Light and Energy in action…
DAYLIGHTING IN BUILDINGS

Gillian Isoardi
Applied Optics Group
School of Physical & Chemical Sciences
QUT
Light as Waves

- Electric field and Magnetic field components
- Electric field most significant in interactions with materials
- Transverse wave
  \[ \lambda: \text{wavelength} \]
  \[ f: \text{frequency} \]
  \[ v: \text{velocity} \]
Electromagnetic radiation
The eye as a detector

- Light travels: object → cornea → aqueous humor → lens → vitreous humor → retina
- Receptors on retina detect light and send signal through optic nerve to brain
The eye as a detector

• Cones
  – Less sensitive to light
  – 3 types (red, green, blue) \(\rightarrow\) colour vision

• Rods
  – More sensitive to light
  – One type
The eye as a detector

• Note
  – Blind spot
  – Cones concentrated in centre of retina
  – Rods dominate peripheral vision

Distribution of the rods and cones in the retina.
The eye as a detector
Solar Spectrum

Image ref: http://www.easthorse.net/cm/spectrum.htm
Daylighting

- Using sunlight and skylight to light, or enhance the lighting of, an interior space.
Why Daylight

• To save energy (to reduce electricity consumption)
  – Environmental benefit
  – Economic benefit
• To create attractive interior spaces
  – Human factors benefit
• To meet building codes, standards or rating schemes
Daylight and schools

- **2003 study**: ~ 8000 students in over 450 classrooms
  - Ample and pleasant **views** consistently associated with positive performance
  - **Glare** from windows associated with reduced performance

- **1999 study**: students with the most daylight in their classrooms progressed:
  - 20% faster on math tests and
  - 26% faster on reading tests

- Students in classrooms with the largest window areas were found to progress:
  - 15% faster in math and
  - 23% faster in reading
Benefits of Daylighting

• **Reduction in electricity usage**
  – Dim electric lights
• **Lower operating costs**
  – Less total power consumed
• **Improvement in aesthetic appeal**
  – View + external link
  – Health and comfort
• **Environmental Benefits**
  – Less electricity → less CO₂
Possible negative effects

• **Glare**
  – Direct sunlight in field of view

• **Excess Heat**
The sun + glass = greenhouse
Greenhouse Effect

- Glass transmits Visible + Near Infrared
- Inside... Visible + Near Infrared absorbed and Visible + Far Infrared reflected (FIR ~ heat)
- Since glass does not transmit Far Infrared, it is trapped inside
A possible solution: “Cool” Window Glass

- Filters out UV and IR
- Allows Visible radiation to pass
- Same amount of light but less heat

Selective Absorbers
  - blue-green tints

Selective Reflectors
  - modified low-E coatings
  - coated glass and plastic

Transmittance vs. Wavelength
Emerging Technology: Electrochromic Windows

Switchable thin-film coating on glass
Electrochromic (Smart) Windows

- Control the Transmission of a window with a switch!
- Electric potential and current create chemical change in the glass film
Scattering in the Earth’s Atmosphere

• Why is the sky blue during the day?
  → Blue scatters the most
Absorption in the Earth’s Atmosphere

• Why is the sunset sky redder?
  ➔ Blue is most strongly absorbed
Measuring light

• **Illuminance**: the amount of light falling on an area
  – Unit of **lux**
  – Typically experienced values:
    • Sunlight at midday 120,000 lux
    • An office desk 320 lux
    • Moonlight (full moon) 0.2 lux
Black body radiators

Black body \( \rightarrow \) absorbs all energy incident and then reradiates all energy absorbed

examples:
- a poker in a fire
- the sun (or any star)
Colour Temperature of daylight

For an interesting applet on Colour Temperature, see:
http://micro.magnet.fsu.edu/primer/java/colortemperature/index.html

Table 2.1: Colour temperature of various sources including skylight

<table>
<thead>
<tr>
<th>Source</th>
<th>Colour Temperature (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incandescent</td>
<td>2 850</td>
</tr>
<tr>
<td>White Fluorescent</td>
<td>3 000</td>
</tr>
<tr>
<td>Cool White Fluorescent</td>
<td>4 100</td>
</tr>
<tr>
<td>Overcast sky</td>
<td>7 000</td>
</tr>
<tr>
<td>Blue Sky</td>
<td>10 000 +</td>
</tr>
<tr>
<td>Sun</td>
<td>See graph below</td>
</tr>
</tbody>
</table>

Figure 2.1: Graph showing diurnal variation in Indicative Exterior Illuminances (klx) due to sunlight (shown on vertical axis) and Colour Temperature of sunlight (shown in comment boxes).
Comparing the sun to other light sources

Image ref: http://micro.magnet.fsu.edu/primer/lightandcolor/lightsourcesintro.html
A simple spectroscope

- Can be made with a box and diffraction grating (e.g. a CD)

See also: http://www.advancedaquarist.com/2006/7/aafeature/view
# Efficacy of Daylight

<table>
<thead>
<tr>
<th>Source</th>
<th>Typical Luminous Efficacy (lm/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incandescent</td>
<td>12 – 25</td>
</tr>
<tr>
<td>Compact Fluorescent</td>
<td>40 – 60</td>
</tr>
<tr>
<td>Linear Fluorescent</td>
<td>70 – 95</td>
</tr>
<tr>
<td>Sunlight</td>
<td>80 – 120</td>
</tr>
<tr>
<td>Skylight</td>
<td>150 +</td>
</tr>
</tbody>
</table>
A dynamic light source

Image ref: www.squ1.org
Earth’s orbit – Equinox and Solstice
e.g. Brisbane (latitude $-27.5^\circ$)
Getting the light in the building: Light Transport

By reflection…
Light Shelves

- Useful for shading
- Not effective at light redirection
- Reflective surface requires cleaning
Lightshelves: UK and US

BRE Building, UK

SMUD Building, CA
Louvre and Blind Systems

- Variety of configurations
- Shading and some light redirection
Getting the light in the building:
Light Transport

By total internal reflection…
Prismatic Glazing

- For shading or sunlight redirection
- Colour dispersion
- Can cause glare
Sun Directing Glazings

• Sun redirection and shading
• Designed for moderate solar angles
• Increase illuminance and improve distribution
Light Pipes

- Can allow sunlight to access core areas of building
Light pipes

• Sun collector – heliostat (must track sun)
  – Can be made in an electronics experiment using diodes

• Pipe system
  – Can use reflective shaft
  – More efficient total internal reflection
    • Optic fibres
    • Water filled pipes
Fibre optic cables

- If light beamed into a fibre internal reflects off the sides at an angle greater than the critical angle, the light is totally internally reflected. Thus there is no loss of energy when the beam reflects off the glass/air interface.
Fibre optic communications

- Glass fibre can be used to channel a beam of light over a very large distance (80 – 140 km for a single mode fibre before regeneration is required).
- Losses occur within glass (exponential attenuation), repeaters used to boost the signal.

West coast to east coast fibre optic cable passing Taylorville (near Wakerie), in South Australia

Single mode fibre 9 μm diameter
Bandwidth > 1 Terabit per second
- 125 Gbytes per second ≅
- 18 movie DVDs per second!
- 18 million simultaneous phone calls
  (Enough for all adult Australians to talk on the phone!)
My research project…

Design, manufacture and testing of a light redirecting device for vertical windows.
Obstacles to Daylighting a Commercial Building

- Deep, open plan offices + Vertical windows =
  - *daylight penetration less than office depth*
  - *bright perimeter zone and dim core areas*

- Must control heat gains and glare
How to achieve the benefits of daylight (while avoiding negative effects)

- Redistribute daylight away from perimeter
  - Shades occupants
  - Increases daylight at core
  - Balances spatial distribution of light (uniformity)
The proposed device

- Acrylic panel with air cavities to redirect sunlight

- Features
  - curved reflecting surface
  - total internal reflection
  - similar size to conventional glazing
The proposed device

Light redirecting panel in clerestory

Manual shade control system on view window
What is required for success?

- Sunlight redirected towards ceiling and deep into the room (exiting at low angles above horizontal)
- Glare avoided (no light exiting below horizontal and into occupants’ field of view)
- Consistent over all solar angles
Ray tracing Investigation