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# Evaluating the construction and reliability of an arduino sensor designed for in situ measurement of window efficiency


**Ann Czeponis[1], Lindsey Dahl[2], Julian Wang[3], Yanxiao Feng[3]**

[1]Our Lady of Lourdes Regional School, [2]Erie Public Schools, [3]The Pennsylvania State University


## Objective

To manipulate the home-based construction of a cost effective arduino sensor designed for in situ measurement of window efficiency. To determine the reliability of its measurements in a variety of temperatures and sunlit conditions, and to investigate ways to expand the sensor for ease of consumer use.

## Rationale

Windows play a critical role in managing the comfort of living and work spaces. The impact of windows on energy consumption is critical to managing household and commercial budgets. The glazing properties of windows greatly impact window efficiency. Yet it can be difficult for consumers to determine if the cost of retrofitting or upgrading windows can be justified due to the difficulty in measuring current window performance

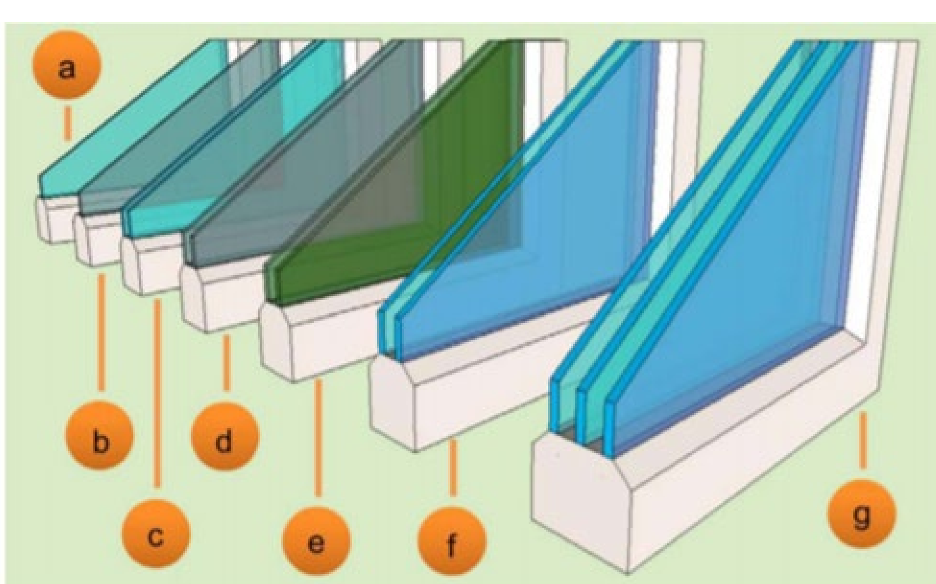
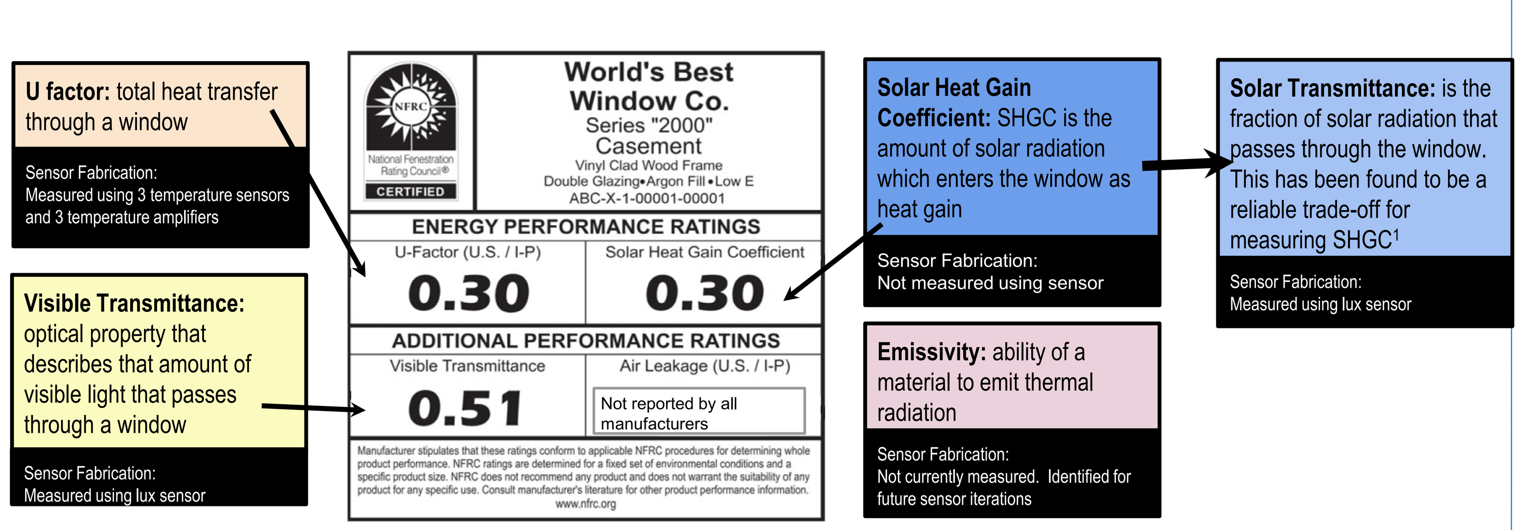



**Fig. 1.** Various glazing types: (a) single pane window with clear glass, (b) single pane window with gray tint glass, (c) double glazing unit (DGU) with clear glass, (d) DGU with gray tint glass, (e) DGU with selective tint glass, (f) DGU with low-E glass and (g) triple glazing unit (TGU) with low-E glass . Reprinted from Ref. [22] with permission from Elsevier Ltd.

The National Fenestration Rating Council has established criteria for window performance. Window performance measurement is done with relative ease in controlled testing; however in-situ measurement of window performance has proven to be cost-prohibitive to most consumers.

A reliable sensor that provides consumers with window efficiency data can be used to make an informed and cost saving decision about retrofitting or replacement.




$$U = \frac{T_i - T_{si}}{(T_{si} - T_o) * R}$$

Where, U is the U-factor of the glass ($W/m^2$ K); $T_i$ is the temperature of object surface exposed to air inside of the glass (in °C); $T_{si}$ is the temperature of the interface between the object and the glass (in °C); $T_O$ is the outside glass surface temperature (in °C); and R is the thermal resistance of the 3D printed object (in $m^2 \cdot K/W$).

$$VT = \frac{L}{L_T}$$

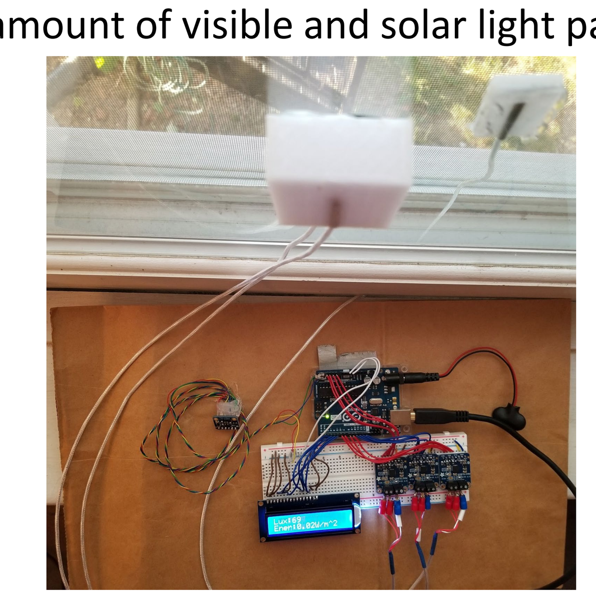
Where, VT is Visible Transmittance and L is the daylighting passing through glazing, and LT is the total daylight landing on glazing.

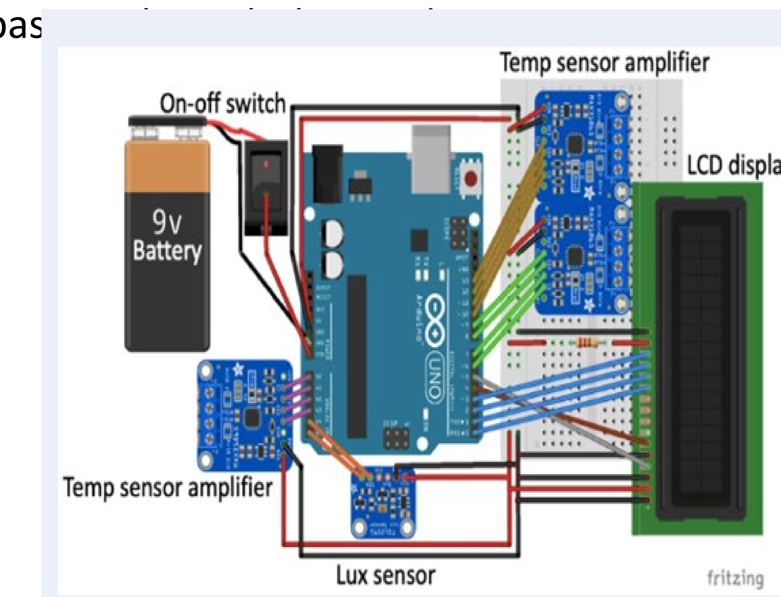
$$\tau_s = \frac{E}{E_T}$$

Where, $\tau_s$ is Solar Transmittance and E is the solar irradiance passing through glazing, and $E_T$ is the total solar irradiance landing on glazing.

## Sensor Design and Home Fabrication

The Arduino based sensor was designed by Dr. Julian Wang and Ph.D candidate Yanxiao Feng to measure U factor, solar transmittance and visible transmittance. The design was constructed to be cost effective, easy to operate and reliable. The window property platform is made up of 1 TSL2591 light sensors and 3 Max31865 temperature amplifiers. These sensors together are used to calculate the U factor of in situ windows. The solar and visible transmittance values can be calculated using the lux sensor. Light measurements are taken on the outside and inside of the window to calculate the amount of visible and solar light pas

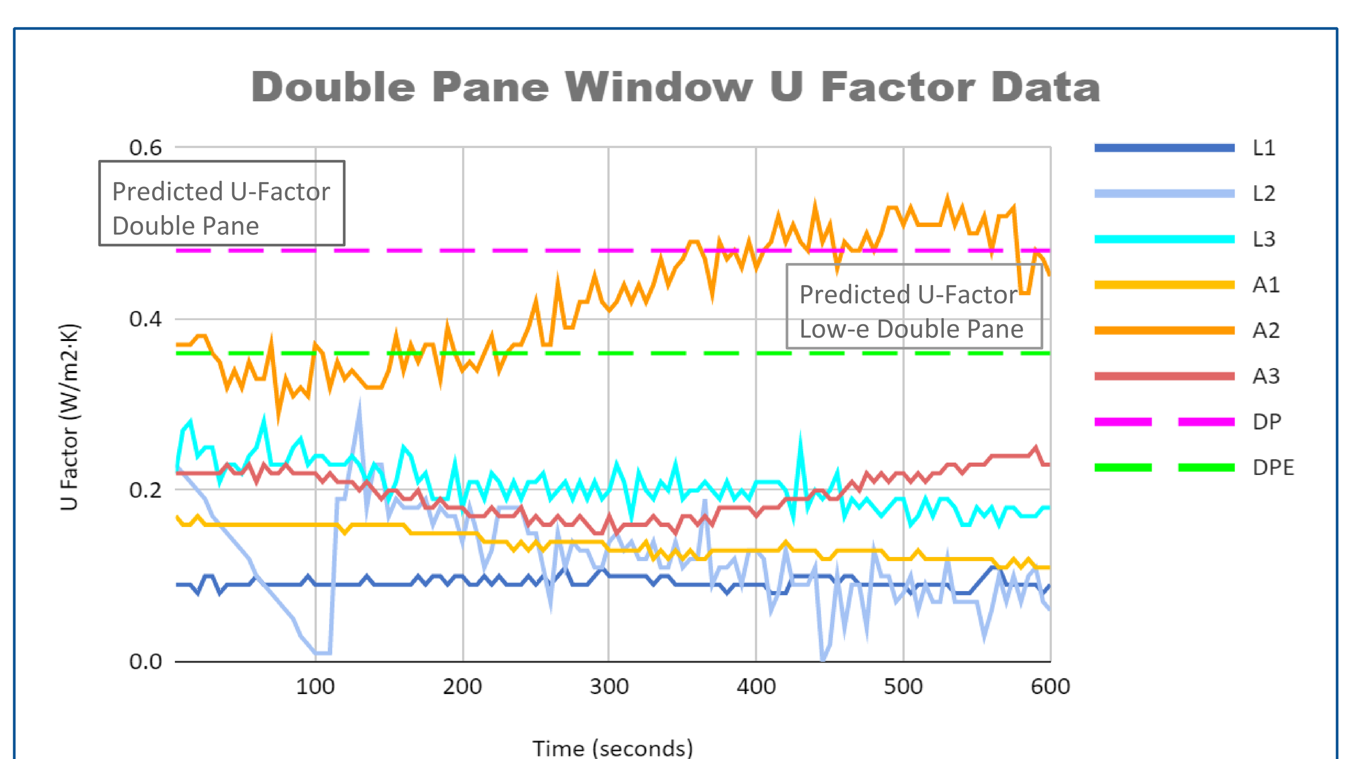





## Sensor Experimentation

| Test Site | Average U Factor ($W/m^2 \cdot K$) | Visible Transmittance | Solar Transmittance |
|---|---|---|---|
| L1 | 0.09 | .98 | 0.39 |
| L2 | 0.12 | .93 | 0.44 |
| L3 | 0.21 | .72 | 0.48 |
| A1 | 0.14 | .75 | 0.66 |
| A2 | 0.42 | .54. | 0.57 |
| A3 | 0.2 | .60 | 0.60 |

Table represents data generated from arduino sensor. Ann and Lindsey each tested the same window 3 times over 3 days.




Graph represents U-Factor data generated from arduino sensor. Ann and Lindsey each tested the same window 3 times over 3 days.

## Testing Constraints and Limitations

- U Factor testing must be conducted once sensor has reached a steady state (approximately 35 minutes) and avoid direct sunlight.
- Ideally there would be approximately an 8 degree temperature difference to test U factor.
- Window must open in order to get internal and external sensors positioned
- The sensors need to be calibrated before use.
- The R values of the blocks need to be measured and recorded by a laboratory.

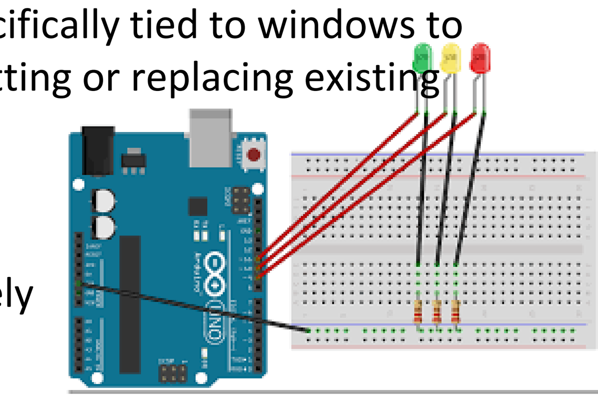
## Implications

It is estimated that nearly 58% of energy use for a building is impacted by windows. This is not an insignificant percentage of a family, business or agency budget. A reliable, convenient and cost effective means of measuring window efficiency could provide end-users with relevant data upon which they could base decisions about window replacement or retrofitting options. The development of a reliable sensor that generates meaningful data stands to positively impact consumers financial and thermocomfort as well as benefitting the environment by reducing energy needs.

## Future Work

Sensor construction and reliability testing pointed to several aspects of the sensor that merit further consideration.

- investigating a cost effective wireless module for temperature sensor T1. to elimate open window and test fixed windows and sashes
- extending the capability of the sensor to include a method for detecting the presence of low-e coating on in situ windows.
- altering the size or materials of the 3-D printed cuboids that house the temperature sensors to allow for a more stable T3 measurement.
- joining this research with research currently being done by Yanxiao Feng that seeks to isolate the energy costs specifically tied to windows to generate a cost benefit analysis of retrofitting or replacing existing windows.
- expanding the sensor to include indicator lights that alert the end user of optimal testing conditions, since reliability is closely tied to testing conditions.



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## References


[1] Feng, Yanxiao & Duan, Qiuhua & Wang, Julian & Baur, Stuart. (2019). Approximation of Building Window Properties Using In situ Measurements. Building and Environment. 169. 106590. 10.1016/j.buildenv.2019.106590.



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