Solar Energy Utilisation in Buildings

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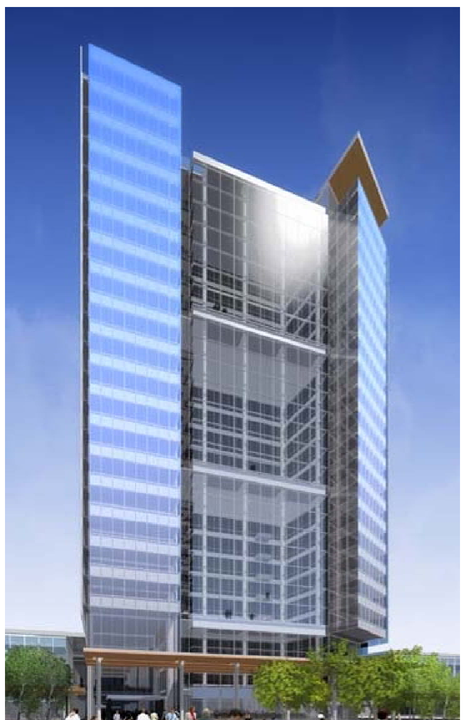
- Modern Buildings
  - Change in architectural style
  - Highly transparent façade

Ryerson Library, Toronto
1974

Quebecor, Montreal
Under-construction

- Reasons for design change
  - Architectural Expression
  - Health and Productivity of Workers
    - Natural Light beneficial
  - Energy
    - Reduce artificial lighting
    - Solar gains

Bank of America, NY
First LEED Platinum high rise



Manitoba Hydro
Energy Efficiency
Orientation
Natural Ventilation

New York Times Building

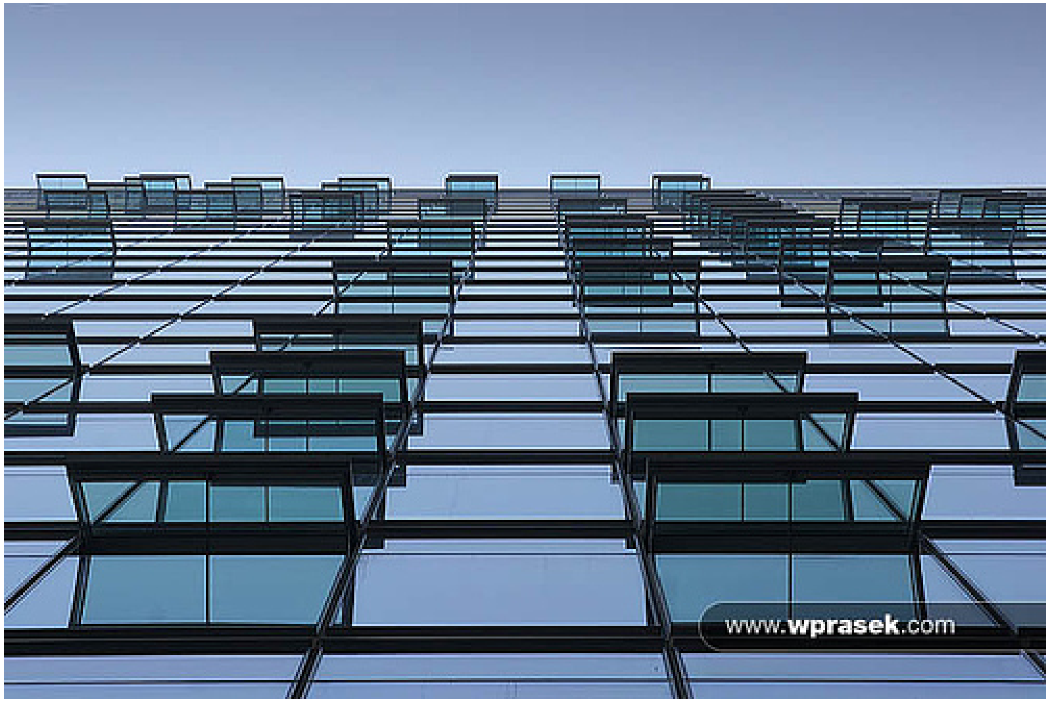
- The evolution of commercial building façades:
  - From static to active (dynamic)

Office buildings – Active / dynamic façades

- Interior/exterior automated shading systems

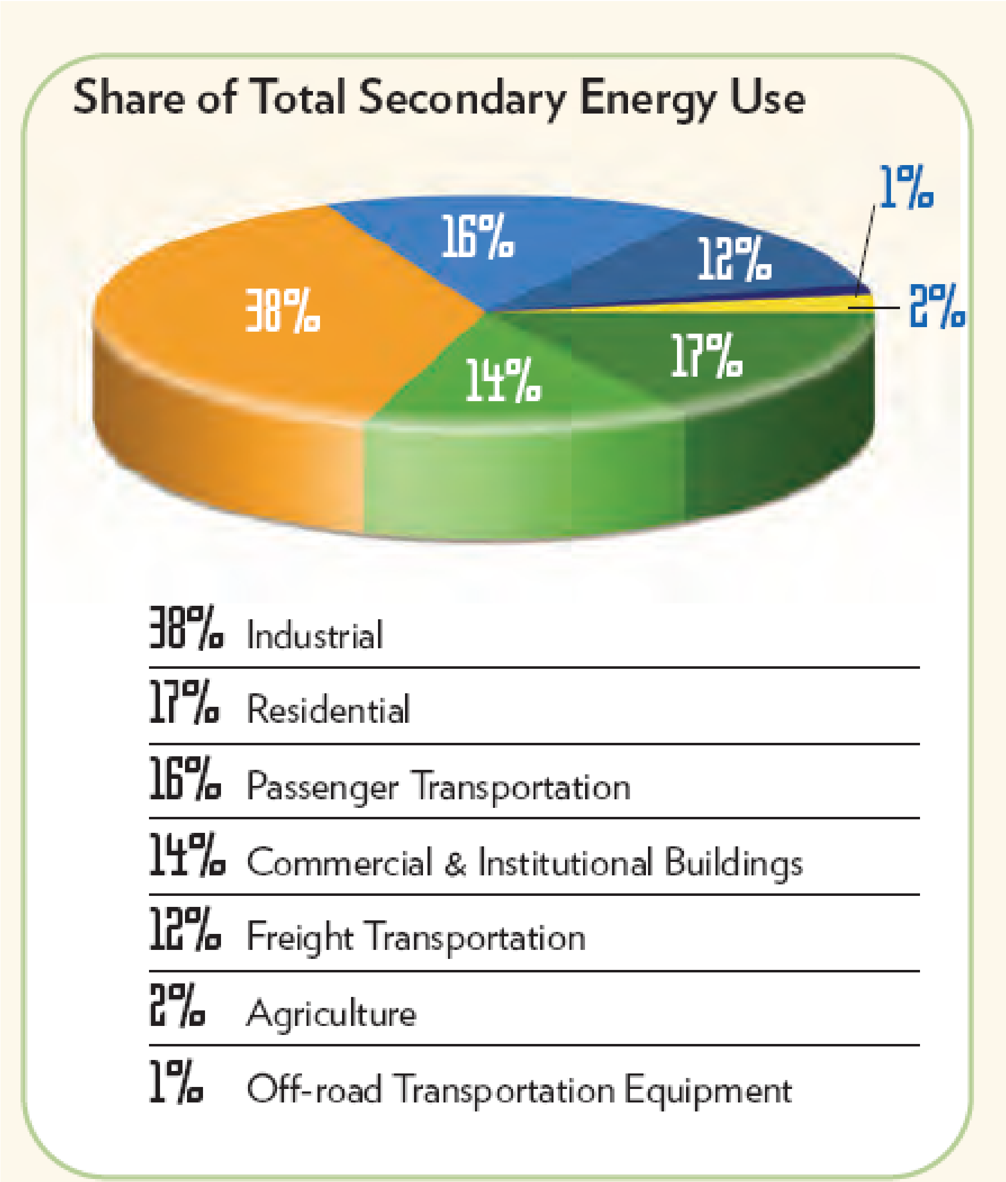
Office buildings – Active / dynamic façades

- Operable windows (motorized)



Facades with integrated semitransparent photovoltaic panels

Arise home (5 kW PV)



NRCan (2007)

- Buildings account for about 30% of Canada's energy consumption, 50% of its electricity consumption and roughly 28% of its greenhouse gas (GHG) emissions (NRCan, 2007)

Solar energy utilisation in buildings

- Renewable energy generation using radiation from the sun is carried out in two forms:
  - thermal generation, for heating air or water;
  - electric generation using Photovoltaic systems

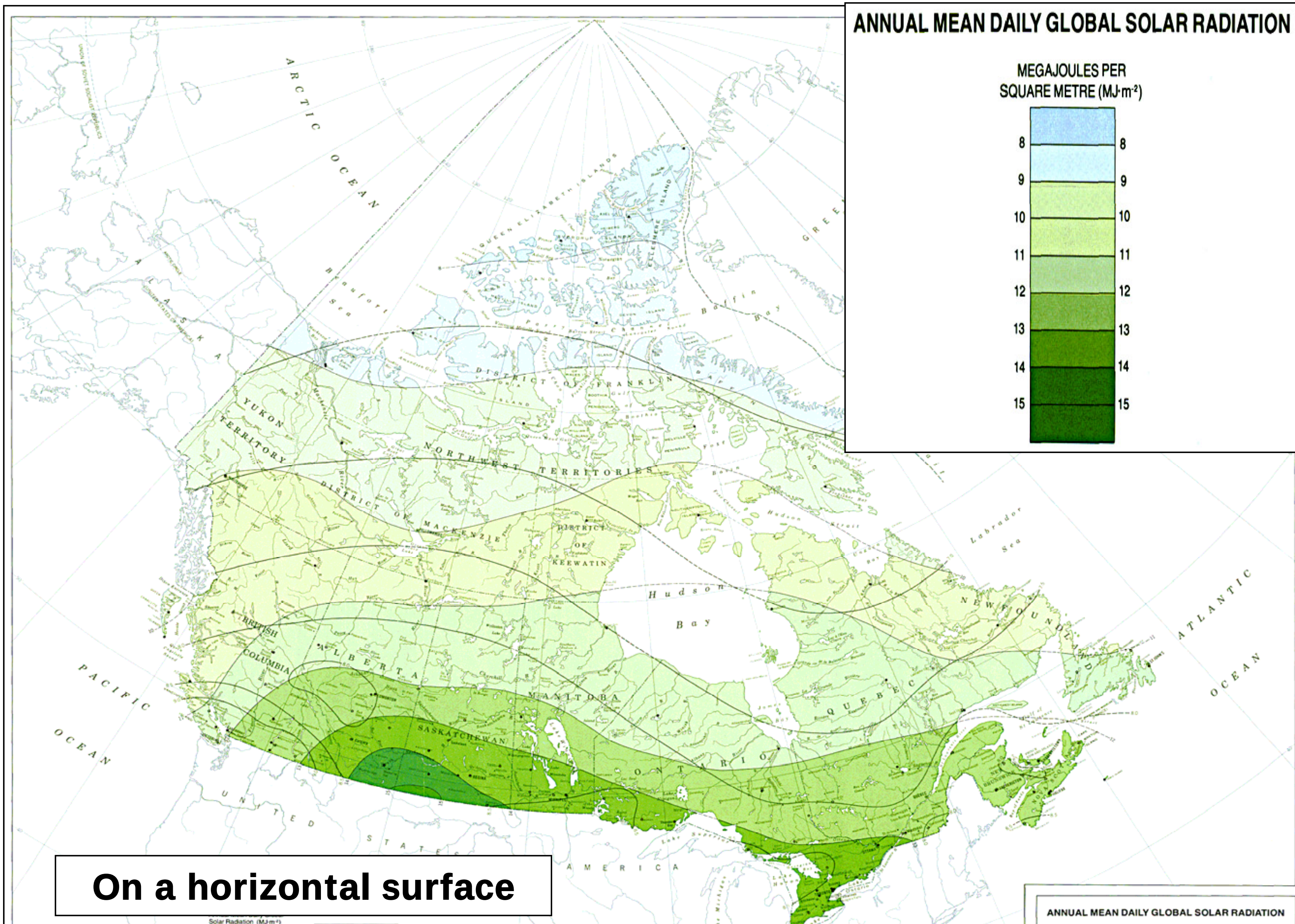
- Passive solar heating

- Integration

Where is solar energy used in buildings?

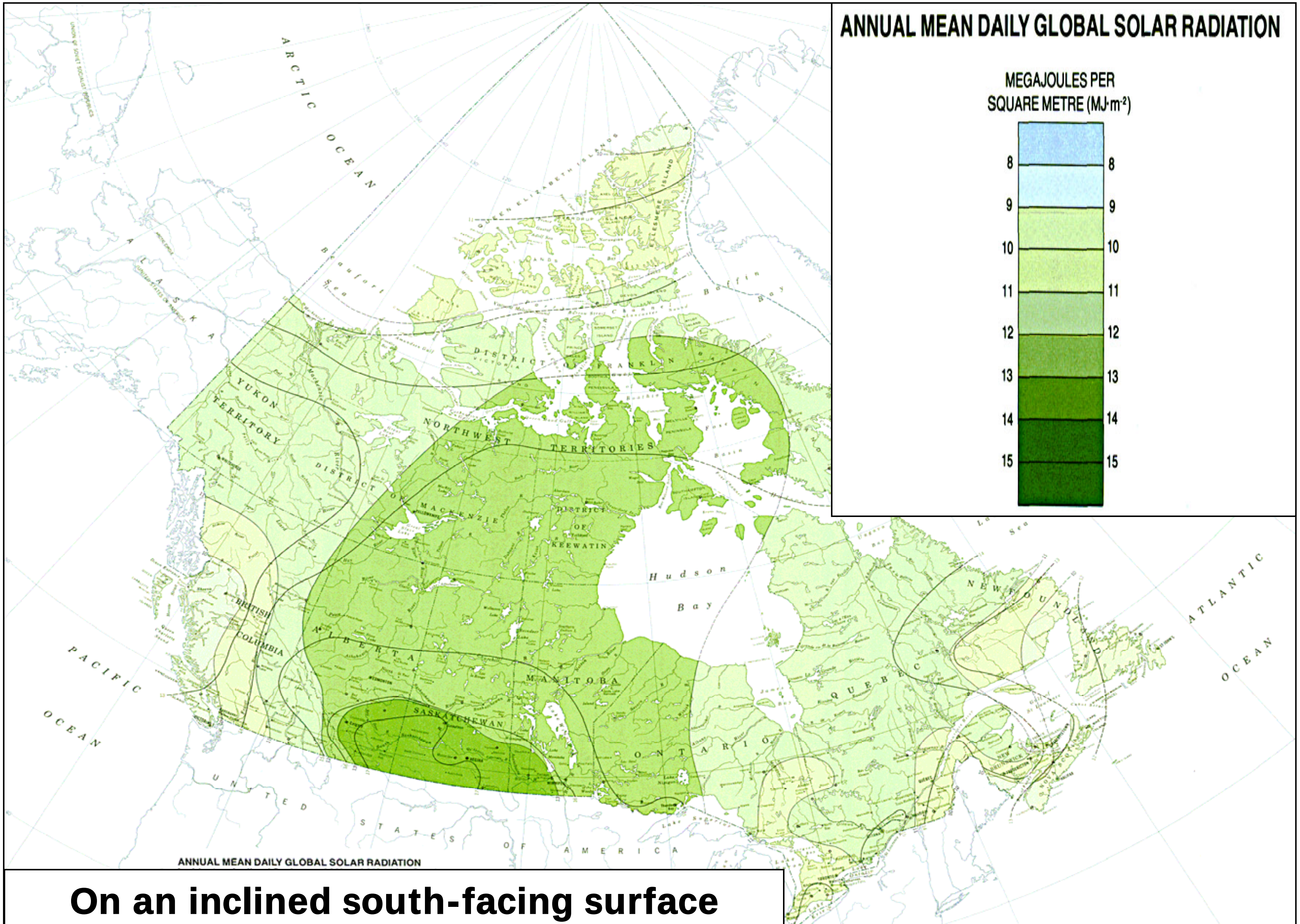
- Hot water
- Heating buildings
- Lighting (natural daylight)
- Electricity generation (photovoltaics)
- Cooling buildings (absorption/desiccant cooling)

Solar energy availability in Canada



On a horizontal surface

Solar energy availability in Canada

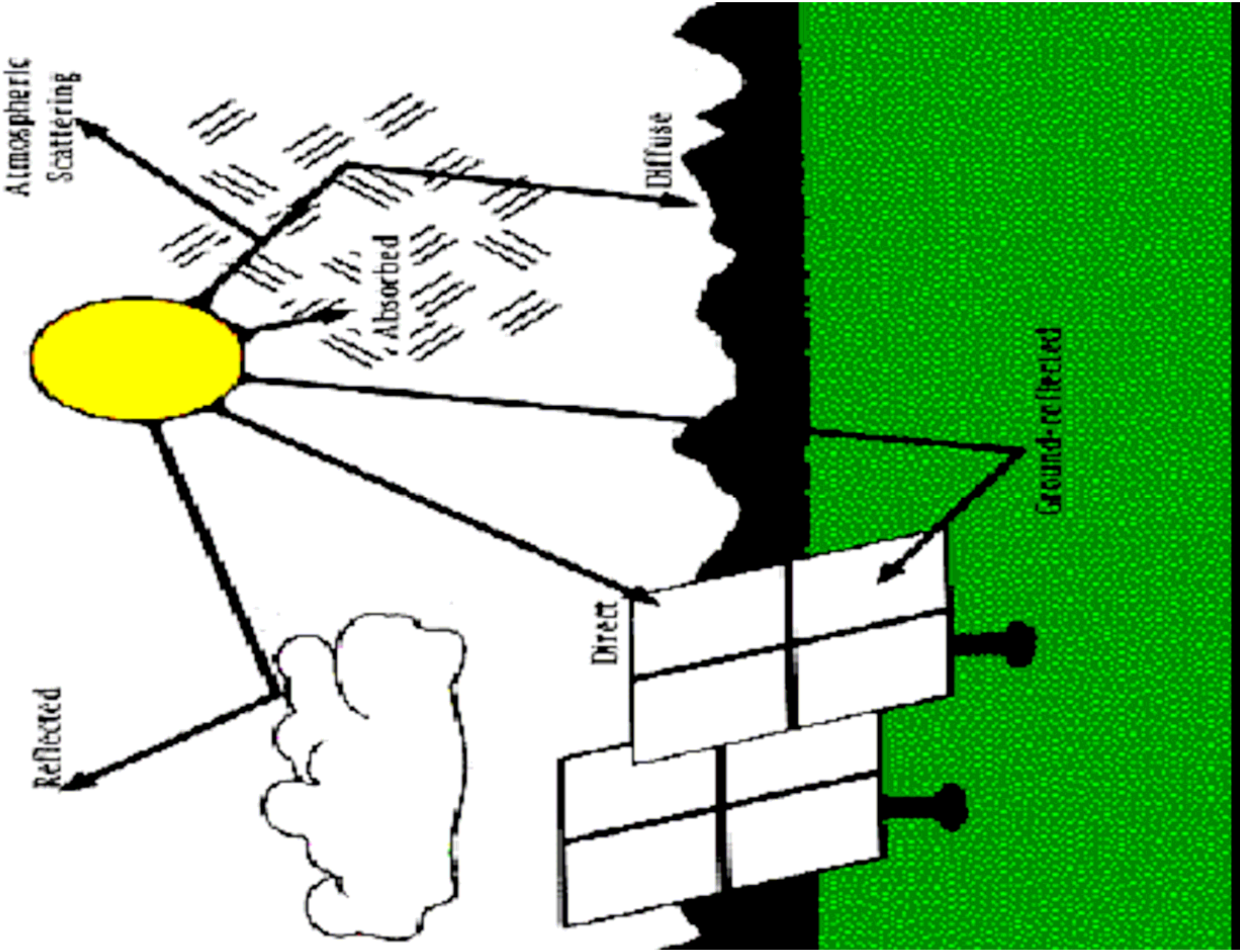


On an inclined south-facing surface

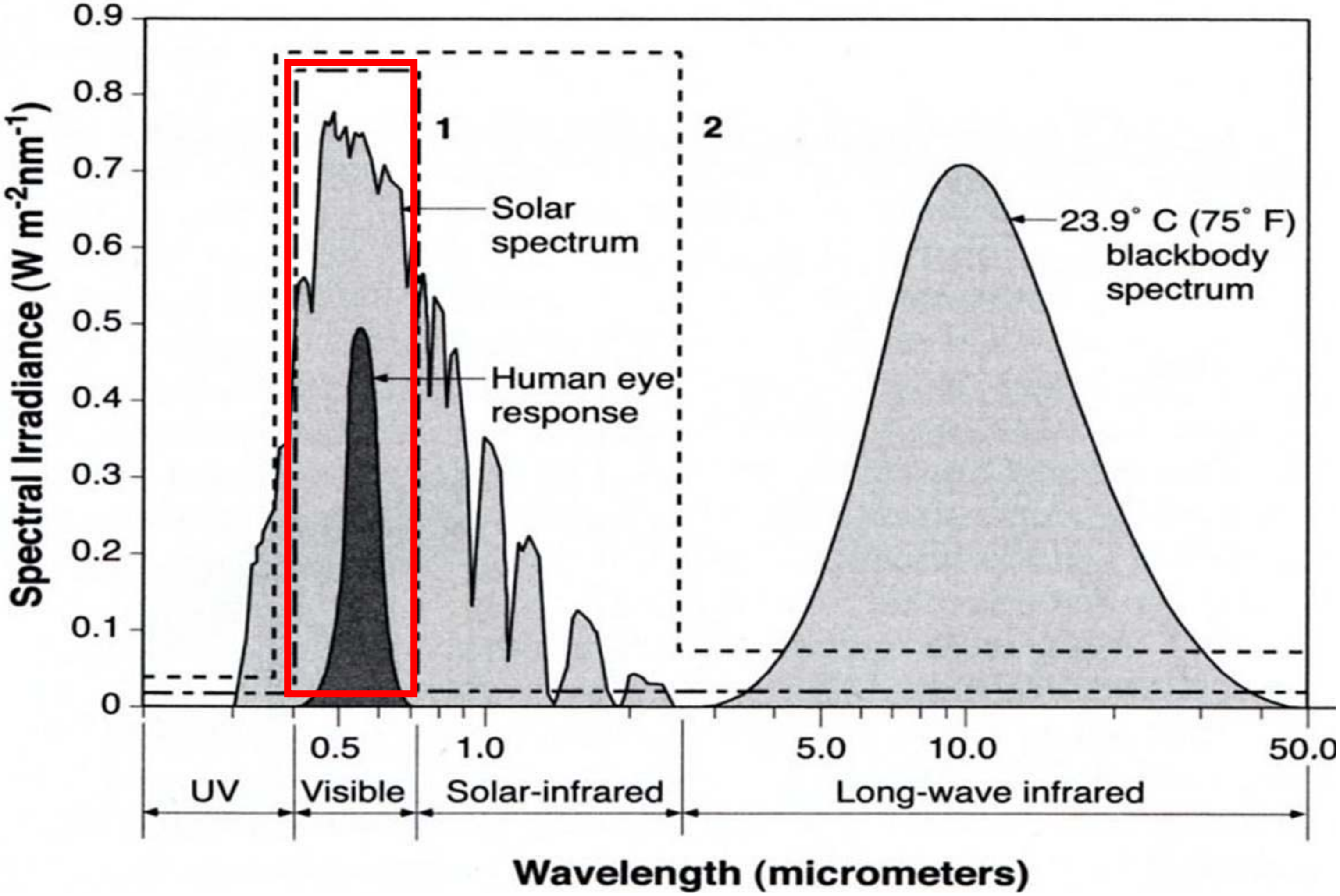
Solar radiation definitions

- Beam (direct) solar radiation: the radiation received from the sun without having been scattered in the atmosphere
- Diffuse (sky) solar radiation: the radiation received from the sun after its direction has been changed by scattering in the atmosphere
- Ground-reflected solar radiation: the radiation received from the sun after it is reflected on the ground
- Total (global) radiation: the sum of beam, diffuse and reflected solar radiation on a surface

Direct and diffuse solar radiation

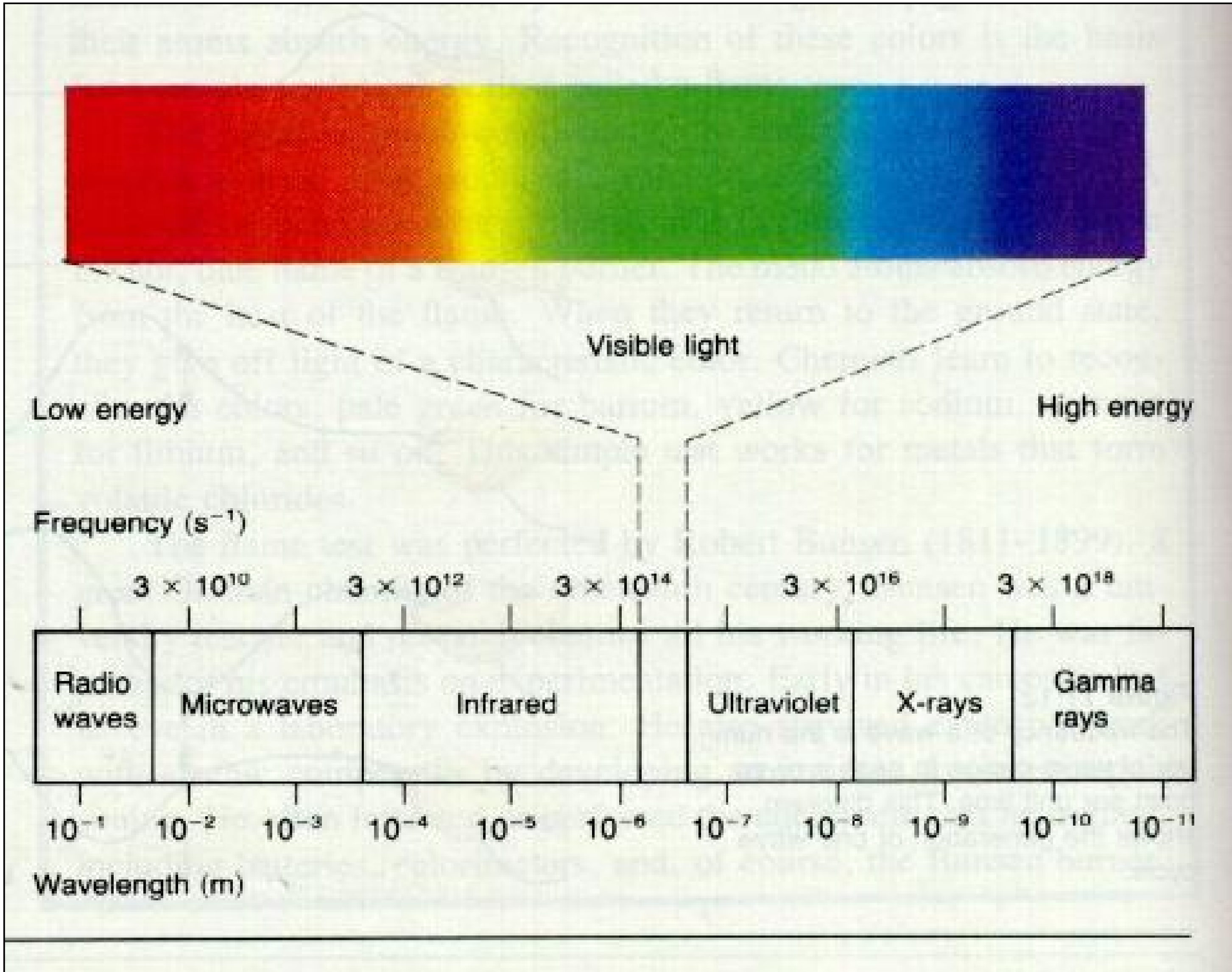


The solar spectrum



More than 42% of solar radiation is in the visible range

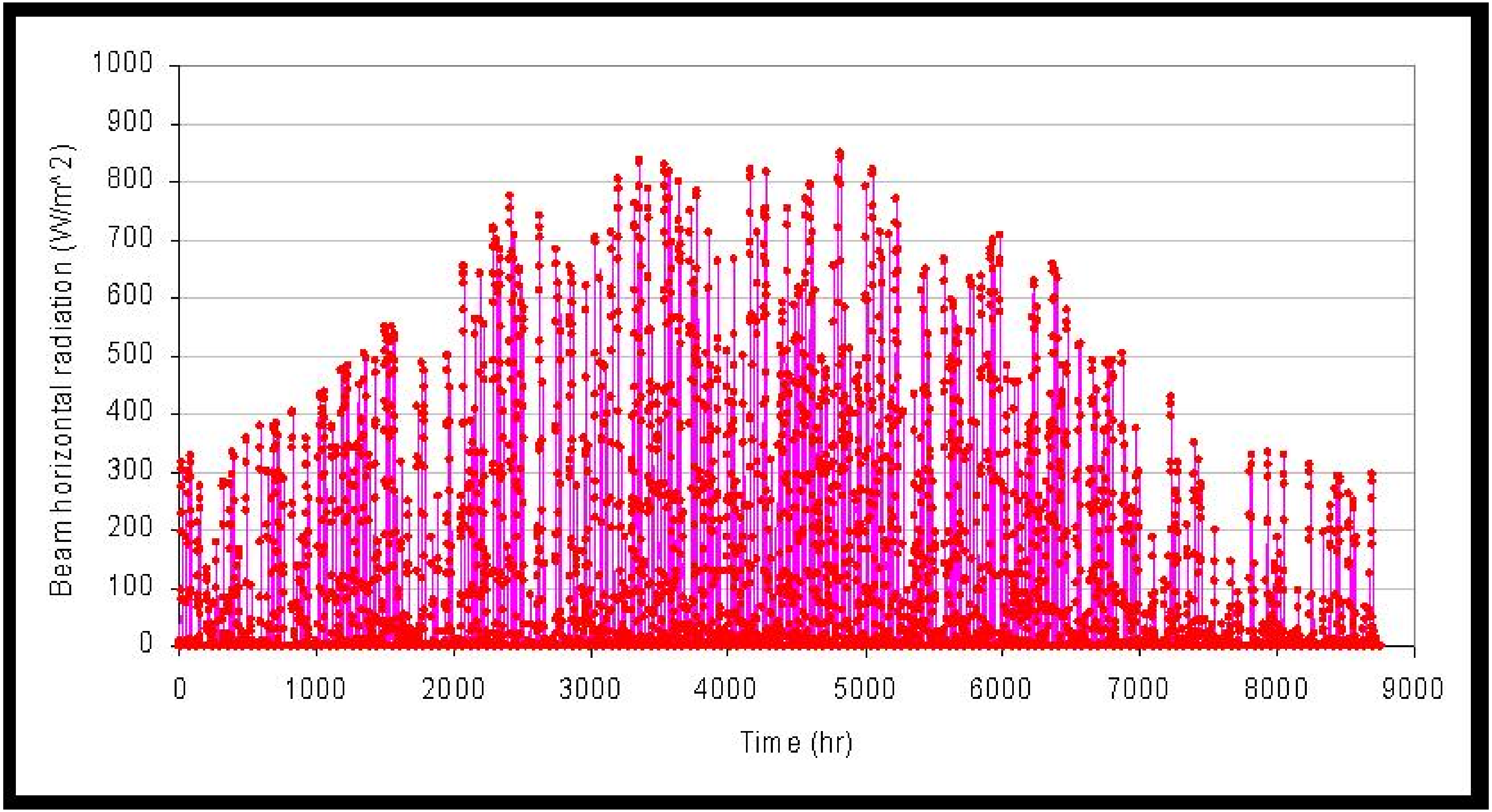
The solar spectrum



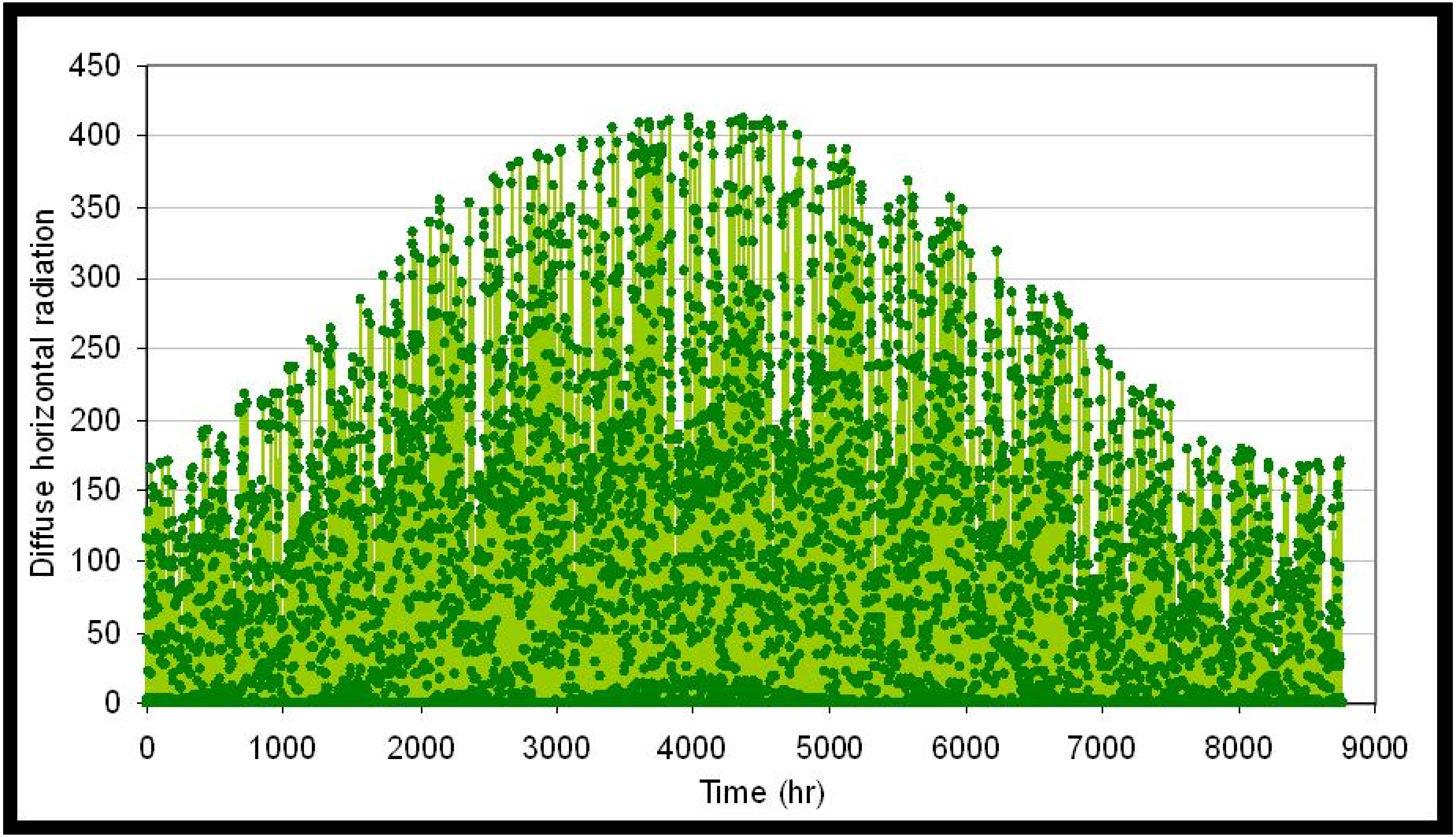
Prediction of solar radiation incident on a surface- input parameters

- Surface location (latitude, longitude)
- Solar time and solar position
- Day number in the year
- Atmospheric conditions
- Surface orientation
- Surface slope (tilt)
- Ground reflectance

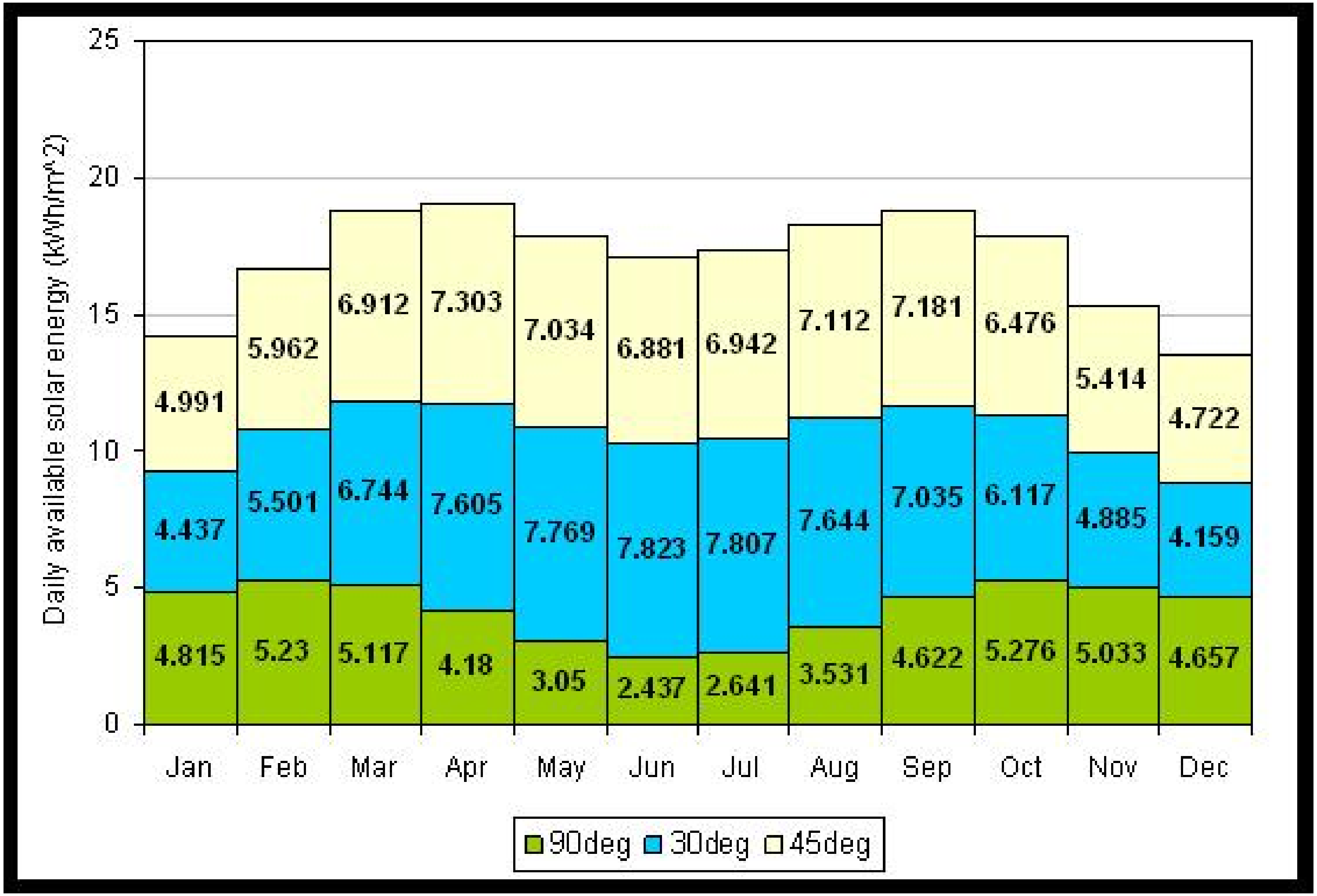
Beam horizontal radiation



Diffuse horizontal radiation

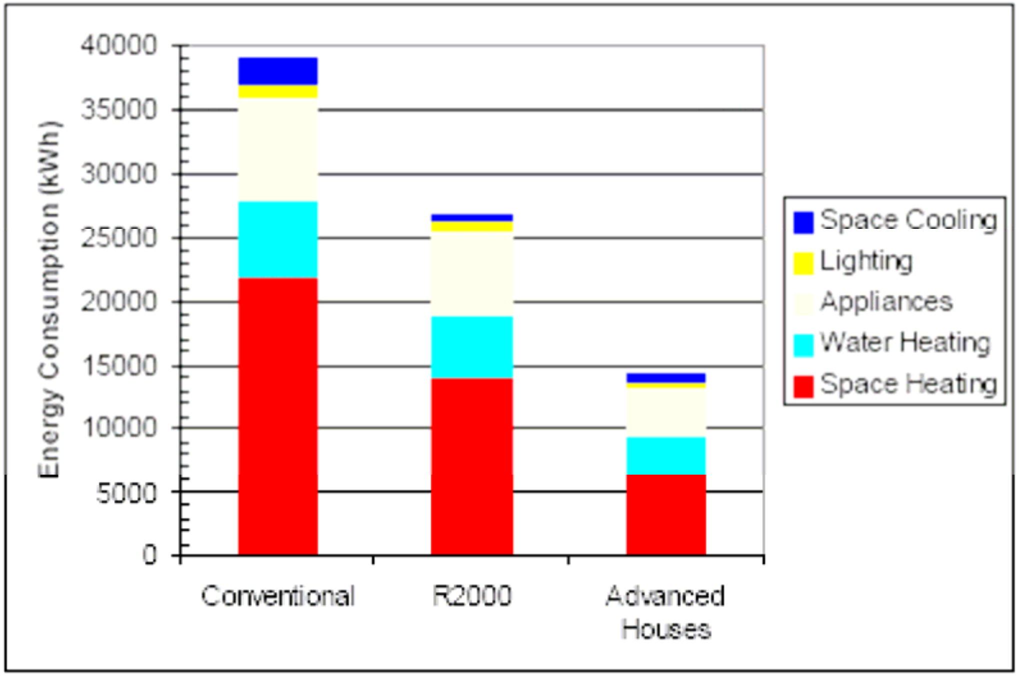


Solar energy availability - clear days kWhrs / m²



Surface tilt angle is critical

Canadian Facts



A typical Canadian home consumes yearly 25,000 kWh. Solar energy incident on 40 square metres of roof area is of the order of 50,000 kWh per year for Southern Canada.

The average annual net energy consumption of an Advanced House is in the range 46-110 kWh per square meter of floor area.

Fact: The annual solar energy incident on a roof of a typical house far exceeds its total energy consumption.

Source: Athienitis (2007)

- An average house equipped with a 4kW photovoltaic-thermal system may reduce its average energy consumption by 50%;

- A very efficient house with optimal combinations of passive solar, Building Integrated Photovoltaics (BIPV), heat pumps and smart control may approach net-zero energy consumption.

"EQuilibrium" Sustainable Housing - national housing design and demonstration initiative led by CMHC

EcoTerra Net Zero House

Alstonvale Net Zero House

Estimated annual energy consumption ~ 7000 kWh (2500 kWh for heating); Candanedo et al. (2008)

Net-zero homes: designed to produce as much energy annually as they consume.

Photovoltaic systems

- Grid-connected solar Photovoltaics (PV), that convert sunlight into electricity, continue to be the fastest-growing power generation technology in the world, with a 50 percent increase every year in cumulative installed capacity, over the past 5 years.

- It is expected that Canada will at least quadruple its grid-connected PV capacity in the next few years from its current installed capacity of about 20MW.

PV sizing

PV sizing is based on peak thermal loads plus electrical loads:

- ✓Heating
- ✓Cooling
- ✓Appliances
- ✓Lighting

Maximum energy

The maximum energy that can be generated by the PV system depends on:

- Size of PV panels
- Efficiency of PV panels
- Placement and tilt
- Orientation
- Solar energy availability
- Combination of other technologies (PIBV/T)

Example calculation of electricity generated

Sunny day – 700 W/m^2 on roof

Roof area: 50 m^2

Efficiency of PV panels: 10%

Electricity produced: 700 W/m^2 * 50 m^2 * 0.1 = 3500 W = 3.5 kW

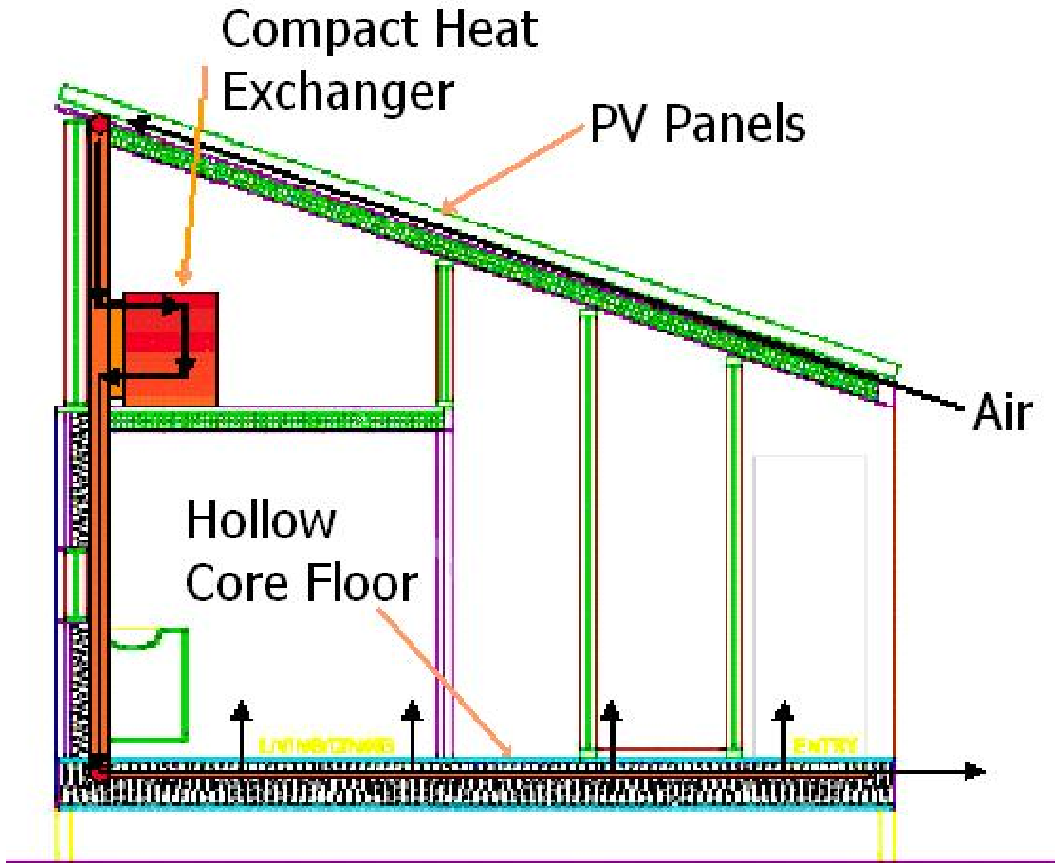
Canadian facts

- Typical Canadian home consumes yearly 25,000 kWh. Solar energy incident on 40 square metres of roof area is of the order of 50,000 kWh per year for southern Canada.
- On most houses it is easy to find a surface on the roof or façade about 40 sq. m. to install a 3-5 kW PV system.

Roof slope is critical

Building integrated-photovoltaic thermal systems (BIPV/T)

- Generate electricity and heat
- Maximize combined solar energy utilization



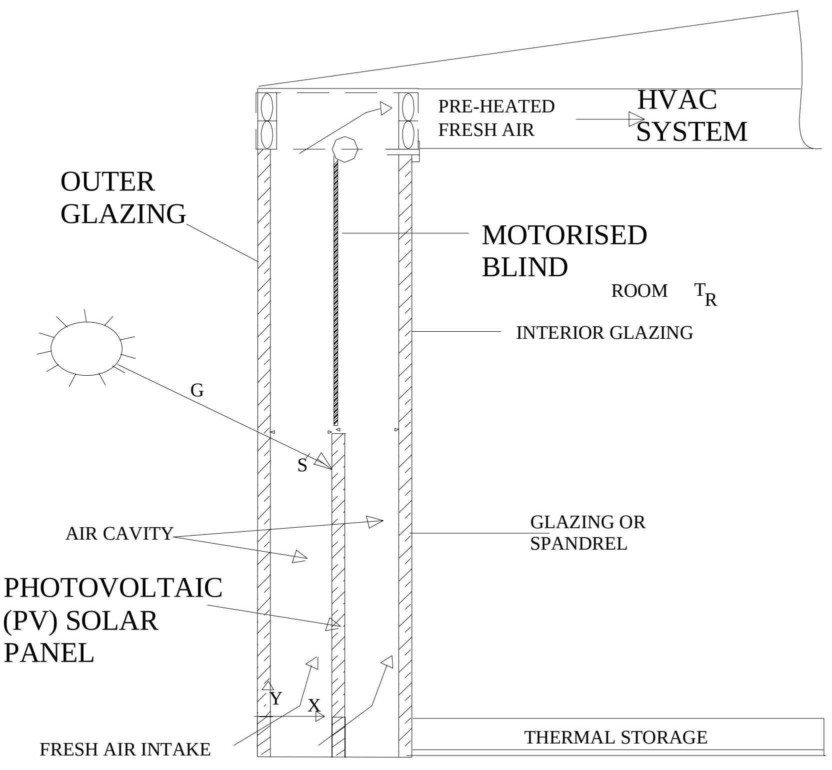
Source: Pasini and Athienitis (2006)

Building-integrated PV

- Building-integrated does not mean simply PV on roof
- PV panels are nicely and effectively integrated in the building envelope
- Redesign the components in an innovative manner to develop the solar building as an optimized system
- Effective integration of electricity, heat and daylighting is ideal

BIPV/T façade concept

- A facade or roof surface facing between southeast and southwest in Montreal receives 4-6 kWh/m^2 on a clear day in March
- PV systems can convert between 10-18% into electricity
- 20-60% can heat air or water
- 10-30% may be utilized for daylighting



Tzempelikos et al. (2007)

Potential benefits – Office buildings

- Building integrated renewable energy systems allow for the construction of buildings that can provide their own heat and electricity, while relying less on external sources.

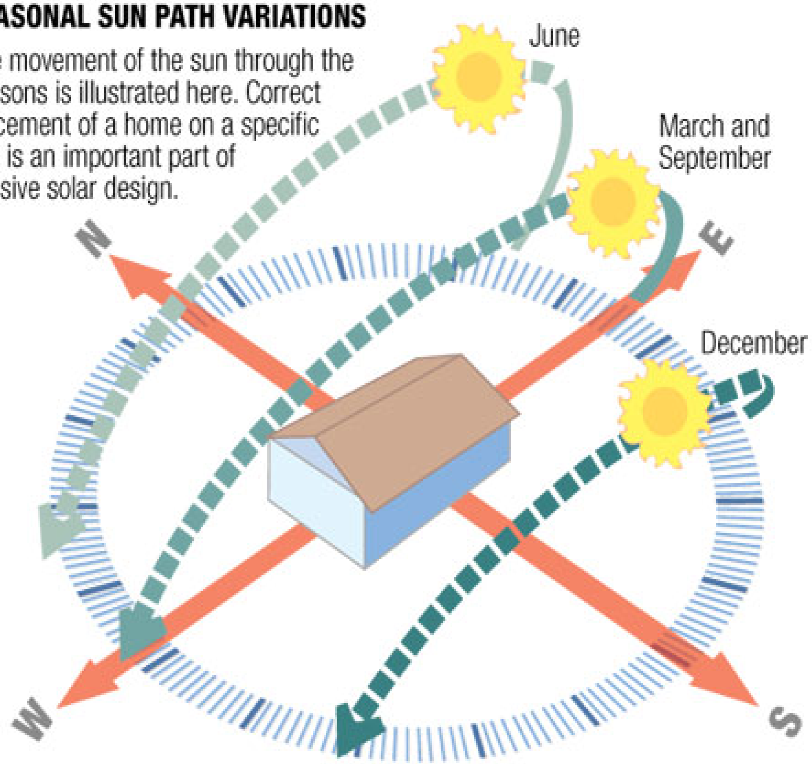
- Aside from the obvious environmental benefits associated with using renewable solar energy, the ability to generate heat and electricity at the site of consumption eliminates the cost and inefficiencies inherent in off-site generation. These include electric line transmission losses, and the energy required to pump oil and compress natural gas.

ENERGY: **PASSIVE SOLAR DESIGN IN WISCONSIN**

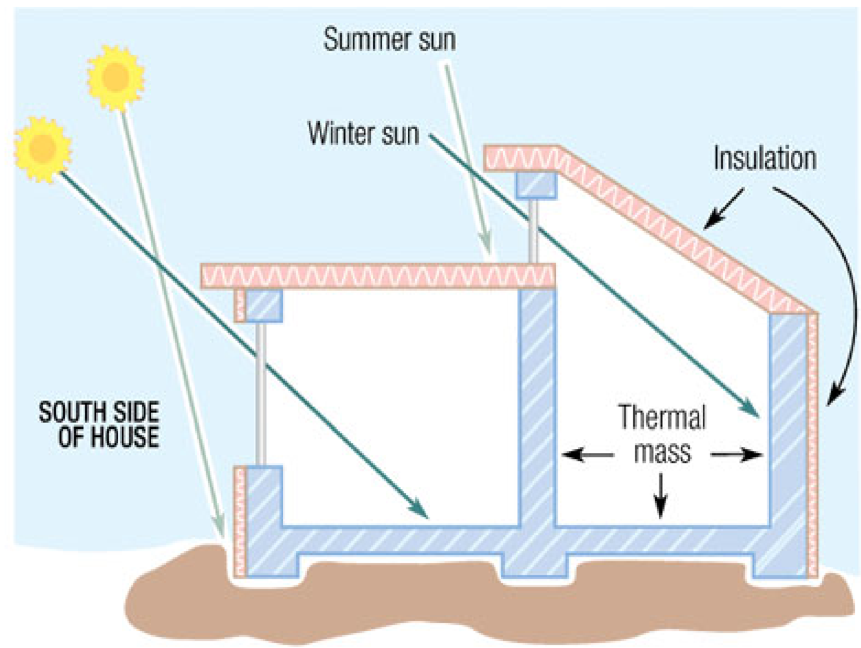
Homes with large windows on the south side generally are more energy efficient, solar power proponents say. Homeowners who don't take this into account waste money and energy, they say.

SEASONAL SUN PATH VARIATIONS

The movement of the sun through the seasons is illustrated here. Correct placement of a home on a specific site is an important part of passive solar design.



SUN ANGLES AND SHADING



Passive solar design takes advantage of the differing positions of the sun in summer and winter. The winter sun can enter the windows and be soaked up by the thermal mass of walls and floors. In summer, overhangs at the windows keep the sun's heat out.

Source: Focus on Energy

BOB VEIERSTAHLER/rveierstahler@journalsentinel.com

Solar energy utilisation in buildings

- Renewable energy generation using radiation from the sun is carried out in two forms:
  - thermal generation, for heating air or water;
  - electric generation using Photovoltaic systems
- Passive solar heating
- Integration

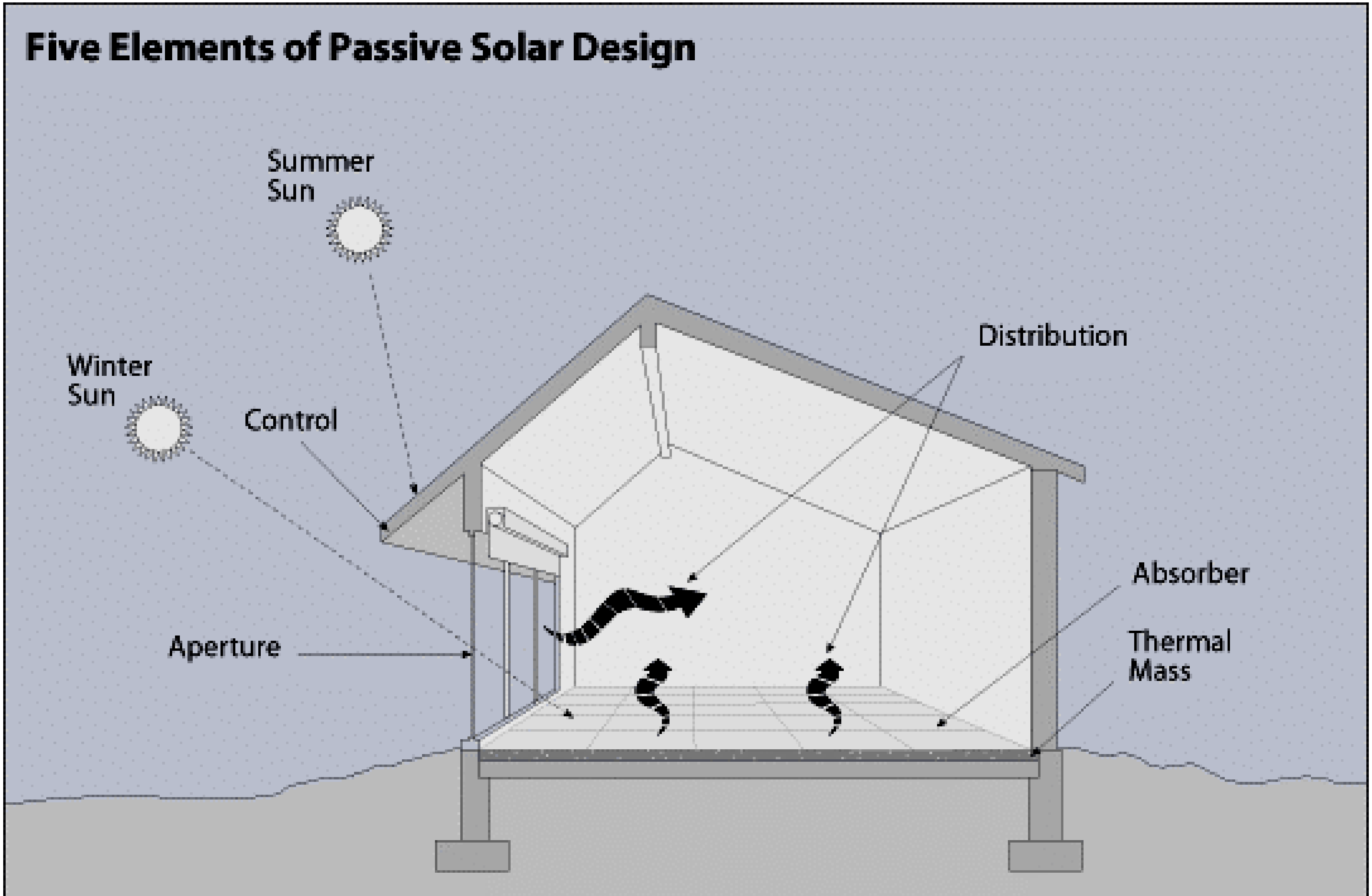
Introduction to passive solar design

- The goal of passive solar design is to collect and use energy from the sun to reduce the energy consumption while maintaining a comfortable environment.

- Solar energy is not an alternative to other strategies, such as energy conservation and energy-efficient heating systems, but a complement to them.

- However, careful attention to the principles of passive solar design is required to prevent overheating, excessive air conditioning, discomfort near glass and condensation on window panes.

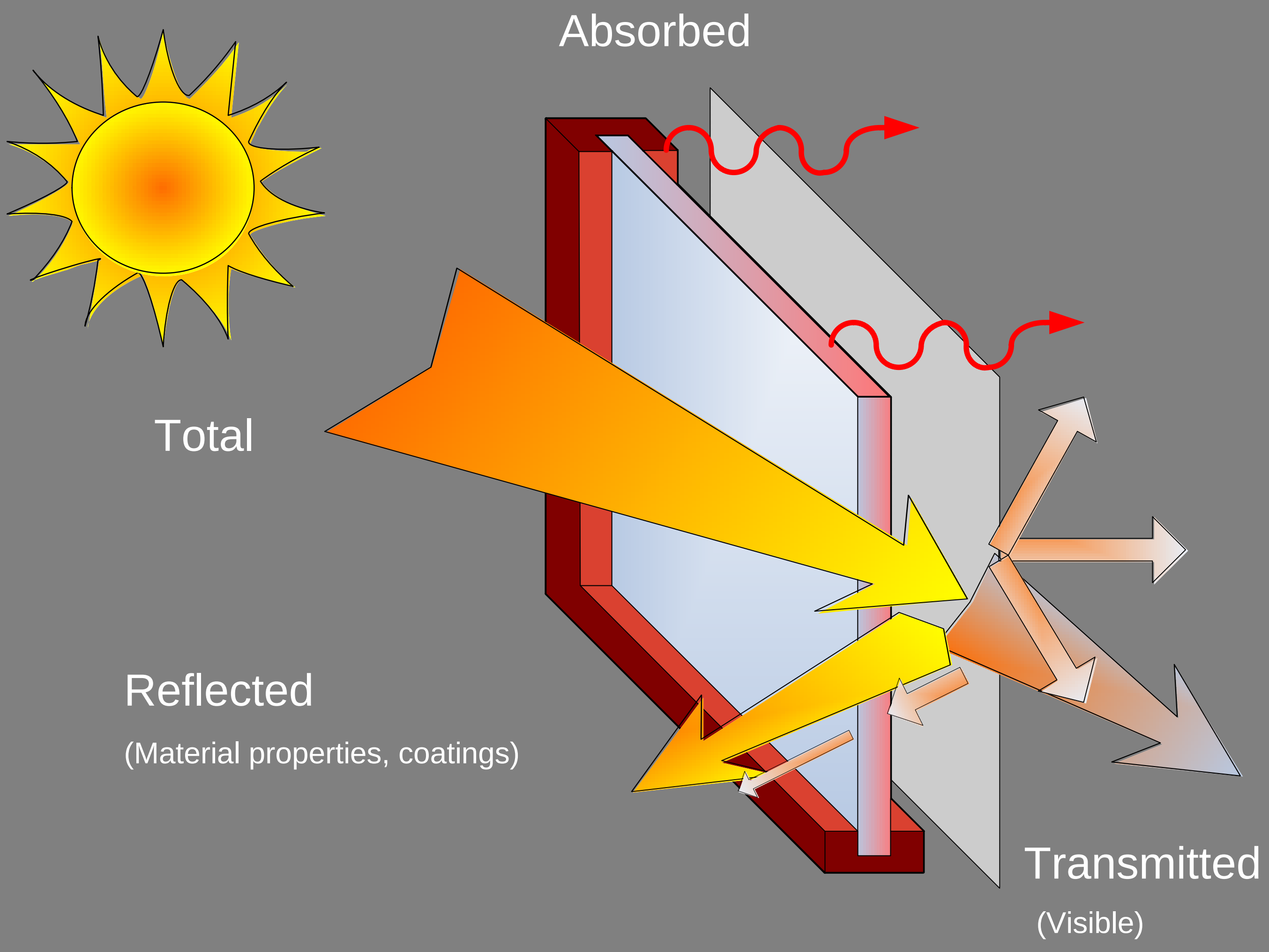
Elements of passive solar design



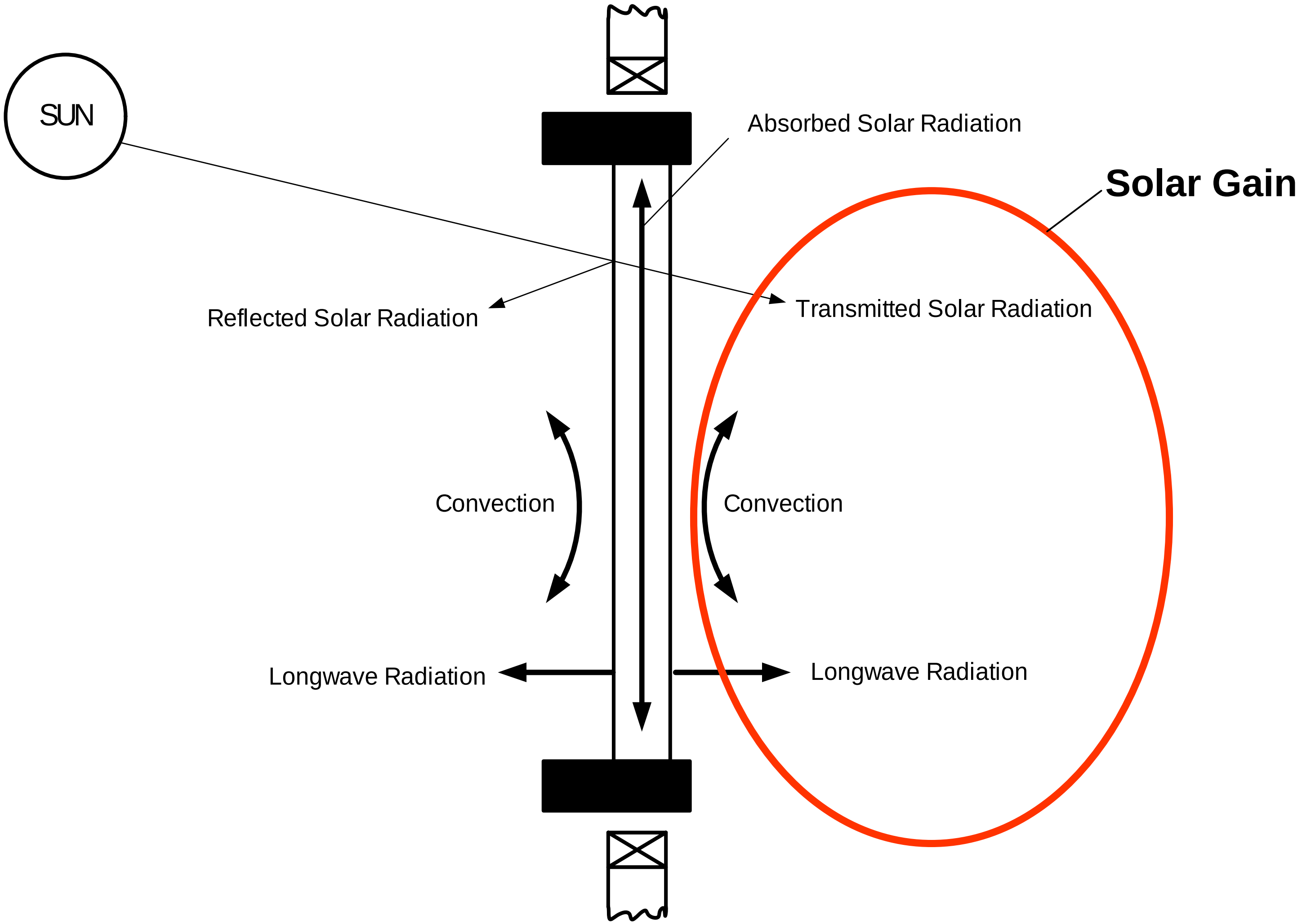
Elements of passive solar design

- Large aperture on south façade
- Minimum glass on north façade, little on west
- Use clear glass for maximizing daylight with low thermal conductance and low-e coatings for less heat losses.
- Place exposed thermal mass near big windows, on the floor.
- Do not use carpets/furniture above thermal mass.
- Have good air circulation.
- Provide good insulation and protect from air leakage.
- Efficiently control excessive solar gains during the summer (shading control).

Fenestration



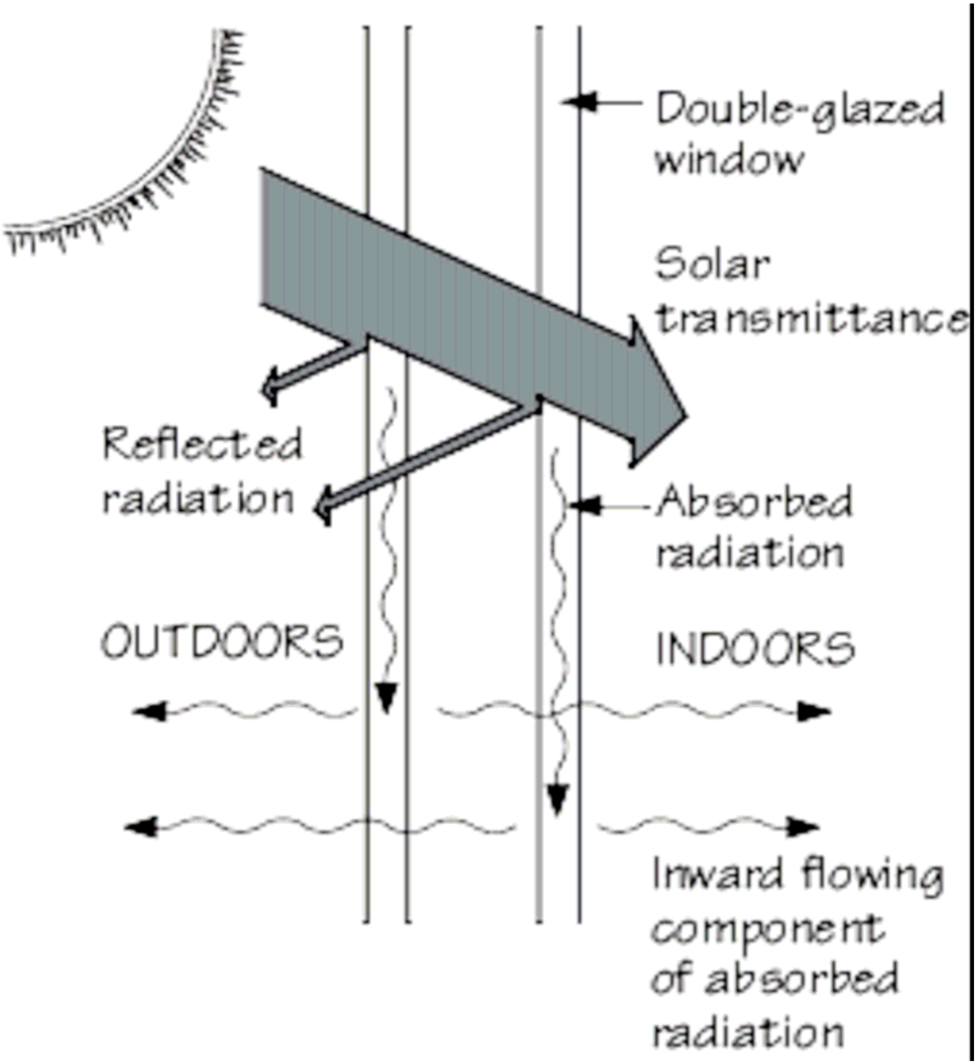
Solar radiation on windows -thermal impact



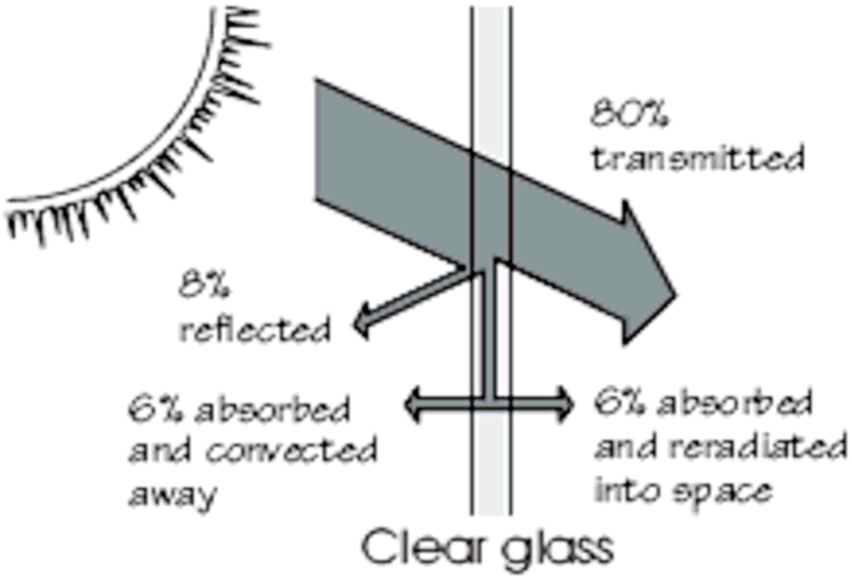
Glazing basic properties

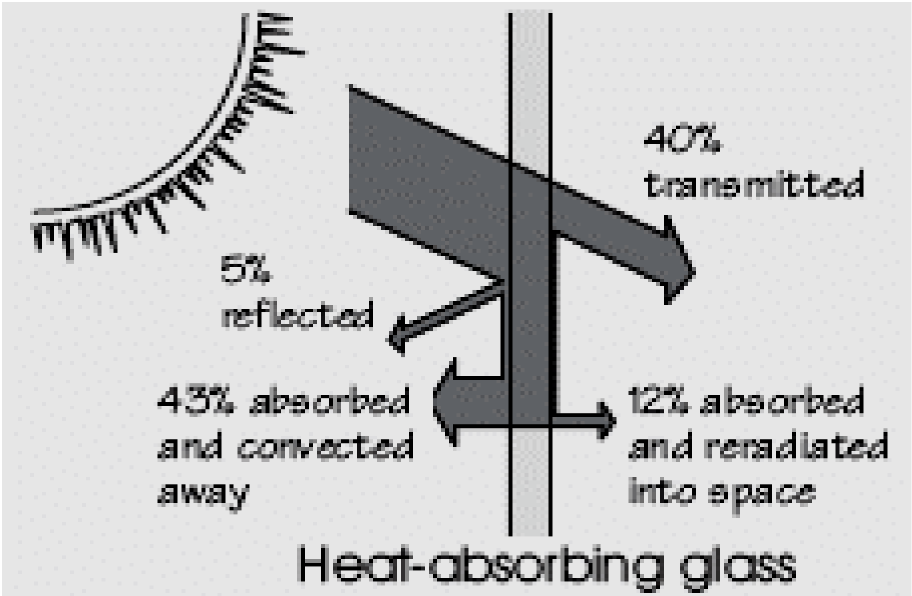
- Transmittance
- Reflectance
- Absorptance

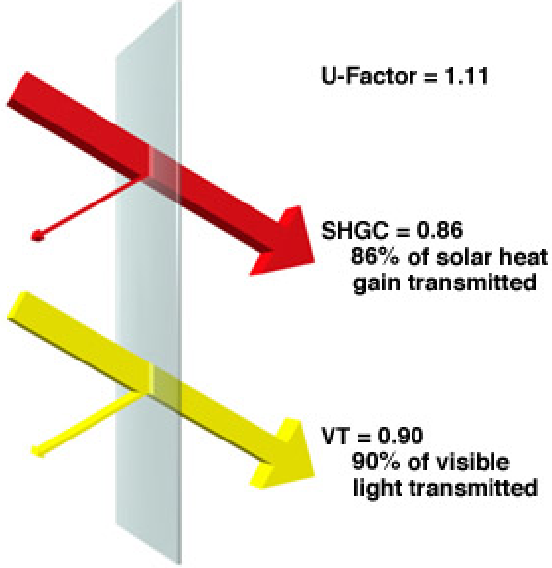
Depend on wavelength

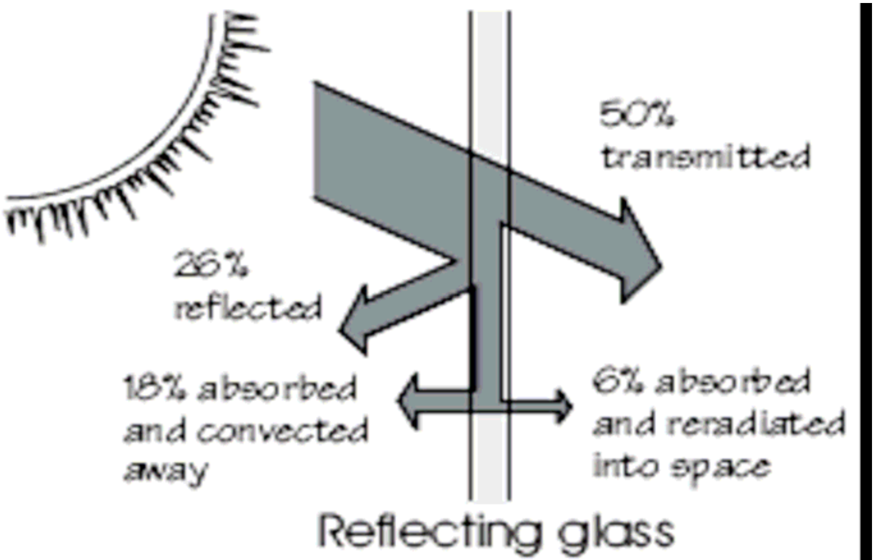


Glazing typical properties









Radiation

- Opaque objects absorb 40%–95% of incoming solar radiation from the sun, depending on their color—darker colors typically absorb a greater percentage than lighter colors.
- Inside a home, infrared radiation occurs when warmed surfaces radiate heat towards cooler surfaces. For example, your body can radiate infrared heat to a cold surface, possibly causing you discomfort. These surfaces can include walls, windows, or ceilings in the home.
- Clear glass transmits 80%–90% of solar radiation, absorbing or reflecting only 10%–20%. Although glass allows solar radiation to pass through, it absorbs the infrared radiation. The glass then radiates part of that heat back to the home's interior. In this way, glass traps solar heat entering the home.

Window/Glazing properties

U-factor

The rate at which a window, door, or skylight conducts non-solar heat flow - measured in W/(m^2 C)

- For windows, skylights, and glass doors, a U-factor may refer to just the glass or glazing alone. National Fenestration Rating Council U-factor ratings represent the entire window performance, including frame and spacer material.
- The lower the U-factor, the more energy-efficient the window, door, or skylight.

Typically 2.5 W/m^2C

Window/Glazing properties

Solar heat gain coefficient (SHGC)

- A fraction of solar radiation admitted through a window, door, or skylight—either transmitted directly and/or absorbed, and subsequently released as heat inside a home.
- The lower the SHGC, the less solar heat it transmits and the greater its shading ability.
- A product with a high SHGC rating is more effective at collecting solar heat gain during the winter.
- A product with a low SHGC rating is more effective at reducing cooling loads during the summer by blocking heat gained from the sun.
- Factors: climate, orientation, and external shading.

Solar heat gain through fenestration

- Total instantaneous heat gain:

$$q_t = \underbrace{SC \times SHGF}_{\text{solar gain}} - \underbrace{U\,(t_o - t_i)}_{\text{heat loss}}$$

- Where:
  - SC = Shading Coefficient (from tables)
  - SHGF = Solar Heat Gain Factor
  - U = thermal conductance of fenestration unit
  - temperature difference

Shading coefficients

TABLE 9.4

Shading Coefficients for Some Glazing Units
(From Stephenson, D.G., Canadian Building Digest 101, Table 1, DBR/NRCC, 1968) [**9.6**]

Type of Window	Shading coefficient (SC) No shade	With curtain Min.	With curtain Max.	With venetian blind
Single glazing				
Clear sheet glass	1.00	0.45	0.65	0.55
Regular plate glass	0.95	0.45	0.65	0.55
Heat-absorbing plate	0.70	0.40	0.50	0.47
Double glazing				
Regular plate Air space Regular plate	0.83	0.40	0.60	0.50
Heat-absorbing plate Air space Regular plate	0.55	0.33	0.43	0.36
Regular plate-reflective Air space Regular plate	0.25	—	—	—

Hutcheon, 1995

Solar Heat Gain Factor

- depends on:
  - latitude
  - times of year
  - times of day
  - orientation of receiving surface

Solar Heat Gain Factor

(SHGF)

TABLE 9.5

Solar Heat-Gain Factors, W/m², for 45°N Latitude
(From Stephenson, D.G., *Tables of solar altitude, azimuth intensity and heat gain factors,* NRCC 9528, 1967) [**9.3**]

January 21	North	East	South	West	Horizontal
08:00	8	199	137	8	17
09:00	29	422	454	29	111
10:00	42	358	646	42	222
11:00	50	177	756	50	299
12:00	53	57	792	57	326
13:00	50	50	756	177	299
14:00	42	42	646	358	222
15:00	29	29	454	422	111
16:00	8	8	137	199	17
Daily totals, W • h/m²	312	1346	4798	1346	1628

July 21	North	East	South	West	Horizontal
05:00	32	71	5	5	9
06:00	117	472	38	38	119
07:00	83	651	68	63	286
08:00	87	679	107	82	454
09:00	97	606	209	97	595
10:00	107	457	318	107	704
11:00	114	252	394	114	772
12:00	116	126	420	126	795
13:00	114	114	394	252	772
14:00	107	107	318	457	704
15:00	97	97	209	606	595
16:00	87	82	107	679	454
17:00	83	63	68	651	286
18:00	117	38	38	472	119
19:00	32	5	5	71	9
Daily totals, W • h/m²	1360	3785	2700	3785	6664

Ottawa: 45˚24'
Toronto: 43˚40'

Hutcheon, 1995

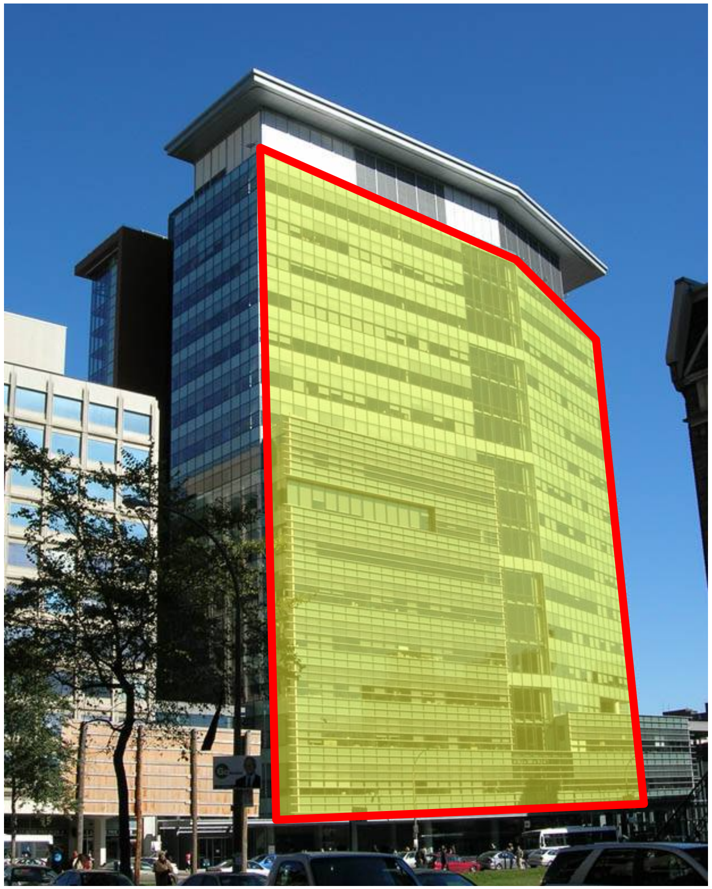
Solar Heat Gain - example

Find the solar heat gain at 10:00 solar time for January 21st for a window on a south wall at 45˚N (Northern hemisphere). The window is double glazing, regular plate.

- From table: SHGF = 646 W/m^2
- From table: SC = 0.83
- Solar heat gain = SHGF x SC = 646 x 0.83 = 536 W/m^2

- Find the total heat gain, if the temperature difference between indoors and outdoors is 45˚C
  - U = 2.8 $W/m^2 \cdot C$
  - Heat-transmission loss = U x (t_o – t_i) = 2.8 x 45 = 126 W/m^2
  - TOTAL HEAT GAIN: 536 – 126 = 410 W/m^2

Example : Solar Heat Gain


EV building – Concordia University

- Orientation
  - Near south
  - Area ~ 3,120 m^2
- Annual Incident Solar Energy
  - ~1150 kW-hr / m^2 (CANMET)
- Assume
  - Perfect coatings (only visible ~ 42%)
  - 75% visible transmittance
  - 66% glazed
- Energy
  - 800 MW-hr / yr
    - At peak periods

Control this Energy!

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Useful solar radiation information

www.satel-light.net

Illuminance and irradiance data for every map pixel in Europe and elsewhere

Environment Canada

http://www.climate.weatheroffice.ec.gc.ca

Climate normals, averages and online data

EnergyPlus website:

http://www.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm