An Introduction to Building Physics

Sustainable Building Design Education

ACKNOWLEDGEMENT

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Introduction to Building Physics: Outline

- **Introduction**
- **Purpose of Buildings**
- **Thermal Performance of Buildings**
  - » Thermal Comfort
  - » Psychrometric Chart
  - » Optimizing energy use for thermal comfort
  - » Climate
  - » Internal loads
  - » Building Heat Transfer
  - » Mass Transfer
  - » Passive Strategies
  - » Active Strategies
- **Visual Performance of Buildings**
  - » Light basics
  - » Visual Comfort
  - » Optimizing energy use for visual comfort
  - » Climate
  - » Passive Strategies
  - » Active Strategies

Introduction

Building Physics

- Analysis of the state and operation of the building envelope
- Hygrothermal, acoustical and light related properties of building components (roofs, facades, windows, partition walls, etc.), rooms, buildings and building assemblies
- Essential for designing, constructing and operating high-performance buildings

NOTE: This module covers only the Thermal and Visual (light related) aspects of Building Physics

Purpose of Buildings

Occupant Comfort

Thermal comfort

Visual comfort

Acoustic comfort

Air quality

Building Envelope
- Walls
- Roofs
- Fenestration
- Foundations

Physical Processes
- Heat Transfer
- Moisture Transfer
- Air (mass) Transfer
- Light Transfer

Thermal Performance of Buildings

Thermal Comfort

"That condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation"

PERSONAL PARAMETERS
personal choices

- Activity (Metabolic rate)
- Clothing

ENVIRONMENTAL PARAMETERS
Building envelope and HVAC

- Air temperature
- Mean Radiant temperature
- Air speed
- Humidity

SOURCE: ANSI/ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy

Comfort Parameters - Personal

Activity (Metabolic rate)

- **M** (metabolic rate): the rate of transformation of chemical energy into heat and mechanical work by metabolic activities within an organism, usually expressed in terms of unit area of the total body surface or met units

- **1 met** = 58.2 W/m^2, which is equal to the energy produced per unit surface area of an average person, seated at rest

Activity	Metabolic Rates [M]	
	Met Units	W/m^2
Sleeping	0.7	40
Standing, relaxed	1.2	70
Car driving	1.2-2.0	60-115
Walking at 0.9m/s	2.0	115
Cooking	1.6-2.0	95-115
Playing Basketball	5.0-7.6	290-440

SOURCE: ANSI/ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy

Comfort Parameters - Personal

Body surface area (A_{DU})

	Weight [kg]				
Height [cm]	40	50	60	70	80
190	1.56	1.70	1.84	1.96	2.08
180	1.49	1.64	1.77	1.89	2.00
170	1.43	1.57	1.69	1.81	1.91
160	1.37	1.50	1.62	1.73	1.83
150	1.30	1.42	1.54	1.65	1.75

Comfort Parameters - Personal

Clothing Insulation

- clo: a unit used to express the thermal insulation provided by garments and clothing ensembles
- 1 clo = 0.155 $m^2 \cdot K/W$

Ensemble Description	I_{cl} (Clo)
Trousers + short-sleeved shirt	0.57
Long-sleeved coveralls + T-shirt	0.72
Sweat pants + sweat shirt	0.74
Trousers + long-sleeved shirt + suit jacket	0.96
Insulated coveralls + long-sleeved thermal underwear (+ bottoms)	1.37

Comfort Parameters - Environmental

Air Temperature

- The average temperature of the air surrounding the occupant
- Usually given in degrees Celsius (°C) or degrees Fahrenheit (°F)
- Affects the sensible cooling load

Mean Radiant Temperature

- Uniform temperature of an imaginary black enclosure in which radiant heat transfer from the human body equals the radiant heat transfer in the actual non-uniform enclosure
- Spatial average of the temperature of surfaces surrounding the occupant weighted by their view factors with respect to the occupants

SOURCE: ANSI/ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy

Comfort Parameters - Environmental

Radiation exchange

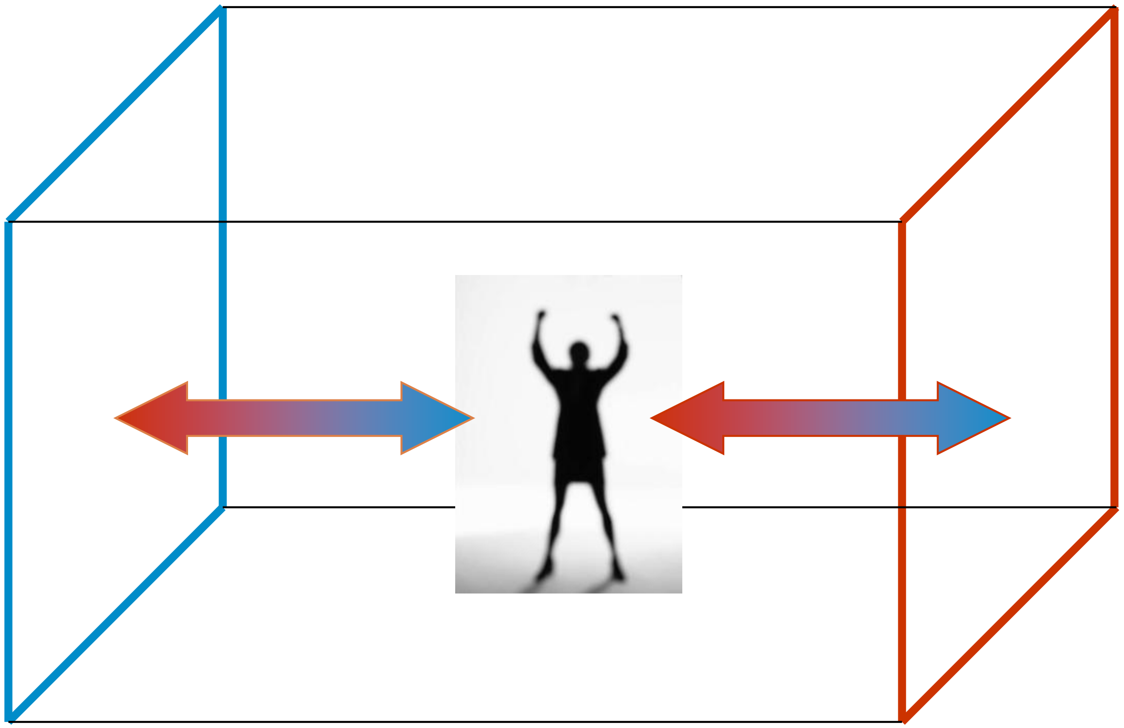
θ_U mean radiant temperature (MRT)

Rough approximation:

$$\theta_U \approx \frac{(\sum A_i \theta_i)}{\sum A_i}$$

θ Surface temperature

A Area



Comfort Parameters - Environmental

Air Speed

- The average speed of the air to which the body is exposed
- A certain minimum desirable wind speed is needed for achieving thermal comfort at different temperatures and relative humidity values

Dry Bulb Temperature	Relative Humidity (Percentage)						
Cº	30	40	50	60	70	80	90
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
28	*	*	*	*	*	*	*
29	*	*	*	*	*	*	*
30	*	*	*	*	*	*	*
31	*	*	*	*	*	0.06	0.23
32	*	*	*	0.09	0.29	0.60	0.94
33	*	0.04	0.24	0.60	1.04	1.85	2.10
34	0.15	0.46	0.94	1.60	2.26	3.05	**
35	0.68	1.36	2.10	3.05	**	**	**
36	1.72	2.70	**	**	**	**	**

*None

**Higher then those acceptable in practice.

Minimum Wind Speeds (m/s) for Just Acceptable Warm Conditions

Dry Bulb Temperature	Relative Humidity (Percentage)						
Cº	30	40	50	60	70	80	90
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
28	*	*	*	*	*	*	*
29	*	*	*	*	*	0.06	0.19
30	*	*	*	0.06	0.24	0.53	0.85
31	*	0.06	0.24	0.53	1.04	3.04	2.10
32	0.20	0.46	0.94	1.59	2.26	**	**
33	0.77	1.36	2.12	3.00	**	**	**
34	1.85	2.72	**	**	**	**	**
35	3.20	**	**	**	**	**	**

*None

**Higher then those acceptable in practice.

Desirable Wind Speeds (m/s) for Thermal Comfort Conditions

SOURCE: ANSI/ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy; Bureau of Indian Standards, National Building Code of India 2005, Part 8 Building Services, Section 1 Lighting and Ventilation

Comfort Parameters - Environmental

Humidity

- Moisture content of the air
- Expressed in terms of several thermodynamic variables, including vapor pressure, dew point temperature, relative humidity and humidity ratio
- Affects the latent cooling load

Comfort Parameters & Design Implications

	Parameters	Significance	Design/IEQ Implications
Personal	ACTIVITY LEVEL	Poses a problem to designers if an indoor space has to be designed for people with different activity levels	Determines thermal output of individuals which directly affects cooling/heating load of a conditioned space
	CLOTHING INSULATION	Important factor in the perception of thermal comfort; use of clothing to adjust to thermal environment is a good example of adaptive control.	In office environment, chair upholstery can increase the resistance by as much as 0.15 clo; difference in the clo values of male and female dresses should be taken into account while designing indoor environment
Environmental	AIR TEMPERATURE	Most important parameter for determining thermal comfort	Determines thermostat set points, sensible loads and influences the perception of Indoor Environmental Quality (IEQ)
	MEAN RADIANT TEMPERATURE	Key factor in the perception of thermal discomfort resulting from radiant asymmetry	Can reduce the requirement of conditioned air
	AIR SPEED	Key factor in the perception of draft due to elevated air velocity	Can be used to reduce thermal discomfort in conjunction with passive design
	RELATIVE HUMIDITY	Excessive dry or humid conditions are immediately perceived as uncomfortable	Enthalpy-based economizer, although difficult to control has good potential to save energy and provide greater thermal comfort

Thermal Comfort Indices

PMV/PPD

- *Predicted Mean Vote (PMV):* An index that predicts the main value of the votes of a large group of persons on the seven point thermal sensation scale
- *Predicted Percentage Dissatisfied (PPD):* An index that establishes a quantitative prediction of the percentage of thermally dissatisfied people determined form PMV

SOURCE: http://www.esru.strath.ac.uk/Reference/concepts/thermal_comfort.htm

Thermal Comfort Indices

PMV/PPD

Scale

-3 cold

-2 cool

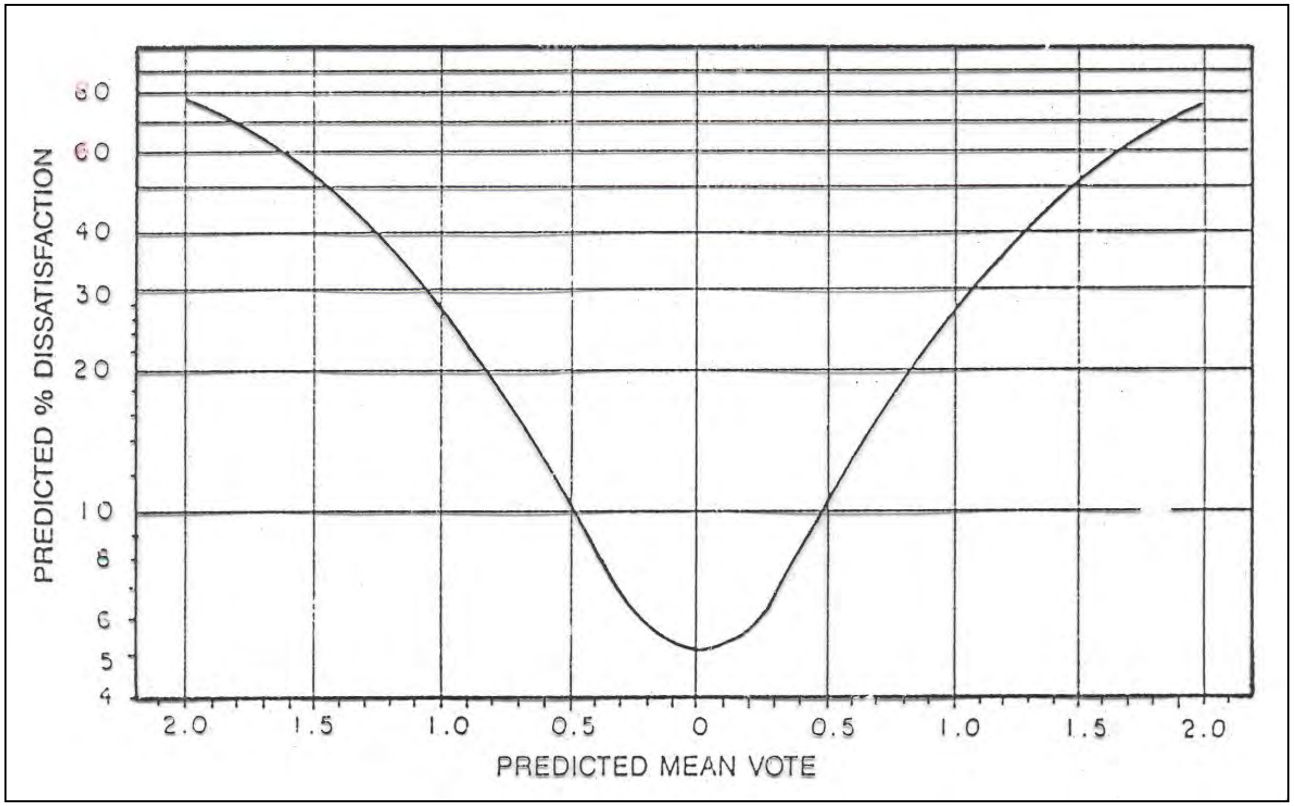
-1 slightly cool

0 neutral

1 slightly warm

2 warm

3 hot



PPD – Predicted Percentage of Dissatisfied

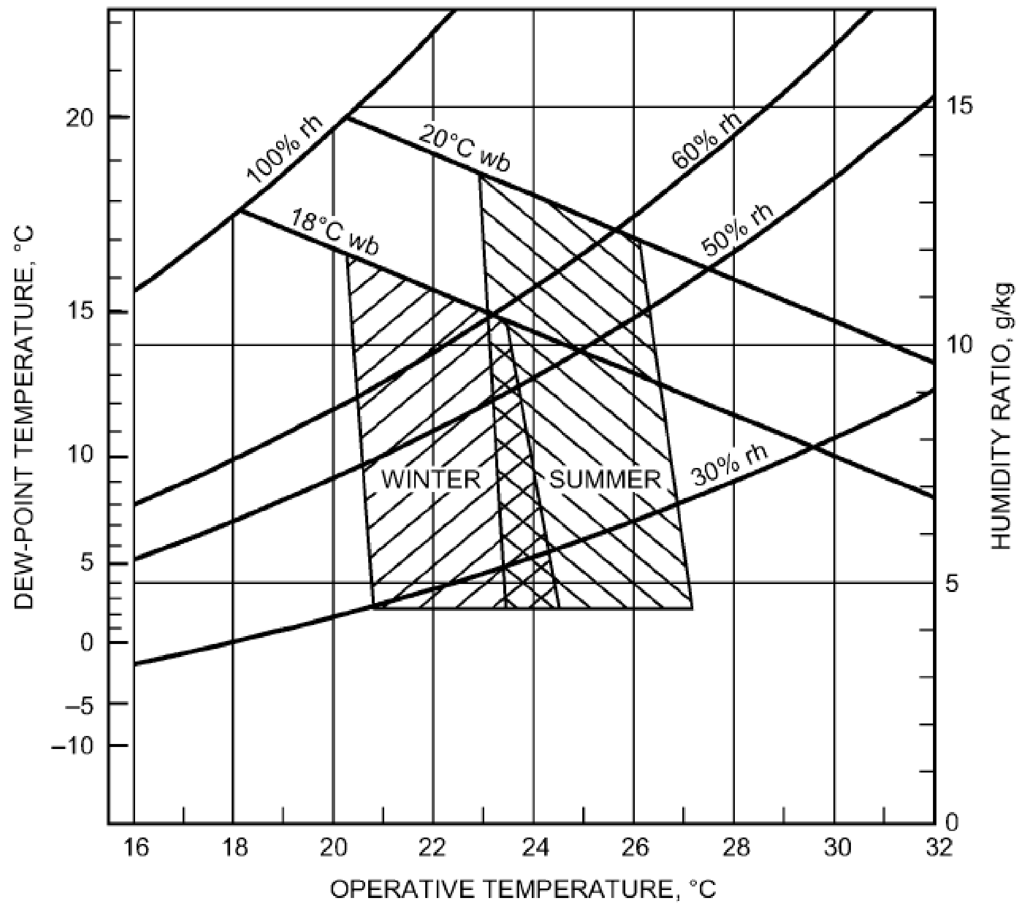
PMV – Predicted Mean Vote

Thermal Comfort Indices

Thermal comfort – Recommendations

Example: ASHRAE Standard 55-2004

- Summer and winter comfort zones (for 80% satisfaction rate, defined based on thermal sensation scale from -0.5 to +0.5)
- sedentary or slightly active people
- Clo-value: 0.9 (winter), 0.5 (summer)



*Borders of the comfort zones coincident with lines of constant ET**

Thermal Comfort Indices

Adaptive comfort theory

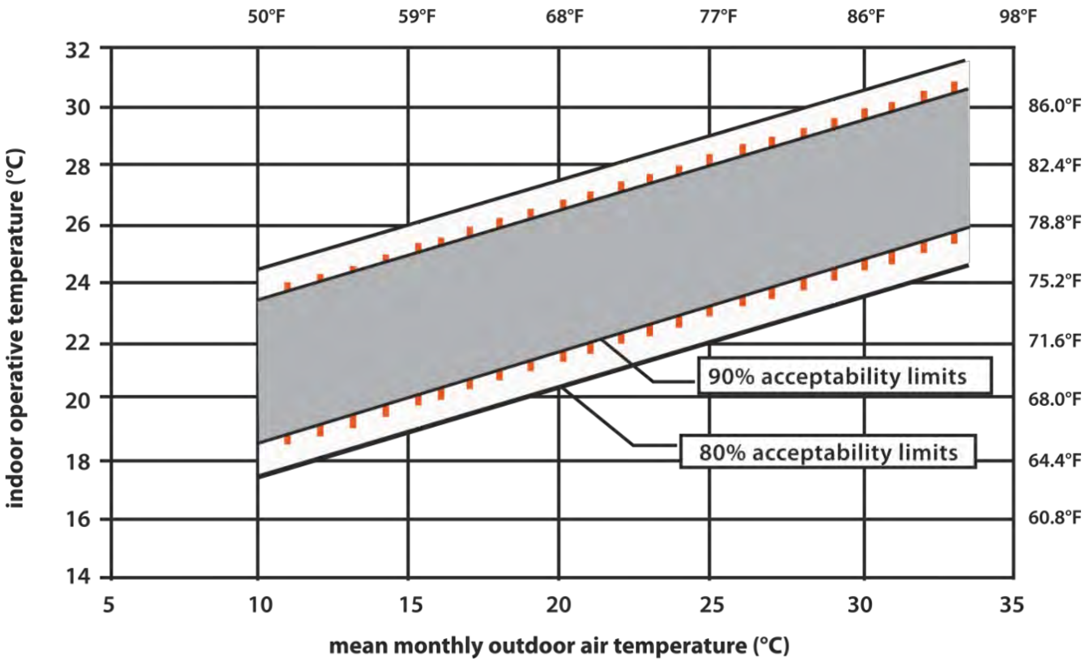
ASHRAE Standard 55-2004

- People naturally adapt and make adjustments in order to reduce discomfort
- Short term adjustments: altering clothing, posture, activity level, rate of working, diet, ventilation, air movement
- Long term adjustments: control of shivering, skin blood flow, sweating
- Important factor behind adaptive process: outside weather conditions

$$t_{oc} = 18.9 + 0.255 \times t_{out}$$

t_{oc} operative comfort temperature

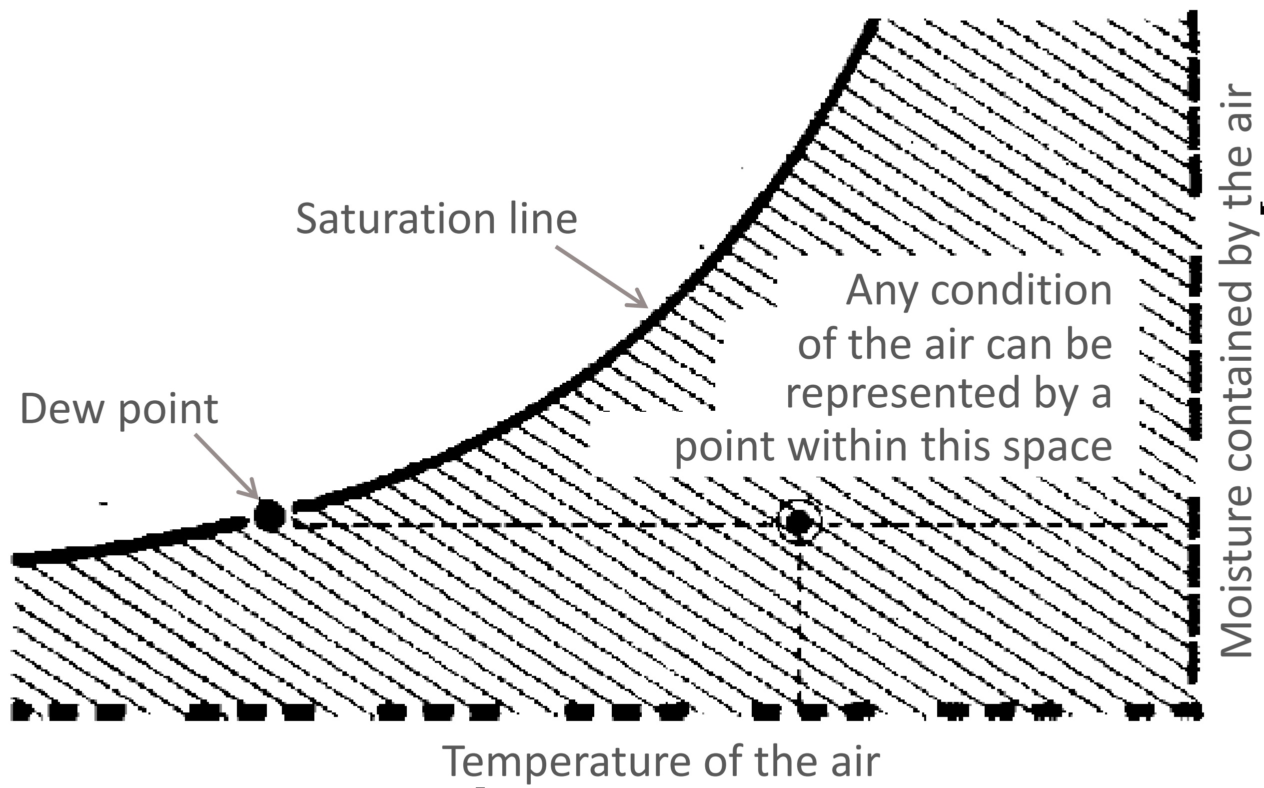
t_{out} mean outside temperature of the month [°C]



Psychrometric Chart

Psychrometry

Study of the measurement of the moisture content of atmospheric air.
The term is commonly taken to mean the study of the atmospheric moisture and its effect on buildings and building systems.

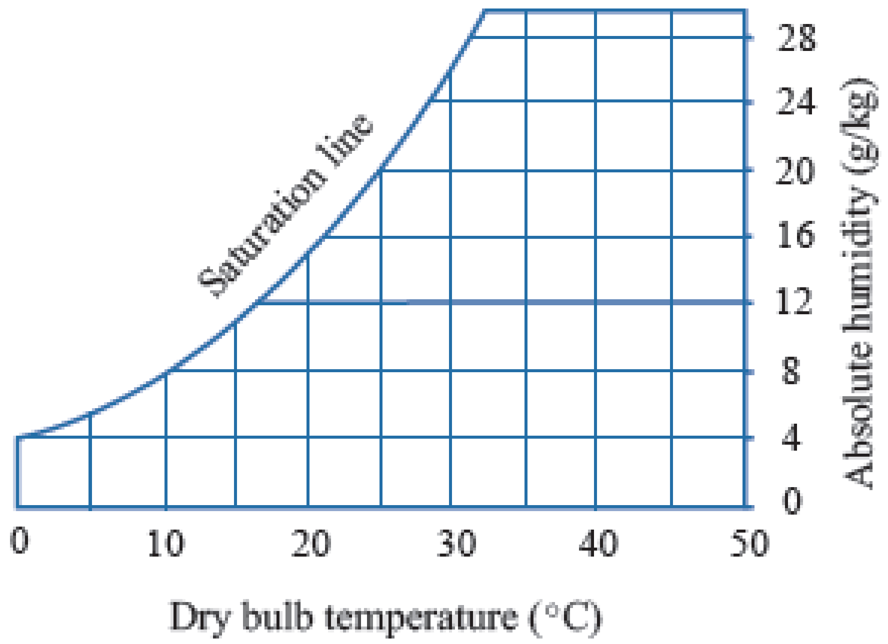


The basic relationship expressed by the Psychrometric chart

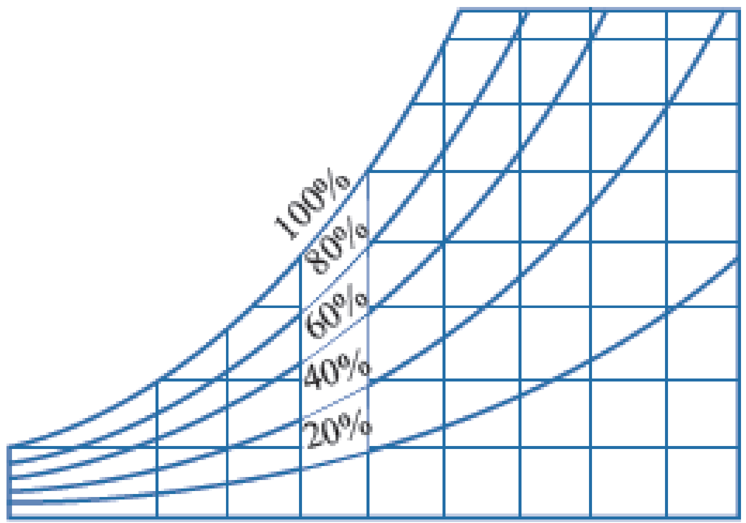
Psychrometric Chart

Humidity

Absolute humidity AH and saturation line



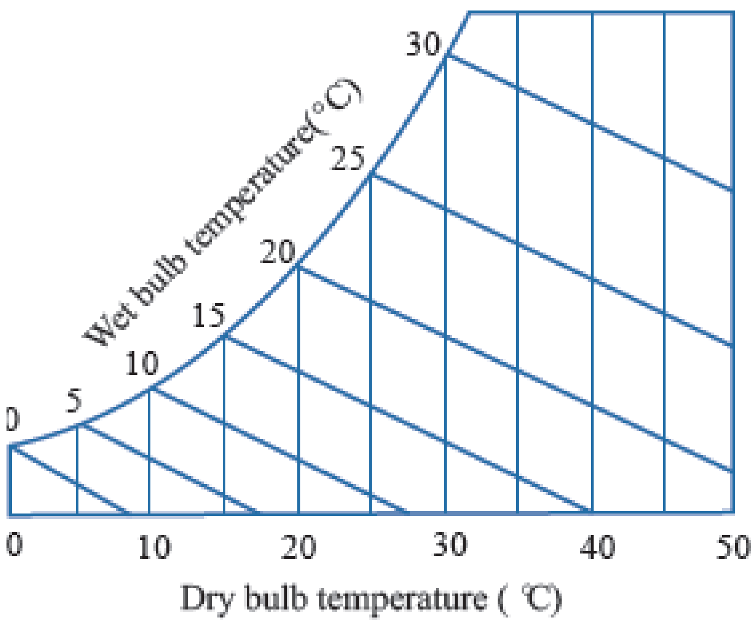
Relative humidity RH



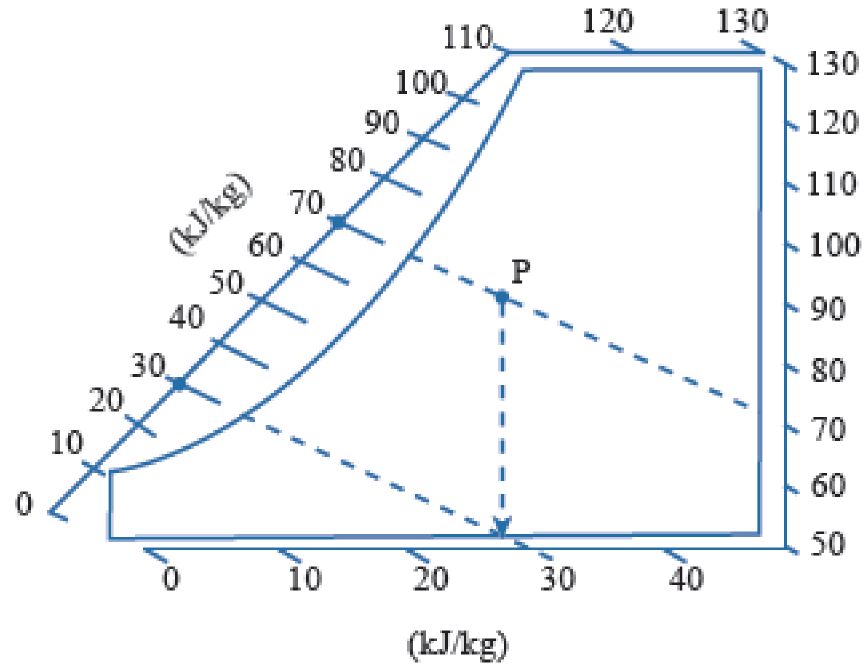
Psychrometric Chart

Humidity

Wet bulb temperature

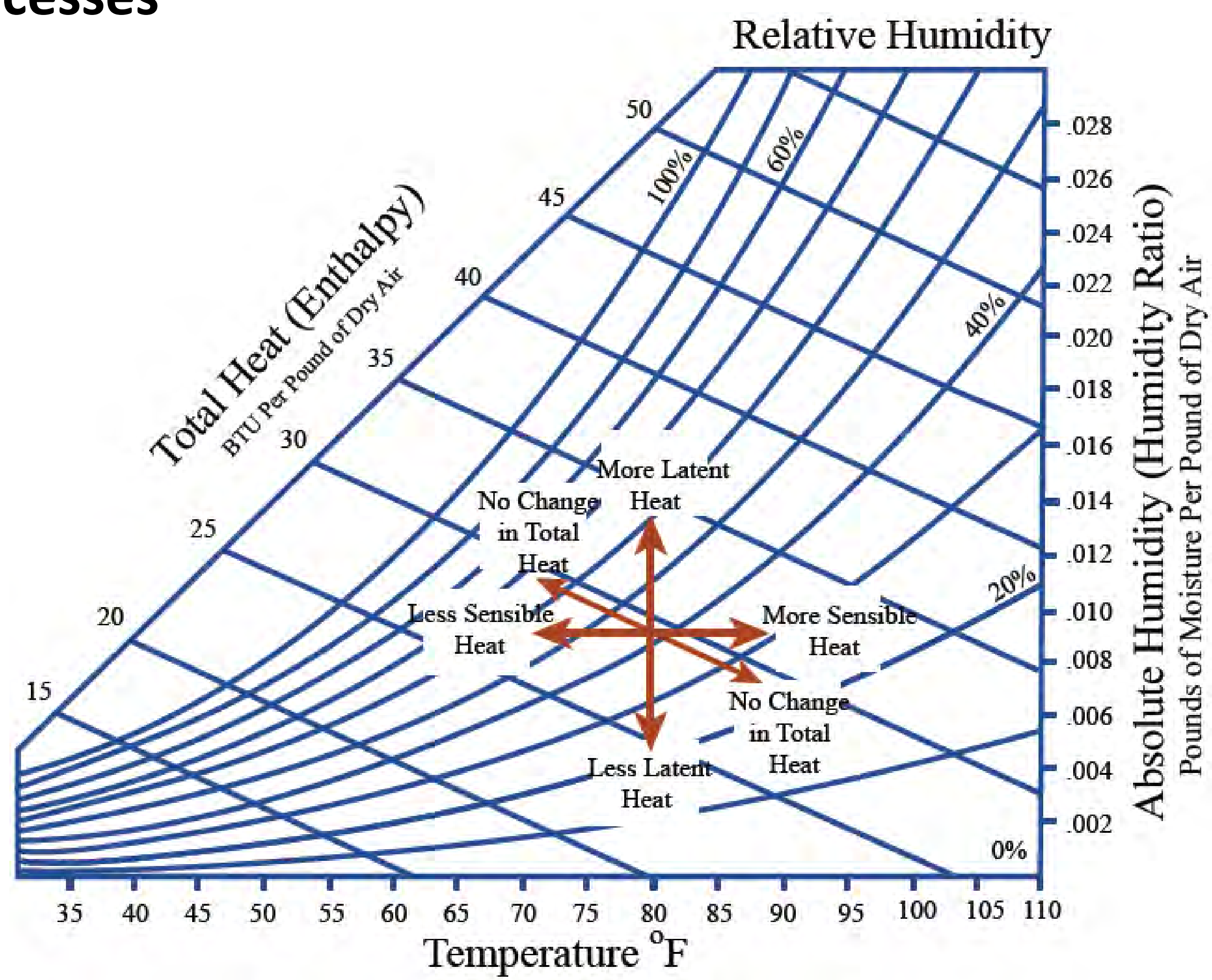


Enthalpy



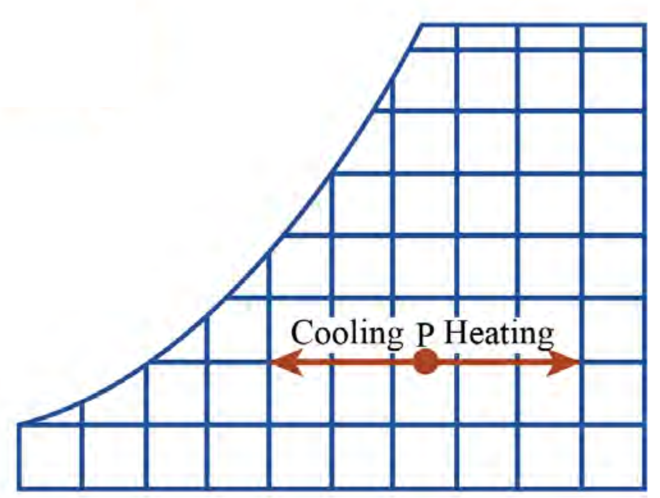
Psychrometric Chart

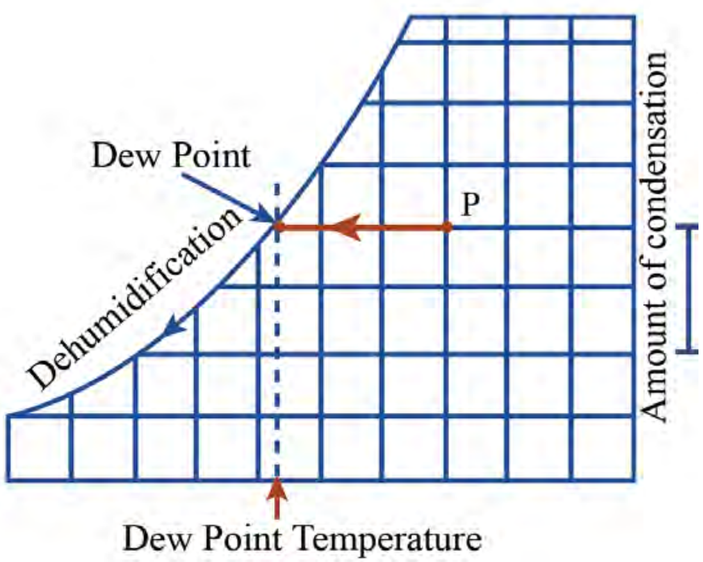
Psychrometric processes



Psychrometric Chart

Psychrometric processes





Heating and cooling

The addition or removal of heat, without any change in the moisture content absolute humidity (AH), resulting in the change in DBT. The status point will move horizontally to the left (cooling) or to the right (heating).

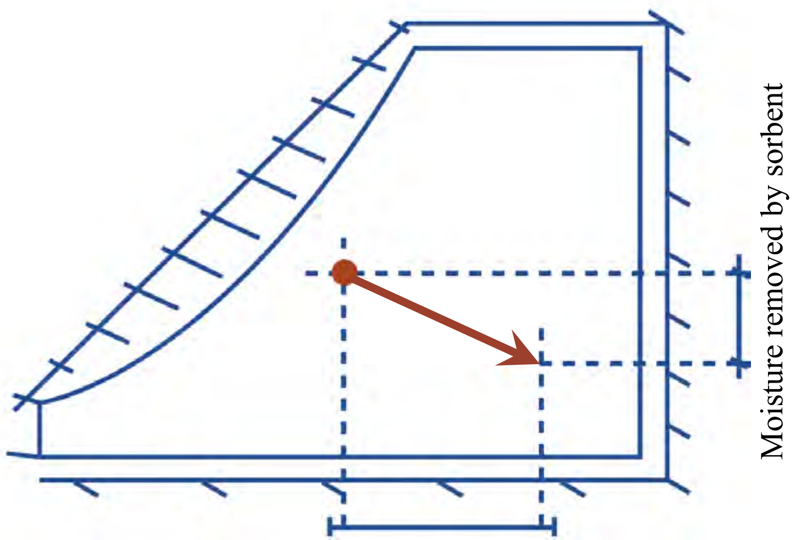
Note that while the AH does not change, the change in temperature means the relative humidity (RH) changes. It increases if the temperature lowers and vice versa.

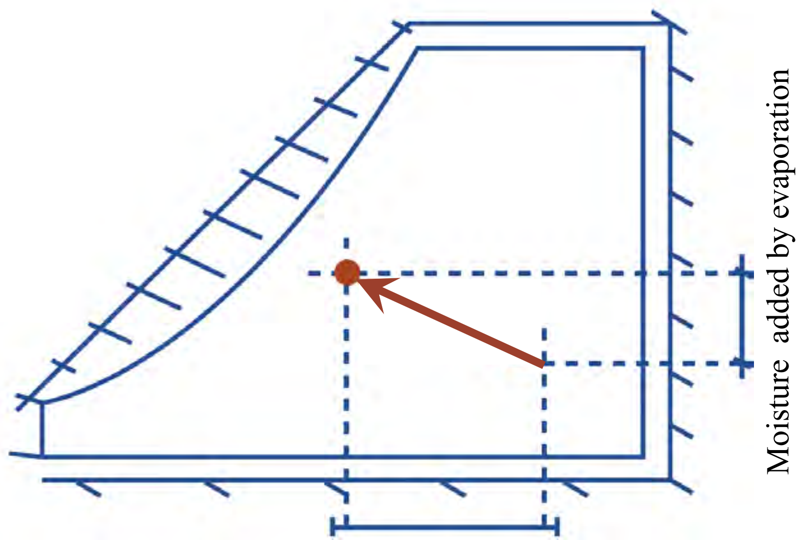
Dehumidification by cooling

If, as a result of cooling, the point moving towards the left reaches the saturation line, some condensation will start. The DBT corresponding to this point is referred to as the dew-point temperature of the original atmosphere. If there is further cooling, the status point will move along the saturation line and condensation will occur. The reduction in the vertical ordinate (on the AH scale) represents the amount of moisture precipitated i.e., condensed out. This process will reduce the absolute humidity, but will always end with 100% RH.

Psychrometric Chart

Psychrometric processes





Adiabatic humidification (Evaporative cooling)

If moisture is evaporated into an air volume without any heat input or removal (this is the meaning of the term 'adiabatic'), the latent heat of evaporation is taken from the atmosphere. The sensible heat content - thus the DBT - is reduced, but the latent heat content is increased. The status point moves up and to the left, along a WBT line. This is the process involved in evaporative cooling.

Note that by this process, the relative humidity is increased. It increases only until it hits the saturation line, at which it becomes 100%. Beyond it there is no decrease in sensible temperature. This is the reason why during hot and humid months, evaporative cooling is ineffective and uncomfortable.

Adiabatic dehumidification (by sorbents)

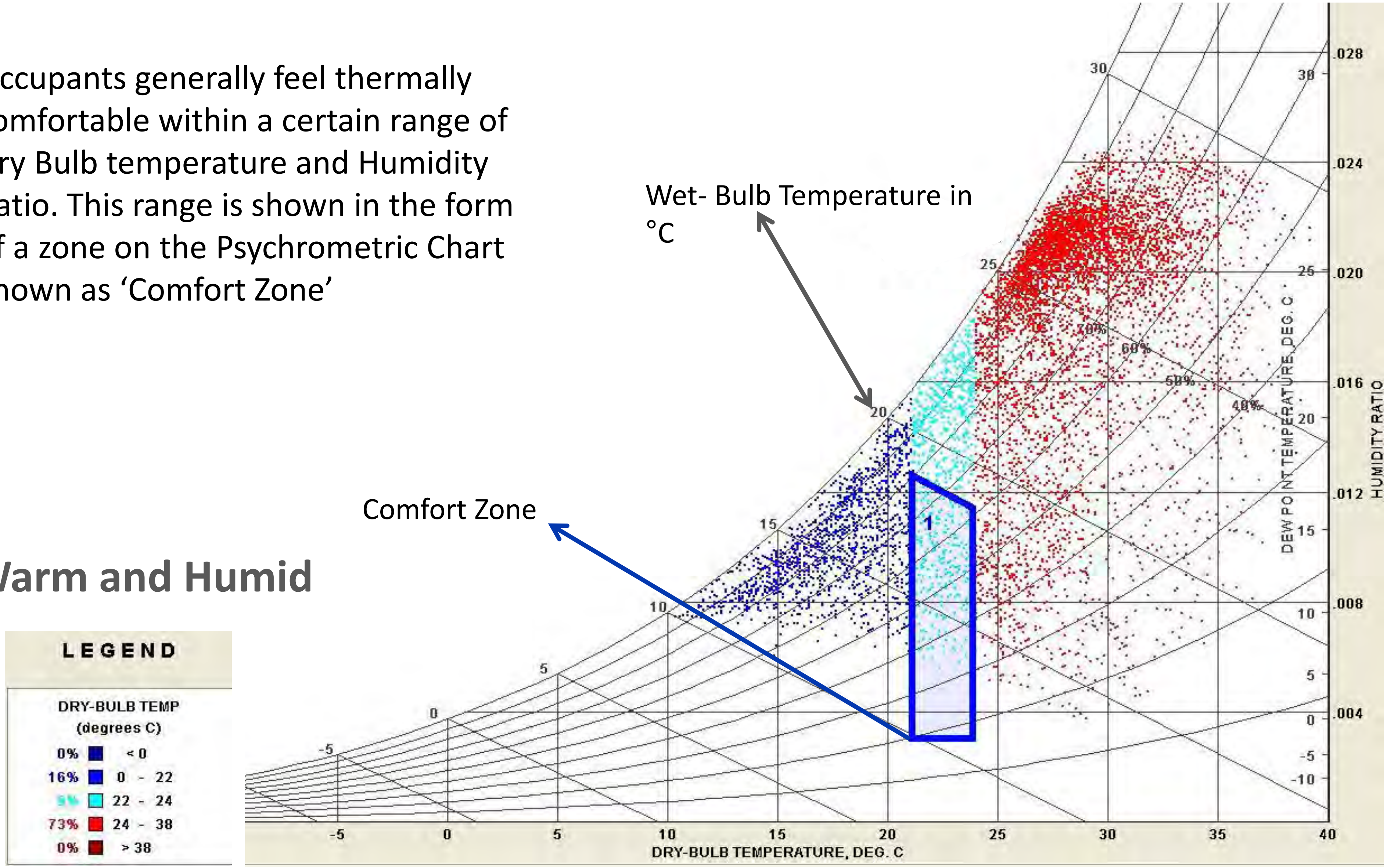
If the air is passed through a chemical sorbent material (e.g., silica gel), some of the moisture is removed and the latent heat of evaporation is released. There will be an increase in sensible heat content, thus in the system (i.e., if the process is adiabatic), the state point will move down and towards the right along an enthalpy line. This process, in effect is the reverse of the previous one.

SOURCE: MIT OpenCourseWare http://ocw.mit.edu/courses/architecture/; http://www.suryakund.com/BCDC/chart/chart2.html

Psychrometric Chart

Occupants generally feel thermally comfortable within a certain range of Dry Bulb temperature and Humidity Ratio. This range is shown in the form of a zone on the Psychrometric Chart known as 'Comfort Zone'

Warm and Humid



SOURCE: Climate Consultant Software

Optimizing energy use for thermal comfort

External Factors (Climate)

Temperature
Relative humidity
Solar Radiation
Wind Speed and Direction
Miscellaneous factors

Internal Factors (Loads)

People
Equipments
Lights

Passive Strategies

- Appropriate orientation
- Shading devices
- Daylight design
- Thermal mass (time lag)

Active Strategies

- Fans
- Evaporative Coolers
- Air-Conditioners

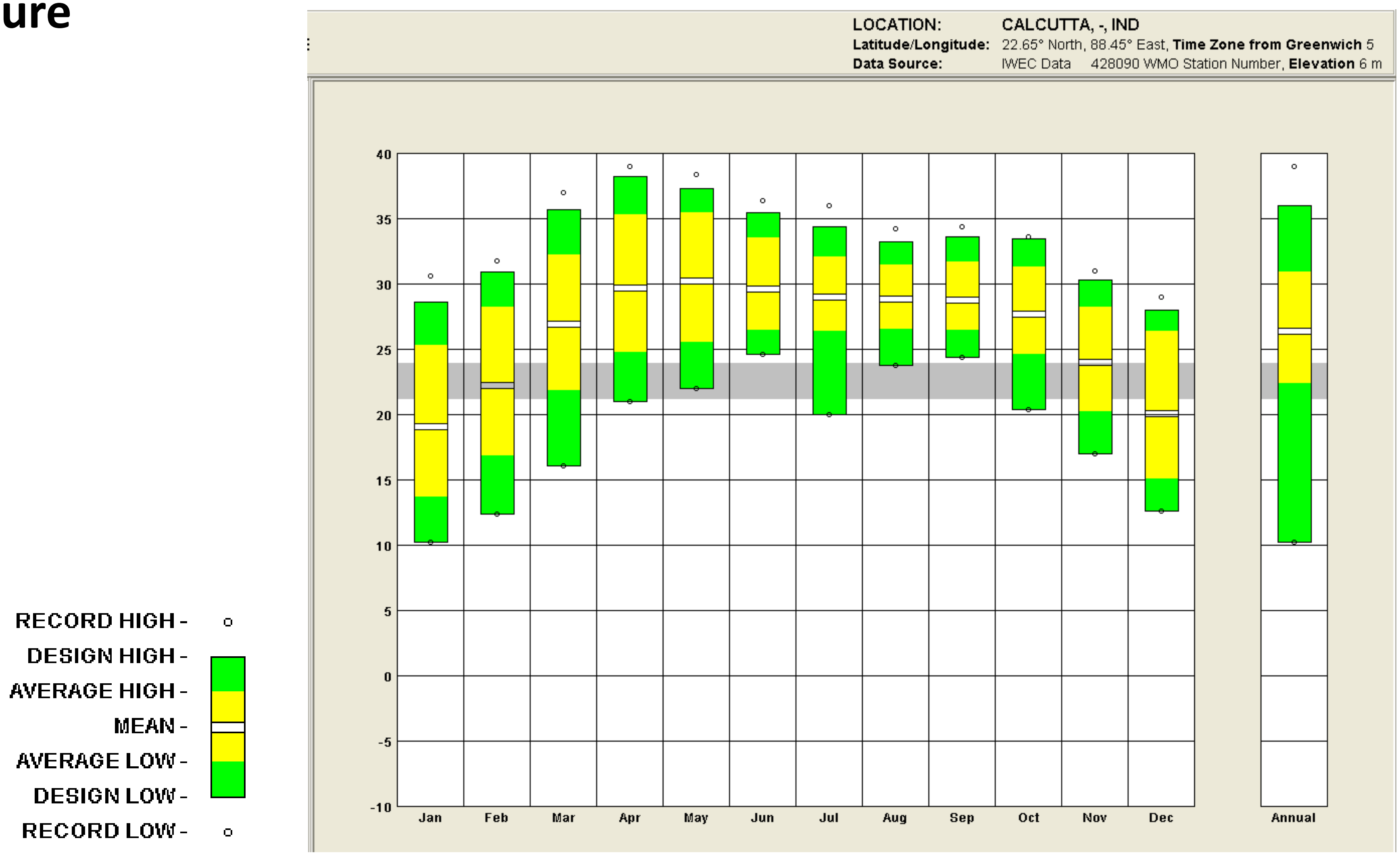
Climate

Temperature

- Dry Bulb Temperature: ambient air temperature
- Wet Bulb Temperature: temperature at which water (liquid or solid), by evaporating into moist air at dry-bulb temperature t and humidity ratio W, can bring air to saturation adiabatically at the same temperature t* while total pressure p is constant.
- Outdoor air temperature is a major climatic variable affecting energy demand
- The indices used to reflect demand for energy are usually discussed in terms of "degree days"
  - Heating Degree Days (HDD) & Cooling Degree Days (CDD)
  - Heat Transfer between the building envelope & external environment determines the heating/cooling needs for the building
  - Energy demand is directly proportional to the number of HDD/CDD

Climate

Temperature



SOURCE: Climate Consultant Software

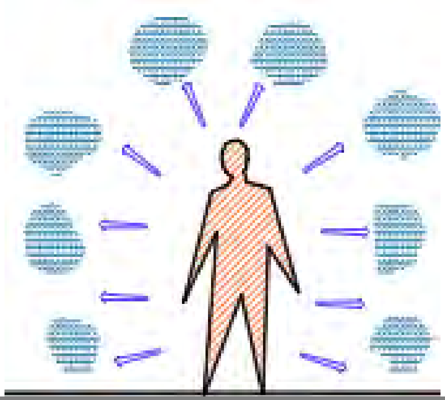
Climate

Relative Humidity

- Air humidity, which represents the amount of moisture present in the air, is usually expressed in terms of 'relative humidity' (Expressed as a percentage)
- In areas with high humidity levels :
  - Transmission of solar radiation is reduced
  - Evaporation is reduced
  - High humidity accompanied by high ambient temperature causes discomfort

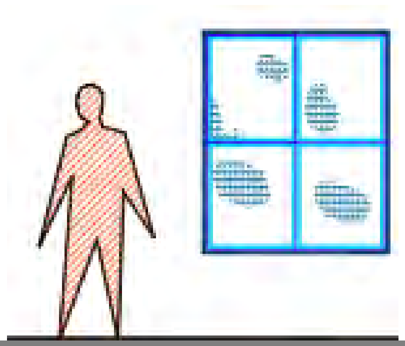
Effect of high temperature and high humidity

Causes discomfort is perspiration is not dissipated – air movement by cross ventilation can reduce discomfort



Effect of high temperature and low humidity

Dry air leads to faster rate of evaporation if accompanied by high temperature resulting in dehydration and heat stroke – evaporative cooling can provide comfort

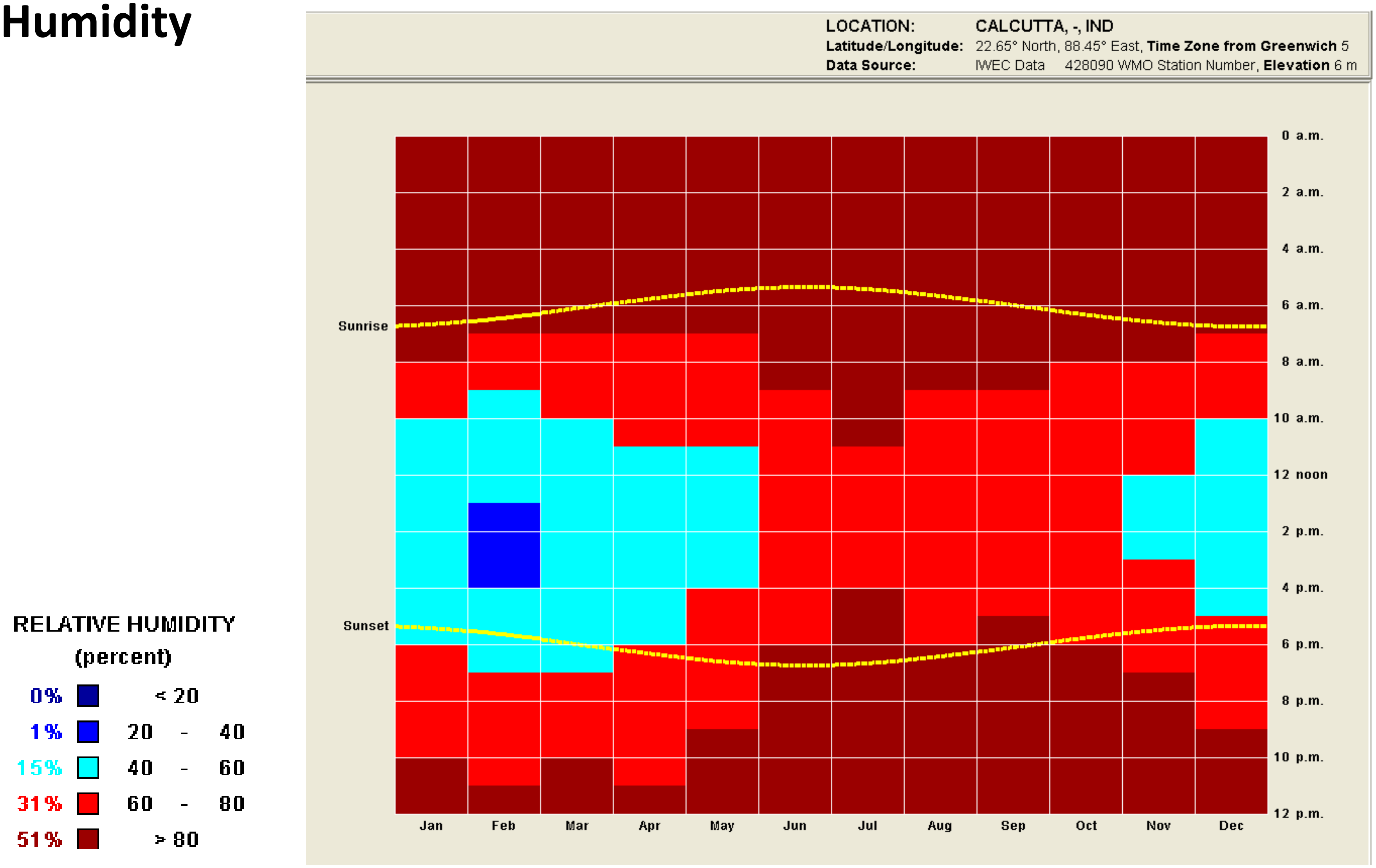


Effect of low temperature and high humidity

Results in condensation occurring on cooler side of surface – may lead to deterioration of building materials

Climate

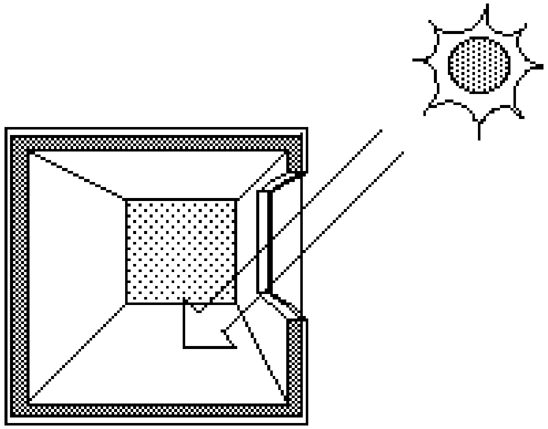
Relative Humidity



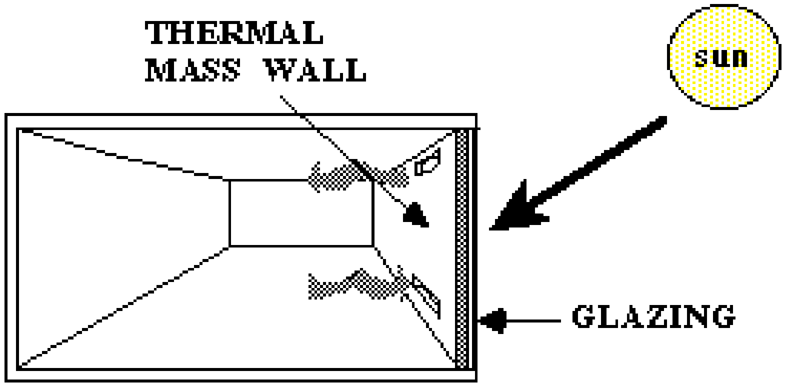
Climate

Solar Radiation

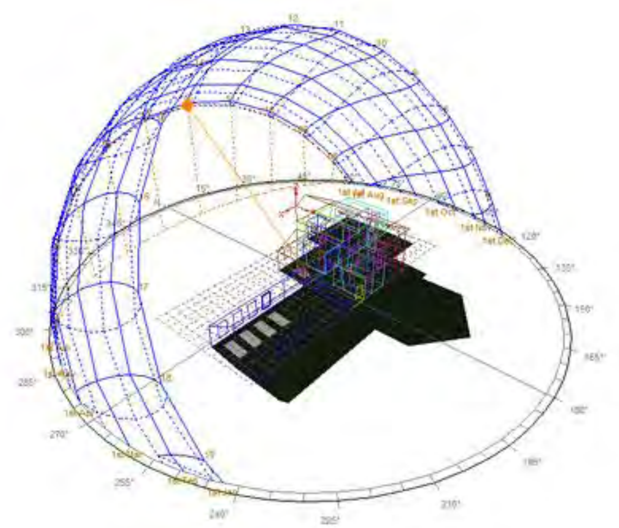
- Global Solar Radiation Components (Direct and Diffused)
- Building Solar Gain (Direct and Indirect)



Direct gain



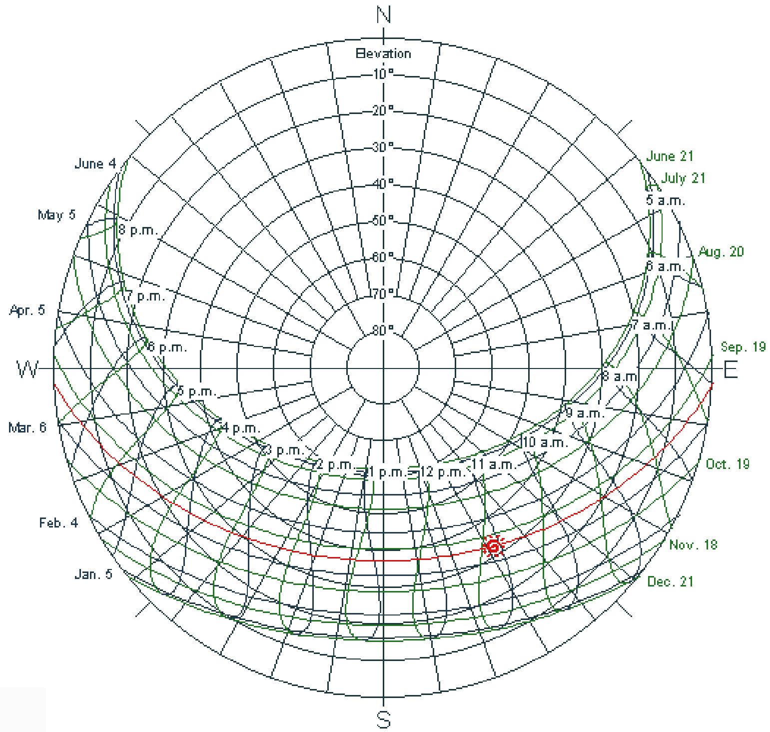
Indirect gain

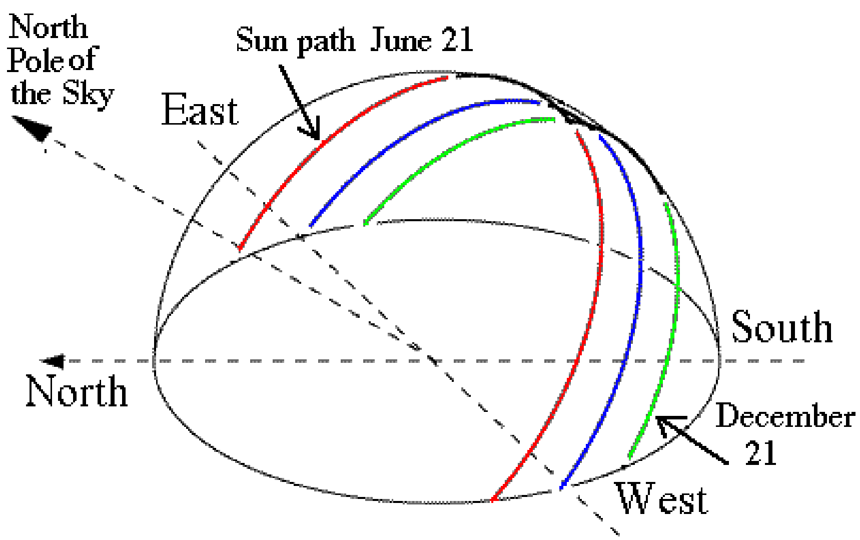


Sunpath diagram

Climate

Solar constant





$$=1390 \ [W \cdot m^{-2}]$$

Climate

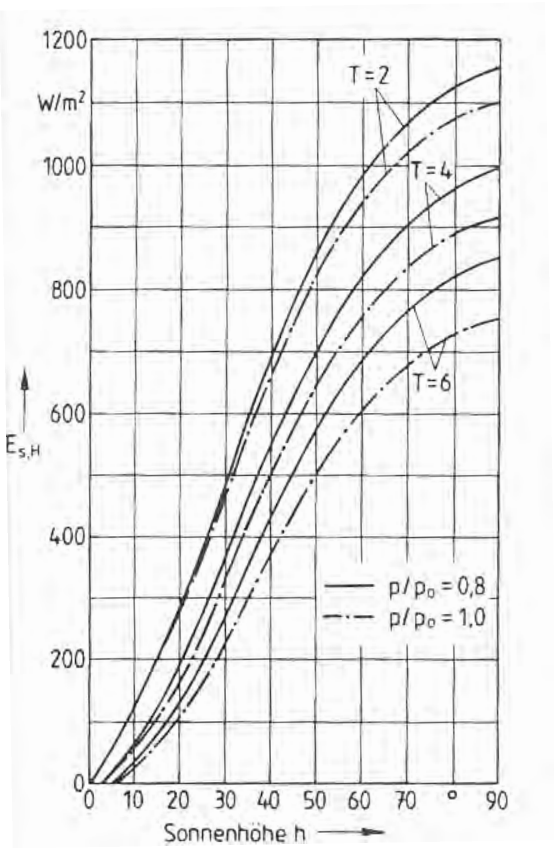
Direct solar radiation

Horizontal component

p/p_0 = 1 (see level)

p/p_0 = 0.8 (mountain; 2000 m)

T	City	Country
Summer	6	4
Winter	4	2



Intensity of direct horizontal irradiance (Es,H) as a function of solar altitude h, turbidity T, and air pressure ratio p/p0

Climate

Diffuse and global radiation

Horizontal component diffuse

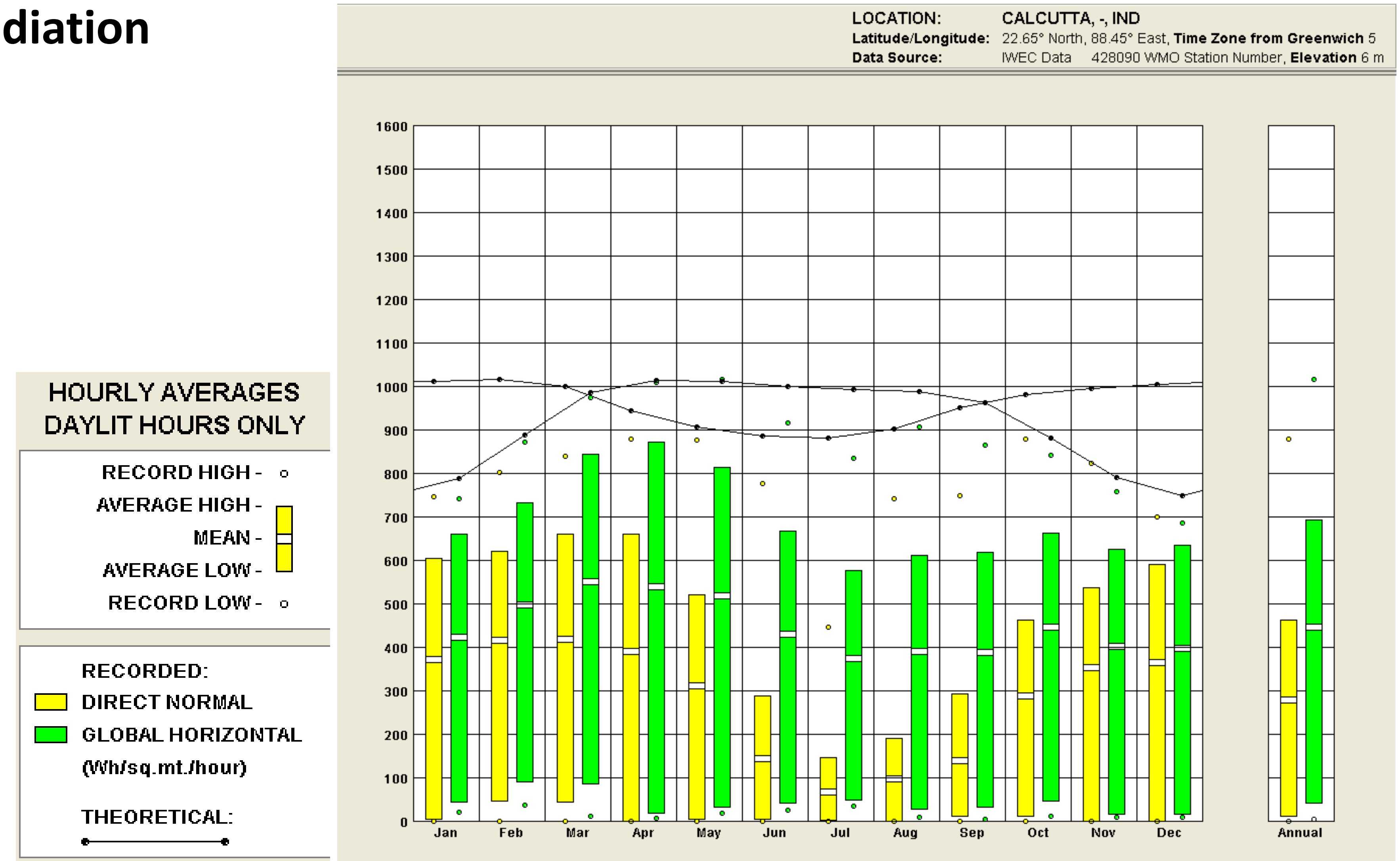
$$E_H = \frac{1}{3}\left[E_0 \cdot \sin(h) - E_{S,H}\right] \quad [W \cdot m^{-2}]$$

Horizontal component global

$$E_{Glob} = E_{S,H} + E_H \quad [W \cdot m^{-2}]$$

Climate

Solar Radiation

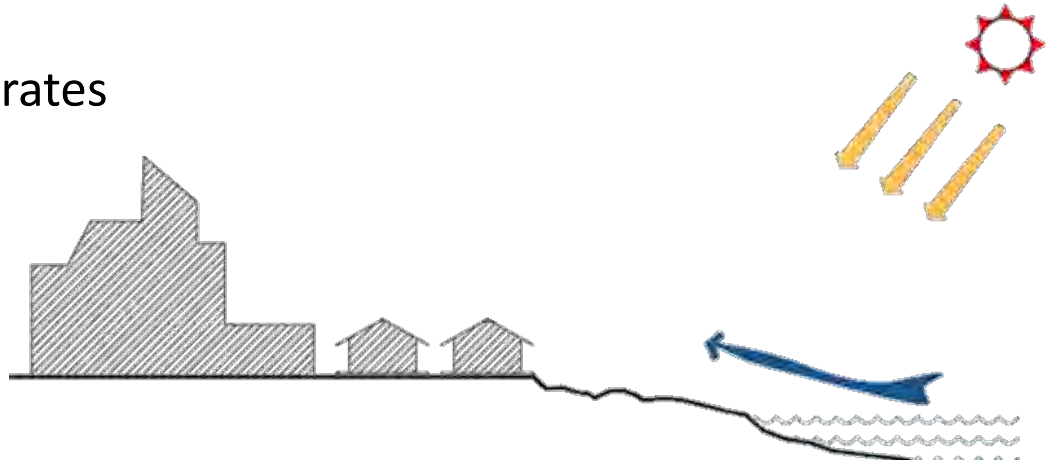


Climate

Wind Speed & Direction

- Wind is the movement of air due to a difference in atmospheric pressure, caused by differential heating of land and water mass on the earth's surface by solar radiation and rotation of earth
  - Wind speed is expressed in m/s and measured by a anemometer

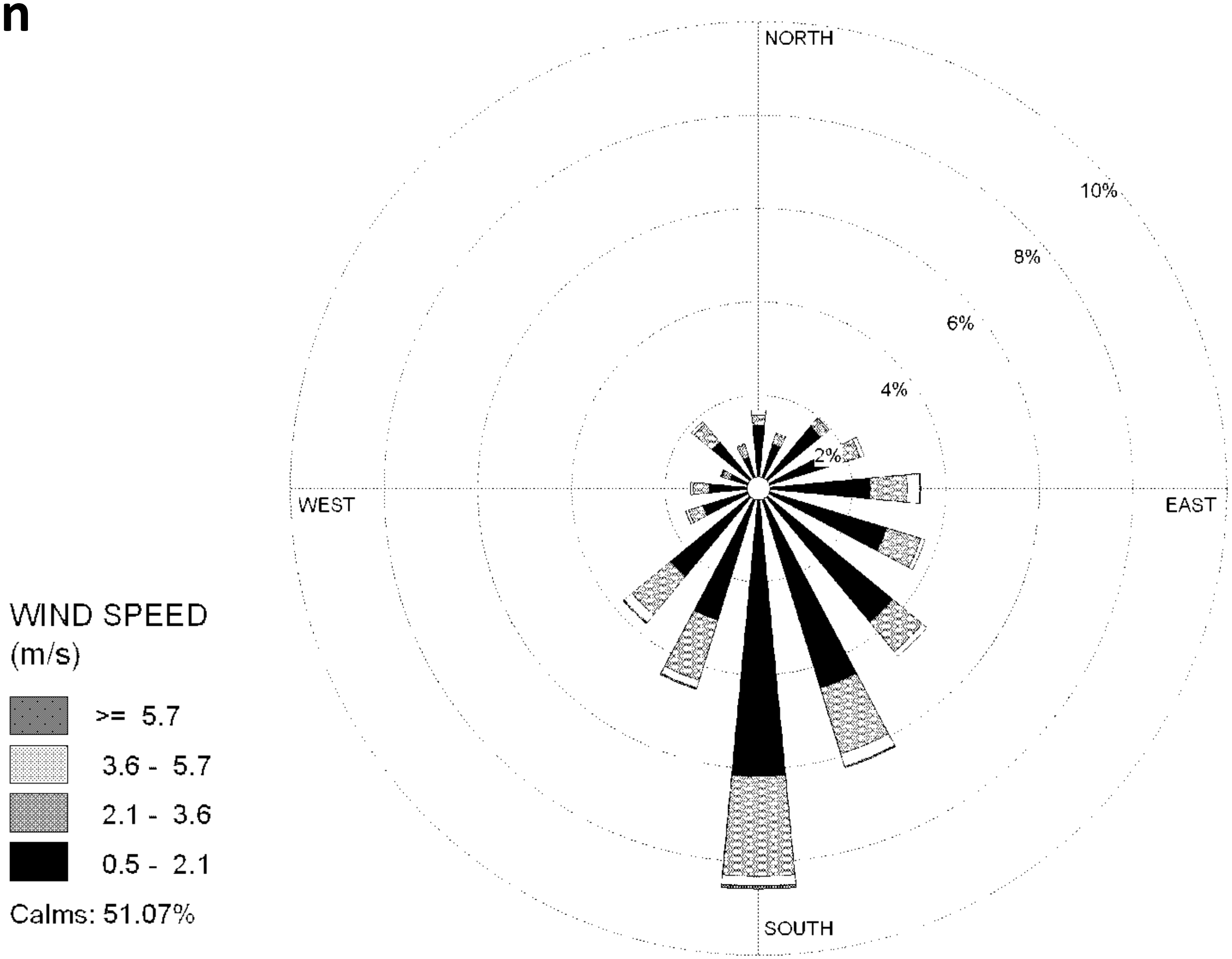
- Affects indoor comfort conditions by influencing the convective heat exchanges of a building envelope
  - Impacts ventilation and infiltration rates



Terrain and massing of buildings affect wind speed

Climate

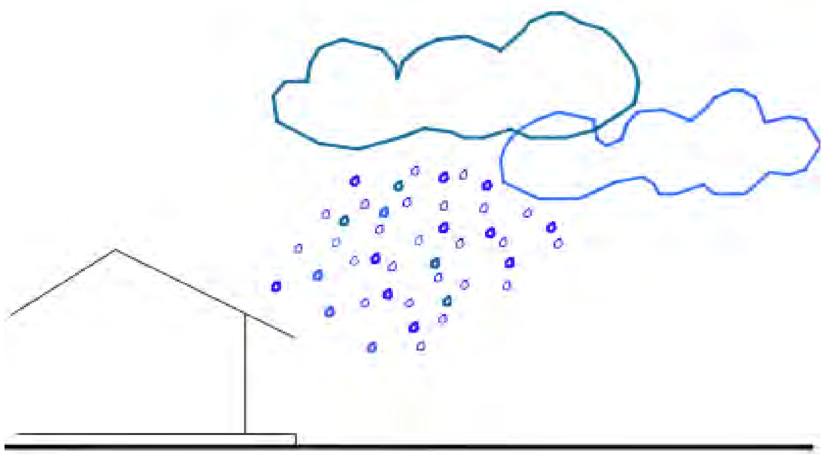
Wind Speed & Direction



Climate

Miscellaneous

- ***Precipitation***
  - Precipitation includes water in all its forms rain, snow, hail or dew
  - It is usually measured in millimeters (mm) by using a rain gauge



Rainfall in warmer regions tends to cool structure and surroundings

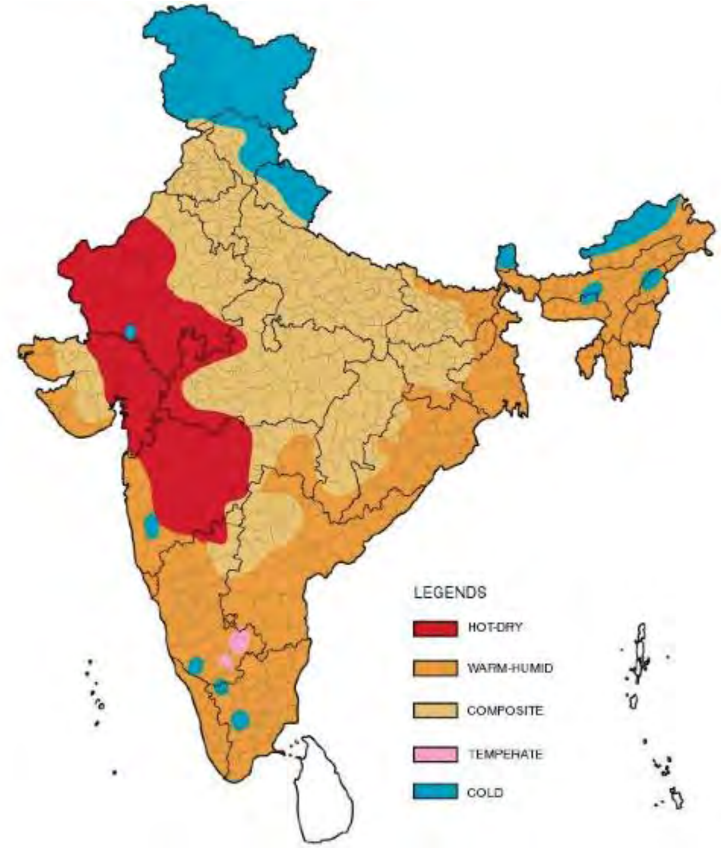
- ***Cloud Cover***
  - Regulates the amount of solar radiation reaching the earth's surface. Thus a cloudy day is cooler than a day we have a clear sky. Similarly at night when the earth is in cooling mode it cools off quickly under the clear sky than a cloudy one

- ***Atmospheric Pressure***
  - The rate at which a human body can cool itself depends upon the rate at which it can evaporate sweat from the body surface and Atmospheric pressure is an important parameter in determining Evaporation rate

Climate

Places with similar patterns of combinations of these climatic factors over time, are said to belong to the same climate zone

- Based on these factors our country can be divided into five climatic zones.
  - Hot and Dry
  - Warm and Humid
  - Temperate
  - Cold (Sunny/Cloudy)
  - Composite



Climate

	Hot and Dry	Warm and Humid	Temperate	Cold (Sunny/cloudy)	Composite
Temperature	High	Moderately high during the day and night	Moderate	Moderate summer temperature and very low winter temperature	High in summer and Very Low in winter
Humidity and Rainfall	Low	High	Moderate	Low in cold- sunny and high in cold- cloudy	Low in summer and high in monsoons
Solar Radiation and sky conditions	Intense as sky is mostly clear	Diffused when sky is cloud covered and intense when sky is clear	Same throughout the year and sky is generally clear	High in cold- sunny and low in cold- cloudy	High in all seasons except monsoons
Wind	Hot during the day and cool at night	Calm to very high winds from prevailing wind direction	High winds during summers depending on topography	Cold winds in winter	Hot winds in summer, cold winds in winter and strong winds in monsoons

SOURCE: Bansal, N. K. & G. Minke (1990), Climatic Zones and Rural Housing in India. Jeulich, Germany; Krishan, A., N. Y. Baker & S. V. Szokolay (2001), Climate Responsive Architecture: A Design Handbook for Energy Efficient Buildings, Tata McGraw Hill

Climate

Climate classifications (Köppen-Geiger)

A	**Tropical humid**	**Af**	**Tropical wet**	**No dry season**
		Am	Tropical monsoonal	Short dry season; heavy monsoonal rains in other months
		Aw	Tropical savanna	Winter dry season
B	**Dry**	**BWh**	**Subtropical desert**	**Low-latitude desert**
		BSh	Subtropical steppe	Low-latitude dry
		BWk	Mid-latitude desert	Mid-latitude desert
		BSk	Mid-latitude steppe	Mid-latitude dry
C	**Mild Mid-Latitude**	**Csa**	**Mediterranean**	**Mild with dry, hot summer**
		Csb	Mediterranean	Mild with dry, warm summer
		Cfa	Humid subtropical	Mild with no dry season, hot summer
		Cwa	Humid subtropical	Mild with dry winter, hot summer
		Cfb	Marine west coast	Mild with no dry season, warm summer
		Cfc	Marine west coast	Mild with no dry season, cool summer
D	**Severe Mid-Latitude**	**Dfa**	**Humid continental**	**Humid with severe winter, no dry season, hot summer**
		Dfb	Humid continental	Humid with severe winter, no dry season, warm summer
		Dwa	Humid continental	Humid with severe, dry winter, hot summer
		Dwb	Humid continental	Humid with severe, dry winter, warm summer
		Dfc	Subarctic	Severe winter, no dry season, cool summer
		Dfd	Subarctic	Severe, very cold winter, no dry season, cool summer
		Dwc	Subarctic	Severe, dry winter, cool summer
		Dwd	Subarctic	Severe, very cold and dry winter, cool summer
E	**Polar**	**ET**	**Tundra**	**Polar tundra, no true summer**
		EF	Ice Cap	Perennial ice
H	**Highland**			

Climate

Climate classifications (Atkinson)

Climate	Description
Cold	Heating demand most of the year.
Temperate	Seasonal variation between (moderate levels of) heating and cooling demand.
Hot-dry	Overheating, typically large diurnal temperature variation
Warm-humid	Some overheating, aggravated by high humidity. Smaller diurnal temperature.

Climate

The number of degree days in a regular 24 hour period is determined by the difference between the base temperature and the average of the high and low temperatures for a specific day

	Hot and Dry Ahmedabad	**Warm and Humid** Kolkata	**Temperate** Bangalore	**Cold (Sunny/cloudy)** Guwahati	**Composite** New Delhi
Heating Degree Days base 10 °C ($HDD_{10.0}$)	0	0	0	0	1
Heating Degree Days base 18.3 °C (HDD18.3)	11	16	0	57	286
Cooling Degree Days base 10 °C (CDD10.0)	6466	6081	5163	5329	5767
Cooling Degree Days base 18.3 °C (CDD18.3)	3435	3056	2121	2344	3011

Internal loads

People

- 1 person ≈ 1 x 100W light bulb heat output

Degree of Activity		Total Heat, W: Adult Male	Total Heat, W: Adjusted, M/F[a]	Sensible Heat, W	Latent Heat, W	% Sensible Heat that is Radiant[b]: Low V	% Sensible Heat that is Radiant[b]: High V
Seated at theater	Theater, matinee	115	95	65	30		
Seated at theater, night	Theater, night	115	105	70	35	60	27
Seated, very light work	Offices, hotels, apartments	130	115	70	45		
Moderately active office work	Offices, hotels, apartments	140	130	75	55		
Standing, light work; walking	Department store; retail store	160	130	75	55	58	38
Walking, standing	Drug store, bank	160	145	75	70		
Sedentary work	Restaurant[c]	145	160	80	80		

Representative rates at which heat and moisture are given off by human beings in different states of activity

SOURCE: ASHRAE Handbook Fundamentals 2005

Internal loads

Equipment

	Continuous, W	Energy Saver Mode, W
Computers[a]		
Average value	55	20
Conservative value	65	25
Highly conservative value	75	30
Monitors[b]		
Small (13 to 15 in.)	55	0
Medium (16 to 18 in.)	70	0
Large (19 to 20 in.)	80	0

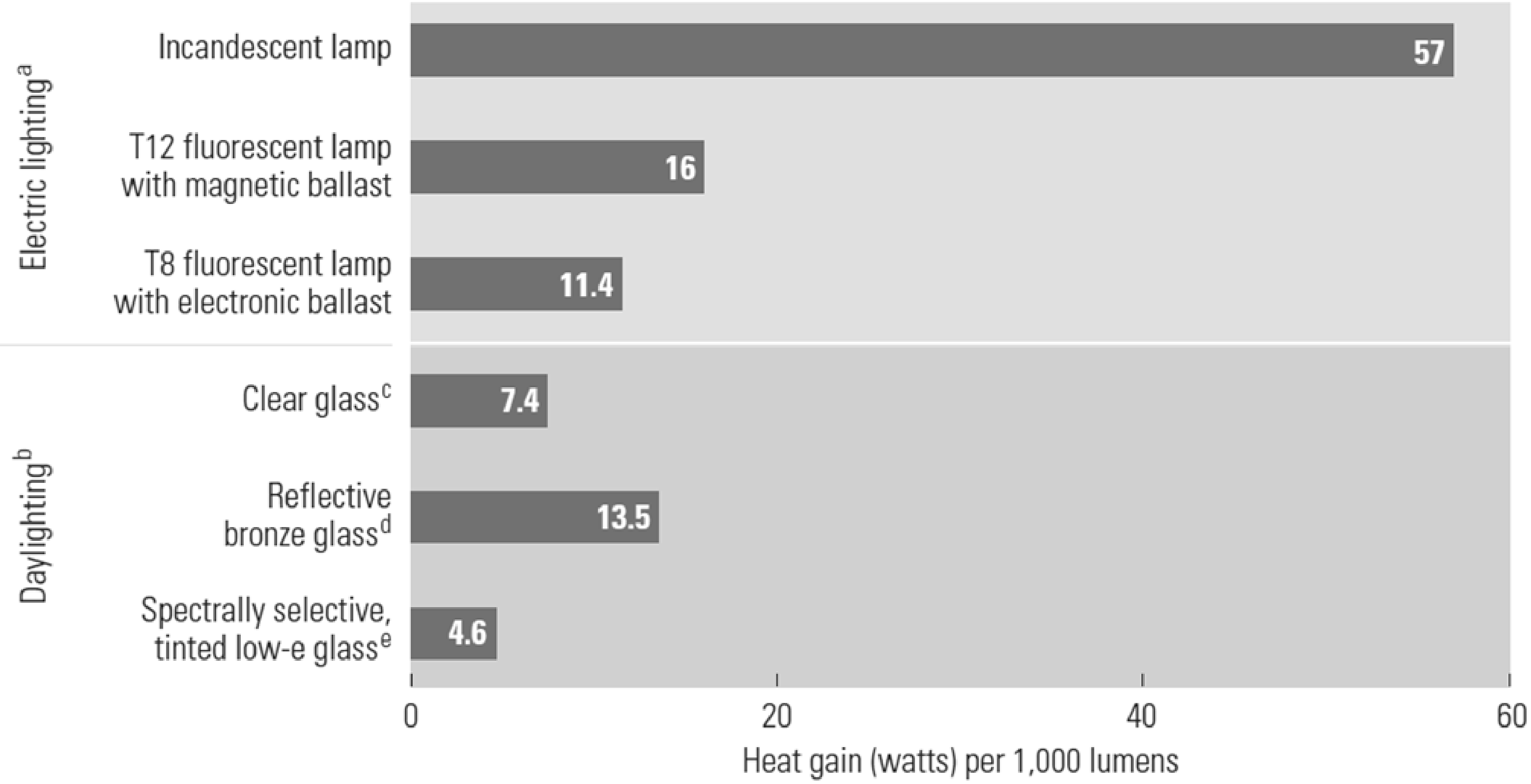
Recommended heat gain from typical computer equipment

		Energy Rate, W		Recommended Rate of Heat Gain,[a] W			
				Without Hood			With Hood
Appliance	**Size**	**Rated**	**Standby**	**Sensible**	**Latent**	**Total**	**Sensible**
Hot plate (single burner, high speed)		2800	—	1310	910	2220	1040
Microwave oven (residential type)	30 L	600 to 1400	—	600 to 1400	—	600 to 1400	0
Refrigerator (small) per cubic metre of interior space	0.17 to 0.71 m^3	1730	—	690	—	690	0
Steam kettle (small), per litre of capacity	23 to 45 L	260	—	21	14	35	10
Toaster (small pop-up)	4 slice	2470	—	1310	1160	2470	790
Oven (small convection), per cubic metre of oven space	0.04 to 0.15 m^3	107000	—	—	—	—	1520

Recommended rates of heat gain from typical commercial cooking appliances

Internal loads

Lights



Building heat gain from different light sources

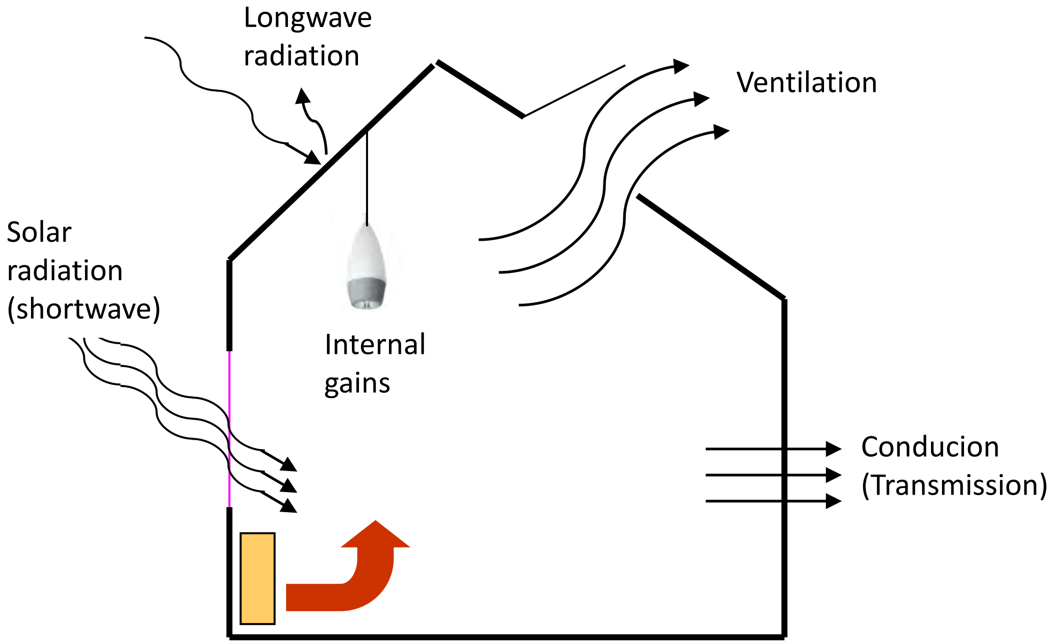
With proper glazing selection in a building, daylight will contribute far less heat per unit of light delivered to the interior than electric lights do.

SOURCE: E Source Technology Atlas Series, Volume I Lighting (2005)

Building Heat Transfer

Overview

- Conduction through envelope
- Convective heat transfer through ventilation
- Short-wave solar radiation transmission through transparent building envelope elements
- Absorption of shortwave solar radiation by building components
- Emission of long-wave radiation through building elements
- Heat transfer between solid and fluid media through radiation and convection
- Heat transfer due to people, lighting, equipment, and HVAC systems



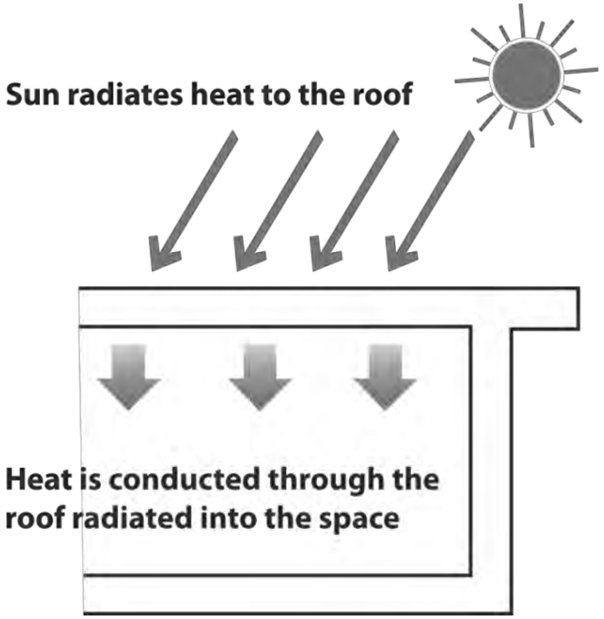
TOTAL ENVELOPE HEAT TRANSFER

= Conduction + Convection + Radiation

Building Heat Transfer

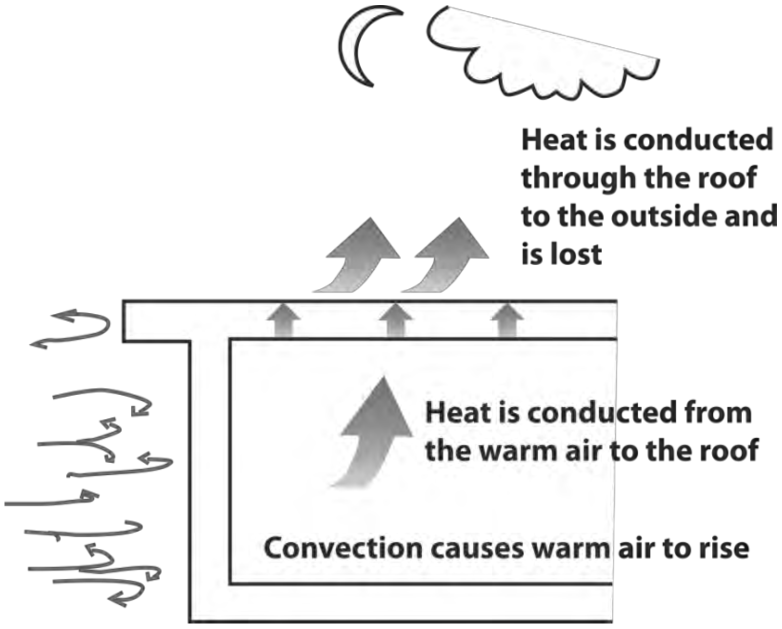
Day Time Heat Transfer

Heat Transfer takes place from OUTSIDE TO INSIDE of the building ($T_{out} > T_{in}$)



Night Time Heat Transfer

Heat Transfer takes place from INSIDE to OUTSIDE of the building ($T_{out} < T_{in}$)



Building Heat Transfer

Basics of thermal physics

Work, Energy

- ***Kinetic Energy***

  $K = 0.5.m.v^2$

- ***Potential Energy***

  $U = m.g.h$

- ***Mechanical Energy***

  $E = K + U$

- ***Thermal energy (heat)***

- K … kinetic energy [J]
- U … potential energy [J]
- E … mechanical energy [J]
- m … mass [kg]
- v … speed [$m.s^{-1}$]
- g … (earth) acceleration [$m.s^{-2}$]
- h … (Fall) height [m]

Building Heat Transfer

Temperature

- A measure of the random motion of atoms/molecules.
- Can be measured using thermometers
- Expressed in units of degrees Celsius or degrees Kelvin
- Zero degree Kelvin (absolute zero or the lowest possible temperature) denotes absence of any random atomic motion.
- The freezing point of water corresponds to 0 °C or 273 K, whereas the boiling point of water corresponds to 100 °C or 373 K.

$$T = \theta + 273.16 \quad [K]$$

$$\theta = T - 273.16 \quad [°C]$$

Temperature difference ($\Delta\theta$) should be expressed in degree Kelvin.

Building Heat Transfer

Heat

- Heat is thermal energy.
- It is transferred between bodies of different temperature.
- It is expressed in units of Joules (J) or Kilowatthours (kWh).
- 1 Joule corresponds to 0.278×10^{-6} kWh.
- 1 kWh corresponds to 3.6 MJ (Mega Joules).

Building Heat Transfer

Specific heat capacity

The energy content of a substance depends on its:

- temperature
- mass
- specific heat

The specific heat capacity c of a substance denotes the amount of needed heat to raise the temperature of a unit mass of a substance 1 K. The unit of specific heat is thus: $J \cdot kg^{-1} \cdot K^{-1}$

Material	c [$J \cdot kg^{-1} \cdot K^{-1}$]
Brick	800
Concrete	840
Limestone	910
Plaster	1000
Light-weight concrete	1000
Mineral wool	1000
Wood	1200
Water	4187
Air	1006

Building Heat Transfer

Material phase change (between solid, liquid, and gas states)

- During phase change, materials absorb or emit thermal energy, without change of temperature.

- The amount of heat needed to change the phase of one kg of a substance:
  - the latent heat of fusion (changes between liquid and solid phases) or
  - the latent heat of vaporization (changes between liquid and gas phases).
  - (unit: $J \cdot kg^{-1}$)

Building Heat Transfer

The first law of thermodynamics

- The first law of thermodynamics establishes a relationship between a system's
  - internal energy,
  - the work performed by (or to) the system, and
  - the heat removed from (or added to) the system.

- The internal energy of system performing work or losing heat falls, whereas a system's internal energy rises if it gains heat or is subjected to work.

$$\Delta U = Q - W$$

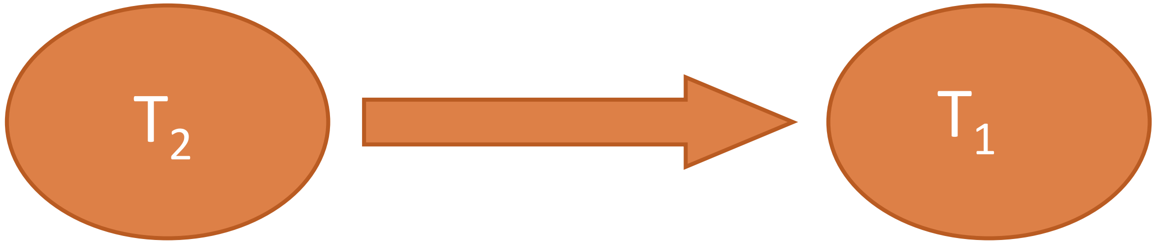
ΔU change in internal energy
Q heat added to the system
W work done by the system

Building Heat Transfer

The second law of thermodynamics

- The second law of thermodynamics established that the natural (spontaneous) direction of heat flow between bodies is from hot to cold.

- The second law could also be stated in terms of entropy: in natural systems the entropy increases with time (entropy is a measure of disorder in a system).



$(T_2 > T_1)$

Building Heat Transfer

Heat transfer between entities (bodies, regions of space)

- **Conduction**
- **Convection**
- **Radiation**

Building Heat Transfer

Conduction

- Conduction occurs when two bodies of different temperature are put in contact. As the faster molecules (of the warmer object) collide with the slower ones (of the cooler object), they lose some of their energy in the process, leading to a convergence of the two temperature levels.

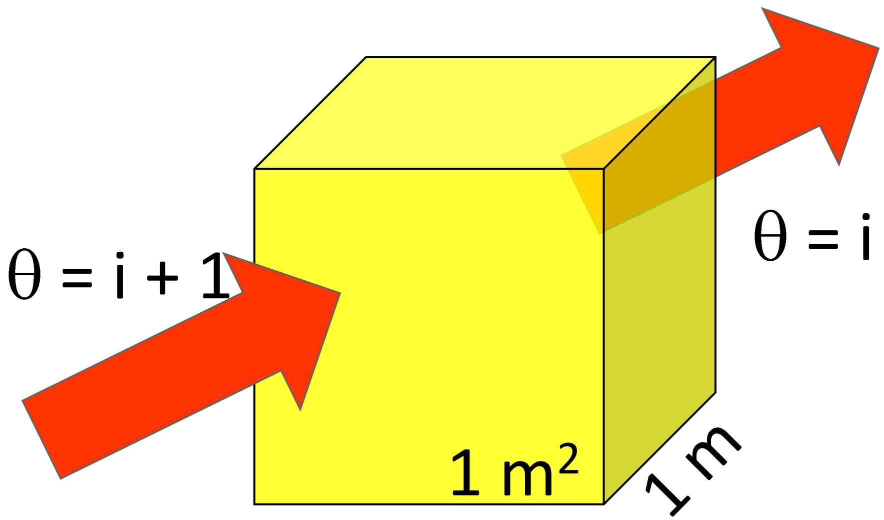
- Some materials (such as metals) are good conductors, others (such as wood) are poor conductors. Poor conductors (such as vacuum or trapped layers of air in a double-glazing) act as insulator.

Building Heat Transfer

λ: thermal conductivity in $W \cdot m^{-1} \cdot K^{-1}$

(function of moisture and temperature)

- Energy flow through 1 m^2 of a 1meter thick material given a 1 K (steady-state) temperature difference



Thermal conductivity of various materials

Material	l [$W \cdot m^{-1} \cdot K^{-1}$]
Brick	0.6
Concrete	1.7
Granite	3.5
Gypsum	0.22
Iron	84
Light-weight concrete	0.14
Mineral wool	0.04
Wood	0.14

Building Heat Transfer

Fourier law

(conductive heat flow in a homogeneous isotropic material)

$$q = -\lambda \nabla T = -(\lambda \frac{\partial T}{\partial x}, \lambda \frac{\partial T}{\partial y}, \lambda \frac{\partial T}{\partial z})$$

- In case of one-dimensional heat flow

$$q = q_x = -\lambda \frac{\partial T}{\partial x}$$

λ : thermal conductivity in $W \cdot m^{-1} \cdot K^{-1}$

Building Heat Transfer

Steady-state (time-independent) heat conduction in 1 dimension through a single-layered flat element (thickness d, thermal conductivity l) with surface temperatures θ_i and θ_e

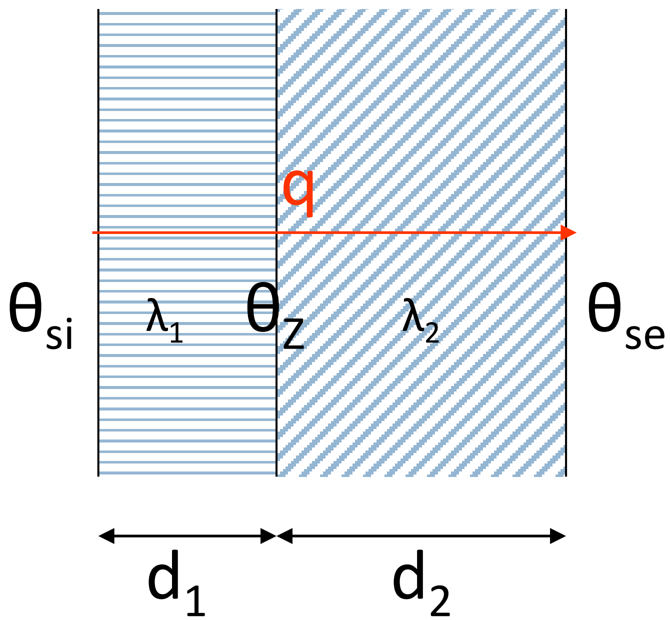
$$q = \lambda \frac{\theta_i - \theta_e}{d} = \frac{\Delta\theta}{\frac{d}{\lambda}}$$

d/λ: thermal resistance in $m^2 \cdot K \cdot W^{-1}$

Building Heat Transfer

Thermal resistances of multi-layered components

$$q = \frac{\theta_{si} - \theta_{se}}{R_T}$$



R_T: Total thermal resistance of the multi-layered building element

$$R_T = \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + \ldots\ldots + \frac{d_n}{\lambda_n} = \sum_{i=1}^{n} \frac{d_i}{\lambda_i}$$

$\lambda_{1,2}$ ... Thermal conductivity

$d_{1,2}$ ... Thickness

θ_{si} ... Indoor surface temperature

θ_{se} ... Outdoor surface temperature

θ_Z ... Interstitial temperature

Building Heat Transfer

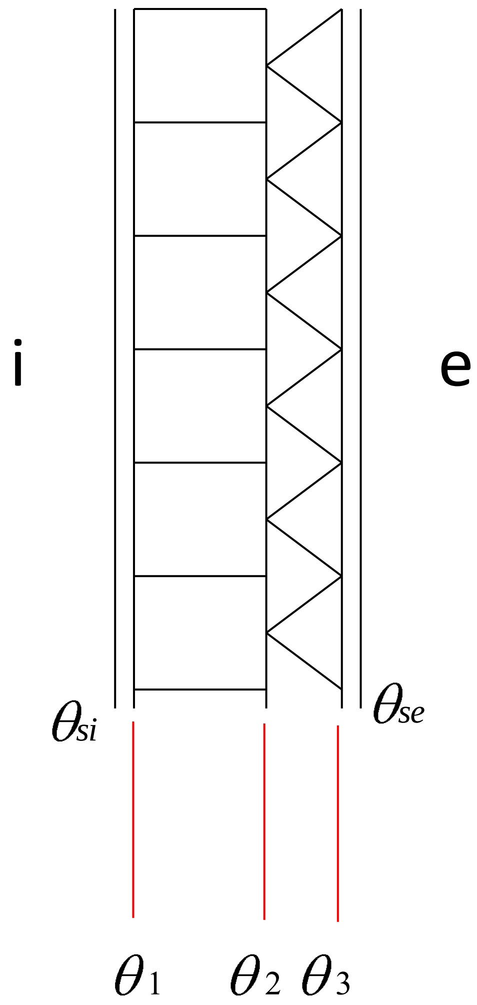
Layer temperatures:

$$\theta_i = \frac{R_{\rightarrow i} \cdot \theta_{si} + R_{\rightarrow e} \cdot \theta_{se}}{R_T}$$

θ_i: Temperature at position i

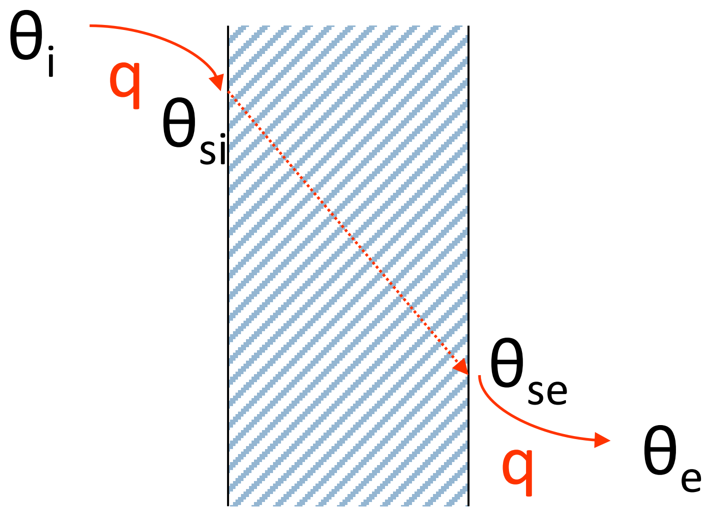
$R_{\rightarrow i}$: Thermal resistance up to position i

$R_{\rightarrow e}$: Thermal resistance from position i



Building Heat Transfer

Surface temperatures



$$\theta_{si} = \theta_i - U \cdot R_i(\theta_i - \theta_e)$$

$$\theta_{se} = \theta_e + U \cdot R_e(\theta_i - \theta_e)$$

θ_i *Indoor temperature*

θ_e *Outdoor temperature*

θ_{si} *Indoor surface temperature*

θ_{se} *Outdoor surface temperature*

Building Heat Transfer

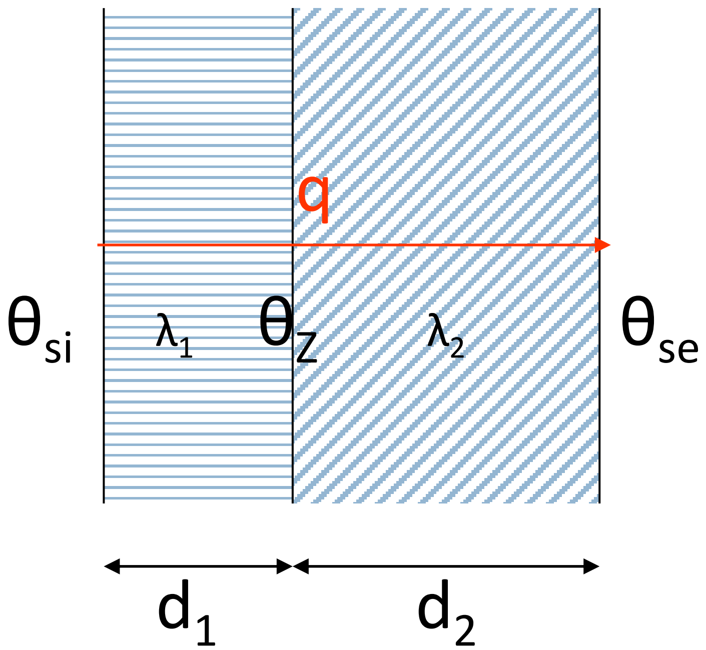
Interstitial temperature

multi-layered building component

$$\theta_z = \theta_i - U \cdot \left(R_{si} + \frac{d_1}{\lambda_1} \right) (\theta_i - \theta_e)$$

$$U = \frac{1}{R_{si} + R_T + R_{se}} \qquad \left[\mathrm{W \cdot m^{-2} \cdot K^{-1}} \right]$$

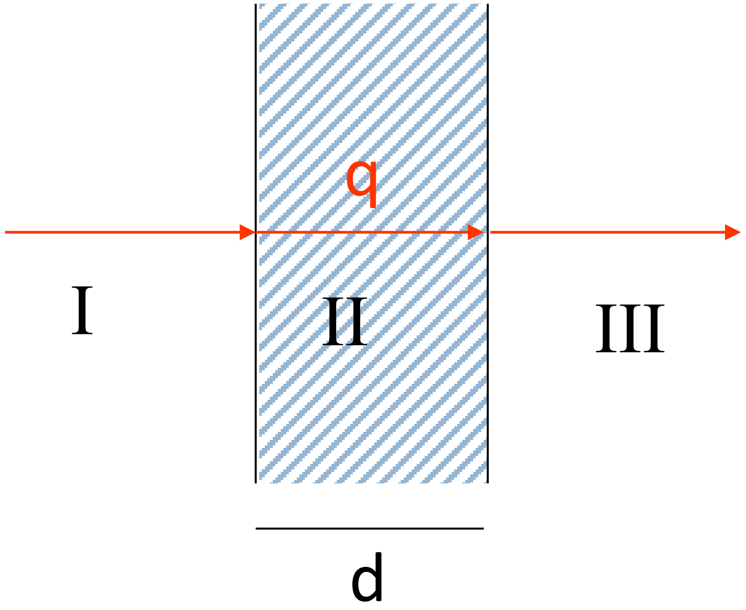
$$R_T = \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} \qquad \left[\mathrm{W \cdot m^{-2} \cdot K^{-1}} \right]$$



Building Heat Transfer

Heat flow

1. One-dimensional steady state heat flow q through a planar building component
2. Heat flow from indoor air to indoor surface
3. Flow through the component
4. Flow from outdoor surface to outdoor air



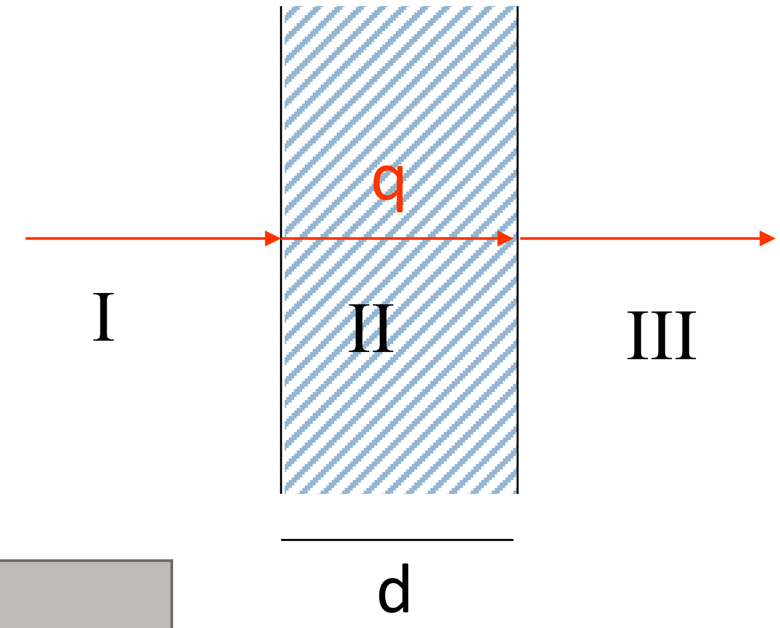
$$q = \left(\frac{1}{R_{si} + \frac{d}{\lambda} + R_{se}} \right) (\theta_i - \theta_e)$$

$$R = \frac{d}{\lambda} \qquad R_{si} = \frac{1}{h_i} \qquad R_{se} = \frac{1}{h_e}$$

Building Heat Transfer

Thermal transmittance

$$U = \frac{1}{R_{si} + R + R_{se}} \quad \left[W \cdot m^{-2} \cdot K^{-1} \right]$$



Surface resistance (ISO 6946)		
Heat flow direction	R_{si} [$m^2 \cdot K \cdot W^{-1}$]	R_{se} [$m^2 \cdot K \cdot W^{-1}$]
Horizontal (±30°)	0.13	0.04
Up	0.10	0.04
Down	0.17	0.04

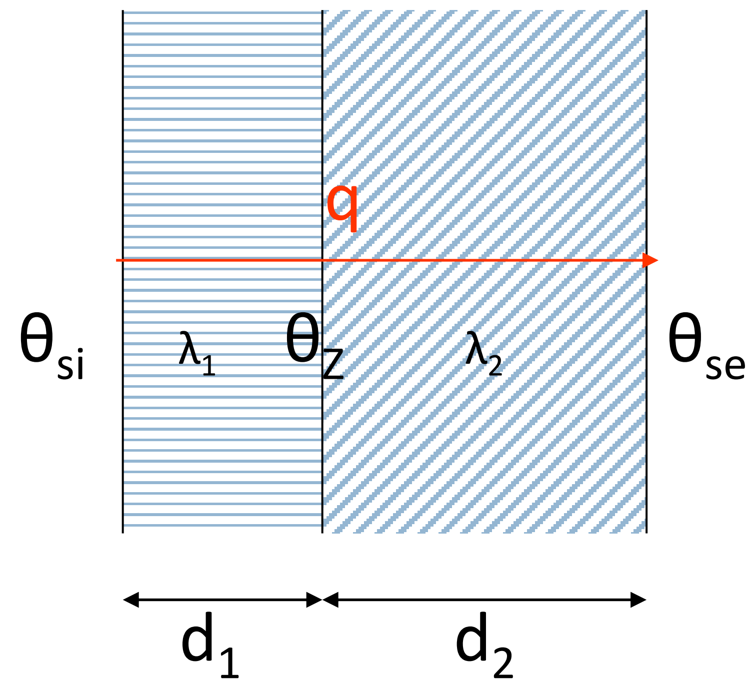
Building Heat Transfer

Thermal transmittance

multi-layered building component

$$U = \frac{1}{R_{si} + R_T + R_{se}} \qquad \left[W \cdot m^{-2} \cdot K^{-1} \right]$$

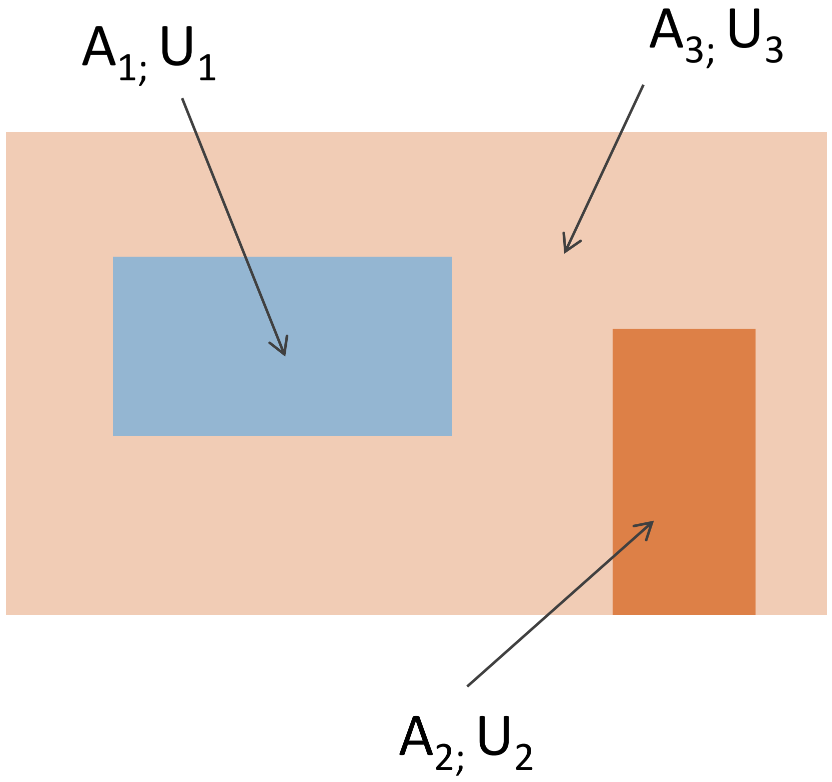
$$R_T = \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} \qquad \left[W \cdot m^{-2} \cdot K^{-1} \right]$$



Building Heat Transfer

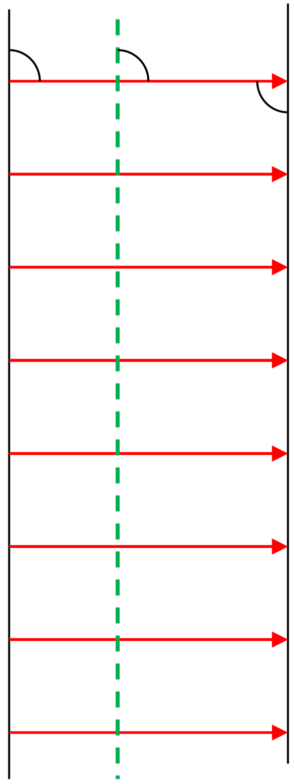
Mean thermal transmittance
(elements in parallel)

$$U_m = \frac{\sum_{i=1}^{n} A_i U_i}{\sum_{i=1}^{n} A_i}$$



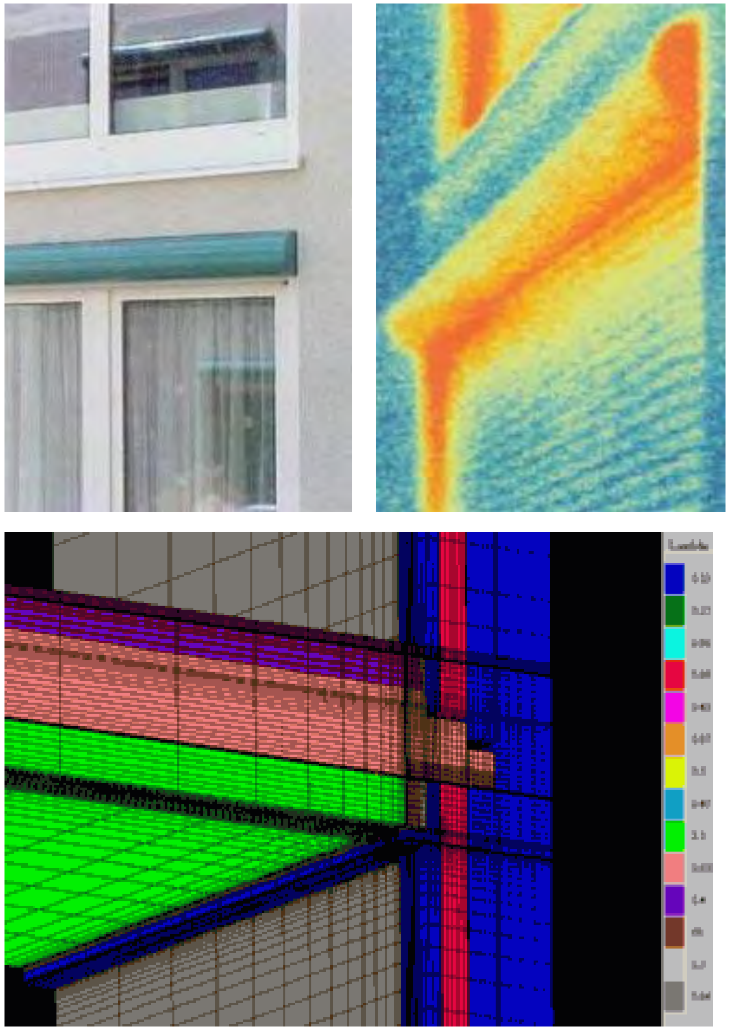
Building Heat Transfer

Thermal bridges



Heat flow lines

Isotherms



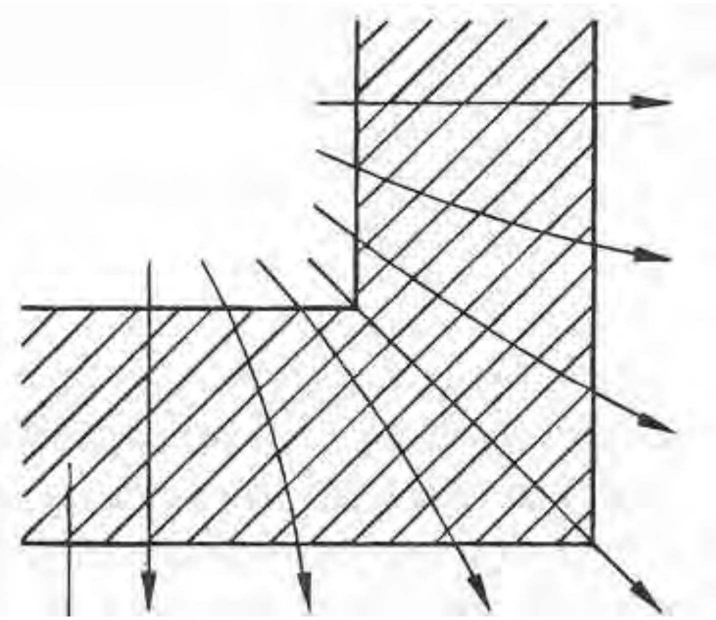
Building Heat Transfer

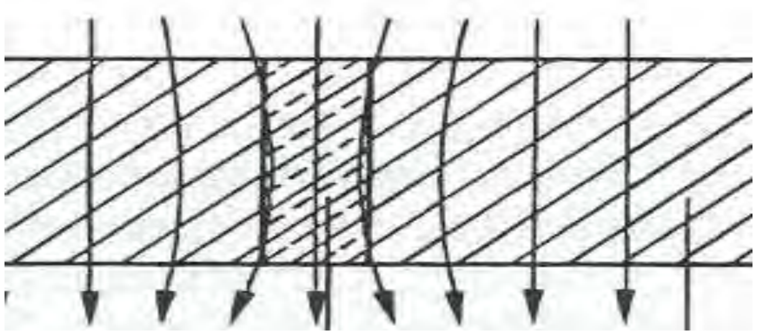
Thermal bridges

- Geomteric thermal bridges

- Structural (material related) thermal bridges

- Consequences*:*
  - Higher heat losses
  - Lower indoor surface temperatures





Building Heat Transfer

Linear thermal transmittance:

$$\psi = \frac{\Phi_{2D} - \Phi_0}{L\Delta\theta} \qquad \left[W \cdot m^{-1} \cdot K^{-1}\right]$$

Local thermal transmittance:

$$\chi = \frac{\Phi_{3D} - \Phi_0}{\Delta\theta} \qquad \left[W \cdot K^{-1}\right]$$

Φ_{2D}; Φ_{3D}: (2 or 3-dimensional) heat flow

Φ_0 : heat flow from one-dimensional reference

L: length of the linear thermal bridge

Building Heat Transfer

Mean thermal transmittance of flat element with thermal bridges

$$U = U_0 + \frac{\sum_{i=1}^{n} (\psi_i L_i) + \sum_{j=i}^{m} \chi_j}{A}$$

U_0 thermal transmittance of the base element

A element surface

n number of linear thermal bridges (with length L_i)

m the number of point-like thermal bridges

Building Heat Transfer

Convection

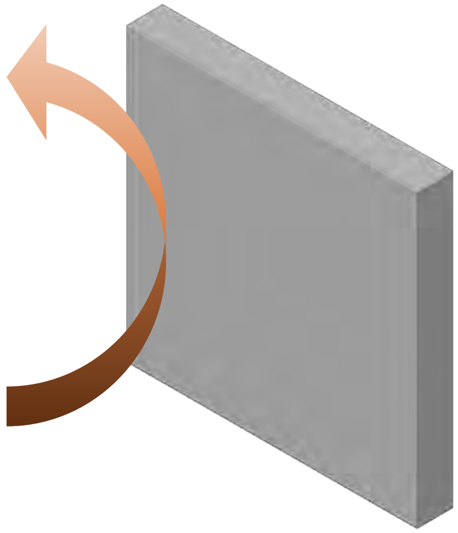
- Convection is a process by which heat is transferred via moving parcels of heated liquid or gas.
- For example, heated air expands and rises (given reduced density) and transports thus thermal energy.
- Heat transfer between a fluid and the surface of a solid involves convection:
  - Natural convection is caused by fluid density differences
  - Forced convection is induced by wind, HVAC, etc.

Building Heat Transfer

Convection

Convective heat flow rate between fluid and surface:

$$q_c = h_c(\theta_{fl} - \theta_s)$$



θ_{fl} fluid temperature

θ_s surface temperature

h_c convective surface film coefficient [$W.m^{-2}.K^{-1}$]

Building Heat Transfer

Radiation

- Radiation denotes a process by which energy is transferred via electromagnetic waves. The electrons in a radiation-receiving body absorb the energy, causing faster atom movements in the body and increasing temperature.

- Radiation – as opposed to conduction and convection – does not require physical contact and a material medium (it can occur across vacuum). All bodies with a non-zero (K) temperature emit radiation.

Building Heat Transfer

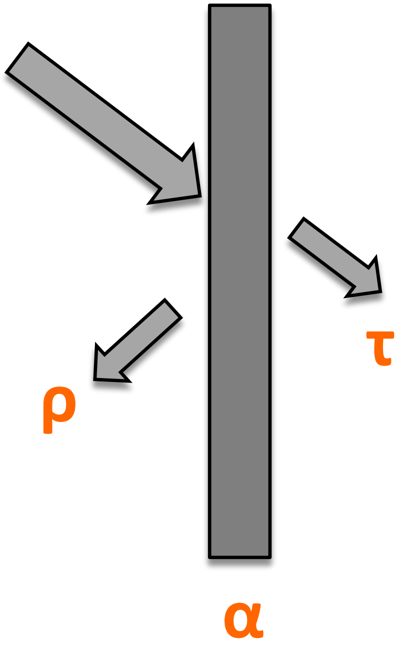
Electromagnetic radiation

- Electromagnetic thermal radiation does not require a medium.
- Surfaces with T > 0 K emit radiation as a function of surface properties and temperature.
- Propagation speed (c) in vacuum: 299,793 km·s^{-1}
- l=c/frequency

Wavelength	Radiation
$l \leq 10^{-6}$ mm	cosmic radiation
$10^{-6} < l \leq 10^{-4}$ mm	gamma rays
$10^{-4} < l \leq 10^{-2}$ mm	x-rays
$10^{-2} < l \leq 0.38$ mm	UV radiation
$0.38 < l \leq 0.76$ mm	Light
$0.76 < l \leq 10^{3}$ mm	IR radiation
10^{3} mm $< l$	Radio waves

Building Heat Transfer

Solar Radiation = Reflection + Absorption+ Transmission



$\rho \rightarrow$ Reflectance

$\alpha \rightarrow$ Absorption

$\tau \rightarrow$ Transmittance

$$\rho + \alpha + \tau = 1$$

$$\rho = \frac{\text{Reflected radiation}}{\text{Incident radiation}}$$

$$\alpha = \frac{\text{Absorbed radiation}}{\text{Incident radiation}}$$

$$\tau = \frac{\text{Transmitted radiation}}{\text{Incident radiation}}$$

Building Heat Transfer

Solar (short-wave) radiation

Incident solar radiation on a building surface

$$q = \alpha_{sol} \cdot I_{sol}$$

α_{sol} absorbtivity for solar radiation

I_{sol} normal component of the incident solar radiation

Building Heat Transfer

Electromagnetic radiation

Stefan-Bolzmann Law (black bodies)

$$M_b = \sigma \cdot T^4$$

$$\sigma = \text{Stefan-Boltzmann-Constant} = 5.67x10^{-8}\ W \cdot m^{-2} \cdot K^{-4}$$

Wien's Displacement Law

$$\lambda_{max} = \frac{2896x10^{-6}}{T}$$ h

Building Heat Transfer

Grey bodies

$$M = \varepsilon \cdot \sigma \cdot T^4$$

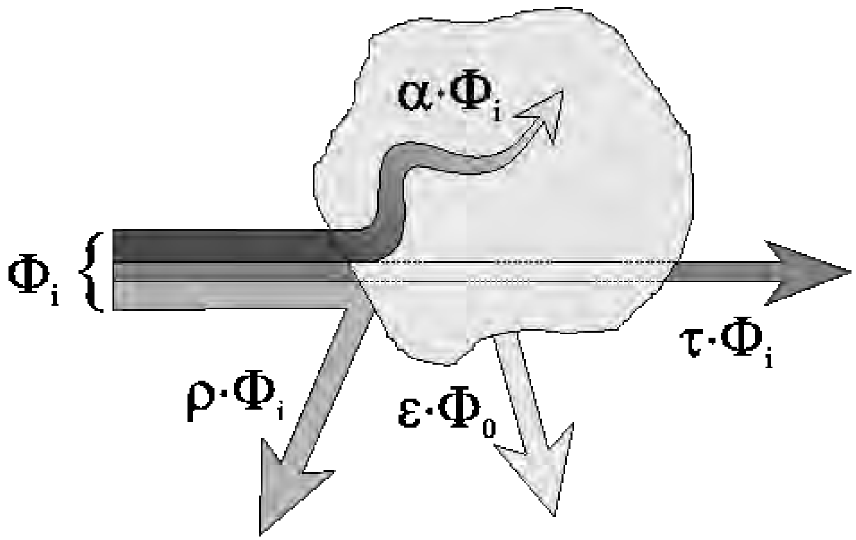
Emissivity

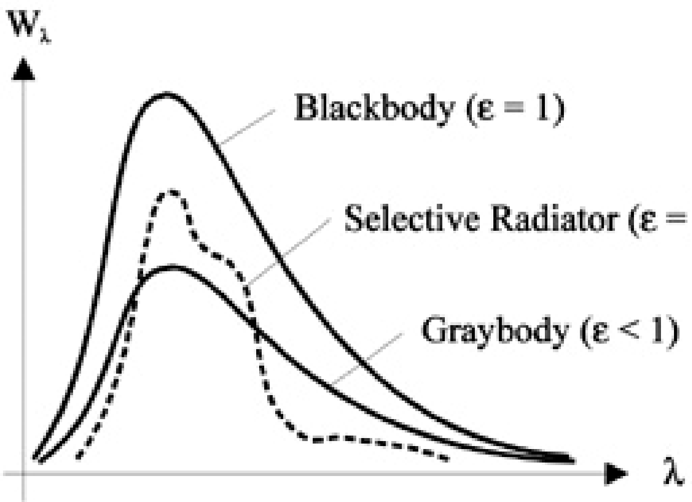
- ratio of the specific radiation of a real body M to that of a black body Ms

$$\varepsilon = \frac{M}{M_b}$$

- Given conservation of energy:

$$\varepsilon = \alpha$$





Building Heat Transfer

Absorptance and emissivity of surfaces

Building element surface	Absorptance (solar radiation) T = 6000 K	Emissivity (thermal radiation) T = 300 K
Lime sand stone, gray	0.60	0.96
Concrete, smooth	0.55	0.96
Brick facing, red	0.54	0.93
Aluminium raw	0.20	0.05
Aluminium anodized	0.33	0.92
Plaster, white	0.21	0.97
Plaster, gray, blue	0.65	0.97
Glass	0.08	0.88
Paint, white	0.25	0.95

Building Heat Transfer

A general heat balance equation (simplified)

$$Q = (Q_T + Q_V) - \eta \cdot (Q_i + Q_s)$$

Q: Heating/Cooling demand

Q_T: Heat transfer via transmission

Q_V: Heat transfer via ventilation

Q_i: Internal gains

Q_s: Solar gain

η: Efficiency of gains

(function of thermal mass)

Rough η assumptions
for heat loss calculations

Type of construction	h
massive	1
medium	0.97
light	0.9

Building Heat Transfer

Conduction (transmission)

$$Q_T = L_T \cdot \Delta\theta \quad [W]$$

$$L_T = L_e + L_u + L_g + L_\psi + L_\chi \quad [W \cdot K^{-1}]$$

Conductance of

L_T K the zone envelope

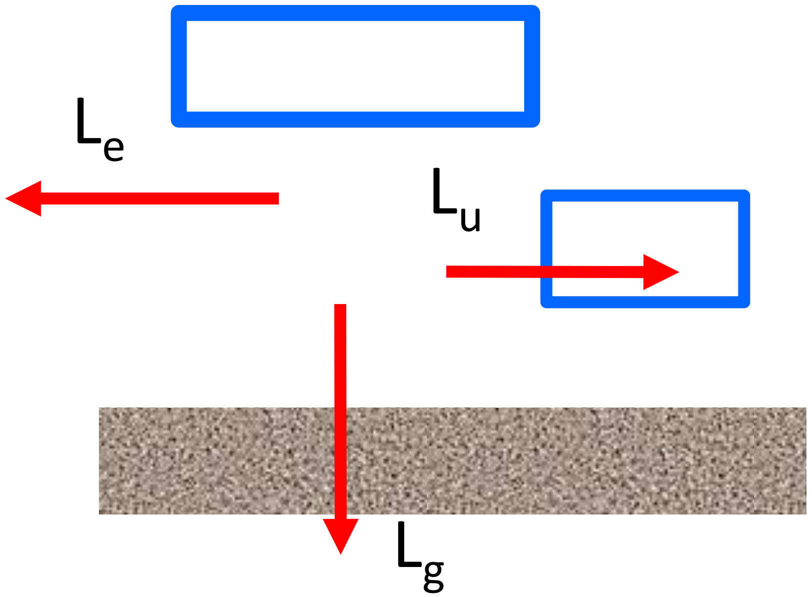
L_e K elements adjacent to outdoor air

L_u K elements adjacent to other zones

L_g K elements adjacent to ground

L_ψ K linear thermal bridges

L_χ K point - like thermal bridges



Building Heat Transfer

Transfer of Energy due to internal vibrations of molecules, without a net displacement of the molecules themselves

$$Q_{Conduction} = U \cdot A \cdot (\theta_i - \theta_s)$$

Q = Heat transfer through conduction

U or U-factor = Overall heat transfer co-efficient ($W/(m^2 \cdot K)$)

A = Surface area

delta T = Temperature difference across surface; $T_{in}(\theta_i) - T_{out}(\theta_s)$ (K)

- ECBC regulates the U-factor
- Surface area is determined by building design
- Delta T is determined by climatic conditions

Building Heat Transfer

- Reduce U-factor
  - Provide adequate insulation based on climate zone (Batt & Blankets , Loose Fill, Rigid, or Reflective systems)
  - Adopt cavity construction to increase insulation property of roof/wall
- Reduce exposed surface area (A)
  - Minimize exposed surface area of walls and roof in hot climates, and maximize exposed surface areas in cold climates
- Regulate Thermostat Settings (Delta-T)
  - Optimize temperature difference between indoor and outdoor while maintaining thermal comfort
- Other Energy Efficiency Tips for Roofs and Walls
  - Apply light colored surface finishes to increase solar reflectivity
  - Shelf shading of exposed wall surfaces through building form

Building Heat Transfer

Ventilation

$$Q_V = \rho_a \cdot c_a \cdot n \cdot V_n \cdot \Delta\theta$$

$$Q_V \cong 0.33 \cdot n \cdot V_n \cdot \Delta\theta \quad [W]$$

ρ_a ... Density of air ($kg.m^{-3}$)

c_a ... Specific heat capacity of air ($J.kg^{-1}.K^{-1}$)

V_n ... Ventilated net zone volume (m^3)

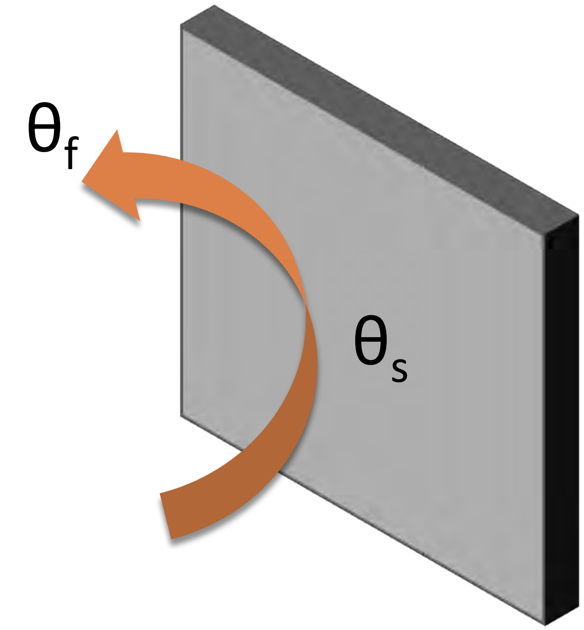
n ... Air change rate (h^{-1})

Building Heat Transfer

- Heat transfer in gases and liquids. Example: Warm air rising (or cool air falling) on a wall's inside surface, inducing air movement.
- Flux due to local temperature and density differences (Natural or free convection) or due to mechanical devices (forced convection)
- Heat transfer by convection takes place at the surfaces of walls, floors and roofs

$$Q_{Convection} = h_{cv} \cdot A \cdot (\theta_s - \theta_f)$$

Q_c = Heat transfer through convection
h_{cv} = Heat Transfer Coefficient
θ_s=Temperature of the surface
θ_f=Temperature of the fluid



Convection	Heat transfer coefficient in air h_{cv} in $W/m^2 \cdot K$
Free	3 - 10
Forced	10 - 100

Building Heat Transfer

Solar heat gain (transparent)

$$Q_s = A \cdot E \cdot g \cdot z$$

A: area of the transparent element
E : incident solar radiation
g : fraction of transmitted solar radiation
z: reduction factor for shading

Building Heat Transfer

Solar heat gain (opaque)

Sol-air temperature (θ_{sa})

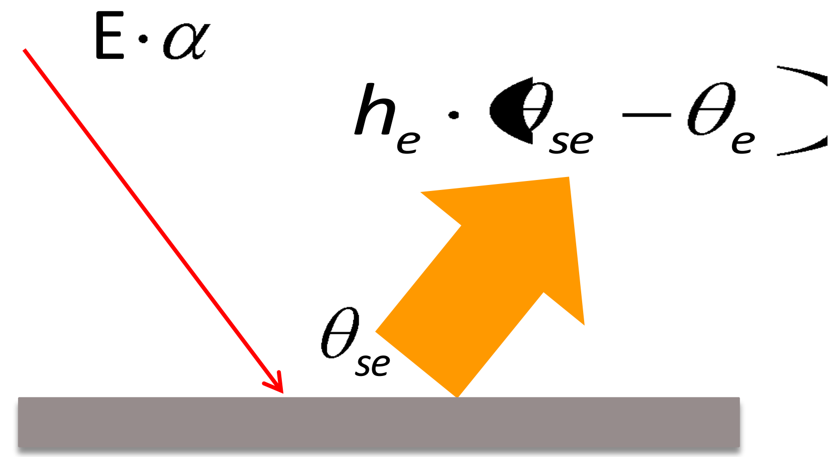
$$E \cdot A \cdot \alpha = A \cdot h_e \cdot (\theta_{se} - \theta_e)$$

$$\theta_{se} = \theta_e + E \cdot \alpha \cdot R_{se}$$

$$\theta_{se} \approx \theta_{sa}$$ (ignoring heat flow into element)

$$\theta_{sa} = \theta_e + (E \cdot \alpha - RE) \cdot R_{se}$$

RE: radiant emission (20…90 $W \cdot m^{-2}$)
α: solar absorptance
E : incident solar radiation



Building Heat Transfer

Internal gains (Equipment, lights, people)

$$Q_i = q_i \cdot A_{zone}$$

$q_i \ldots$ Heat emission rate $[W \cdot m^{-2}]$

$A_{ZONE} \ldots$ Zone area $[m^2]$

Mass transfer

Transfer of:

- Air
- Water vapor
- Water
- Dissolved solids
- Fluids (gases, liquids)

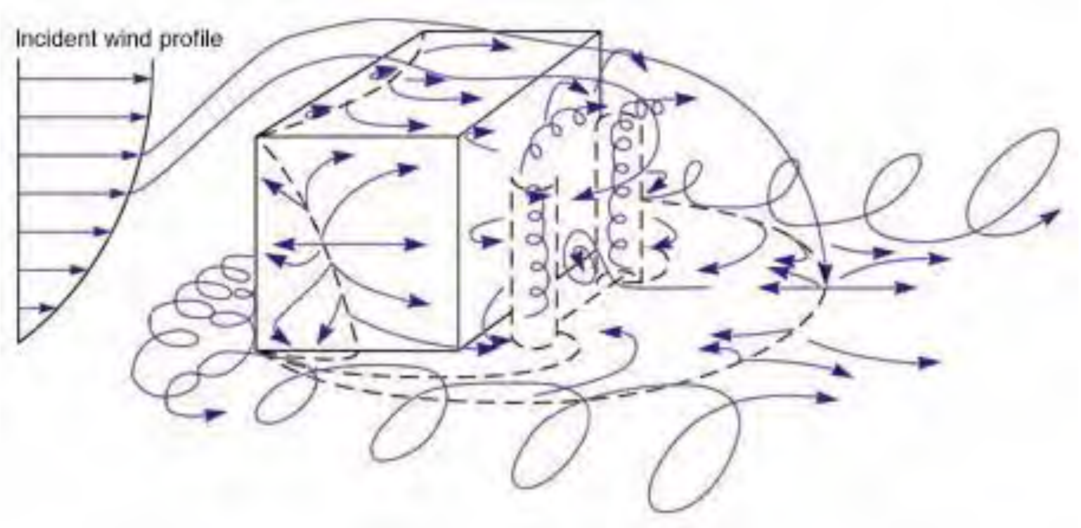
Through construction elements

- Moisture: Water, water vapor, substances (e.g. salts) dissolved in liquid phase, ice (for q < °C)

Mass transfer

Air

- Building-related air flow:
  - Ventilation: intentional
  - Infiltration (air leakage)



- Driving forces:
  - Wind pressure
  - Stack pressure (temperature-induced)
  - Mechanical devices (e.g. fans)

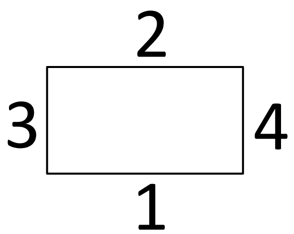
Mass transfer

Wind Pressure on a building's surface:

$$P_w = C_p \frac{\rho_a v^2}{2}$$

C_p wind pressure coefficient

v wind velocity at reference height [$m \cdot s^{-1}$]



Example of a low-rise building

Surface	**C_p**
Wall 1	0.4
Wall 2	-0.2
Wall 3	-0.3
Wall 4	-0.3
Roof (front; rear: pitch angle <10°)	-0.6
Roof (front; rear: pitch angle between10° and 30°)	-0.35
Roof (front; pitch angle > 30°)	0.3
Roof (rear: pitch angle > 30°)	-0.5

Mass transfer

Wind

Reference height for wind speed: building height

$$U_z = U_m \cdot k \cdot z^a$$

Terrain coefficient	k	a
open, flat country	0.68	0.17
Country + scattered wind breaks	0.52	0.20
urban	0.35	0.25
city	0.21	0.33

U_m wind speed, weather station at a height of 10 m [$m \cdot s^{-1}$]

U_z wind velocity at building height

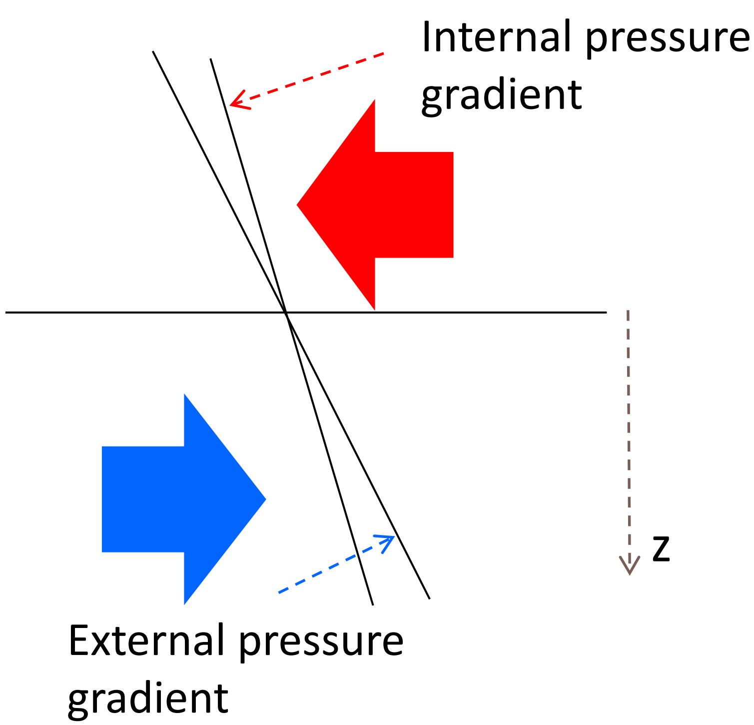
Mass transfer

Stack effect

Pressure difference at vertical distance z downward of neutral pressure plane

$$\Delta P_S = z \cdot (\rho_e - \rho_i) \cdot g$$

$$\Delta P_S = z \cdot 3456 \ (\frac{1}{T_e} - \frac{1}{T_i})$$



ρ_e, ρ_i Outdoor and indoor air density
T_e, T_i Outdoor and indoor air temperature [K]

Mass transfer

Mechanical ventilation

Pressure difference over envelope:

ΔP_v

- Extract ventilation: fan removes air from space (ΔP_v positive)
- Supply ventilation: air is mechanically induced in building (ΔP_v negative)
- Balanced ventilation: Combination of extract and supply ventilation

Mass transfer

Air exchange rate

- Denotes how many times per unit time (typically an hour) the volume of a space is exchanged with fresh outdoor air [h^{-1}]

Air tightness

- Air tightness of building envelope is desirable so as to avoid unintentional air infiltration. It is specified in terms of air exchange rate at a specific – intentionally introduced – pressure (e.g. 50 Pa)

Mass transfer

Moisture

Sources:

- Indoor humidity (occupants, cooking, bathing, washing/drying clothes)
- Construction moisture (typically higher in initial phase)
- Precipitation (rain, snow, hail)
- Water leakage
- Liquid water and water vapor in the ground

Mass transfer

Water vapor presence in air

- Partial water vapor pressure P_v [Pa]
- Water vapor concentration ρ_v [$kg \cdot m^{-3}$]
- Water vapor ratio x [$kg.kg^{-1}$]

$$P_v = R_v \cdot T \cdot \rho_v$$

R_v Specific gas constant for water vapor = 461.52 $J \cdot kg^{-1} \cdot K^{-1}$

T temperature [K]

Mass transfer

Maximum possible water vapor concentration in air ρs [kg.m^{-3}]

$$\rho_s = \frac{a \cdot (b + 0.01 \cdot \theta)^n}{R_v \cdot (\theta + 273.15)}$$

	a [Pa]	b	n
0 ≤ q ≤ 30 °C	288.68	1.098	8.02
-20 ≤ q ≤ 0 °C	4.689	1.486	12.3

R_v Specific gas constant for water vapor = 461.52 J·kg^{-1}·K^{-1}

θ temperature [°C]

Relative humidity ϕ [%]

$$\phi = 100 \cdot \frac{\rho_v}{\rho_{v,s}} \quad [\%]$$

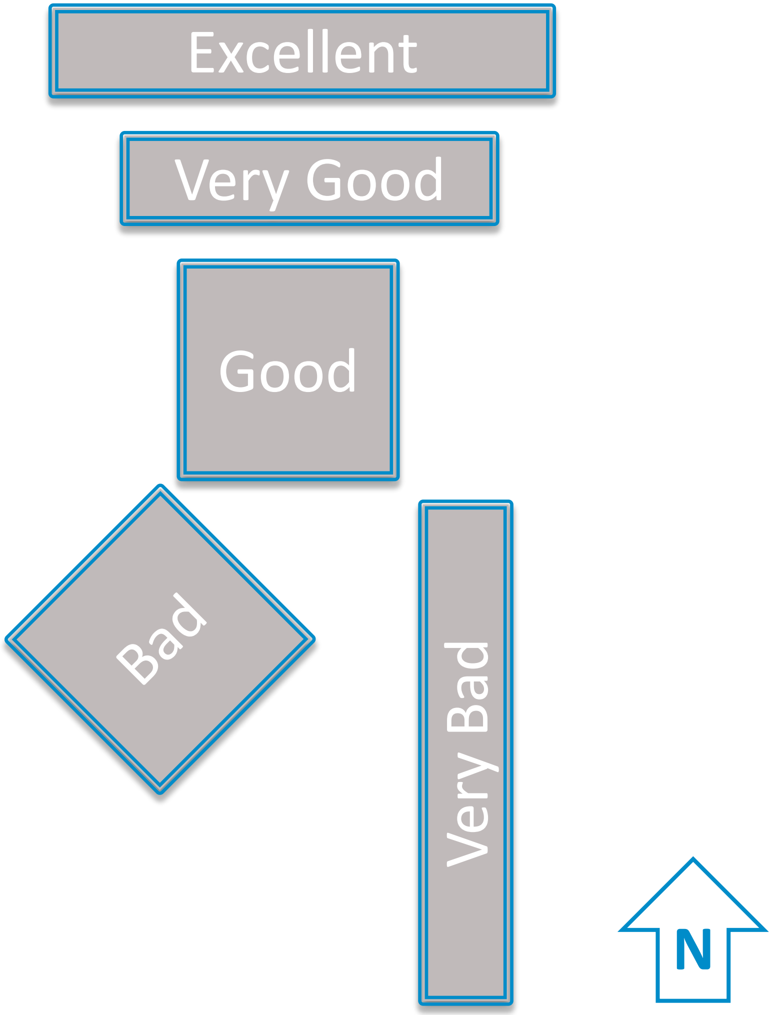
Passive Strategies

- Appropriate orientation
- Shading devices
- Thermal mass

Passive Strategies

- **Appropriate orientation**
- Shading devices
- Thermal mass

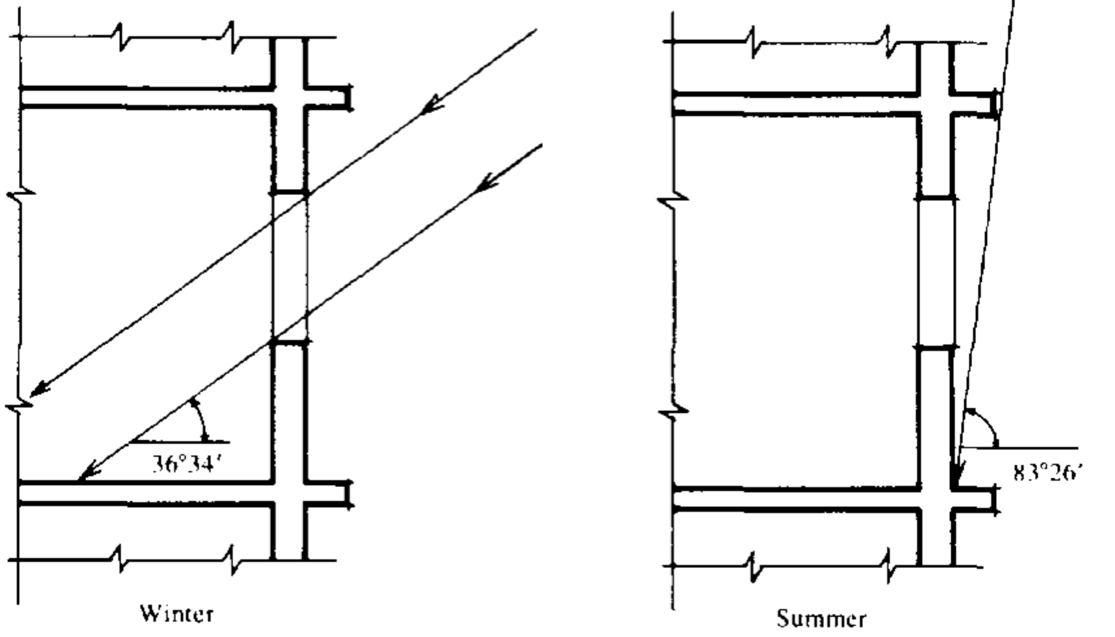
  - Daylight penetration and fenestration design has implications on heat gain/loss through the building
    - Directly impacts energy use for electric lighting and HVAC
  - Careful orientation of fenestration can help achieve thermal and visual comfort
  - Daylight harvesting through the north and south façades should be maximized in order to reduce lighting electrical loads



Passive Strategies

- Appropriate orientation
- **Shading devices**
- Thermal mass

  - Reduce heat gain and cooling energy use
  - Eliminate glare & reduce contrast ratios
  - Enhance visual comfort

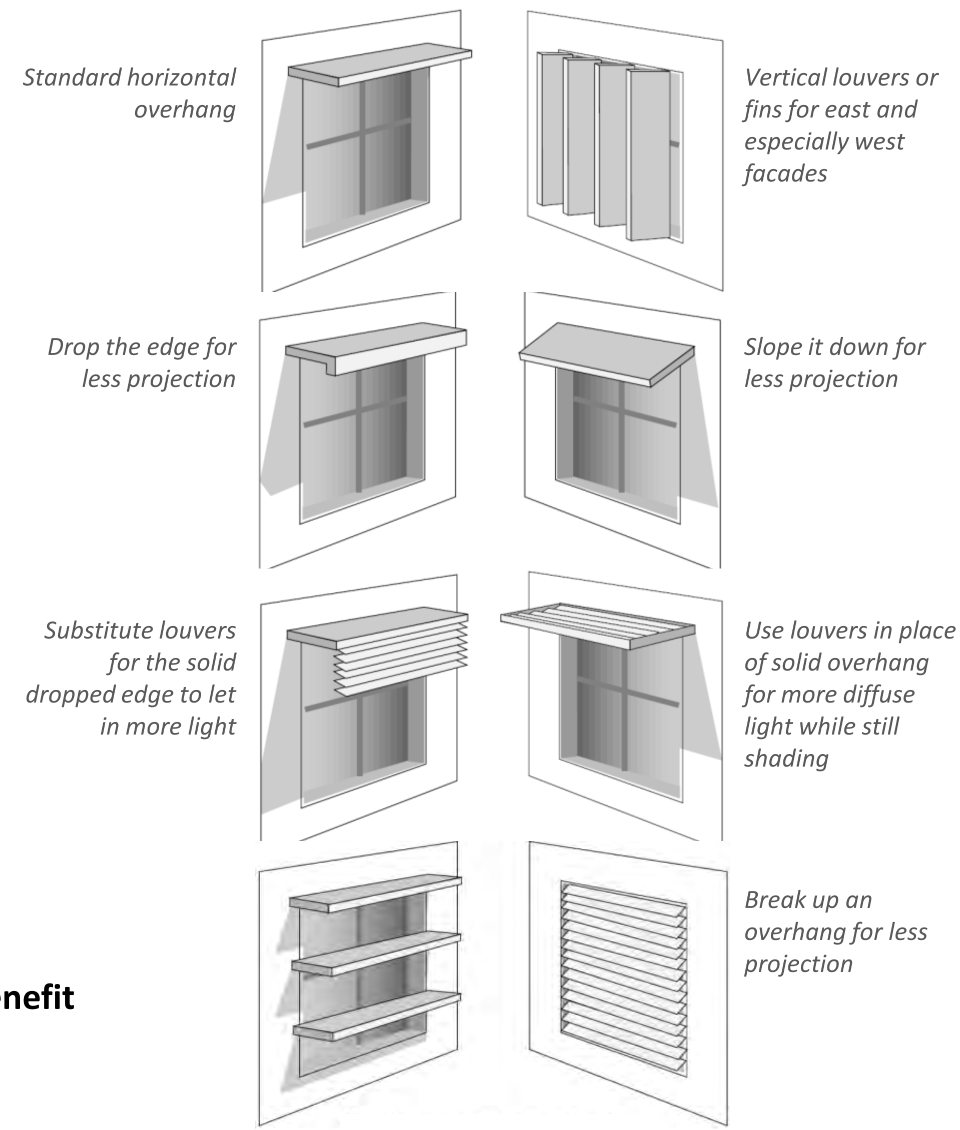


SOURCE: Hathy, Fassan, Walter Shearer & Abdal-Rahmān Sultān (1986) ,Natural energy and vernacular architecture: principles and examples with reference to hot arid climates, University of Chicago Press

Passive Strategies

- Appropriate orientation
- **Shading devices**
- Thermal mass

- **Types of Shading devices**
- **Exterior Devices**
  - **Use horizontal form for south windows**
  - **Vertical form for east and west windows**
  - **Priority to west and south shading**
  - **Shading on north needed for glare control**
- **Interior Devices**
  - **Limited ability to reduce heat gain**
  - **Light colors to reflect heat back out**
  - **Best option for glare control**
- **Fixed vs. Operable**
  - **Operable shades maximize adaptability**
  - **Combine multiple shading strategies for maximum benefit**



Passive Strategies

- Appropriate orientation
- Shading devices
- **Thermal mass**

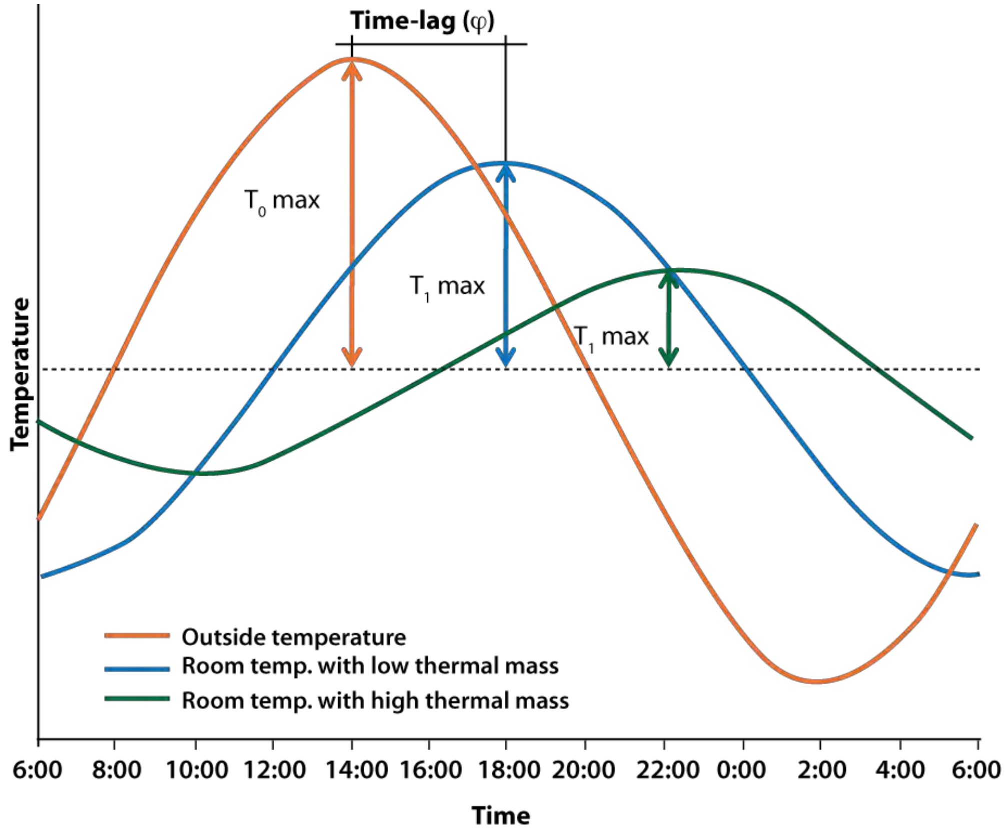
  - Thermal mass (thermal capacitance or heat capacity) is the capacity of a body to store heat (J/°C or J/K)

  - For a homogeneous material, thermal mass is simply the mass of material present times the specific heat capacity of that material. Specific Heat (c) values (at room temperature) for:
    - Air = 1006 J/(kg.K)
    - Water = 4187 J/(kg.K)
    - Or, to warm up 1 Liter water at 14,5°C by 1 K, 4187 J is needed

  - Thermal mass provides "inertia" against temperature fluctuations, sometimes known as the *TIME LAG*

Passive Strategies

- Appropriate orientation
- Shading devices
- **Thermal mass**
  - Thermal mass can be used effectively to absorb daytime heat gains (reducing cooling load) and release the heat during the night (reducing heat load)



Passive Strategies

- Appropriate orientation
- Shading devices
- **Thermal mass**
  - Traditional types of thermal mass include water, rock, earth, brick, concrete, cement, ceramic tile etc.




	Specific Heat kJ/(kg·K)	Density kg/m^3	Conductivity 'k' W/(m·K)	Resistivity '1/k' K·m/W
Water	4.187	1000	0.58	1.72
Burnt Brick	0.88	1820	0.811	1.23
Dense Concrete	0.88	2410	1.74	0.57
Timber	1.68	480	0.072	13.89

SOURCE: Bureau of Indian Standards (1988), Handbook on Functional Requirements of Buildings (Other than Industrial Buildings) (SP : 41)

Passive Strategies

Comfort can be achieved for substantial part of the day, week, month, year, in a passive manner

LEGEND

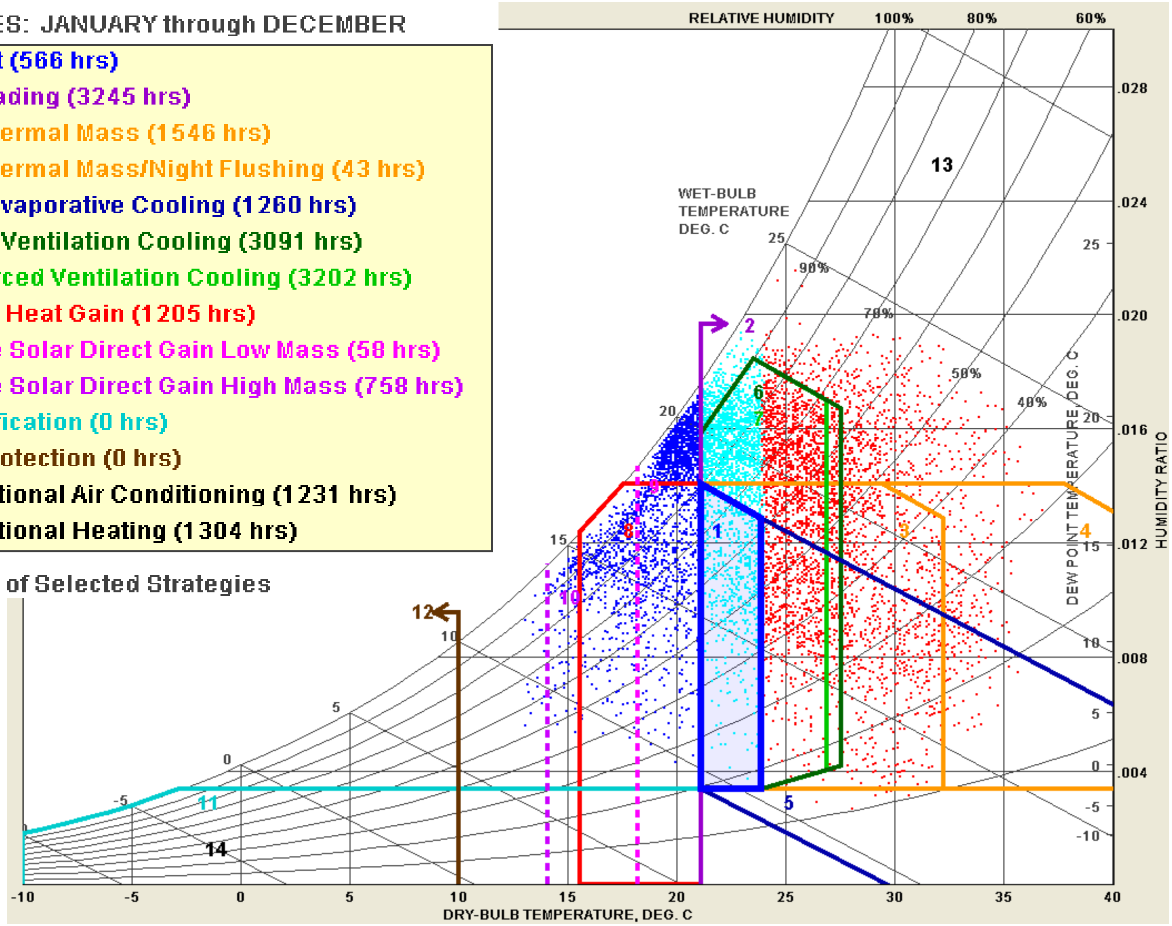
DRY-BULB TEMP (degrees C)

0%	■	< 0
30%	■	0 - 22
26%	■	22 - 24
42%	■	24 - 38
0%	■	> 38

DESIGN STRATEGIES: JANUARY through DECEMBER

6.5%	1 Comfort (566 hrs)
37.0%	2 Sun Shading (3245 hrs)
17.6%	3 High Thermal Mass (1546 hrs)
0.5%	4 High Thermal Mass/Night Flushing (43 hrs)
14.4%	5 Direct Evaporative Cooling (1260 hrs)
35.3%	6 Natural Ventilation Cooling (3091 hrs)
36.6%	7 Fan-Forced Ventilation Cooling (3202 hrs)
13.8%	8 Internal Heat Gain (1205 hrs)
0.7%	9 Passive Solar Direct Gain Low Mass (58 hrs)
8.7%	10 Passive Solar Direct Gain High Mass (758 hrs)
0.0%	11 Humidification (0 hrs)
0.0%	12 Wind Protection (0 hrs)
14.1%	13 Conventional Air Conditioning (1231 hrs)
14.9%	14 Conventional Heating (1304 hrs)

100.0% Composite of Selected Strategies



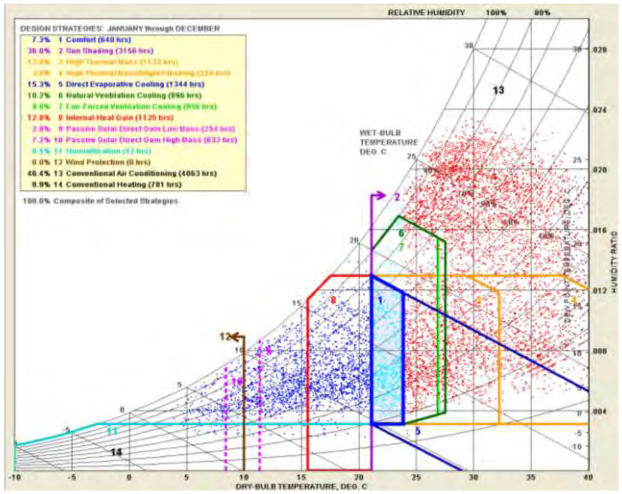
Applicability of PASSIVE STRATEGIES towards maintaining comfortable ambient conditions in TEMPERATE climate

Passive Strategies

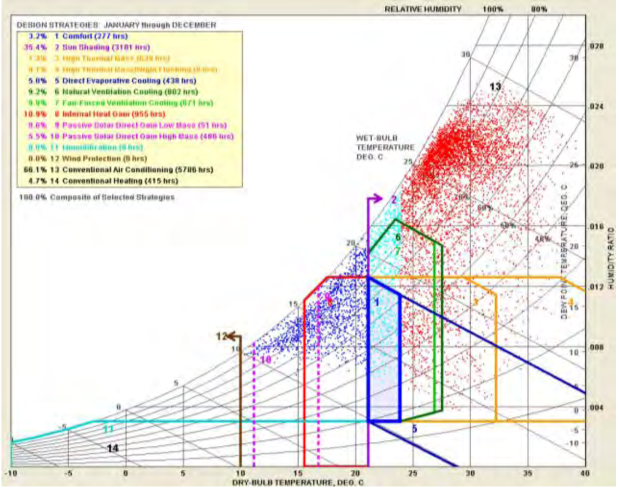
DRY-BULB TEMP
(degrees C)

0%		< 0
92%		0 - 22
6%		22 - 24
0%		24 - 38
0%		> 38

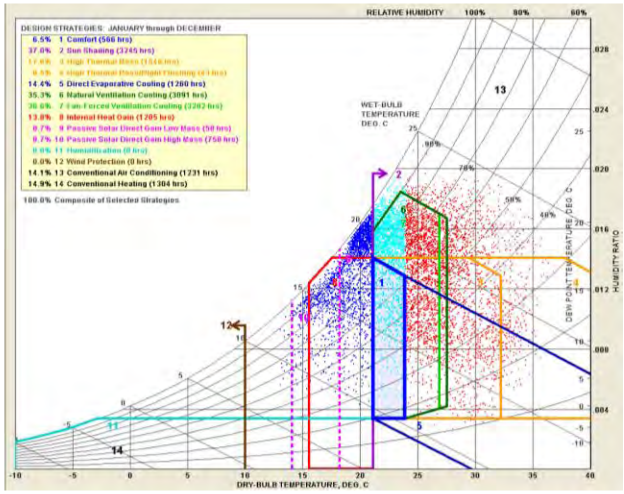
Hot and Dry



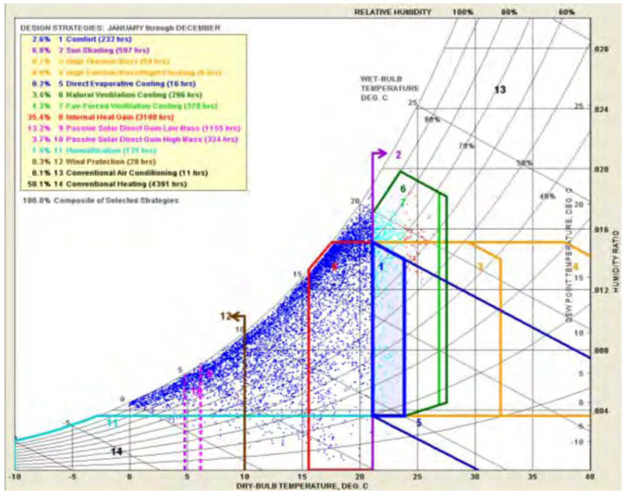
Warm and Humid



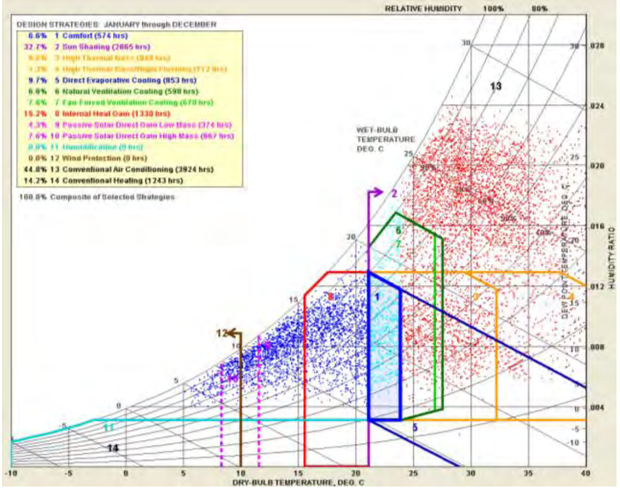
Temperate



Cold (Sunny/cloudy)



Composite



Active Strategies

When passive strategies do not provide required comfort conditions they are supplemented with active strategies:

- Fans
- Evaporative coolers
- Air-conditioners

Active Strategies

- **Fans**
  - The most common - least expensive, least power intensive
  - Increase the rate of evaporation from the skin by increasing the air speed near the occupant
- **Evaporative coolers**
  - Suitable for hot and dry conditions (due to high rate of evaporation in such climates)
- **Air-conditioners**
  - Maintain both temperature and humidity within the space and are most energy intensive

Visual Performance of Buildings

Light Basics

Light: visible segment of the electro-magnetic radiation

Radiation	λ [µm]
g, X	<0.001
UV	0.001 – 0.38
Light	**0.38 – 0.78**
IR	0.78 - 1000
Microwaves, radio waves	>1000

ca. 98% terrestrial solar energy within 0.25 - 3 mm (under 0.25 Absorption due to ozone layer, above 3 due to H_2O, CO_2)

Light Basics

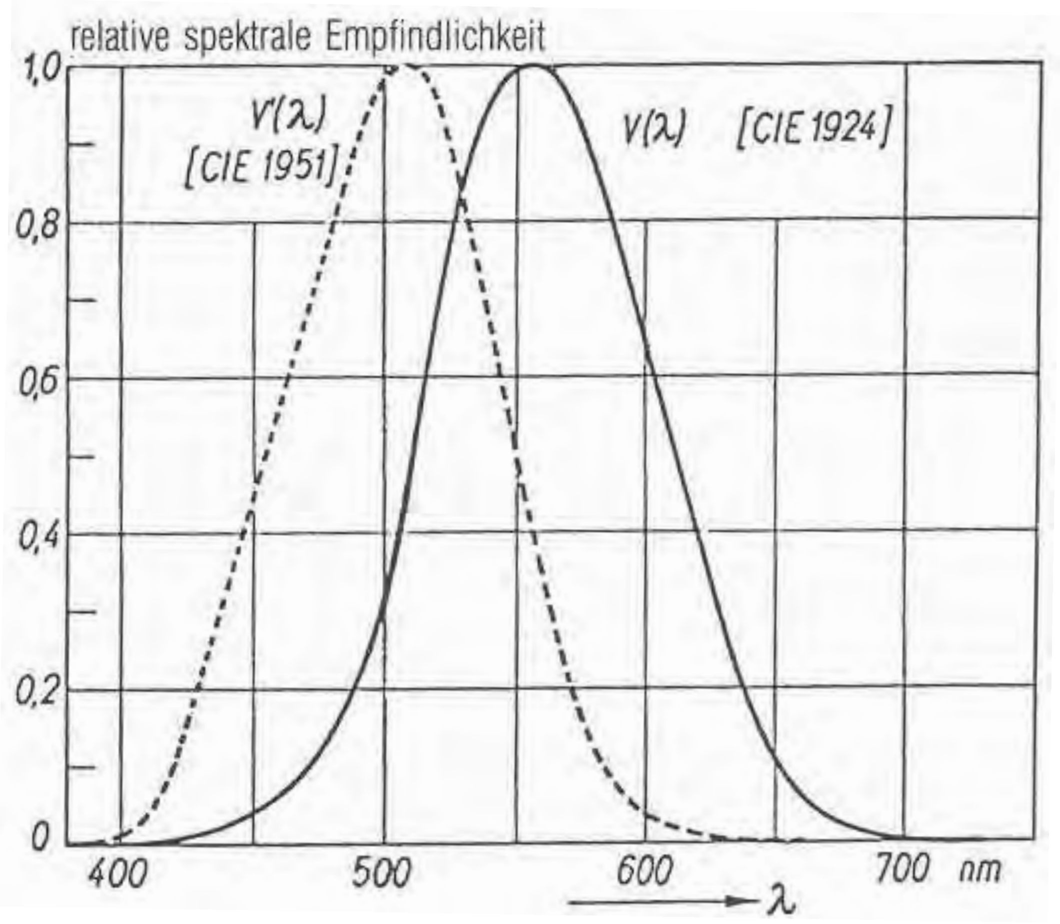
Radiation and light

- Φ_e Radiant flux [W]
  Purely physical
- Φ Luminous flux [lm]
  Related to human eye sensitivity

$$\phi = c \int_{380nm}^{780} \phi_{e\lambda} v(\lambda) d(\lambda)$$

$c = 683\ lm \cdot W^{-1}$

Spectral sensitivity of the human eye



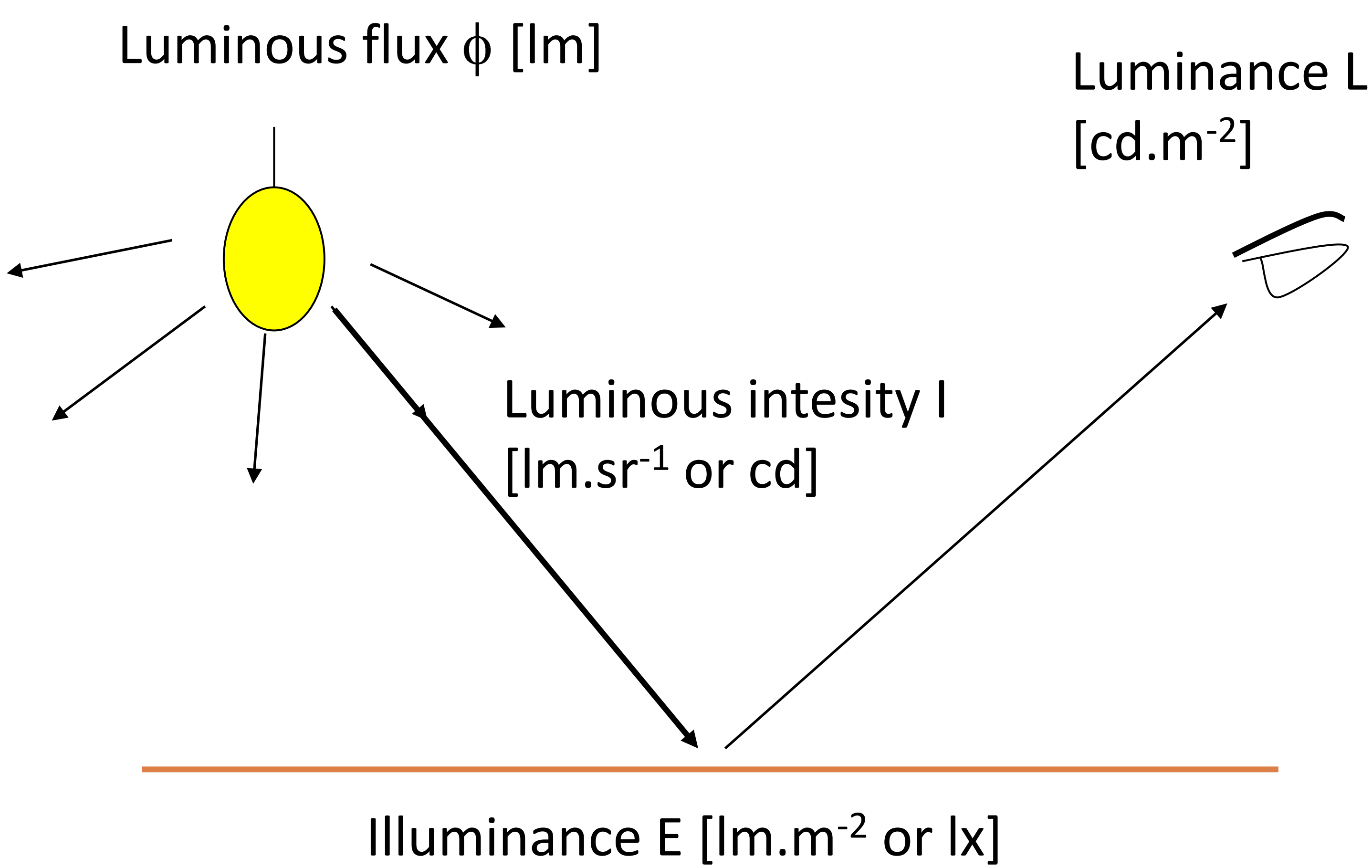
Light Basics

Lighting terms and units

Term	Symbol	Unit
Luminous flux	ϕ	lm
Luminous intensity	I	cd $(lm \cdot sr^{-1})$
Illuminance	E	lx $(lm \cdot m^{-2})$
Luminance	L	$cd \cdot m^{-2}$
Luminous efficacy	r	$lm \cdot W^{-1}$

Light Basics

Lighting terms and units

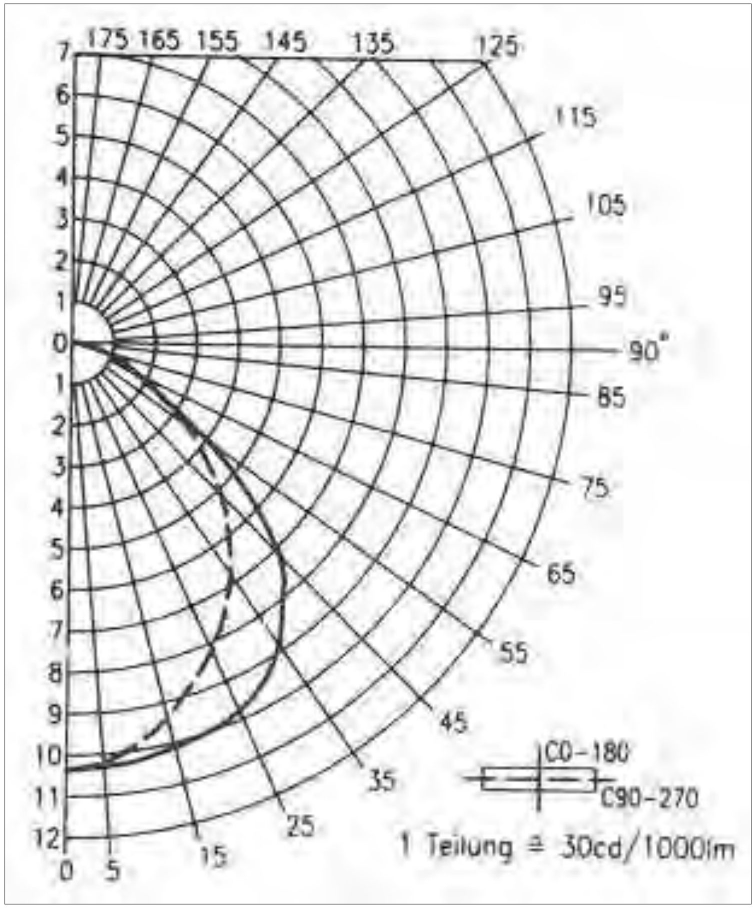


Light Basics

Luminous intensity I

- Spatial distribution of luminous flux
- [cd or lm.sr^{-1}]

Example of luminous intensity distribution fluorescent lamps



Light Basics

Illuminance

- Describes the quantity of luminous flux falling on a surface
- Measured in lux (lx)
- Decreases by the square of the distance (inverse square law)

$$E = \frac{\phi}{A} \quad [\mathrm{lx}]$$

Light Basics

Illuminance

Condition	Illumination (ftcd)	Illumination (lux)
Sunlight	10,000	107,527
Full Daylight	1,000	10,752
Overcast Day	100	1,075
Very Dark Day	10	107
Twilight	1	10.8
Deep Twilight	.1	1.08
Full Moon	.01	.108
Quarter Moon	.001	.0108
Starlight	.0001	.0011
Overcast Night	.00001	.0001

Outdoor lux levels

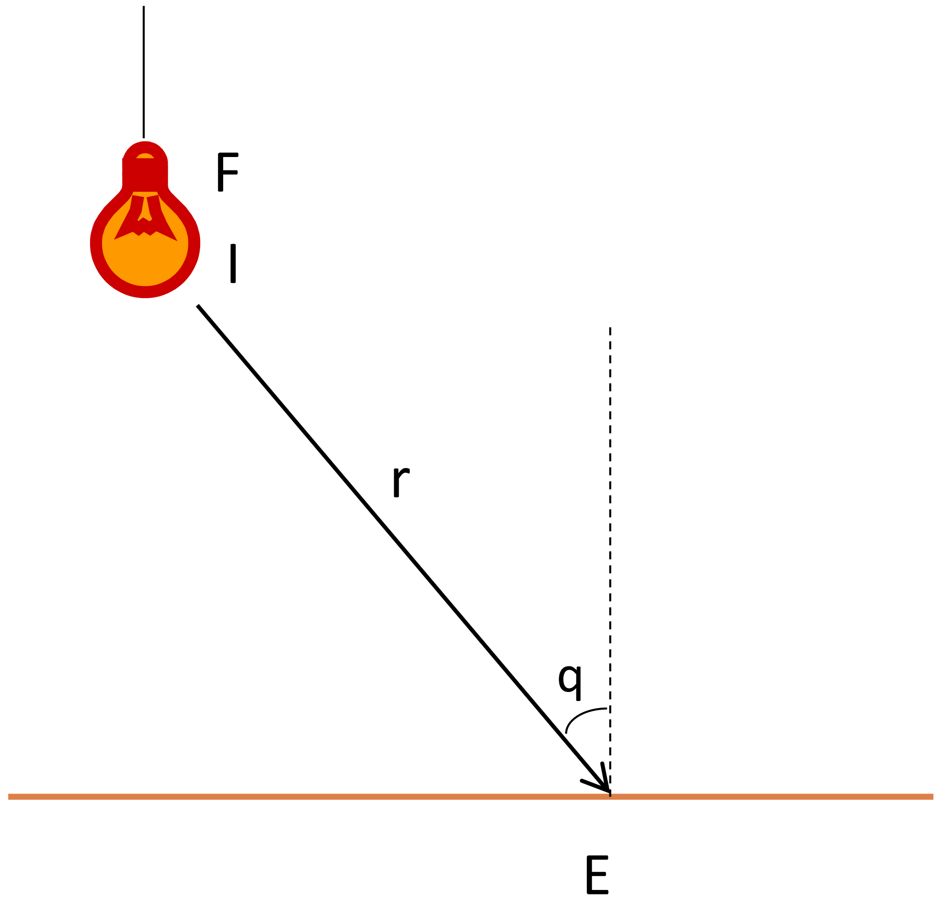
Activity	Illumination (*lux, lumen/m²*)
Public areas with dark surroundings	20 - 50
Simple orientation for short visits	50 - 100
Working areas where visual tasks are only occasionally performed	100 - 150
Warehouses, Homes, Theaters, Archives	150
Easy Office Work, Classes	250
Normal Office Work, PC Work, Study Library, Groceries, Show Rooms, Laboratories	500
Supermarkets, Mechanical Workshops, Office Landscapes	750
Normal Drawing Work, Detailed Mechanical Workshops, Operation Theatres	1,000
Detailed Drawing Work, Very Detailed Mechanical Works	1500 - 2000
Performance of visual tasks of low contrast and very small size for prolonged periods of time	2000 - 5000
Performance of very prolonged and exacting visual tasks	5000 - 10000
Performance of very special visual tasks of extremely low contrast and small size	10000 - 20000

Recommended indoor lux levels

Light Basics

Inverse square law

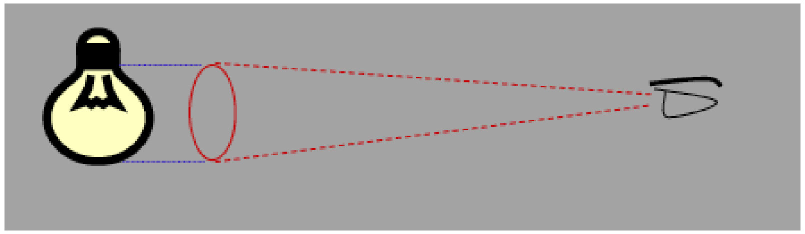
$$E = \frac{I}{r^2} \cdot \cos\theta \quad [\mathrm{lx}]$$



Light Basics

Luminance

- The only basic lighting parameter that is perceived by the eye
  - Objective base of perception of brightness
- Specifies the brightness of a surface and is essentially dependent on its reflectance (finish and color)



$$L = \frac{I}{A_{proj}} \quad [\mathrm{cd} \cdot \mathrm{m}^{-2}]$$

Light Basics

Luminance

- Alternative Description

$$L = \frac{E_{ref}}{\pi} \qquad [cd \cdot m^{-2}]$$

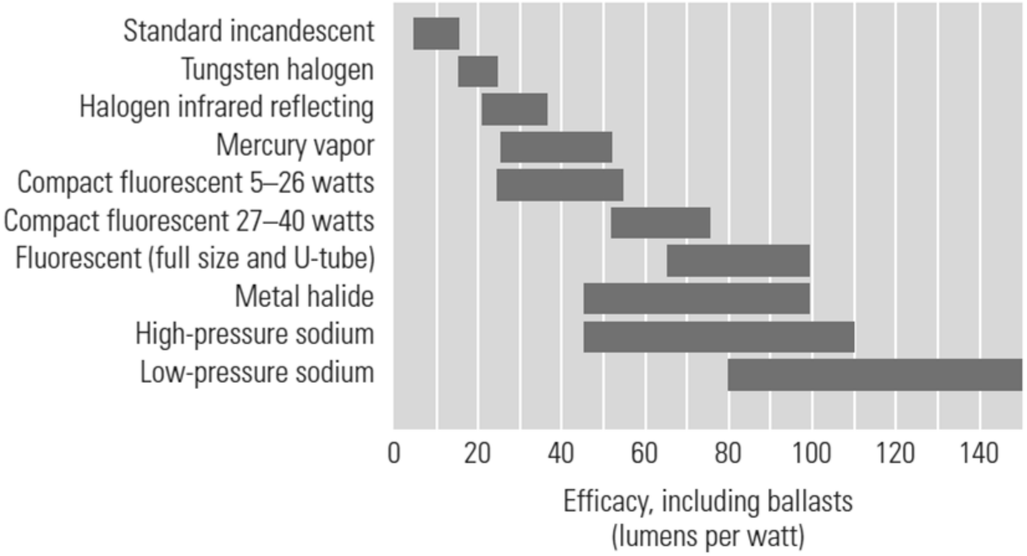
Luminance – recommended levels

	luminance L [cd·m^{-2}]
Surface of streets	1 ... 2
Walls	25 ... 150
Ceilings	50 ... 250
Working Planes	100 ... 500
Lamps	1000 ... 7000

Light Basics

Luminous Efficacy

- Energy efficiency of lighting systems is measured in terms of 'Luminous Efficacy'.
- The Luminous Efficacy is the ratio of the luminous flux to the electrical power consumed (lm/W)
- It is a measure of a lamp's economic efficiency



Lamp efficacy of major light sources

SOURCE: E Source Technology Atlas Series, Volume I Lighting (2005)

Light Basics

Daylight: simplified calculation

- Daylight Factor

$$DF = \frac{E_i}{E_e} \cdot 100 \quad [\%]$$

E_i: Illuminance inside

E_e: Illuminance outside

Daylight Factor: DF

DF_m	Remark
Less than 2 %	Electrical lighting necessary
2 ... 5 %	Impression of Daylight, Supplementary electrical lighting
More than 5%	No electrical lighting during daytime (possible thermal issues)

Light Basics

Daylight Factor Calculation

$$DF_m = \frac{A_G}{A_R} \cdot \frac{\theta \cdot \tau_d}{\left(1 - \rho_m{}^2\right)} \quad [\%]$$

A_G...Area of room surfaces [m^2]
θ...angle of visible sky [°]
P_m...average room surfaces reflectance [-]
A_R...Net Glazing Area [m^2]
τ_d...Diffuse transmittance of glazing [-]

Light Basics

Glazing – transmission and pollution factors

Glazing	τ_{diff} [-]
clear, single	0.8
clear, double	0.7
Low-e, double	0.65

Diffuse transmittance

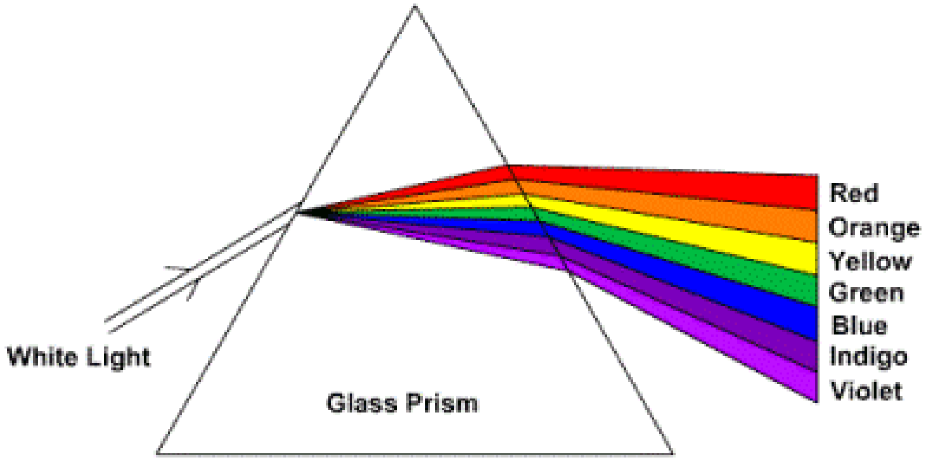
Orientation	Urban Context	Clear Atmosphere (no pollution)
Vertical	0.8	0.9
Horizontal	0.6	0.7

Dirt factors

Light Basics

Color temperature

- Color of light ~ color temperature
- temperature of a black body that evokes the same color sensation as the light in question

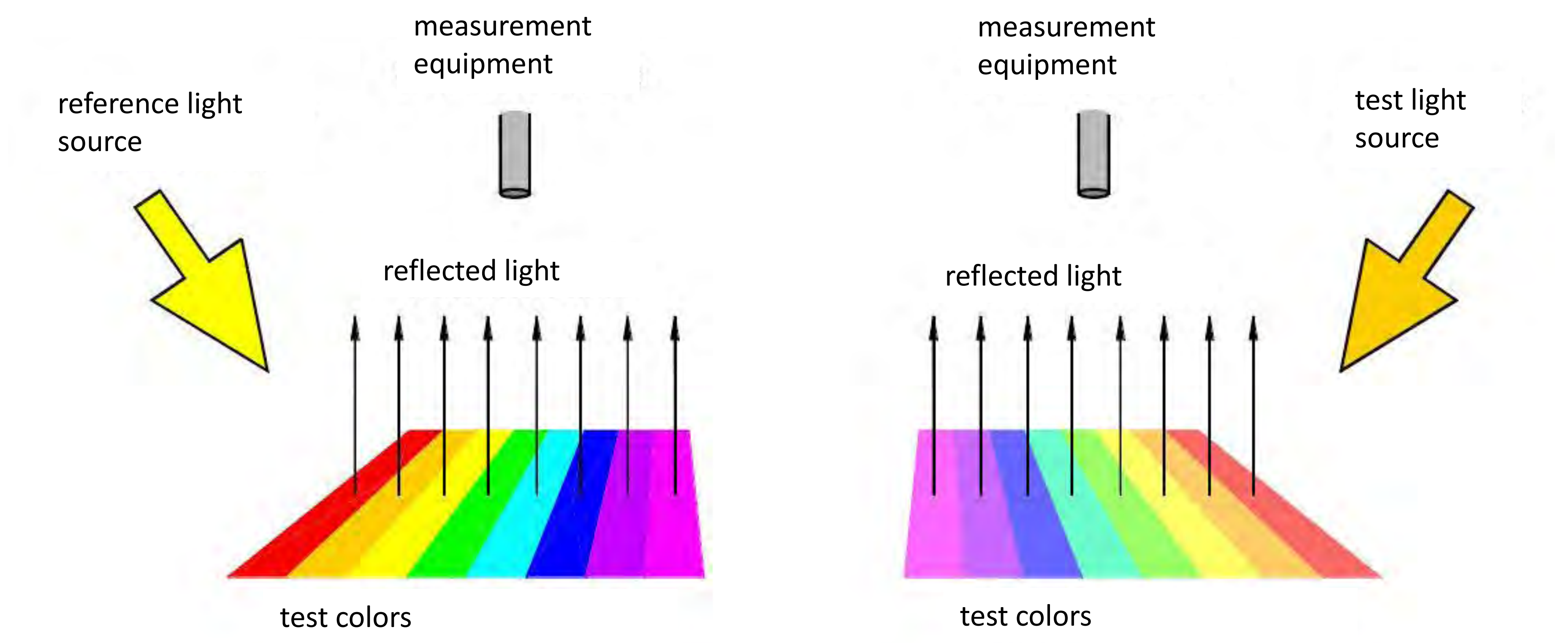


White light: a mixture of multiple colors

Light Basics

Color rendering index (CRI)

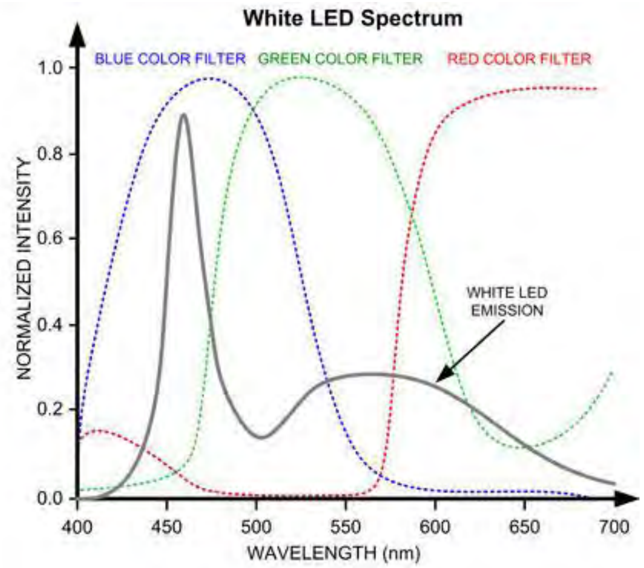
- calculated by comparing reflected colors under a test source and a reference (perfect) light source



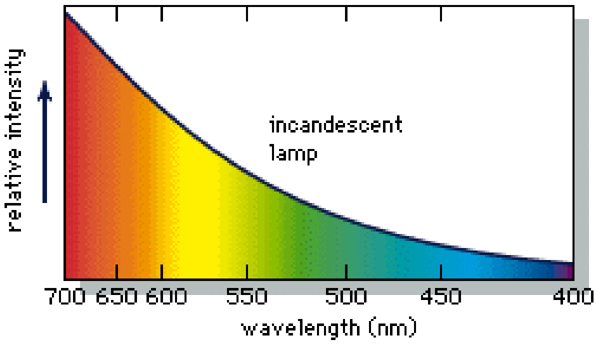
Light Basics

Lamps

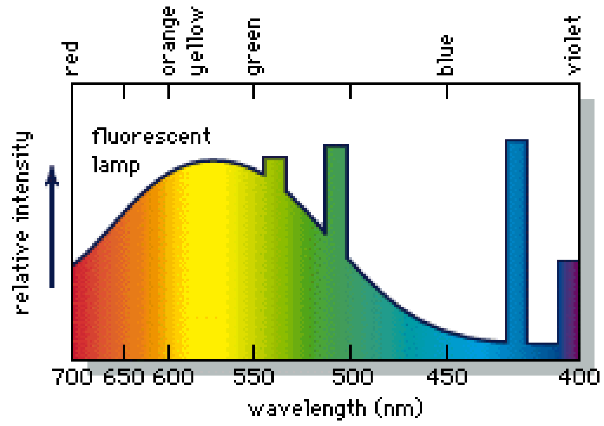
Light emitting diode



Incandescent lamps



Discharge lamps



Light Basics

Lamps

Lamp	Luminous flux [lm]	Luminous efficacy [lm/W]	Color temperature [K]	Color rendering index [CRI]	Power [W]
Incandescent/halogen	120/8400	6-27	2700-3200	100	15-2000
Low-pressure sodium vapor	1800-32500	100-200	1700	n.a.	18-180
High-pressure sodium vapor	1300-90000	50-130	2000, 2200, 2500	25-80	35-1000
High- prressure mercury vapor	1700-59000	35-60	3400,4000	40-55	50-1000
Fluorescent	200-8000	60-105	2700, 3000, 4000, 6500	60-95	5-80
Compact fluorescent	200-12000	50-85	2700,3000,4000, 6500	80	5-165
Metal-halogen vapor	5300-22000	75-140	3000,4000,5600	65-95	70-2000
Ceramic Metal-halogen vapor	3300-14000	90-95	3000-4200	80-90	20,35,70,150
LED	10-250	Up to 50	4000-5000	65-90	1-5

Visual Comfort

Factors that affect visual comfort

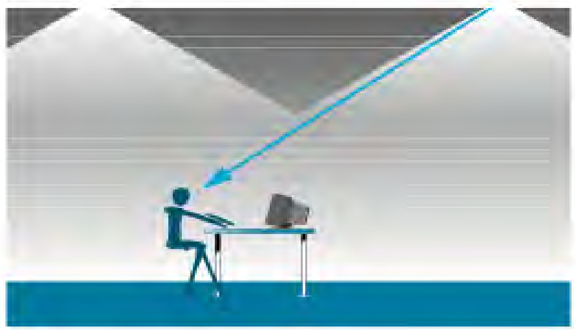
- ***Illumination*** matched to task requirements
  - Ideally with the use of daylight as far as possible
- ***Glare***
- ***View*** (connection to outdoors)

Visual Comfort

- High luminance levels or large luminance differences in the field of view
  - Difficulty seeing in the presence of light
  - Visual Comfort = No GLARE
- Influence Factors
  - Luminance of source
  - Size of source
  - Position of source
  - State of adaption
    - (Brightness of Background)

Visual Comfort

DIRECT GLARE
Light source in field of view

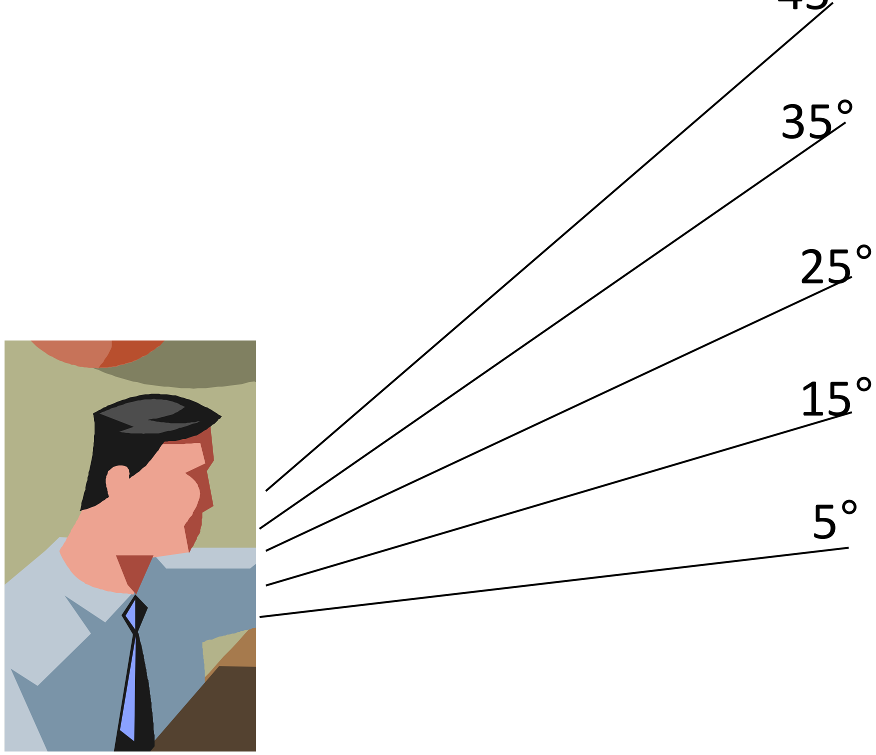


REFLECTED GLARE
Reflection of a light source

Direct glare		Reflected glare
• luminaires without glare control • very bright surfaces	cause	• reflective surfaces • incorrect luminaire arrangement • incorrect workstation position
• loss of concentration • more frequent mistakes • fatigue	effect	• loss of concentration • more frequent mistakes • fatigue
• luminaires with limited luminance levels • blinds	remedy	• matching luminaire to workstation (layout) • indirect lighting • matt surfaces

Visual Comfort

Recommended maximum luminance levels for luminaires



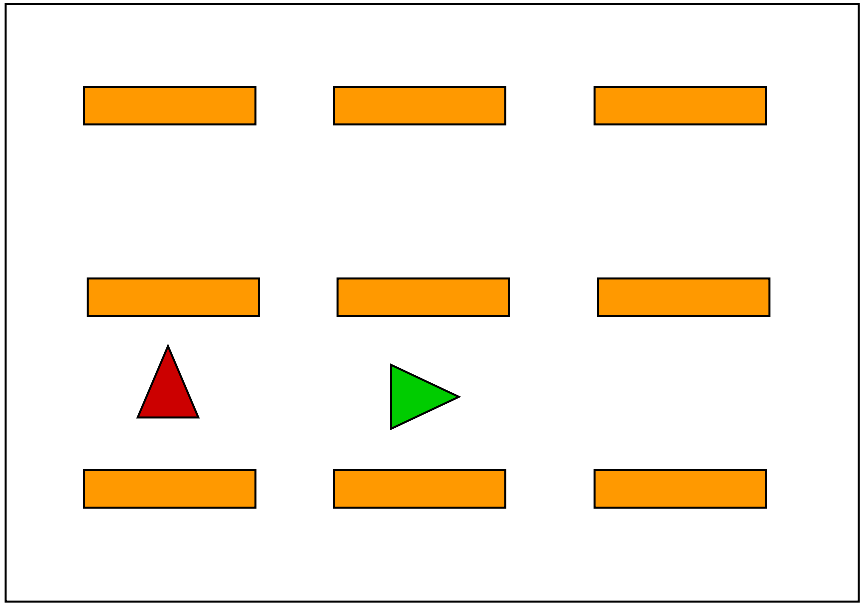
	Average Luminance	Maximum Luminance * [cd·m^{-2}]
45°	2550	7700
35°	1850	5500
25°	1300	2500
15°	850	2500
5°	600	1700

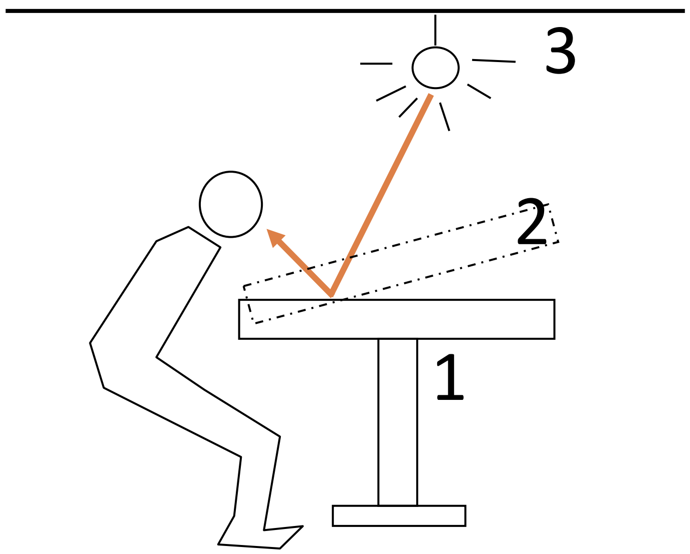
* *small "highlights"*

Visual Comfort

Measures against reflected glare

- Location of System-Elements
- Layout of workstations
- inclined working area
- Flexible (relocatable) sources





Visual Comfort

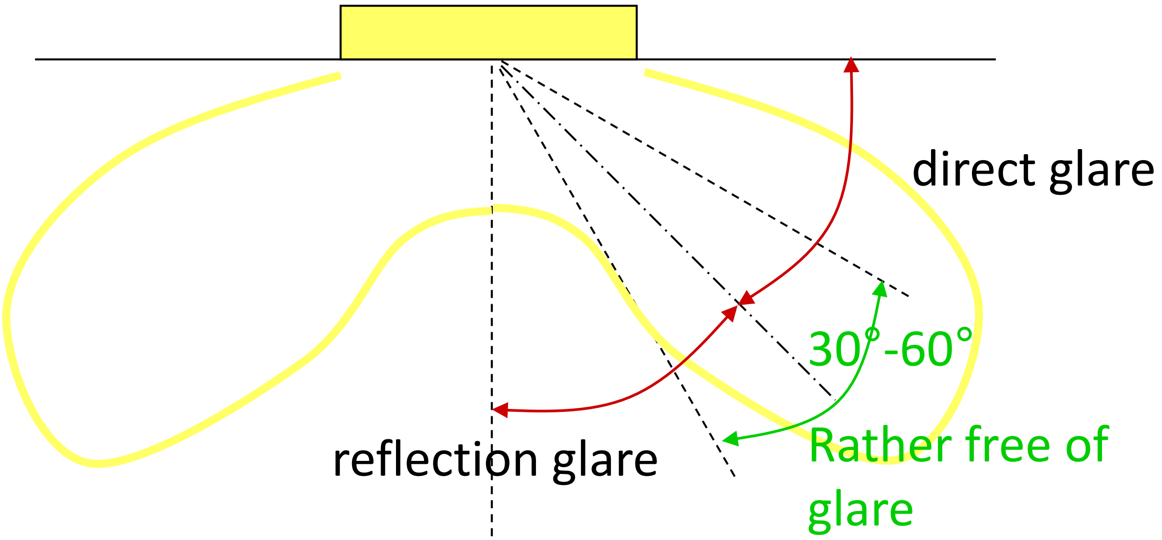
Measures against reflected glare

- Use of glare-free light sources (e.g. task lights)
- High illuminance
- Low energy use (compared with high output ceiling luminaires)
- Individual control
- Improving visual quality of Tasks, e.g.
  - Properties of paper
  - Declination of working tables

Visual Comfort

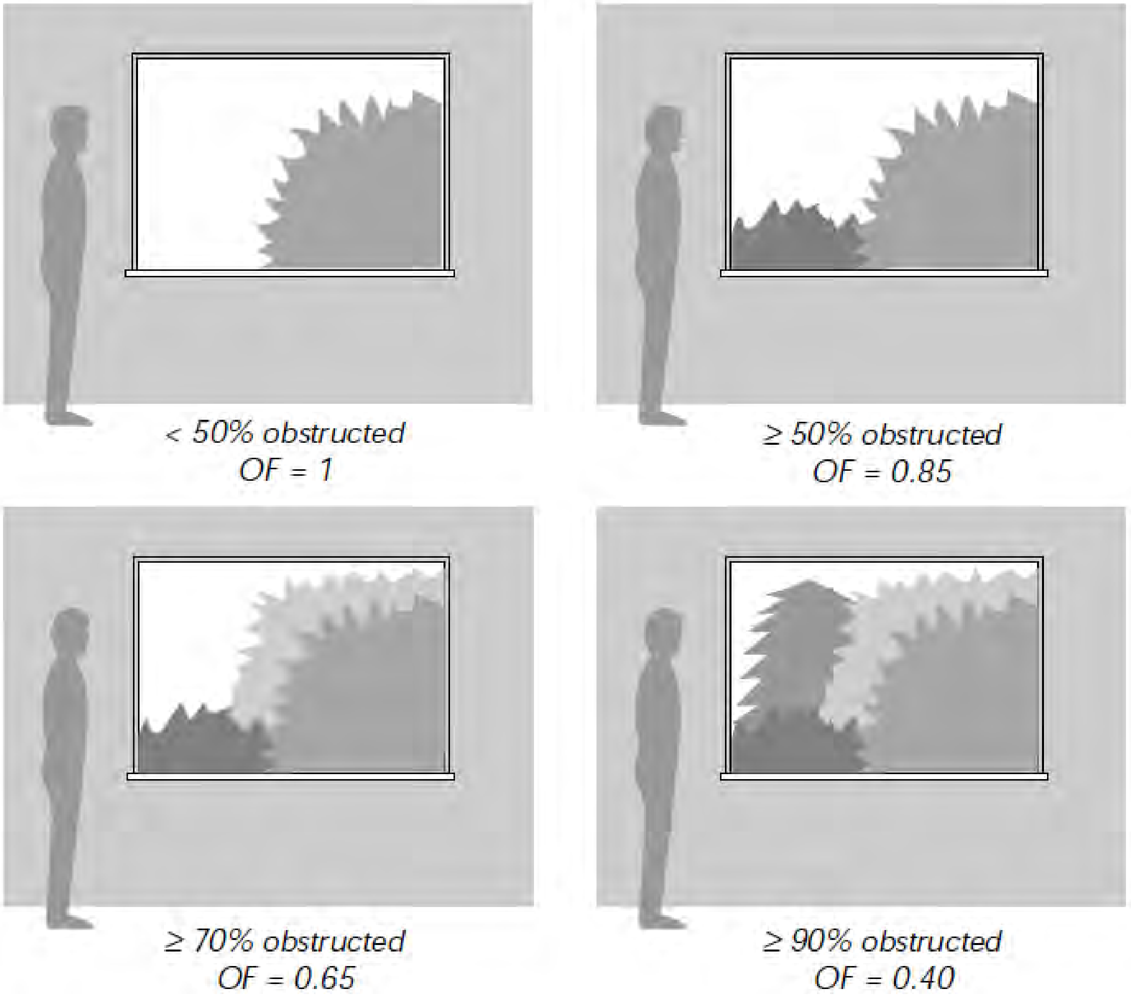
Measures against reflected glare

- Properties of Luminaires
- Dimming
- Large-area "low-output" sources
- Indirect / semi-indirect sources
- Differentiated distribution of luminance



Visual Comfort

Connection to Outside (View)



Obstruction Factor (OF)

SOURCE: Tips for Daylighting with Windows: The Integrated Approach, LBNL-39945, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA

Optimizing energy use for visual comfort

External Factors (Climate)

- Daylight Availability
- Building Site and Obstructions

Internal Factors (Loads)

Space characteristics

- Fenestration
  - Location
  - Position
  - Design – glazing, shading
- Room surfaces – color, texture
- Space plan

Occupant behaviour

- Nature of activity (Lighting requirements)
- Controls

Electrical Lighting

Passive Strategies

- Appropriate orientation
- Skylights, atria
- Elements – light shelves, reflectors, louvers, blinds
- Fenestration Design - Glazing selection
- Light transport systems

Active Strategies

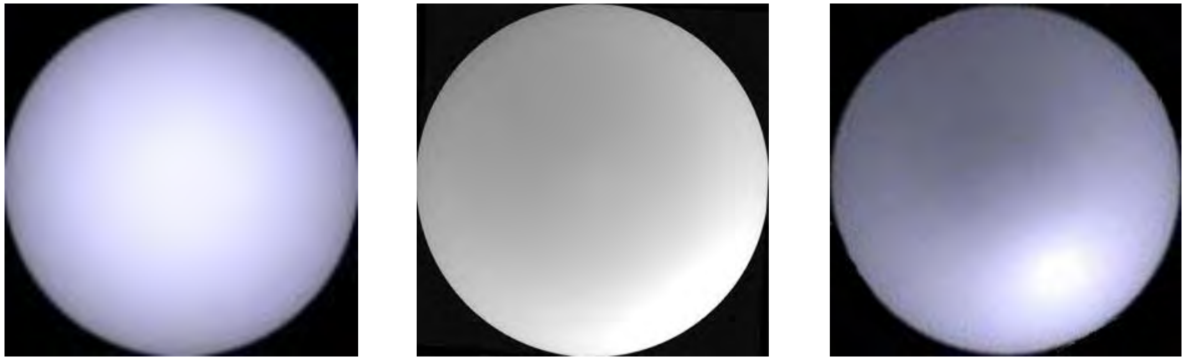
- Efficient electrical lighting
- Lighting controls

Climate

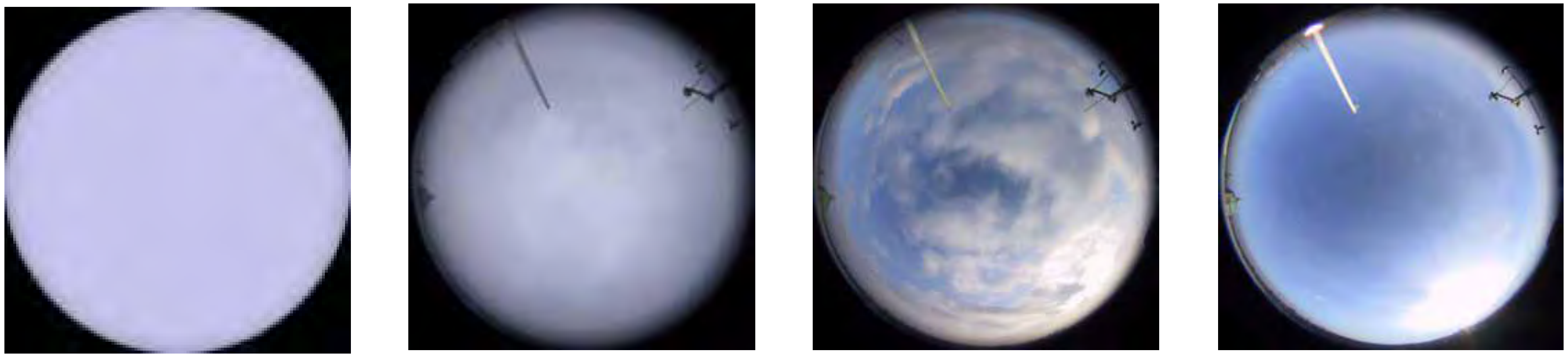
Daylight availability

- Sky luminance
  - Sky type – Cloudiness

CIE standard sky models



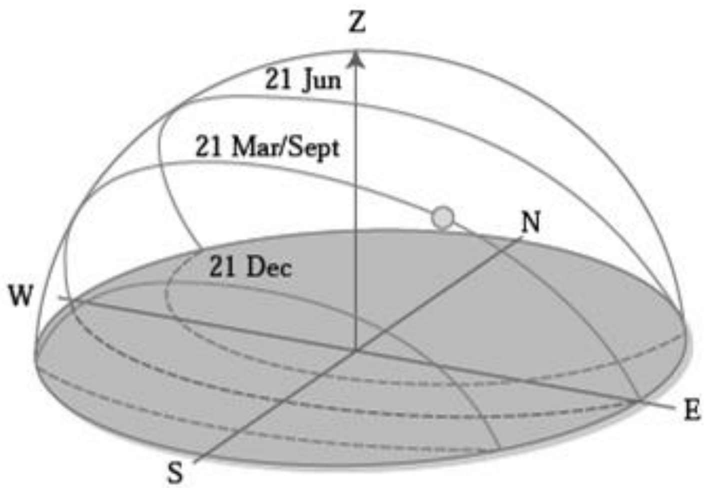
Uniform Sky | Overcast sky | Intermediate sky | Clear sky

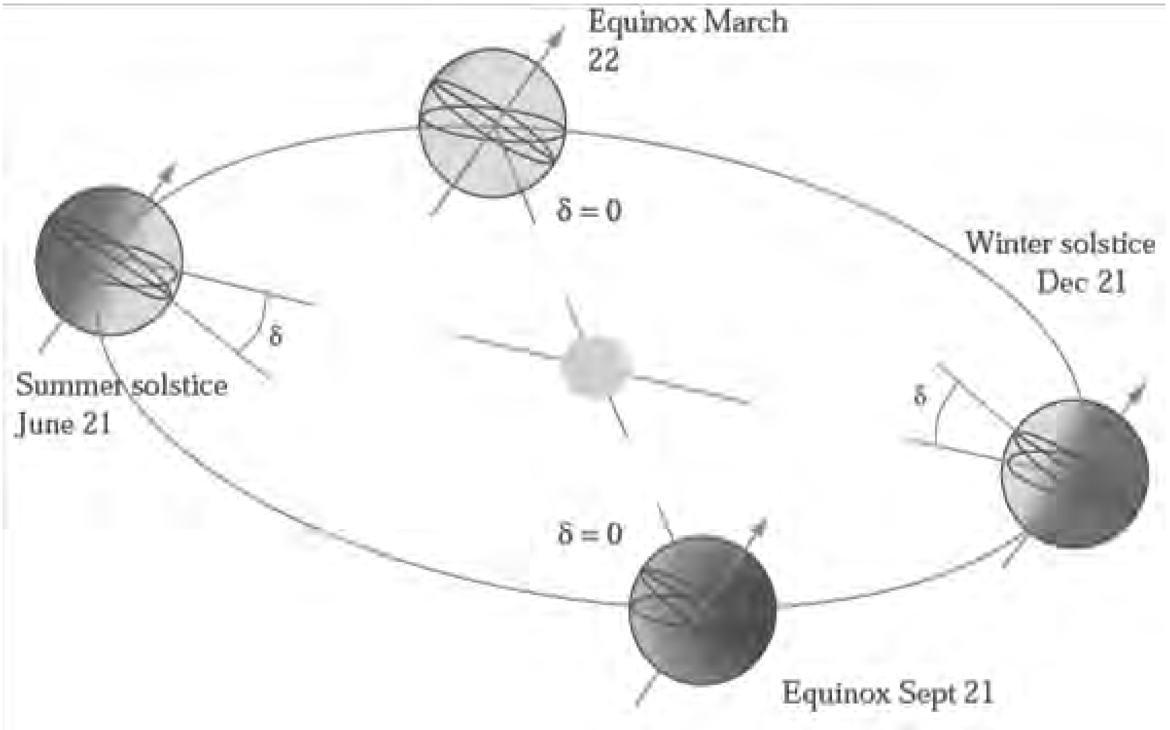


Climate

Daylight availability

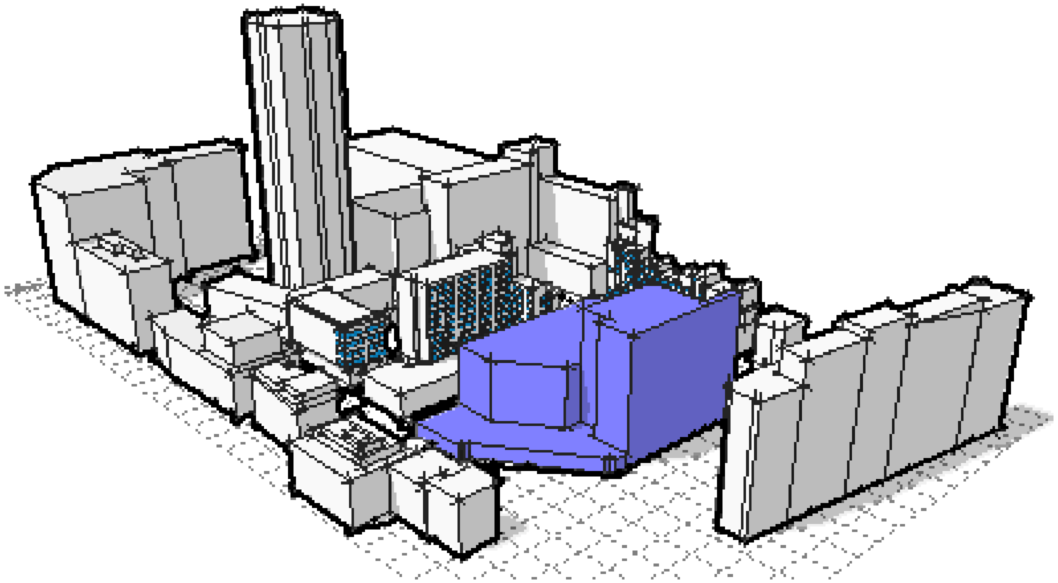
- Altitude
- Latitude
- Azimuth





Climate

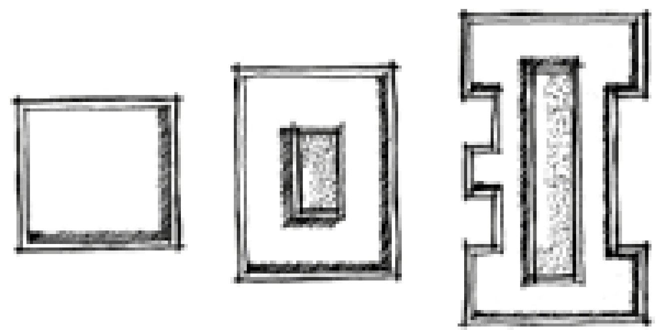
Building Site and Obstructions

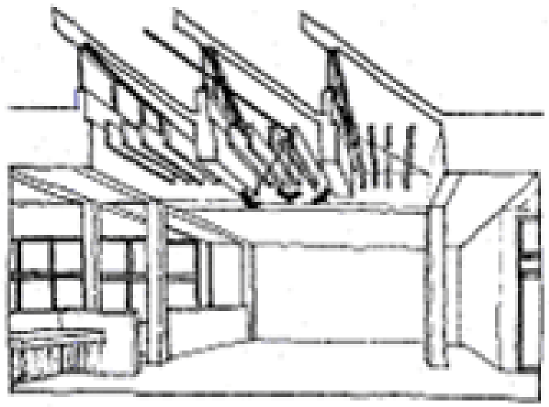


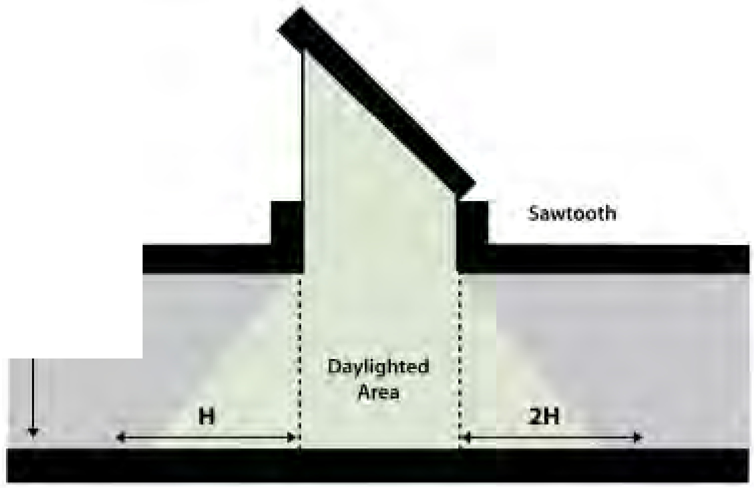
Passive Strategies

Building form and skin

- Form (increase perimeter)
- Orientation
- Skylights, atria



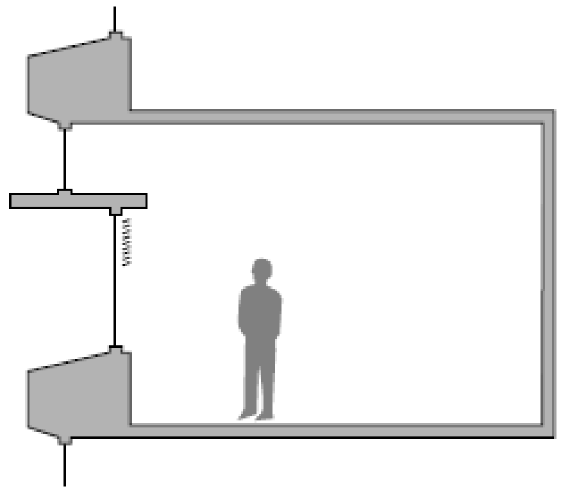




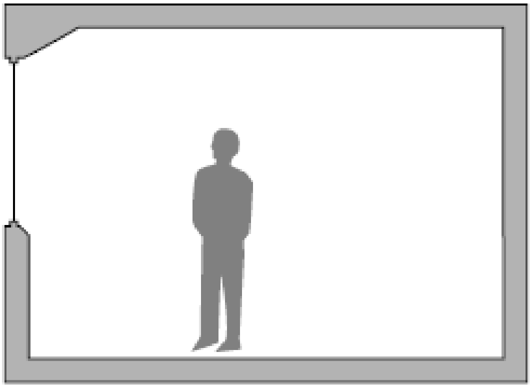
Passive Strategies

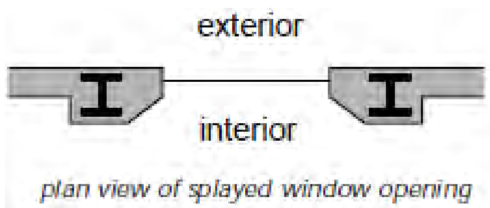
Building form and skin

- Increase exposure to daylight
- Shape building for self-shading
- Take a deep façade approach
- Incorporate envelope features that improve Daylighting
- Balance daylight admittance



Deep wall section provides self-shading, allows easy integration of light shelf, creates surfaces that mitigate glare, and reduces noise transmission. Sloped surfaces also help soften glare.





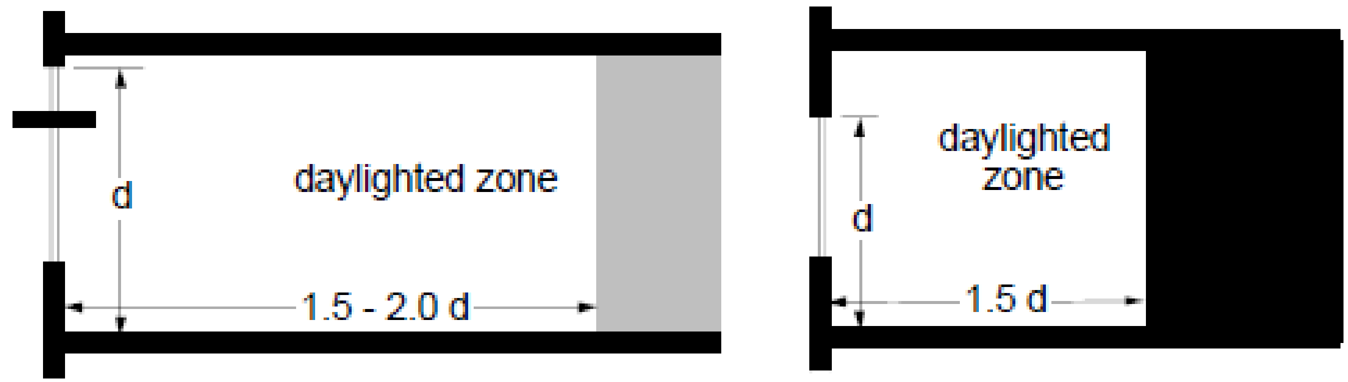
Sloped surfaces, such as this splayed window opening, help soften glare. These surfaces should be light-colored abd provide an intermediate brightness between window and room surfaces, making an easier transition for the eye.

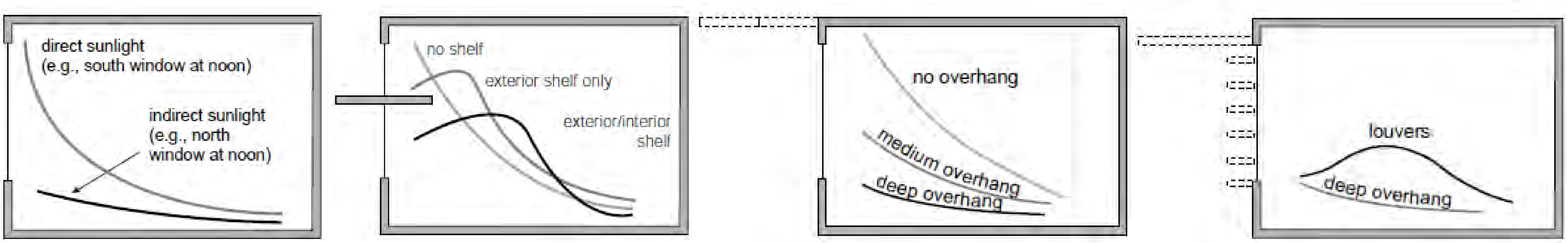
SOURCE: Tips for Daylighting with Windows: The Integrated Approach, LBNL-39945, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA

Passive Strategies

Room

- Fenestration
  - Location
  - Position
  - Design
    - Overhangs
    - Light shelves
    - Louvers
    - Blinds



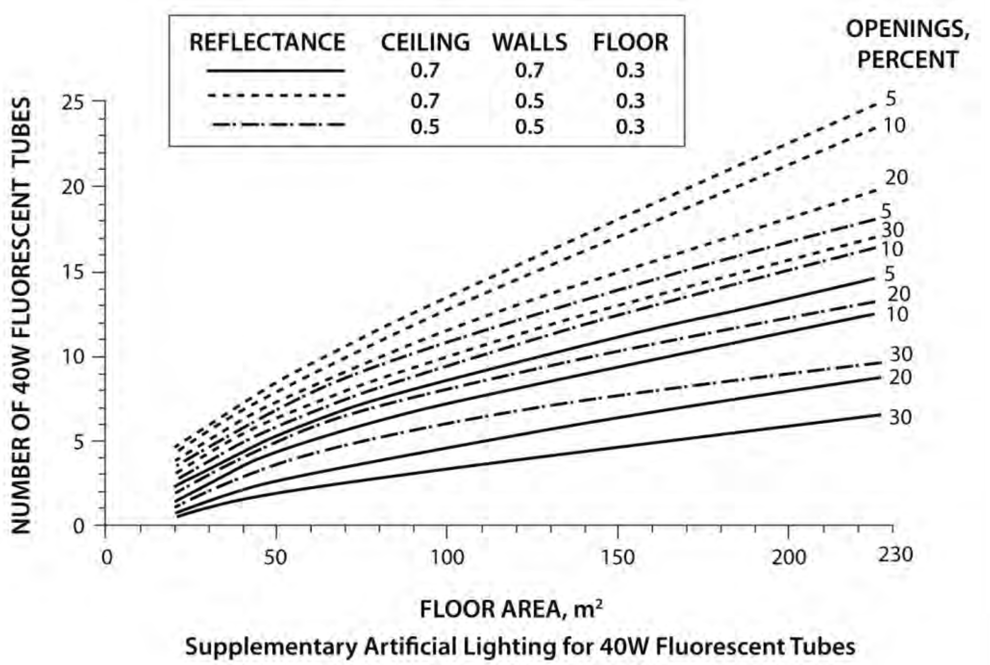


SOURCE: Tips for Daylighting with Windows: The Integrated Approach, LBNL-39945, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA

Passive Strategies

Room

- Surfaces
  - High surface reflectivity of the Ceiling, Walls and Floor decreases the need for powered lighting and thus reduces the electricity consumption
  - The figure on the right shows this in the terms of the reduced 40 W fluorescent tubes



Supplementary artificial lighting for 40W Fluorescent tubes

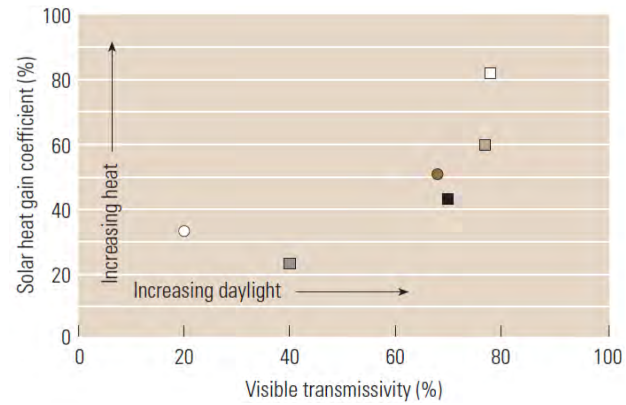
$$\text{Openings, Percent} = \frac{\text{Window area}}{\text{floor area}} \times 100$$

Passive Strategies

Systems

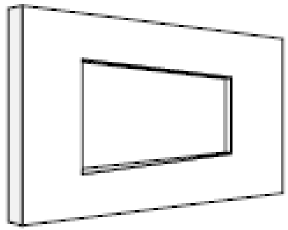
- Glazing
  - Tinted
  - Reflective
  - Low-e
  - Spectrally selective
- Trade-off between solar heat gain and daylight

Glazing	Visible	SHGC
Clear □	0.82	0.78
Low-e coating ▩	0.77	0.60
Dark reflective bronze tint ○	0.20	0.33
Spectrally selective green tint ●	0.68	0.51
Spectrally selective low-e (clear) ■	0.70	0.43
Spectrally selective low-e with green tint ▩	0.40	0.23

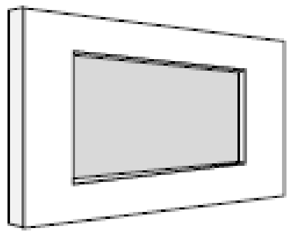


Total solar and visible light transmissions for selected glazing units

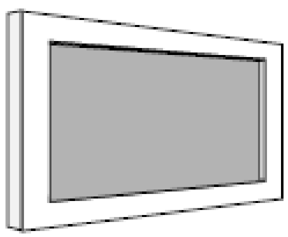
Glazing units with high visible light transmission and low solar heat gain coefficients (SHGC, the fraction of the incident solar energy transmitted through a window) are best for daylighting in buildings dominated by cooling loads.



Clear Glass
WWR = 0.30
high VT = 0.88



Tinted Glass
WWR = 0.50
medium VT = 0.53



Heavily Tinted or Reflective
WWR = 0.70
low VT = 0.38

Effective aperture

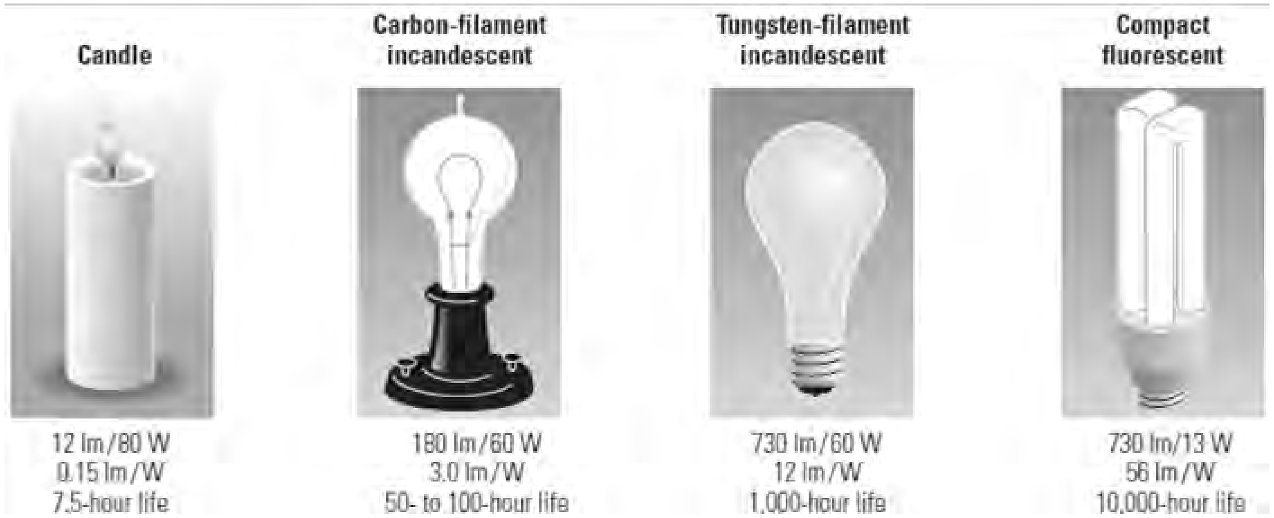
Effective aperture (EA) = visible transmittance (VT) X window-to-wall ratio (WWR). These three windows all have the same EA of 0.26

SOURCE: E Source Technology Atlas Series, Volume I Lighting (2005); Tips for Daylighting with Windows: The Integrated Approach, LBNL-39945, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA

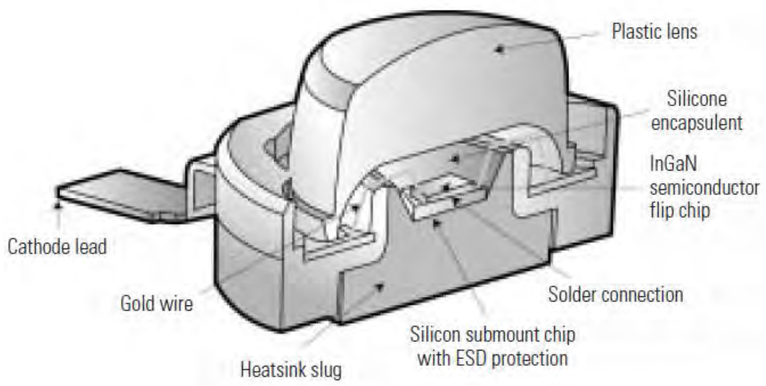
Active Strategies

Energy-efficient electric lighting based on

- Task
- Level of quality desired
- Amount of light required



A brief history of lighting



LED operation

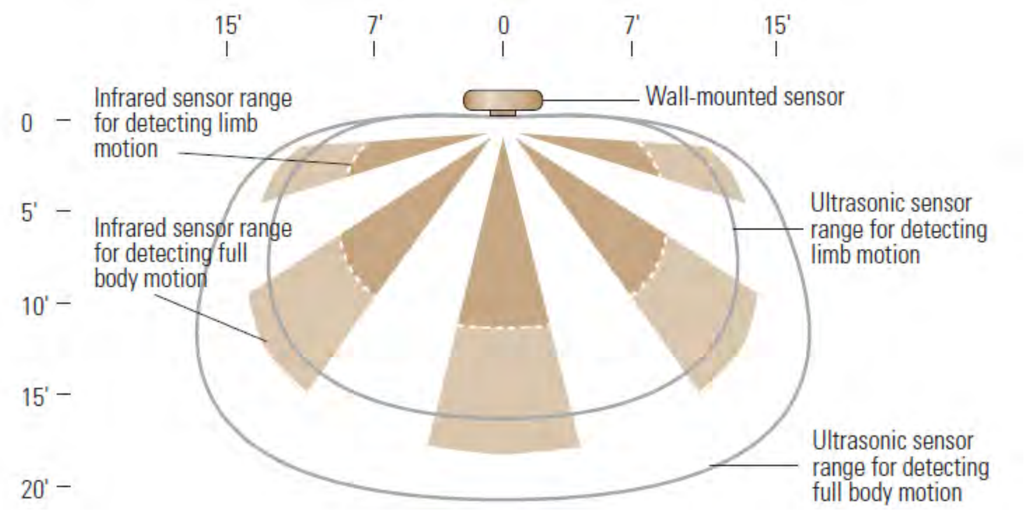
The compact fluorescent lamp has improved the product efficacy and lifetime 50-fold as compared with the tungsten-filament lamp and by half a million compared with the candle.

SOURCE: E Source Technology Atlas Series, Volume I Lighting (2005)

Active Strategies

Use of lighting controls

- On-off controls
  - Manual switches
  - Elapsed-time switches
  - Clock switches
  - EMS (Energy Management Systems) controls
  - Photocell controls
  - Occupancy controls
  - Switched power strips
- Dimming controls
  - Power reducers
  - Stepped-dimming controls
  - Continuous-dimming controls



Representative sensor coverage diagram

Ultrasonic sensors can detect motion at any point within the contour lines shown in the graph. Infrared sensors "see" only in the wedge-shaped zones and they generally don't see as far as ultrasonic units. Some sensors are further straight ahead than to the side. The ranges shown here are representative; some sensors may be more or less sensitive.

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Energy Conservation Building Code (ECBC)

Sustainable Building Design Education

USAID | INDIA
FROM THE AMERICAN PEOPLE

Building physics TU VIENNA Building ecology

ECO III

ENERGY IS LIFE BEE CONSERVE IT

ACKNOWLEDGEMENT

This presentation was prepared by International Resources Group (IRG) for the Energy Conservation and Commercialization Project (ECO-III), and was made possible by the support of the American People through the United States Agency for International Development (USAID). The contents of this presentation are the sole responsibility of IRG and do not necessarily reflect the views of USAID or the United States Government. The ECO-III Project would like to acknowledge Ministry of Power and the Bureau of Energy Efficiency of Government of India for their support.

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ECBC Training Workshop Objectives

- **Energy Conservation Building Code (ECBC) Awareness**
  - Need for the ECBC: Energy Scenario Globally & in India
  - ECBC Introduction
  - ECBC & other building codes in India
  - Impact of the ECBC
- **Provide Administrative Guidance**
  - ECBC Scope & Administration
  - Compliance Approaches (Mandatory, Prescriptive, and Whole Building Performance)
  - Compliance requirements
- **Provide Guidance for Code Compliance**
  - Technical examples/exercises, compliance forms etc.

ECBC Training Workshop Objectives

- **Provide Technical Guidance**
  - Building thermal performance basics
  - Energy efficiency tips
  - Examples/Case Studies
- **Provide Useful List of Resources and Reference Materials**
- **ECBC knowledge Evaluation**
  - Interactive Q & A sessions and quiz/test

ECBC Workshop Outline

- MODULE 1: ECBC Awareness
- MODULE 2: ECBC Scope & Administration
- MODULE 3: Building Envelope
- MODULE 4: Heating, Lighting & Ventilation (HVAC)
- MODULE 5: Service Hot Water & Pumping
- MODULE 6: Lighting
- MODULE 7: Electric Power
- MODULE 8: Demonstrating Compliance

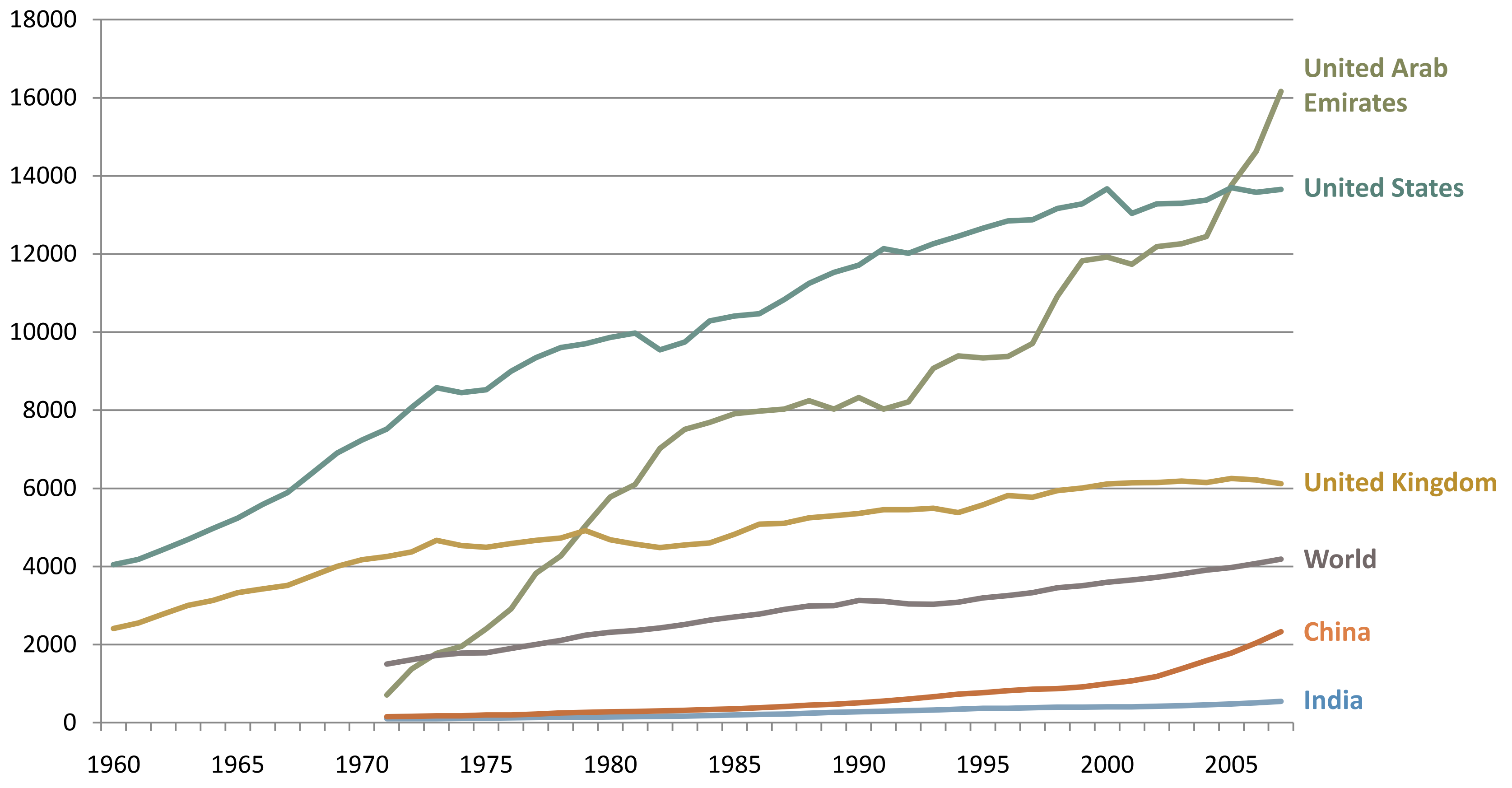
Energy Conservation Building Code (ECBC)

MODULE 1: ECBC Awareness

ECBC Awareness: Outline

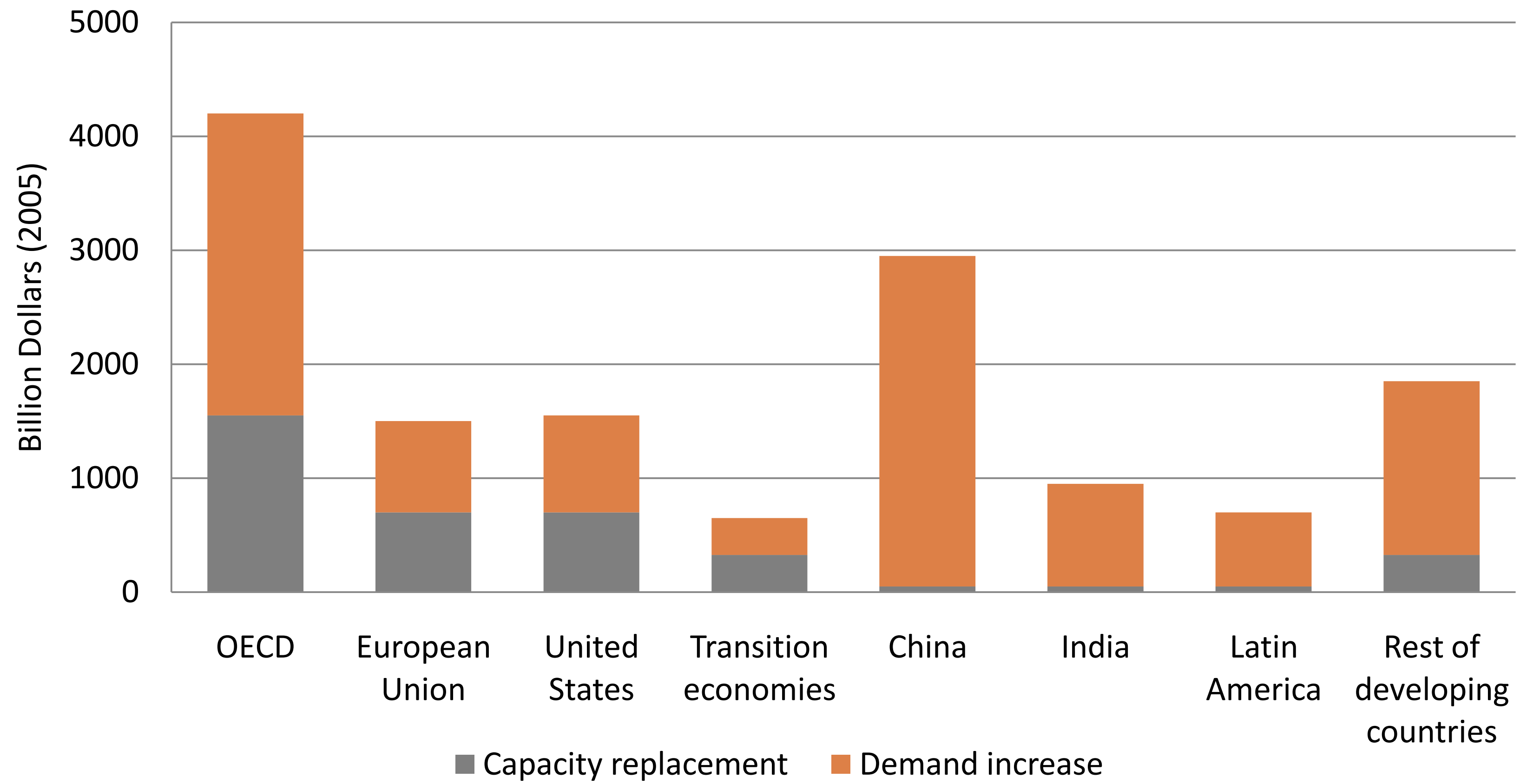
- WORLD Energy Scenario
- Energy Scenario in INDIA
- About the ECO-III Project
- Introduction to ECBC
- Significance of ECBC

WORLD Energy Scenario



Electric Power Consumption (kWh Per Capita)

WORLD Energy Scenario



Cumulative Power Sector Investment 2005-2030

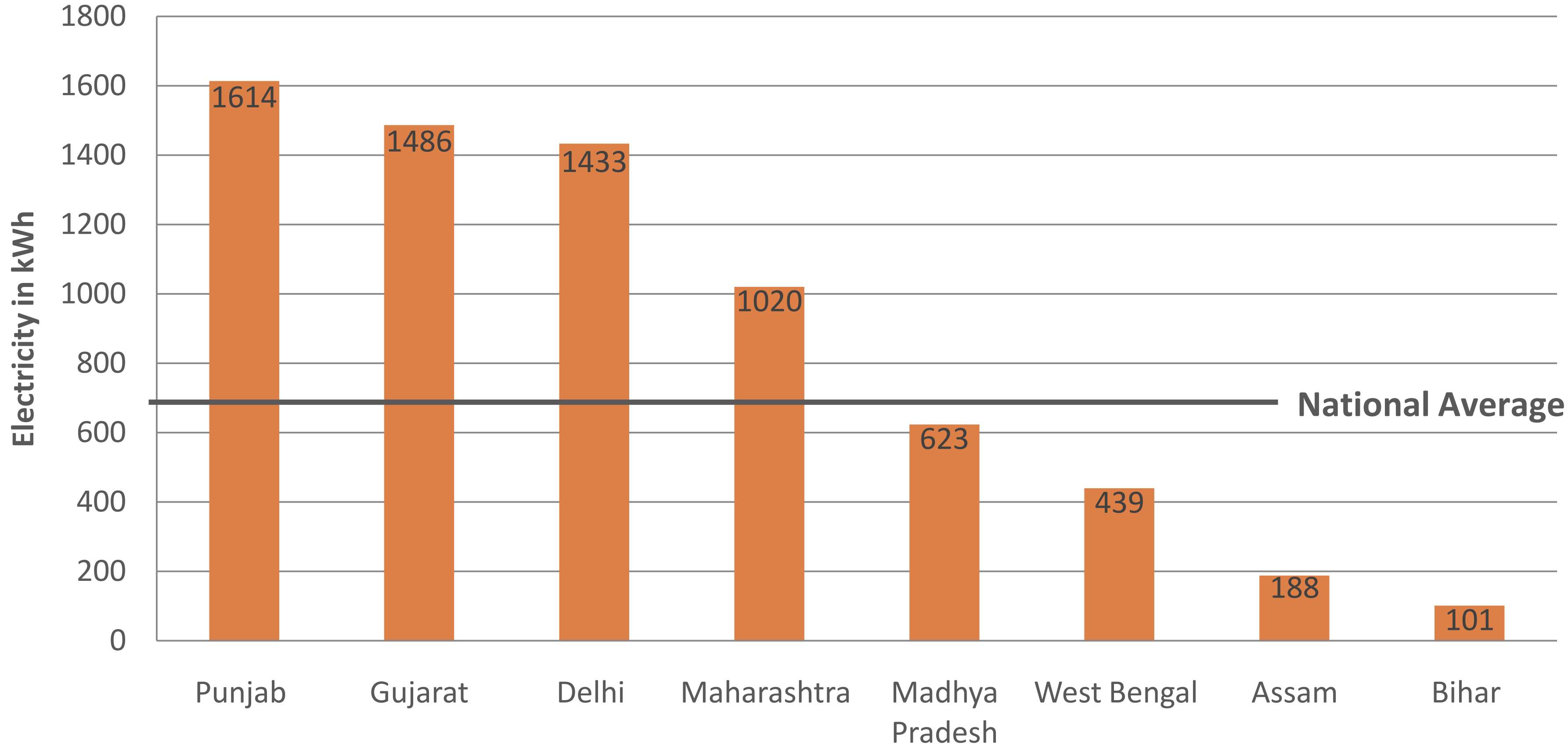
The largest investments are needed in developing countries, especially countries like China and India, mostly to meet surging demand

SOURCE: International Energy Agency, World Energy Outlook 2006

Energy Scenario in INDIA

- 16% of global population
- 4.5% Compound Annual Growth Rate (CAGR) in primary energy demand (1997-2007)
- Capital Investment needed on Supply Side - approx. $1 trillion
- Installed Capacity in India – approx. 160,000 MW
- Projected Capacity in 2030 – 800,000 MW
  - 600 MW capacity addition each week for the next 20 years
- Continued deficit supply in 2007-08 (MoP)
  - Peak power deficit of 16.6%
  - Energy Deficit of 9.9%
- Capacity Added by China in last two years – 180,000 MW
  - More than total installed capacity in India
- 66% of India's Commercial Buildings Stock in 2030 has not been built yet
- No other country in the history would have encountered the growth in the AC load that India is poised to experience

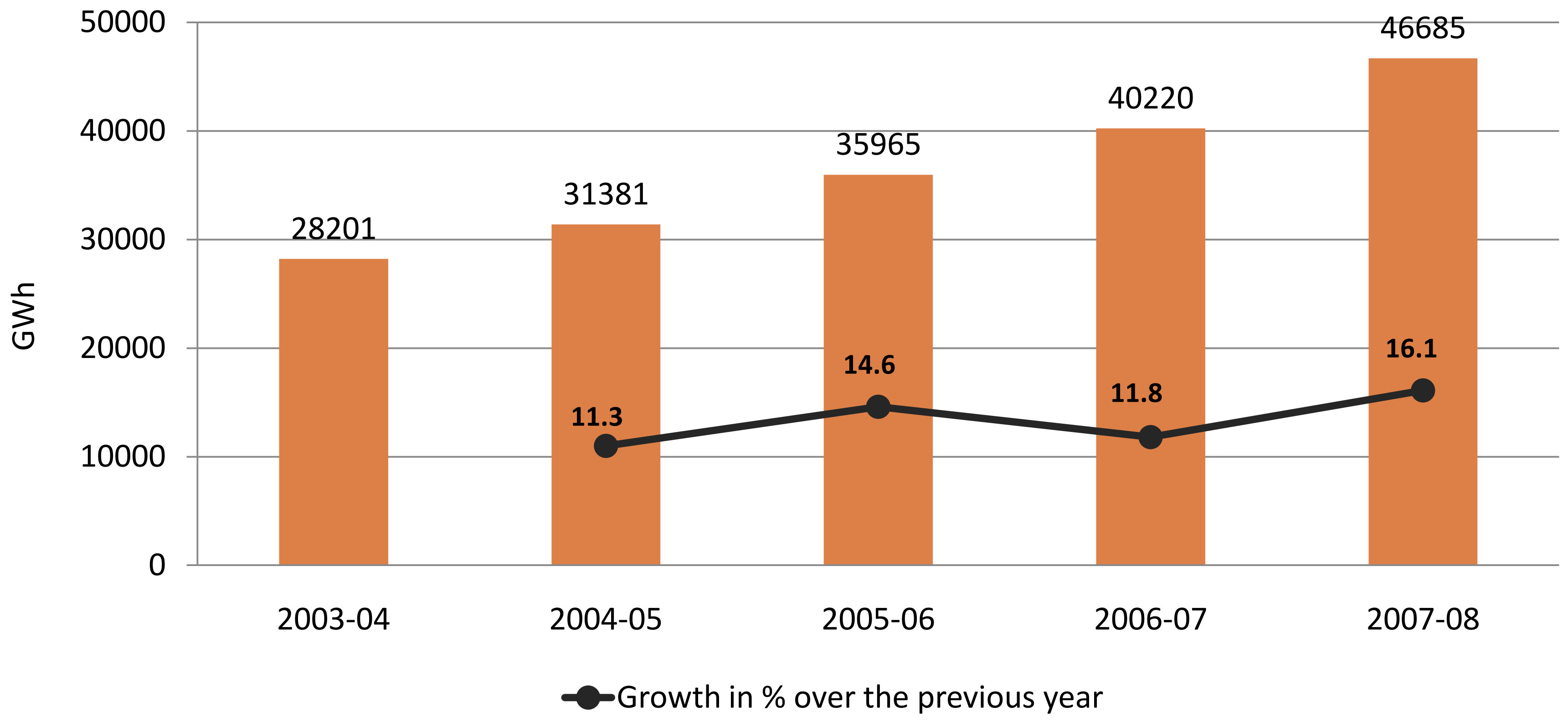
Energy Scenario in INDIA



State-wise Per Capita Electricity Consumption during 2007-08

SOURCE: Central Electricity Authority, Year End Review 2007-08

Energy Scenario in INDIA



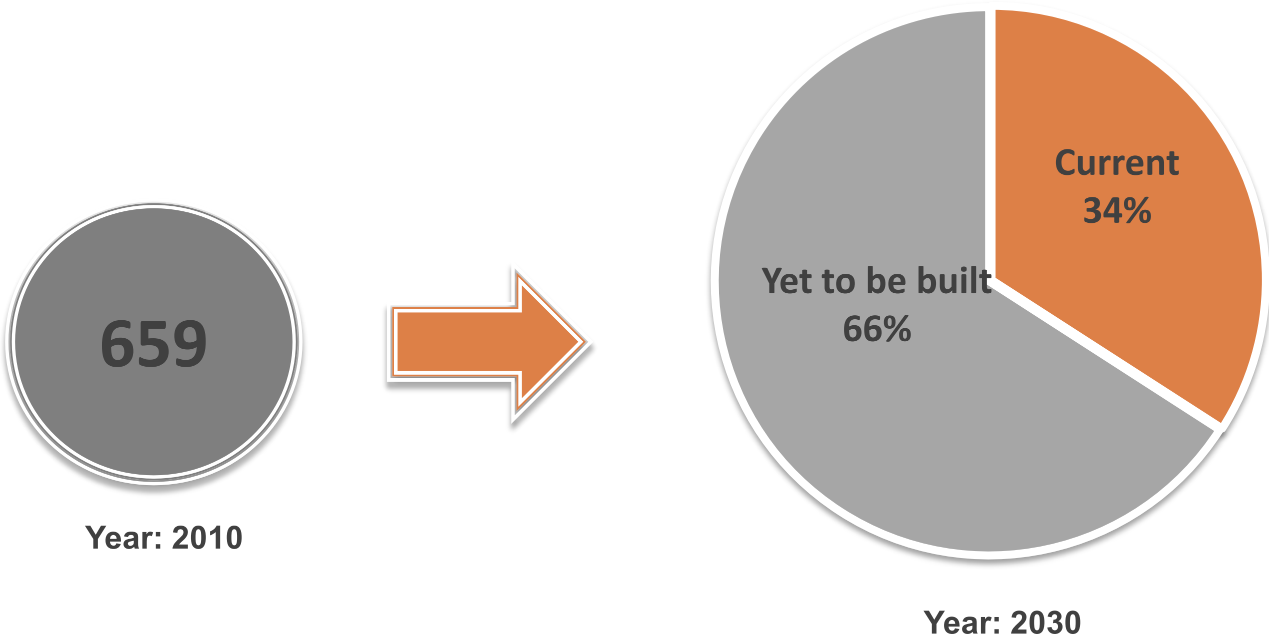
Growth of Electricity Consumption in Commercial Sector in India (2003-08)

SOURCE: Central Electricity Authority, General Review 2009

Commercial Buildings Growth Forecast

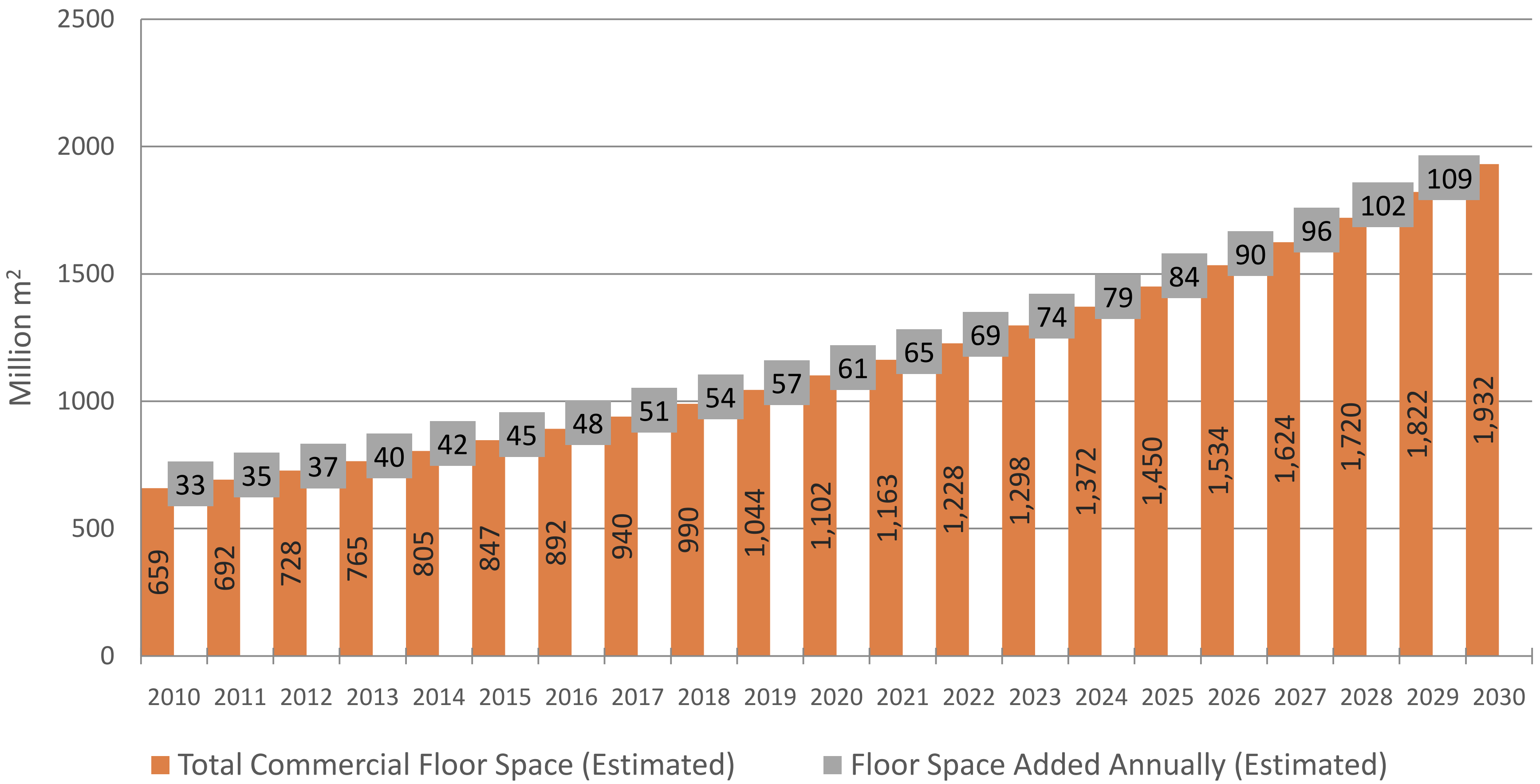
- Currently, ~ 659 million m^2 (USAID ECO-III Internal Estimate Using MOSPI, CEA and Benchmarked Energy Use data)

- In 2030,~ 1,900 million m^2 (estimated) *
  - 66% building stock is yet to be constructed



** Assuming 5-6% Annual Growth*

Commercial Buildings Growth Forecast



Commercial Floor Space Projection for India *(Assuming 5-6% Annual growth)*

SOURCE: USAID ECO-III Project, New Delhi

Changing Face of Indian Architecture

TRADITIONAL/VERNACULAR BUILDINGS

Selective use of HVAC |Climatic responsive architecture | Passive heating/cooling | Low Energy Use

MODERN BUILDINGS

Climate controlled | Hi-Tech | Energy Intensive | Emulates western modern architecture

Commercial Buildings in MUMBAI

Commercial Buildings in GURGAON

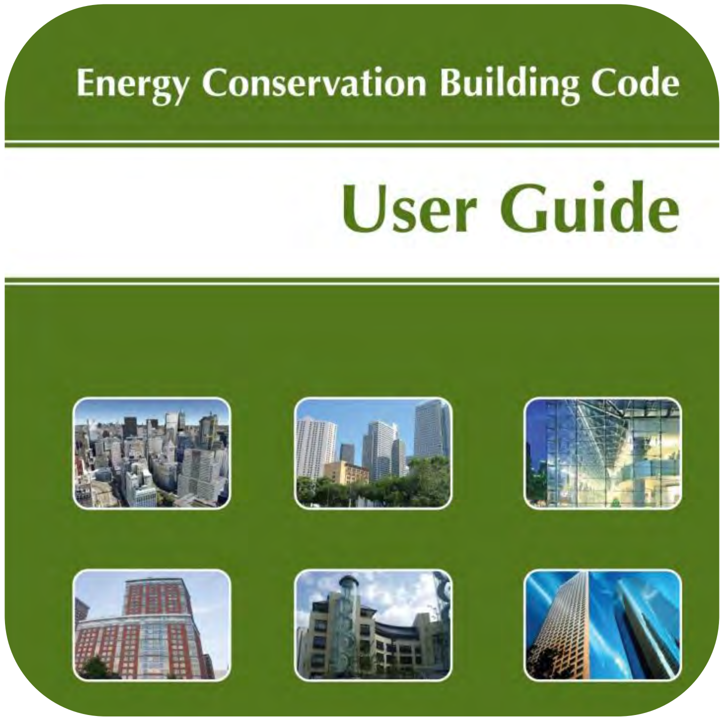
About the ECO-III PROJECT

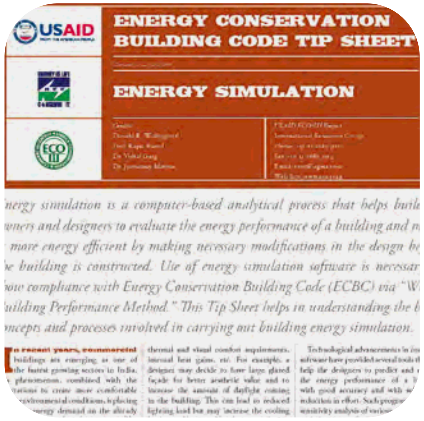
- Bilateral Project Between US and Govt. of India
  - Implemented jointly with BEE
  - Phase III started in Nov. 2006
  - Implemented by IRG and its partners
- Focused on BEE Thrust Areas
  - Energy Conservation Action Plan for Designated State Agencies (SDAs)
  - Energy Efficiency in Buildings (new and existing)
  - Energy Efficiency in Municipalities (Water Pumping & Street Lighting)
  - Energy Efficiency in Small and Medium Enterprises (SME)
  - Curriculum Enhancement of Academic Institutes
- Market transformation through innovative approaches
  - Alliance for an Energy-Efficient Economy
  - Regional Energy Efficiency Centers
  - Capacity Building for Implementation of DSM Programs

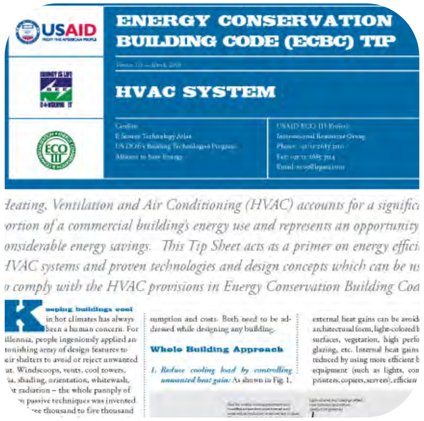
ECBC Implementation: ECO-III Milestones

- Technical Content Development and Capacity Building
  - ECBC (version 2), ECBC User Guide, Tip Sheets, and Design Guides
  - More than 20,000 hard copies of technical resources
  - ECBC professional training module
  - All technical documents posted on ECO-III and BEE web site
- Awareness and Training Workshops on ECBC
  - Organized/Participated in 14 ECBC Training and Awareness workshops
  - Launched a major capacity building effort in building energy simulation
  - Linking ECBC to Architectural Curriculum
- Next Steps
  - ECBC Implementation Framework
  - ECBC Compliance Check Tools
  - Certified Building Energy Professional

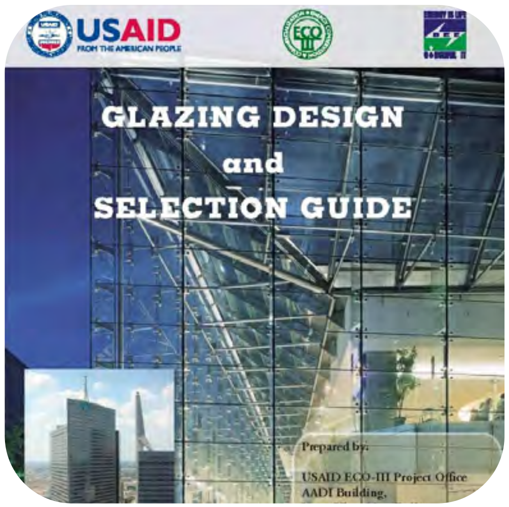
ECBC User Guide and Tip Sheets

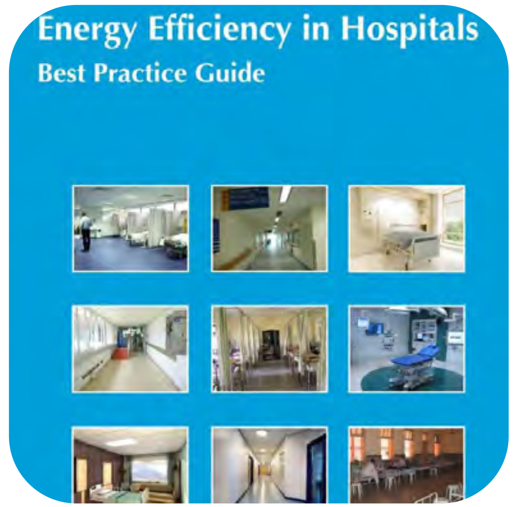


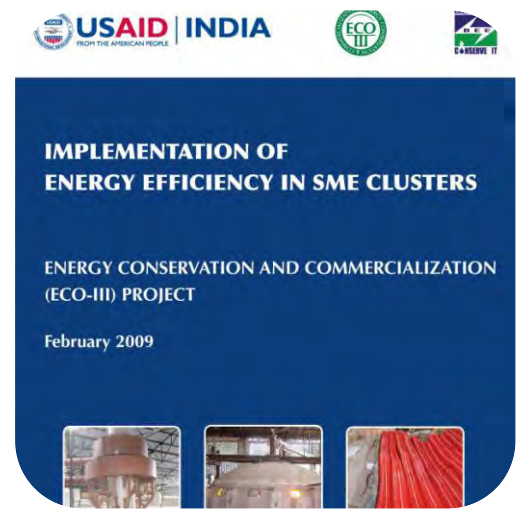


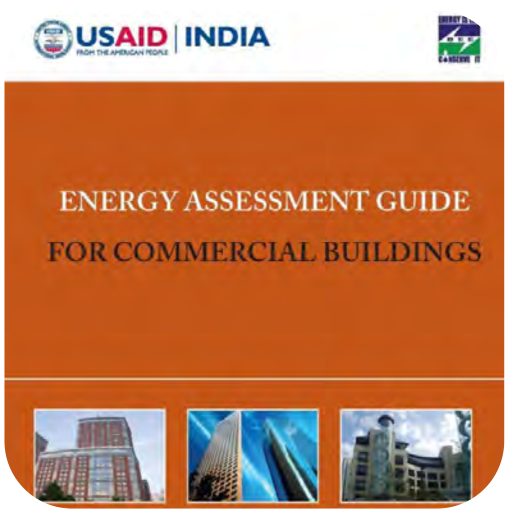


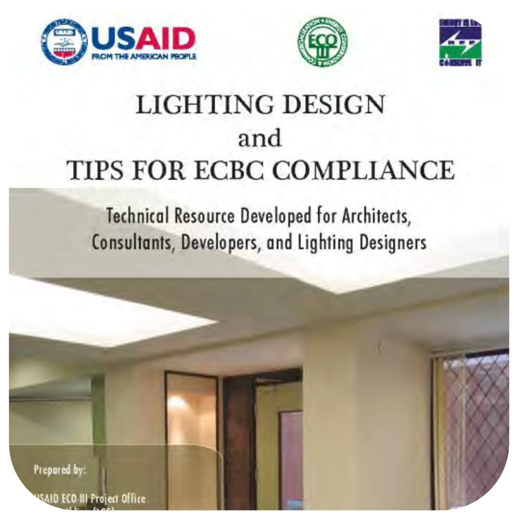
Building Energy Efficiency Guides











Introduction to ECBC

- ECBC sets minimum energy efficiency standards for design and construction of commercial buildings
- ECBC encourages energy efficient design or retrofit of buildings so that
  - Does not constrain the building function, comfort, health, or the productivity of the occupants
  - It has appropriate regard for economic considerations
- Addresses local design conditions and helps improve existing construction practices
- Emphasis on Integrated Building Design approach
- First generation code – ease of use and continuous improvement

BACKGROUND: Energy Conservation Act 2001

- Government of India - creation of Bureau of Energy Efficiency (BEE)
- Powers and Functions of BEE vis-à-vis ECBC
  - Prescribe ECBC for efficient use of energy
  - Take suitable steps to prescribe guidelines for ECBC
  - Link Energy Performance Index (from the EC Act) to the ECBC Prescriptive Compliance Approach in order to facilitate the implementation of the Code

    [On Page 5, clause (j) of the EC Act, 2001 currently reads:
    "energy conservation building codes" means the norms and standards of energy consumption expressed in terms of per square meter of the area wherein energy is used and includes the location of the building]
- Power of State Government:
  - The State Govt., in consultation with BEE, may
  - amend ECBC to suit the regional and local climatic conditions with respect to use of energy in the buildings
  - direct the owner or occupier of a building (if notified as a Designated Consumer) to comply with the provisions of ECBC

ECBC and NAPCC

Prime Minister's National Action Plan on Climate Change (NAPCC)

- National Solar Mission
- National Mission for Enhanced Energy Efficiency
- **National Mission on Sustainable Habitat**
- National Water Mission
- National Mission for Sustaining the Himalayan Ecosystem
- National Mission for a Green India
- National Mission for Sustainable Agriculture
- National Mission on Strategic Knowledge for Climate Change

National Mission on Sustainable Habitat:

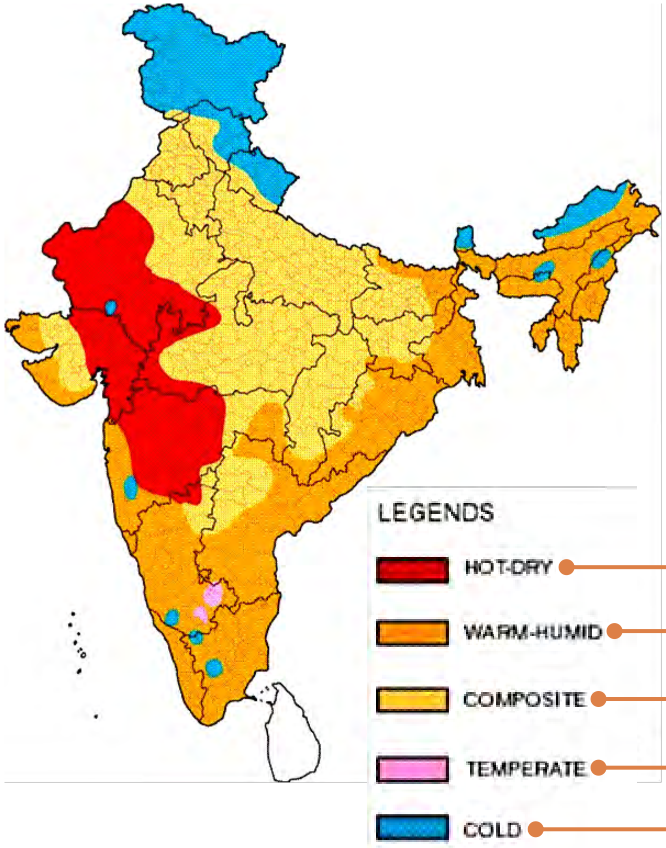
- **Promoting Energy Efficiency in the Residential and Commercial Sector**
  - **The Energy Conservation Building Code, which addresses the design of new and large commercial buildings to optimize their energy demand, will be extended in its application and incentives provided for retooling existing building stock.**
- Management of Municipal Solid Waste
- Promotion of Urban Public Transport

SOURCE: Prime Minister's Council on Climate Change (2008), National Action Plan on Climate Change, Government of India, New Delhi

Development of ECBC

- Broad Stakeholder participation
  - Building Industry, Manufacturers, Professionals, Govt. Agencies etc.
- ECO-II facilitated the development of ECBC
  - ECBC committee of experts
- An extensive data collection was carried out for construction types and materials, glass types, insulation materials, lighting and HVAC equipment
- Base case simulation models were developed
- The stringency analysis was done through detailed energy and life cycle cost analysis
- A stringency level for each code component was established

Climate Zones in India



High temperature • Low humidity and rainfall • Intense solar radiation and a generally clear sky • Hot winds during the day and cool winds at night

Temperature is moderately high during day and night • Very high humidity and rainfall • Diffused solar radiation if cloud cover is high and intense if sky is clear • Calm to very high winds from prevailing wind directions

This applies when 6 months or more do not fall within any of the other categories • High temperature in summer and cold in winter • Low humidity in summer and high in monsoons • High direct solar radiation in all seasons except monsoons high diffused radiation • Occasional hazy sky Hot winds in summer, cold winds in winter and strong wind in monsoons

Moderate temperature • Moderate humidity and rainfall • Solar radiation same throughout the year and sky is generally clear • High winds during summer depending on topography

Moderate summer temperatures and very low in winter • Low humidity in cold/sunny and high humidity in cold/cloudy • Low precipitation in cold/sunny and high in cold/cloudy • High solar radiation in cold/sunny and low in cold/cloudy • Cold winds in winter

SOURCE: Bureau of Indian Standards, National Building Code of India 2005, Part 8 Building Services, Section 3 Air Conditioning, Heating and Mechanical Ventilation; Bansal, N. K. & G. Minke (1990), Climatic Zones and Rural Housing in India; Krishan, A., N. Y. Baker & S. V. Szokolay (2001), Climate Responsive Architecture: A Design Handbook for Energy Efficient Buildings, Tata McGraw Hill

ECBC and Other Programs

Program	Organization	Compliance Required	Building Type	Building With	Scope	Linkage to ECBC
ECBC	Ministry of Power/BEE	Voluntary	Commercial	Connected Load >= 500kW Contract Demand >= 600kVA	Energy Efficiency	NA
LEED-India	CII-Green Business Center	Voluntary	Commercial/ Institutional	-	Sustainable design/green building	Refers to ECBC for energy efficiency credits
GRIHA	MNRE	Voluntary	Residential/ Commercial/ Institutional	-	Sustainable design/green building	Refers to ECBC for energy efficiency credits
Environmental Impact Assessment (EIA)	Ministry of Environment and Forests	Mandatory	Commercial/ Residential	Applicable to Large Projects	Environmental Impact	ECBC and Environmental Clearance requirements are related

Significance of ECBC

- Regulates building thermal performance & energy use according to climate zone
  - Encourages climatic responsive building design
- Encourages use of daylighting, shading, natural ventilation, solar energy etc.
  - Energy efficiency strategies appropriate for India
- Focuses on energy performance of buildings rather than green building design
  - Material properties, water use, building site etc. not regulated
  - Green Building Design standards will refer to ECBC for energy performance

ECBC and Energy Savings

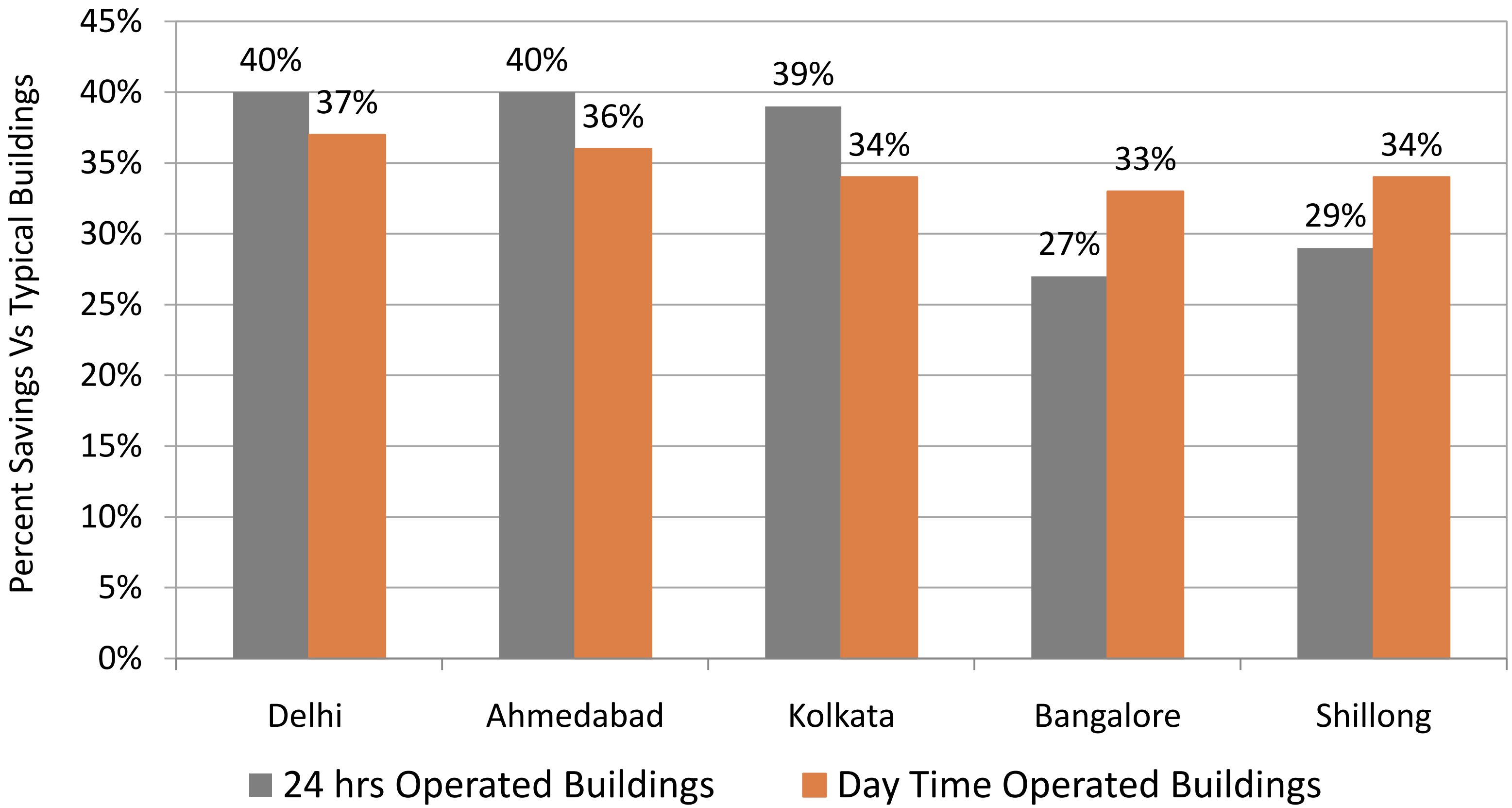
- Average energy use for lighting and HVAC
  - A typical “Class A Office” building consumes 150 kWh/m²/year.

Number of Buildings	Building Type	Floor Area (m²)	Annual Energy Consumption (kWh)	Benchmarking Indices	
OFFICE BUILDINGS				kWh/m²/year	kWh/m²/hour
145	One shift Buildings	16,716	20,92,364	149	0.068
55	Three shifts Buildings	31,226	88,82,824	349	0.042
88	Public Sector Buildings	15,799	18,38,331	115	0.045
224	Private Sector Buildings	28,335	44,98,942	258	0.064
10	Green Buildings	8,382	15,89,508	141	-
HOSPITALS				kWh/m²/year	kWh/bed/year
128	Multi-specialty Hospitals	8721	24,53,060	378	13,890
22	Government Hospitals	19,859	13,65,066	88	2,009
HOTELS				kWh/m²/year	kWh/room/year
89	Luxury Hotels (4 and 5 Star)	19,136	48,65,711	279	24,110
SHOPPING MALLS				kWh/m²/year	kWh/m²/hour
101	Shopping Malls	10,516	23,40,939	252	0.05642

- Mandatory enforcement of ECBC shall reduce the energy use by 30-40% to 120-160 kWh/m²/year
- Nationwide Mandatory enforcement of ECBC will yield energy saving of 1.975 billion kWh in the 1st Year itself

SOURCE: Building Energy Benchmarking study undertaken by the USAID ECO-III Project, New Delhi

ECBC and Energy Savings



NATIONAL ENERGY SAVINGS = CODE STRINGENCY X LEVEL OF COMPLIANCE X ADOPTION RATE

SOURCE: ECBC Impact Analysis done by IECC under USAID ECO-III Project, New Delhi

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Impact of ECBC Compliance

- Market Development for EE products
  - Building Insulation
  - Energy Efficient Windows (Glass and Frames)
  - High-Efficiency HVAC Equipment
- Improved Design Practices
  - Lighting and Daylighting
  - Natural Ventilation/Free-Cooling Systems
- Improved Building Performance
- Lesser addition of Power Generation Capacity
- Lower HVAC Loads, reduced energy consumption and costs

End of MODULE

- ***World Energy Scenario***
- ***Energy Scenario in INDIA***
- ***About the ECO-III Project***
- ***Introduction to ECBC***
- ***Significance of ECBC***

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Energy Conservation Building Code (ECBC)

MODULE 2: ECBC Scope & Administration

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Building physics TU Building ecology

TU VIENNA

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ACKNOWLEDGEMENT

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ATTRIBUTION

ECBC Scope & Administration: Outline

- ECBC Scope
- ECBC Compliance Process
- Administration and Enforcement

ECBC Scope

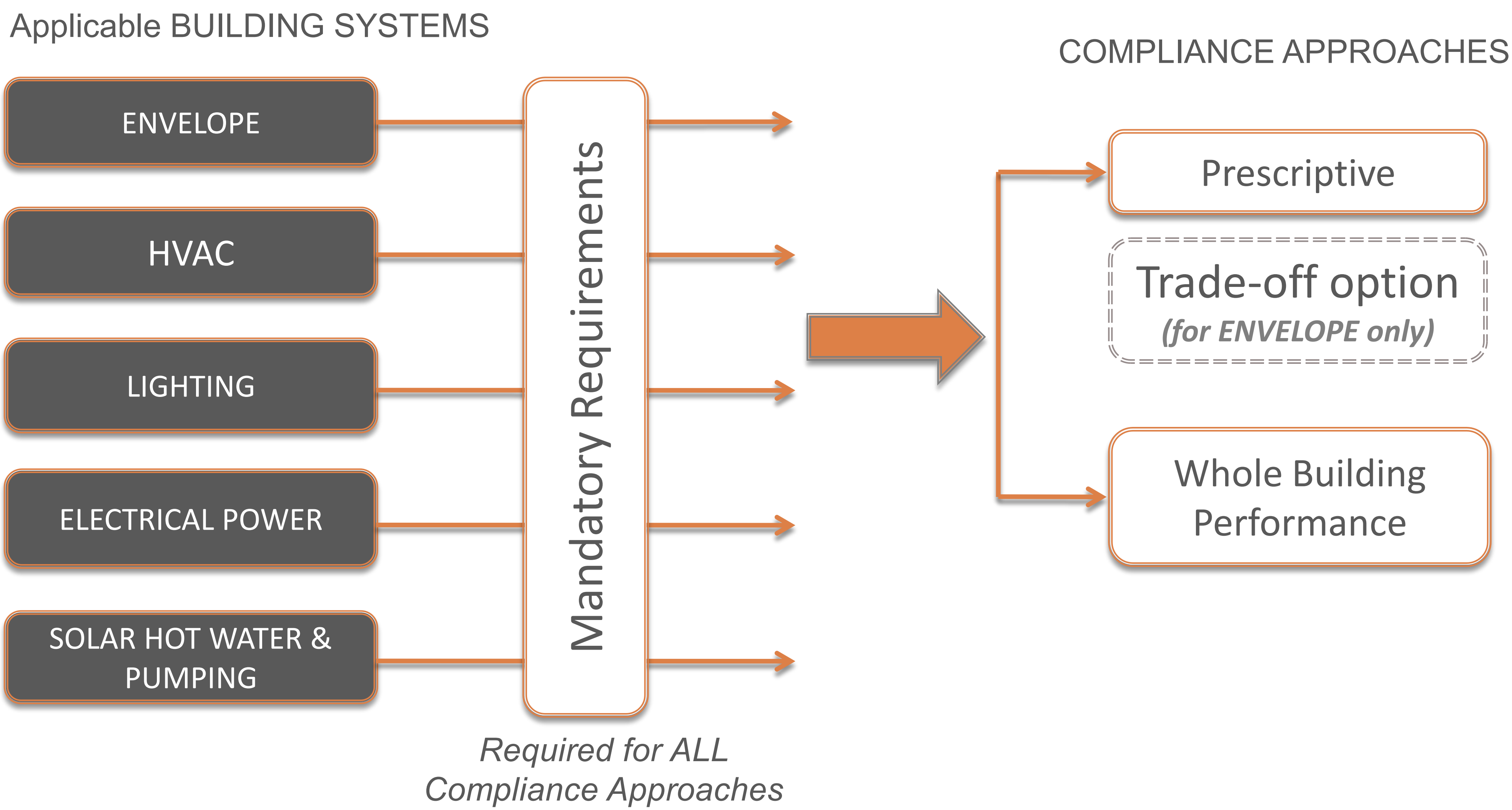
- **New Buildings with**
  - Connected load in excess of 500kW

    or
  - Contract demand in excess of 600 kVA
- **Also applies to Additions and Major Renovation**
  - When addition + existing building area > 1000 m^2
  - Renovated portions and systems of a 1000 m or larger building

ECBC Scope

- **Applicable building systems**
  - Building Envelope
  - Mechanical systems and equipment, including HVAC
  - Service hot water and pumping
  - Interior and exterior lighting
  - Electrical power and motors
- **Exceptions**
  - Buildings that do not use either electricity or fossil fuels
  - Equipment and portions of building systems that use energy primarily for manufacturing processes
  - Safety, Health and Environmental codes take precedence

ECBC Compliance Process



Compliance Approaches

- **PRESCRIPTIVE**
  - Each building/system component should have specific performance value
  - Requires little energy expertise; provides minimum performance requirements; no flexibility

- **TRADE-OFF**
  - Applies to Building Envelope ONLY
  - Component performance value can be less BUT Overall performance of the envelope complies with ECBC
  - Allows some flexibility through the balance of some high efficiency components with other lower efficiency components

- **WHOLE BUILDING PERFORMANCE**
  - Allows flexibility in meeting or exceeding energy efficiency requirements by optimizing system interactions
  - Component and Systems Modeling: Envelope, Lighting, HVAC
  - Physical Processes: Day lighting, Heat-flow, Airflow

Compliance Approaches

Approaches	Mandatory Provisions of ECBC	Flexibility	Expert Knowledge	Linear Approach	Use of Energy Simulation
PRESCRIPTIVE	Required	Low	Low	Yes	No
TRADE-OFF	Required	Medium	Medium	No	May be
WHOLE BUILDING PERFORMANCE	Required	High	High	No	Yes

Administration and Enforcement

	Programming (1)	Schematic Design	Design Development	Construction Documents (2)	Plans Check (3)	Bidding & Negotiation	Construction Management (4)	Commissioning	Field Inspection (5)	Acceptance
Design Team	X	X	X	X	X	X	X	X	X	X
General Contractor						X	X	X	X	X
Building Department					X				X	
Owner	X	X	X	X	X	X	X	X	X	X

1. Understand requirements of the ECBC and apply to building design
2. Construction documents submitted with the permit application contain ECBC compliance information that can be verified (Compliance Forms and Checklists)
3. Building officials verify through plans that building is ECBC compliant
4. Plans & specifications are followed to ensure ECBC compliance
5. Commissioning & Operations and Maintenance Guidelines provided to building operators

SOURCE: Adapted with suggested improvements from the ECBC User Guide, USAID ECO-III Project, New Delhi

End of MODULE

- ***ECBC Scope***
- ***ECBC Compliance Process***
- ***Administration and Enforcement***

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Energy Conservation Building Code (ECBC)

MODULE 3: Building Envelope

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ATTRIBUTION

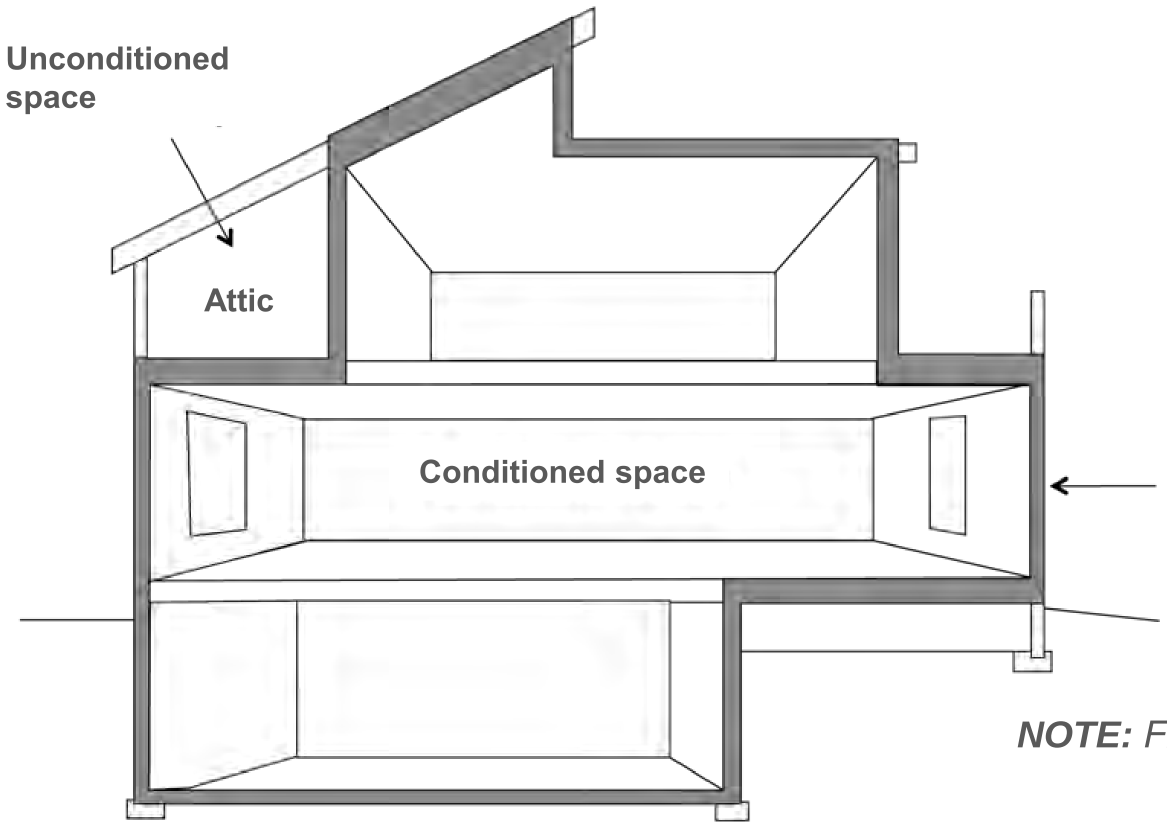
Building Envelope: Outline

- Building Envelope
- Opaque Construction
  - Heat Transfer
  - ECBC Requirements
- Cool Roofs
  - ECBC Prescriptive Requirements
- Fenestration
  - Heat Transfer
  - ECBC Requirements
- Air Leakage
  - ECBC Mandatory Requirements
- ECBC Compliance Forms

Building Envelope

Surface that separates external environment from the interior (occupied) space

- ***Opaque Construction:*** Roof, Walls and Floors
- ***Fenestration:*** Windows, Doors and Skylights



NOTE: *Floors are not regulated through the ECBC*

Building Envelope Design Considerations

- ***Climate & microclimate***
  - Temperature, humidity, solar radiation, wind speed/direction, landform, vegetation, water bodies, open spaces, etc.
- ***Building Orientation & Form***
  - Orientation of the building, surface-to-volume ratio and exposed surface area

COMPOSITE CLIMATE

MODERATE CLIMATE

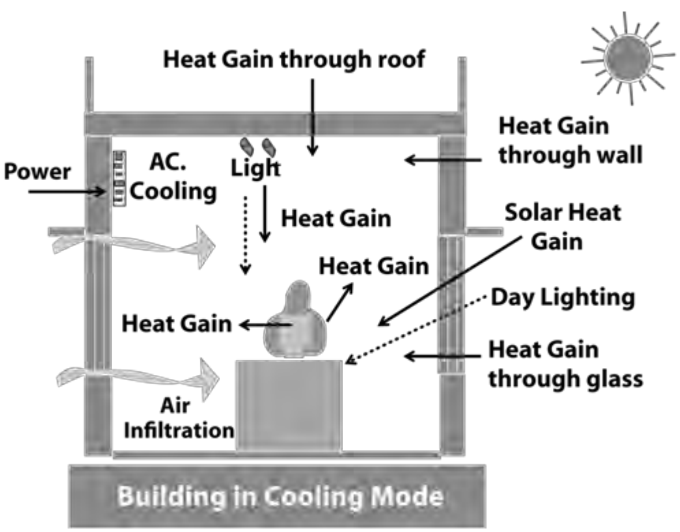
HOT-DRY CLIMATE

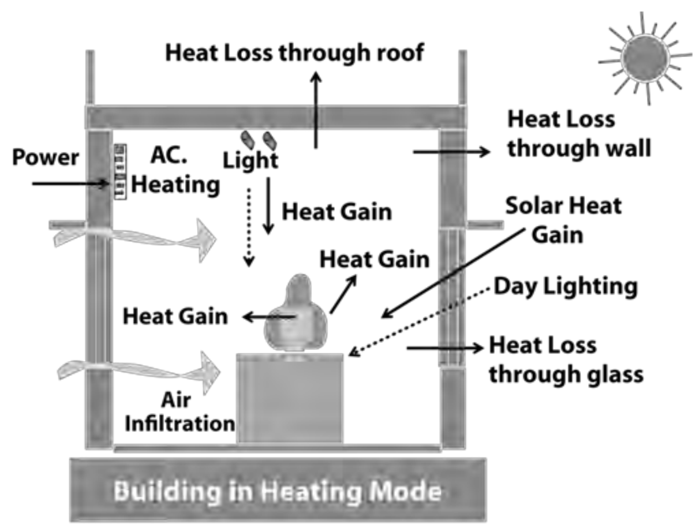
COLD CLIMATE

Building Envelope Design Considerations

- ***Building Envelope Component Design***
  - Area, orientation and tilt of the building envelope components
  - Roof form design, choice of shading devices, fenestration size, placement of windows, construction specifications etc.

- ***Building Material Specification***
  - Insulating Properties (U-values, SHGC), emissivity & color/texture





NOTE:

- *ECBC requirements affect envelope component design & material selection*
- *ECBC requirements impact heat transfer through buildings by regulating building insulation, area of fenestration and air leakage through buildings*

Opaque Construction

ECBC Building Envelope Requirements

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Opaque Construction: Outline

- **Heat Transfer**
  - R-value (Insulation)
  - U-value
- **ECBC Requirements**
  - Mandatory Requirements
  - Prescriptive Requirements

Heat Transfer

Mode of Heat Transfer	Affected By	ECBC's role in regulating Heat Transfer
CONDUCTION	Thermal Properties of Materials & Effectiveness of Insulation	U-factors/ R-values of roofs & walls
CONVECTION	Air movement at the surface	Building Envelope Sealing Requirements
RADIATION	Indirect and direct solar radiation	• R-values of roofs & walls • Cool Roofs

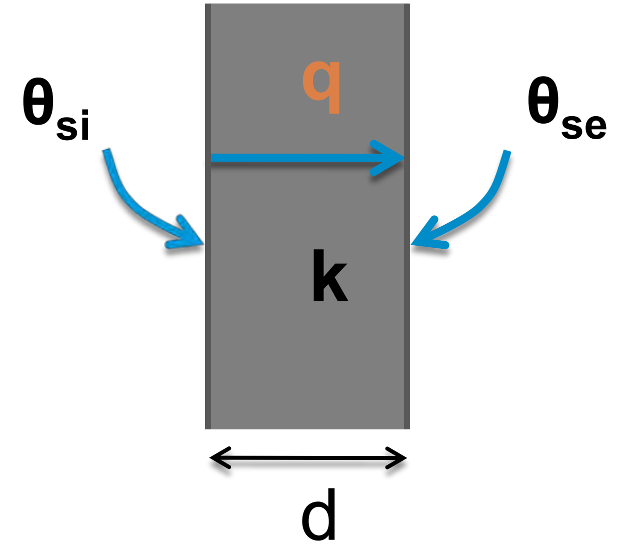
Heat Transfer

Thermal Property	Units	Effect of Thickness	Relationship
CONDUCTIVITY [k]	W/m·K	For unit thickness (m)	
RESISTIVITY [r]	m·K/W	For unit thickness (m)	1/k
RESISTANCE [R-value]	m^2·K/W	For thickness of construction (d)	d/k
CONDUCTANCE (Single Layer) [U-value]	W/m^2·K	For thickness of construction (d)	1/R-value
CONDUCTANCE (Multiple Layers) [U-factor]	W/m^2·K	For thickness of construction (d)	1/R-$value_{(Total)}$

R-value

- Thermal resistance : R-value

$$R = \frac{\text{Thickness of the material (d)}}{\text{Thermal conductivity of the material (k)}}$$



Thermal resistances of multi-layered components

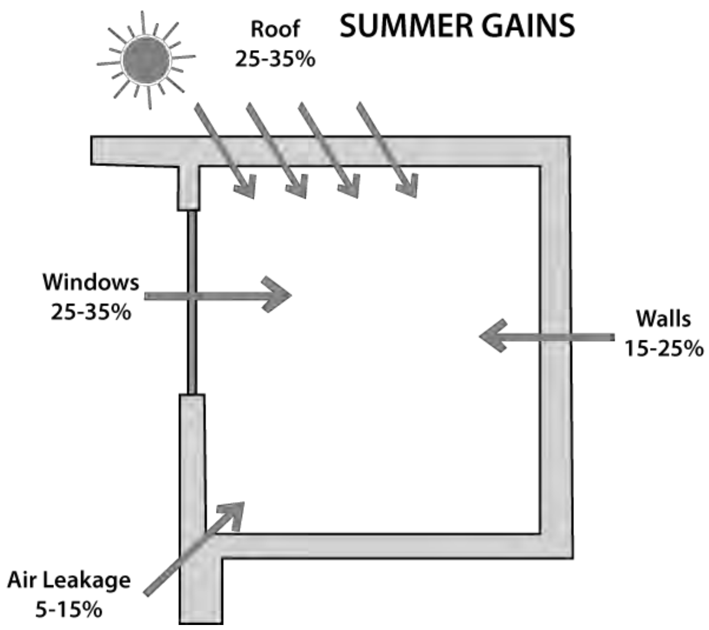
$$R_T = \frac{d_1}{k_1} + \frac{d_2}{k_2} + \ldots + \frac{d_n}{k_n} = \sum_{n}^{1} \frac{d_n}{k_n}$$

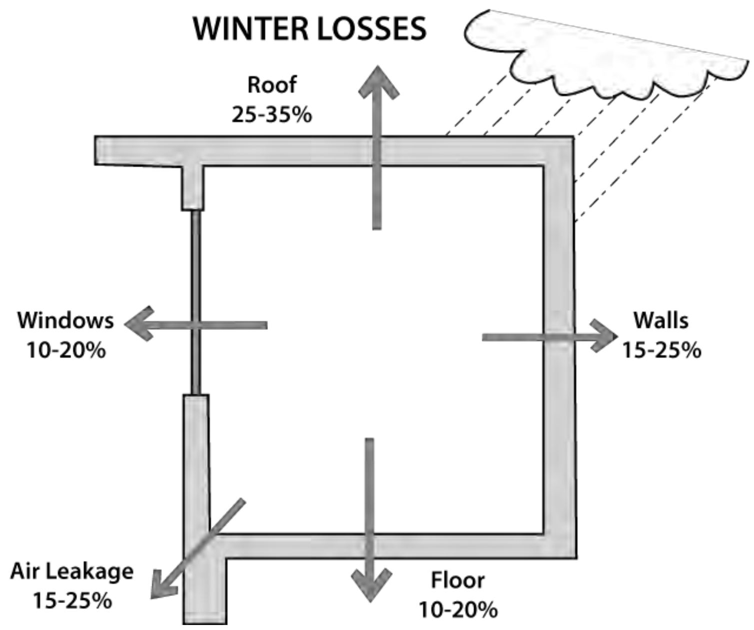
k : Conductivity
d : Thickness in m
θ_{si} : Indoor surface temperature
θ_{se} : Outdoor surface temperature

- Effectiveness of thermal insulation to retard the heat flow
- Higher R-value indicates higher insulating properties
  - (Units = $m^2 \cdot K/W$)

Building Insulation

- One of the ways to improve energy efficiency, especially in air conditioned buildings
- **Has high R-value**
- Increases thermal comfort in cooling & heating mode
- Helps in reducing heating and cooling costs





U-value

- Thermal Conductance (Heat Transfer Coefficient): U-value

$$U = \frac{1}{R}$$

- Measures heat transfer through the envelope due to a temperature difference between the indoors and outdoors (Unit = $W/m^2 \cdot K$)
- U-factor of composite wall/roof assembly as $1/R_T$
- Rate of the heat flow, therefore, lower numbers are better

ECBC Requirements: Mandatory

- U-factors shall be determined from the default tables in Appendix C §11 or determined from data or procedures contained in the ASHRAE Fundamentals, 2005.

Description	Density kg/m^3	Conductivity[b] (K), $W/(m \cdot K)$	Conductance (C), $W/(m^2 \cdot K)$	Resistance[c] (R) 1/k, $K \cdot m^2/W$	Resistance[c] (R) For Thickness Listed (1/C), $K \cdot m^2/W$	Specific Heat $kJ/(kg \cdot K)$
BUILDING BOARD						
Asbestos cement board..............	1900	0.58	—	1.73	—	1.00
Asbestos-cement board....3.2 mm	1900	—	187.4	—	0.05	—
Asbestos-cement board....6.4 mm	1900	—	93.7	—	0.011	—
Gypsum or plaster board. 9.5 mm	800	—	17.6	—	0.056	1.09

ECBC Requirements: Prescriptive

- For opaque construction, individual building envelope components must comply with:
  - **Maximum U-factor or Minimum R-value** (Exterior roofs , ceilings and opaque walls)
  - **Solar Reflectance & Emittance** (Cool Roofs)

- Compliance requirements vary according to:
  - The climate zone of the building location
  - Occupancy of the building (24 hour use or daytime use)

ECBC Requirements: Prescriptive (Opaque Walls)

- Maximum U-factor is prescribed for the complete wall assembly
- Minimum R-value is prescribed for insulation alone (excluding air films)

Table 4.2: Opaque Wall Assembly U-factor and Insulation R-value Requirements

Climate Zone	**Hospitals, Hotels, Call Centers (24-Hour)**		**Other Building Types (Daytime)**	
	Maximum U-factor of the overall assembly (W/m²-°C)	Minimum R-value of insulation alone (m²-°C/W)	Maximum U-factor of the overall assembly (W/m²-°C)	Minimum R-value of insulation alone (m²-°C/W)
Composite	U-0.440	R-2.10	U-0.440	R-2.10
Hot and Dry	U-0.440	R-2.10	U-0.440	R-2.10
Warm and Humid	U-0.440	R-2.10	U-0.440	R-2.10
Moderate	U-0.440	R-2.10	U-0.440	R-2.10
Cold	U-0.369	R-2.20	U-0.352	R-2.35

ECBC Requirements: Prescriptive (Roofs)

- Maximum U-factor is prescribed for the complete roof assembly
- Minimum R-value is prescribed for insulation alone (excluding air films)

Climate Zone	**24-Hour use buildings Hospitals, Hotels, Call Centers etc.**		**Daytime use buildings Other Building Types**	
	Maximum U-factor of the overall assembly (W/m^2-°C)	Minimum R-value of insulation alone (m^2-°C/W)	Maximum U-factor of the overall assembly (W/m^2-°C)	Minimum R-value of insulation alone (m^2-°C/W)
Composite	U-0.261	R-3.5	U-0.409	R-2.1
Hot and Dry	U-0.261	R-3.5	U-0.409	R-2.1
Warm and Humid	U-0.261	R-3.5	U-0.409	R-2.1
Moderate	U-0.409	R-2.1	U-0.409	R-2.1
Cold	U-0.261	R-3.5	U-0.409	R-2.1

- Recommendations made for proper placement, installation and protection of insulation

Cool Roofs

ECBC Building Envelope Requirements

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ECBC Requirements: Prescriptive

For roofs with slope less than 20 degree

- Initial solar reflectance of no less than 0.70
- Initial emittance no less than 0.75

Initial reflectance/emittance may decrease over time, depending on the product, due to aging, dirt, and microbial accumulation.

Efficiency Recommendation for Cool Roofing Products (U.S. DOE)

Efficiency Recommendation[a]				
Roof slope	Recommended Solar Reflectance		Best Available Solar Reflectance [b]	
	Initial	3 Years after Installation	Initial	3 Years after Installation
Low-slope (<2:12)	65% or greater	50% or greater	87%	85%
High-slope[c] (<2:12)	25% or greater	15% or greater	77%	60%

a) Following this recommendation will provide the greatest benefit where cooling energy costs exceed heating costs
b) Roof products must be tested when new and after three years of exposure, according to ASTM E-903
c) For products that can be installed on both low- and high-slope roofs, "Low-slope" guidelines should be followed.

Fenestration

ECBC Building Envelope Requirements

Fenestration: Outline

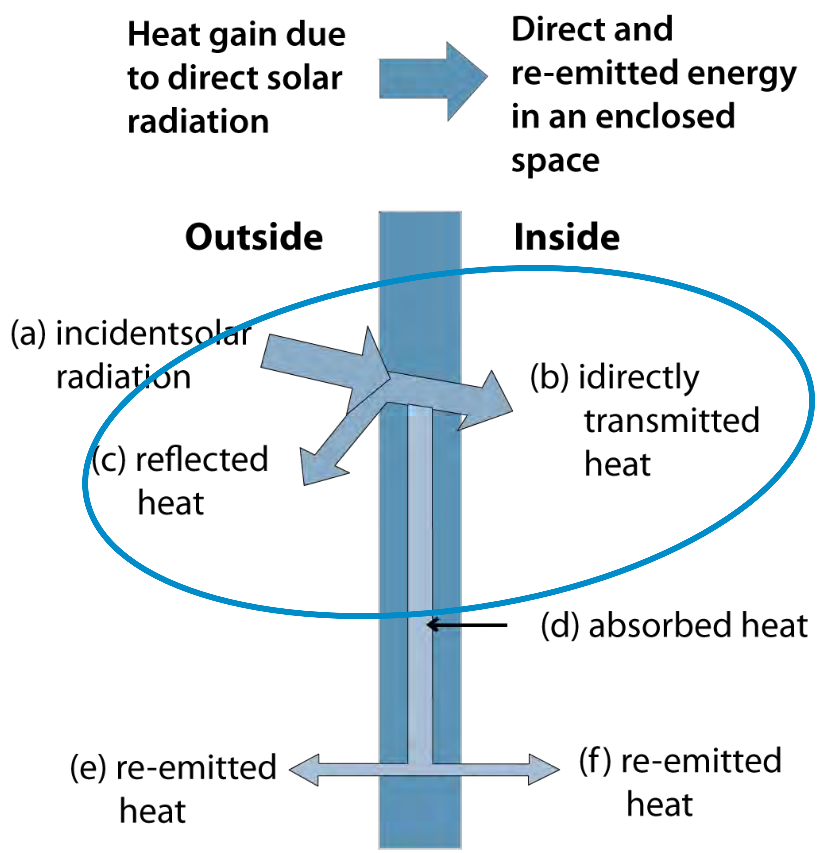
- **Heat Transfer**
  - Solar Heat Gain Coefficient (SHGC)
  - Shading Coefficient (SC) and SHGC
  - Visual Light Transmittance (VLT)
- **ECBC Requirements**
  - ECBC Mandatory Requirements
  - ECBC Prescriptive Requirements

Heat Transfer

Mode of Heat Transfer	Affected By	ECBC's role in regulating Heat Transfer
CONDUCTION	Thermal properties of fenestration assembly	• U-factors& Solar Heat Gain Coefficient (SHGC) of glazing • Wall-Window Ratio (WWR) • Skylight Roof Ratio (SSR)
CONVECTION	Air movement at the surface	• Maximum Air Leakage
RADIATION	Indirect and direct solar radiation	• Solar Heat Gain Coefficient of Glazing and Skylights • Wall Window Ratio (WWR) • Skylight Roof Ratio (SSR)

Solar Heat Gain Coefficient (SHGC)

- Ratio of solar heat gain that passes through fenestration to the total incident solar radiation that falls on the fenestration
- Indicates how well fenestration insulates heat caused by direct solar rays
- Lower SHGC means lesser heat transfers into the building through the window
- Depends on properties of glazing material & Window Operation (Fixed or Operable)
- In hot climates, SHGC is more significant than U-factor



SHGC of 0.4 allows 40% solar radiation through and reflects 60% away

Shading Coefficient (SC) & SHGC

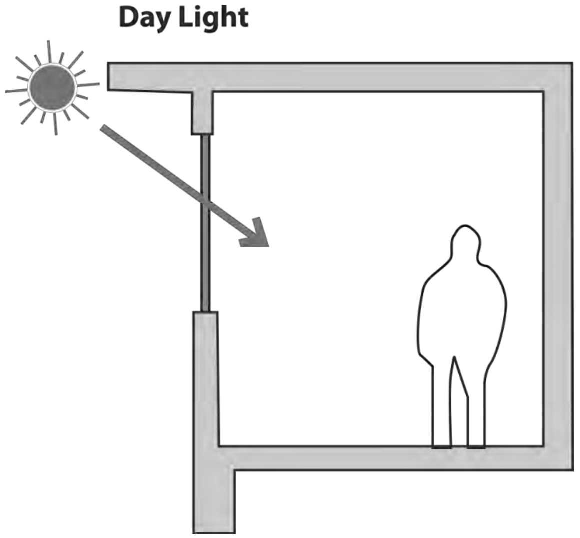
- The solar heat gain coefficient (SHGC) has replaced the shading coefficient (SC) as the standard indicator of a window's shading ability.

- Relationship between SC and SHGC
  - SHGC is expressed as a number between 0 and 0.87
  - SC as a number between 0 and 1
  - SHGC = SC × 0.87

- SHGC may be expressed in terms of the glass alone or may refer to the entire window assembly
  - SC is typically indicated for the glass alone, and does not take into consideration the effects of the frame

Visual Light Transmittance (VLT)

- Fraction of visible light transmitted through the glazing
  - Affects daylight and visibility
  - Varies between 0 & 1
- VLT is concerned with the visible portion of the solar spectrum as opposed to SHGC, which takes into account the entire solar radiation
- Typically, lower the SHGC, lower the VLT
  - Higher insulating property glass will reduce daylight
- Higher the VLT, more light is transmitted
  - Balance is needed between daylight requirements & heat gain through windows



ECBC Requirements: Overview

- ECBC regulates heat gain through fenestration through
- Size and Orientation
  - ECBC regulates maximum glazing area (Window-to-Wall Ratio)
- Shading Devices
  - ECBC takes into account reduction in heat gain through use of shading devices
- Glazing Properties
  - ECBC regulates Solar Heat Gain Factor (SHGC), U-value and Visual Light Transmittance (VLT)

ECBC Requirements: Mandatory

- U-factors AND SHGC (Appendix C of the ECBC)
- In accordance with ISO-15099 AND labeled and certified by the manufacturer
- U-Factors and SHGC must be certified by an accredited independent testing laboratory

Table 11.1: Defaults for Unrated Vertical Fenestration (Overall Assembly including the Sash and Frame)

		Clear Glass			Tinted Glass		
Frame Type	**Glazing Type**	**U-Factor (W/m^2-°C)**	**SHGC**	**VLT**	**U-Factor (W/m^2-°C)**	**SHGC**	**VLT**
All frame types	Single Glazing	7.1	0.82	0.76	7.1	0.70	0.58
Wood, vinyl, or fiberglass frame	Double Glazing	3.3	0.59	0.64	3.4	0.42	0.39
Metal and other frame type	Double Glazing	5.1	0.68	0.66	5.1	0.50	0.40

ECBC Requirements: Prescriptive
(Vertical Fenestration)

- Fenestration area is limited to a maximum of 60% of the gross wall area for the prescriptive requirement.
- Maximum area weighted U-factor and maximum area weighted SHGC requirements

Table 4.3: Vertical Fenestration U-factor and SHGC Requirements (U-factor in W/m2-°C)

		WWR≤40%	40% <WWR≤60%
Climate	**Maximum U-factor**	**Maximum SHGC**	**Maximum SHGC**
Composite	3.30	0.25	0.20
Hot and Dry	3.30	0.25	0.20
Warm and Humid	3.30	0.25	0.20
Moderate	6.90	0.40	0.30
Cold	3.30	0.51	0.51
See Appendix C §11.2.1 for Defaults values of Unrated Fenestration			

Reduced SHGC to compensate for increase in heat gain through a larger window to wall (WWR) ratio

Less stringent requirements for moderate Climates. Higher U-Factors and SHGC

ECBC Requirements: Prescriptive
(Vertical Fenestration)

- Minimum VLT defined as function of Window Wall Ratio (WWR), where Effective Aperture > 0.1, equal to or greater than the Minimum VLT requirements of Table 4.5.

Table 4.5: Minimum VLT Requirements

Window Wall Ratio	Minimum VLT
0 - 0.3	0.27
0.31-0.4	0.20
0.41-0.5	0.16
0.51-0.6	0.13

Lower VLT requirements to offset the increased heat transfer through higher WWR

Effective Aperture

- *Light admitting potential of vertical fenestration*
- *Depends on glazing property and size of opening*

Effective Aperture = Visual Light Transmittance (VLT) * Window to Wall Ratio (WWR)

ECBC Requirements: Prescriptive
(Vertical Fenestration)

ECBC Exception To Vertical Fenestration Requirements

- Applies to fenestration with shading devices (Overhangs/Fins)
- Adjustment to window SHGC through a multiplication (M) factor to account for reduced solar heat gain from windows that are well shaded
- “M Factor” shall be determined for each orientation, latitude of the building site and unique shading condition

ECBC Exception To SHGC Requirements

- Vertical Fenestration areas located more than 2.2 m (7 ft) above the floor level are exempt from the SHGC requirement in Table 4.3 if
  - The total Effective Aperture for the elevation is less than 0.25, including all fenestration areas greater than 1.0 m (3 ft) above the floor level
- An interior light shelf is provided at the bottom of this fenestration area, with an interior projection factor not less than:
  - 1.0 for E-W, SE, SW, NE, and NW orientations
  - 0.5 for S orientation, and
  - 0.35 for N orientation when latitude is < 23 degrees.

M-factor (ECBC Table 4.4)

- M-factor captures the effectiveness of shading devices to provide solar protection
- Varies according to latitude of site, choice of shading option and projection factor

FOR EXAMPLE:
Combination of Overhang + Fins provides maximum solar protection. Thus, M-Factors are the lowest

Projection Factors (PF) need to be calculated

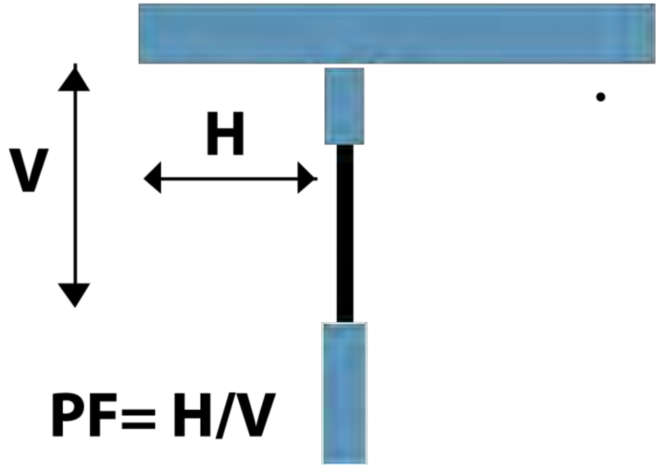
		Overhang "M" Factors for 4 Projection Factors				Vertical Fin "M" Factors for 4 Projection Factors				Overhang+Fin "M" Factors for 4 Projection Factors			
Project Location	Orientation	0.25-0.49	0.50-0.74	0.75 - 0.99	1.00 +	0.25-0.49	0.50-0.74	0.75-0.99	1.00 +	0.25-0.49	0.50-0.74	0.75 - 0.99	1.00 +
North latitude 15° or greater	N	.88	.80	.76	.73	.74	.67	.58	.52	.64	.51	.39	.31
	E/W	.79	.65	.56	.50	.80	.72	.65	.60	.60	.39	.24	.16
	S	.79	.64	.52	.43	.79	.69	.60	.56	.60	.33	.10	.02
Less than 15° North latitude	N	.83	.74	.69	.66	.73	.65	.57	.50	.59	.44	.32	.23
	E/W	.80	.67	.59	.53	.80	.72	.63	.58	.61	.41	.26	.16
	S	.78	.62	.55	.50	.74	.65	.57	.50	.53	.30	.12	.04

Projection Factor (PF) Calculation

- PF is needed to determine M-factor

PF = H (Horizontal) / V (vertical)

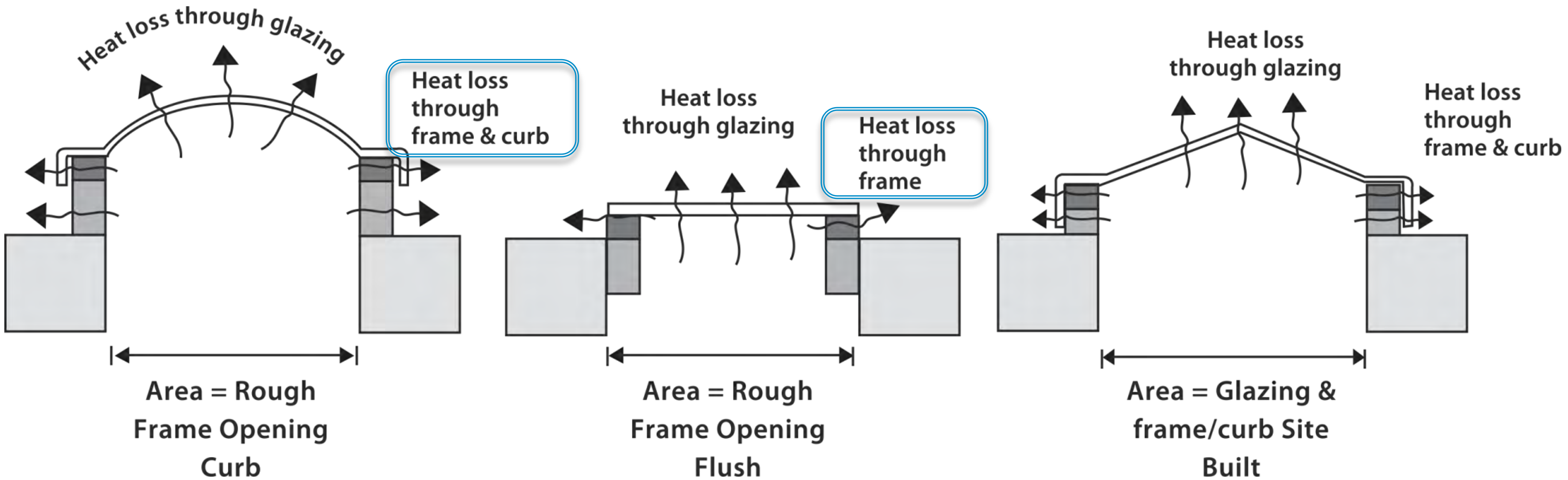
- **PF= Ratio of overhang projection divided by height from window sill to bottom of overhang (must be permanent)**



- **Solar heat gain Coffecient**
  - **Requirements dependent on:**
    - **Overhang projection factor**
    - **M- Factor from Table 4.3.3-2**
    - **Orientation**
    - **And Climate Zone**
  - **Without Overhang: SHGC range 0.25-0.51 based on climate zone.**

ECBC Requirements: Prescriptive (Skylights)

- ECBC regulates all fenestration (skylights) with slope of less than 60 Deg.
- U-Factor and SHGC requirements according to
  - Installation of skylight (Flush mounted/curb mounted)
  - Skylight Roof Ratio (SSR)



ECBC Requirements: Prescriptive (Skylights)

- Maximum U-factor and SHGC requirements of Table 4.6
  - Lower U-factors limit for flush mounted installation
- Skylight area is limited to a maximum of 5% of the gross roof area or Skylight Roof Ratio (SRR) =< 5%
  - Higher the SRR; lower the maximum SHGC required

	Maximum U-factor		Maximum SHGC	
Climate	**With Curb**	**w/o Curb**	**0-2% SRR**	**2.1-5% SRR**
Composite	11.24	7.71	0.40	0.25
Hot and Dry	11.24	7.71	0.40	0.25
Warm and Humid	11.24	7.71	0.40	0.25
Moderate	11.24	7.71	0.61	0.4
Cold	11.24	7.71	0.61	0.4

Higher SHGC limits for moderate and cold climate zones where heat gain through windows is less of a concern

Air Leakage

ECBC Building Envelope Requirements

ECBC Requirements: Mandatory

- Air Leakage through doors and fenestration
  - for glazed swinging entrance doors and revolving doors shall not exceed 5.0 $l/s\text{-}m^2$.
  - Other fenestration and doors shall not exceed 2.0 $l/s\text{-}m^2$.

- Building Envelope Sealing
  - The following areas of the enclosed building envelope shall be sealed, caulked, gasketed, or weather-stripped to minimize air leakage:
    - Joints around fenestration and door frames
    - Openings between walls and foundations and between walls and roof and wall panels
    - Openings at penetrations of utility services through, roofs, walls, and floors
    - Site-built fenestration and doors
    - Building assemblies used as ducts or plenums
    - All other openings in the building envelope

ECBC Building Envelope Requirements: Overview

Building Component	Mandatory Requirements	Prescriptive Requirement
OPAQUE CONSTRUCTION (Roofs and Walls)	Building Envelope Sealing Requirements [ECBC 4.2.3]	Maximum U-factors & Minimum R-values of roofs & walls [ECBC 4.3.1 & 4.3.2) Cool Roof Specifications [ECBC 4.3.1.1]
FENESTRATION (Doors, Windows and Skylights)	Calculation of U-factors & Solar Heat Gain Coefficient (SHGC) of glazing [ECBC 4.2.1 & 4.2.1.2] Air Leakage Maximum Limits [ECBC 4.2.1.3]	Maximum U-factors & SHGC, Wall-Window Ratio (WWR), & Visible Transmission (VLT) of Glazing [ECBC 4.3.3] Skylight Roof Ratio (SSR); Maximum U-factors & SHGC of glazing [ECBC 4.3.4]

ECBC Compliance Forms

15.1 Envelope Summary

Envelope Summary

2007 Energy Conservation Building Code Compliance Forms

Project Info	Project Address	Date
		For Building Department Use
	Applicant Name:	
	Applicant Address:	
	Applicant Phone:	

Project Description	☐ New	☐ Addition	☐ Alteration	☐ Change of Use
Compliance Option	☐ Prescriptive	☐ Envelope Trade-Off (Appendix D)	☐ Whole Building Performance	

	○ Hospital, hotel, call center (24 hour)		○ Other building types (daytime)		
Vertical Fenestration Area Calculation Note: Vertical fenestration area can not exceed 60% of the gross wall area for prescriptive compliance	Total Vertical Fenestration Area (rough opening)	divided by	Gross Exterior Wall Area	times 100 equals	% Vertical Fenestration
		÷		X 100 =	
Skylight Area Calculation Note: Skylight area can not exceed 5% of the gross roof area for prescriptive compliance	Total Skylight Area (rough opening)	divided by	Gross Exterior Wall Area	times 100 equals	% Skylight
		÷		X 100 =	

Hospital, hotel, call center (24 hour)	
OPAQUE ASSEMBLY	
Roof *Minimum Insulation R-value*	
Wall *Minimum Insulation R-value*	
FENESTRATION	
Vertical	
Maximum U-factor	
Maximum SHGC	
Overhang (yes or no)	
If yes, enter Projection Factor	
Side fins (yes or no)	
If yes, enter Projection Factor	
Skylight	
Maximum U-factor	
Maximum SHGC	

Other building type (daytime)	
OPAQUE ASSEMBLY	
Roof *Minimum Insulation R-value*	
Wall *Minimum Insulation R-value*	
FENESTRATION	
Vertical	
Maximum U-factor	
Maximum SHGC	
Overhang (yes or no)	
If yes, enter Projection Factor	
Side fins (yes or no)	
If yes, enter Projection Factor	
Skylight	
Maximum U-factor	
Maximum SHGC	

Building Permit Plans Checklist **ENVELOPE Checklist**

2007 Energy Conservation Building Code Compliance Forms

Project Address | Date

The following information is necessary to check a building permit application for compliance with the building envelope requirements in the Energy Conservation Building Code 2007.

Applicability (yes, no, n.a.)	Code Section	Component	Information Required	Location on Plans	Building Department Notes
MANDATORY PROVISIONS (Section 4.2)					
	4.2.1	Fenestration rating			
	4.2.1.1	U-factor	Specify whether per 4.2.1.1 or default in Appendix C		
	4.2.1.2	SHGC	Specify whether per 4.2.1.2 or default in Appendix C		
	4.2.1.3	Air leakage	Specify leakage rates		
	4.2.2	Opaque U-factors	Specify whether per default in Appendix C or ASHRAE		
	4.2.3	Bldg. env. sealing	Indicate sealing, caulking, gasketing, and weather stripping		
PRESCRIPTIVE COMPLIANCE OPTION (Section 4.3)					
	4.3.1	Roof	Indicate R-values on roof sections		
	4.3.1.1	Cool roof	Indicate minimum reflectance and emittance on plans		
	4.3.3	Opaque Walls	Indicate R-values on wall sections		
	4.3.3	Vertical fenestration	(1) Indicate U-factors on fenestration schedule. Indicate if values are rated or default. If values are default, then specify frame type, glazing layers, gap width, low-e. (2) Indicate SHGC or SC on fenestration schedule. Indicate if values are rated or default. (3) Indicate if overhangs or side fins are used for compliance purposes. If so, provide projection factor calculation.		
	4.3.4	Skylight	(1) Indicate U-factors on fenestration schedule. Indicate if values are rated or default. If values are default, then specify frame type, glazing layers, gap width, low-e. (2) Indicate SHGC or SC on fenestration schedule. Indicate if values are rated or default.		
BUILDING ENVELOPE TRADE-OFF OPTION (Section 4.4)					
			Provide calculations		

End of MODULE

- ***Building Envelope***
- ***Opaque Construction***
  - ***Heat Transfer***
  - ***ECBC Requirements***
- ***Cool Roofs***
  - ***ECBC Prescriptive Requirements***
- ***Fenestration***
  - ***Heat Transfer***
  - ***ECBC Requirements***
- ***Air Leakage***
  - ***ECBC Mandatory Requirements***
- ***ECBC Compliance Forms***

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Energy Conservation Building Code (ECBC)

MODULE 4: Heating Ventilation & Air Conditioning

USAID | INDIA FROM THE AMERICAN PEOPLE

Building physics TU VIENNA Building ecology

TU VIENNA

ECO III

ENERGY IS LIFE BEE CONSERVE IT

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HVAC: Outline

- **Introduction**
- **Whole Building Design Approach**
- **ECBC Requirements**
  - **Mandatory**
  - **Prescriptive**
- **ECBC Compliance Forms**

Introduction

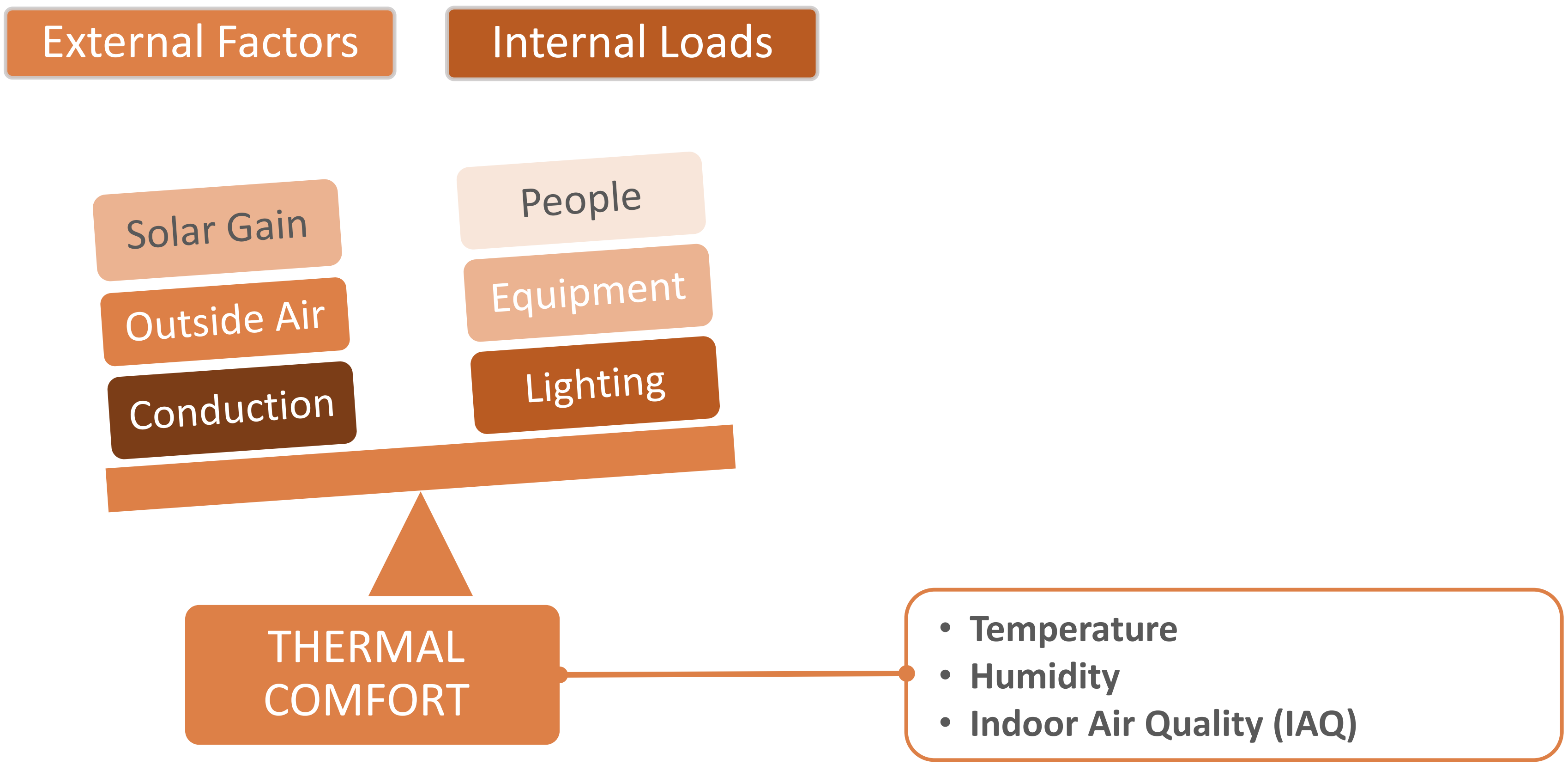
H V AC

Heating

Ventilating
- Natural Ventilation
- Mechanical Ventilation

Air Conditioning
- Cooling
- Dehumidification
- Humidification

Introduction



Whole Building Design Approach

1. **Reduce cooling loads by controlling unwanted heat gains**
2. **Expand the comfort envelope** (reduced latent heat load, air movement – ceiling fans, less insulated furniture, more casual dress codes)
3. **Optimize the delivery systems** (reducing velocity, pressure and friction in ducts and piping)
4. **Apply non-refrigerative cooling techniques**
5. **Serve the remaining load with high-efficiency refrigerative cooling**
6. **Improve controls** (sensors, signal delivery, user interface, simulators, etc.)

SOURCE: E Source Technology Atlas Series, Volume II Cooling (1997)

ECBC Requirements: Overview

- **ECBC Mandatory Requirements**
  - Natural ventilation
  - Equipment Efficiency
  - Controls
  - Piping and Ductwork
  - System Balancing
  - Condensers
- **ECBC Prescriptive Requirements**
  - Economizers
    - Reduce energy consumption by using cooler outdoor air to cool the building whenever possible
  - Hydronic Systems
    - Variable fluid flow saves water and reduces energy use in water based systems

ECBC Requirements: Mandatory

Natural Ventilation

- As per National Building Code of India 2005

Select NBC Design Guidelines for Natural Ventilation	
Building Orientation	0-30 Deg. In the direction of Prevailing winds
	45Deg. In the direction of east and west winds
Inlet Openings	Located on the windward side
Outlet Openings	Located on the leeward side
Height of the Openings	Recommended sill height:
	For sitting on chair 0.75 m
	For sitting on bed 0.60 m
	For sitting on floor 0.40 m
Total Area (Inlet+ Outlet) of the Openings	For total area of openings between 20% to 30% of floor area, the average indoor wind velocity is around 30% of outdoor velocity

SOURCE: Bureau of Indian Standards, National Building Code of India 2005, Part 8 Building Services, Section 1 Lighting and Ventilation

ECBC Requirements: Mandatory

Minimum Equipment Efficiencies

- Cooling equipment shall meet or exceed the minimum efficiency requirements in ECBC Table 5.1. Equipment not listed shall comply with ASHRAE 90.1-2004 §6.4.1

Equipment Class	Minimum COP	Minimum IPLV	Test Standard
Air Cooled Chiller <530 kW (<150 tons)	2.90	3.16	ARI 550/590-1998
Air Cooled Chiller ≥530 kW (≥150 tons)	3.05	3.32	ARI 550/590-1998
*Centrifugal Water Cooled Chiller < 530 kW (<150 tons)	5.80	6.09	ARI 550/590-1998
*Centrifugal Water Cooled Chiller ≥530 and <1050 kW (≥150 and <300 tons)	5.80	6.17	ARI 550/590-1998
*Centrifugal Water Cooled Chiller ≥ 1050 kW (≥ 300 tons)	6.30	6.61	ARI 550/590-1998
Reciprocating Compressor, Water Cooled Chiller all sizes	4.20	5.05	ARI 550/590-1998

- Unitary Air Conditioner shall meet IS 1391 (Part 1); Split air conditioner shall meet IS 1391 (Part 2); Packaged air conditioner shall meet IS 8148; Boilers shall meet IS 13980 with above 75% thermal efficiency.

ECBC Requirements: Mandatory

Equipment Efficiencies at IPLV

- Efficiencies at Integrated Part Load Performance (IPLV) values can be calculated as follows:
  IPLV = 0.01 A + 0.42B + 0.45C + 0.12D

  For COP and EER:
  Where: A = COP or EER at 100%; B = COP or EER at 75%; C = COP or EER at 50%; D = COP or EER at 25%

  For kW/Ton:

$$IPLV = \frac{1}{\frac{0.01}{A} + \frac{0.42}{B} + \frac{0.45}{C} + \frac{0.12}{D}}$$

  Where: A = kW/Ton at 100%; B = kW/Ton at 75%; C = kW/Ton at 50%; D = kW/Ton at 25%

ECBC Requirements: Mandatory

Controls (Timeclock)

- Code specifies the mandatory use of time clocks to allow scheduling for 24-hour building.
- Allow scheduling for 24-hour building
  - Can start and stop the system under different schedules for three different day-types per week
- Take power outages into consideration
  - Is capable of retaining programming and time setting during loss of power for a period of at least 10 hours
- Allow custom scheduling
  - Includes an accessible manual override that allows temporary operation of the system for up to 2 hours

ECBC Requirements: Mandatory

Controls (Temperature)

- Ensure adequate dead band between cooling & heating set points to avoid conflicting thermostat control conditions
- For systems that provide simultaneous heating and cooling
  - Controls shall be capable of providing a temperature dead band of 3°C (5°F) within which the supply of heating and cooling energy to the zone is shut off or reduced to a minimum.
- For systems that provide separate heating and cooling
  - Thermostats shall be interlocked to prevent simultaneous heating and cooling.

ECBC Requirements: Mandatory

Controls (Cooling Towers & Closed Circuit Fluid Coolers)

- To minimize energy consumption by reducing fan speed during lower ambient conditions
  - All cooling towers and closed circuit fluid coolers shall have either two speed motors, pony motors, or variable speed drives controlling the fans.

ECBC Requirements: Mandatory

Piping and Ductwork

- To minimize energy losses, ECBC requires that piping of heating and cooling systems, (including the storage tanks,) must be insulated
  - ECBC specifies required R-values of insulation based on the operating temperature of the system

Heating System	
Designed Operating Temperature of Piping	Insulation with Minimum R-value ($m^2 \cdot K/W$)
60°C and above	0.74
Above 40°C and below 60°C	0.35
ECBC Insulation Specs. for Heating System	

Cooling System	
Designed Operating Temperature of Piping	Insulation with Minimum R-value (m2·K/W)
Below 15°C	0.35
Refrigerant Suction Piping	
Split System	0.35
ECBC Insulation Specs. for Cooling Systems	

- To maintain thermal integrity of the insulation
  - Insulation exposed to weather shall be protected by aluminum sheet metal, painted canvas, or Plastic cover. Cellular foam insulation shall be protected as above, or be painted with water retardant paint.

ECBC Requirements: Mandatory

System Balancing

- Achieve energy efficiency by optimizing air/water distribution rates for all systems
- Balancing should be done prior to occupancy
- ECBC mandates system balancing be included in specifications in the construction documents
- Construction documents shall require
  - All HVAC systems be balanced in accordance with generally accepted engineering standards.
  - A written balance report including O&M guidelines be provided for HVAC systems serving zones with a total conditioned area exceeding 500 m2 (5,000 ft2).

ECBC Requirements: Mandatory

System Balancing (Air System Balancing)

- Air systems shall be balanced in a manner to minimize throttling losses. Then, for fans greater than 0.75 KW (1.0 HP), fans must then be adjusted to meet design flow conditions.

- *Air System Balancing refers to adjustment of airflow rates through air distribution system devices such as fans and diffusers.*
- *It is achieved through adjusting the position of dampers, splitter vanes, extractors, etc.*
- *Design options for improving air distribution efficiency include using*
  - *Variable-air-volume systems*
  - *VAV diffusers*
  - *Low-pressure-drop duct design*
  - *Low-face-velocity air handlers*
  - *Fan sizing and variable-frequency-drive motors*
  - *Displacement ventilation systems*

ECBC Requirements: Mandatory

System Balancing (Hydronic System Balancing)

- Hydronic systems shall be proportionately balanced in a manner to first minimize throttling losses; then the pump impeller shall be trimmed or pump speed shall be adjusted to meet design flow conditions.

- *Hydronic System Balancing refers to the adjustment of water flow rates through distribution system devices such as pumps and coils, by manually adjusting the position of valves, or by using automatic control devices, such as flow control valves.*
- *A balanced hydronic system is one that delivers even flow to all of the devices on that piping system.*
- *When a system is balanced, all of the pressure drops are correct for the devices which translates into reduced energy use & costs for pumping.*

ECBC Requirements: Mandatory

Condensers

- ECBC regulates condenser locations to ensure:
  - There is no restriction to the air flow around condenser coils
  - No short circuiting of discharge air to the intake side
  - Heat discharge of other adjacent equipment is not near the air intake of the condenser
- Care shall be exercised in locating the condensers in such a manner that the heat sink is free of interference from heat discharge by devices located in adjoining spaces and also does not interfere with such other systems installed nearby.
- ECBC regulates condenser water quality
  - to eliminate mineral buildup in condensers and chilled water systems (Mineral deposits create poor heat transfer situations there by reducing the efficiency of the unit)
- All high-rise buildings using centralized cooling water system shall use soft water for the condenser and chilled water system.

ECBC Requirements: Prescriptive

Prescriptive requirements apply if the HVAC system meets the following criteria:

- Serves a single zone
- Cooling (if any) is provided by a unitary packaged or split-system air conditioner or heat pump
- Heating (if any) is provided by a unitary packaged or split-system heat pump, fuel-fired furnace, electric resistance heater, or baseboards connected to a boiler
- Outside air quantity is less than 1,400 l/s (3,000 cfm) and less than 70% of supply air at design conditions

Other HVAC systems shall comply with ASHRAE 90.1-2004, §6.5

ECBC Requirements: Prescriptive

Air Side Economizer

Each individual cooling fan system that has a design supply capacity over 1,200 l/s (2,500 cfm) and a total mechanical cooling capacity over 22 kW (6.3 tons) shall include either:

- An air economizer capable of modulating outside-air and return-air dampers to supply 100% of the design supply air quantity as outside-air;

OR

- A water economizer capable of providing 100% of the expected system cooling load at outside air temperatures of 10°C (50°F) dry-bulb/7.2°C (45°F) wet-bulb and below.

ECBC Requirements: Prescriptive

Air Side Economizer

ECBC encourages use of ventilation fans in the economizer mode to pre-cool the building prior to daily occupancy in the cooling season.

- Economizers shall be capable of providing partial cooling even when additional mechanical cooling is required to meet the cooling load.
- Air-side economizers shall be tested in the field following the requirements in Appendix F (of the Code) to ensure proper operation.

ECBC Requirements: Prescriptive

Variable Flow Hydronic Systems

- Chilled or hot-water systems shall be designed for variable fluid flow and shall be capable of reducing pump flow rates to no more than the larger of:
  - 50% of the design flow rate, or
  - The minimum flow required by the equipment manufacturer for proper operation of the chillers or boilers

- Automatic Isolation Valves
  - Water cooled air-conditioning or heat pump units with a circulation pump motor greater than or equal to 3.7 kW (5 hp) shall have two-way automatic isolation valves on each water cooled air-conditioning

    OR
  - heat pump unit that are interlocked with the compressor to shut off condenser water flow when the compressor is not operating.

ECBC Requirements: Prescriptive

Variable Flow Hydronic Systems

- Variable Speed Drives
  - Chilled water or condenser water systems that must comply with either ECBC §5.3.2.1 /5.3.2.2 and that have pump motors greater than or equal to 3.7 kW (5 hp) shall be controlled by variable speed drives.

ECBC Compliance Forms

Mechanical Summary

2007 Energy Conservation Building Code Compliance Forms

Project Info	Project Address:	Date
		For Building Dept. Use
	Applicant Name:	
	Applicant Address:	
	Applicant Phone:	

Project Description Briefly describe mechanical system type and features. ☐ Includes Plans	
Compliance Option	☐ System ☐ Prescriptive ☐ Whole Building
Equipment Schedules	The following information is required to be incorporated with the mechanical equipment schedules on the plans. For projects without plans, fill in the required information below.

Cooling Equipment Schedule

Equip. ID	Brand Name	Model No.	Capacity kW	Total L/s	OSA CFM or Econo?	SEER or EER	IPLV	Location

Heating Equipment Schedule

Equip. ID	Brand Name	Model No.	Capacity kW	Total L/s	OSA cfm or Econo?	Input kW	Output kW	Efficiency

Mechanical Permit Checklist — MECHANICAL Checklist

2007 Energy Conservation Building Code Compliance Forms

Project Address | Date

The following information is necessary to check a building permit application for compliance with the mechanical requirements in the Energy Conservation Building Code 2007

Applicability (yes, no, n.a.)	Code Section	Component	Information Required	Location on Plans	Building Department Notes
HEATING, VENTILATING, AND AIR CONDITIONING (Chapter 5)					
MANDATORY PROVISIONS (Section 5.2)					
	5.2.2	Equipment efficiency	Provide equipment schedule with type, capacity, efficiency		
	5.2.3	Controls			
	5.2.3.1	Time clocks	Indicate thermostat with night setback, 3 different day types, and 2-hour manual override		
	5.2.3.2	Temp. & dead band	Indicate temperature control with 3 degree C dead band minimum		
	5.2.3.3	Cooling tower, fluid cooler	Indicate two-speed motor, pony motor, or variable speed drive to control the fans		
	5.2.4.1	Piping & ductwork			
	5.2.4.1	Piping insulation	Indicate R-value of insulation		
	5.2.4.1	Ductwork insulation	Indicate R-value of insulation		
	5.2.4.1	Ductwork sealing	Specify sealing types and locations		
	5.2.5	System balancing	Specify system balancing		
PRESCRIPTIVE COMPLIANCE OPTION (Section 5.3)					
	5.3		Indicate whether project is complying with ECBC Prescriptive Option OR with ASHRAE Standard 90.1-2004		
	5.3.1	Economizer			
	5.3.1.1	Air economizer	Indicate 100% capability on schedule		
	5.3.1.2	Integrated operation	Indicate capability for partial cooling		
	5.3.1.3	Field testing	Specify tests		
	5.3.2	Variable flow hydronic			
	5.3.2.1	Pump flow rates	Indicate variable flow capacity on schedules		
	5.3.2.2	Isolation valves	Indicate two-way automatic isolation valves		
	5.3.2.3	Variable speed drive	Indicate variable speed drive		

End of MODULE

- ***Introduction***
- ***Whole Building Design Approach***
- ***ECBC Requirements***
  - ***Mandatory***
  - ***Prescriptive***
- ***ECBC Compliance Forms***

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Energy Conservation Building Code (ECBC)

MODULE 5: Service Hot Water & Pumping

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Building physics TU Building ecology
TU VIENNA
ECO III
ENERGY IS LIFE BEE CONSERVE IT

ACKNOWLEDGEMENT

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ATTRIBUTION

Service Hot Water & Pumping: Outline

- Introduction
- Types of Water Heaters
- ECBC Requirements
  - Mandatory
- ECBC Compliance Forms

Introduction

Water heating is a thermodynamic process using an energy source to heat water above its initial temperature.

Hot Water Use

Domestic

- Cooking
- Cleaning
- Bathing
- Space heating

Commercial

- Hotels
  - Cooking
  - Laundry
  - Bathing
- Hospitals
  - Cleaning
  - Disinfection
  - Bathing

Industrial

SOURCE: http://en.wikipedia.org/wiki/Water_heating

Introduction

Source Type

Conventional
- Electricity
- Natural Gas / LPG
- Oil
- Solid Fuels

Alternative
- Solar energy (Passive / Active)
- Heat pumps
- Hot water recycling
- Geothermal heating

System type

- Storage
- Instantaneous

SOURCE: http://en.wikipedia.org/wiki/Water_heating

Introduction

- **Energy loss**
  - Inefficiency of heating equipment
  - Heat loss from hot water storage tanks
  - Heat loss from distribution network (piping)

- **Opportunities for improvement**
  - Use hot water heating system that has a Thermostat
  - Reduce Water Heating Temperature. For each 5.5°C (10°F) reduction in water temperature, can lead to 3-5% savings in energy costs
  - Insulate the storage tanks, pipes and heat traps

Types of Water Heaters

- **Storage Heaters** (Gas or Electric)
  - Designed to heat and store water at less than 80°C
  - Water temperature is controlled with a thermostat
  - Storage electric water heaters have a manufacturer's specified capacity of at least two gallons.
- **Storage Heat Pump**
  - An electric water heater that uses a compressor to transfer thermal energy from one temperature level to a higher temperature level for the purpose of heating water
  - It includes all necessary auxiliary equipment such as fans, storage tanks, pumps or controls.
- **Instantaneous** (Gas or Electric)
  - Instantaneous water heaters provide hot water only as it is needed
    - Controlled manually or automatically by water flow activated control and/or thermostatic controls
  - Water heaters heat water directly without the use of a storage tank

Types of Water Heaters

- **Indirect Gas**
  - A water heater consisting of a storage tank with no heating elements or combustion devices
  - Connected via piping and recirculating pump to a heat source consisting of a gas or oil fired boiler, or instantaneous gas water heater
- **Solar** (Passive or Active)
  - Systems which collect and store solar thermal energy for water heating applications
  - Passive systems do not require electricity to recirculate water, whereas active systems require electricity to operate pumps or other components
  - Passive systems are not readily available in the market and generally need to be designed for a particular usage

ECBC Requirements: Mandatory

ECBC through mandatory requirements seeks to minimize energy usage in water heating systems by:

- Solar water heating
- Equipment efficiency
- Supplementary water heating system
- Piping insulation
- Heat traps
- Swimming pool (covers)

ECBC Requirements: Mandatory

Solar Water Heating

- Residential facilities, hotels and hospitals with a centralized system shall have solar water heating for at least 1/5 of the design capacity
  - ***EXCEPTION:*** Systems that use heat recovery for at least 1/5 (20 percent) of the design capacity are exempted

ECBC Requirements: Mandatory

Equipment Efficiency

- Solar water heater shall meet the performance/ minimum efficiency level mentioned in IS 13129 Part (1&2)
  - IS 13129 (Part 1) provides information on the 'Performance Rating Procedure Using Indoor Test Methods'
  - IS 13129 (Part 2) provides the information on the 'Procedure for System Performance Characterization and Yearly Performance Prediction'.
  - These standards however, do not provide any performance/minimum efficiency levels

- Gas Instantaneous Water heaters shall meet the performance/minimum efficiency level mentioned in IS 15558 with above 80% thermal efficiency
  - As per this IS 15558, thermal efficiency of the water heaters (under test conditions) shall not be less than:
  - 84 percent for water heaters with a nominal heat input exceeding 10 kW
  - 82 percent for water heaters with a nominal heat input not exceeding 10 kW

ECBC Requirements: Mandatory

Equipment Efficiency

- Electric water heater shall meet the performance / minimum efficiency level mentioned in IS 2082
  - IS 2082 (Part 1) specifies the standing loss in the heaters

Rated Capacity in Liters	Loss in kWh/day for 45° Difference
6	0.792
10	0.99
15	1.138
25	1.386
35	1.584
50	1.832
70	2.079
100	2.376
140	2.673
200	2.97

SOURCE: Bureau of Indian Standards (1991), IS 2082 (Part 1): 1993 (Reaffirmed 2004) Edition 5.4 (2002-05) Stationary Storage Type Electric Water Heaters-Specification (Fourth Revision)

ECBC Requirements: Mandatory

Supplementary Water Heating System

- Supplemental Water Heating System shall be designed to maximize efficiency and shall incorporate and prioritize the following design features as shown:
  - Maximum heat recovery from hot discharge system like condensers of air conditioning units
  - Use of gas-fired heaters wherever gas is available
  - Electric heater as last resort

ECBC Requirements: Mandatory

Piping Insulation

- The entire hot water system including the storage tanks, pipelines shall be insulated conforming to the relevant IS standards on materials and applications.

Heating System	
Designed Operating Temperature of Piping	Insulation with Minimum R-value ($m^2 \cdot K/W$)
60°C and above	0.74
Above 40°C and below 60°C	0.35

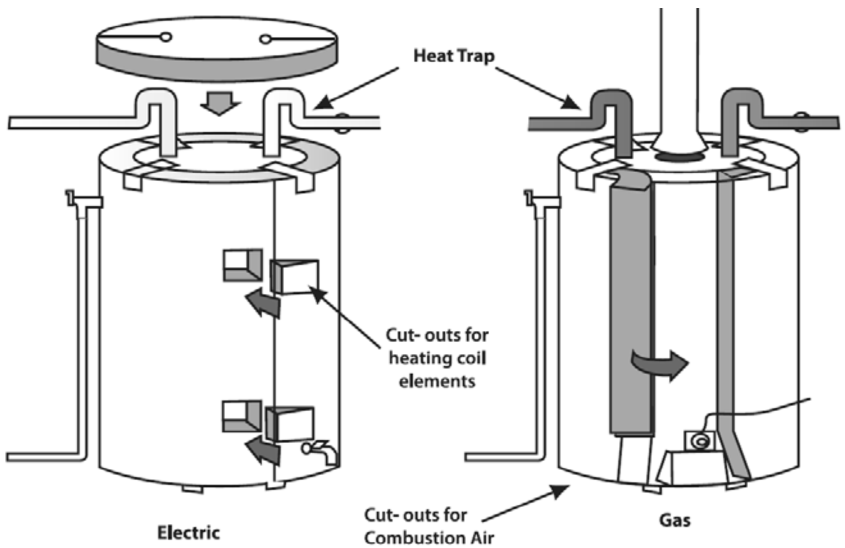
ECBC Requirements: Mandatory

Heat Traps

- Vertical pipe risers serving storage water heaters and storage tanks not having integral heat traps and serving a non-recirculating system shall have heat traps on both the inlet and outlet piping as close as practical to the storage tank

- *Heat traps are valves or loops of pipe that allow water to flow into the water heater tank but prevent unwanted hot-water flow out of the tank*

- *Heat traps can help save energy and cost on the water heating bill by preventing convective heat losses through the inlet and outlet pipes*



Heat trap elements

ECBC Requirements: Mandatory

Swimming Pools

- Heated pools shall be provided with a vapor retardant pool cover on or at the water surface. Pools heated to more than 32°C (90°F) shall have a pool cover with a minimum insulation value of R-2.1 (R-12).
  - ***EXCEPTION:*** Pools deriving over 60% of their energy from site-recovered energy or solar energy source.

ECBC Compliance Forms

Compliance submittals demonstrate the following:

- At least 20% of the heating requirement shall be met from solar heat/heat recovery
- Not more than 80% of the heat shall be met from electrical heating
- Wherever gas is available, not more than 20% of the heat shall be met from electrical heating
- ECBC Appendix G 15.4 Mechanical Checklist

SERVICE WATER HEATING AND PUMPING (Chapter 6)							
MANDATORY PROVISIONS (Section 6.2)							
			6.2.1	Solar water heating	Provide calculations to justify capacity to meet 20% threshold		
			6.2.2	Equipment efficiency	Provide equipment schedule with type, capacity, efficiency		
			6.2.4	Piping insulation	Indicate R-value of insulation		
			6.2.5	Heat traps	Indicate heat trap on drawings or provide manufacturers specifications to show that equipment has internal heat trap		
			6.2.6	Pool covers	Provide vapor retardant cover for pools		
			6.2.6	Pools over 32°C	Provide R-2.1 insulation		

End of MODULE

- ***Introduction***
- ***Types of Water Heaters***
- ***ECBC Requirements***
  - ***Mandatory***
- ***ECBC Compliance Forms***

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Energy Conservation Building Code (ECBC)

MODULE 6: Lighting

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ATTRIBUTION

Lighting: Outline

- Introduction
- Whole Building Design Approach
- ECBC Requirements
  - Mandatory
  - Prescriptive
- ECBC Compliance Forms

Introduction

- Lighting is a major energy consumer in commercial buildings
- Lighting accounts for 15% of total energy consumption in India
  - Commercial Buildings 20-40%
- In most commercial buildings, lighting is one of the largest sources of internal heat gain
  - Heat generated from electric lighting contributes significantly to the energy needed for cooling of buildings
  - Each kilowatt-hour (kWh) reduction in lighting energy approximately saves 0.4 kWh in cooling energy
- Lighting is one of the fastest developing energy-efficient technologies

Whole Building Design Approach

1. **Improve the space**
2. **Optimize light quality**
3. **Capture Daylight**
   - Daylighting Design Approaches
   - Energy savings and demand reduction
   - Glazing selection
   - Redirecting daylight
   - Controls for daylight dimming
4. **Consider lighting quantity**
5. **Energy-efficient electric lighting**
6. **Use of lighting controls**

SOURCE: E Source Technology Atlas Series, Volume I Lighting (2005)

ECBC Requirements: Overview

ECBC Lighting Requirements apply to:

- **Interior spaces** of buildings
- **Exterior building features,** including façades, illuminated roofs, architectural features, entrances, exits, loading docks, and illuminated canopies
- **Exterior building grounds** lighting that is provided through the building's electrical service
- The **mandatory requirements** for lighting mostly relate to **interior and exterior lighting controls.**
- The **prescriptive requirements** limit the **installed electric wattage** for interior building lighting.
    - Demonstrated through the Building Area Method or the Space Function Method

ECBC Requirements: Mandatory

Automatic Lighting Control

- Interior lighting systems in buildings larger than 500 m^2 (5,000 ft^2) shall be equipped with an automatic control device.
  - All office areas less than 30 m^2 (300 ft^2) shall be equipped with occupancy sensors.
  - For other spaces, this automatic control device shall function on either:
    - A scheduled basis at specific programmed times. An independent program schedule shall be provided for areas of no more than 2,500 m^2 (25,000 ft^2) and not more than one floor;

      or
    - Occupancy sensors that shall turn the lighting off within 30 minutes of an occupant leaving the space. Light fixtures controlled by occupancy sensors shall have a wall-mounted, manual switch capable of turning off lights when the space is occupied.

ECBC Requirements: Mandatory

Space Control

- Each space shall have at least one control device to independently control the general lighting
- Each control device shall be activated either manually by an occupant or automatically by sensing an occupant.
- Each control device shall:
  - Control a maximum of 250 m^2 for a space less than or equal to 1,000 m^2, and a maximum of 1,000 m^2 for a space greater than 1,000 m^2
  - Be capable of overriding the shutoff control required in Automatic Lighting Shutoff for no more than 2 hours
  - Be readily accessible and located so the occupant can see the control

ECBC Requirements: Mandatory

Daylighting Control

If Daylighting strategy is used in the design, ECBC requires controls that can reduce the light output of luminaires in the daylit space.

- Luminaire in daylighted areas greater than 25m^2 shall be equipped with either a manual or automatic control device that:
  - Is capable of reducing the light output of the luminaires in the daylighted areas by at least 50%
  - Controls only the luminaires located entirely within the daylighted area
- There are also control requirements for exterior lighting (with photosensor or time switches) and specialty lighting applications (i.e. displays, hotel rooms, task lighting).

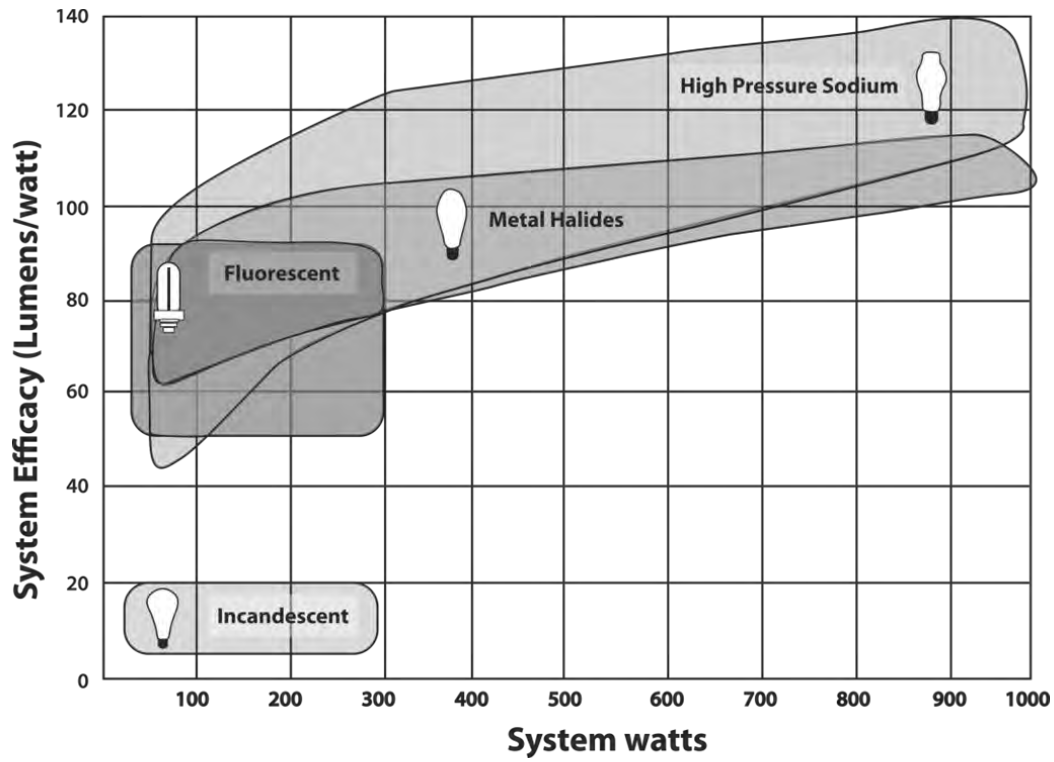
ECBC Requirements: Mandatory

Exit Signs

- Internally-illuminated exit signs shall not exceed 5W per face.

Exterior Building Grounds Lighting

- Lighting for exterior building grounds luminaires which operate at greater than 100W shall contain lamps having a minimum efficacy of 60 lm/W unless the luminaire is controlled by a motion sensor



Exterior Grounds Lighting and specific Technologies

NOTE: *Luminaires meeting these requirements include fluorescent, mercury vapor and high pressure sodium*

SOURCE: (Image) Adapted from ASHRAE/IESNA Standard 90.1-1999

ECBC Requirements: Prescriptive

Interior Lighting Power

- Prescriptive lighting requirements limit the installed electric wattage for interior building lighting
- Trade-offs of interior lighting power allowance among portions of the building for which a different method of calculation has been used are NOT permitted
- Installed lighting power is calculated and compared using the maximum permissible interior lighting power densities
  - Specified for various building types (Building Area Method)

    OR
  - Building space functions (Space Function Method)

ECBC Requirements: Prescriptive

Building Area Method

1. Determine the allowed lighting power density (LPD) from Table 7.1 of ECBC for each appropriate building area type
2. Calculate the gross lighted floor area type
3. Multiply the allowed watts/sq.mt. Listed for each selected building type by the corresponding lighted floor areas to determine the allowed LPD
4. The sum of all the interior lighting power for various areas of the building cannot exceed the total watts to be in compliance

Table 7.1: Interior Lighting Power-Building Area Method

Building Area Type	LPD (W/m^2)	Building Area Type	LPD (W/m^2)
Automotive Facility	9.7	Multifamily Residential	7.5
Convention Center	12.9	Museum	11.8
Dining: Bar Lounge/Leisure	14.0	Office	10.8
Dining: Cafeteria/Fast Food	15.1	Parking Garage	3.2
Dining: Family	17.2	Performing Arts Theater	17.2
Dormitory/Hostel	10.8	Police/Fire Station	10.8
Gymnasium	11.8	Post Office/Town Hall	11.8

ECBC Requirements: Prescriptive

Space Function Method

1. Determine the appropriate building type and their allowed lighting power densities, which varies according to the function of the space
2. For each space enclosed by partitions 80% or greater than ceiling height, determine the gross interior floor area.
3. The lighting power allowance for a space is the product of the gross lighted floor area of the space times the allowed lighting power density for that space.
4. The interior lighting power allowance for the building is the sum of the lighting power allowances for all spaces.

Table 7.2: Interior Lighting Power – Space Function Method

Space Function	LPD (W/m^2)	Space Function	LPD (W/m^2)
Office-enclosed	11.8	• For Reading Area	12.9
Office-open plan	11.8	Hospital	
Conference/Meeting/Multipurpose	14.0	• For Emergency	29.1
Classroom/Lecture/Training	15.1	• For Recovery	8.6
Lobby*	14.0	• For Nurse Station	10.8
• For Hotel	11.8	• For Exam Treatment	16.1
• For Performing Arts Theater	35.5	• For Pharmacy	12.9

ECBC Requirements: Prescriptive

Exterior Lighting Power

- The connected exterior lighting power must not exceed the allowed limits by ECBC.
- Trade-offs between applications are not permitted.

Table 7.3: Exterior Building Lighting Power

Exterior Lighting Applications	Power Limits
Building entrance (with canopy)	13 W/m^2 (1.3 W/ft^2) of canopied area
Building entrance (without canopy)	90 W/lin m (30 W/lin f) of door width
Building exit	60 W/lin m (20 W/lin f) of door width
Building facades	2 W/m^2 (0.2 W/ft^2) of vertical facade area

ECBC Compliance Forms

15.5 Lighting Summary

Lighting Summary

2007 Energy Conservation Building Code Compliance Forms

Project Info	Project Address	Date
		For Building Department Use
	Applicant Name:	
	Applicant Address:	
	Applicant Phone:	

Project Description	☐ New Building	☐ Addition	☐ Alteration	☐ Change of Use

Compliance Option	☐ Prescriptive	☐ Systems Analysis

Alteration Exceptions (check box, if appropriate)	☐ Less than 50% of the fixtures are new and installed lighting wattage is not being increased

Maximum Allowed Lighting Wattage (Interior, Section 7.3)

Location (floor/room no.)	Occupancy Description	Allowed Watts per m² **	Area in m²	Allowed x Area
	** Document all exceptions		Total Allowed Watts	

Proposed Lighting Wattage (Interior)

Location (floor/room no.)	Fixture Description	Number of Fixtures	Watts/ Fixture	Watts Proposed
	Total Proposed Watts may not exceed Total Allowed Watts for Interior		Total Proposed Watts	

Maximum Allowed Lighting Wattage (Exterior, Section 7.4)

Location	Description	Allowed Watts per m² or per lm	Area in m² (or lm for perimeter)	Allowed Watts x m² (or x lm)
			Total Allowed Watts	

Proposed Lighting Wattage (Exterior)

Location	Fixture Description	Number of Fixtures	Watts/ Fixture	Watts Proposed
	Total Proposed Watts may not exceed Total Allowed Watts for Exterior		Total Proposed Watts	

15.6 Lighting Permit Checklist

Lighting Permit Checklist **LIGHTING Checklist**

2007 Energy Conservation Building Code Compliance Forms

Project Address	Date

The following information is necessary to check a building permit application for compliance with the lighting requirements in the Energy Conservation Building Code 2007

Applicability (yes, no, n.a.)	Code Section	Component	Information Required	Location on Plans	Building Department Notes
LIGHTING (Chapter 7)					
MANDATORY PROVISIONS (Section 7.2)					
	7.2.1	Lighting controls			
	7.2.1.1	Automatic shutoff	Indicate automatic shutoff locations or occupancy sensors		
	7.2.1.2	Space control	Provide schedule with type, indicate locations		
	7.2.1.3	Daylight zones	Provide schedule with type and features, indicate locations		
	7.2.1.4	Exterior lighting control	Indicate photosensor or astronomical time switch		
	7.2.1.5	Additional control	Provide schedule with type, indicate locations		
	7.2.2	Exit signs	Indicate 5 watts maximum		
	7.2.3	Exterior building grounds lighting	Indicate minimum efficacy of 60 lumens/Watt		
PRESCRIPTIVE INTERIOR LIGHTING POWER COMPLIANCE OPTION (Section 7.3)					
	7.3		Indicate whether project is complying with the Building Area Method (7.3.2) or the Space Function Method (7.3.3)		
	7.3.2	Building area method	Provide lighting schedule with wattage of lamp and ballast and number of fixtures. Document all exceptions.		
	7.3.3	Space function method	Provide lighting schedule with wattage of lamp and ballast and number of fixtures. Document all exceptions.		
	7.3.4.1	Luminaire wattage	Indicate on plans		
PRESCRIPTIVE EXTERIOR LIGHTING POWER COMPLIANCE OPTION (Section 7.3.5)					
	7.3.5	Exterior Lighting Power	Provide lighting schedule with wattage of lamp and ballast and number of fixtures. Document all exceptions.		
ELECTRICAL POWER (Chapter 8)					
MANDATORY PROVISIONS (Section 8.2)					
	8.2.1	Transformers	Provide schedule with transformer losses		
	8.2.2	Motor efficiency	Provide equipment schedule with motor capacity, efficiency		
	8.2.3	Power factor correction	Provide schedule with power factor correction		
	8.2.4	Check metering	Provide check metering and monitoring		

End of MODULE

- ***Introduction***
- ***Whole Building Design Approach***
- ***ECBC Requirements***
  - ***Mandatory***
  - ***Prescriptive***
- ***ECBC Compliance Forms***

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Energy Conservation Building Code (ECBC)

MODULE 7: Electrical Power

USAID | INDIA
FROM THE AMERICAN PEOPLE

Building physics TU VIENNA Building ecology

TU VIENNA

ENERGY IS LIFE BEE CONSERVE IT

ACKNOWLEDGEMENT

This presentation was prepared by International Resources Group (IRG) for the Energy Conservation and Commercialization Project (ECO-III), and was made possible by the support of the American People through the United States Agency for International Development (USAID). The contents of this presentation are the sole responsibility of IRG and do not necessarily reflect the views of USAID or the United States Government. The ECO-III Project would like to acknowledge Ministry of Power and the Bureau of Energy Efficiency of Government of India for their support.

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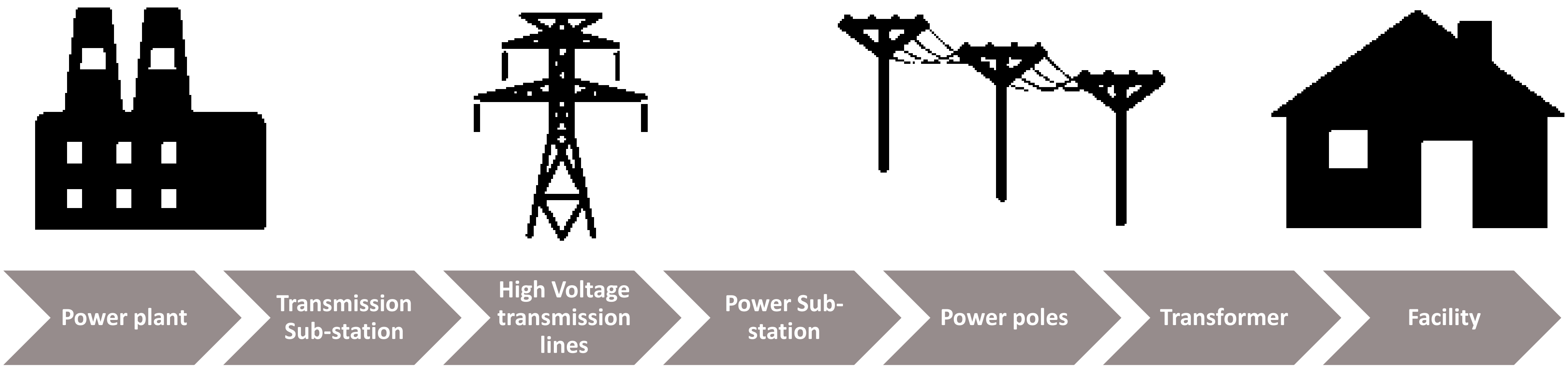
Electrical Power: Outline

- Introduction
- Transformers
- Electric Motors
- ECBC Requirements
  - Mandatory
- ECBC Compliance Forms

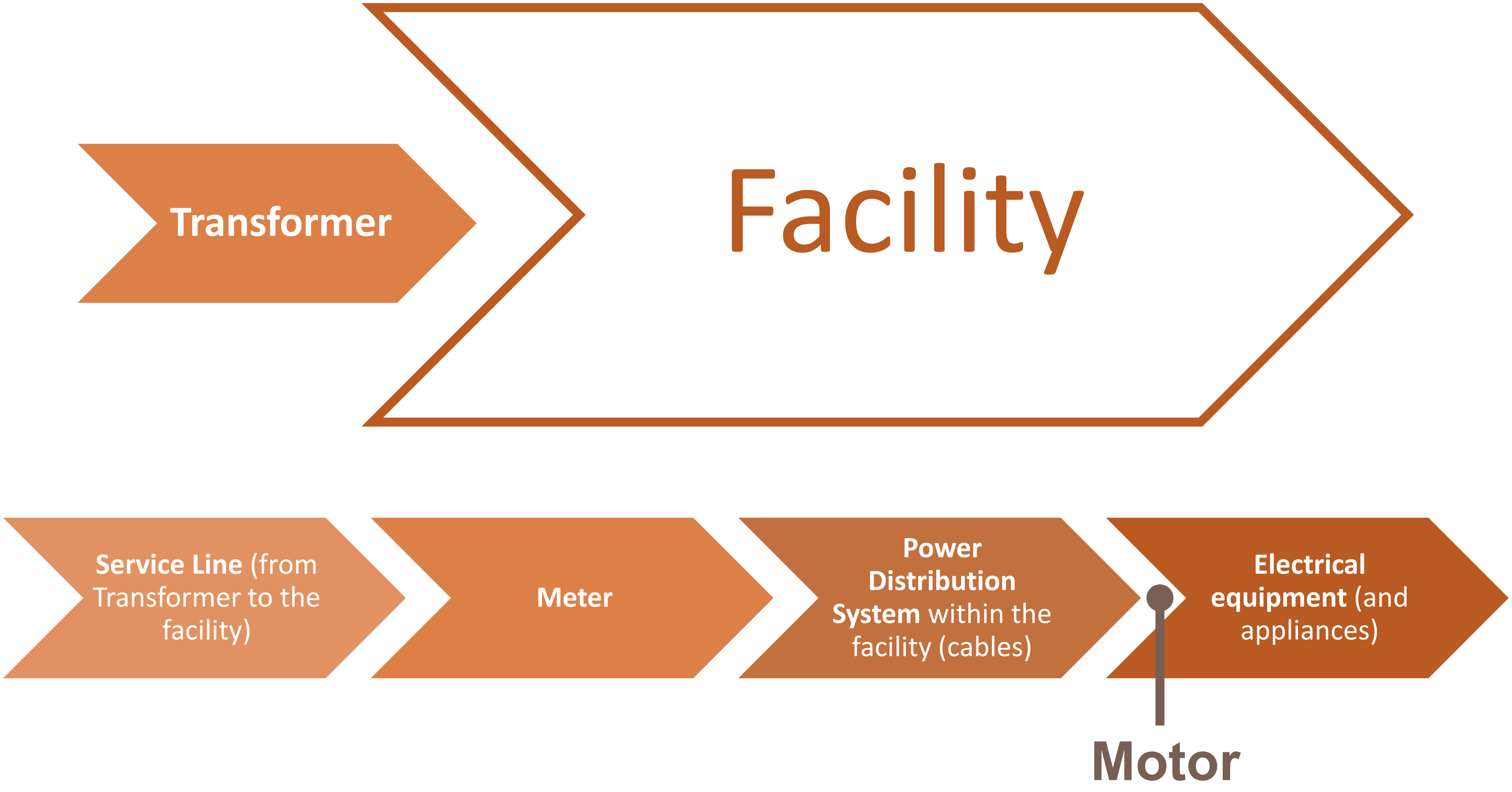
Introduction

ELECTRICAL POWER comprises of all physical components that make up the electric equipment and systems installed in a facility

Power Distribution System

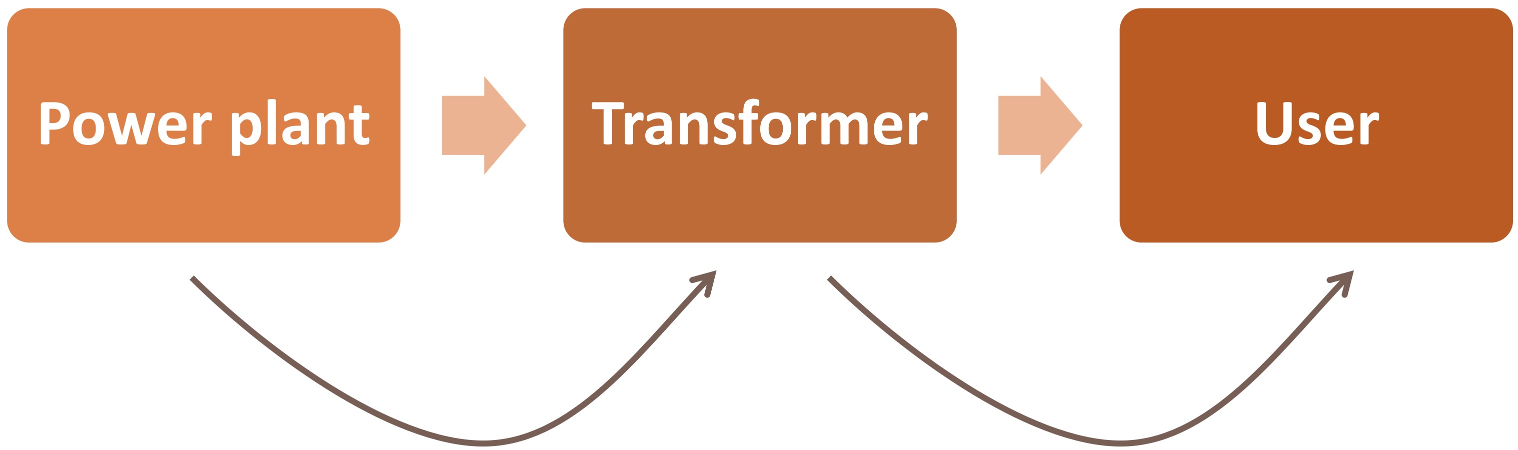


Introduction



Transformers

Device to either increase (Step-up) or decrease (Step-down) the input supply voltage



High-tension voltage (400kV-33kV)

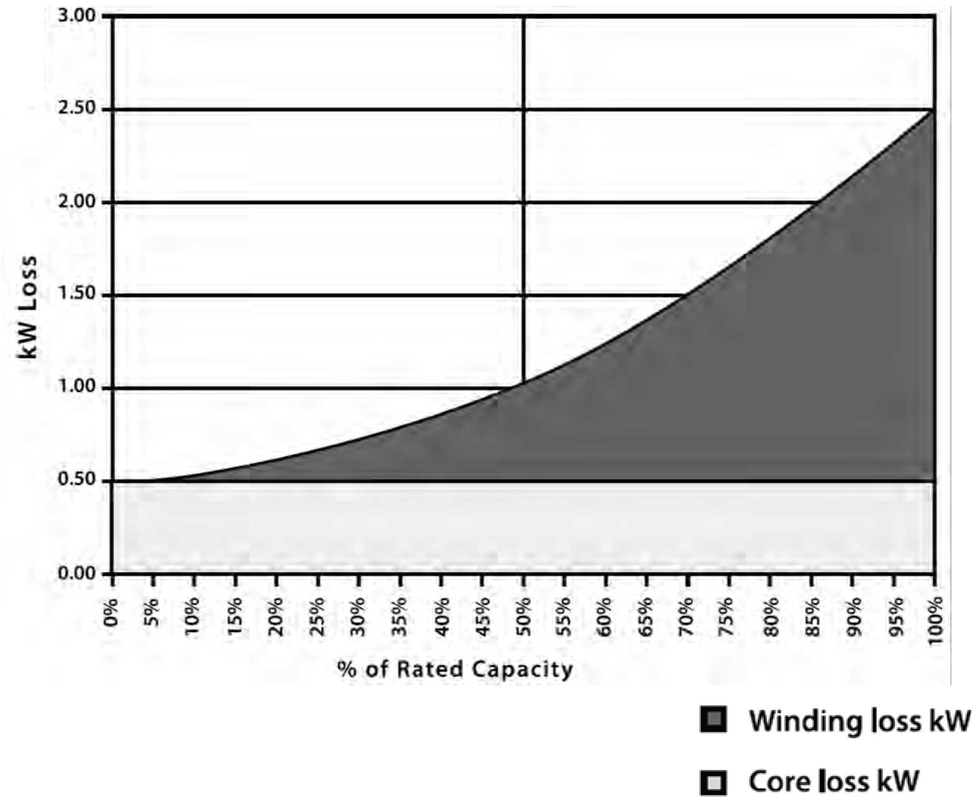
- *Reduced conductor size and investment on conductors*
- *Reduced transmission losses and voltage drop*

Voltage stepped-down (11kV-230V) for power supply distribution to various sections and equipment

Transformers

Efficiency

- varies anywhere between 96 to 99%.
- depends on the design and operating load
- Transformer losses consist of two parts:
  - ***No-load Loss:*** Occurs whenever the transformer is energized & it does not vary with load
  - ***Load Loss (Copper Loss):*** Associated with full-load current flow in the transformer windings & varies with the square of the load current (P=I2R)



Transformer loss Vs % load

Electric Motors

Device to convert electrical energy into mechanical energy

- Drives equipment such as pumps, blowers and fans, compressors, conveyers and production lines

Energy → **Motor** → **Application**

[**Electrical Energy (W)**]

[produces TORQUE] → [leads to **Mechanical work (hp)**]

Electric Motors

- **Winding:** number of turns of insulated wire, usually copper, wrapped around the core of steel laminations.
- **Rewinding:** a repair technique for induction motors where the old windings are removed and new windings are installed, either in the stator, rotor, or both.
- **Power Factor:** The ratio between the real power (in watts or kW) and apparent power (the product of the voltage times the current measured in volt-amperes or kVA).
- **Power Factor Correction:** The application of capacitors to compensate the lagging power factor caused by induction motors.
  - *Power factor correction (PFC) may be applied either by an electrical power transmission utility to improve the stability and efficiency of the transmission network or, correction may be installed by individual electrical customers*

Electric Motors

Motor input ≠ consumption

- **Motor efficiency:** ratio of the useful mechanical power output to the total electric power input to the motor.
  - ***Nameplate efficiency:*** efficiency provided by a motor manufacturer and the nominal efficiency for that motor design. Actual motor efficiency can be above or below this value.
- Electrical energy input is measured in watts (W), while output is given in horsepower (hp).
- 1 hp = 746 W

SOURCE: E Source Technology Atlas Series, Volume II DrivePower (1999)

ECBC Requirements: Overview

- ECBC has only **Mandatory requirements** for electric power systems installed in buildings
- The mandatory requirements of the Code, cover the following electrical equipment and systems of building:
  - Transformers
  - Energy-efficient Motors
  - Power Factor Correction
  - Electrical Metering and Monitoring
  - Power Distribution Systems

ECBC Requirements: Mandatory

Transformers (Maximum Allowable Power Transformer Losses)

- Power transformers of the proper ratings and design must be selected to satisfy the **minimum acceptable efficiency at 50% and full load rating.**
- The transformer must be selected such that it **minimizes the total of its initial cost in addition to the present value of the cost of its total lost energy** while serving its estimated loads during its respective life span.

ECBC lists various transformer sizes of dry-type and oil-filled transformers and their associated losses at 50% and full load rating.

ECBC Requirements: Mandatory

Transformers (Maximum Allowable Power Transformer Losses)

DRY TYPE TRANSFORMER LOSSES

Table 8.1: Dry Type Transformers- total losses for dry type transformers should conform as per the draft standard of Indian Standard IS 2026: Part 11 2007

Rating KVA	Max. Losses at 50% loading kW*	Max. Losses at 100% loading kW*	Total losses at 50% loading kW*	Total losses at rated load kW*
	Up to 22 kV class		33 kV class	
100	0.94	2.4	1.12	2.4
160	1.29	3.3	1.42	3.3
200	1.5	3.8	1.75	4
250	1.7	4.32	1.97	4.6
315	2	5.04	2.4	5.4
400	2.38	6.04	2.9	6.8
500	2.8	7.25	3.3	7.8

ECBC Requirements: Mandatory

Transformers (Maximum Allowable Power Transformer Losses)

OIL FILLED TRANSFORMER LOSSES

Table 8.2: Oil Filled Transformers- Total losses for oil filled transformers should conform as per the following table as specified in Central Electricity Authority norms.

Rating KVA	Max. Losses at 50% loading kW*	Max. Losses at 100% loading kW*	Total losses at 50% loading kW*	Total losses at rated load kW*
	Up to 11 kV class		33 kV class	
100	520	1800	560	1820
160	770	2200	780	2580
200	890	2700	900	3000
250	1050	3320	--	--
315	1100	3630	1300	4300
400	1450	4630	1520	5100
500	1600	5500	1950	6450
630	2000	6640	2300	7600

ECBC Requirements: Mandatory

Transformers (Measurement and Reporting of Transformer Losses)

- All measurement of losses shall be carried out by using calibrated digital meters of class 0.5 or better accuracy and certified by the manufacturer.
- All transformers of capacity of 500 kVA and above would be equipped with additional metering class current transformers (CTs) and potential transformers (PTs) additional to requirements of Utilities so that periodic loss monitoring study may be carried out.

ECBC Requirements: Mandatory

Energy Efficient Motors

- **Minimum acceptable nominal full load motor efficiency** not less than IS 12615 standard for energy-efficient motors
  - (All permanently wired polyphase motors of 0.375 kW or more serving the building and expected to operate more than 1,500 hours per year and all permanently wired polyphase motors of 50kW or more serving the building and expected to operate more than 500 hours per year)
- Motor **horsepower ratings shall not exceed 20% of the calculated maximum load** being served.
- Motor **nameplates shall list the nominal full-load motor efficiencies and the full-load power factor.**

ECBC Requirements: Mandatory

Energy Efficient Motors

- Motor users should insist on **proper rewinding practices for any rewound motors, or, the damaged motor should be replaced with a new, efficient one**
- **Certificates** shall be obtained and kept on record indicating the **motor efficiency.** During rewinding of motors, the core characteristics of the motor should not be lost during removal of damaged parts. **After rewinding, a new efficiency test** shall be performed and a similar record shall be maintained.

ECBC Requirements: Mandatory

Power Factor Correction

- All electricity supplies exceeding 100 A, 3 phases shall maintain their **power factor between 0.95 lag and unity** at the point of connection.

- *Benefits of Power Factor Correction*
  - *Reduced power consumption & electricity bills*
  - *Improved electrical energy efficiency*
  - *Extra kVA availability from the existing supply*
  - *Reduced I2R losses from transformer and distribution equipment*
  - *Minimized voltage drop in long cables*

- *Ways to correct the power factor*
  - *Minimize operation of idling or lightly loaded motors*
  - *Avoid operation of equipment above its rated voltage*
  - *Replace standard motors as they burn out with energy-efficient motors*
  - *Install capacitors in your AC circuit to decrease the magnitude of reactive power*

ECBC Requirements: Mandatory

Check-Metering and Monitoring

- **Services exceeding 1000 kVA** shall have permanently installed **electrical metering to record demand (kVA), energy (kWh), and total power factor.** The metering shall also display current (in each phase and the neutral), **voltage** (between phases and between each phase and neutral), and Total **Harmonic Distortion** (THD) as a percentage of total current

- Services not exceeding 1000 kVA but **over 65 kVA** shall have permanently installed **electric metering to record demand** (kW), **energy** (kWh), and **total power factor** (or kVARh)

- Services **not exceeding 65 kVA** shall have permanently installed electrical **metering to record energy (kWh)**

ECBC Requirements: Mandatory

Power Distribution System Losses

- The power cabling shall be adequately sized as to **maintain the distribution losses not to exceed 1% of the total power usage.**

- **Record of design calculation for the losses** shall be maintained.

- *Advantages of optimally sized distribution system:*
  - *Lower heat generation*
  - *Increased flexibility of installation*
  - *Reduced energy consumption and cost*

ECBC Compliance Forms

ELECTRICAL POWER (Chapter 8)							
MANDATORY PROVISIONS (Section 8.2)							
			8.2.1	Transformers	Provide schedule with transformer losses		
			8.2.2	Motor efficiency	Provide equipment schedule with motor capacity, efficiency		
			8.2.3	Power factor correction	Provide schedule with power factor correction		
			8.2.4	Check metering	Provide check metering and monitoring		

End of MODULE

- ***Introduction***
- ***Transformers***
- ***Electric Motors***
- ***ECBC Requirements***
  - ***Mandatory***
- ***ECBC Compliance Forms***

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MODULE 8: ECBC Compliance

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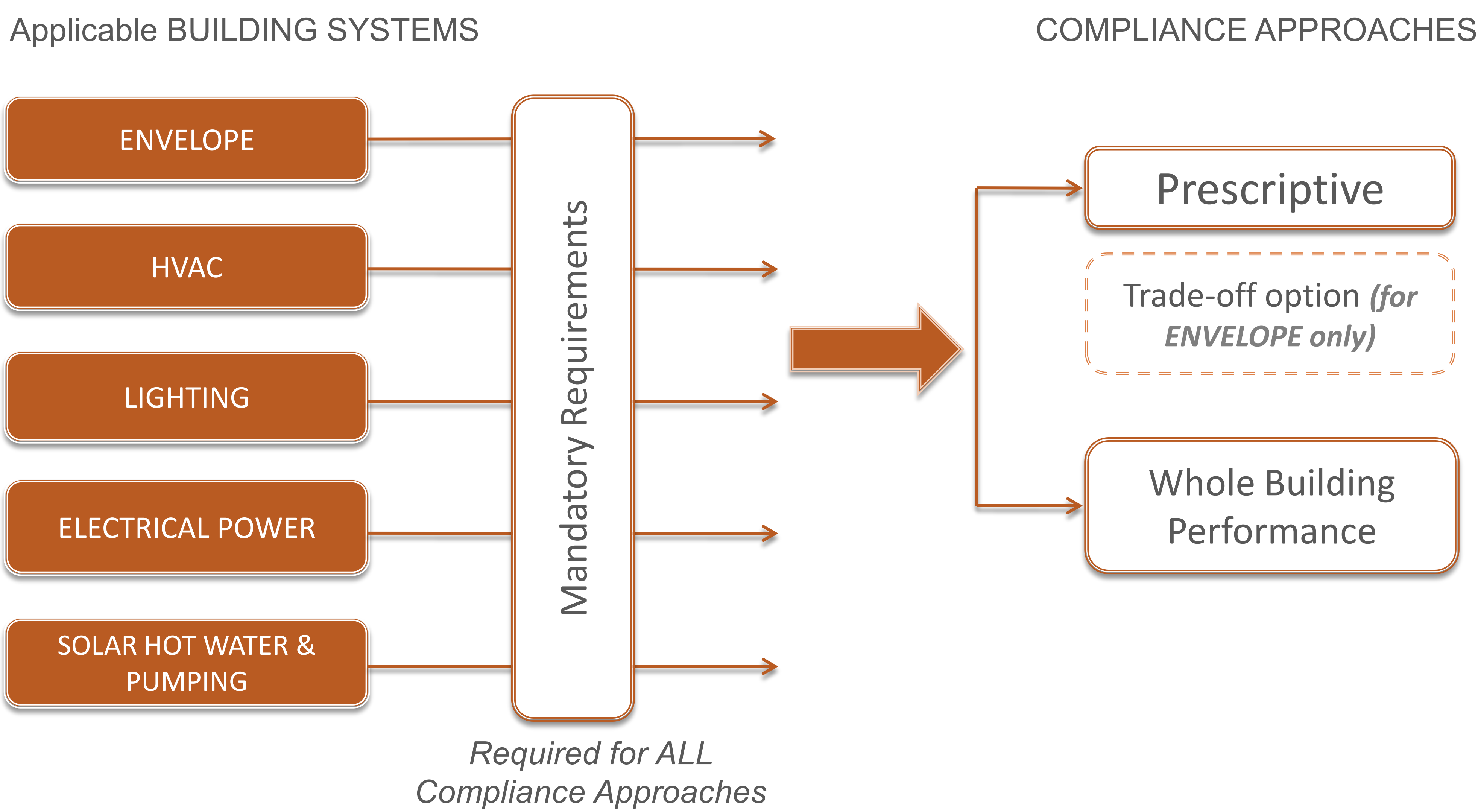
ATTRIBUTION

ECBC Compliance: Outline

- ECBC Compliance Process
  - Mandatory Requirements
  - Prescriptive Requirements
  - Trade-off Compliance
  - Demonstrating Compliance
  - Whole Building Performance (WBP) Compliance

ECBC Compliance Process



ECBC Compliance Process

Mandatory Requirements

- Must be met by all buildings

Prescriptive Requirements

- Minimum performance criteria for all building systems are set by ECBC
  Envelope performance varies according to climate zone and building occupancy type
- *Easy to follow method:* Does not require expert knowledge
  Building materials and systems chosen and specified according to ECBC requirements
- Does not allow flexibility
  All requirements must be met
- Does not involve computer simulation

ECBC Compliance Process

Mandatory Requirements

- **Building Envelope**
  - Rating and determination of U-factor & SHGC using procedures and methods as per referenced standards
  - Building sealing requirements
- **Heating, Ventilation & Air Conditioning**
  - System and equipment types, sizes, efficiencies, and controls, piping insulation; duct sealing, insulation and location & system balancing

Prescriptive Requirements

- **Building Envelope**
  - Prescribed values of U-factor, Solar Heat Gain Coefficient (SHGC), Visual Light Transmittance (VLT), Wall Window Ratio (WWR) & Skylight Roof Ratio (SRR)
- **Heating, Ventilation & Air Conditioning**
  - Economizers and Variable Speed Drives

ECBC Compliance Process

Mandatory Requirements

- **Service Hot Water & Pumping**
  - Equipment Efficiencies, Solar Hot Water Heating, Heat Traps, Piping insulation & swimming pool covers
- **Lighting**
  - Lighting controls, maximum wattage for exit lights, motion sensors for exterior lighting
- **Electric Power**
  - Transformer losses, motor efficiencies, power factor correction and electric metering and monitoring

Prescriptive Requirements

- **Service Hot Water & Pumping**
  - None
- **Lighting**
  - Maximum wattage allowance for interior and exterior lighting systems
- **Electric Power**
  - None

Trade-off Compliance

- **Applicable only to the Building Envelope. All other building systems need to follow the Prescriptive Compliance path**

- **Offers a flexible alternative to the Prescriptive Compliance of the building envelope**
  - **Involves manual calculation of the Envelope Performance Factor**
  - Envelope Performance Factor (EPF) of proposed design should be less than that of standard design, even if individual components do not comply prescriptively
  - *For example, shading devices help achieve a lower EPF by reducing SHGC*

- **Cost effective alternative for Code compliance**

Envelope Performance Factor (EPF)

$$EPF_{Total} = EPF_{Roof} + EPF_{Wall} + EPF_{Fenest}$$

$$EPF_{Roof} = C_{Roof} \sum_{S=1}^{n} U_S A_S$$

$$EPF_{Wall} = C_{Wall,Mass} \sum_{S=1}^{n} U_S A_S + C_{Wall,Other} \sum_{S=1}^{n} U_S A_S$$

$$\begin{aligned} EPF_{Fenest} = {} & C_{1Fenest,\,North} \sum_{W=1}^{n} SHGC_W M_W A_W + C_{2\,Fenest,\,North} \sum_{W=1}^{n} U_W A_W + \\ & C_{1Fenest,\,NonNorth} \sum_{W=1}^{n} SHGC_W M_W A_W + C_{2\,Fenest,\,NonNorth} \sum_{W=1}^{n} U_W A_W + \\ & C_{1Fenest,\,Skylight} \sum_{S=1}^{n} SHGC_S M_S A_S + C_{2\,Fenest,\,Skylight} \sum_{S=1}^{n} U_S A_S \end{aligned}$$

where

EPF_{Roof} : Envelope performance factor for roofs. Other subscripts include walls and fenestration.

A_s, A_w : The area of a specific envelope component referenced by the subscript "s" or for windows the subscript "w".

$SHGC_w$: The solar heat gain coefficient for windows (w). SHGCs refers to skylights.

M_w : A multiplier for the window SHGC that depends on the projection factor of an overhang or sidefin.

U_s : The U-factor for the envelope component referenced by the subscript "s"

C_{Roof} : A coefficient for the "Roof" class of construction

C_{Wall} : A coefficient for the "Wall"

$C_{1\ Fenest}$: A coefficient for the "Fenestration 1"

$C_{2\ Fenest}$: A coefficient for the "Fenestration 2"

Values of "C" are taken from Table 12.1 through Table 12.5 for each class of construction.

Demonstrating Compliance

ECBC compliance is demonstrated on plans and specifications that show all pertinent data and features of the building, equipment, and systems in detail. Details shall include, but are not limited to:

- **Building Envelope:**
  - Insulation materials and their R-values
  - Fenestration U-factors, SHGC, visible light transmittance (if using the trade-off approach), and air leakage
  - Overhang and side-fin details
  - Envelope sealing details

- **Heating, Ventilation & Air Conditioning (HVAC):**
  - Type of systems and equipment, including their sizes, efficiencies, and controls
  - Economizer details
  - Variable speed drives
  - Piping insulation
  - Duct sealing
  - Insulation type and location
  - Report on HVAC balancing

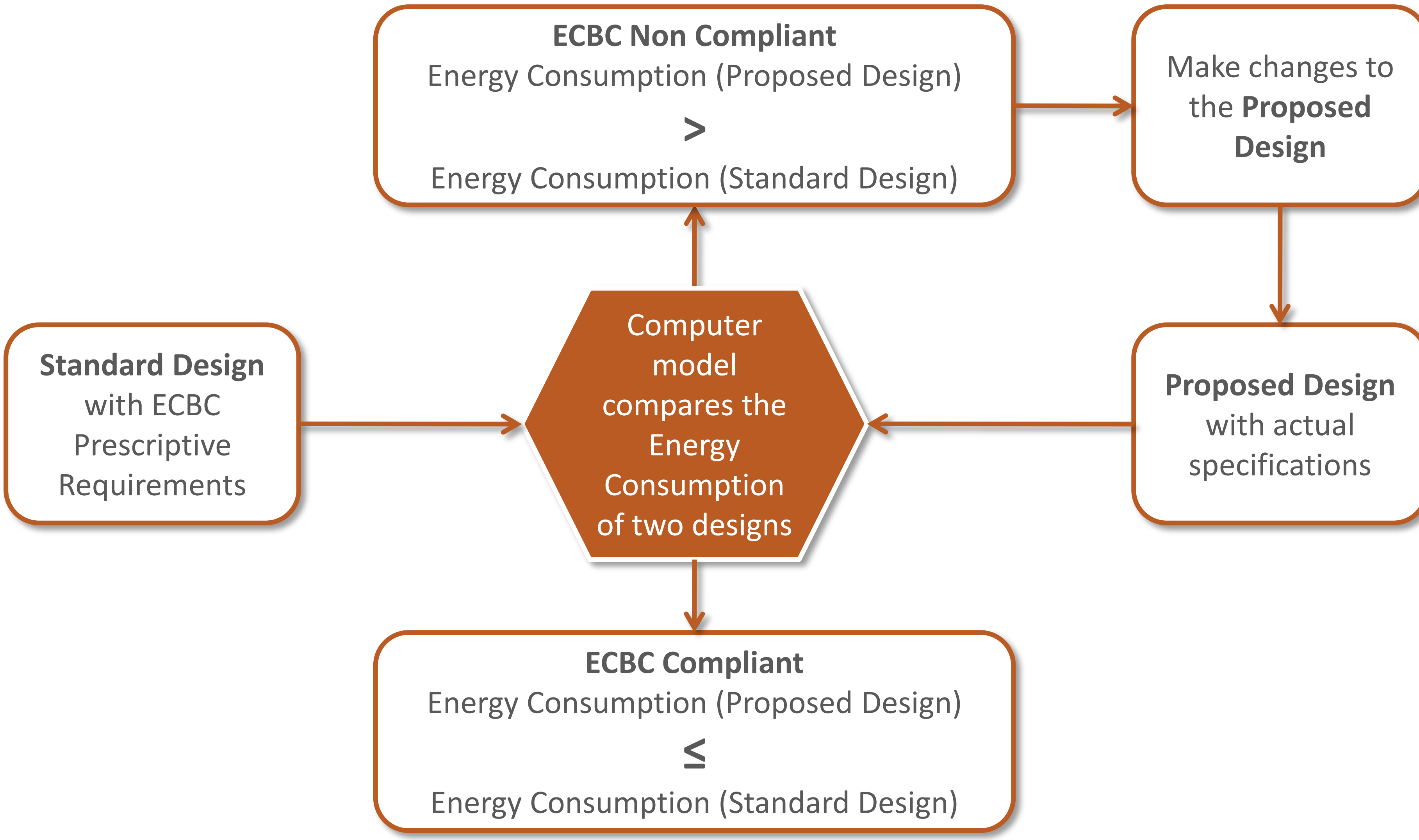
Demonstrating Compliance

- **Service Hot Water and Pumping:**
  - Solar water heating system details
- **Lighting:**
  - Schedules that show type, number, and wattage of lamps and ballasts
  - Automatic lighting shutoff details
  - Occupancy sensors and other lighting control details
  - Lamp efficacy for exterior lamps
- **Electrical Power:**
  - Schedules that show transformer losses, motor efficiencies, and power factor correction devices
  - Electric check metering and monitoring system details

Whole Building Performance (WBP) Compliance

- **WBP should be followed:**
  - When the building doesn't comply via other methods
  - To allow design flexibility/ innovation
  - To evaluate viability of alternative Energy Conservation Measures (ECMs)
- **Use of building energy simulation is necessary to show compliance with ECBC via Whole Building Performance method**
- **For Code compliance**
  - Energy Use of Proposed Design < Energy Use of Standard Design

WBP Compliance Process



SOURCE: ECBC User Guide, USAID ECO-III Project, New Delhi

End of MODULE

- ***ECBC Compliance Process***
  - ***Mandatory Requirements***
  - ***Prescriptive Requirements***
  - ***Trade-off Compliance***
  - ***Demonstrating Compliance***
  - ***Whole Building Performance (WBP) Compliance***

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