Energy saving analysis of windows coated with spectrally selective NIR glazing films in winter

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Outline

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- Photothermal Mechanisms
- Experiments
- Calculations
- Results
  - Optical Properties
  - Thermal Properties
  - Energy Savings

Introduction

- 41% of primary energy consumption but 74% of electricity.[1]
  - Thermal mass, building orientation, heating, ventilation and HVAC
- 30 ~40% windows are single-pane, especially in older buildings, and they are responsible to over 50% of the total energy lost through windows in the United States.[2]
- 35% of windows in the US building stock occupied Low-e coating.[2]
- We developed a spectrally photothermal coating to convert solar infrared to thermal energy that can increase the inner surface temperature of windows, thus reducing heat transfer between the window and the room interior in winter.

- *This project is supported by the NSF award:#1847024: CAREER: Understanding the Thermal and Optical Behaviors of the Near Infrared (NIR)-Selective Dynamic Glazing Structures*

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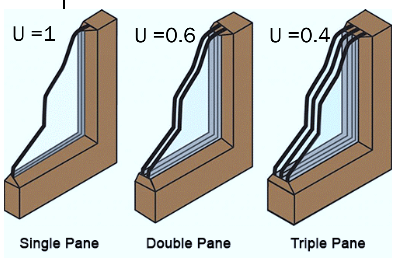
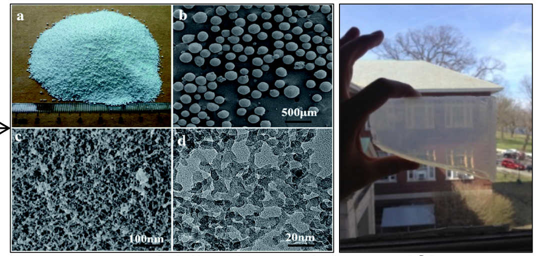
Introduction

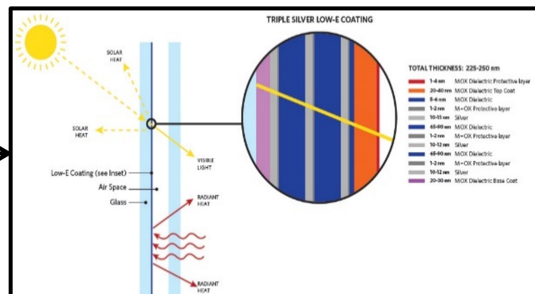


U → 0.6

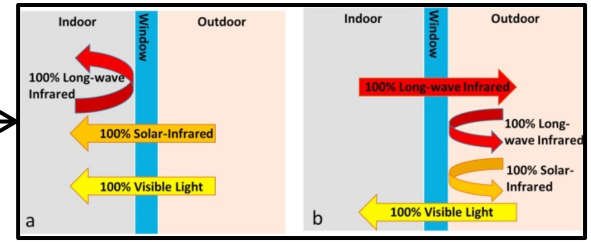


Adding insulation layer[3]

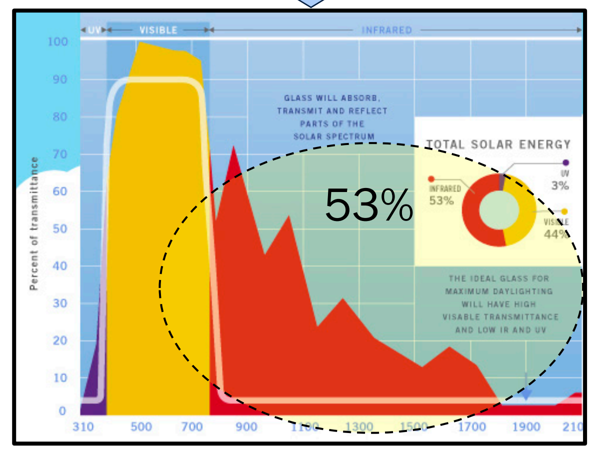
U → 0.6



Adding spectrally selective coatings[4]



Ideal windows

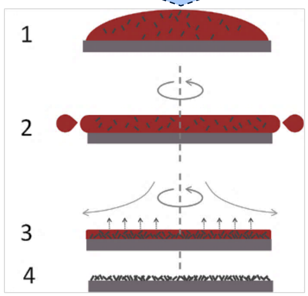


Solar irradiance

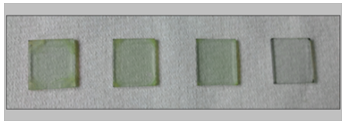
- **Research Question**: Single-pane retrofits (40% and 2.0 Quads) to compete with double-pane windows
- **Existing Methods:** structural and spectral based tracks
- **Our solution**: Photothermal Windows

Introduction

Experimental stage from materials, characterizations, physical models, to climatic chamber testing

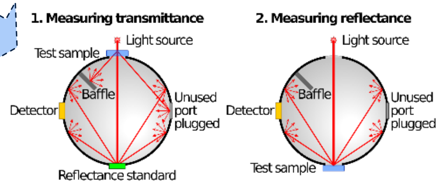


Spin coating

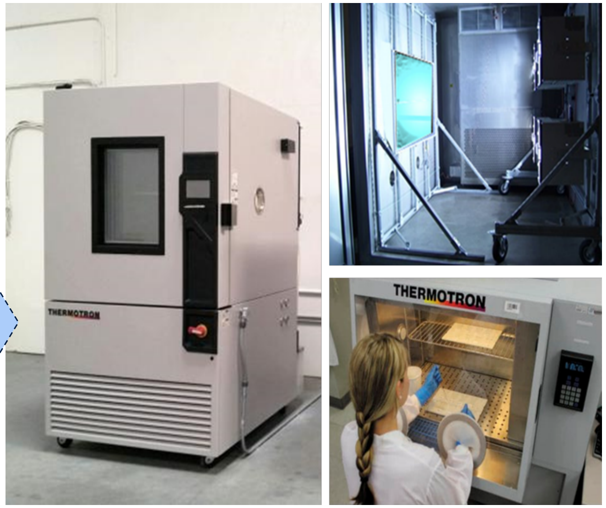


Glass samples

Scaled physical model



Spectral responses (emissivity and transmissivity)



Testing in thermal chamber with solar simulator

Materials side: Nanoscale materialization and characterization

Architectural Engineering side: Micro-to-Macro scale thermal and optical behaviors

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Fe_3O_4@$Cu_{2-x}S$ nanoparticles

- Biomedical applications for past two decades.
- Two stages:
  - Photonic energy absorption, may exists in photonic extinctions(scattering and absorption). Potential to be good NIR absorber.[5]
  - Photon-induced heat generation, receive incident light energy and gain energy from photons, which is absorption.
- The conjugated structure can perform like a whole unit and molecular oscillations are possible contributing factors to conversions of heat via photon irradiation.[6]

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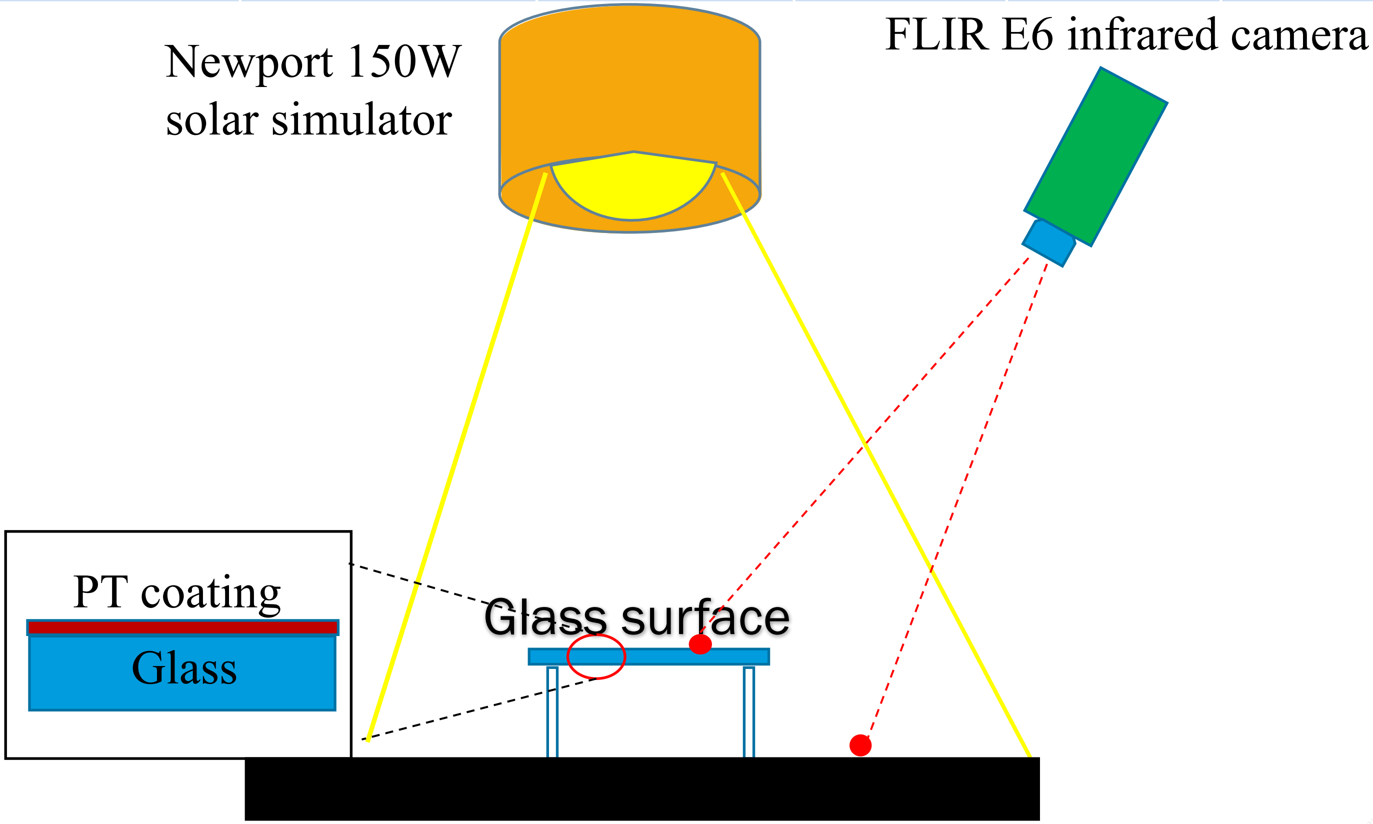
Experiments

Sample size	0.0254*0.0254 *0.01 m^3	Heat capacity	0.840 J/gmK	ΔT	5.43K
Sample material	Photothermal+Glass	Ambient air temperature	298.15K	PT Heat coefficient	0.41685



Calculations/Equations[7]

$$E_{abs} = Q_{conv} + Q_{cond} + Q_{rad} + \mathrm{Q}_{mal} * t$$

$$Q_{conv} = \mathrm{h}A_s(T_s - T_\infty)$$

$$Q_{rad} = \varepsilon\sigma A_s(T_s - T_\infty)$$

$$Q_{cond} = \mathrm{k}A_s(T_s - T_\infty)/L$$

$$\mathrm{Q}_{mal} = \mathrm{c} * \mathrm{m} * \Delta\mathrm{T} * \mathrm{dt}$$

Where h=$Nu_L * \frac{k}{L}, L\ is\ height\ of\ window, T_\infty$ is ambient temperature, T_s is surface temperature, c is heat capacity, m is mass, A_s is surface area.

$$q_{abs} = G_h * \alpha$$

$$E_{abs} = q_{abs} * \mathrm{A}$$

$$q_{trans} = G_h * \tau$$

Where G_h is the global horizontal irradiance, α is absorption, τ is transmittance

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Calculations/Equations[7]

- External free convection flows, find conductivities k.
- Use Nusselt number for both conduction and convection calculations.

$$Nu_L = 0.68 + \frac{0.670 * Ra_L^{1/4}}{[1 + (0.492/Pr)^{9/16}]^{4/9}}, Ra_L \le 10^9$$

$$Ra_L = GR_L * \mathrm{Pr} = \frac{\mathrm{g} * \beta * (T_s - T_\infty) * \mathrm{L}^3}{v * \alpha}$$

where density ρ, dynamic viscosity μ, specific heat Cp, Prandtl number Pr, Rayleigh number Ra_L are related to temperature and humidity of the air.

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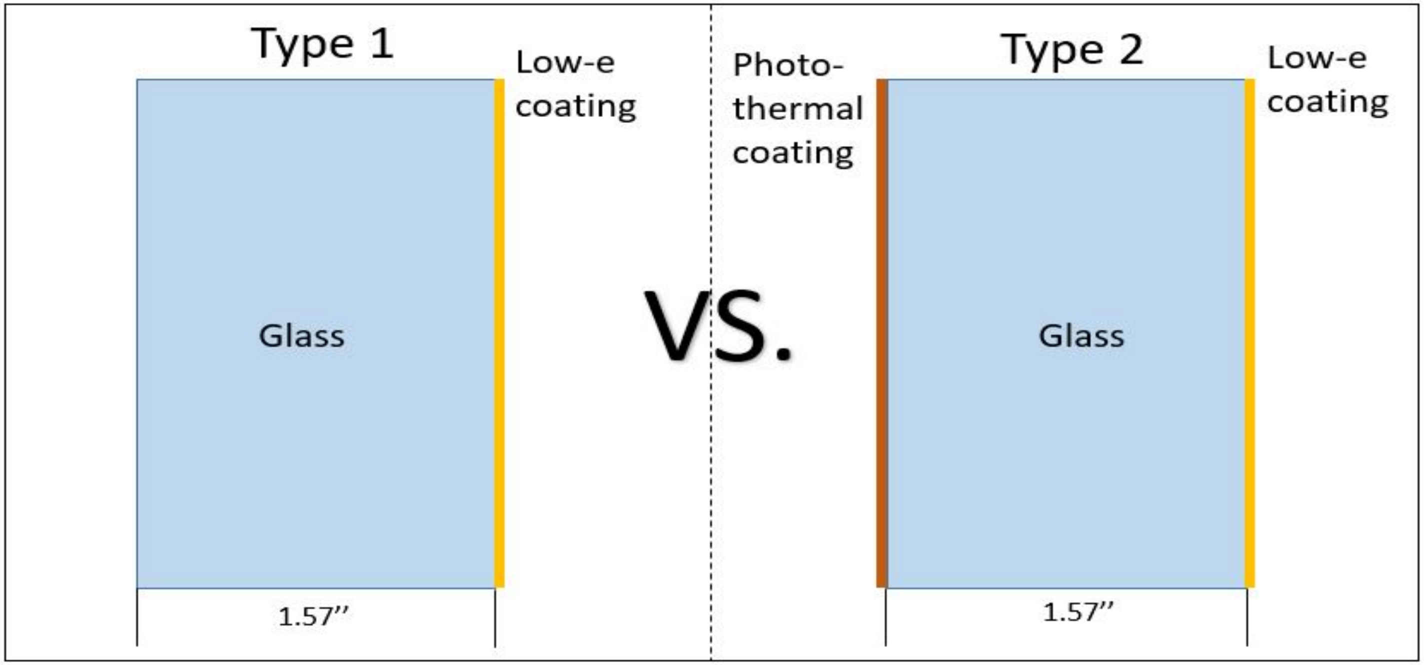
Simulations, Window properties



	U factor, W/m²K	SHGC	VT
Glass +LowE, Type 1	3.458	0.650	0.861
PT+glass+LowE, Type 2	3.458	0.634	0.843

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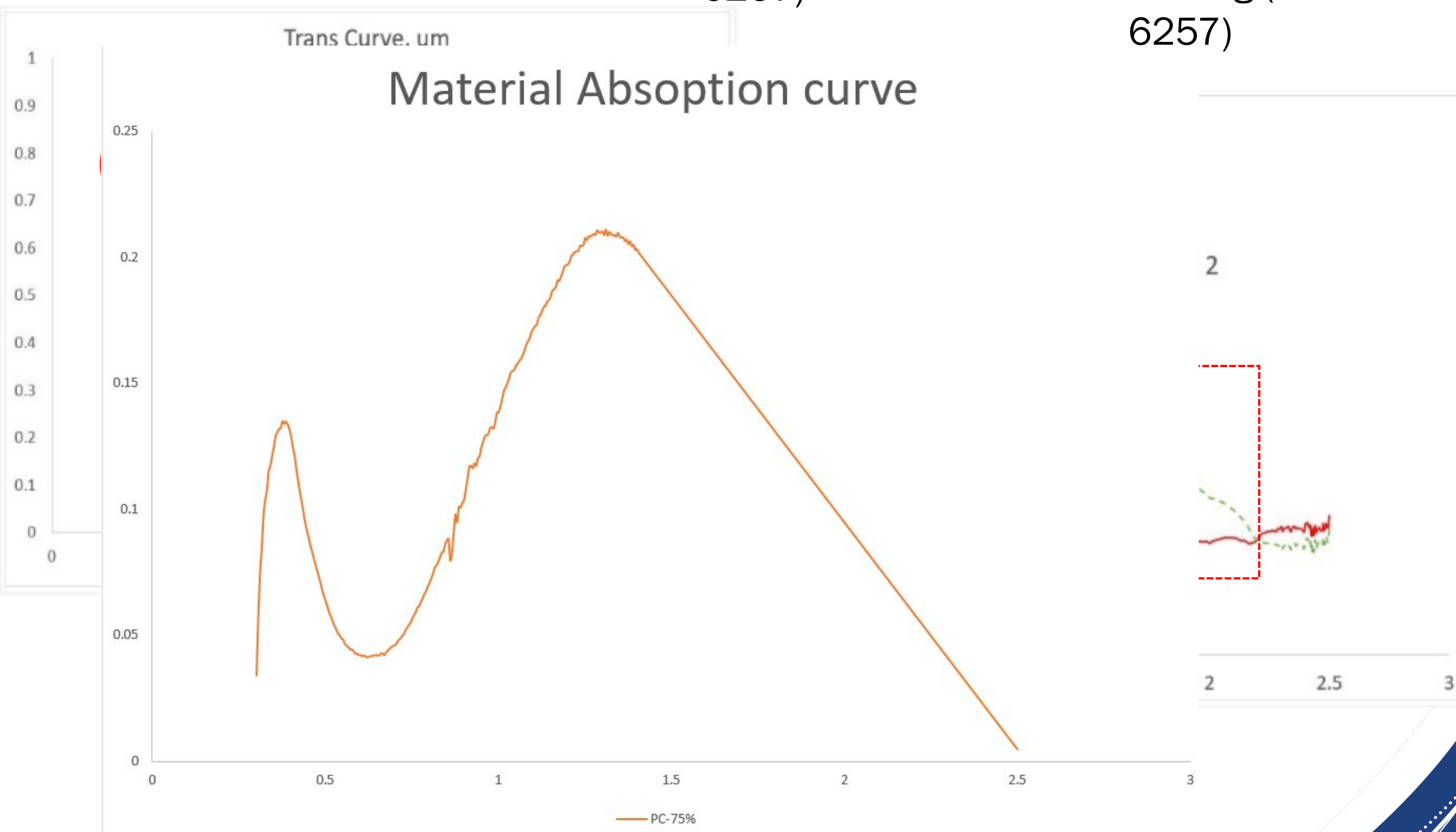
Optical Properties

Type 1:Clear glass (NFRC ID 8203) +low-e coating (NFRC ID 6257)

Type 2:Photothermal thin film + Clear glass (NFRC ID 8203) +low-e coating (NFRC ID 6257)



Numerical results, thermal properties

Assumption: 300 W/m^2 solar irradiation

	Q_{abs}, W/m^2	Q_{trans}, W/m^2	Surface Temperature, K	Heat transfer to indoor, W/m^2
Type 1	39.20	193.90	285.08	-39.89
Type 2	46.58	184.57	291.51	-17.78

	Net energy Saving, W/m^2	Performance	Percentage, %
Type 1	154.01	0	0
Type 2	166.79	12.78	8.3

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- [2] Carmody, John, Stephen Selkowitz, Eleanor Lee, Dariush Arasteh, and Todd Willmert. "Window System for High-Performance Buildings." (2004): 99-100.
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- [4]Kierantimberlake, https://kierantimberlake.com/updates/investigating-low-e-coating-technology
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- [6] Zhao, Yuan, Jou Lin, David M. Kundrat, Mathias Bonmarin, John Krupczak, Som V. Thomas, Mengyao Lyu, and Donglu Shi. "Photonically-activated molecular excitations for thermal energy conversion in porphyrinic compounds." *The Journal of Physical Chemistry C* (2019).
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