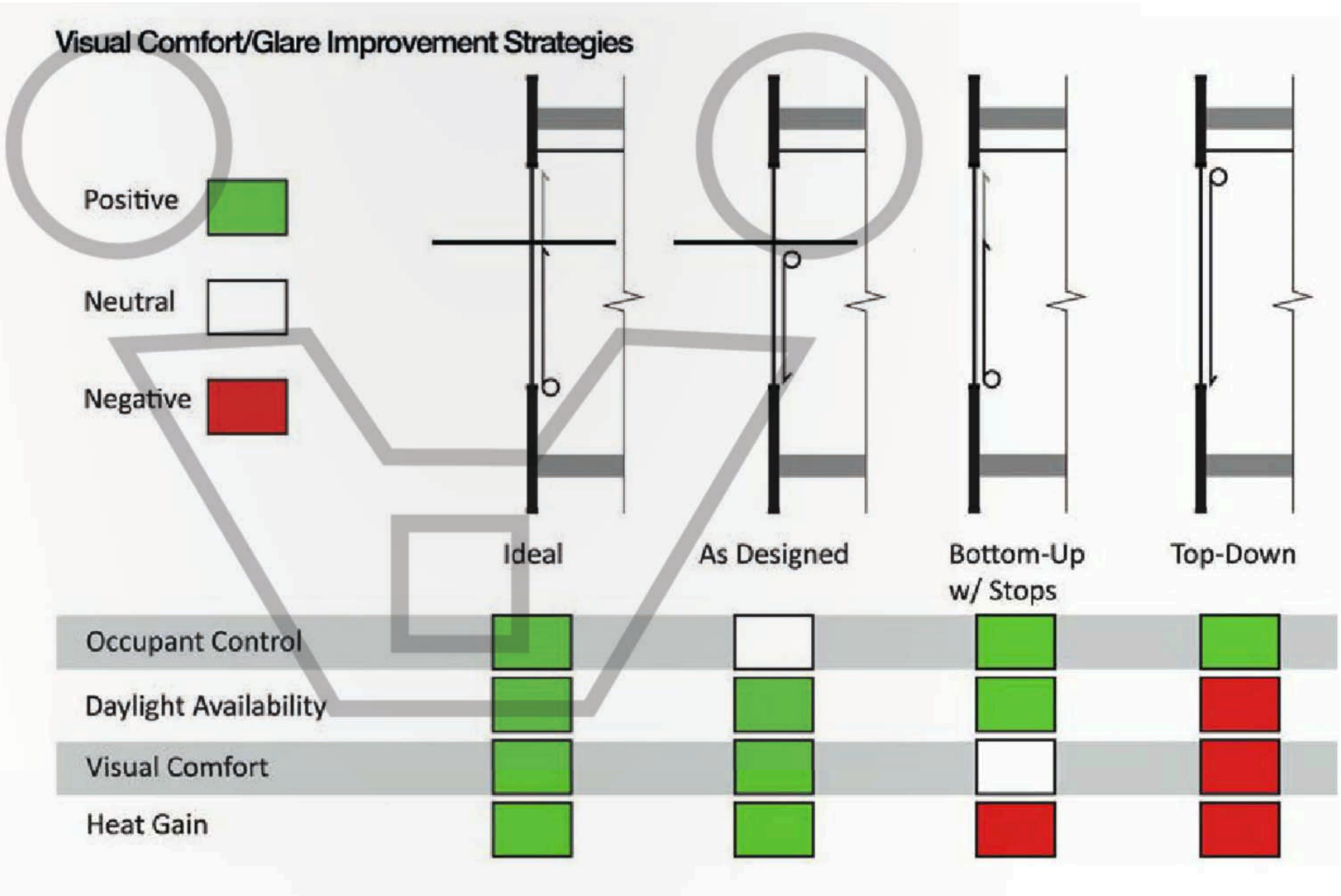
Source: Courtesy of SERA Architects.

Glaring & Shading

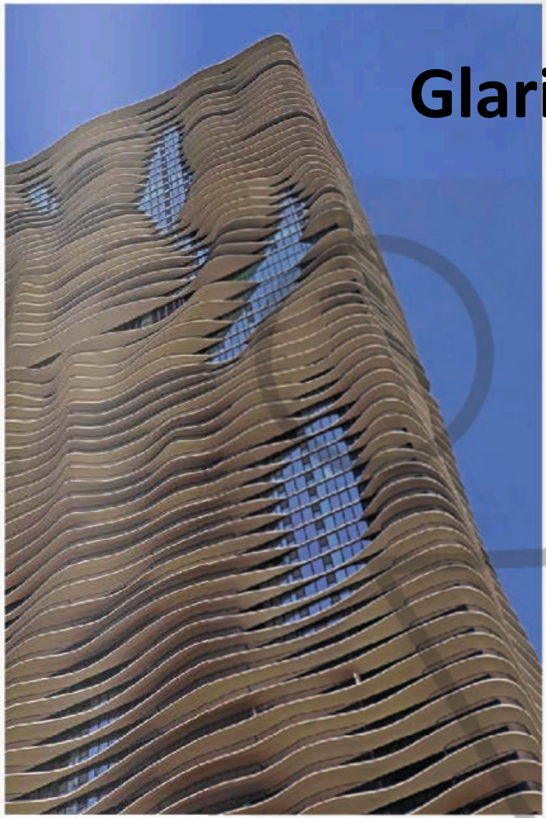
3.6

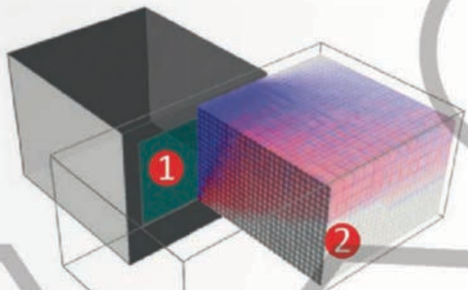
A study prepared for Iowa State University by ZGF Architects LLP rates four window options for user controllability, daylight availability, visual comfort, and heat gain. While simulations predict lighting energy savings due to the use of daylight, these savings are only realized when the system successfully blocks glare or allows users to block glare without blocking daylight.

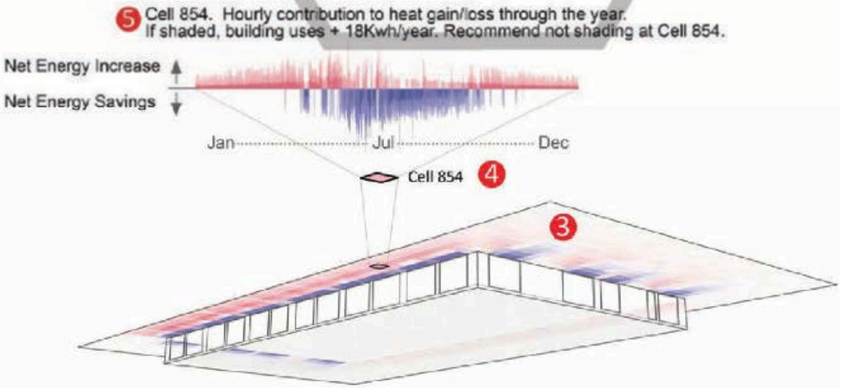
Source: Courtesy of ZGF Architects LLP.



Glaring & Shading







7.30

The Aqua Tower. The parametric aesthetic of the Aqua Tower was investigated using the Shaderade method of shading design.

Source: Photo by Jeff Niemasz.

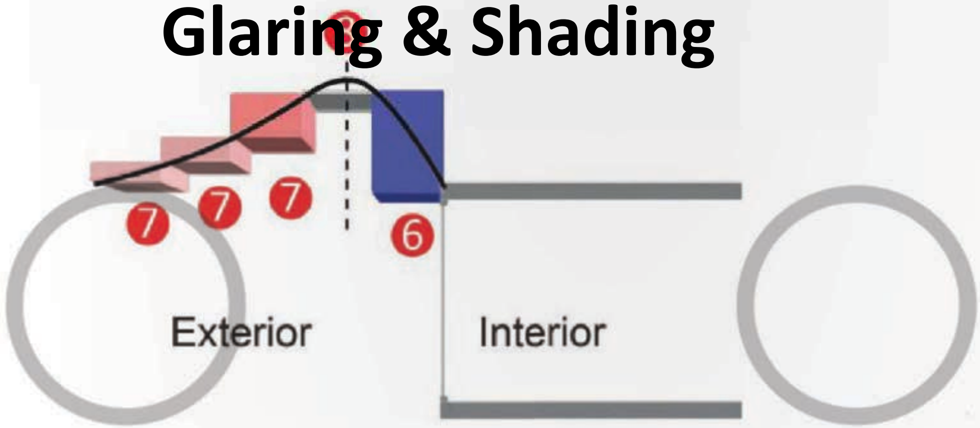
7.31

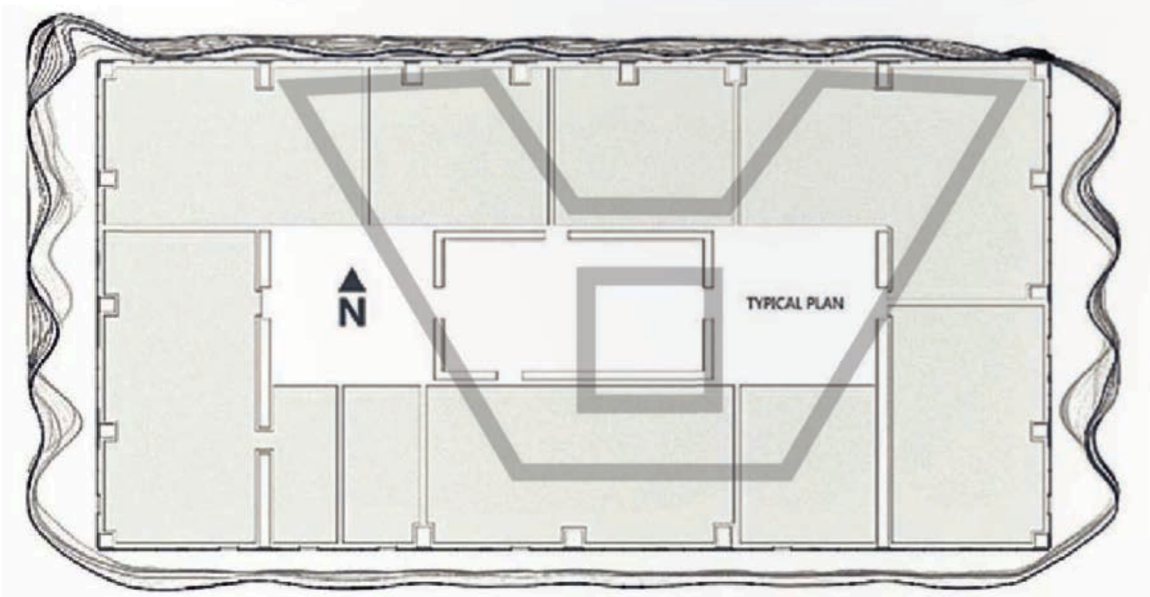
Shaderade Boston cube. Each colored cell shows net higher (red) or lower (blue) energy use if a shading device occupied its area.

7.32

Section through a typical window, showing ideal shading device depth at the inflection point of higher and lower energy use.

Glaring & Shading





7.33

The inflection point.

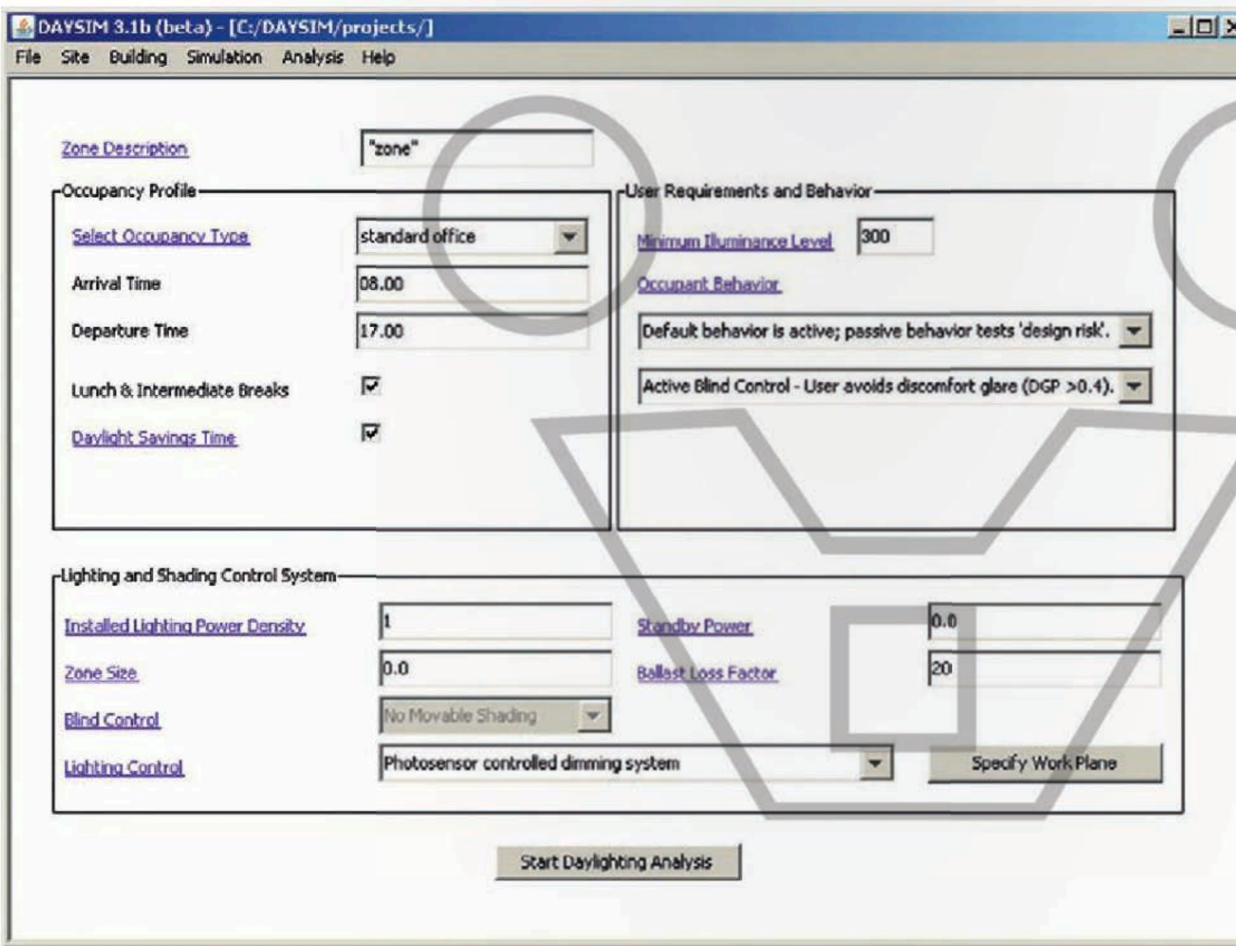
7.34

Plan view of optimized shading.

The Shaderade approach, which advanced earlier work by Eran Kaftan and Dr. Andrew Marsh, involves mapping the annual energy consequences of each position where a shade could affect energy transmission through a window (1) in two or three dimensions (2).

The method begins by running a single simulation of a building shaded only by context, which

Glaring & Shading



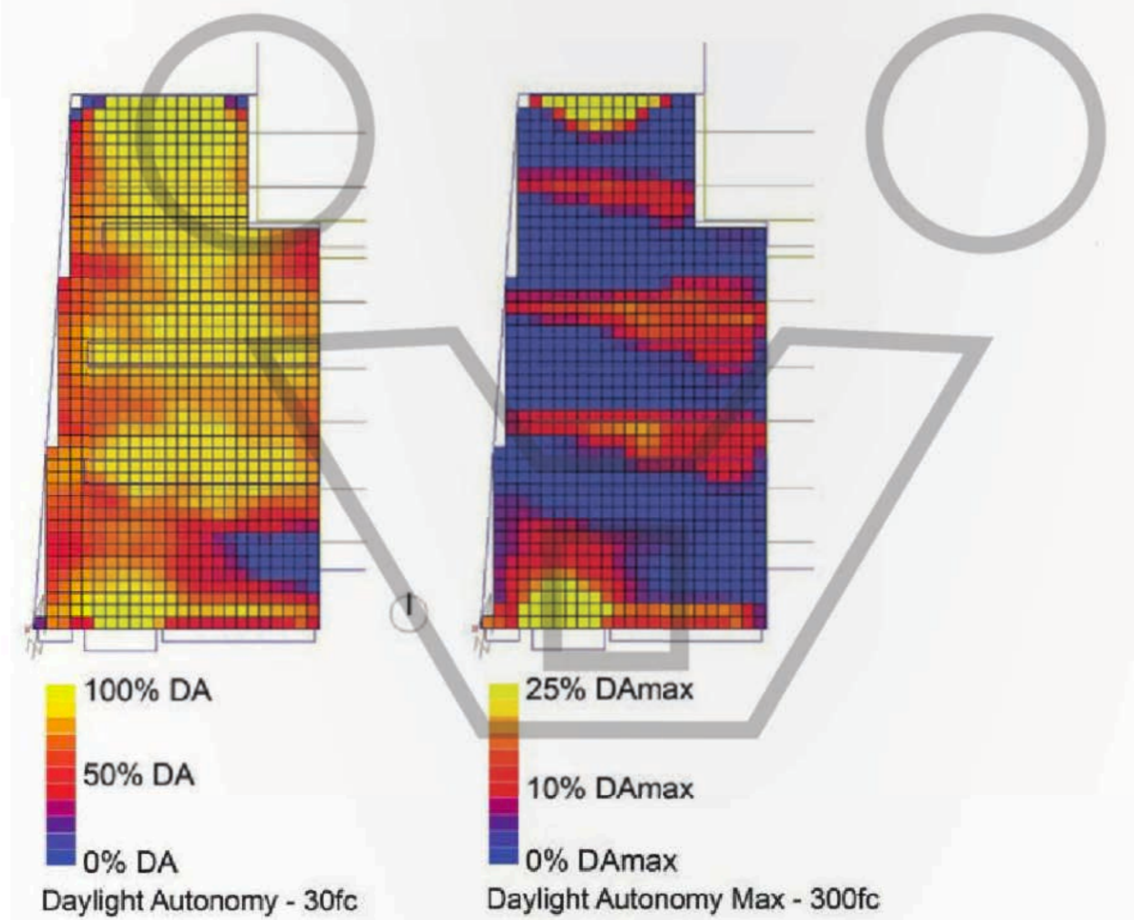
8.10

Daysim software, that estimates daylight autonomy, has a user-inputted minimum lighting threshold, generally the illuminance level recommended for electric lighting. The characteristics of the occupants, the hours of operation, and other information are necessary to accurately estimate when electric lights may be dimmed or off on an annual basis.

A given sensor that reports a DA of 75% means that electric lights would not be necessary at the sensor during 75% of the occupied hours each year. DA presents a best case scenario for lights to be dimmed or off, since glare may cause blinds to be deployed, reducing light levels at the sensor. DA software requires the input of various assumptions about the building or users' operations of blinds as

Glaring & Shading

DAYLIGHT AUTONOMY vs DAYLIGHT AUTONOMY MAX ANALYSIS

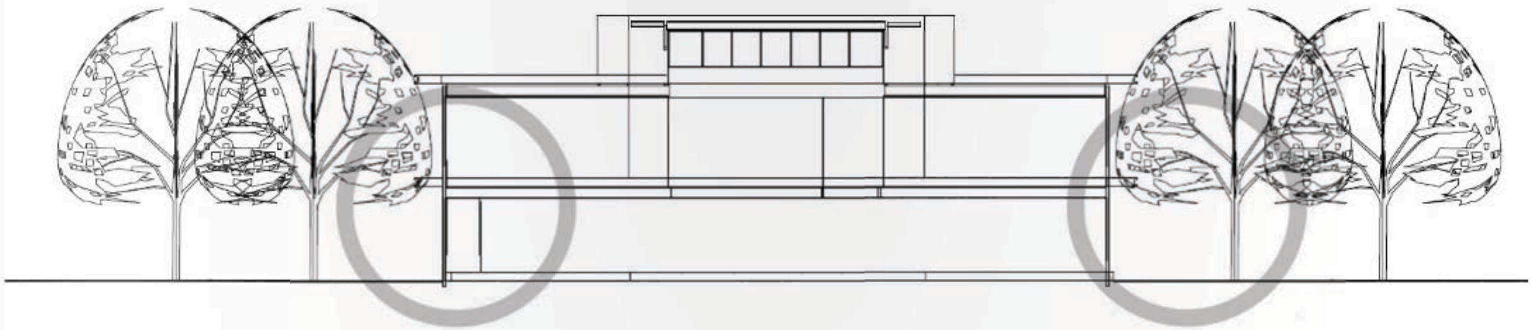


8.24

Plan view of reading room showing annual DA and DAmax. The skylight geometry is shown to provide enough daylight throughout most of the year with over-lighting in only a few places for only around 10% of occupied hours.

Glaring & Shading

GREEN SHADING MODELING



8.53

Sectional line drawing looking south, showing trees at two potential distances from the façade.

Courtesy of Skidmore, Owings & Merrill, Chicago.

8.54

Creation of digital tree geometry.

Courtesy of Skidmore, Owings & Merrill, Chicago.

Simulation

This simulation was performed by SOM's Design Performance Group, which specializes in early design simulations. The Revit-based model was imported and re-built in Rhino for this tree canopy study in the design development phase.

Research was conducted into modeling and defining the optics and seasonal behavior of a Thornless Honeylocust to create a simulated tree. A vector outline (1) of the species was projected onto two sides of a 3D volume. The canopy openness was approximated in the Rhino model (2) to allow direct, dappled light from various directions and a variation of light passing through and reflecting off leaves. This approach reduced meshed surfaces and simulation time.

Research and guidance from Christopher Meek at the University of Washington Integrated Design Lab (IDL) into the optical properties (3) of the leaves were used to create a Radiance material (4) for the leaves using Optics 6 Software. The tree leaves were scheduled to be present in the model between May 15th and October 15th to simulate deciduous vegetation.