Thermal Analysis of NIR Reflecting Cover Glass for Outdoor Displays

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Overview

Motivation

- LCD outdoor displays are becoming increasing common in applications including:
  - Drive through menu boards
  - Transportation hub information kiosks
  - Retail locations
- Outdoor displays must be ruggedized to protect against:
  - Precipitation and moisture
  - Freezing temperatures
    - Causes the display to slow or freeze
  - High heat
    - Degrades the liquid crystal matrix and electronics

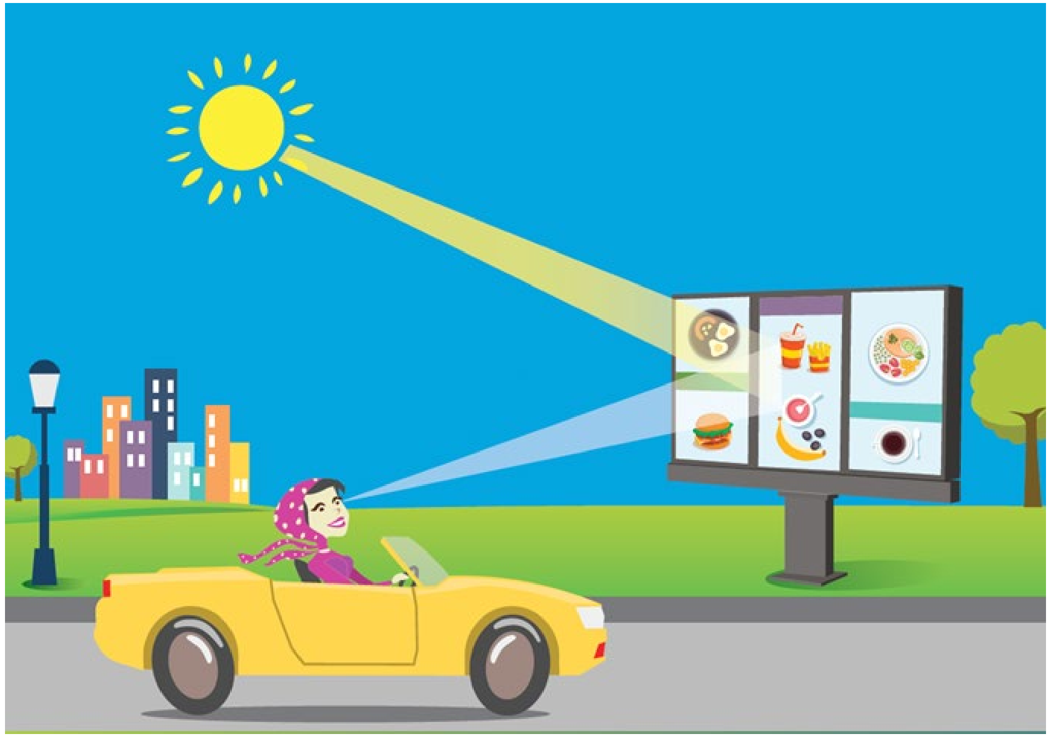
Thermal management is commonly achieved through active cooling involving one or more fans, and/or heat exchangers. A variety of IR blocking films and coatings exist which can reduce the need for such active cooling, which is especially important in warm climates.

Outdoor Displays

Design Considerations

The ideal cover glass solution for warm climates will have the following characteristics:

- High visible transmittance and low visible reflectance for optimum display visibility
- Significant rejection of near-infrared (NIR) solar energy to prevent heat buildup and decrease cooling load
- A high emissivity to permit the transfer of thermal energy from the display to its surroundings
- Ruggedization for outdoor environments: highly resistant to weathering, thermally tempered or heat strengthened for mechanical strength and safety

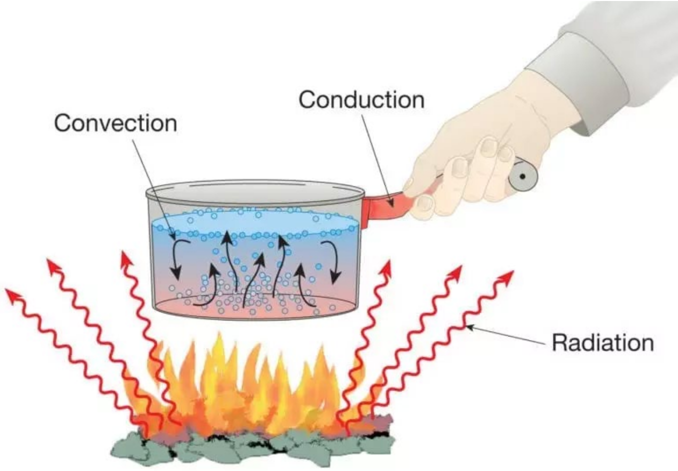


Heat Transfer Basics

- **Conduction**
  - The direct exchange of heat/kinetic energy between adjacent atoms or molecules

- **Convection**
  - The transfer of thermal energy by mass transfer through the movement of fluids such as a liquid or gas

- **Radiation**
  - Transfer of heat by photons in electromagnetic waves



Radiative Heat Transfer

Black Body Radiation and Planck's Law

- The thermal radiation emitted from most objects can be approximated as a black body, an idealized absorber and emitter of which both absorbs and emits all electromagnetic energy

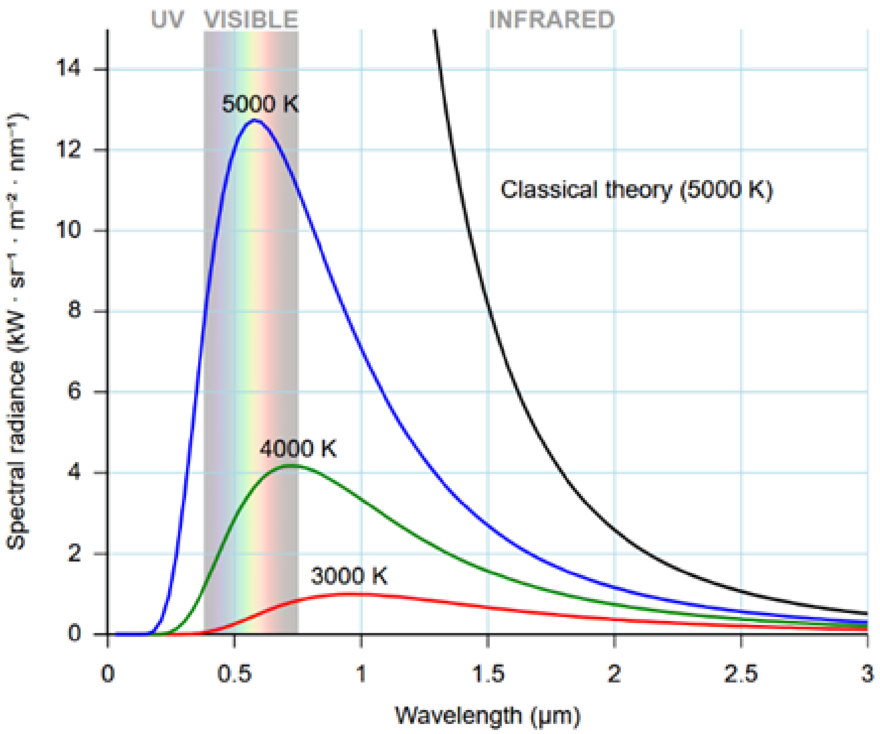
- Planck's law predicts the energy distribution emitted by a black body at a given temperature

- Real objects emit a fraction of the black body energy level, know as emissivity (a blackbody has an emissivity of 1)

- The peak frequency is related to object temperature as described by Wien's law:

$$\lambda_{\text{peak}} = \frac{b}{T}$$

where T = temperature in Kelvin and b = Wien's displacement constant



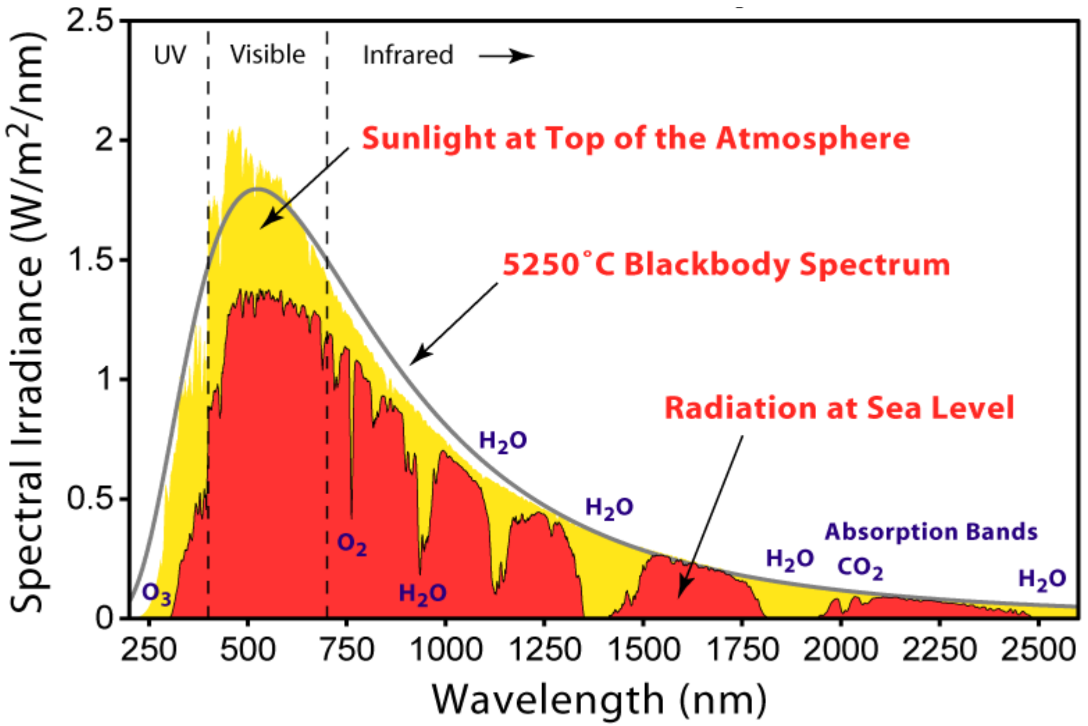
Black Body Energy Distributions Predicted by Planck's Law
(https://en.wikipedia.org/wiki/Planck%27s_law)

Radiative Heat Transfer

Solar Radiation

- The temperature of the surface of the sun is about 5700K, putting its emission peak near 500 nm
- The sun is a non-ideal blackbody, emitting more radiation than expected in the X-ray, UV and radio regions of the electromagnetic spectrum
- Solar radiation is absorbed by materials present in the atmosphere such as water and oxygen at various frequencies as shown at the right
- The Stefan–Boltzmann law describes the energy flux from an object: $E = \varepsilon' \sigma T^4$

where E = total energy flux, ε' = "effective emissivity" (a value between 0 and 1), σ is a constant and T = temperature in Kelvin



Solar Emission Spectrum
(https://en.wikipedia.org/wiki/Sunlight)

Thermal Analysis

Model Development

- Thermal analysis was done with the aid of Lawrence Berkeley National Laboratory (LBNL) simulation software “Optics 6” and “Window 7.7”.
- Thermal calculations within “Window 7.7” were performed using the ISO-15099 standard calculation method under NFRC100-2010 Summer Environmental conditions.
- Boundary conditions are defined as:

System: outdoor display menu board

Irradiance: 783 W/m^2

Temperature Outdoors: 32°C

Display Temperature: 24°C

Outdoor Wind Speed: 2.75 m/s

Coated Surface: exterior

Thermal Analysis

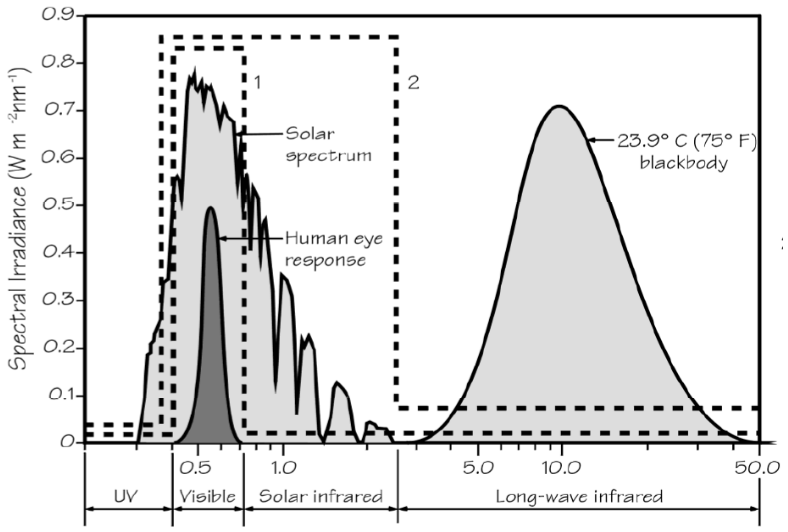
For the purpose of comparing cover glass options for outdoor displays, it is useful to compare the weighted values of transmittance and reflectance over key electromagnetic radiation bands of interest including: the visible, solar infrared and long-wave infrared.

This can be done using the generalized equation:

$$f(\lambda) = \frac{\sum_{\lambda=a}^{\lambda=b} \rho_0(\lambda) S_\lambda \Delta\lambda}{\sum_{\lambda=a}^{\lambda=b} S_\lambda \Delta\lambda}$$

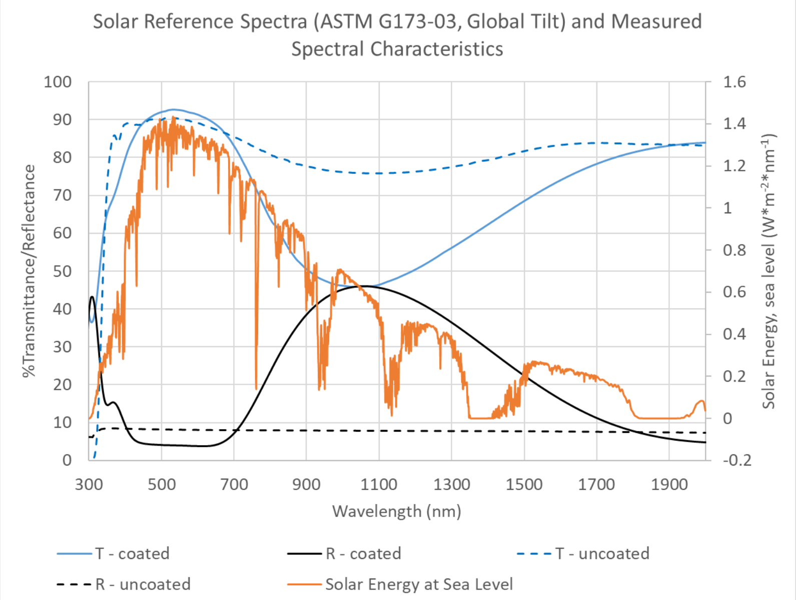
Where λ_a is the lower wavelength, λ_b is the upper wavelength, $p_0(\lambda)$ is the reflectance or transmittance and S_λ is the spectral power distribution of the solar radiation as shown to the right

All solar energy is either transmitted, reflected, or absorbed and converted into heat.



Radiation Bands of Interest

(ASHREA, *2001 Handbook of Fundamentals*)



Transmittance and Reflectance Characteristics vs. Solar Energy Distribution at Sea Level

Thermal Analysis

- The proportion of transmitted and reflected light in the visible wavelength region are import factors affecting the visibility of the display, especially in direct sunlight.
  - The IR Blocker coating decreases visible reflectance while increasing visible transmittance, like an anti-reflection coating.
  - These properties improve sunlight readability by reducing glare and increasing display output brightness but increase solar heat gain.
- The reflectance of solar thermal (non-visible) wavelengths indicates the percentage of non-visible energy rejected by the display cover glass.
  - The addition of the IR Blocker coated NIR reflecting cover glass reflects 32% of the invisible solar thermal radiation compared to just 7% for the uncoated cover glass
  - The increased NIR reflectance more than offsets the increased heating from increased visible transmittance

Optical and Thermal Characteristics for Display Cover Glass with and without "IR Blocker 40" NIR Reflecting Coating

Parameter	Uncoated	Coated with IR Blocker 40	λ(nm) = a	λ(nm) = b
T,solar	77%	72%	300	2500
T,visible	88.4%	92.0%	380	780
R,solar	7%	19%	300	2500
R,visible (coated surface)	4.2%	0.7%	380	780
R,solar thermal	7%	32%	780	2500

*For 5 mm thick display cover glass

Thermal Analysis

Summary

- The addition of the IR Blocker coating causes a net reduction in the solar heat gain coefficient (SHGC)
- The coating has no effect on the relatively high emissivity of the cover glass which enables heat to flow outward from the display to its surroundings
- The active cooling capacity needed for the display decreases which can reduce manufacturing costs
- A significant energy savings for the display owner can also be realized through the reduction of ongoing cooling costs associated with display operation

Thermal Performance Summary Data

Parameter	Uncoated	Coated with IR Blocker 40
Solar Heat Gain Coefficient (SHGC)	0.818	0.754
Emissivity	0.84	0.84
Relative Heat Gain (W/m^2)	**643**	**589**

Case Study Example (55” display)

Location: Los Angeles, CA
Estimated annual energy savings: 175 kWh
Estimated annual cost savings: $30

Outdoor Displays

Conclusion

- ✓ Outdoor displays used in warm climates benefit from a reduction in solar thermal heat load with the addition of a near-infrared reflecting cover glass by a reduction in the necessary active cooling load and associated manufacturing and operating costs.

- ✓ The energy savings benefit the environment through a reduction in energy consumption.

- ✓ The cover glass must have a low reflectance in visible wavelengths to reduce glare from the sun, enhance sunlight readability and decrease the amount of light output necessary for the display.

An optimized cover glass solution with a NIR reflecting coating can provide both thermal and optical benefits simultaneously.