Quantifying Hidden Value
With the Building Enclosure Performance Metric

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Abstract

Oak Ridge National Laboratory (ORNL) is developing a building enclosure performance (BEP) metric to present the overall value of a building’s enclosure system. The intent behind the research is to help building owners quantifiably justify investment in advanced envelope technologies with a metric that measures aesthetic value, structural durability, thermal comfort, and moisture resilience. The BEP metric seeks to combine positive aspects of simulations and post-construction performance measurements, such as energy use intensity (EUI) as provided by energy management information systems (EMIS). In all, there are five major categories that have a significant role in overall building enclosure energy losses: thermal resistance, installation quality, air infiltration, indoor climate, and weather conditions.

The proposed BEP metric allows for evaluation of the building energy performance, which is similar to R-value and EUI. Additionally, the BEP metric is specifically designed to account for all the aspects that involve overall building energy losses, including air infiltration. Lastly, the BEP metric goes further to account for workmanship quality and imperfections of the building thermal resistance due to penetrations and other installations. This presentation will describe how the BEP metric can be applied to various buildings and next steps with field validations.

Speaker

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DR. PALLIN has worked in the building industry since 2006, and spent several years conducting research in Europe. He joined the Building Envelope Systems Research team at ORNL in 2013. Dr. Pallin serves as a risk assessment moisture simulation expert, and works with existing simulation tools in addition to creating new tools to estimate the hygrothermal (heat and moisture) performance of building elements such as walls and roofs.

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INTRODUCTION

Today, engineers, architects, consultants, and building owners rely on static evaluation criteria, such as R-value and U-factor, to evaluate the performance of the building enclosure (envelope). These metrics give insight into the amount of heat transfer through surfaces, but they rarely represent the thermal performance of the whole building. Through discussions with builders and researchers interacting directly with industry (ETRT, 2016/17), Oak Ridge National Laboratory (ORNL) found that not having a metric to represent the actual thermal performance of a building is a clear issue. As a result, ORNL initiated development of a building enclosure performance (BEP) metric, to aid in the evaluation and design process by providing invested parties with more information than U-factor or R-value. As shown in Figure 1, performance metrics that utilize multiple performance factors exist in other industries to help consumers make energy-efficiency-based decisions. A new BEP metric could be analogous to the miles per gallon (mpg) metric used as a fuel economy performance indicator for the automotive industry—with the similar caveat as used with mpg, “Your mileage may vary”—“Your building performance may vary.”

In terms of fuel economy for automobiles, there are several variables that have an impact on the mpg or overall efficiency of the vehicle. These include engine size, valve resistance, combustion time, aerodynamics of the vehicle, etc. Just as there are a number of variables that will impact the fuel economy of a vehicle, there are several variables that impact the energy losses through the building enclosure: airtightness, thermal resistance, outdoor and indoor climates, installation quality, etc. Figure 2 depicts how these variables impact the energy losses through the building enclosure and, thus, the energy demand on the HVAC system. Considering this challenge, ORNL’s goal is to develop a singular metric that can describe the holistic thermal performance of a building enclosure. The BEP metric will be designed to be an inclusive metric to mimic the overall thermal performance of the building enclosure.

Currently, the two most commonly used methods for measuring a building’s thermal performance in America are 1) complex simulations and 2) direct measurements of a building’s energy use intensity (EUI). One can also refer to these two methods as predicted and actual EUI. A downside of running simulations is the time required to setup a simulation model. Additionally, complex simulation models attempt to account for all heat transfer processes across a building enclosure, and thus often require a subject matter expert to produce accurate results (Augenbroe, 2002). Actions to conduct the actual EUI are challenged by the requirement of building energy usage data, making the indicator applicable only as a post-construction evaluation metric. Furthermore, EUI as a performance indicator is highly influenced by the building usage and climatic conditions, a weakness for comparing building performance across regions.

All the variables defined in Figure 2 are accounted for in an EUI, but it is complicated, if not impossible, to understand how each variable affects the EUI value. Because of hidden variables within EUI, comparing such a metric between different buildings is not recommended. Instead, the purpose of the BEP metric will be to represent the actual performance of the building in a relative manner; meaning, the BEP metric should not be influenced too much by the building type, use, or location, but rather in a passive manner, define how well the building enclosure shall perform. Relating back to the mpg performance metric example, one can see the analogy and reason of not including the characteristics of the driver, which obviously can have a huge impact on the fuel economy.

As previously mentioned, typical design calculations evaluate performance of the building enclosure based upon the R-value and U-factor, which may evaluate all conductive energy leaks present within a building. In addition, air changes per hour (ACH) or infiltration rates (CFM/ft²) are typically used to describe the airtightness of building enclosures and require sophisticated simulation work to be accounted for in the early design phase. The goal of a new BEP metric is to produce a standard for measuring that encompasses the benefits of R-value, U-factor, and ACH calculations to...
give interested parties a realistic comparative snapshot of building enclosure thermal performance. Once ORNL defines and validates a BEP metric, the approach could be used through a web tool interface or hand calculated by architects, engineers, building owners, and other industry stakeholders. As such, the BEP metric could be used to compare building designs and gauge how design choice changes influence future enclosure performance. With thermal performance’s dependence on climate, the metric can be used in conjunction with local weather data to produce design-stage enclosure performance results. It is anticipated that the BEP metric will be a useful tool for characterizing the thermal performance of a building enclosure assembly and has the potential to be a major player in the design process for buildings of the future. With a BEP metric available, users will be able to compare their building enclosure’s thermal efficiency easily.

For building code regulations, R-value requirements differ depending on climate zone. The amount of insulation or R-value needed depends on the building’s climate zone (IECC, 2015). R-value is a good indicator of heat transfer via conduction through a wall assembly, but there are other forms of heat transfer happening parallel to conduction. It is important to account for both a climate’s wind and temperature conditions to study how air leakage influences heat transfer and energy loss through the building enclosure, thus emphasizing the importance of air-tightness in different climates (Stockdale, Pallin, Boudreaux, and Buechler).

The measuring of thermal resistance considers components such as walls, roofs, foundations, and fenestrations. Air tightness of a building is often characterized with an ACH value. To find a building’s ACH value, a blower door test is conducted (ASTM E1827, 2017). Tests, which are conducted at varying pressure differentials, provide a unique ACH50 or ACH75 value for a given building. ACH50 and ACH75 represent the air changes per hour of a building pressurized by 50 and 75 Pascals, respectively.

ACH is not necessarily useful for comparing buildings unless geographically nearby, as it is majorly influenced by the wind loading and external temperature conditions of a building. Due to this, it is not climate-independent. Previous studies have shown that ACH is dependent on wind loading (Kraniotis, Thiis, and Aurlien, 2014; Lyberg, 1997; Orme, Liddament, and Wilson, 1998), which can drastically differ—even within a climate zone.

Air leakage is a major contributor to heat loss in buildings, but is often overshadowed by simpler mandatory metrics like R-value and U-factor, and the air leakage is referenced in code as a non-quantitative requirement such as the continuous air barrier requirement. As seen in Figure 3, current codes for air tightness do not necessarily reflect where in the United States air tightness matters most, and codes for thermal resistance do not account for resis-

Figure 2 – General variables that impact the overall energy losses and performance of the building enclosure. The purpose of the BEP metric is to account for as many of these variables as possible.

Figure 3 – The relative importance of airtightness on HVAC energy usage varies greatly over the U.S. (Stockdale et al., 2017). The solid line crossing the map represents a distinction in code requirements for residential buildings (IECC, 2015). Unfortunately, this difference in codes is not actually based on where airtightness matters most. The darker the green, the more building airtightness influences the overall energy losses.
In Figure 3, areas shaded with darker green represent climates in which airtightness matters the most. The proposed BEP metric aims to combine U-factor and ACH into one comparable metric in order to make up for these unaccounted measurements.

**METHOD OF INVESTIGATION**

**Thermal Network**

In order to evaluate the thermal performance of building enclosures, ORNL produced a generic thermal resistance network, taking into account enclosure components such as walls, windows, roofs, doors, and foundations. Thermal capacitive effects (heat storage capacity) were avoided, keeping the method algebraic for ease of use. The initial thermal and simplified resistance model is shown in Figure 4.

**BEP Metric Formulation – Essential Heat Transfer Mechanisms**

Figure 4 depicts several heat transfer mechanisms that are typically relevant for a building and thus are relevant for the BEP metric. This section presents the mechanisms that are considered essential for the BEP metric.

Heat transportation due to air leakage is mainly driven by wind loads and buoyancy effects (e.g., stack effect). These two phenomena will cause an air pressure gradient between the indoor and outdoor environments around the building enclosure. Therefore, it is possible to calculate the resulting air pressure gradient as shown in Equation 1, in which \( P_b \) is the air pressure gradient caused by variations in air temperatures, buoyancy effect (Hagentoft, 2001), so Equation 2 can be used to calculate the localized wind velocity at a mean building elevation.

Equation 4 can also be used to determine the localized wind velocity effects at the building enclosure. \( v_m \) is the localized wind velocity at a typical weather station elevation of 10 m, and \( C_t \) and \( a_t \) are terrain coefficients for a given local terrain.

Once the air pressure gradient is found, the resulting outdoor air infiltration can be determined, and the airtightness of the building is found. Typically, the airtightness, or

- **Table 1 – Wind terrain coefficients for use in Equation 4.**

<table>
<thead>
<tr>
<th>Terrain</th>
<th>( C_t )</th>
<th>( a_t )</th>
</tr>
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<tbody>
<tr>
<td>Open, Flat Country</td>
<td>0.68</td>
<td>0.17</td>
</tr>
<tr>
<td>Country with Wind Breaks</td>
<td>0.52</td>
<td>0.20</td>
</tr>
<tr>
<td>Urban</td>
<td>0.35</td>
<td>0.25</td>
</tr>
<tr>
<td>City</td>
<td>0.21</td>
<td>0.33</td>
</tr>
</tbody>
</table>
The airflow rate, measured at 50 Pa for residential buildings and/or 75 Pa for commercial buildings. Since a blower door test is performed at a particular design pressure, the volumetric flow rate of air as it leaks through a building enclosure can be calculated for any induced pressure gradient impacting building enclosures.

See Equation 6, where $\Delta P$ within the equation represents the air pressure gradient, $G_{air}$ represents volumetric flow rate, and $C$ is the flow coefficient found from empirical testing. The pressure exponent, $n$, is typically assumed to be 0.65, as is common in calculations considering both laminar and turbulent air flows (Urquhart and Richman, 2015).

The impact on energy losses due to air leakage through the building enclosure can be found as shown in Equation 7.

Using Equation 7, the thermal resistance of the building enclosure due to air leakage can be represented as a thermal resistance, as demonstrated in Equation 8.

To fully account for conductive heat transfer, the interior and exterior heat transfer coefficients must be found. These coefficients can be calculated in a variety of ways, but a simple, general convection coefficient equation was chosen for use in the BEP metric. The formulation chosen comes from a linearization of the Nusselt-Jürges convection coefficient as presented by Palyvos, 2008. This is shown in Equation 9, in which $h_w$ is the forced convection coefficient due to wind speed, and $v_w$ represents the wind velocity at a mean surface elevation. The constant is assumed to represent the natural convection portion of a total convection coefficient. This convection coefficient formulation is not sensitive to wind direction or surface roughness values (EnergyPlus, 2018).

For interior surfaces, heat transfer coefficients must be used to account for heat transfer between interior surfaces and interior air. Heat transfer coefficients for still air interacting with building surfaces were extracted from Walton’s TARP reference manual (Walton, 1983) and ASHRAE Fundamentals 2001, Chapter 25 (ASHRAE, 2005). These heat transfer coefficients can be seen tabulated below, in Table 2.

From Table 2, $h_f$ represents the pure natural convection component of heat transfer, and $h_t$ represents the combined heat transfer component of natural convection and radiation heat transfer with interior air. $R_f$ and $R_t$ are reciprocal resistance values of $h_f$ and $h_t$, respectively.

In order to reasonably characterize the BEP metric, lumped conductive R-values and U-factors are required for each opaque building area and all windows, respectively. Opaque areas included within calculation of the metric are roof areas and wall areas. To find the mutual R-value of a wall or roof, it is necessary to account for all component layers and potential thermal bridges. A sample model for a generic wall can be seen in Figure 5.

Figure 5 indicates that thermal bridges become an issue with framing members, such as wood or metal studs. Since framing members often have higher thermal conductivities than insulating materials, heat will “leak” through framing members at higher rates. In order to properly account for this, the lumped thermal resistance for the wall assembly must be taken into account in calculation of the BEP metric. This means that heat transfer through framing members and insulation must be evaluated in parallel, rather than neglecting heat transfer through framing members. As an example, Equation 10 can be used to find the mutual conductive R-value for wall assemblies.

It is suggested that ASHRAE’s indoor still-air heat transfer coefficients found in Table 2 herein should be used. These coefficients account for both radiation and natural convection on interior surfaces (ASHRAE, 2005).

![Equation 5](Image)

$ACH = \frac{G_{air}}{V}$

Equation 5

![Equation 6](Image)

$G_{air} = C \cdot \Delta P^n$

Equation 6

![Equation 7](Image)

$Q_{conv} = \rho \cdot c_p \cdot G_{air} \cdot (T_{out} - T_{in})$

Equation 7

![Equation 8](Image)

$R_{inf} = \frac{A_{tot}}{\rho \cdot c_p \cdot G_{air}}$

Equation 8

![Equation 9](Image)

$h_w = 5.8 + 3.95 \cdot v_w$

Equation 9

<table>
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<td>6.13</td>
<td>0.16</td>
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</table>

Table 2 – ASHRAE heat transfer coefficients and associated thermal resistance values for general building surfaces in contact with still air.
Another major contributor of heat load on buildings is solar irradiance. Global horizontal irradiance (GHI) can be broken into components of direct normal (beam) irradiance (DNI), diffuse horizontal irradiance (DHI), and ground-reflected irradiance, albedo (GRI). These can be seen in Equation 11.

Most solar irradiance values are provided in relation to a horizontal surface. Equation 12 gives a means to calculate solar heat gain from beam irradiance for tilted surfaces.

From (ASHRAE, 2005), \( I_{DNI, abs} \) is the direct normal irradiance absorbed by an inclined plane, \( I_{DNI,stat} \) is the direct normal irradiance measured by a pyrheliometer, \( \beta \) is the tilt angle of the surface with respect to horizontal, \( \chi \) is the local solar zenith angle measured with respect to vertical, \( \xi \) is the local solar azimuth angle measured clockwise with respect to north, and \( \zeta \) is the surface face azimuth angle measured clockwise with respect to north.

The diffuse sky term of the algorithm also differs depending on surface incline (Maxwell, Stoffel, and Bird, 1986), and is expressed as shown in Equation 13.

Equation 13 represents sky diffuse radiation on an incline surface. \( I_{DNI, abs} \) is the diffuse horizontal irradiance absorbed by an inclined plane, and \( I_{DNI,stat} \) is the diffuse horizontal irradiance impacting a horizontal plane. To calculate diffuse radiation on an incline surface due to ground-reflected radiation, use Equation 14.

Here, \( I_{GHI} \) is defined as the global horizontal irradiance impacting a horizontal plane, and \( R_G \) is the ground albedo.

Once all of the incident radiation values are calculated, and using Equation 11, the total amount of solar radiation incident on a surface can be found by using Equation 15.

**INITIAL VALIDATION**

In an attempt to characterize performance of the proposed BEP metric, ORNL used two formulations: 1) a complex model representing all heat transfer mechanisms through the building enclosure, and 2) a second model representing a simplified approach. The complex formulation uses the network framework with time-series weather data on an hourly basis. The second formulation will start off as semi-complex, and then become more simplified as the initial validation of the metric parameters work proceeds. Initially, the more simplified model uses the network framework with data represented as monthly averages. Eventually, annual averages will be used, but further validation
is required before such an approach can be taken. Therefore, the BEP metric formulated will be referred to as an initial version.

To develop a finalized version, ORNL will conduct validation of the new BEP metric—both at the laboratory and in field-level testing. The BEP metric will be tested against data collected from real buildings, field and laboratory testing, and simulations. “Version 1.0” of the BEP metric will be validated only against simulation work. As depicted in Figure 6, ORNL’s approach to developing the BEP metric will include both simulation data and actual building data.

The first version of the BEP metric can be computed by using Equation 16.

As seen in Equation 16, the BEP metric is a combination of the thermal resistance components for heat transfer via opaque components (roof and wall areas), fenestration components, and air leakage through a building enclosure. The R-value and U-factor of building enclosure components can easily be plugged into the equation, meaning that the BEP metric can be used to aid in evaluation of insulation and window assemblies. In order to standardize the BEP metric, users must each use the same convection coefficient formulations to compare BEP metrics between different buildings. For example, convection coefficient formulations can produce drastically different values for the same component, as most are empirical formulations which are used for specific cases. It would be unfair for users to simply use the convection coefficient formulations that provide the lowest values, giving their building the appearance of having a better BEP metric.

Special care must be taken to properly evaluate the air leakage component of the BEP metric. For use of the BEP metric in existing buildings, conducting a blower door test is preferred to properly quantify air leakage. In lieu of such a test, there are data sources for typical air leakage rates found in both residential and commercial buildings (LBNL, 2015; ORNL, 2018).

Besides air leakage, another feature which requires more exploration is the installation factor given by $\delta_{\text{install}}$. This factor is a normalized value that ranges from 0 to 1 and is meant to encompass the potential loss in thermal performance that results from improper installation of enclosure components. Improper window installation, lack of air sealing, and improperly sized insulation layers are examples of factors that will influence the installation. For the current iteration of the BEP metric, building components are expected to be installed at near-laboratory-like conditions, meaning installed R-values and U-factors are the same as those present on component data sheets. This factor will be revisited in future iterations of the BEP metric.

For application purposes, the overall heat transfer through a building enclosure can be calculated together with the BEP metric using Equation 17. (See Nomenclature for descriptions.)

The first term of Equation 17 represents conductive and air infiltration heat losses/gains. The second term represents heat losses/gains due to solar radiation, and the third term represents heat transfer to the ground. As seen in the first term, the BEP metric relies on the total surface area and the temperature gradient between the indoor and outdoor environments. One can see the benefits of being able to compare the BEP metric between different buildings, regardless of the climate in which the buildings are constructed. The main goal of the work presented in this paper will be to implement the second and third terms of the equation into the actual BEP metric.

Using Equation 17, the BEP metric was validated against different modeling schemes. The complex simulation model refers to the details modeled using a whole-building energy modeling tool, EnergyPlus (EnergyPlus, 2018). The results of this comparison can be seen in Figure 7.

Figure 7 represents a validation of the net heat flux through the building.

\[
I_{\text{GRI,abs}} = \frac{1}{2} \cdot I_{\text{GHI,stat}} \cdot R_G \cdot (1 + \cos(\beta))
\]

Equation 14

\[
I_{\text{surf}} = I_{\text{DHI,abs}} + I_{\text{DHI,abs}} + I_{\text{GRI,abs}}
\]

Equation 15

Figure 6 – A complete validation of the BEP metric will consist of comparison with data collected from real buildings, field testing, lab testing, and simulations.
enclosure over the course of a year. The complex model was simulated using hourly values, while the simplified BEP model used monthly averages. Figure 7 illustrates that a strong agreement was found.

Due to the robust nature of heat transfer handled by usage of the BEP metric, the advantages of using this metric within popular energy modeling programs can be seen. With the current iteration of the BEP metric, the steady-state model is used, and the time variable (transient) effects were neglected. In order for the metric to be implemented into popular energy modeling programs, transient modeling implementations may need to be further explored.

With the current iteration, the BEP metric has a significant number of advantages. The metric is significantly more robust than R-value and U-factors alone, which are values for steady-state calculations by nature. The metric also takes airtightness into account in a realistic sense, rather than specifying airflow rates typically seen in literature (ORNL, 2018). Even for those outside of the energy modeling field, the BEP metric has worth as a comparison metric. It is easily calculated, so design options can be evaluated rapidly with recalculation of the BEP metric. The metric is also comparable between buildings, so energy performance can be compared through the metric as a quantitative assessment. This reduces confusion when enclosures are considered as a collection of effective elements, rather than evaluating each component individually. This also prevents the unexpected dependencies between enclosure components, such as the influence of thermal bridges on the overall wall R-value.

CONCLUSION

A concept of a building enclosure performance (BEP) metric was developed and presented in this paper. Results indicate a new BEP metric will be a powerful tool that can be calculated by nonprofessionals and professionals alike. It could be utilized to educate design-stage decisions, compared between building designs to gauge enclosure thermal and airtightness performance, and used to determine heat transfer through a building enclosure using readily available weather data. The BEP metric could also be calculated with established values required on building component specification sheets, so no professional testing of components would be required.

ORNL’s investigation shows that a BEP metric has potential to be used with existing thermal modeling tools or even as a

![Equation 16](image1)

\[
\text{BEP} = \frac{R_{\text{inf}}^{-1} + \frac{A_{\text{opa}}}{A_{\text{tot}}} \left( R_{\text{wall}}^{-1} + R_{\text{roof}}^{-1} \right) + \frac{A_{\text{fen}}}{A_{\text{tot}}} \left( U_{\text{fen}} \right)}{\delta_{\text{install}}}
\]

**Equation 16**

![Equation 17](image2)

\[
Q_{\text{env}} = \text{BEP} \cdot A_{\text{tot}} \cdot (T_{\text{out}} - T_{\text{in}}) + I_{\text{surf}} \cdot \left( \frac{\alpha \cdot A_{\text{opa}} \cdot R_{\text{clad,ext}}}{R_{\text{opa}}} + A_{\text{fen}} \cdot SHGC \right) + \frac{A_{\text{found}} \cdot (T_{\text{ground}} - T_{\text{in}})}{R_{\text{found}}}
\]

**Equation 17**

**Figure 7** – Initial validation between a complex simulation model and a simplified BEP-based model. The validation is made by simulating the net energy heat flux through the building enclosure in Knoxville, TN.
stand-alone calculation. The proposed BEP metric is capable of describing steady-state heat transfer through walls, windows, and roof structures. The metric itself is capable of handling heat transfer with solar heating being handled separately. The BEP metric also has potential to be worked into popular energy modeling tools, due to its straightforward nature. Implementation speeds of the BEP metric for thermal resistance modeling were significantly faster than writing equations for each heat transfer surface during our testing phases. A powerful numeric indicator, the BEP metric can also be used for thermal modeling.

ORNL will conduct additional validation studies to quantify values for the installation factor and further study air leakage schedules, thereby further refining the BEP metric. Currently, it is assumed that all enclosure components are installed in near-laboratory-like conditions, which may not always be true depending on the installer. Any future work done within the field of air leakage studies has potential to improve the BEP metric. There is also potential to implement useful variables that were not used in this study and to integrate the BEP metric into energy modeling tool kits, as it encompasses a large portion of heat-transfer processes within buildings. If used to its full advantage, the BEP metric has the potential to be a new industry standard for measuring building efficiency. Much like the adoption of mpg within the automotive industry, the BEP metric allows investors to have a singular metric to evaluate the thermal effectiveness of their buildings.

FUTURE WORK

The work presented in this paper is the initial step towards establishing a BEP metric that is well defined and can effortlessly be implemented into any phase of the building enclosure design. Future work will focus on further simplifications while still allowing for agreements with complex simulation models in an easy-to-use potentially web-based tool. The BEP model will also be compared to field and laboratory tests, and finally against real building data. Such work is expected to be conducted during 2019.

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REFERENCES


### Symbols

- **at**: Wind Terrain Coefficient
- **A**: Area ($m^2$)
- **ACH**: Air Changes per Hour ($hr^{-1}$)
- **BEP**: Building Enclosure Performance Metric ($W/(m^2 \cdot K)$)
- **C**: Air Flow Coefficient
- **$c_p$**: Specific Heat ($J/(kgK)$)
- **Q**: Heat Transfer ($W$)
- **$h$**: Heat Transfer Coefficient ($W/(m^2 \cdot K)$)
- **I**: Solar Irradiance ($W/m^2$)
- **K**: Wind Induced Pressure Coefficients
- **$k$**: Thermal Conductivity ($W/(m \cdot K)$)
- **$l$**: Length ($m$)
- **$n$**: Pressure Exponent
- **P**: Pressure ($Pa$)
- **$V$**: Volume ($m^3$)
- **$G_{\text{vol}}$**: Volumetric Flow Rate ($m^3/s$)
- **$R$**: Thermal Resistance/Wall R-value ($W/(m^2 \cdot K)$)
- **$R_g$**: Ground Reflectance
- **SHGC**: Solar Heat Gain Coefficient
- **$U$**: U-Factor/Overall Heat Transfer Coefficient ($W/(m^2 \cdot K)$)
- **$V$**: Velocity ($m/s$)
- **$z$**: Elevation

### Subscripts

- **$10m$**: Wind Measurements at Weather Station of 10 m Elevation from Ground Level
- **abs**: Absorbed
- **$b$**: Buoyancy
- **clad**: Cladding
- **cond**: Conduction
- **DHI**: Diffuse Horizontal Irradiance
- **DNI**: Direct Normal Irradiance
- **$e$**: Exterior Surface
- **ext**: Exterior
- **found**: Foundation
- **fen**: Fenestration (window)
- **GHI**: Global Horizontal Irradiance
- **ground**: Property of Ground at Depth of Component Contact
- **$i$**: Indoor Surface
- **in**: Indoor, Interior
- **inc**: Incident
- **inf**: Air Infiltration
- **$m$**: Localized Wind
- **$n$**: Natural Convection
- **o**: Combined Convection and Long-Wave Radiation for Outdoor Surfaces
- **out**: Outside
- **opaq**: Opaque
- **stat**: Observed Value at Weather Station
- **stud**: Vertical Framing Member
- **surf**: Surface
- **$t$**: Terrain
- **tot**: Total Surface Area of Envelope
- **$T$**: Total
- **$th$**: Thermal
- **wall**: Lumped Wall Assembly
- **$w$**: Wind

### Greek Letters

- **$\alpha$**: Absorptivity
- **$\beta$**: Surface Tilt Angle from Horizontal ($^\circ$)
- **$\xi$**: Surface Face Azimuth Angle Measured Clockwise from North ($^\circ$)
- **$\zeta$**: Solar Azimuth Angle Measured Clockwise from North ($^\circ$)
- **$\rho_{\text{air}}$**: Air Density ($kg/m^3$)
- **$\chi$**: Solar Zenith Angle Measured from Vertical ($^\circ$)