PennState College of Education | CSATS Center for Science and the Schools | Research Experiences for Teachers | PennState College of Engineering | ARCHITECTURAL ENGINEERING

Constructing and evaluating the reliability of an Arduino sensor designed for in situ measurements to determine window efficiency

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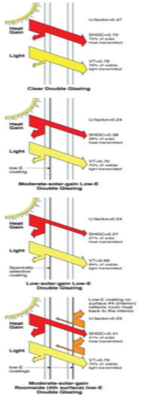
Objective

To implement, test, and expand on the efficiency of a low cost and easy to use in situ window property testing platform. This platform is designed for consumer and classroom measurements to aid in cost saving window replacement decisions.

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. It is estimated that 58% of energy used by a building is impacted by windows.

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 and inaccessible 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 choosing effective replacement windows.

Window Properties

U factor: total heat transfer out of a window
Solar Heat Gain Coefficient: amount of solar radiation which enters the window as heat gain
Solar Transmittance: is the fraction of solar radiation that passes through the window.
Visible Transmittance: optical property that describes that amount of visible light that passes through a window
Emissivity: ability of a material to emit thermal radiation

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

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

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 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 · K/W).

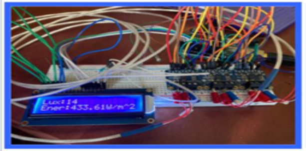
Where, VT is Visible Transmittance and L is the daylighting passing through glazing, and LT is the total daylight landing on glazing.

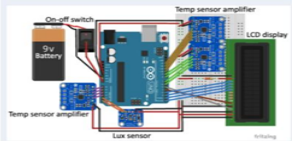
$$\tau_s = \frac{E}{E_T}$$

Where, τ_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 Build

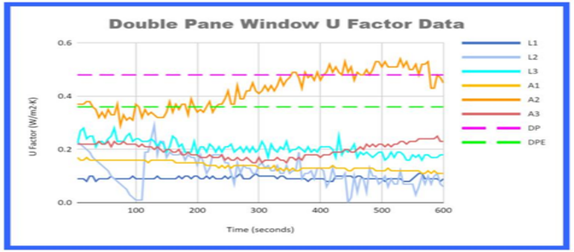
The Arduino based sensor was designed by Dr. Julian Wang and Ph.D candidate Yanxiao Feng to measure U factor, solar transmittance and visible transmittance. The design was constructed to be cost effective, easy to operate and reliable. The window property platform is made up of 1 TSL2591 light sensors 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 passing through the window.





Sensor Experimentation

Test Site	Average U Factor ((W/m^2·K)	Visible Transmittance	Solar Transmittance
L1	0.09	.98	.39
L2	0.12	.93	.44
L3	0.21	.72	.48
A1	0.14	.75	.66
A2	0.42	.54	.57
A3	0.2	.60	.60

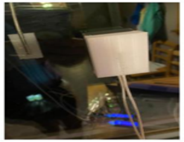


Testing Constraints and Limitations

- U Factor testing must be conducted once sensor has reached a steady state and conducted in the evening or early morning to avoid direct sunlight.
- Under various weather conditions the ideal indoor and outdoor temperature difference has not yet been determined.
- The window must be slightly open in order to get internal and external sensors positioned possibly skewing results.
- Convenient in situ sensor calibration for the sensors is under review.
- The R values of the blocks need to be measured and recorded by a laboratory.

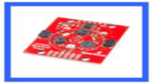
Implications

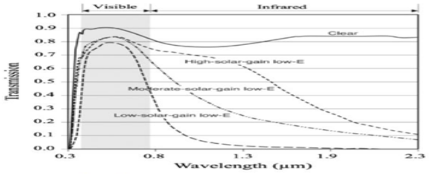
Providing consumers with a method to test window efficiency in a reliable and accessible will provide three main benefits. First the consumer will save money, second the consumer will be able to increase their homes thermocomfort, and lastly by saving energy they will also reap the benefit of impacting planet Earth in a positive way.



Future Work

- Change the temperature 1 sensor to a wireless module.
- Add a sensor and indicator light to indicate optimal testing conditions
- Change the size of the blocks and or the material the blocks are made of.
- Add a spectrometer or filter to the platform to measure the emissivity of the window. Emissivity measurements will be used to determine the presence of Low E coating on window surfaces.





Acknowledgements

CSATS especially Dr. Kathleen Hill, Dr. Matthew Johnson, Tiffany Lewis and Amber Cesare

Archilambda Lab at Penn State especially Dr. Julian Wang and Yanxiao Feng

RET counterpart Ann Czeponis

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.

The RET for Teachers is funded by NSF Building Education Research Experience for Teachers Grant EEC 1855256.