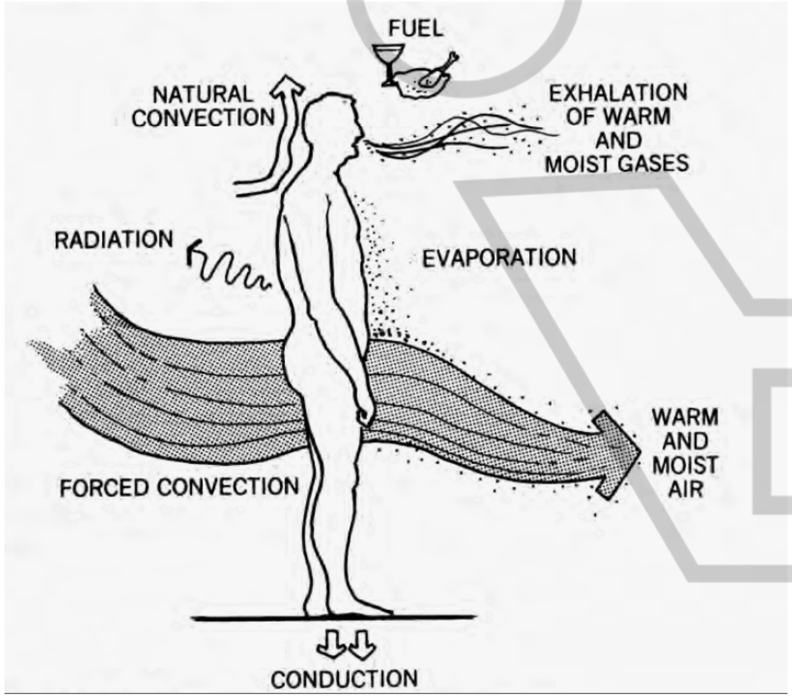
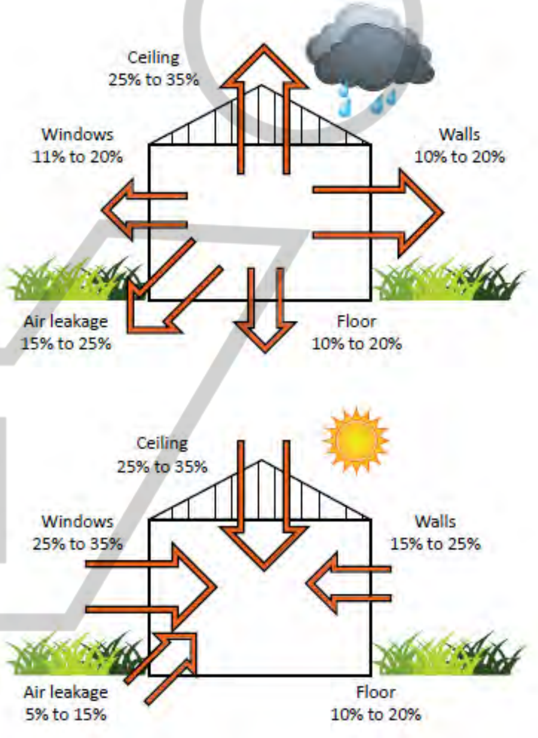
MODELING WIND & VENTILATION FOR HUMAN COMFORT

Environmental elements that affect people's comfort

Environmental elements that affect people's comfort

Energy mediator devices= Human skin & Building skin

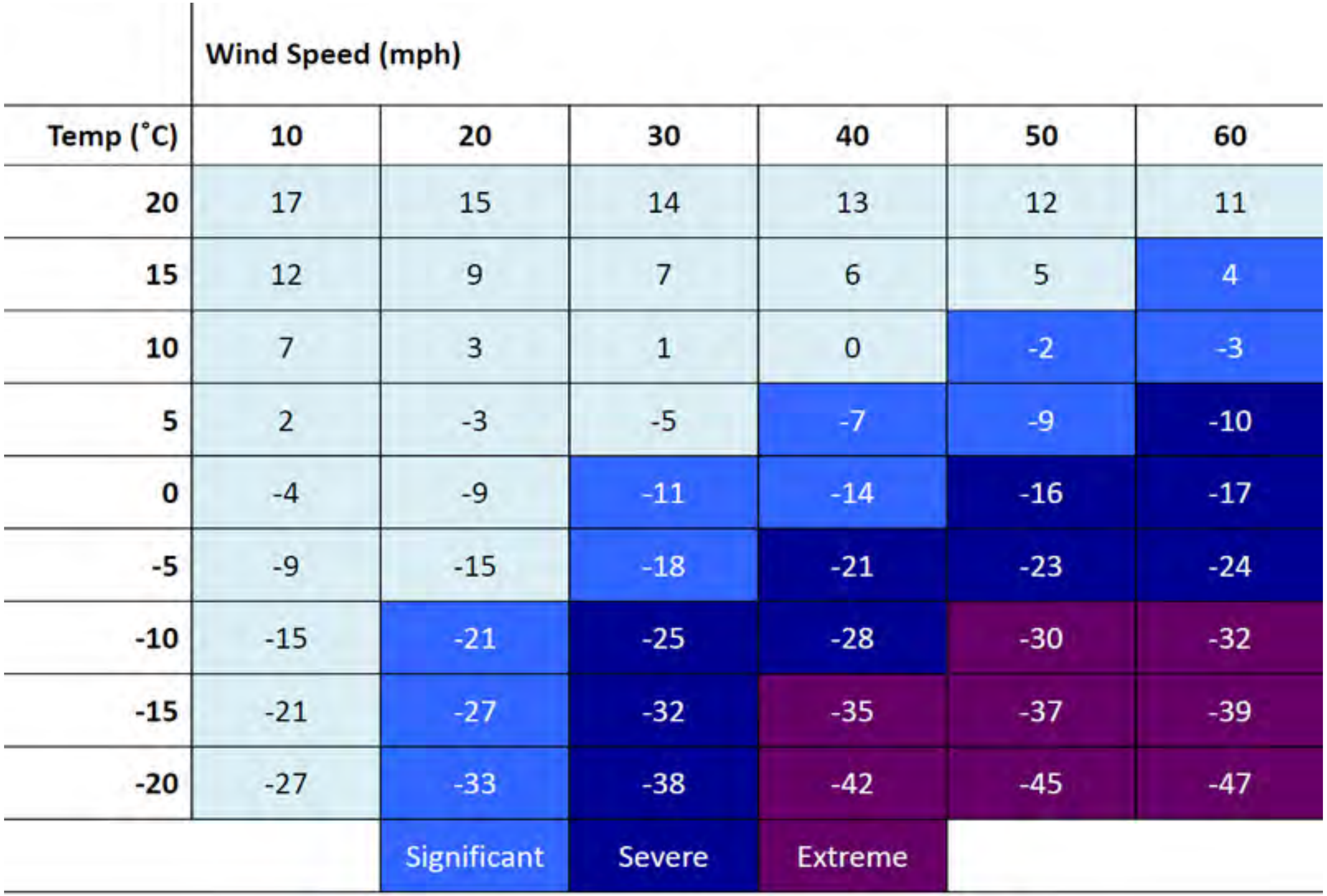




Environmental elements that affect people's comfort

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

EFFECT OF WIND ON TEMPERATURE (Apparent Temperature)

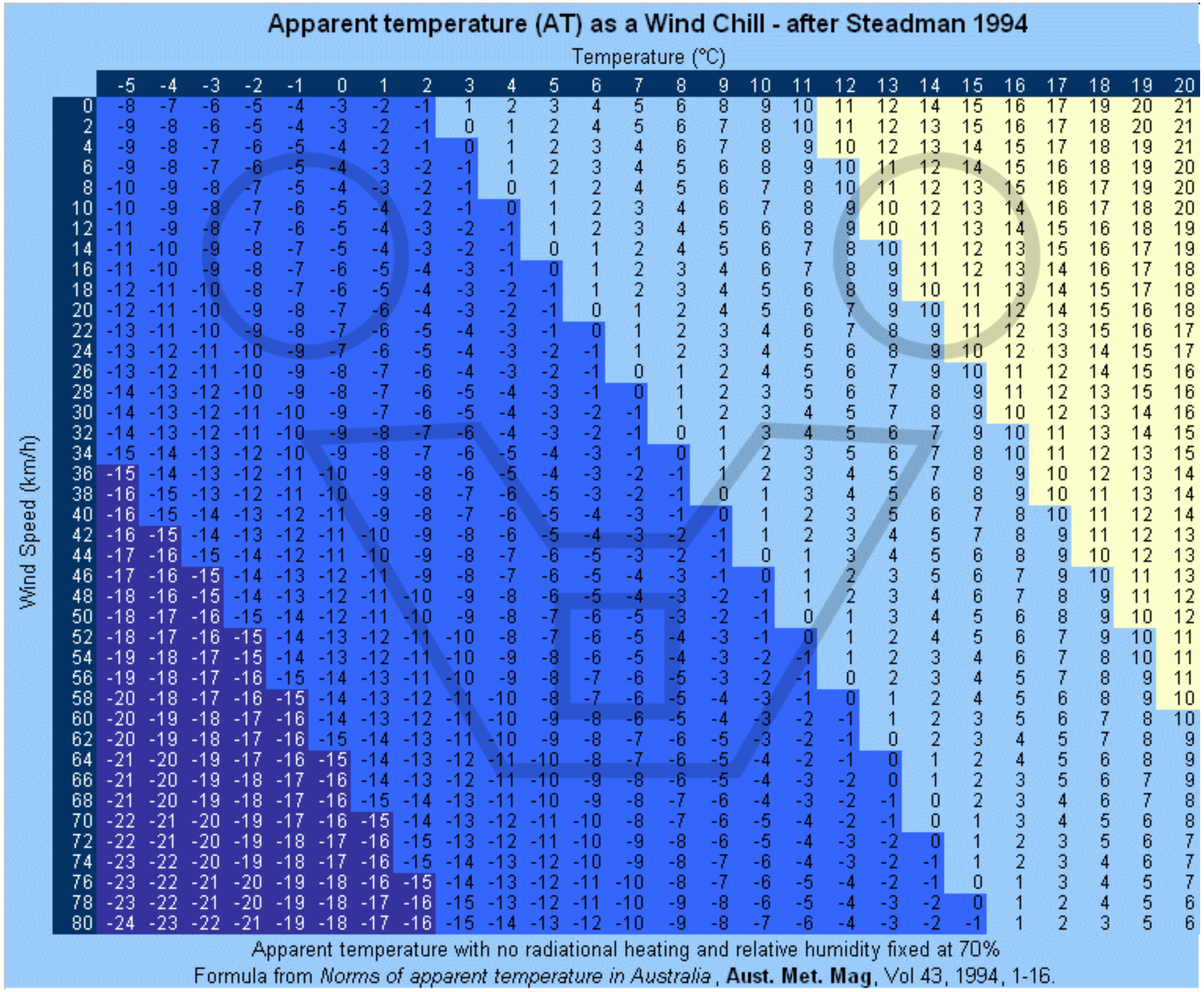


	Wind Speed (mph)					
Temp (˚C)	**10**	**20**	**30**	**40**	**50**	**60**
20	17	15	14	13	12	11
15	12	9	7	6	5	4
10	7	3	1	0	-2	-3
5	2	-3	-5	-7	-9	-10
0	-4	-9	-11	-14	-16	-17
-5	-9	-15	-18	-21	-23	-24
-10	-15	-21	-25	-28	-30	-32
-15	-21	-27	-32	-35	-37	-39
-20	-27	-33	-38	-42	-45	-47
		Significant	Severe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

Wind chill equivalent temperatures from Steadman

Environmental elements that affect people's comfort

Thermal comfort= 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
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Apparent temperature with no radiational heating and relative humidity fixed at 70%

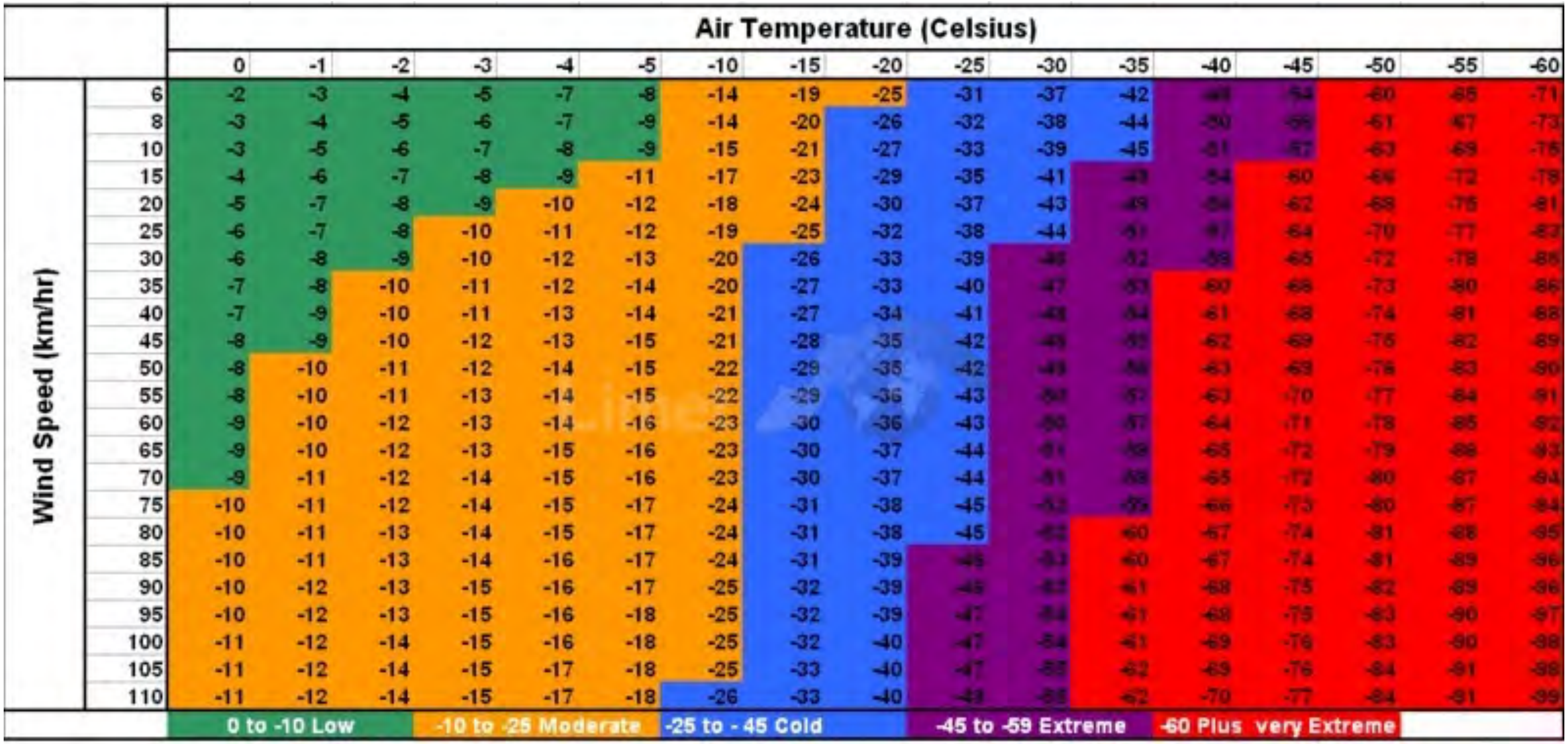
Formula from *Norms of apparent temperature in Australia* , **Aust. Met. Mag**, Vol 43, 1994, 1-16.

Prof. Giuseppe Ridolfi, PhD

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	-55	-61	-67	-73
10	-3	-5	-6	-7	-8	-9	-15	-21	-27	-33	-39	-45	-51	-57	-63	-69	-76
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
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45	-8	-9	-10	-12	-13	-15	-21	-28	-35	-42	-49	-55	-62	-69	-76	-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
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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
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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

MODELING WIND & VENTILATION FOR HUMAN COMFORT

WINDS & PASSIVE VENTILATION

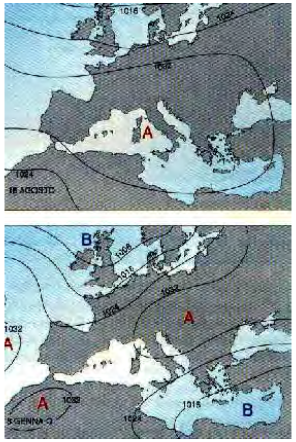
f *[cinetic energy f(velocity), gravitational energy* ***f****(altitude), thermal energy f(temperature), mass/volume f(density)]*

Wind & Passive Ventilation

UN CHIARIMENTO PRELIMINARE:

LA RELAZIONE TRA **ALTA/BASSA PRESSIONE & ALTA/BASSA TEMPERATURA**

IN METEOROLOGIA



freddo

DENSITA'
+pesante

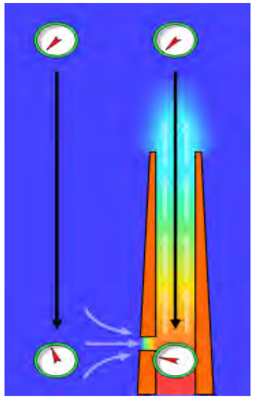
BASSA PRESSIONE

caldo

Densita'
+leggero

ALTA PRESSIONE

IN TERMODINAMICA



Buoyancy Effect

freddo

stasi
cinetica
particelle

BASSA PRESSIONE

caldo

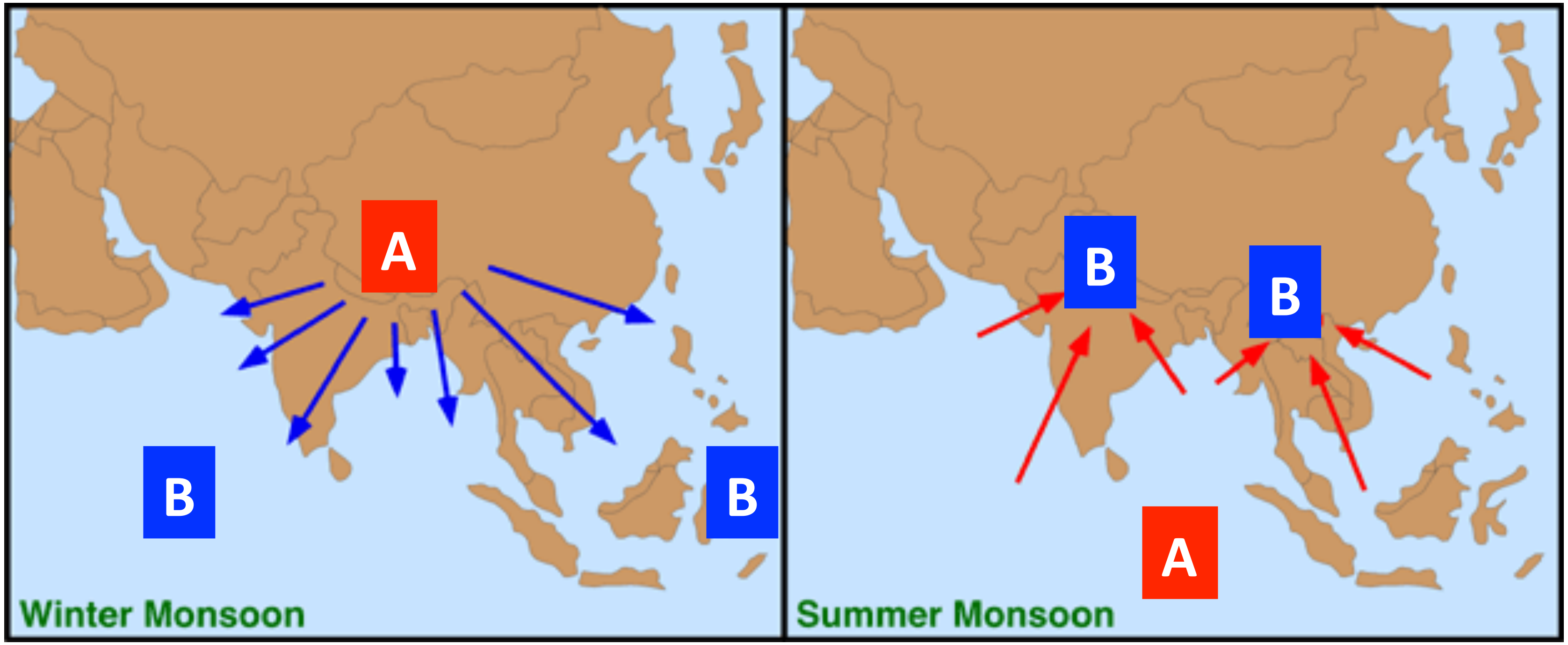
aumento
cinetico
particelle

ALTA PRESSIONE
con espansione del volume
e riduzione di peso

Il surriscaldamento dell'aria comporta la dilatazione del gas e conseguentemente riduzione del peso dell'aria

MOVEMENT OF AIR BY METEREOLOGICAL PRESSURE

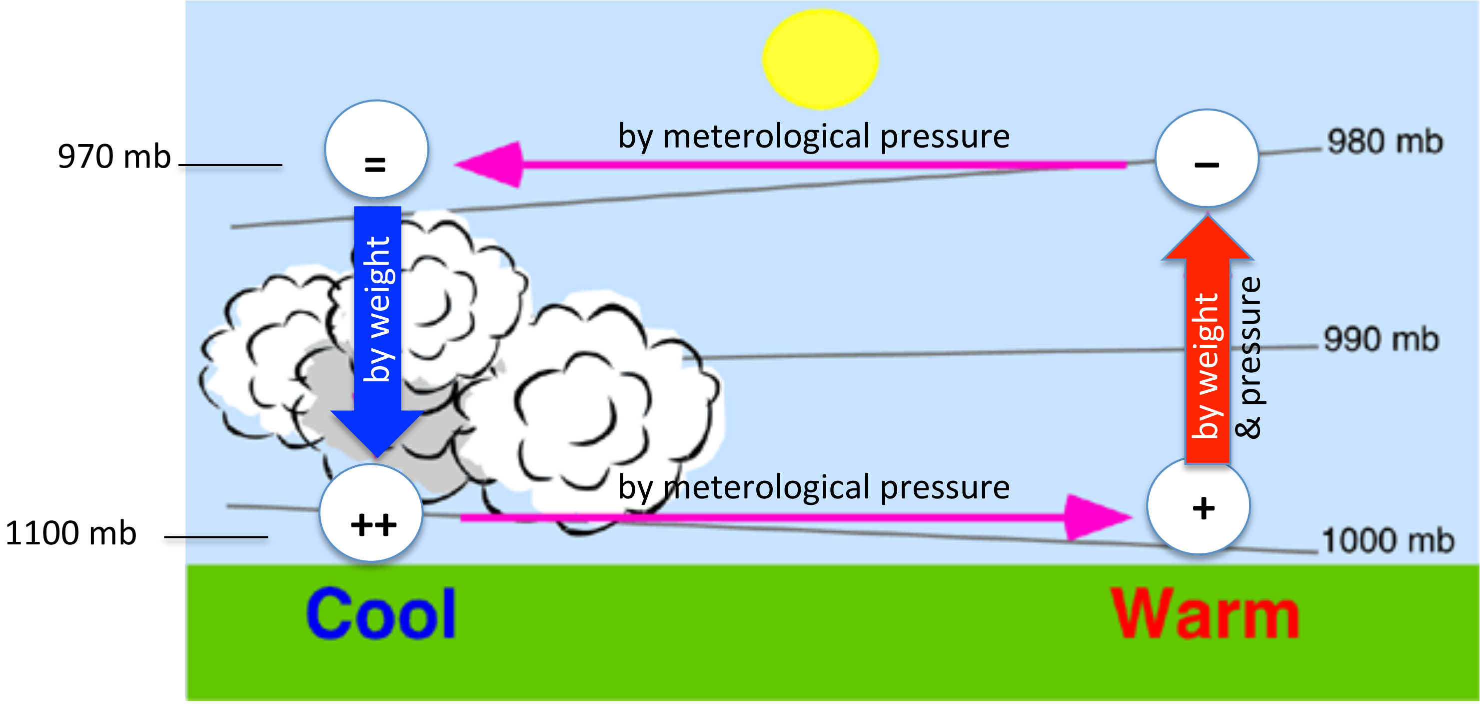
Monson season



Wind & Passive Ventilation

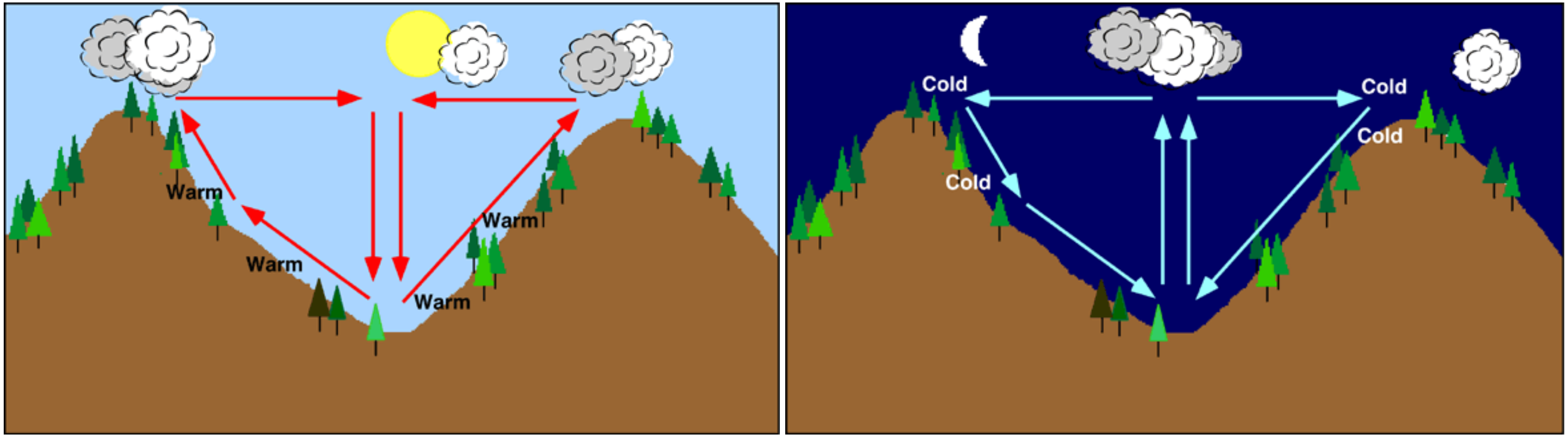
IN METEOROLOGIA

	FROM HIGHER PRESSURE +	TO LOWER PRESSURE −
TEMPERATURE	Lower	Higher
DENSITY	Higher	Lower



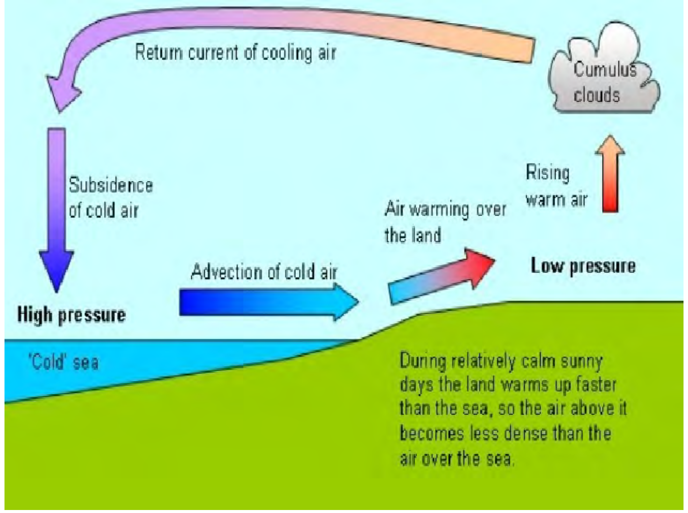
MOVEMENT OF AIR BY WEIGHT AND PRESSURE

Mountain and Valley Breezes

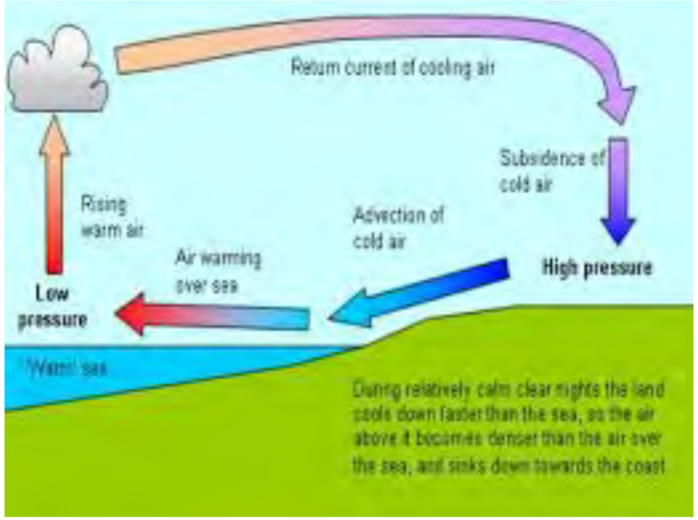


MOVEMENT OF AIR BY WEIGHT AND PRESSURE

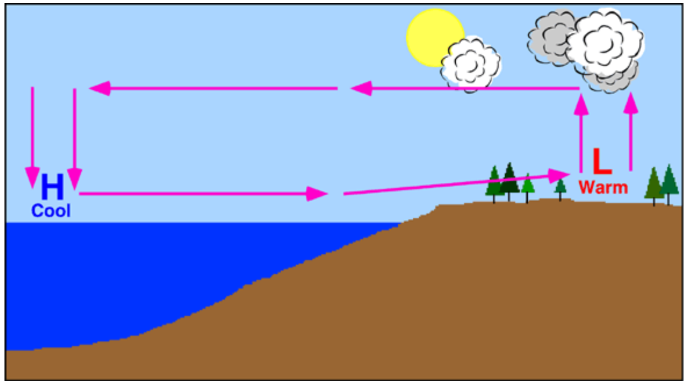
Sea and Land Breezes

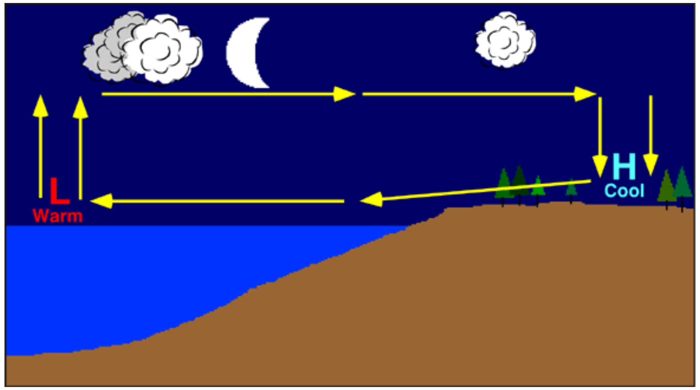


During relatively calm sunny days the land warms up faster than the sea, so the air above it becomes less dense than the air over the sea.



During relatively calm clear nights the land cools down faster than the sea, so the air above it becomes denser than the air over the sea, and sinks down towards the coast



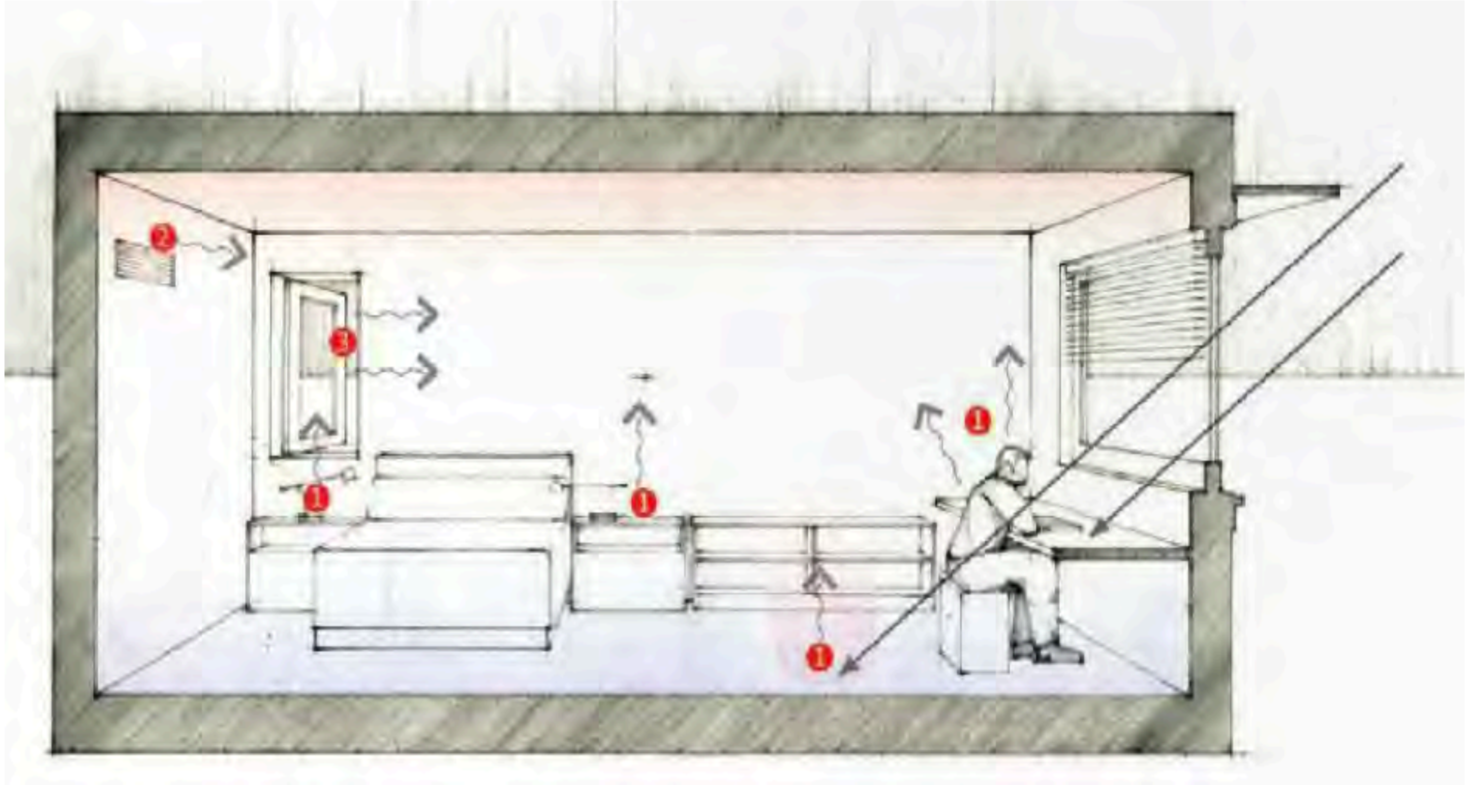


MOVIMENTO PASSIVO DELL’ARIA NEGLI EDIFICI

Cinetica *f* (velocità del vento) spinta direzionale

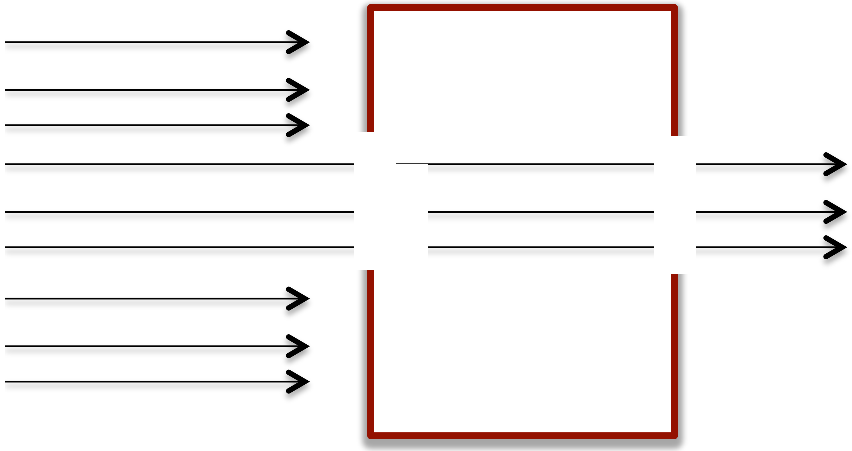
Δ Pressione *f* *(velocità, altitudine)* movimento verso bassa pressione

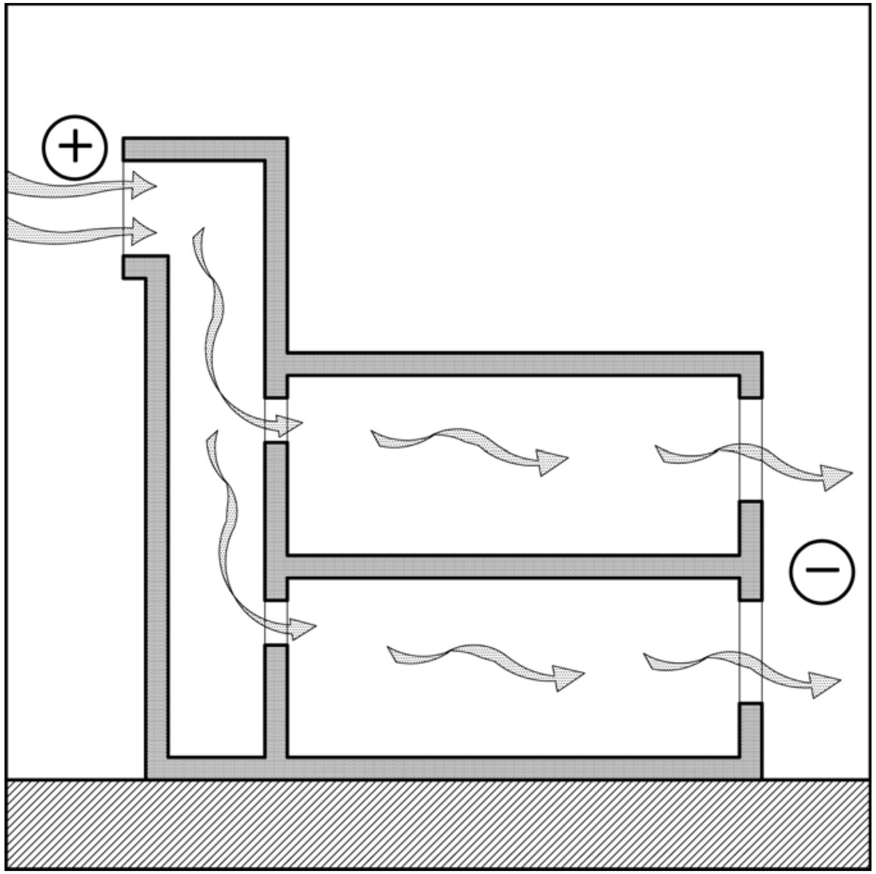
Densità *f* *(temperatura, altitudine)* movimento verso l’alto



MOVIMENTO PASSIVO DELL'ARIA NEGLI EDIFICI

Cinetica ***f*** (velocità del vento) spinta direzionale

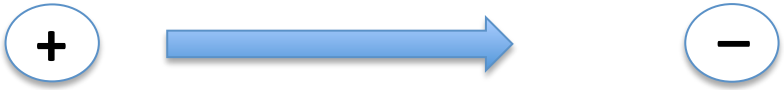




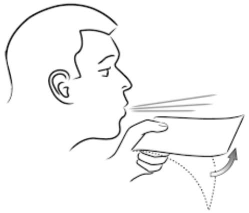
MOVIMENTO PASSIVO DELL’ARIA NEGLI EDIFICI

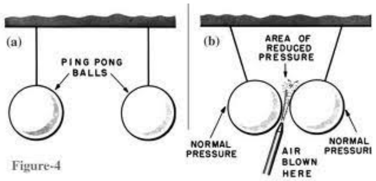
Δ Pressione ***f*** *(velocità, altitudine) movimento verso la bassa pressione*

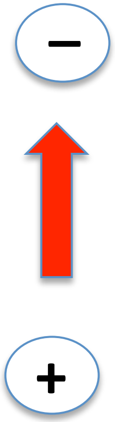
FROM HIGHER PRESSURE **TO LOWER PRESSURE**



Bernoulli principle= higher speed lower pressure

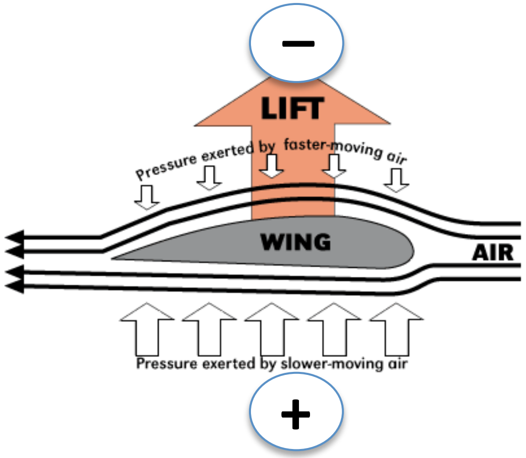






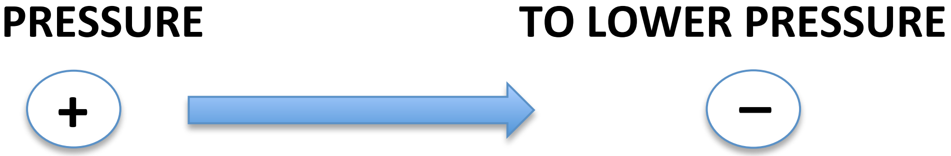
Low pressure

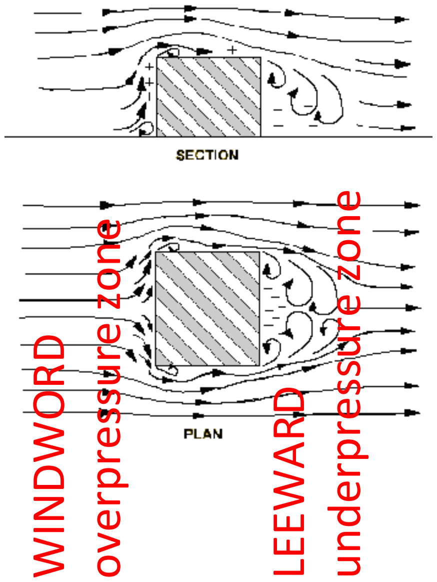
High pressure

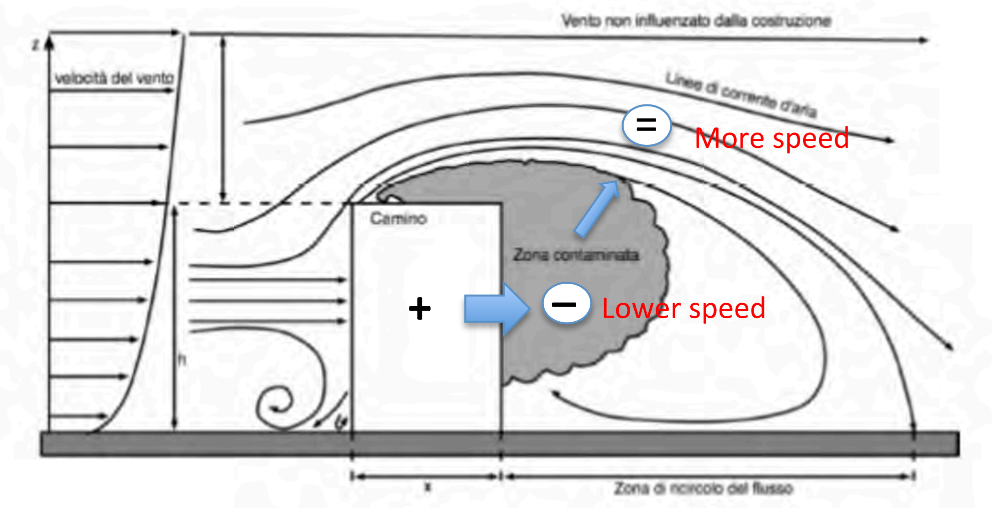


MOVIMENTO PASSIVO DELL’ARIA NEGLI EDIFICI

Δ Pressione ***f*** *(velocità, altitudine) movimento verso la bassa pressione*





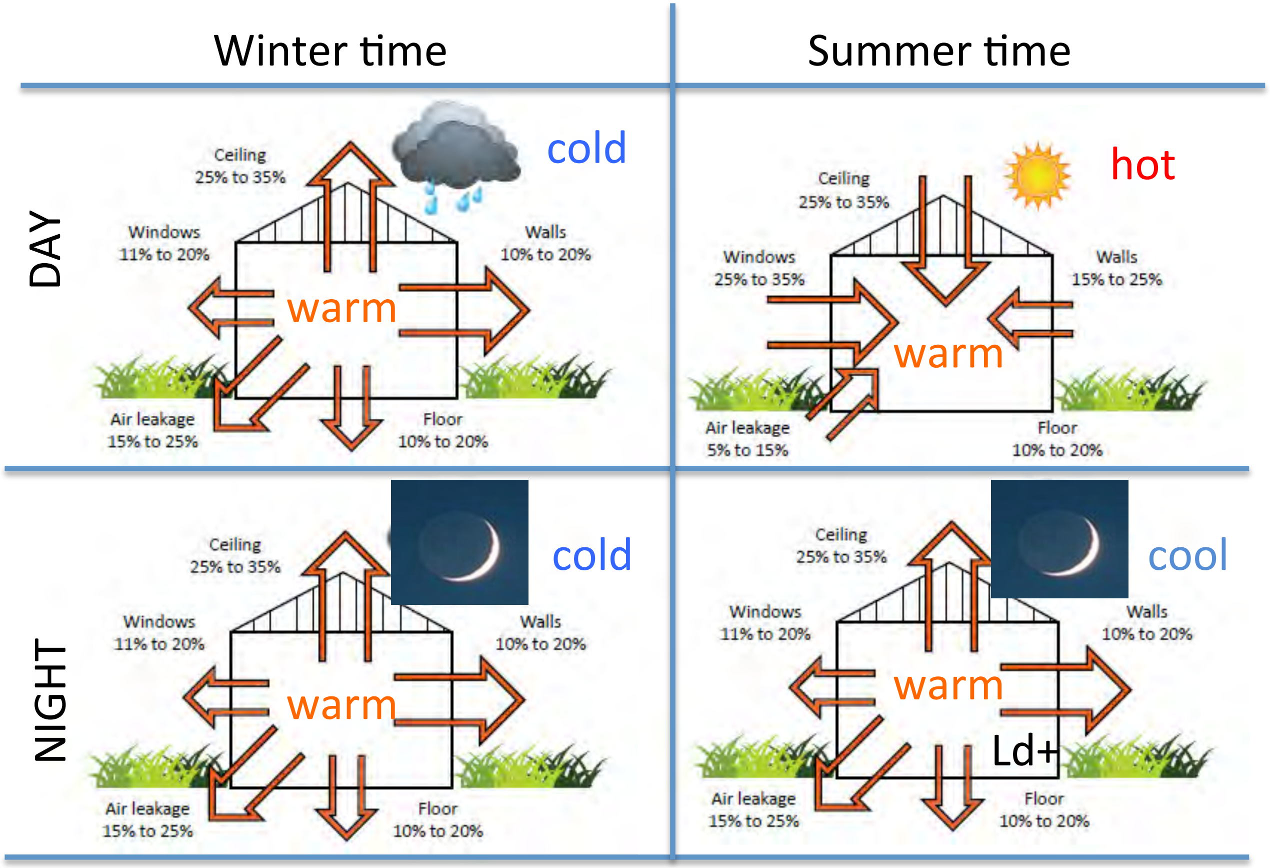


Wind & Passive Ventilation

Δ Pressione ***f*** *(velocità, altitudine) movimento verso la bassa pressione*

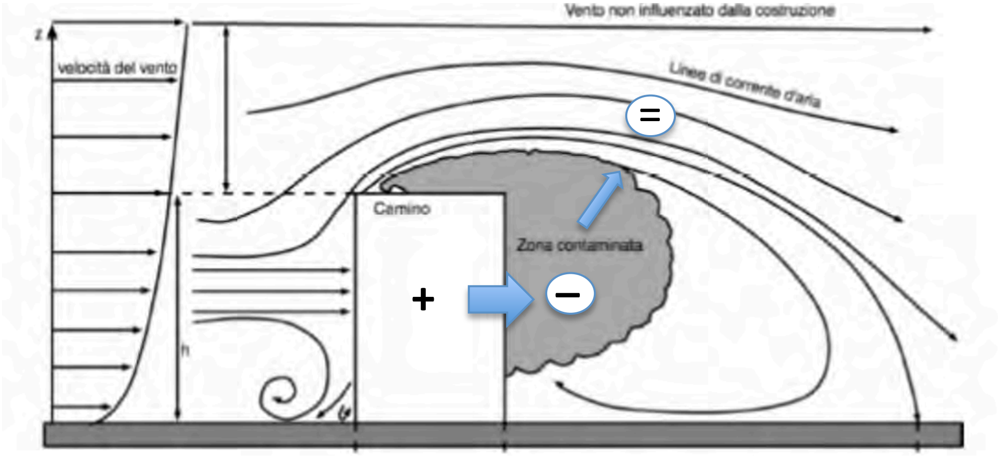
FROM HIGHER PRESSURE **TO LOWER PRESSURE**

+ → −



WINDS & AIRFLOW MODELING

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

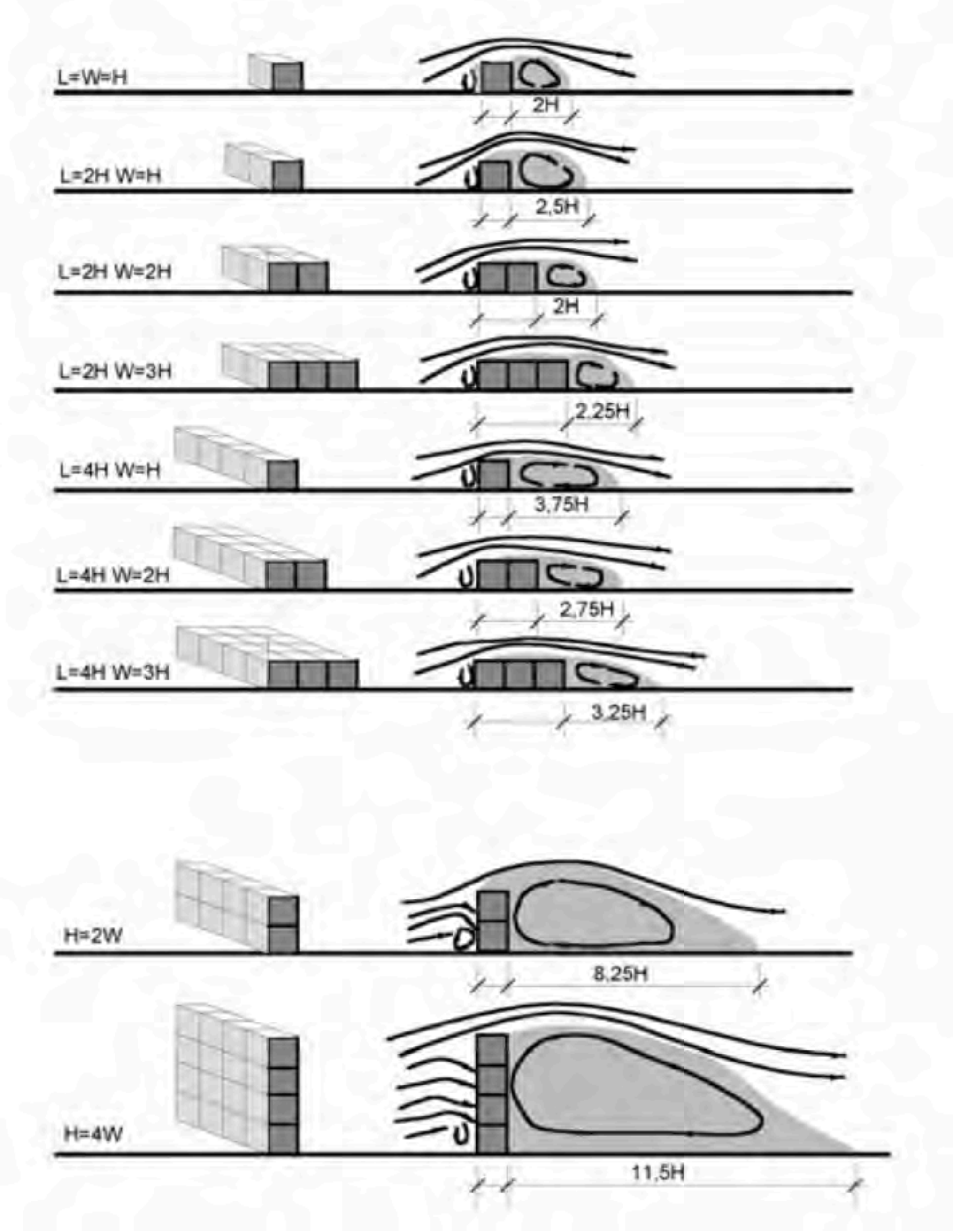
Basic software tool:
Flow Design http://www.autodesk.com/education/free-software/flow-design (student version available)

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

WINDS & AIRFLOW MODELING

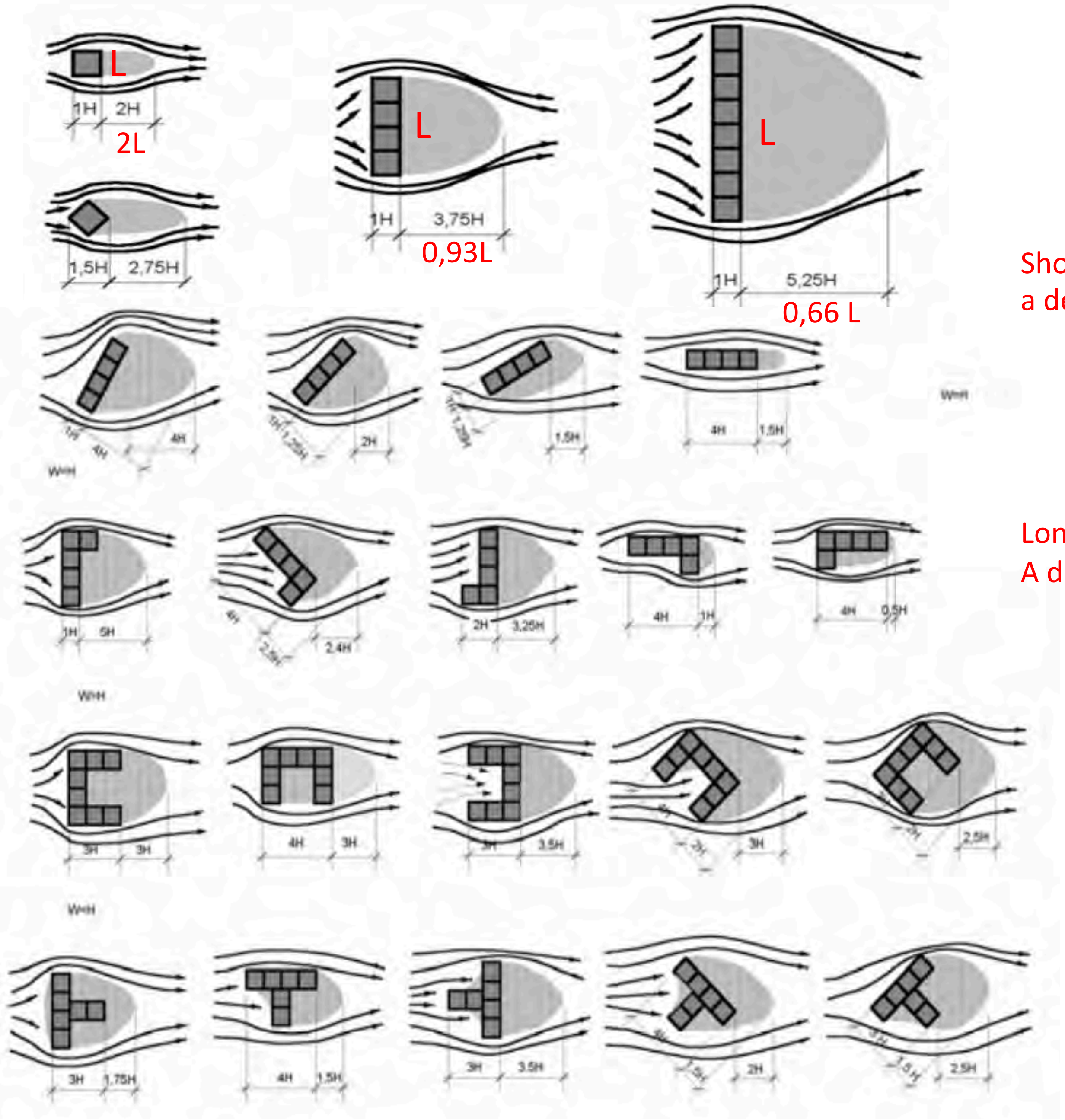


▨ LOW PRESSURE

Skinny buildings create deeper low pressure area

Taller buildings create (proportionally) deeper low pressure area

WINDS & AIRFLOW MODELING



▨ LOW PRESSURE

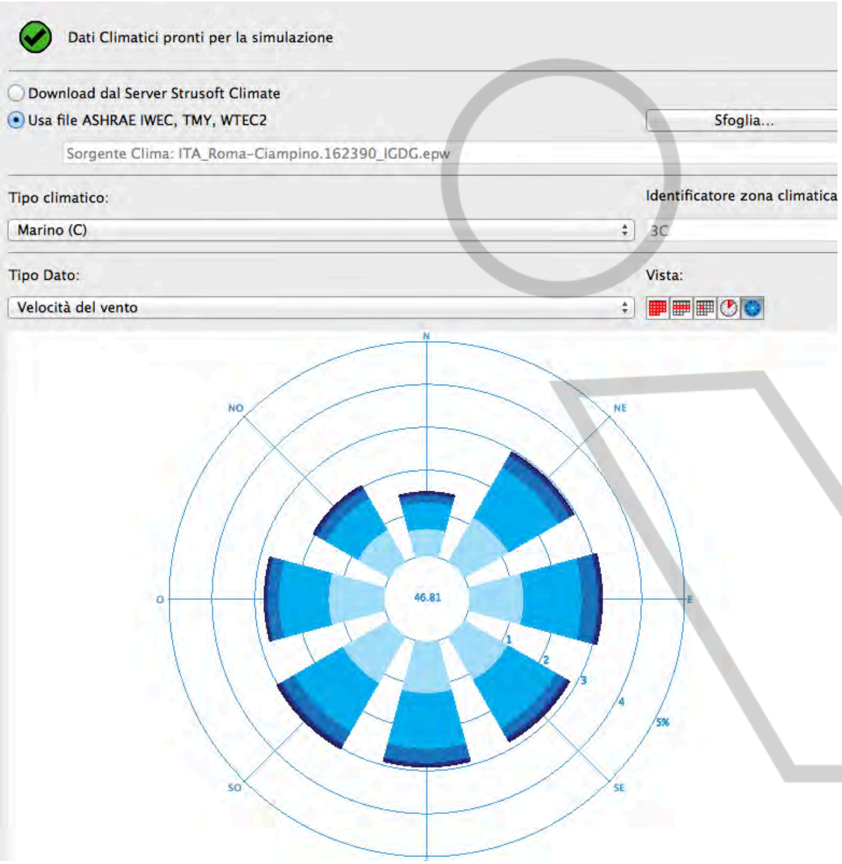
Shorter building creates (proprotionally)
a deeper low pressure area

Longest building create
A deeper low pressure area

WINDS & AIRFLOW MODELING // wind analysis

1- determine the coldest and the hottest seasonal period and hours

2- for that periods find the most frequent wind directions



Dati Climatici pronti per la simulazione

○ Download dal Server Strusoft Climate

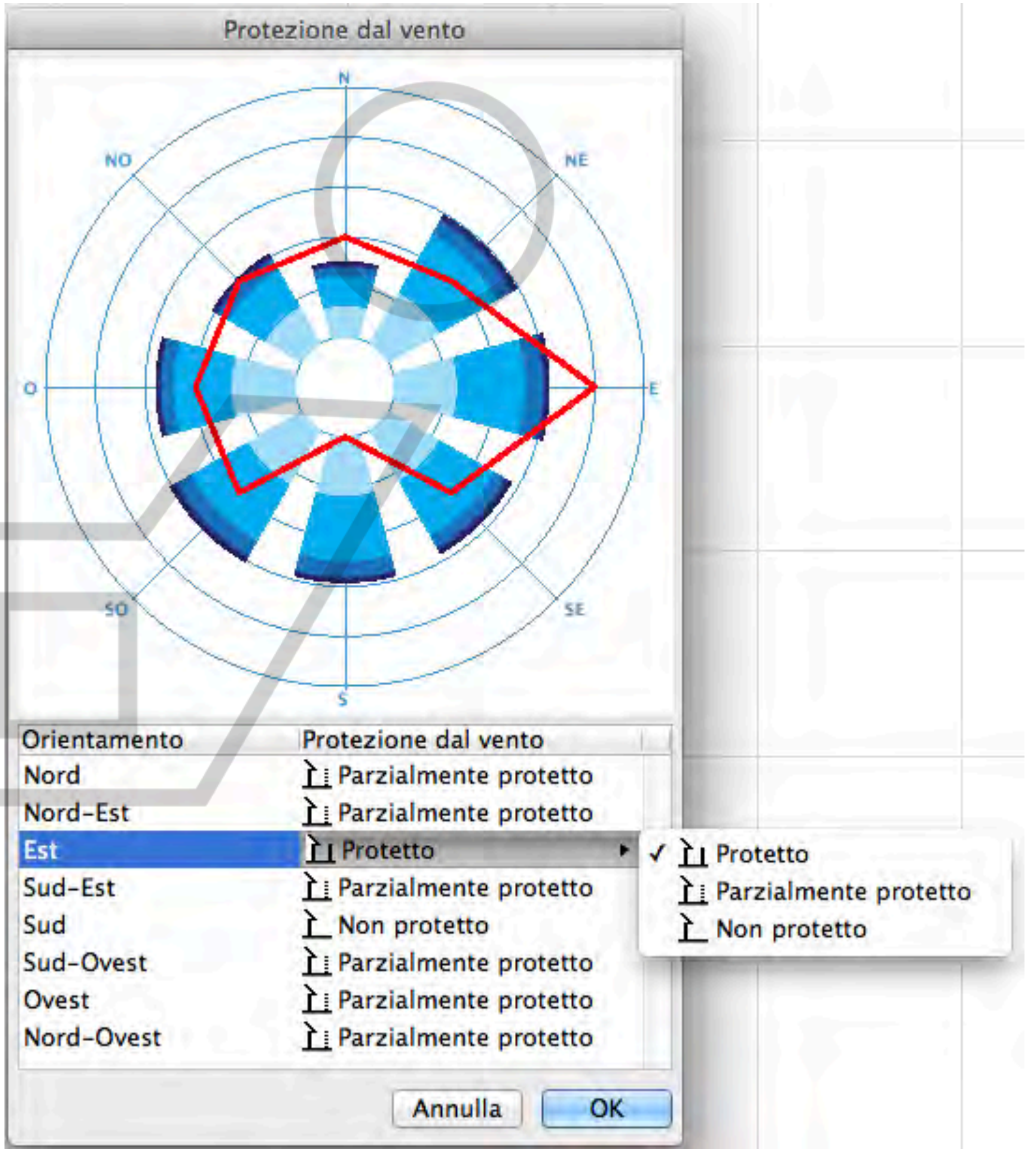
● Usa file ASHRAE IWEC, TMY, WTEC2

Sorgente Clima: ITA_Roma-Ciampino.162390_IGDG.epw

Tipo climatico: Marino (C)

Identificatore zona climatica: 3C

Tipo Dato: Velocità del vento



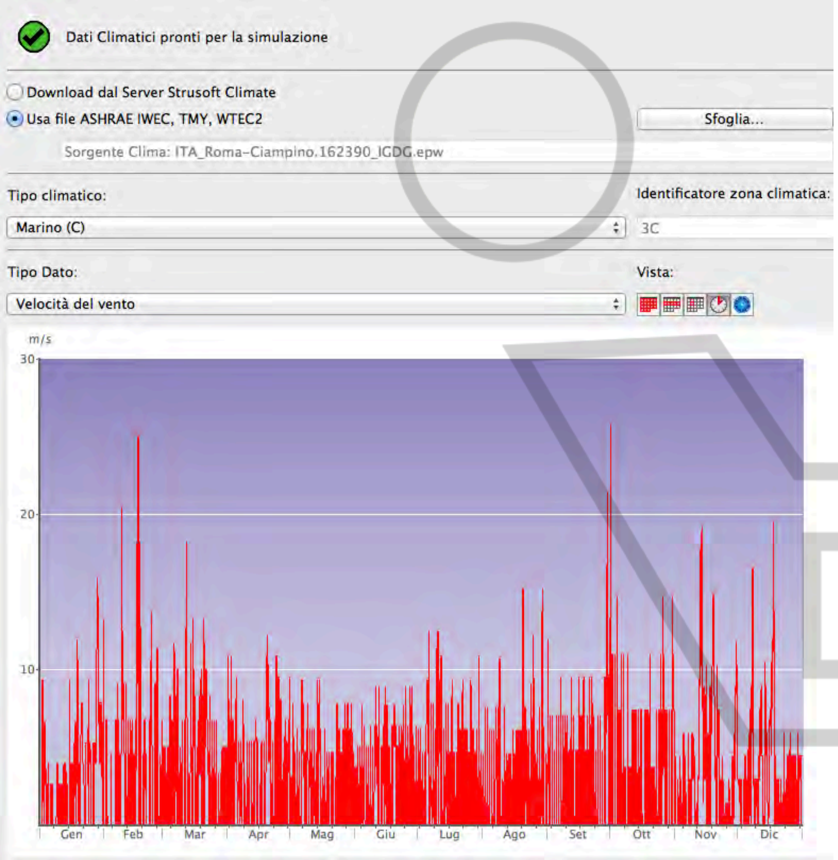
Protezione dal vento

Orientamento	Protezione dal vento
Nord	Parzialmente protetto
Nord-Est	Parzialmente protetto
Est	Protetto
Sud-Est	Parzialmente protetto
Sud	Non protetto
Sud-Ovest	Parzialmente protetto
Ovest	Parzialmente protetto
Nord-Ovest	Parzialmente protetto

WINDS & AIRFLOW MODELING // wind analysis

3- define wind speed for the hottest and coldest periods

4- reduce the speed according to altitude and roughness of the site



Dati Climatici pronti per la simulazione

○ Download dal Server Strusoft Climate

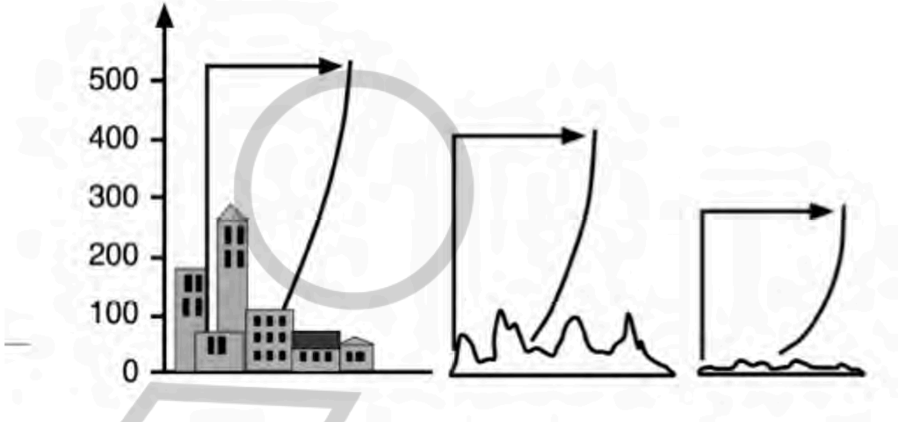
● Usa file ASHRAE IWEC, TMY, WTEC2

Sorgente Clima: ITA_Roma-Ciampino.162390_IGDG.epw

Tipo climatico: Marino (C)

Identificatore zona climatica: 3C

Tipo Dato: Velocità del vento



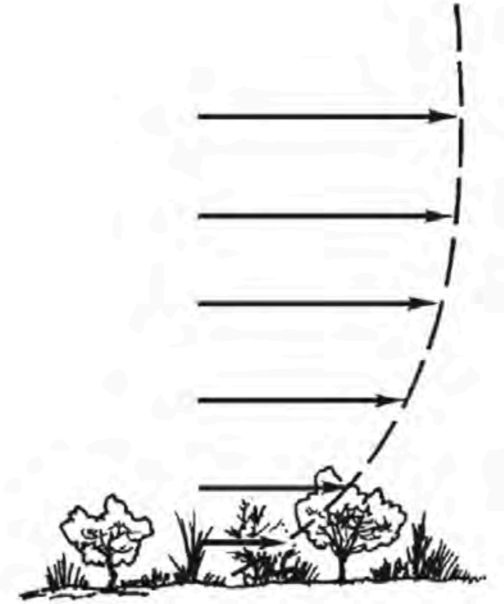
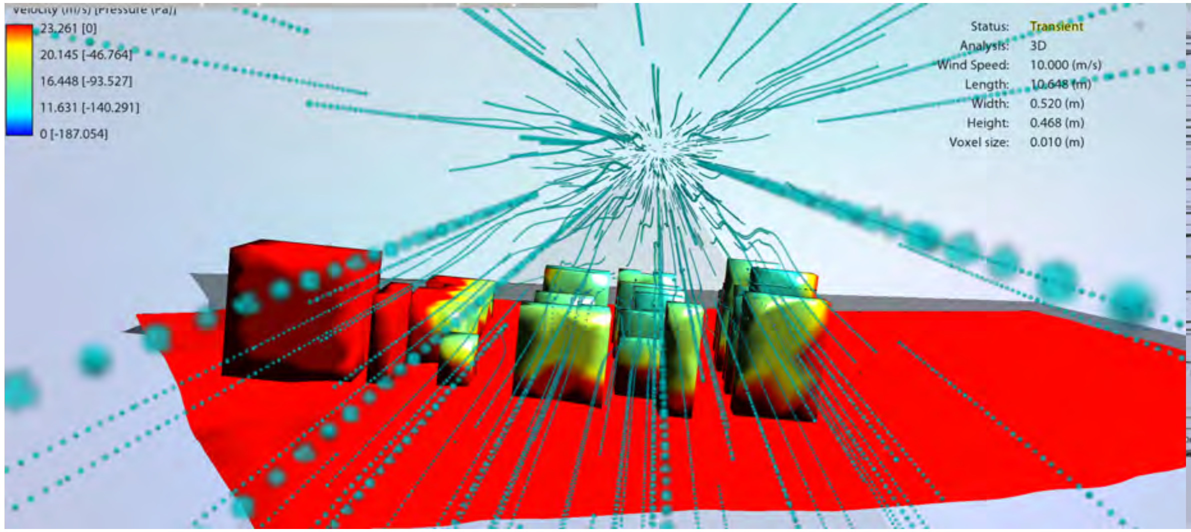


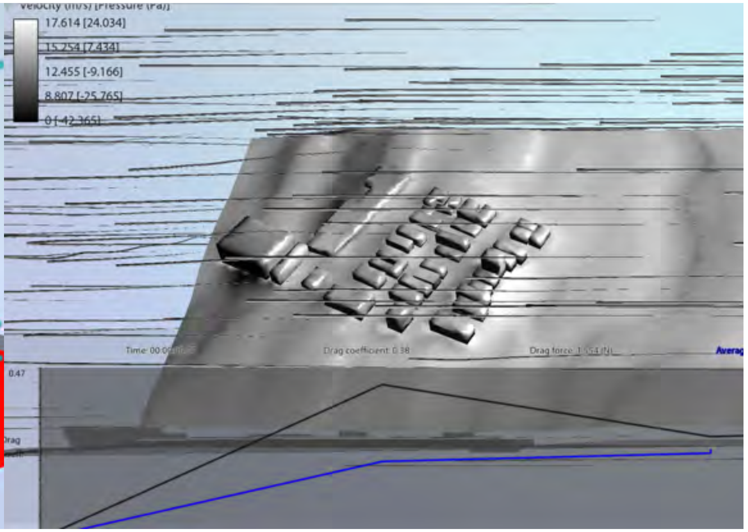
Figure 1—General wind velocity profile near surface (from Rothermel 1983).

WINDS & AIRFLOW MODELING // wind analysis

5- Orient the model according to the wind direction



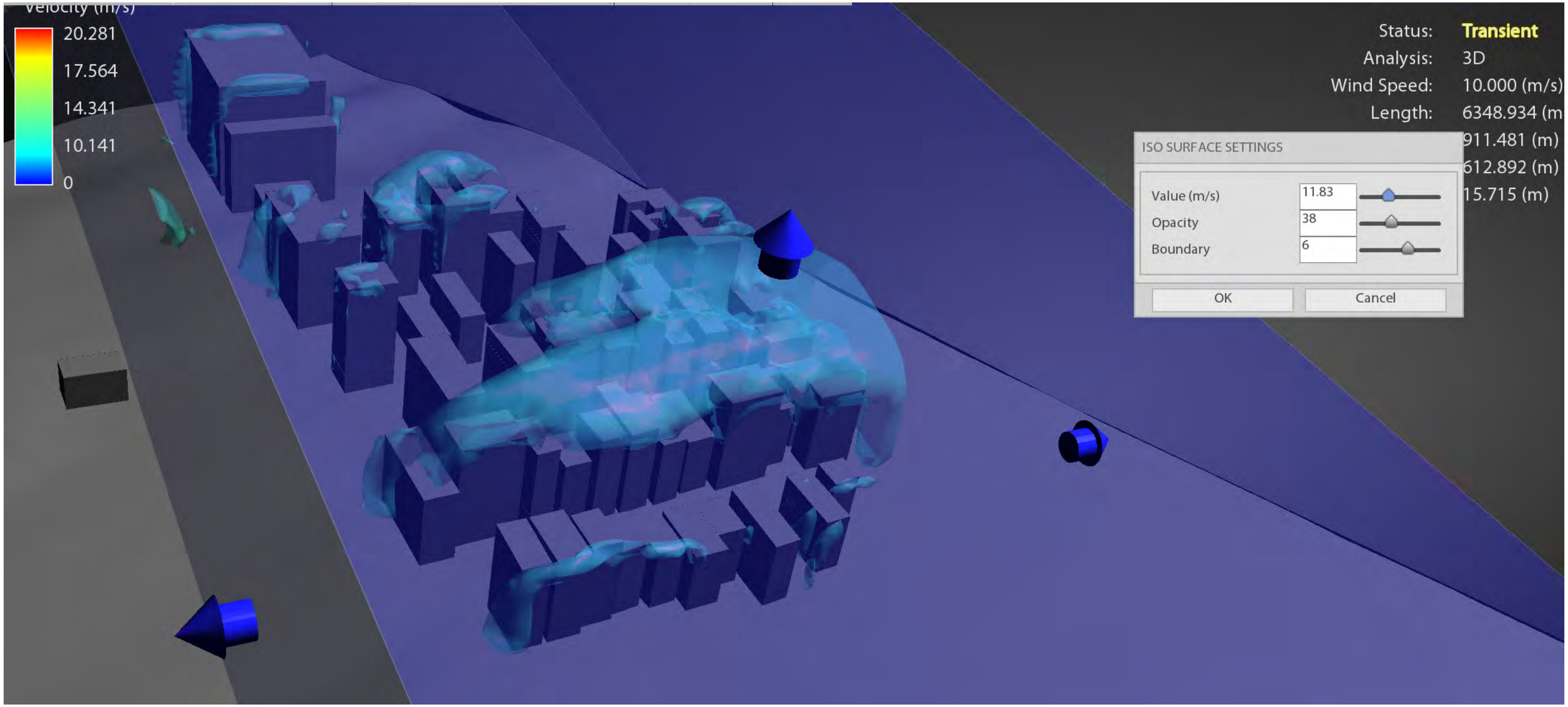
Status: Transient
Analysis: 3D
Wind Speed: 10.000 (m/s)
Length: 10.648 (m)
Width: 0.520 (m)
Height: 0.468 (m)
Voxel size: 0.010 (m)



WINDS & AIRFLOW MODELING // wind analysis

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

NOTE: in order to get a better visualization, wind speed can be proportionally increased

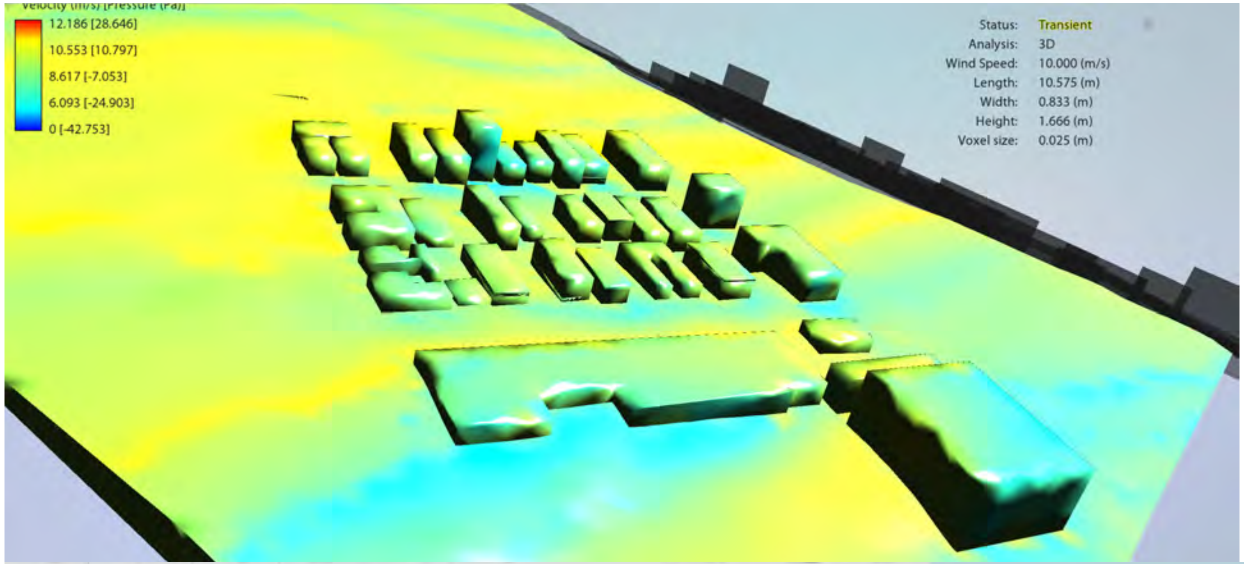


Status: Transient
Analysis: 3D
Wind Speed: 10.000 (m/s)
Length: 6348.934 (m
911.481 (m)
612.892 (m)
15.715 (m)

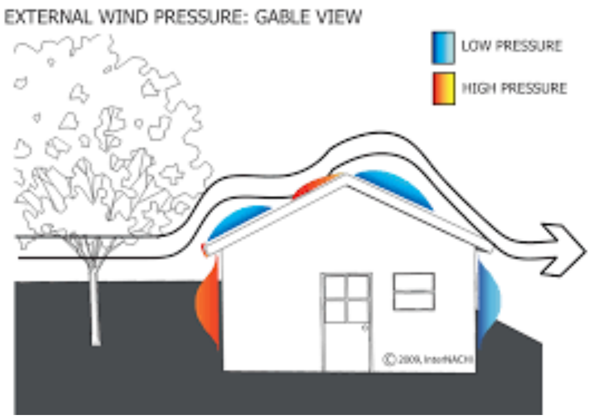
ISO SURFACE SETTINGS
Value (m/s) 11.83
Opacity 38
Boundary 6

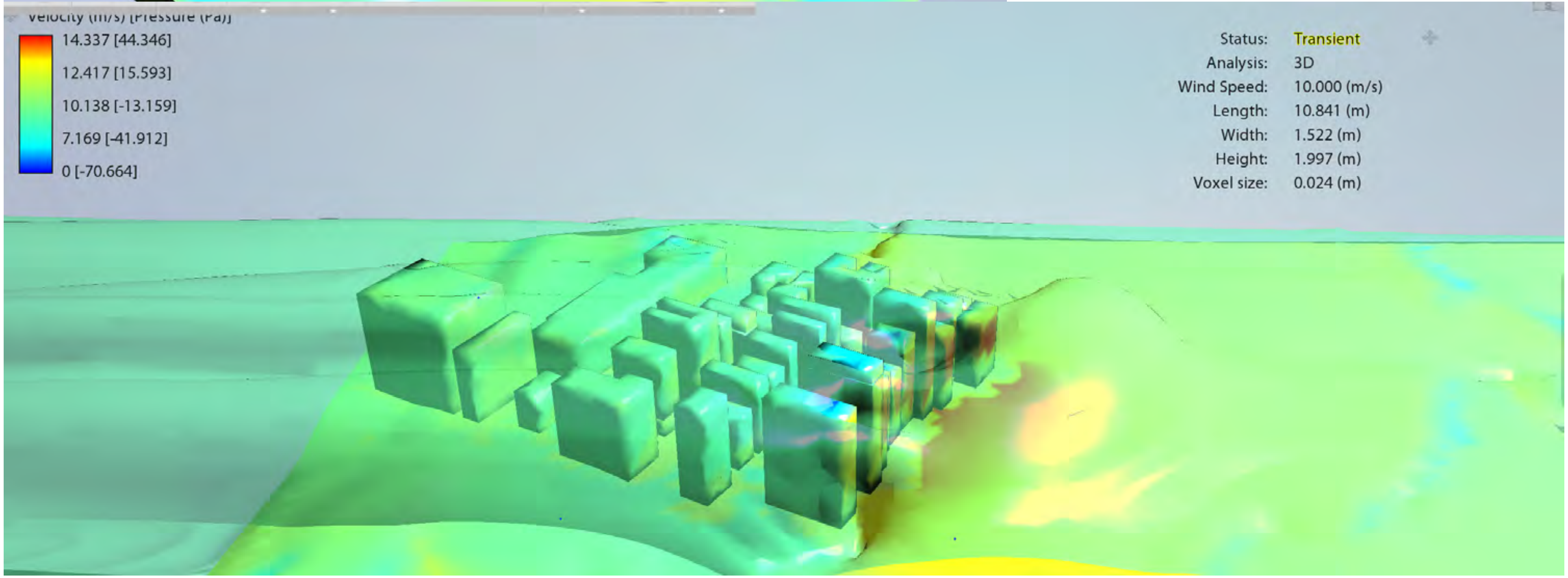
Wind & Passive Ventilation

WINDS & AIRFLOW MODELING // wind analysis



Status: Transient
Analysis: 3D
Wind Speed: 10.000 (m/s)
Length: 10.575 (m)
Width: 0.833 (m)
Height: 1.666 (m)
Voxel size: 0.025 (m)





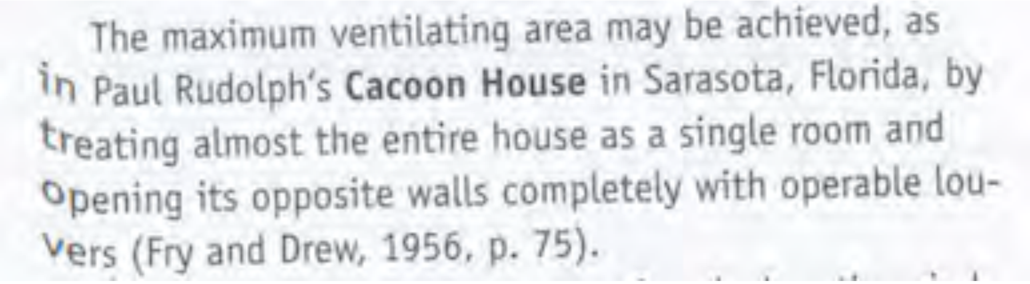
Status: Transient
Analysis: 3D
Wind Speed: 10.000 (m/s)
Length: 10.841 (m)
Width: 1.522 (m)
Height: 1.997 (m)
Voxel size: 0.024 (m)

WINDS & AIRFLOW MODELING // Passive strategies

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

- Effect on ventilation related to the building rooms dimension

Cacoon House, Sarasota, Florida, Paul Rudolph

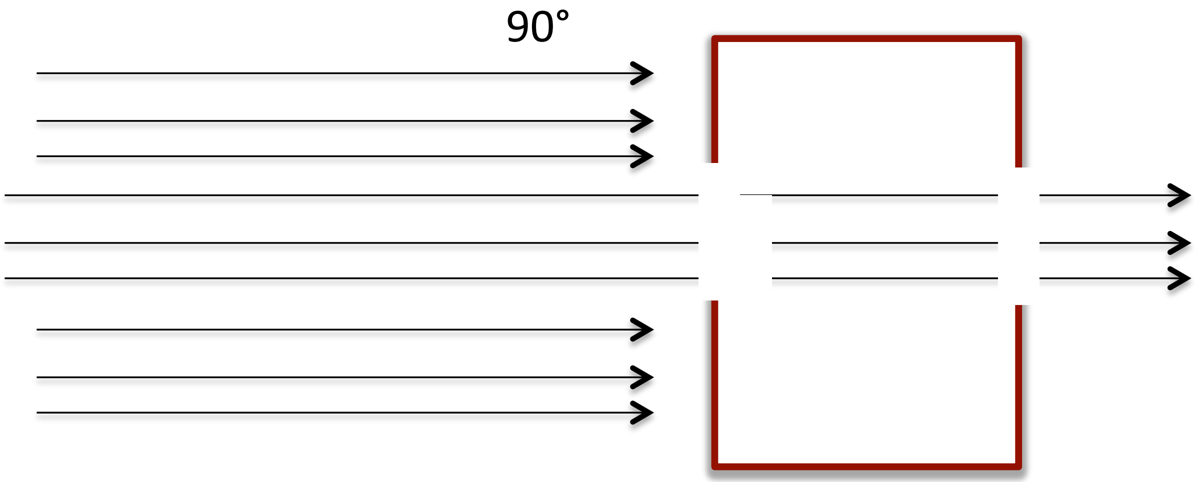


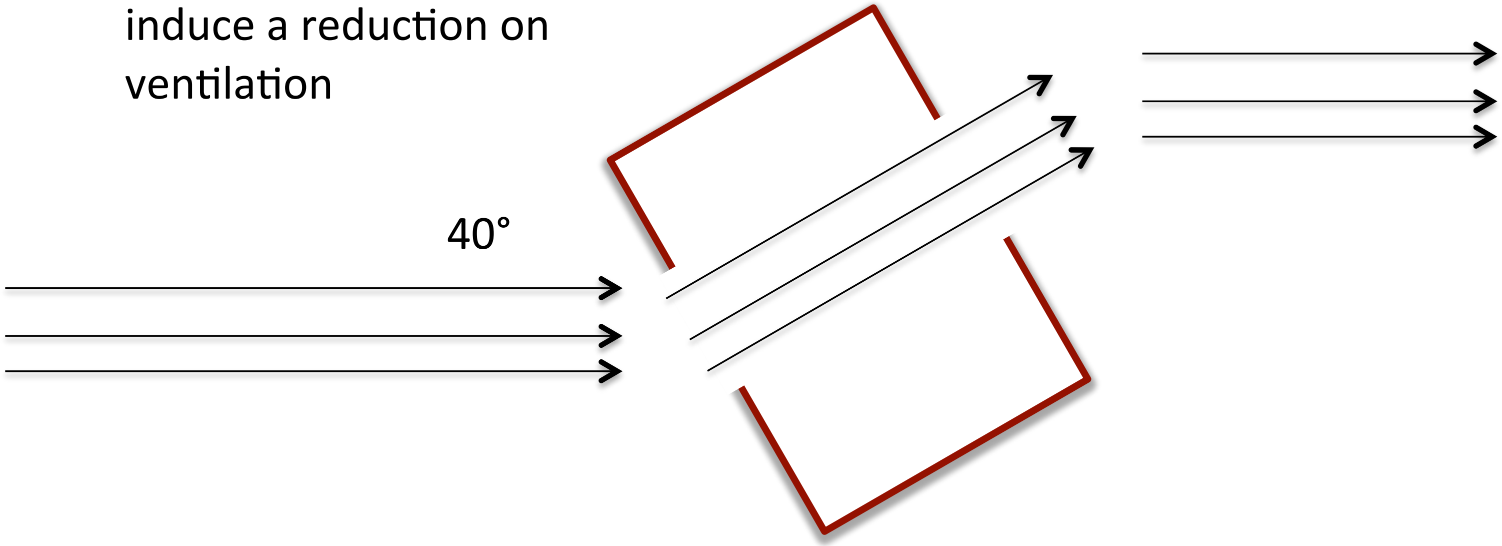
The maximum ventilating area may be achieved, as in Paul Rudolph's **Cacoon House** in Sarasota, Florida, by treating almost the entire house as a single room and opening its opposite walls completely with operable louvers (Fry and Drew, 1956, p. 75).

WINDS & AIRFLOW MODELING // Passive strategies

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

- Effect on ventilation related to the building angle



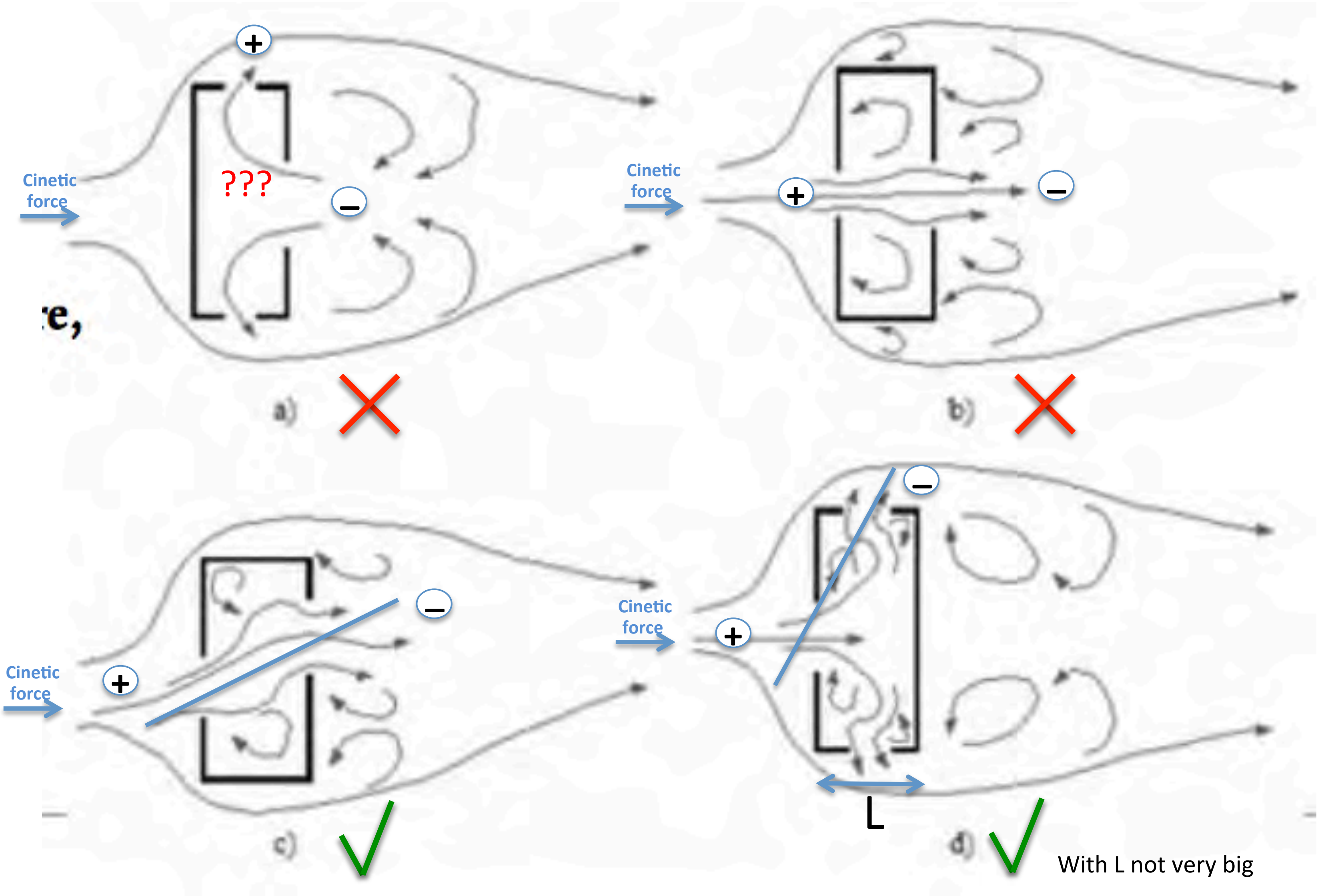


Angles less the 40°
induce a reduction on
ventilation

WINDS & AIRFLOW MODELING // Passive strategies

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

- Designing skin openings for good cross ventilation

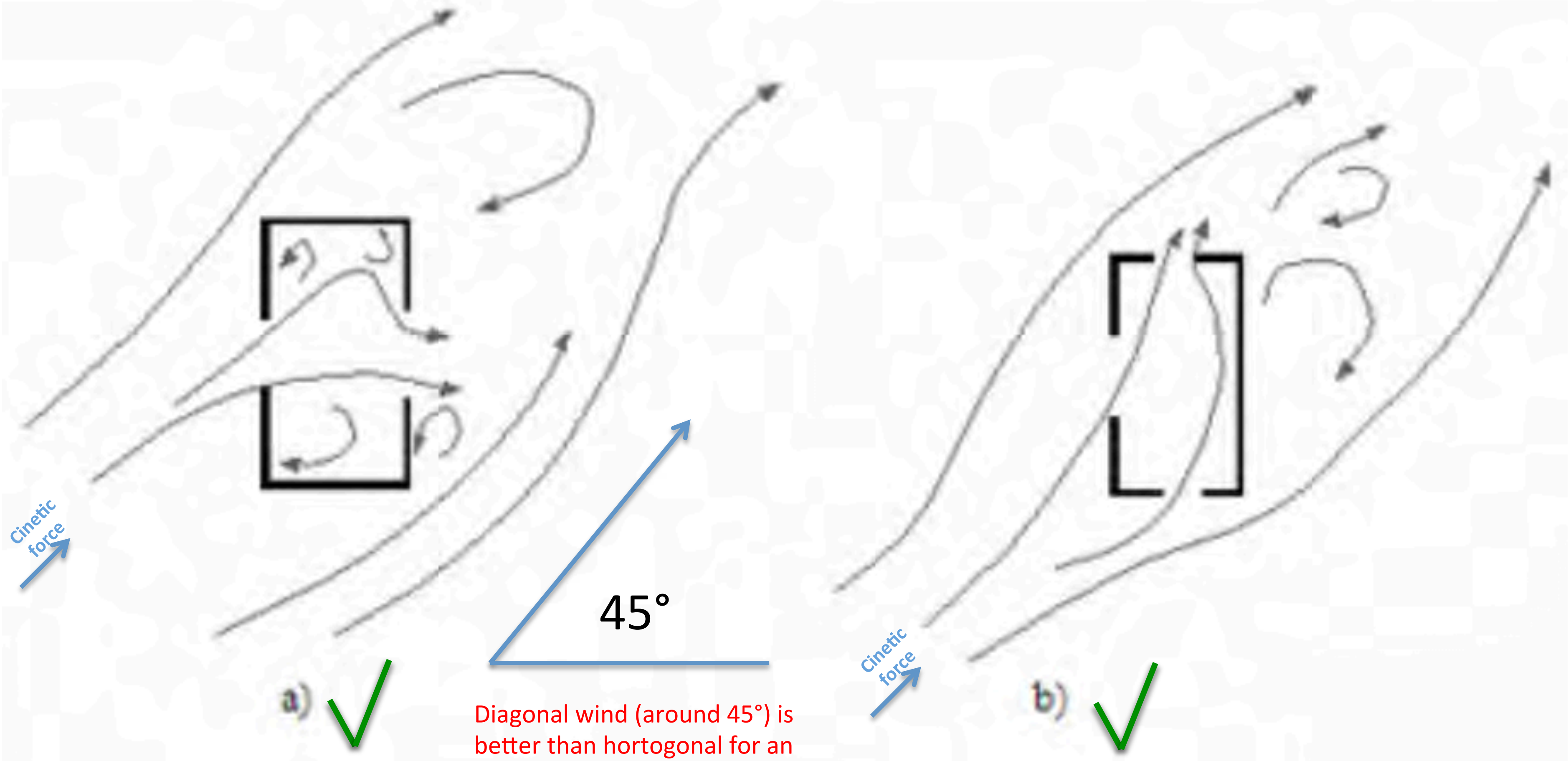


With L not very big

WINDS & AIRFLOW MODELING // Passive strategies

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

- Designing skin openings for good cross ventilation

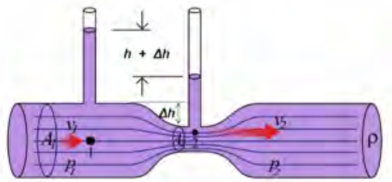


Diagonal wind (around 45°) is better than hortogonal for an homogenous distribution of ventilation inside the building

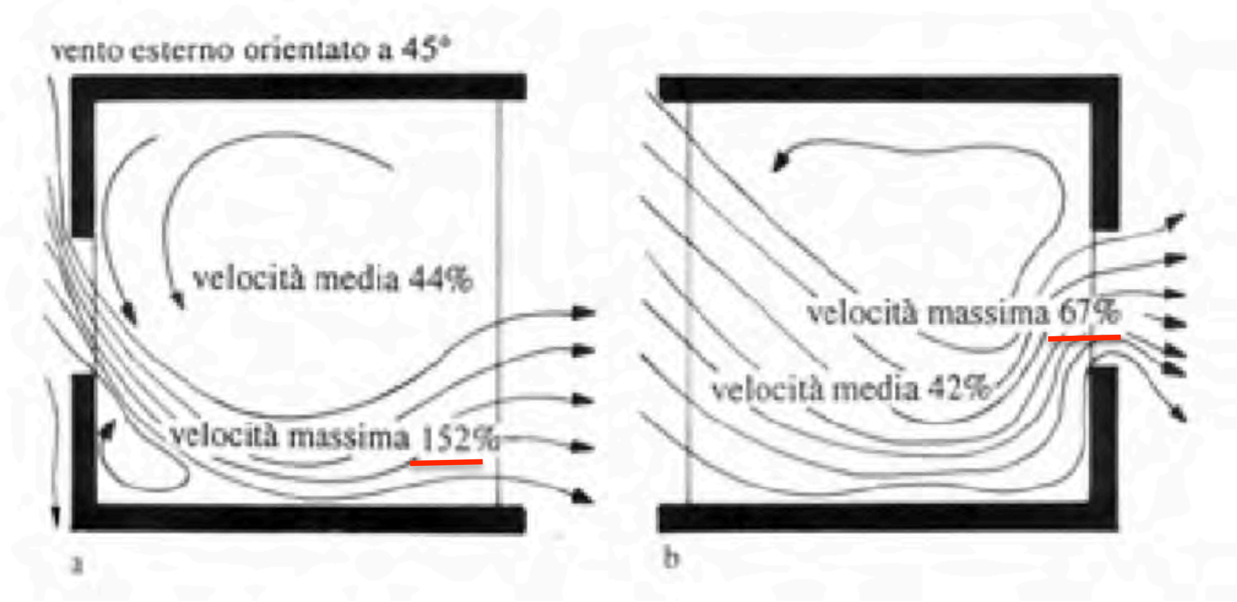
WINDS & AIRFLOW MODELING // Passive strategies

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

- Designing skin openings for good cross ventilation



VENTURI EFFECT : Higher speed (lower pressure) if the entrance is smaller than the e

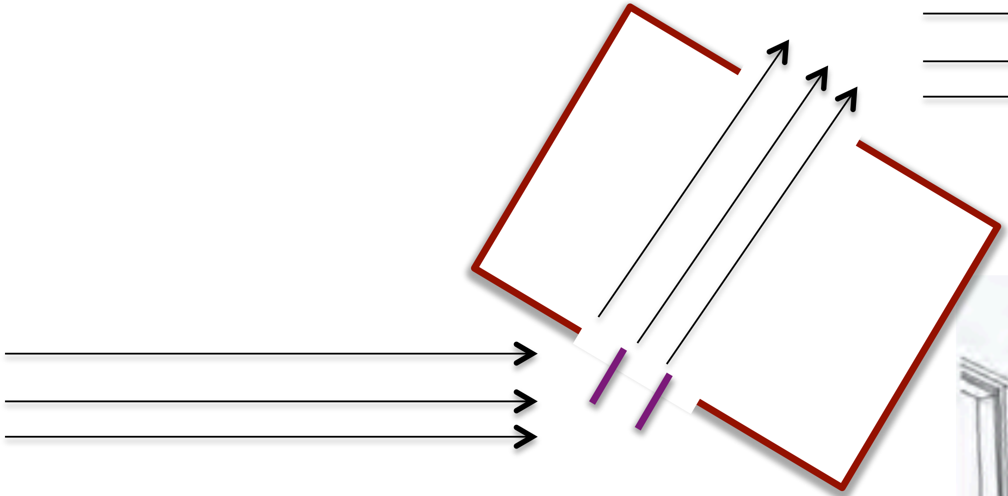


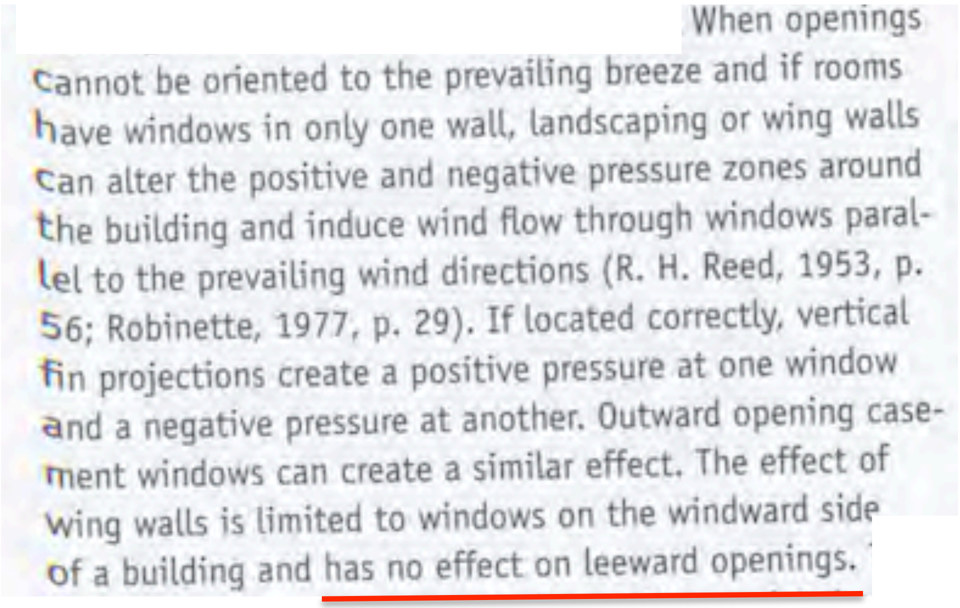
Pairing a large outlet with a small inlet increases incoming wind speed.

WINDS & AIRFLOW MODELING // Passive strategies

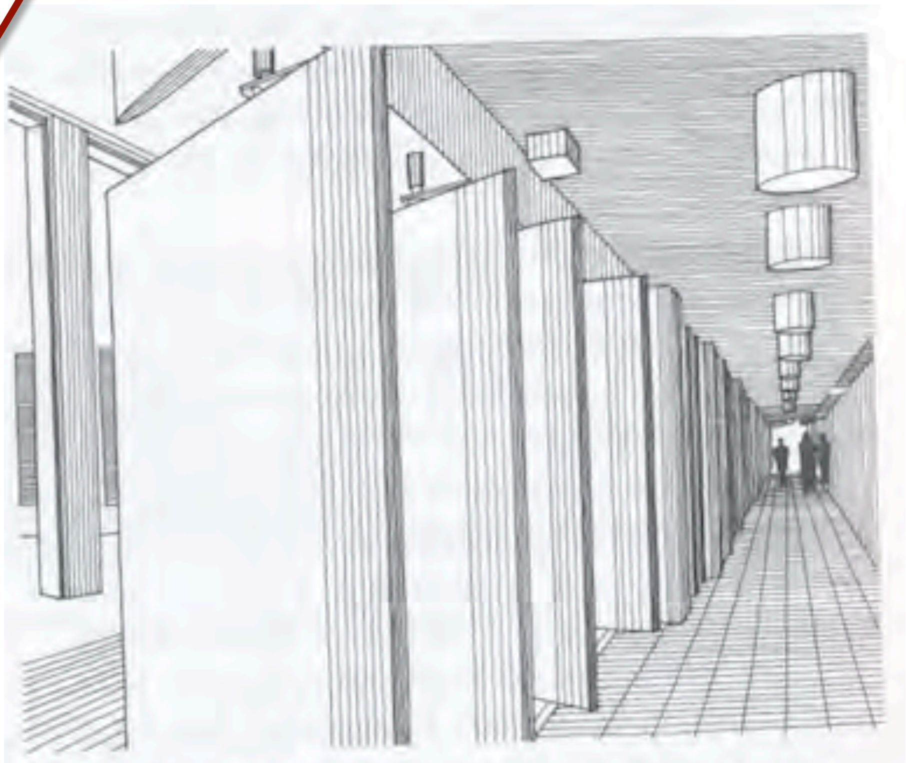
7- Design buildings according the wind pressure zones and cinetic forces

- Designing fins for good cross ventilation





When openings cannot be oriented to the prevailing breeze and if rooms have windows in only one wall, landscaping or wing walls can alter the positive and negative pressure zones around the building and induce wind flow through windows parallel to the prevailing wind directions (R. H. Reed, 1953, p. 56; Robinette, 1977, p. 29). If located correctly, vertical fin projections create a positive pressure at one window and a negative pressure at another. Outward opening casement windows can create a similar effect. The effect of wing walls is limited to windows on the windward side of a building and has no effect on leeward openings.'



Interior View of Alierons, Academy of the Antilles and Guiana, Christiane Hauvette & Jérôme Nouel

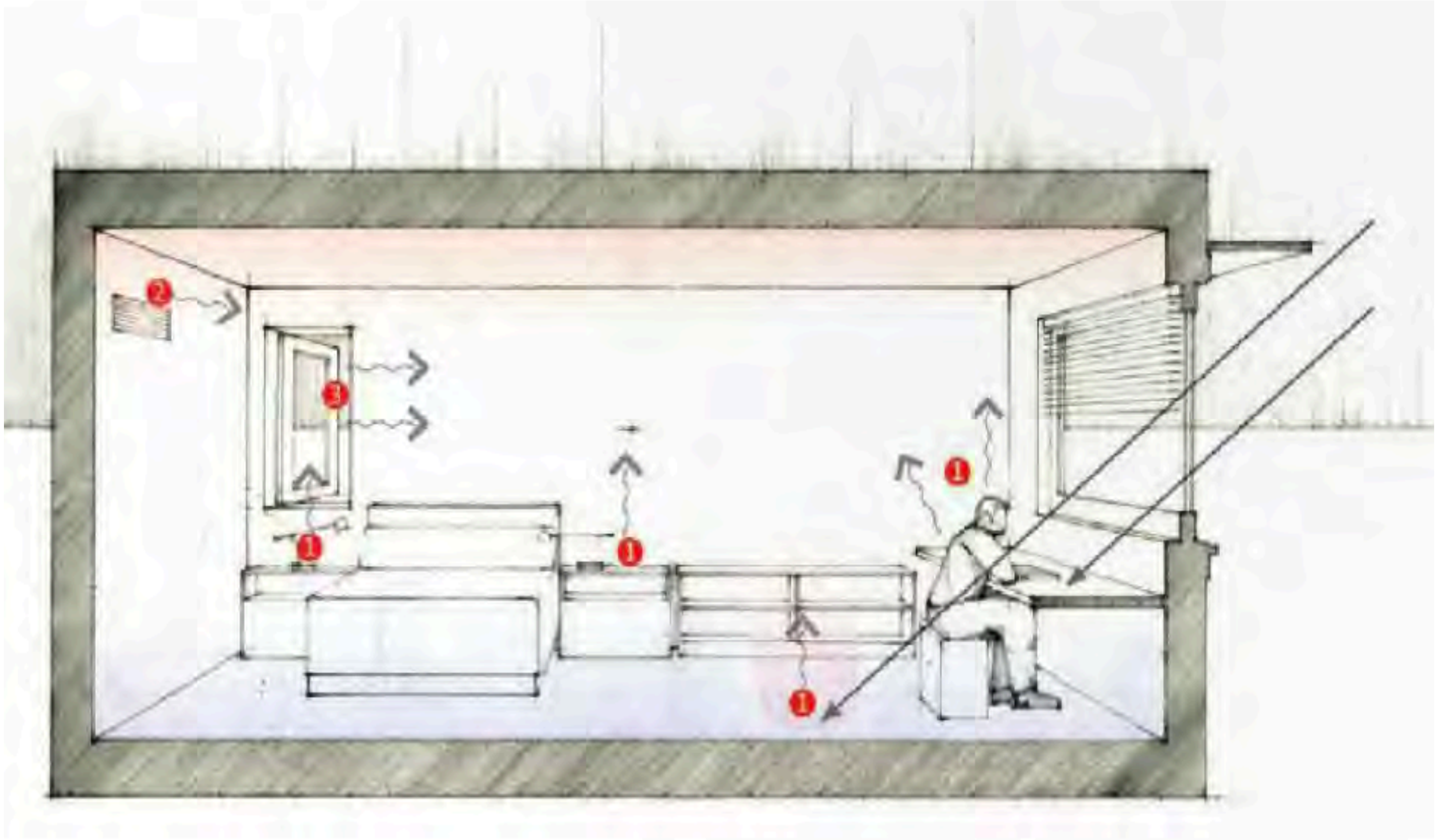
MODELING WIND & VENTILATION FOR HUMAN COMFORT

STACK EFFECT & VENTILATION

Peso ***f*** *(temperatura, altitudine)* movimento verso l'alto

Air movement: VERTICAL VENTILATION

Multiple sources airflow



Stack Effect and Ventilation

MOVEMENT OF AIR IS RELATED TO GAS DENSITY

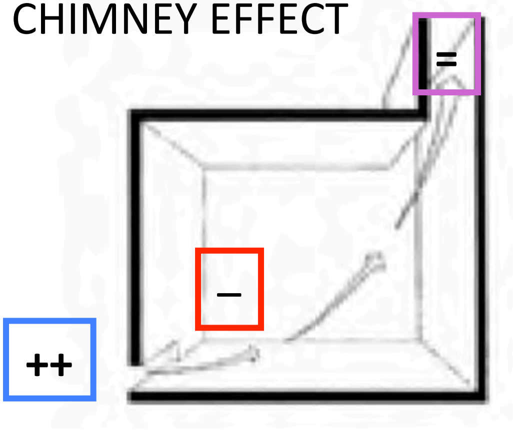
f *[cinetic energy f(velocity), gravitational energy, **f**(altitude), thermal energy f(temperature), mass/volume f(density)]*

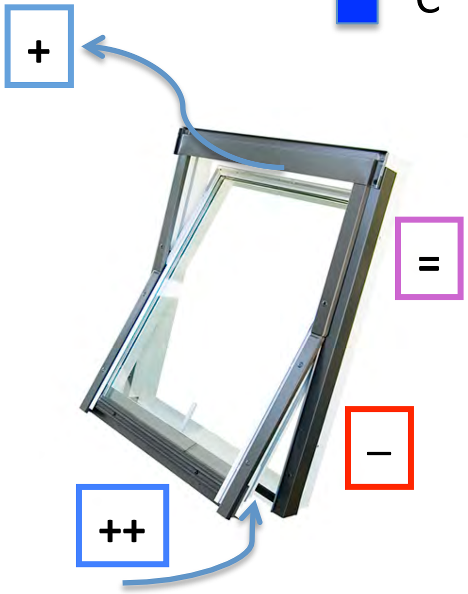
	FROM HIGHER WEIGHT	**TO LOWER WEIGHT**
	+ →	–
DENSITY	Higher	Lower
TEMPERATURE	Lower	Higher
ALTITUDE	Lower	Higher
VELOCITY	Lower	Higher

=	Lower weight
++	Higher weight

🟪
🟥
🟦
🟦 C°

STACK EFFECT or CHIMNEY EFFECT

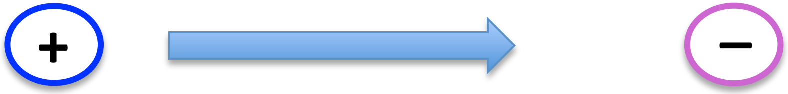


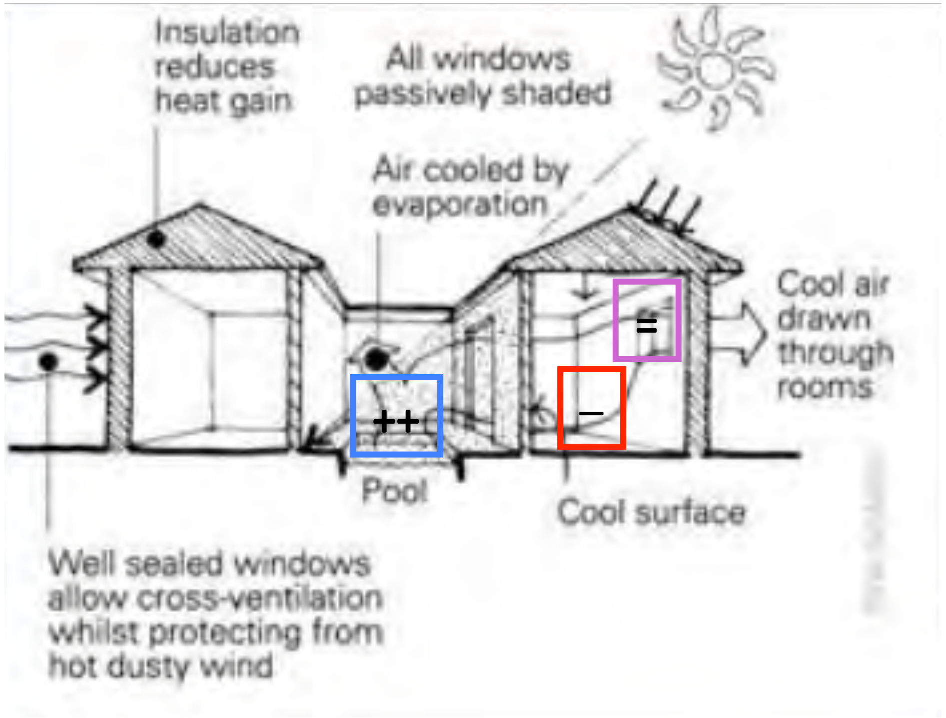


Stack Effect and Ventilation

Air movement: VERTICAL VENTILATION

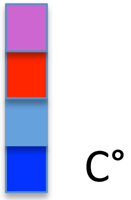
FROM HIGHER WEIGHT **TO LOWER WEIGHT**





= Lower weight

++ Higher weight

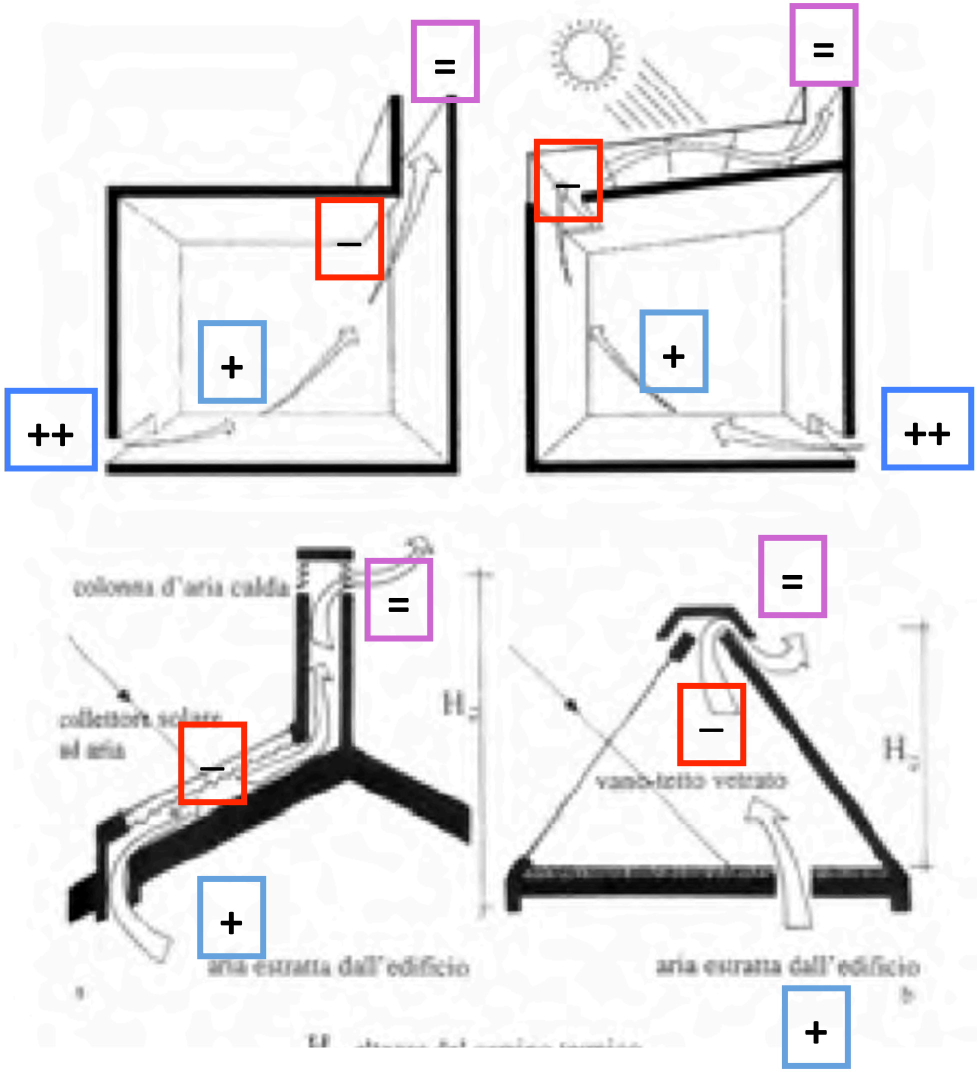


Stack Effect and Ventilation

Air movement: VERTICAL VENTILATION

FROM HIGHER WEIGHT **TO LOWER WEIGHT**

+ → −



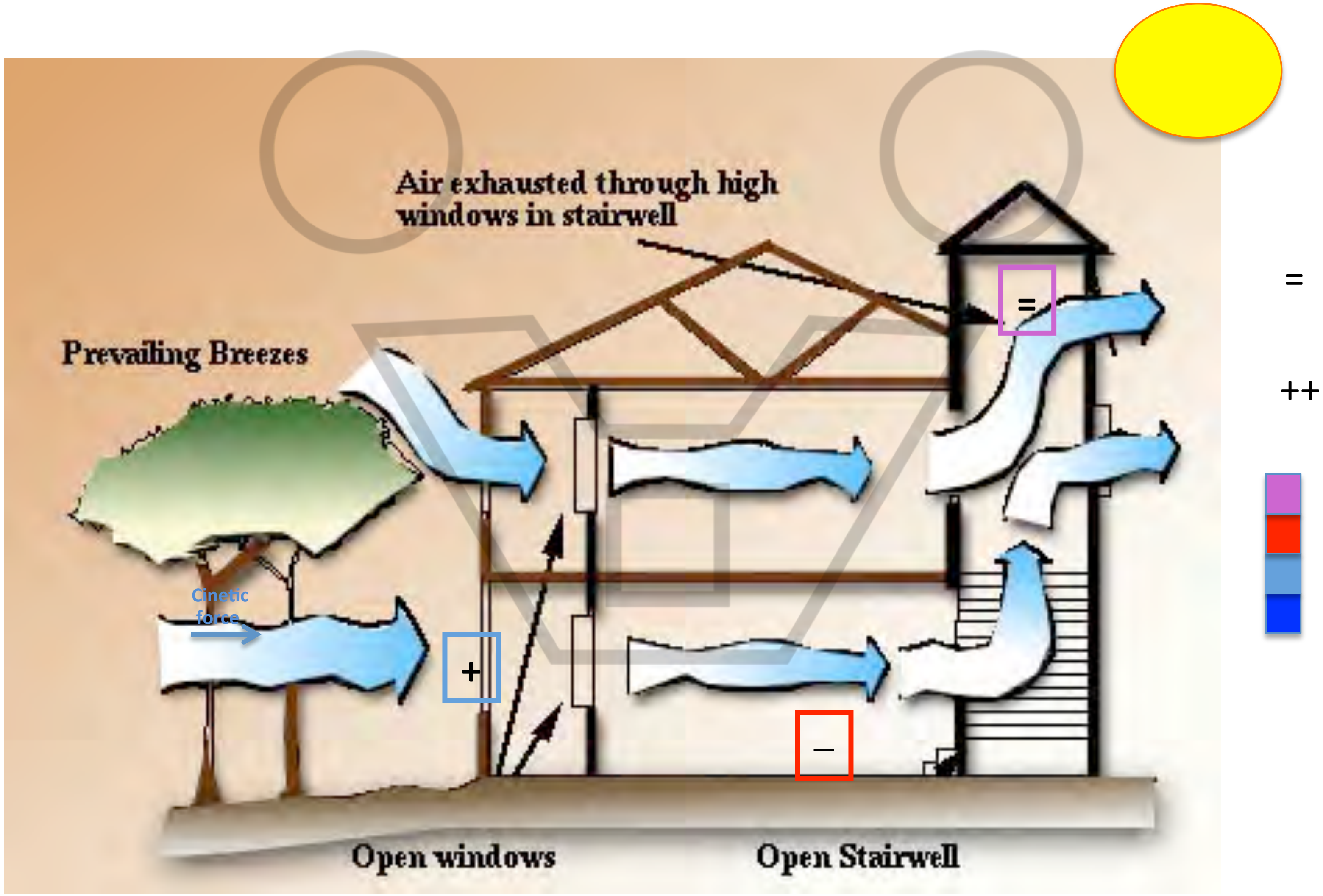
= Lower weight

++ Higher weight

🟪
🟥
🟦
🟦 C°

During the night the stack effect is less effective

Air movement: VERTICAL VENTILATION



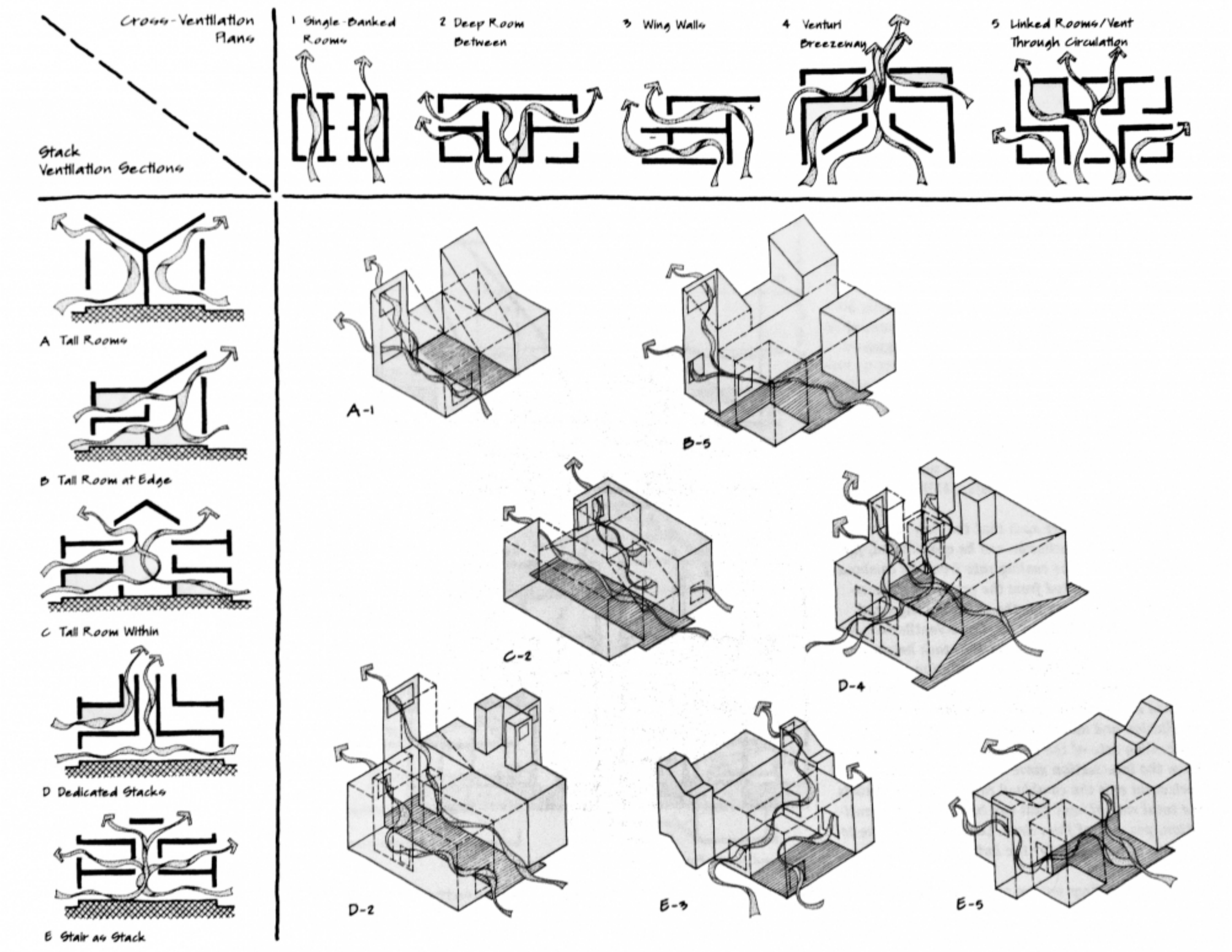
= Lower weight

++ Higher weight

🟪
🟥
🟦
🟦 C°

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

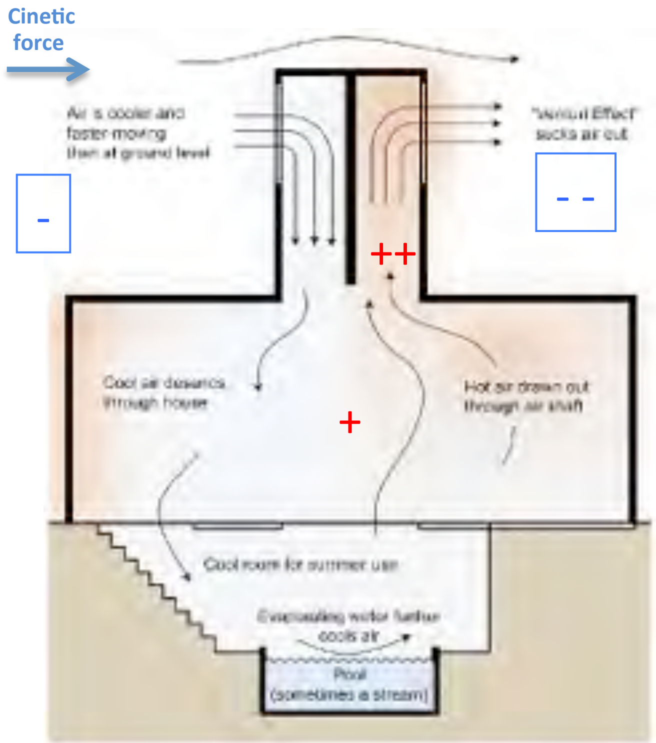
- To heat/cool through thermal convection
- to refresh through the sweating acceleration
- to clean exhausted indoor air
- to prevent condensation, moisture, and germs

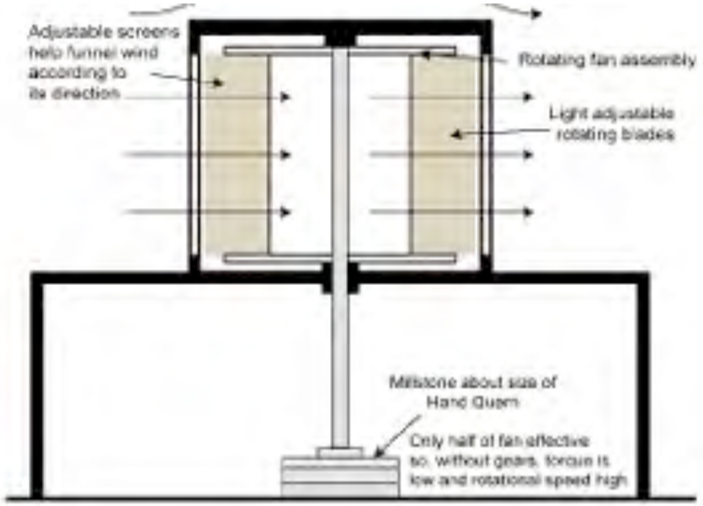
Working with natural ventilation

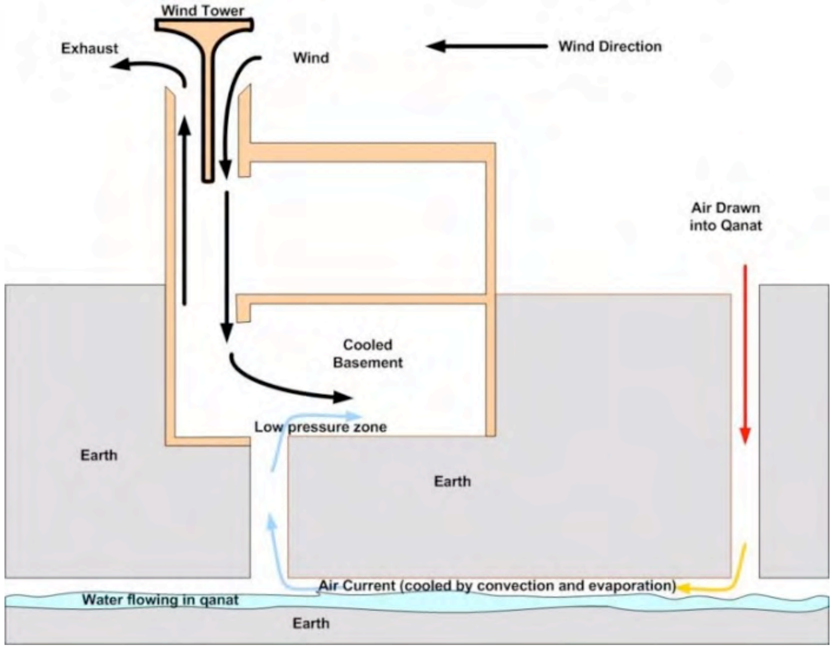
Wind Towers

Working with natural ventilation

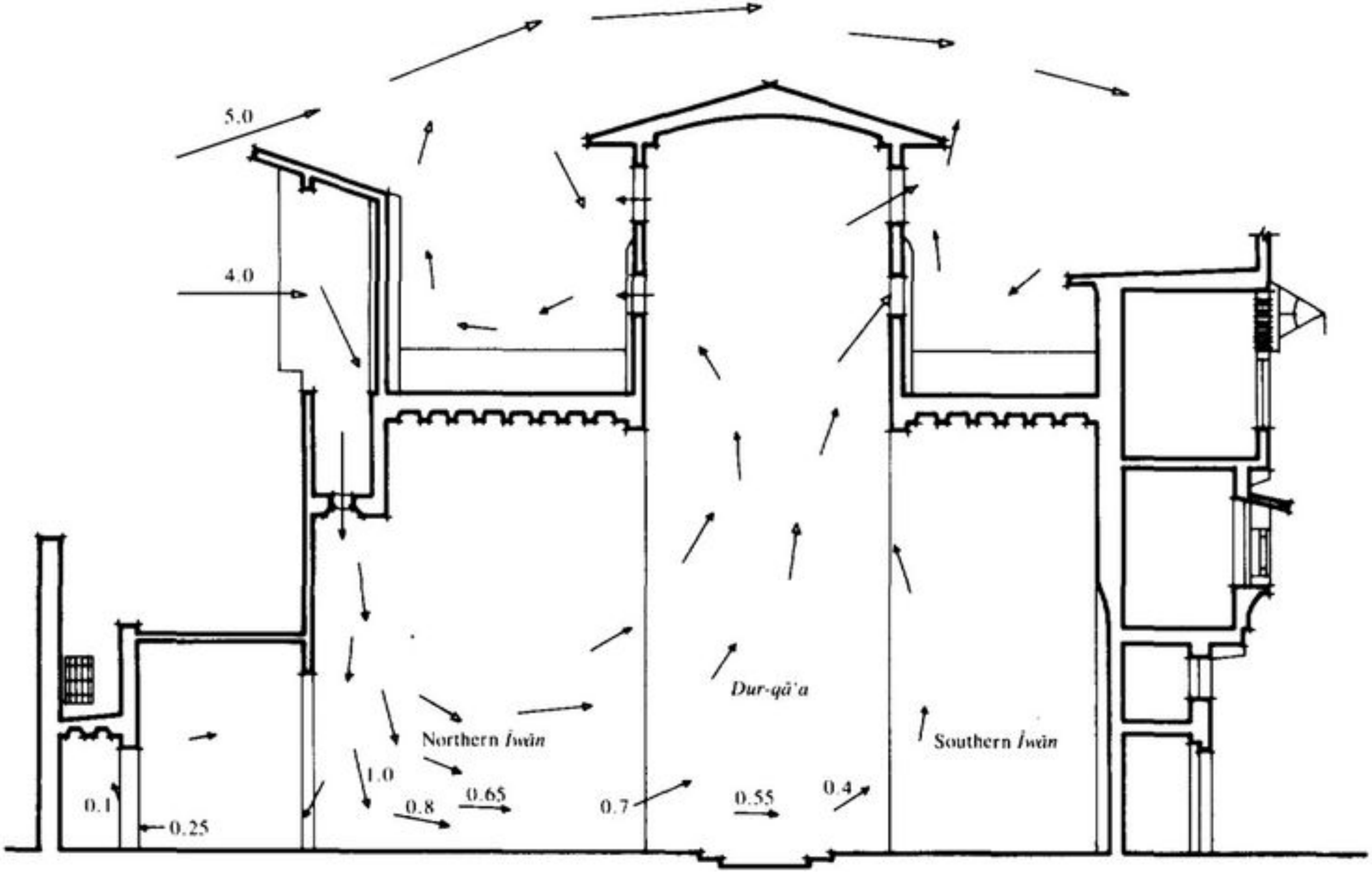
Wind Towers







Wind Towers

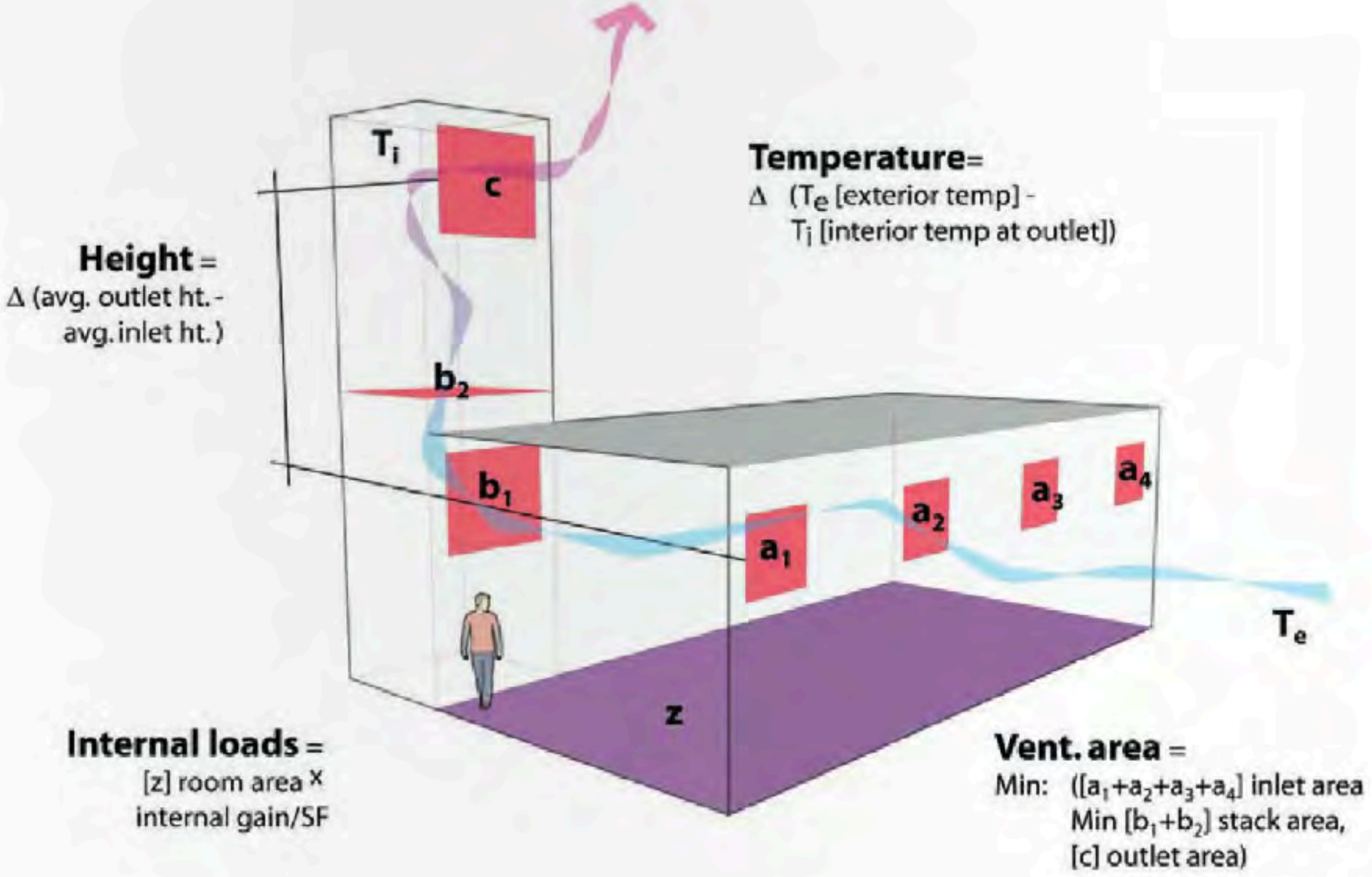

5.0
4.0
Northern Īwān
Dur-qā'a
Southern Īwān
1.0
0.8
0.65
0.7
0.55
0.4
0.1
0.25

Working with natural ventilation

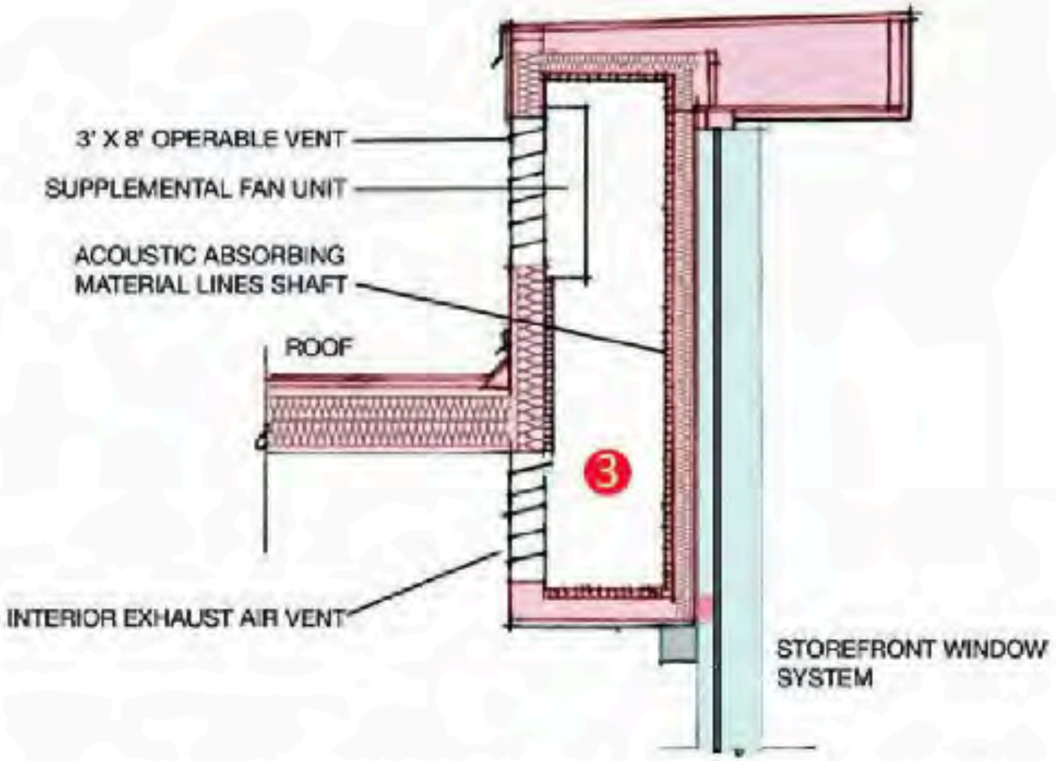
Wind Towers

9.12

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



Exhaust Vent Towers



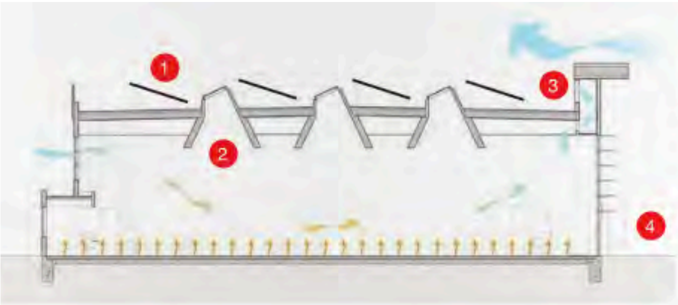
Natural Ventilation Exhaust Vent

9.5

Natural ventilation exhaust vent.

Working with natural ventilation

Chimney



Mode 1 🟦

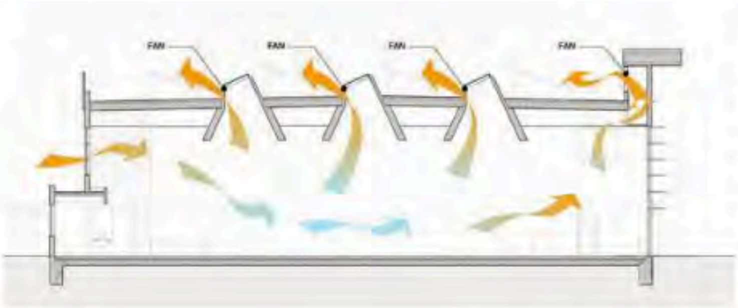
Heating Season.
Minimum outside
air admitted.

Mode 2 🟩

Swing Season.
Outside air quantity
varies to provide coolin
and fresh air. Wind
chimney only.

Mode 3 🟨

Early Cooling Season.
Cooling via wind chimne
and venting skylights.



Mode 4 🟪

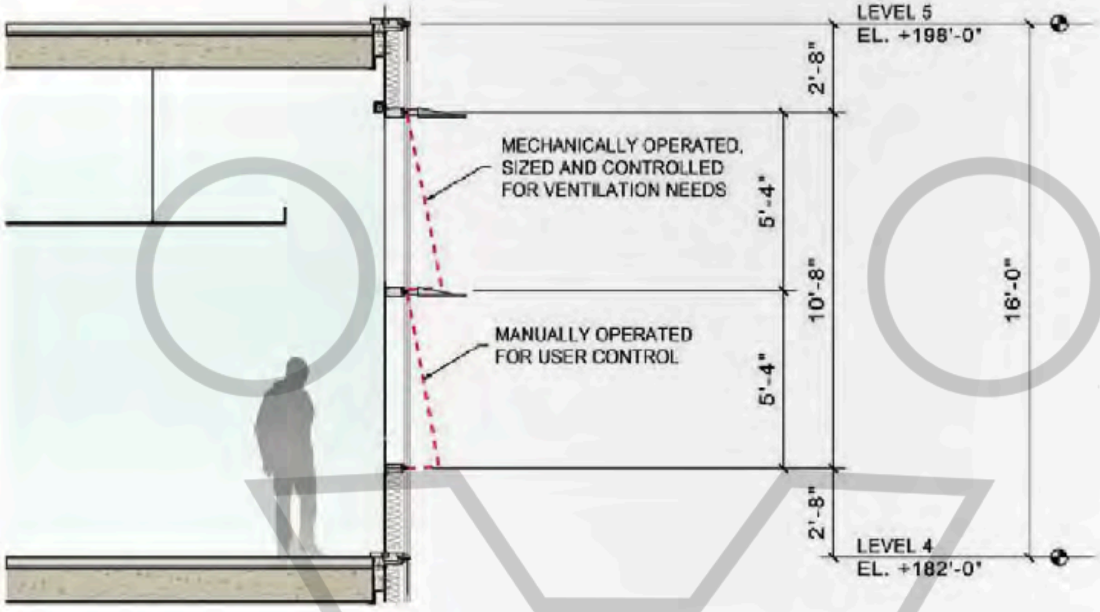
Cooling Season.
Skylight roof fans
maximize outdoor air
for cooling. Nighttime
purging as necessary.

Mode 5 🟫

Peak Cooling.
Minimum fresh air.
Cooling provided by
radiant slab.

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.

Working with natural ventilation

Operable Windows

9.16

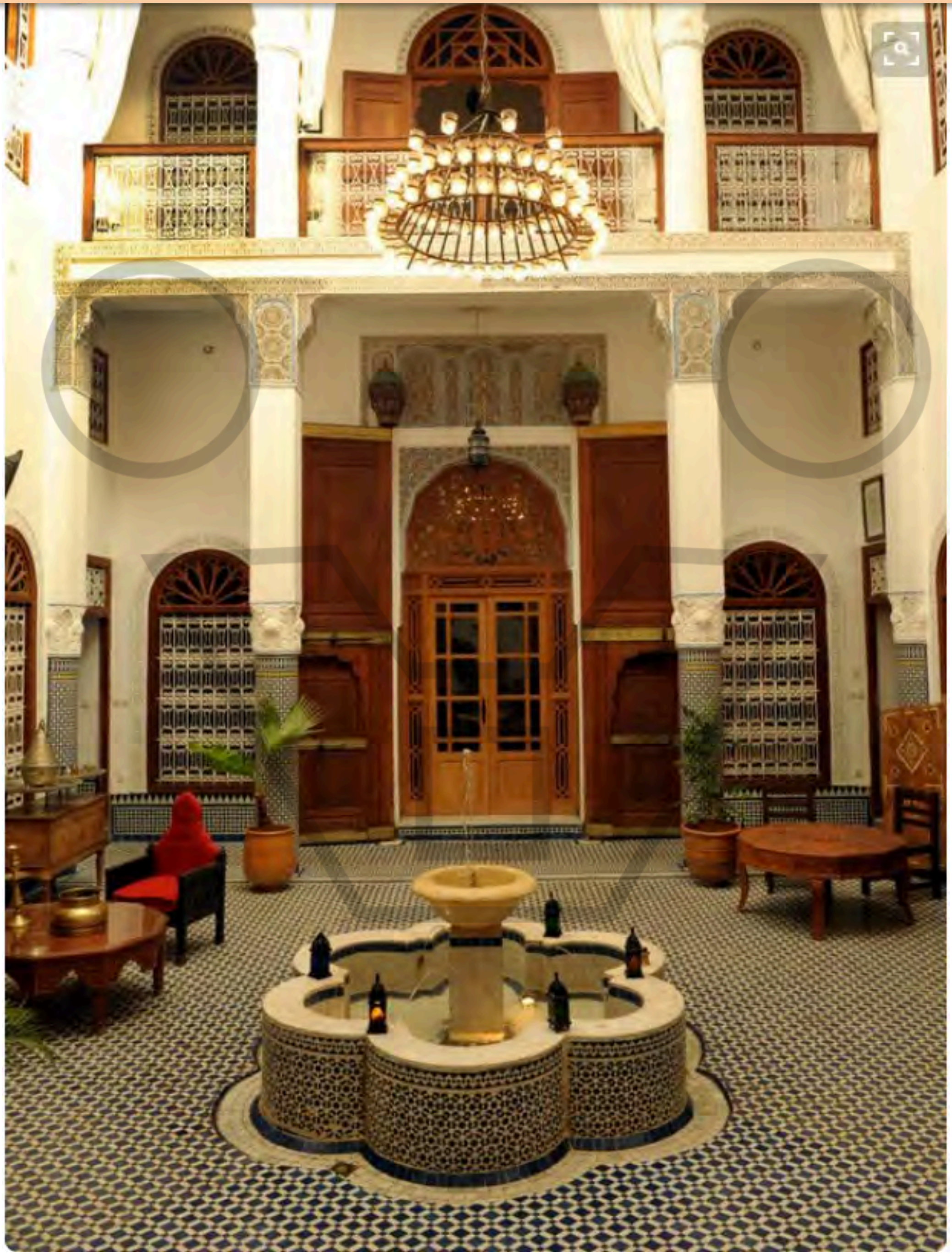
Photograph of the type of operable windows used at the Bullitt Center. Window diagram shows equal opening size around window's perimeter to reduce wear and provide even, controlled airflow.

Source: Photo and diagram courtesty Shuco.

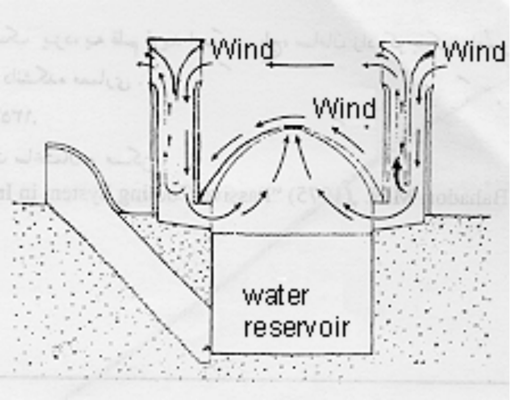
MODELING HUMAN BEHAVIOURS AND COMPUTING COMFORT CONDITIONS

WORKING WITH WATER EVAPORATION IN HOT DRY CLIMATE

Working with water evaporation in hot dry climate



Working with water evaporation in hot dry climate



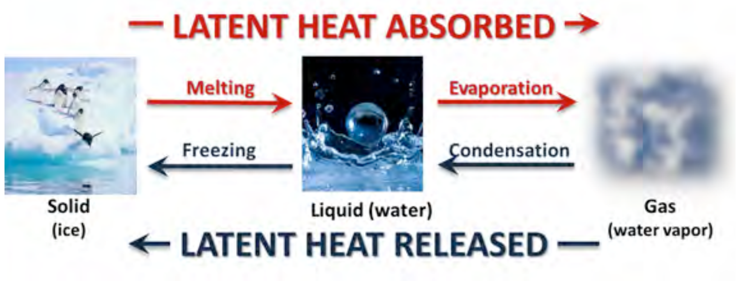
LATENT HEAT vs SENSIBLE HEAT

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.

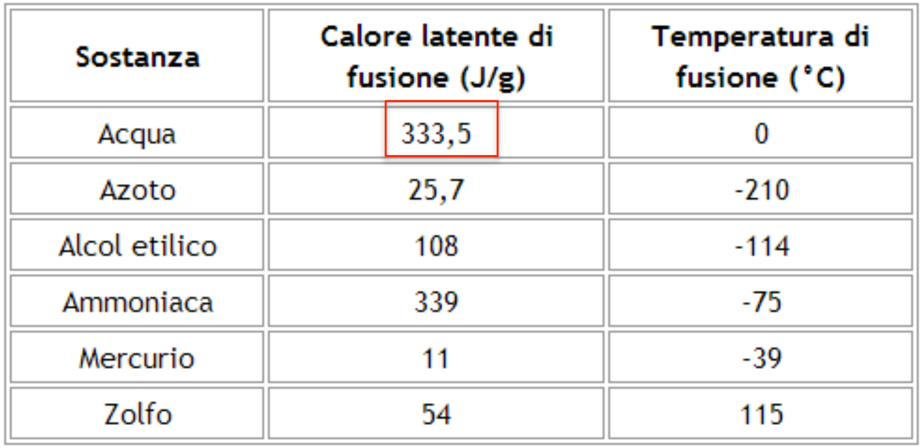
Sensible heat **is the energy required to change the temperature of a substance with no phase change**. The temperature change can come from the absorption of sunlight by the soil or the air itself. Or it can come from contact with the warmer air caused by release of latent heat (by direct conduction). 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

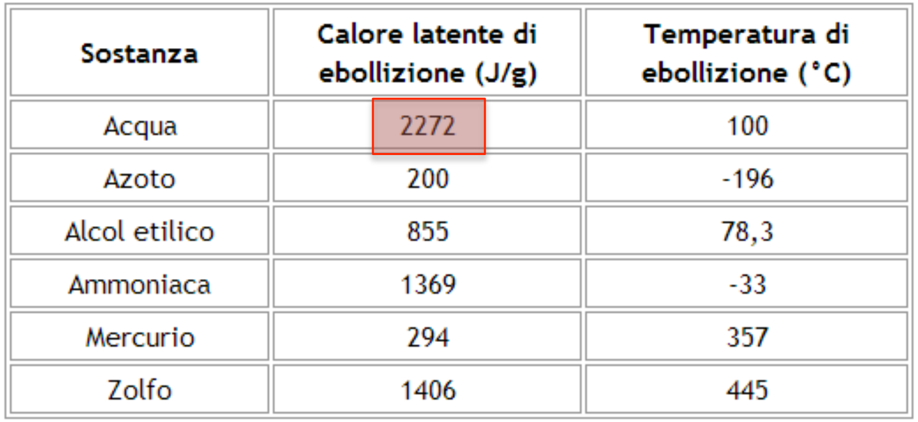


Sostanza	Calore latente di fusione (J/g)	Temperatura di fusione (°C)
Acqua	333,5	0
Azoto	25,7	-210
Alcol etilico	108	-114
Ammoniaca	339	-75
Mercurio	11	-39
Zolfo	54	115

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

→ 1 litro = 630 W/h → 1 litro = 45 W

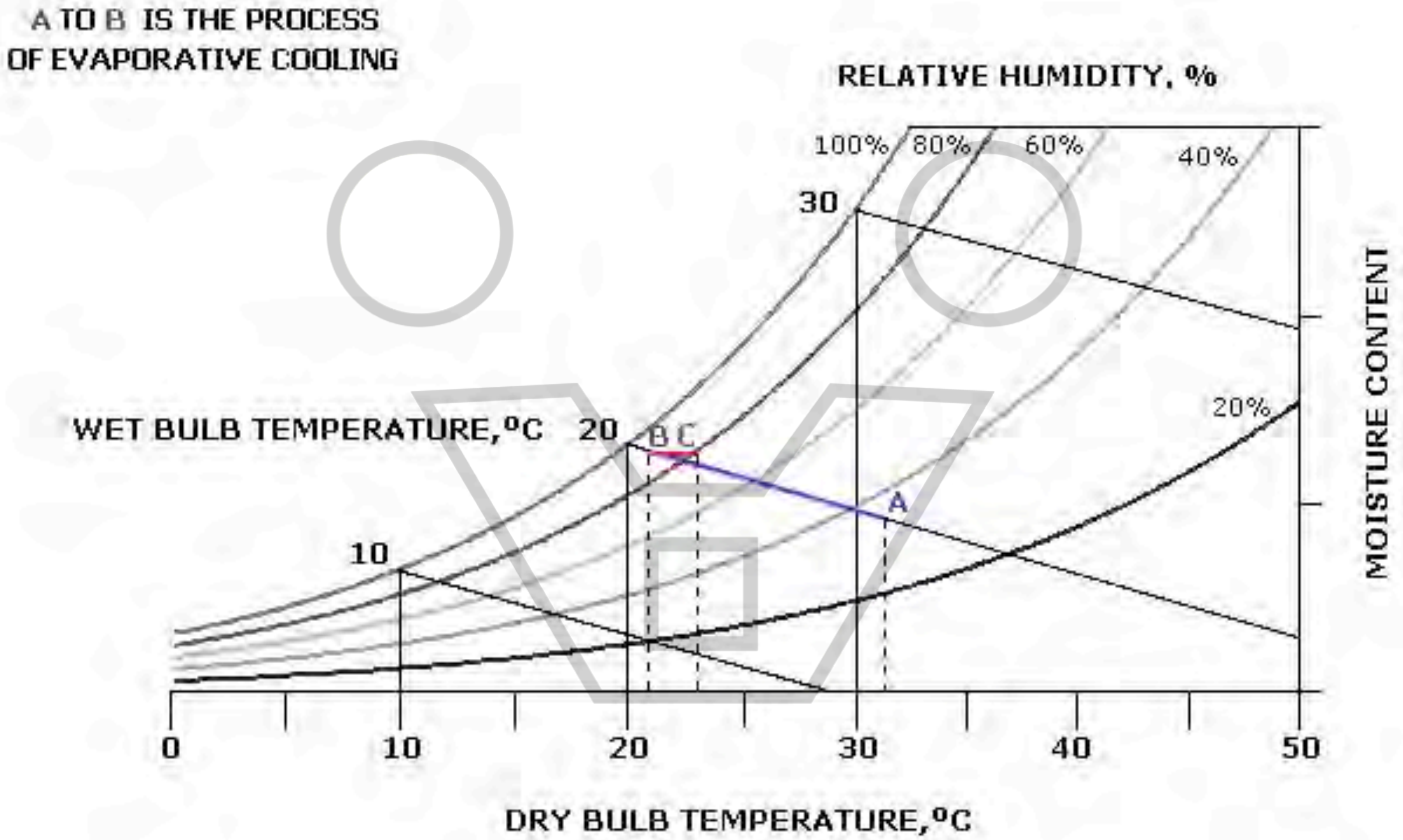
Tempo medio 15-20’



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

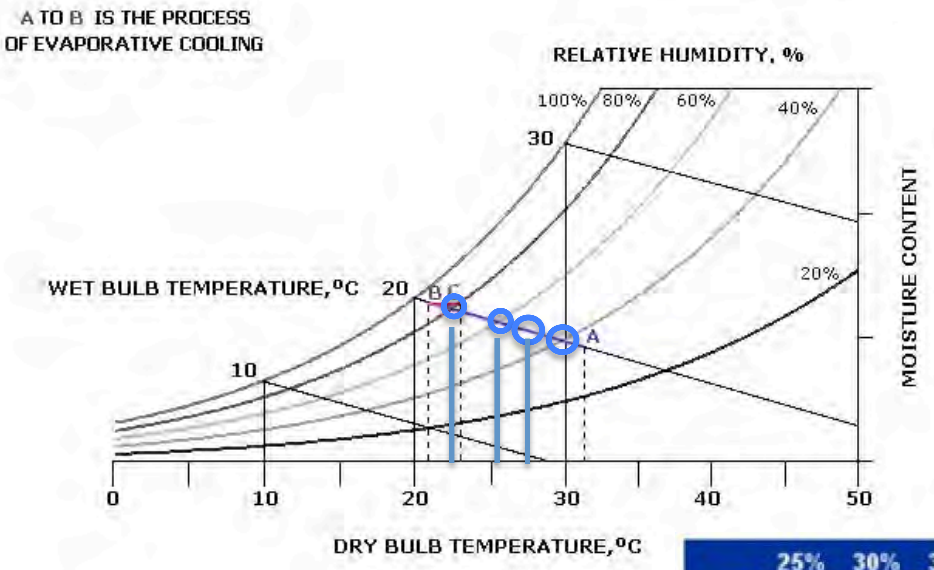
Working with water evaporation in hot dry climate

How much is the benefit from evaporative cooling



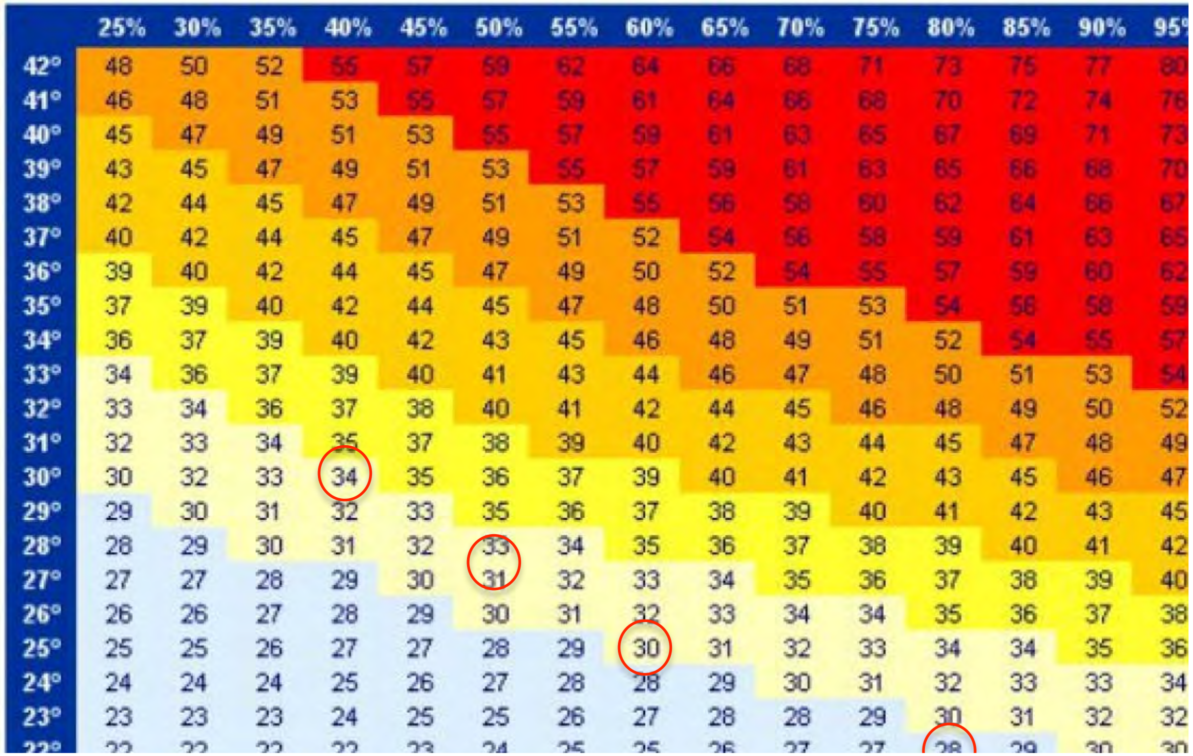
Working with water evaporation in hot dry climate

How much is the benefit from evaporative cooling



REAL TEMPERATURE:
30° (40%) >> 22°(80%) >> diff -8°
APPARENT TEMPERATURE

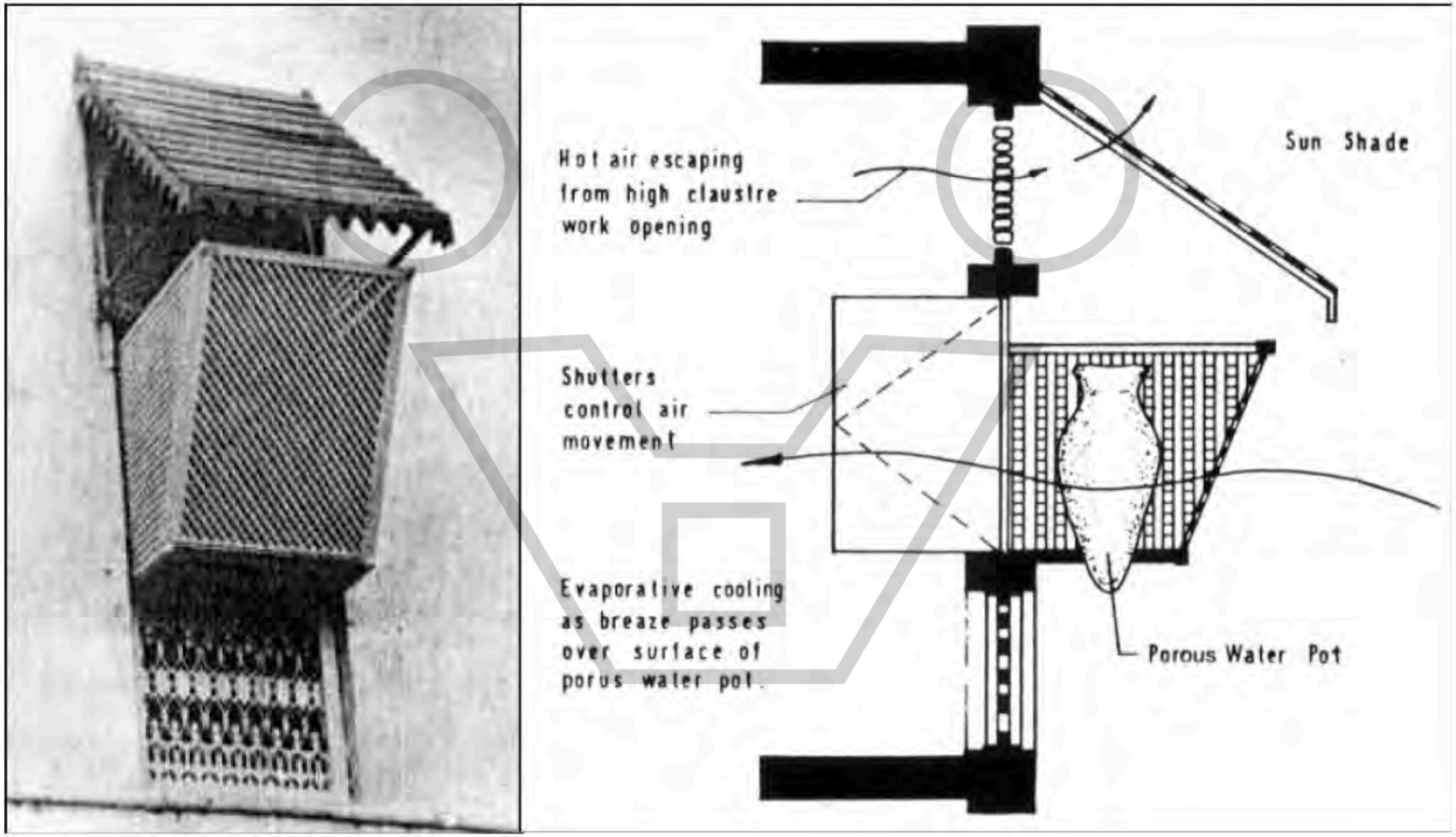
34° >> 30° >> diff -4°
34° >> 28 >> diff -6°
34° >> 32° >> diff -8°



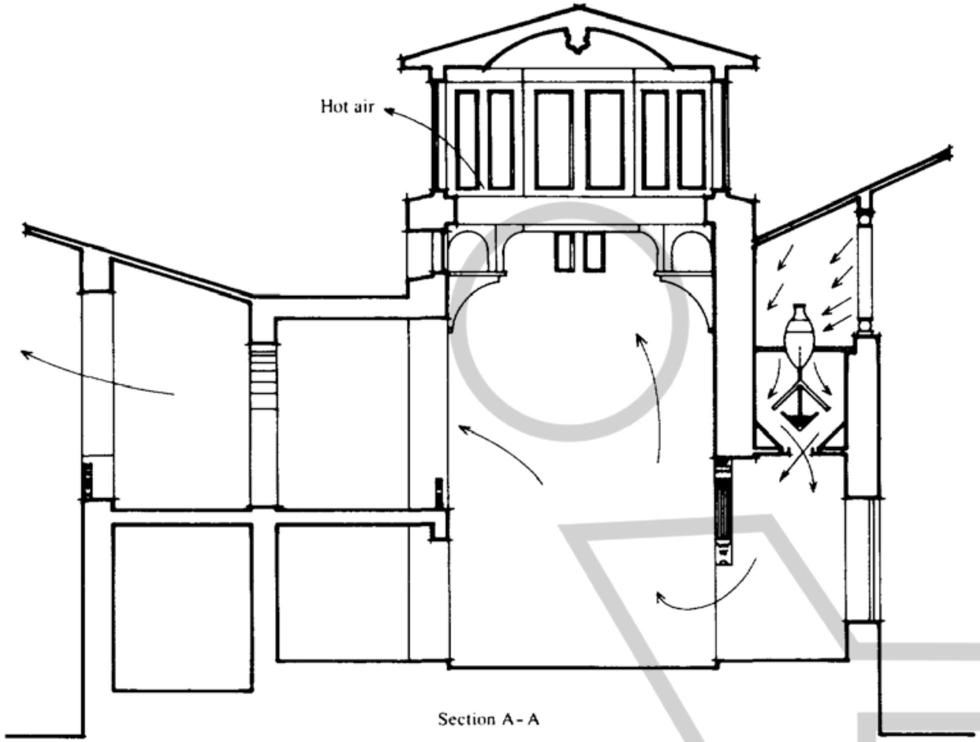
	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95
42°	48	50	52	55	57	59	62	64	66	68	71	73	75	77	80
41°	46	48	51	53	55	57	59	61	64	66	68	70	72	74	76
40°	45	47	49	51	53	55	57	59	61	63	65	67	69	71	73
39°	43	45	47	49	51	53	55	57	59	61	63	65	66	68	70
38°	42	44	45	47	49	51	53	55	56	58	60	62	64	66	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

Working with water evaporation in hot dry climate

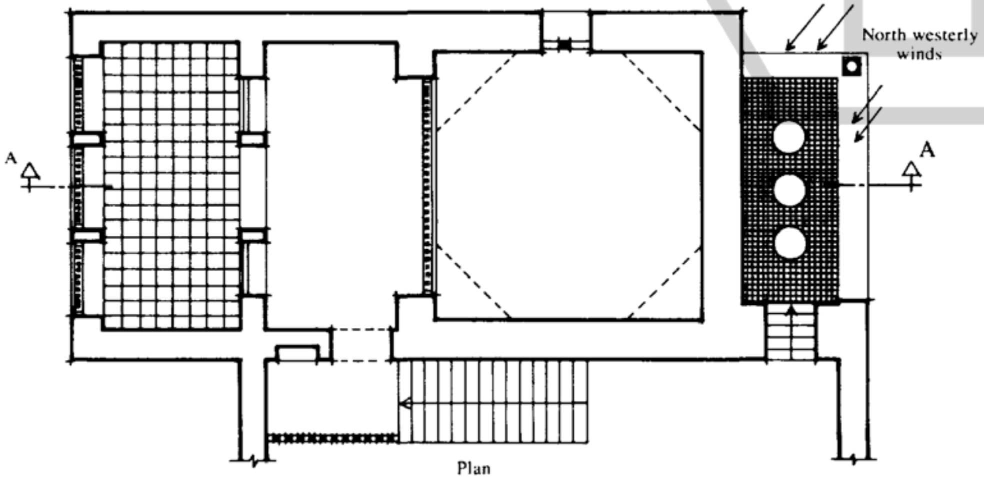
Figure : Muscatese Evaporative cooling window system (Rosa Schiano 2007)



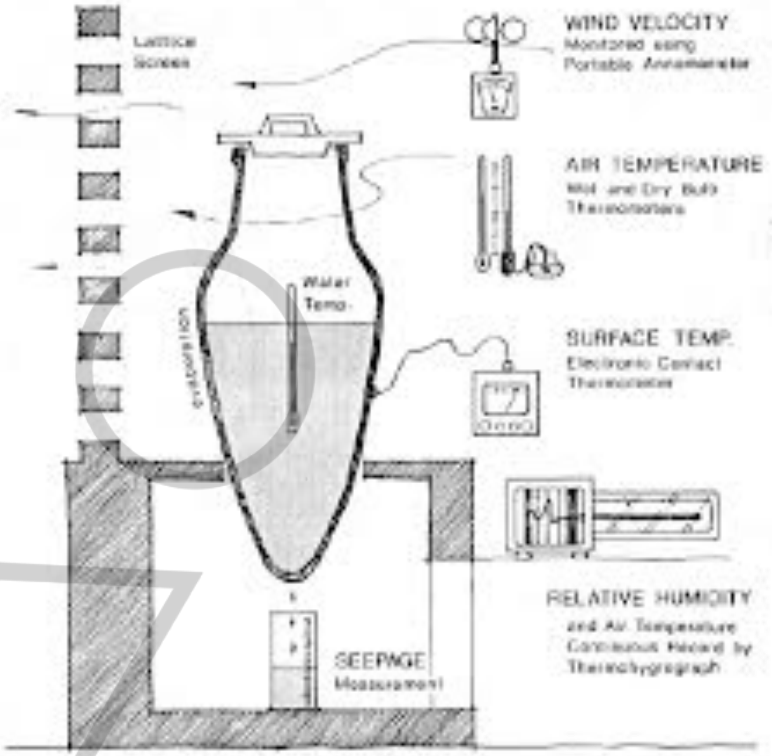
Working with water evaporation in hot dry climate



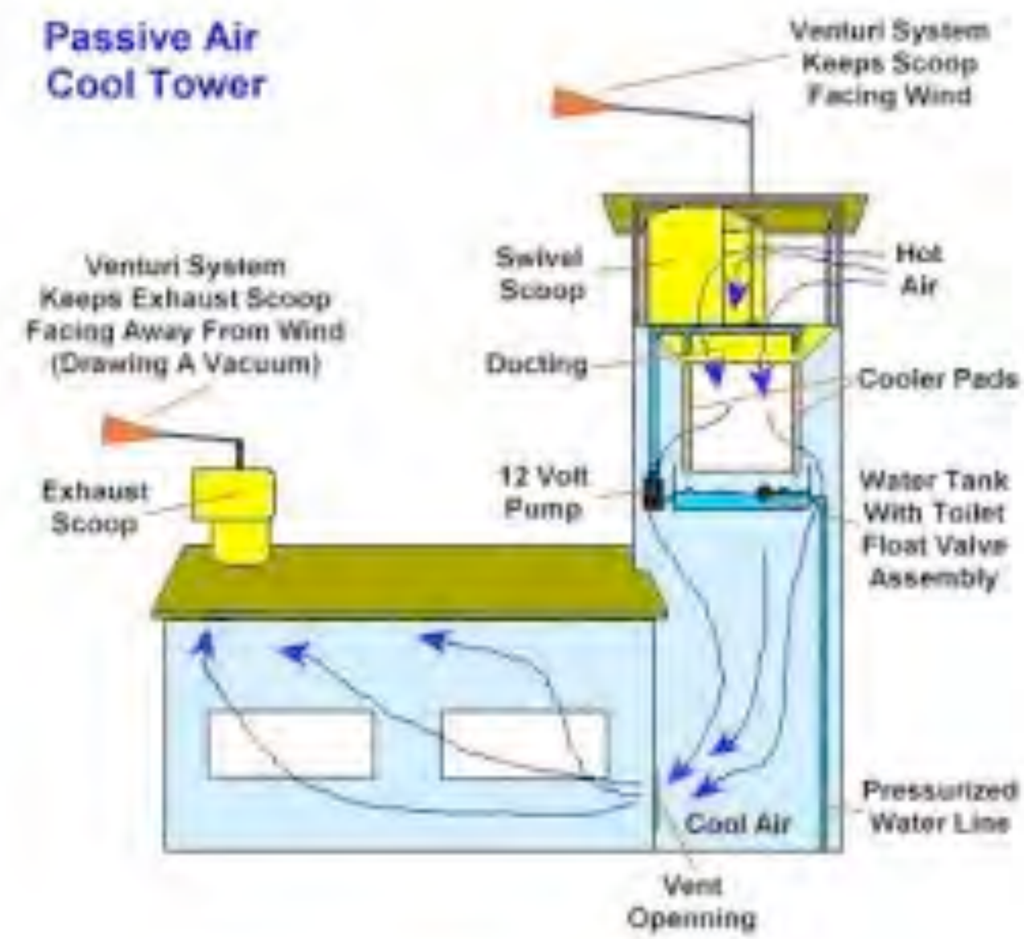
Section A - A

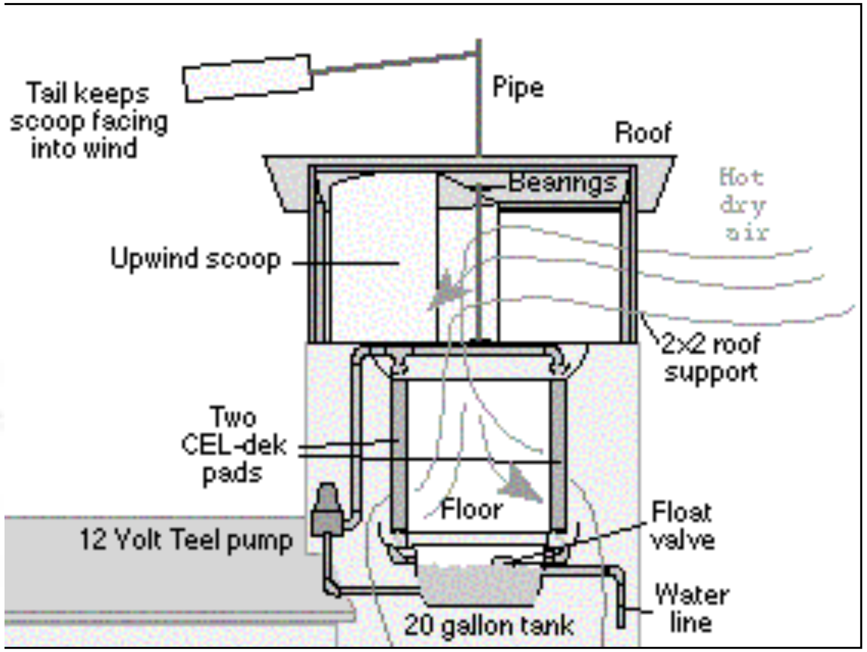


Plan

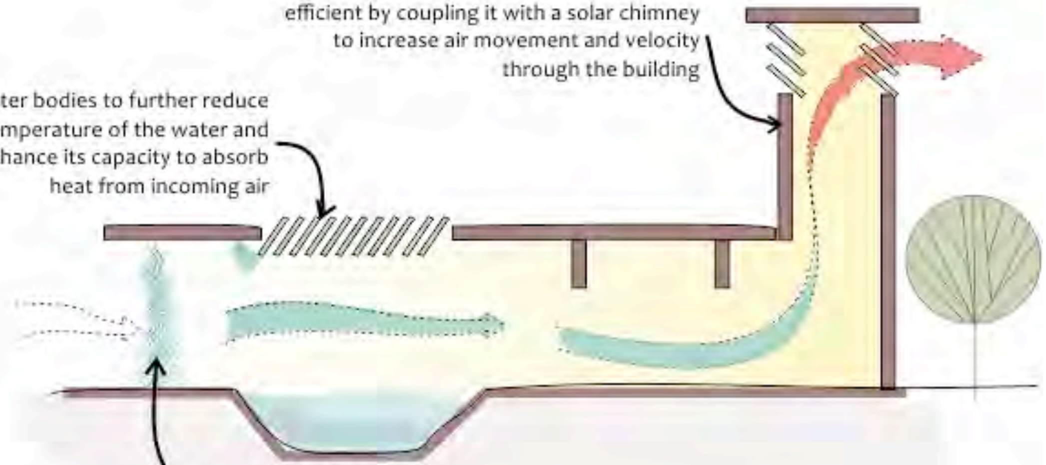


Working with water evaporation in hot dry climate





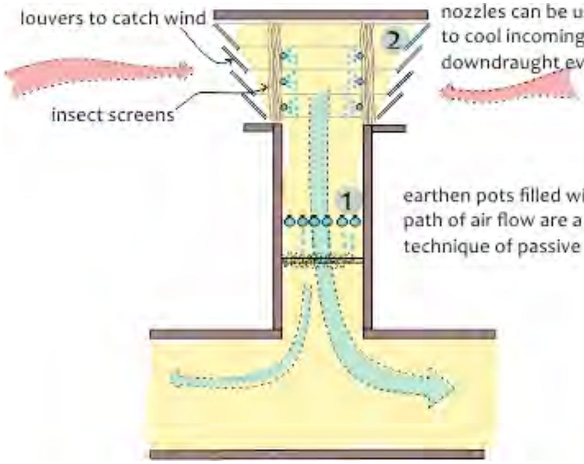
Working with water evaporation in hot dry climate



evaporative cooling can be made more efficient by coupling it with a solar chimney to increase air movement and velocity through the building

shade water bodies to further reduce temperature of the water and enhance its capacity to absorb heat from incoming air

spray devices and screens can be used instead of water pools for the same effect

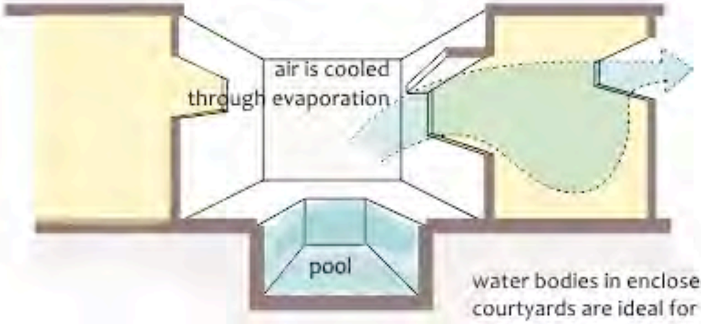


louvers to catch wind

insect screens

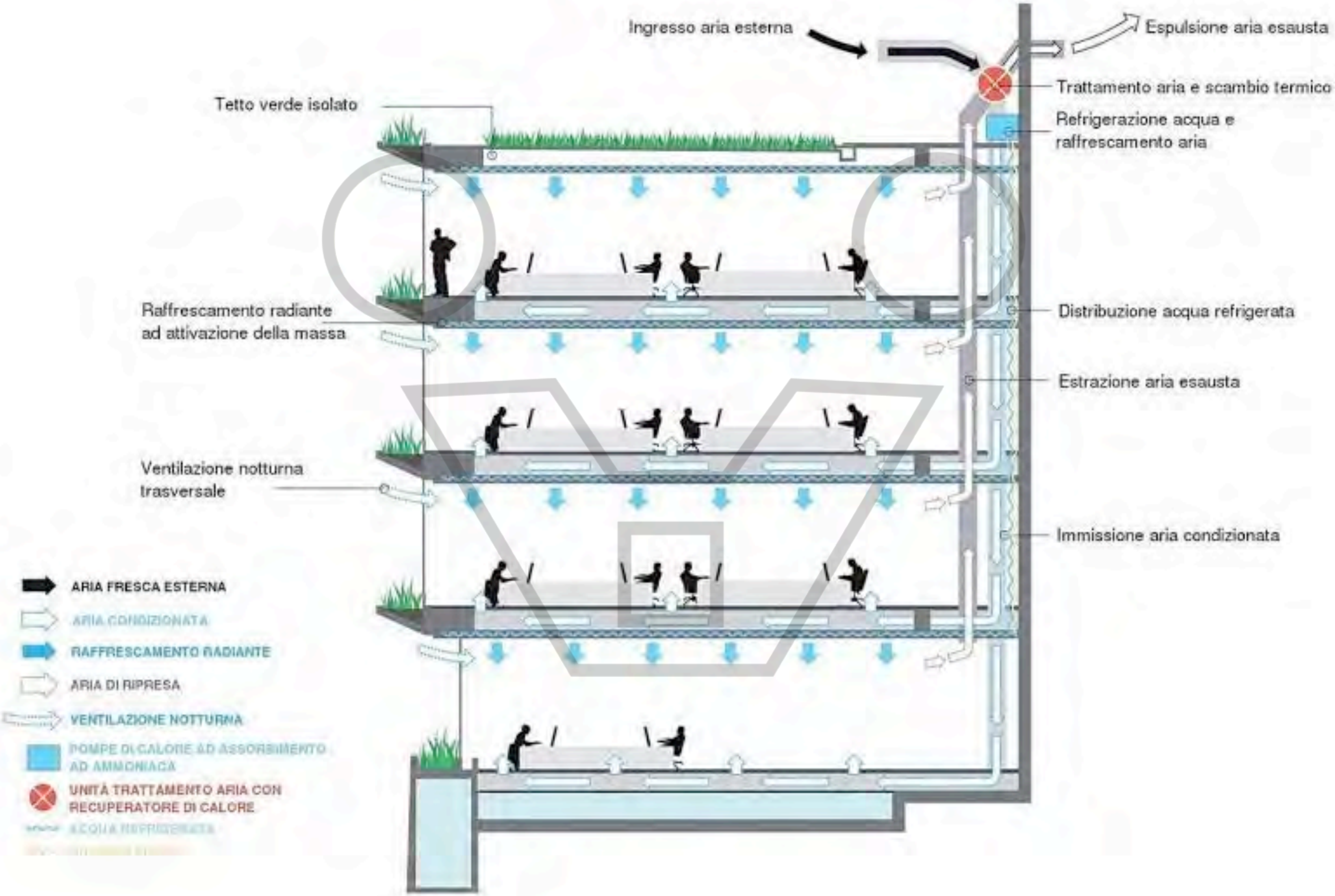
nozzles can be used to spray water or mist to cool incoming air sucked by passive downdraught evaporative cooling tower

earthen pots filled with water placed in the path of air flow are a traditional technique of passive evaporative cooling



water bodies in enclosed courtyards are ideal for evaporative cooling in hot and dry climates

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.

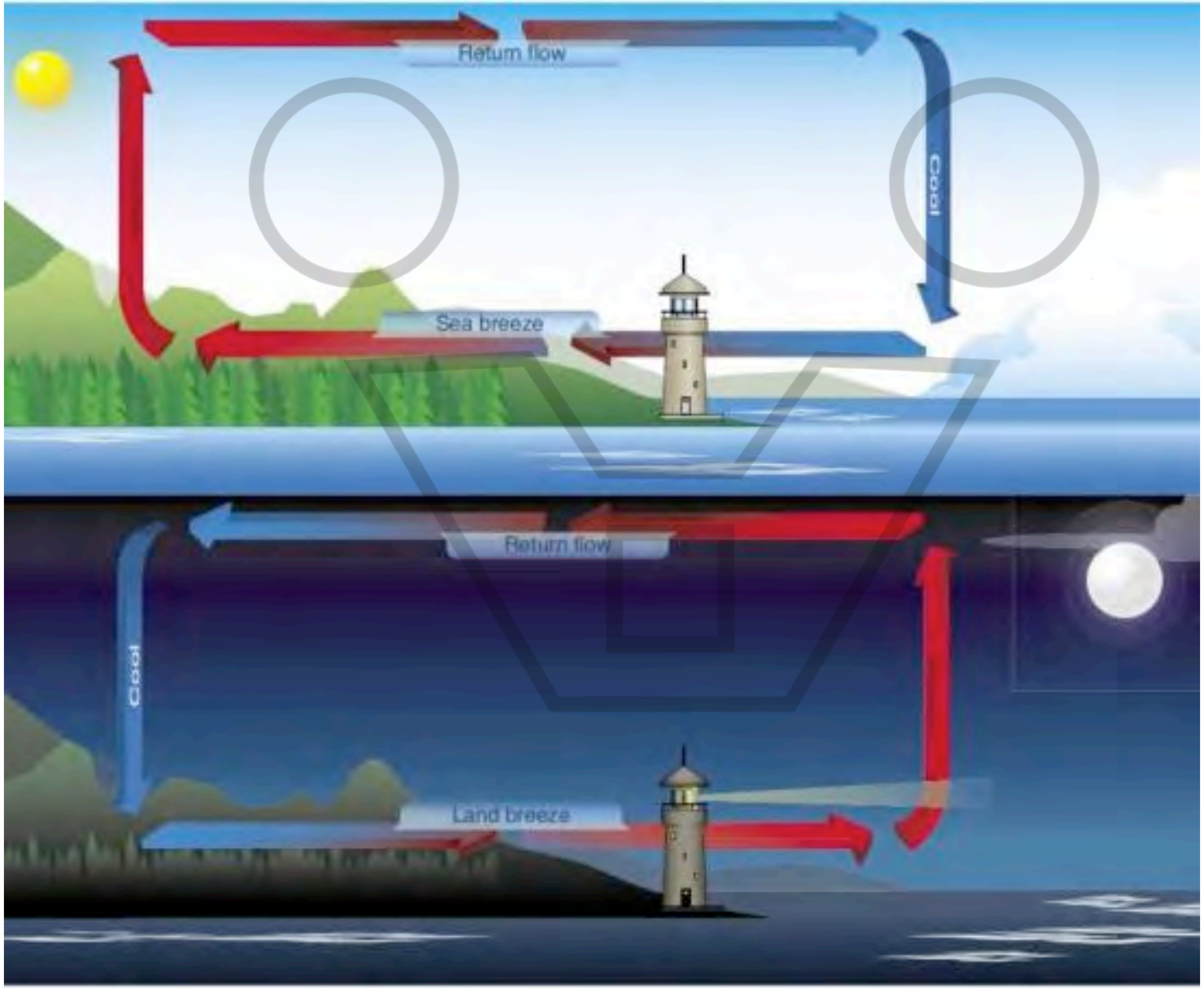
Thermal diffusivity is the thermal conductivity divided by density and specific heat capacity at constant pressure

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



Working with Mass Latency or Thermal Lag

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.

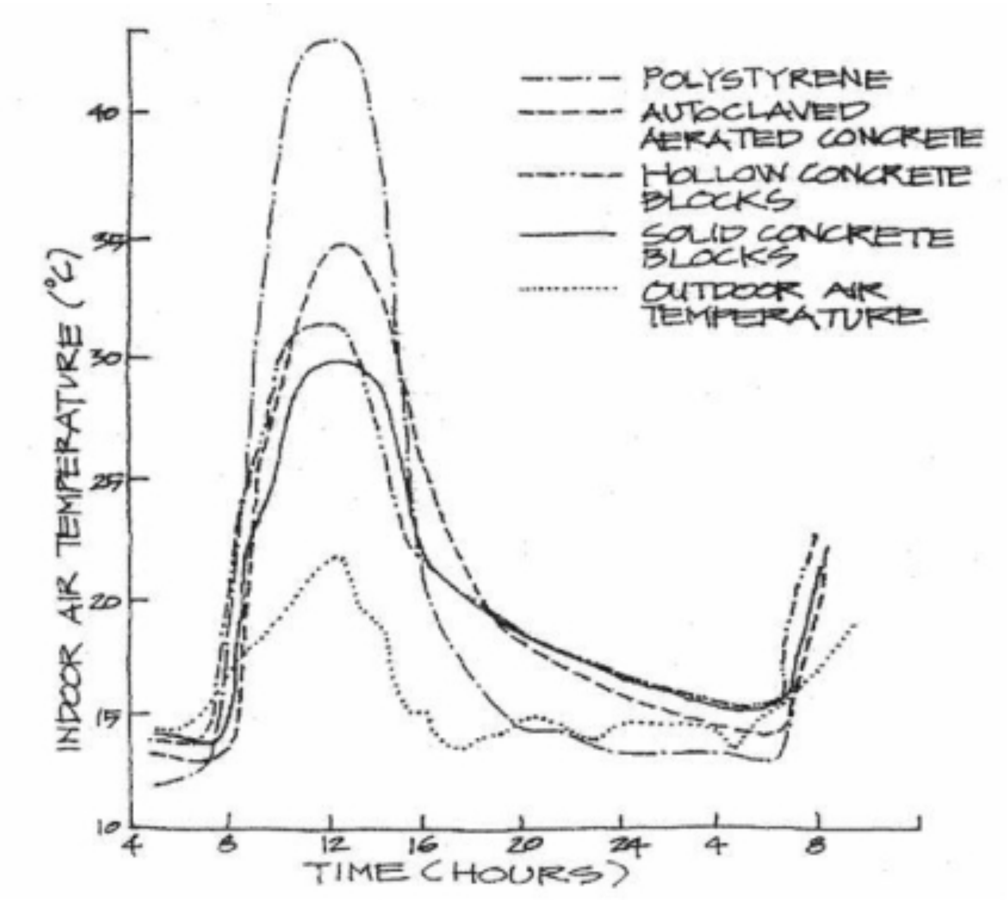
http://www2.ecospecifier.org/

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

Working with Mass Latency or Thermal Lag

Internal temperatures stabilisation



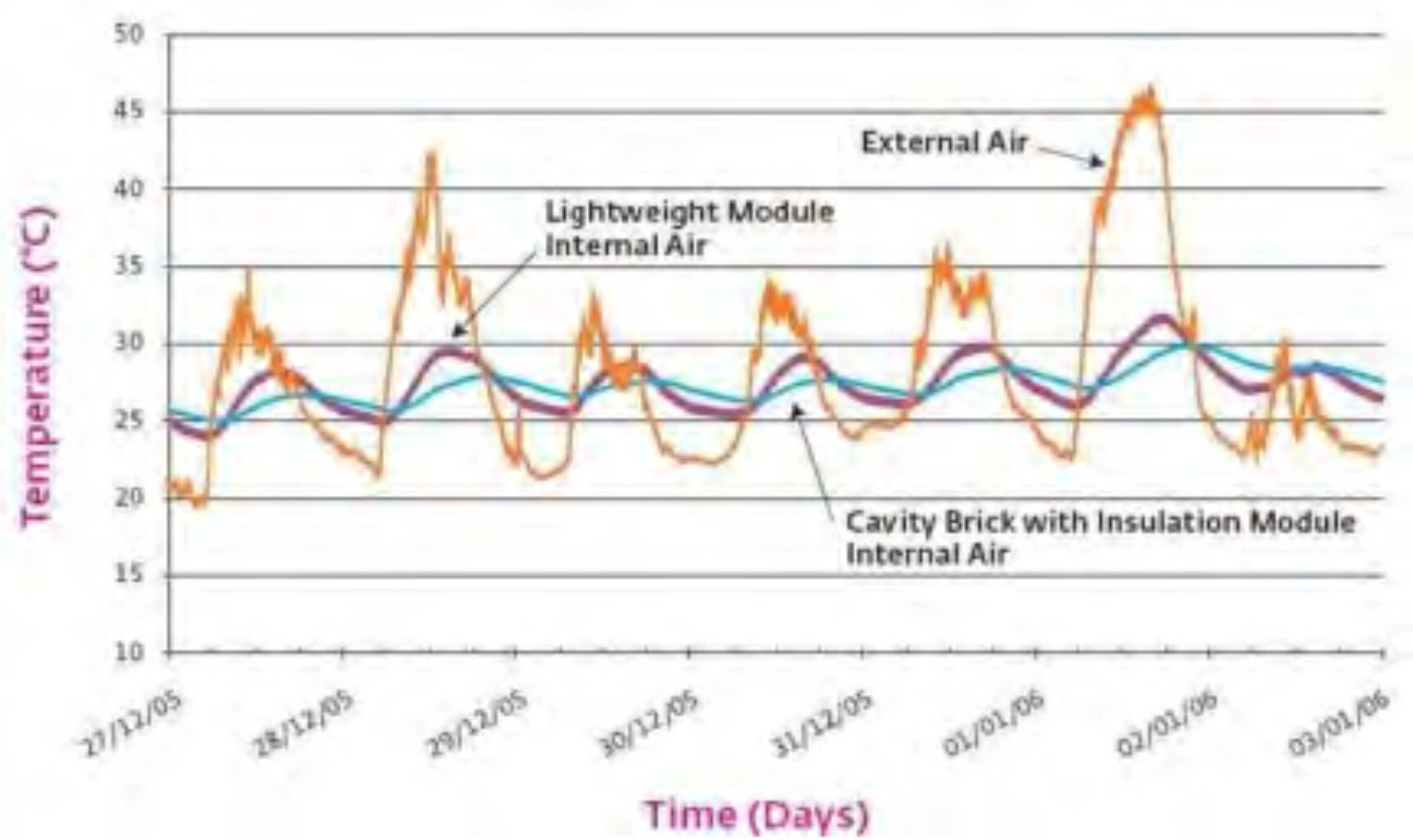
Thermal mass effects on diurnal indoor temperatures of various materials.

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

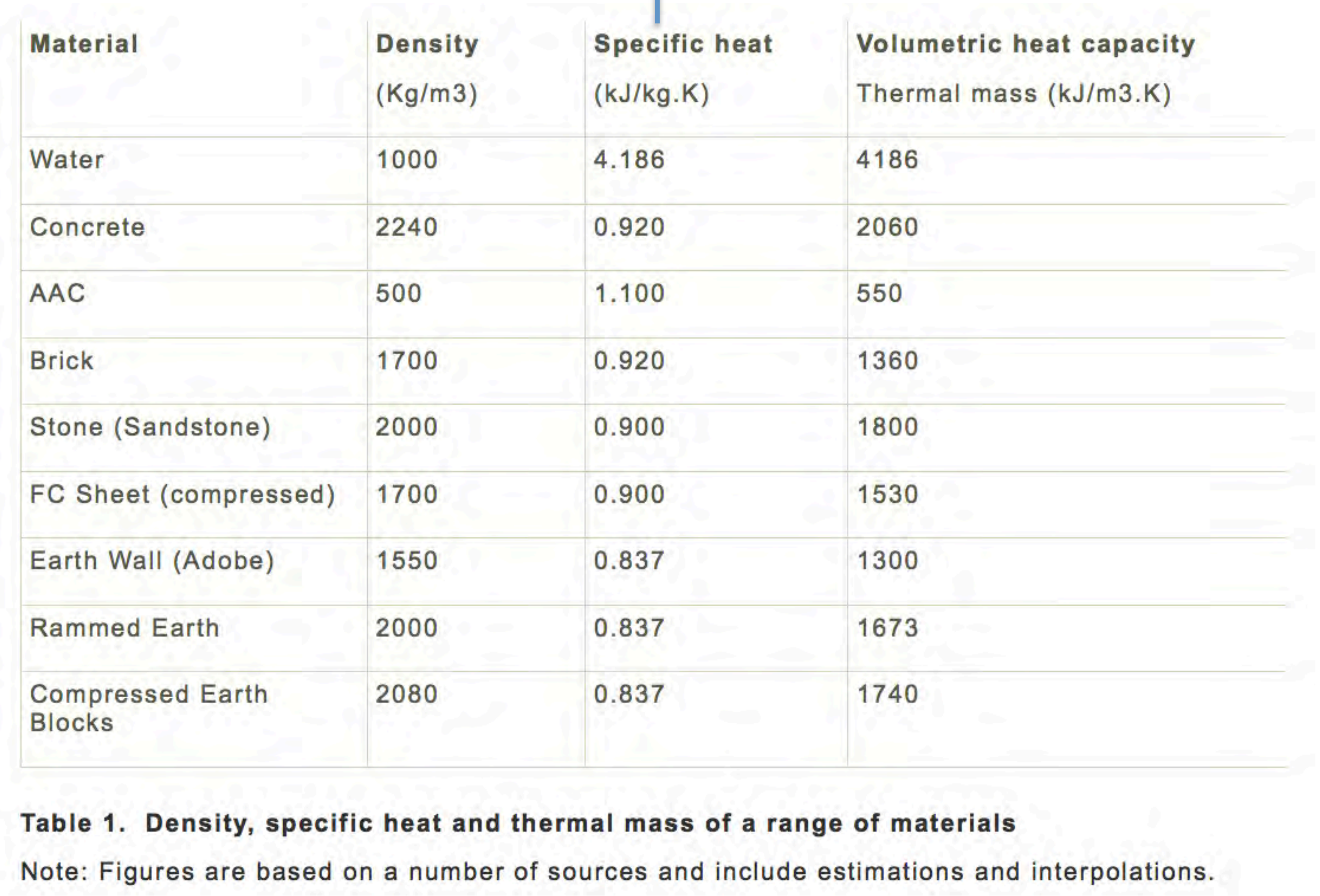


Thermal mass effects on diurnal indoor temperatures of comparative insulated cavity brick & lightweight structures (Think Brick Australia 2006)

Working with Mass Latency or Thermal Lag

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

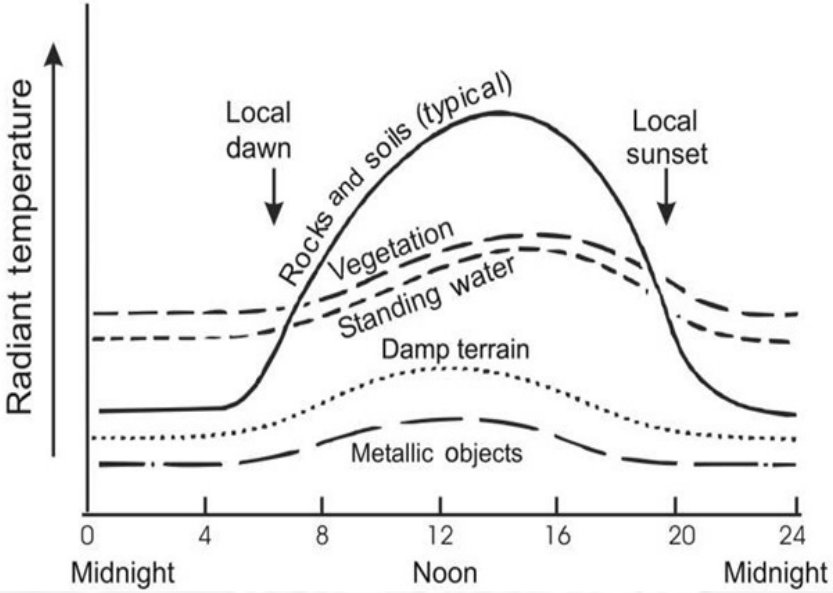
Table 1. Density, specific heat and thermal mass of a range of materials

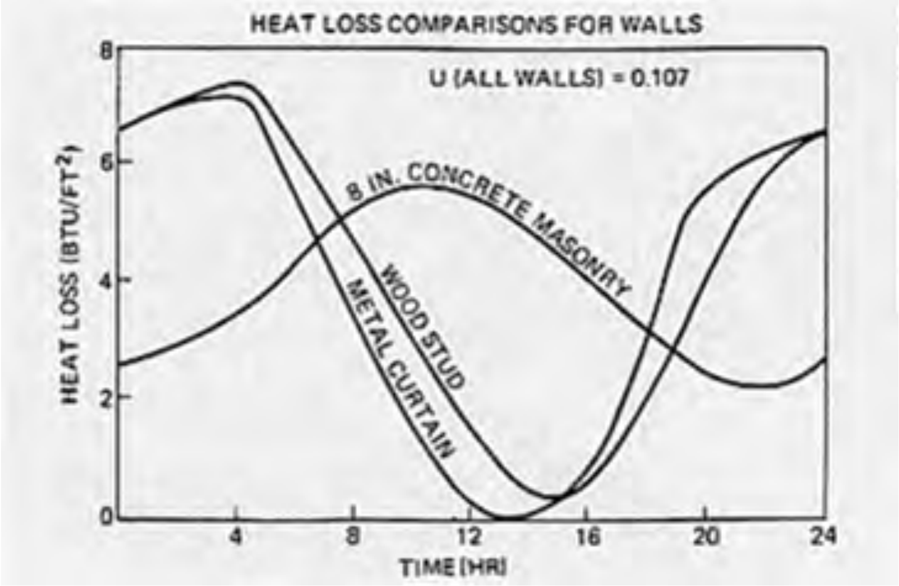
Note: Figures are based on a number of sources and include estimations and interpolations.

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

Working with Mass Latency or Thermal Lag

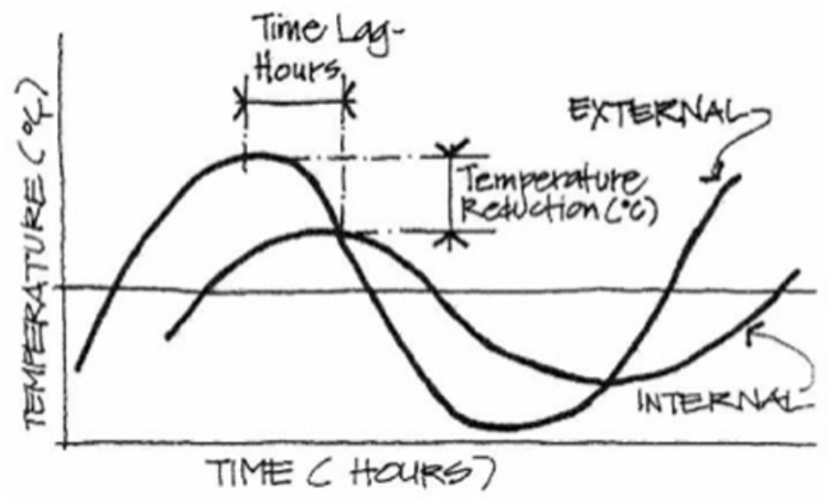
Radiant energy stored by different materials during the 24 hours



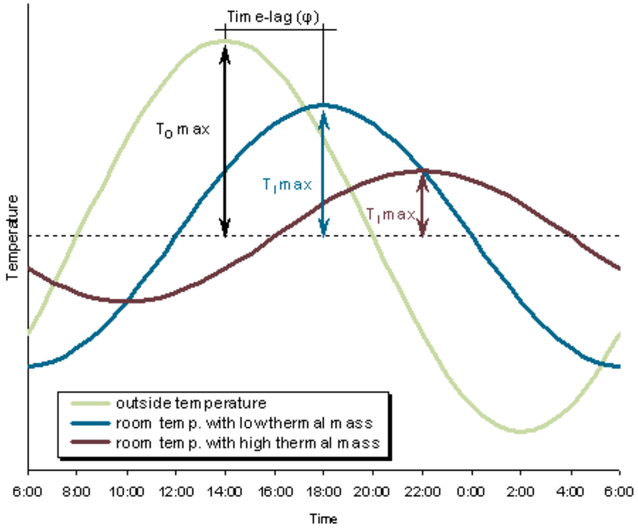


Working with Mass Latency or Thermal Lag

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



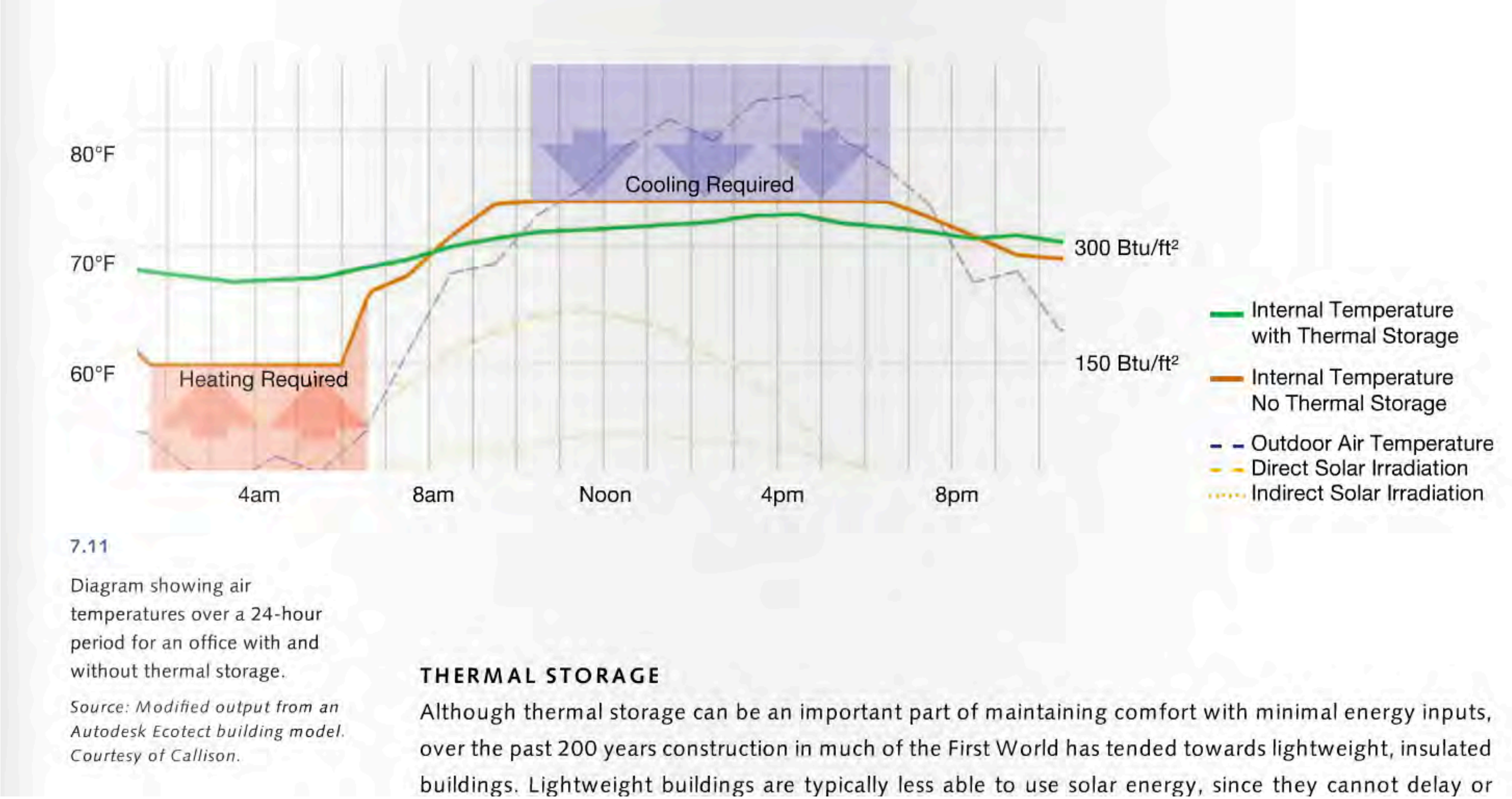
Material (thickness in mm)	**Time lag** (hours)
Insulated Brick Veneer	5.0
Concrete (250)	6.9
Double Brick (250)	7.0
AAC (200)	7.0
Adobe (250)	9.2
Rammed Earth (250)	10.3
Compressed Earth Blocks (250)	10.5
Sandy Loam (1000)	30 days

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.

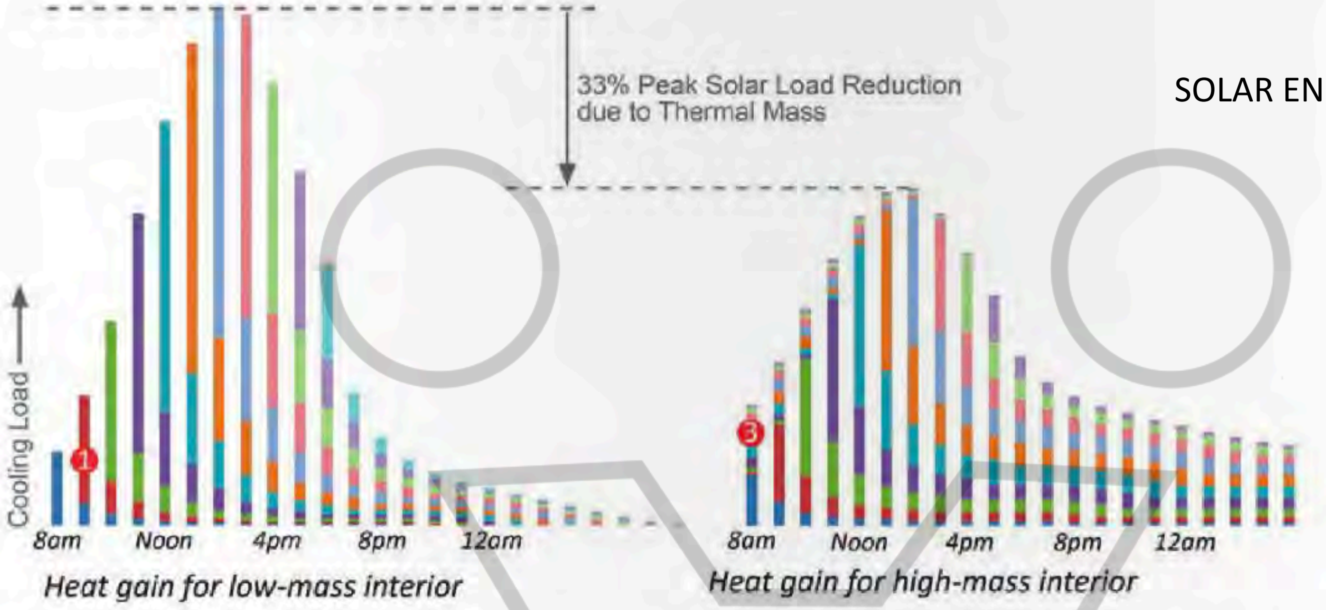
THERMAL STORAGE

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

Working with Mass Latency or Thermal Lag

Effect of Thermal mass storage

SOLAR ENERGY TIME DELAY



Heat gain for low-mass interior

Heat gain for high-mass interior

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%	-	-	-	-	-	-	-	-	-	-	-

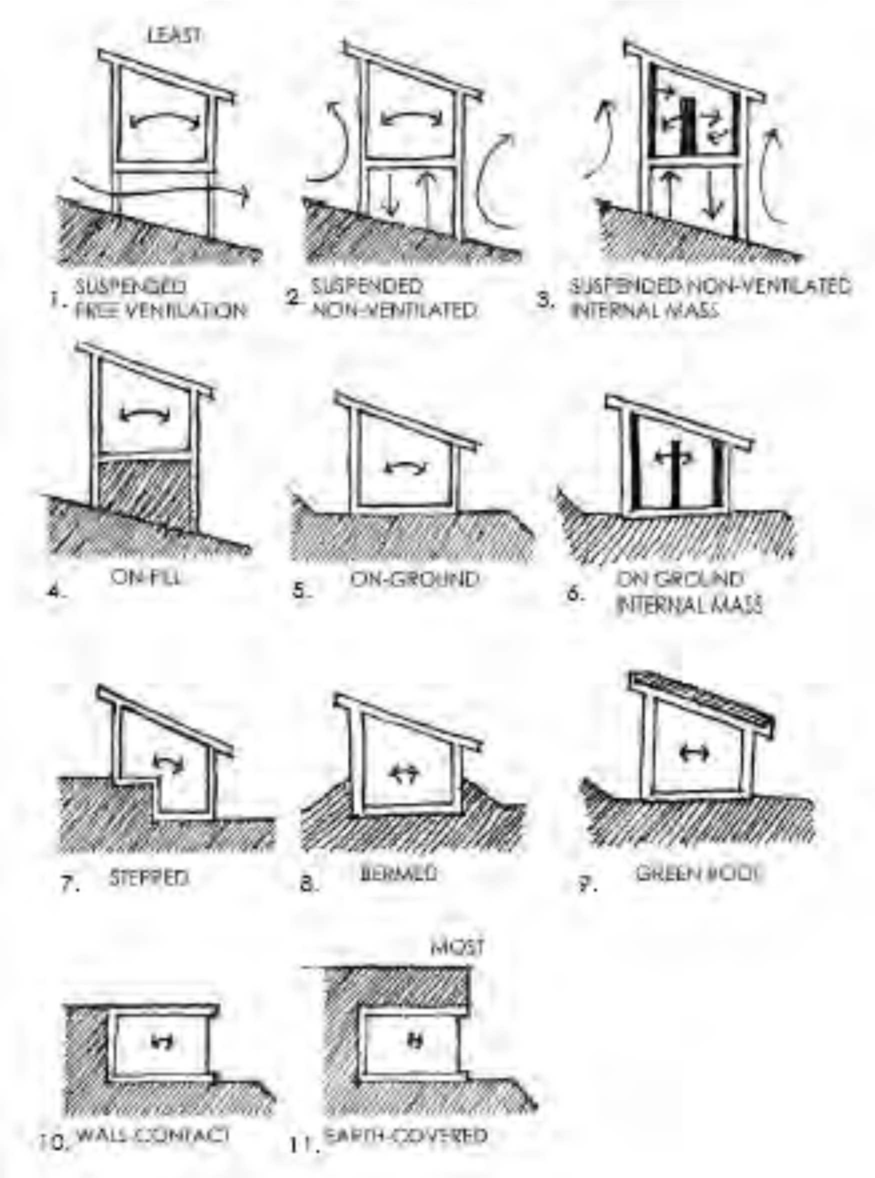
7.12

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

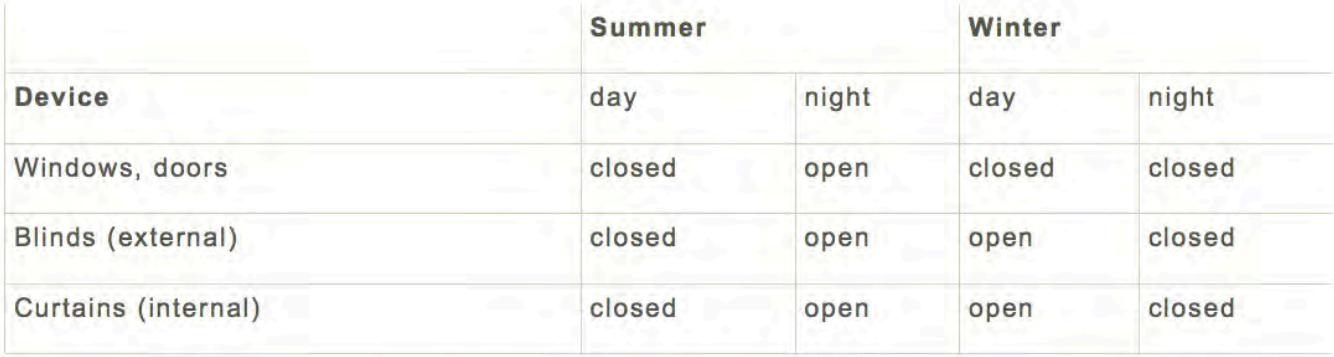
- medium and high-rise commercial and educational structures,

(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.

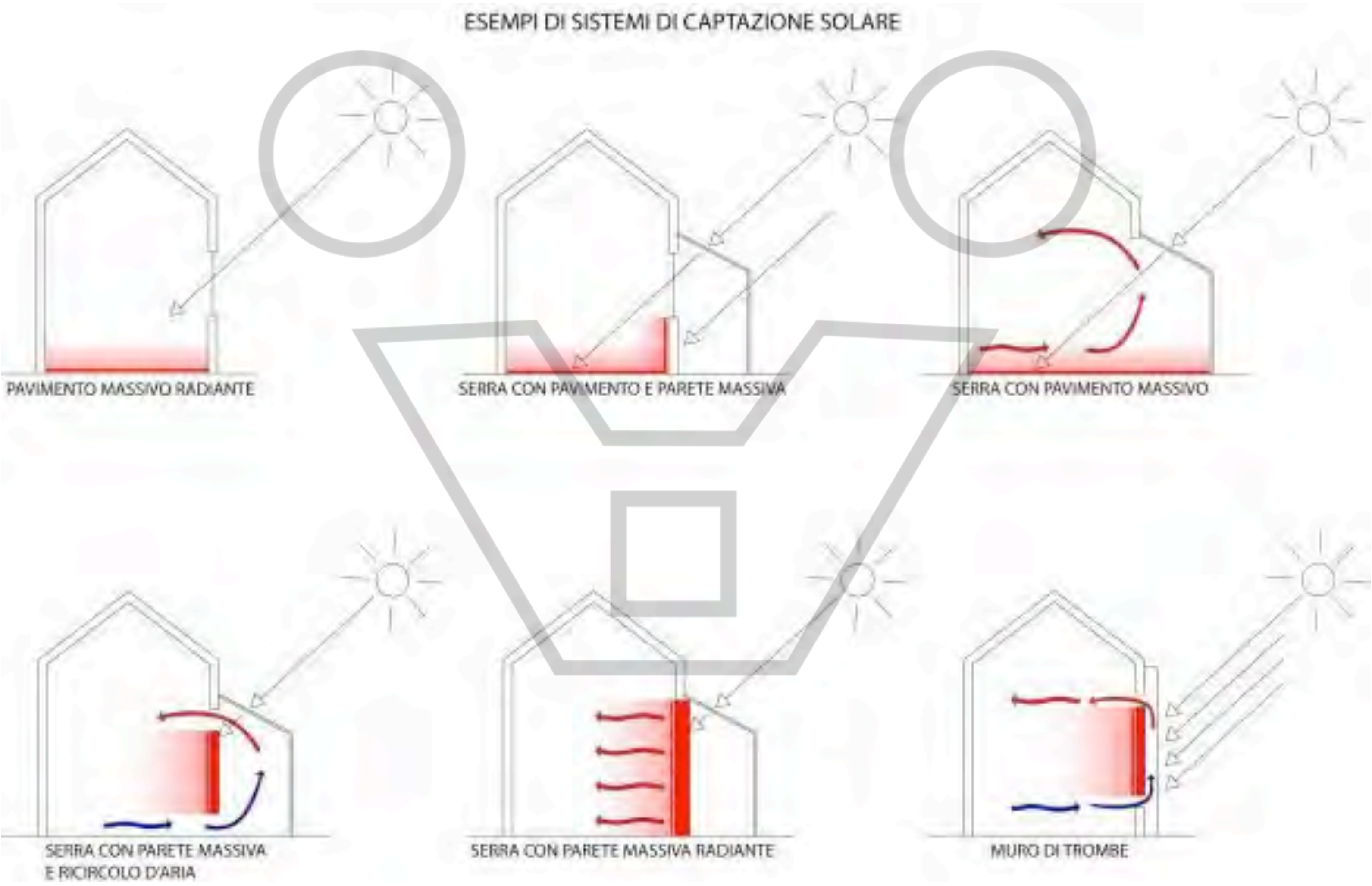


	Summer		**Winter**	
Device	day	night	day	night
Windows, doors	closed	open	closed	closed
Blinds (external)	closed	open	open	closed
Curtains (internal)	closed	open	open	closed

Table 2: User control of shading and ventilation devices

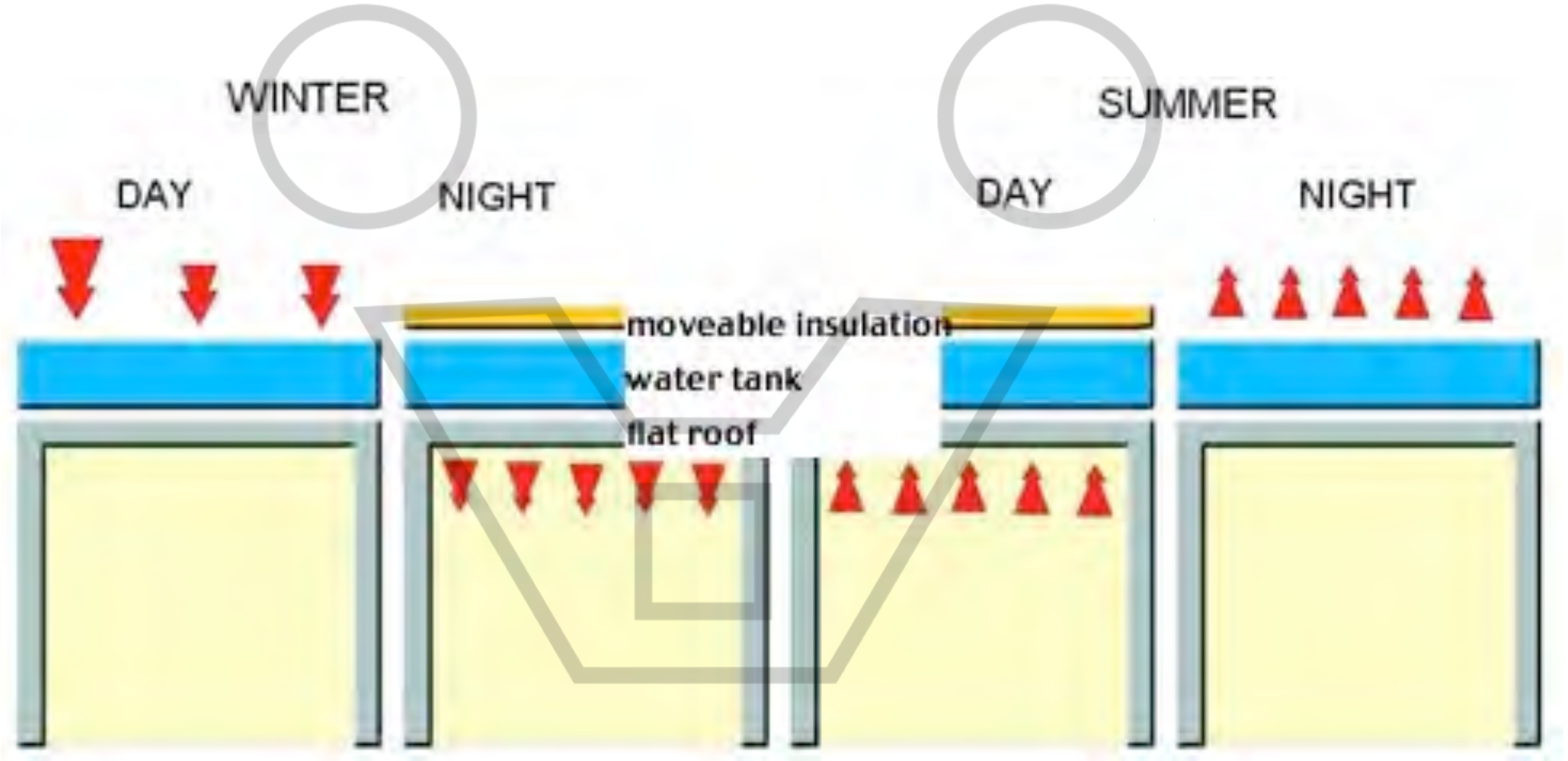
Working with Mass Latency or Thermal Lag

Locating mass in a building

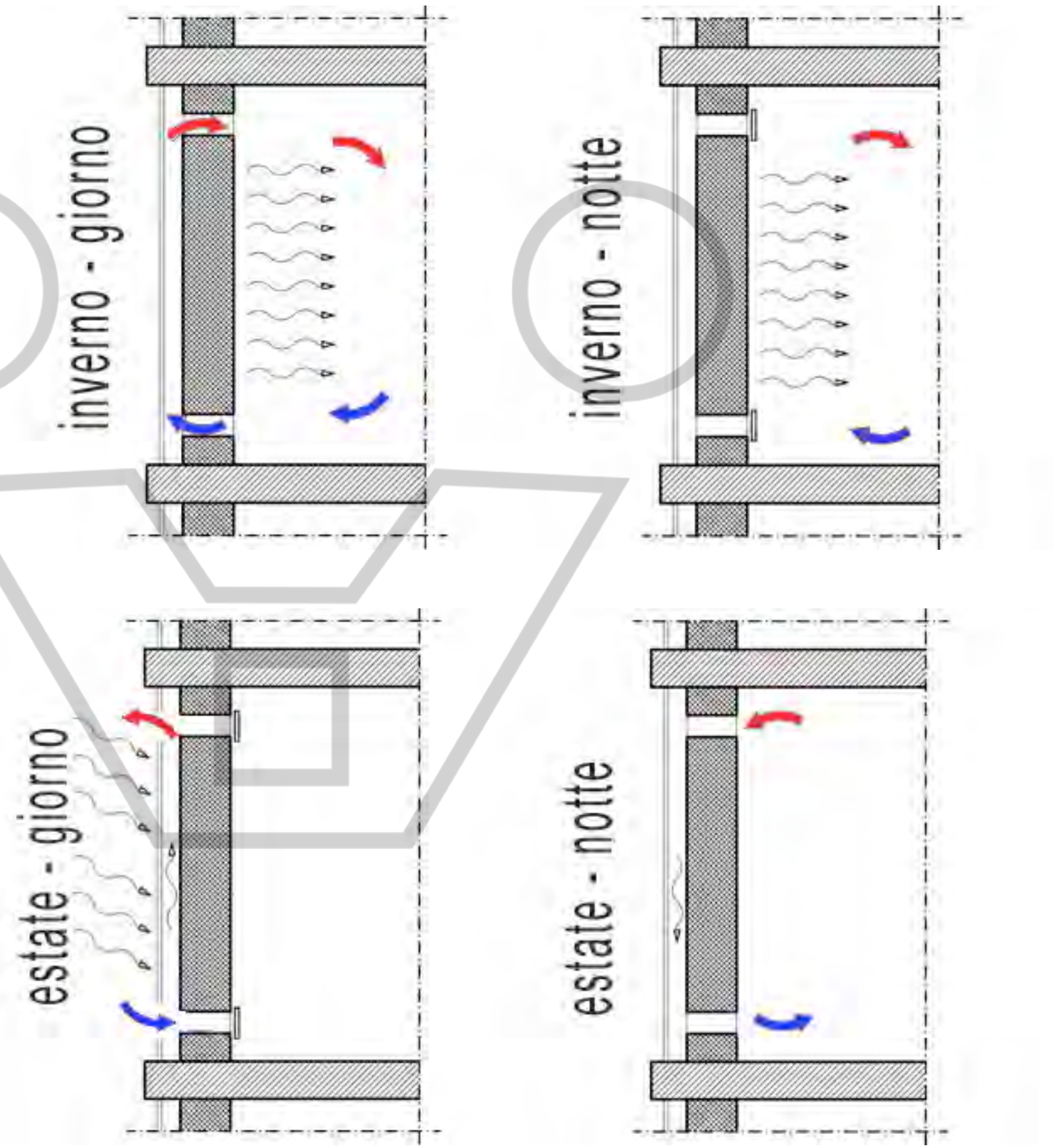


Locating mass in a building

THERMAL STORAGE FOR HOT ARID CLIMATE

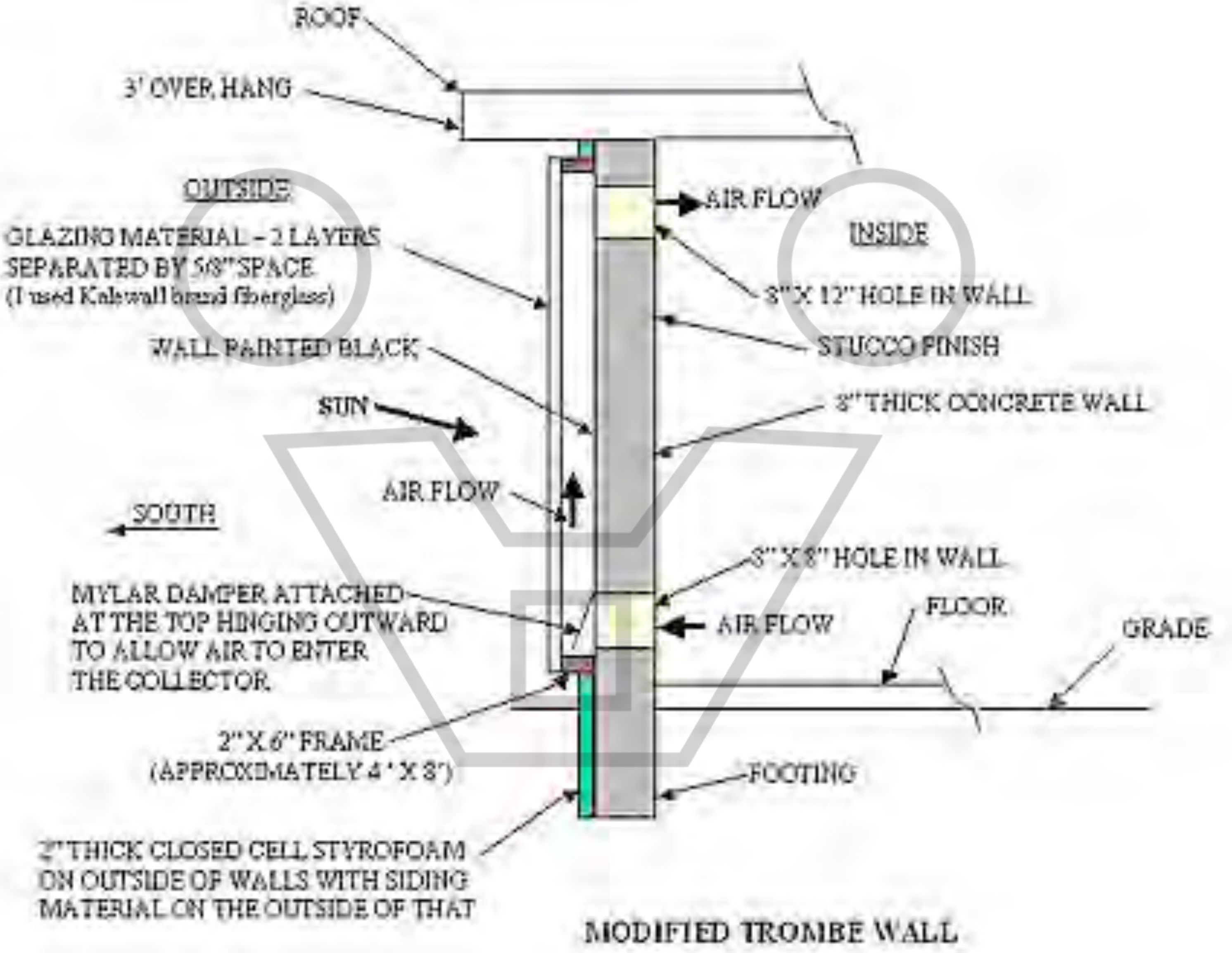


Trombe wall



Working with Mass Latency or Thermal Lag

Modified Trombe wall



Working with Mass Latency or Thermal Lag

Locating mass in a building