**Evaluating Overall Building Envelope U-Value via Low-Cost ESP-Based Data Datalogging System During a Snowstorm in Omaha, NE**

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**Abstract:** The Sustainable Small House (SSH) is a demonstration project of an Accessory Dwelling Unit (ADU) that recently went through its first winter shakedown. To evaluate thermal performance and compare it against theoretical values, a low-cost Internet of Things (IoT) datalogging system was built using ESP32 microcontrollers communicating via the ESP-NOW protocol to continuously monitor indoor temperature and incoming solar irradiance. During the snowstorm, solar gain was minimal, which created ideal conditions for estimating the SSH's overall building envelope U-value. The theoretical U-value and the one calculated from collected data were fairly close, highlighting the value of continuous low-cost data monitoring for assessing thermal properties in situ.

**Keywords:** Accessory Dwelling Unit, Passive Solar, Thermal Performance, Data Monitoring

## 1. Introduction

The Sustainable Small House (SSH) (Figure 1) is a super-insulated structure designed to meet the International Energy Agency's 2050 energy goals through a combination of passive and active solar design. The thermal properties of a building envelope are critical for evaluating its energy efficiency. Given the growing concerns over environmental impacts caused by buildings, these parameters play a vital role in sustainable design. Improved energy efficiency enhances the overall environmental performance of a building (Dakwale et al., 2011).

ESP-based IoT protocols have proven effective for low-cost data logging systems (Mobaraki et al., 2023). For our setup, three DS18B20 temperature sensors connected to an ESP32 were placed at the center of the living room to monitor indoor temperature, with data captured every five minutes. The average of these three temperatures was used for the calculations. To measure solar irradiance, a LI-200R pyranometer was positioned indoors connected to a different ESP32, facing directly toward the south-facing window. The data was sent wirelessly using the ESP-NOW protocol to a master ESP32 connected to a central computer. The outdoor temperature was obtained using Davis Instruments Vantage Pro2 Weather station which was already installed at the building site.

On March 19, 2025, a snowstorm struck Omaha, Nebraska. The storm resulted in minimal solar irradiance (figure 2), allowing for a more accurate evaluation of conductive


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heat transfer without interference from radiant heat gain. This paper presents preliminary results from in situ monitoring of the SSH thermal performance during the snowstorm.

Figure 1: South view of Sustainable Small House in Omaha, Nebraska

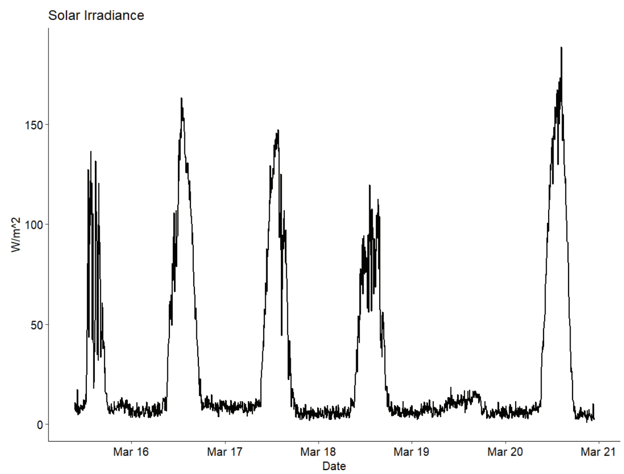


Figure 2: Solar Irradiance at SSH south windows, March 16-21, 2025

## 2. **Theoretical U-Value**

Since the R-values for the building components are known (as shown in Table 1), the theoretical overall U-value of the building envelope was calculated using the formula below. In this equation, $U_i$ represents the U-value of each individual component, and $A_i$ denotes its corresponding surface area. Heat losses through unexposed areas, such as the floor and basement, were not taken into consideration.

$$U_{overall} = \frac{\sum(U_i \times A_i)}{\sum A_i}$$

| Component | R-Value (ft²·°F·h/BTU) | U-value (BTU/hr·ft²·°F) | Surface Area (ft$^2$) |
|---|---|---|---|
| Walls | 50 | 0.0200 | 1279 |

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| | | | |
|---|---|---|---|
| Ceiling/roof | 84 | 0.0119 | 998 |
| Patio Door | 7 | 0.1429 | 53 |
| Front Door | 6.5 | 0.1538 | 28 |
| South Window | 8 | 0.1250 | 67 |
| North Window | 10 | 0.1000 | 7.5 |

Table 1: SSH Components R Values

Using this method, the overall building envelope U-value was calculated to be 0.0240 BTU/hr·ft²·°F.

### 3. Experimental U-value

The overall heat transfer coefficient is calculated using the formula shown below, where $Q$ represents the total heat loss in BTU, $U$ is the heat transfer coefficient (BTU/hr·ft²·°F), $A$ is the total surface area in square feet (ft²), and $\Delta T$ is the temperature difference in degrees Fahrenheit (°F).

$$U = \frac{Q}{A \cdot \Delta T}$$

The overall surface area of the building was determined as 2433 ft$^2$. The temperature difference (ΔT) between indoor and outdoor conditions was plotted (figure 3), and the area under the curve was numerically integrated using the trapezoidal rule, where $T_i$ is the temperature at a given time and $\Delta t$ is the time between each data collection.

$$AUC = \sum_{i=1}^{n} \frac{\Delta T_i + \Delta T_{i+1}}{2} \cdot \Delta t$$

$$AUC \approx 480 \ [°F - hours]$$

Figure 3: Absolute temperature difference between outdoor and indoor

Since the experiment lasted 24 hours, we obtained $\Delta T = 20°\mathrm{F}$.

The heat loss was computed using the formula shown below, where $c_p$ is the specific heat of air and $m$ the mass of air.

$$Q = m \cdot c_p \cdot \Delta T_{indoor}$$

The standard specific heat of dry air, 0.24 BTU/lb·°F, was used for calculation. The mass of air within the structure was determined using the formula:


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$$m = Volume \times Density$$

The density of air was obtained using the "wflo" library in R (Croonenbroeck & Hennecke, 2020). At an average indoor temperature of 55°F, the dry air density at the SSH was determined to be approximately 0.0741 lb/ft³. Over the test period, the total indoor temperature change was 14.1°F. Given the SSH's interior volume of 5,361 ft³, we estimated a total heat loss of 1,344 BTU. Using this data, the overall building envelope U-value was calculated to be 0.0276 BTU/hr·ft²·°F.

## 4. **Conclusion**

This study demonstrated the effectiveness of a low-cost ESP32 microcontroller-based monitoring system for evaluating thermal performance. The experimentally determined U-value closely aligned with the theoretical estimate, with a small discrepancy that may be attributed to heat loss through the floor. Future work could incorporate additional environmental variables—such as humidity, precipitation, and wind speed—to further refine the assessment of the building's thermal performance.

## 5. **References**


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