## *Mechanical Breadth Analysis*

## Thermal Performance of Exterior Wall Systems

### Background Information

Campus Square hosts a sizable curtain wall system along North 3rd Street which spans four stories, and is about one third the square footage of that face of the building. Furthermore, the building implements a brick façade and storefront system throughout the remaining faces of the building. Furthermore, GreenWorks Development chose to install a high performance building envelope for Campus Square, including energy efficient materials such as Energy Star® rated Pella® windows, low-e glazing, a white TPO built up roof system, as well as a more quality exterior wall assembly. All of the aforementioned sustainability efforts were port forth in order to establish a more energy efficient envelope, as well as LEED® implications for the building's gold certification.

As discussed in previous analysis sections, a proposed prefabricated exterior wall system would replace the as-built wall assembly as the primary exterior wall envelope. The two wall systems differ in materials used, as well as construction methods; where the proposed prefabricated system would be constructed out of EIFS exterior insulation and simulated brick stucco, with doors and windows installed.

Early during preconstruction, GreenWorks and Wohlsen decided to eliminate on the of the curtain wall systems from the east side of the building along 3rd Street. Although glazing benefits daylighting efforts within the building space, it degrades thermal efficiency. Through this value engineering effort approximately $20/SF was reduced in the façade price, additionally, savings may occur through thermal savings in operating costs. Figure 24 below highlights the location of the eliminated curtain wall system.

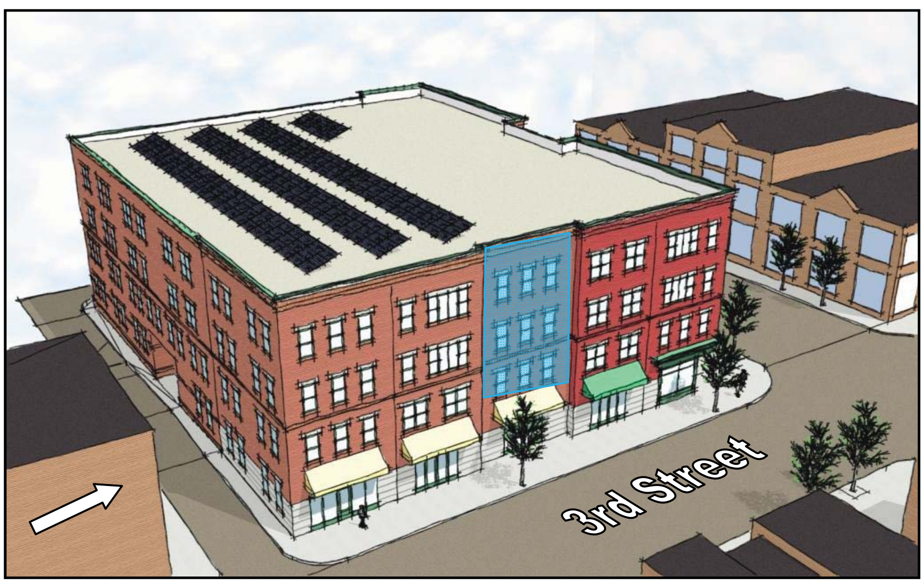


***Figure 24 – Additional Curtain Wall System Location***

Image courtesy Wohlsen Construction Company

**Overall Goals**

The goal of this analysis is to research, measure, and compare the thermal efficiency and moisture infiltration of the different envelope systems, including the proposed prefabricated wall system described in the structural breadth of this report. U-values will be obtained, and heat loss will be calculated comparing the different enclosure systems. The heat loss data, ideally, will demonstrate the thermal advantages of the proposed wall assembly over the as-built condition. Furthermore, a similar comparison will be made of the choice by Wohlsen and GreenWorks to value engineer out a large curtain wall system located on the east side of the building, similar to the one installed on the north side. Conclusions obtained from the analysis will compare energy efficiencies of each assembly.

**Methods**

- Perform literature review of submittals related to envelope materials
- Determine thermal ratings of all materials and assemblies used in envelope systems through the use of the *Heat, Air and Moisture Building Science Toolbox* software
- Perform take-offs of measurements of materials
- Analyze thermal efficiency and heat loss of wall assemblies and glazing
- Compare systems, and determine any energy efficiency benefits of prefabricated systems versus those constructed onsite based on performance.

**Resources**

- *Heat, Air and Moisture Building Science Toolbox*
- *Mechanical and Electrical Equipment for Buildings (Textbook by Benjamin Stein)*
- Submittal Log for Campus Square (Division 8- Doors and Windows)
- Wohlsen Construction Company (Project Manager for Campus Square)

**Expected Outcome**

Although the proposed prefabricated system will result in a higher upfront cost due to manufacturing and installation as indicated in other sections of this report, the added thermal efficiency should assist in reducing operational costs in heating and cooling. Due to the controlled environment of the proposed system's construction, a higher level of quality can be achieved. However, the higher thermal efficiency will be proportional to the increased CSF. The improved exterior wall assembly will reduce thermal penetration into the space of the building, reducing the amount of heating and cooling load the building will experience throughout its lifecycle.

The high efficiency masonry assembly used on Campus Square will prove to be above standard, and the decision of the project team to VE out an additional curtain wall system along Reily Street will prove to be beneficial in thermal savings. Although the curtain wall system is aesthetically pleasing and allows for increased daylighting, the system will prove to be thermally inefficient and less sustainable.

**Heat Loss Analysis**

Calculation of design heat loss is an estimation of the worst likely hourly heat flow from a building to the surrounding environment. This value is used to size heating and cooling systems; the greater the design heat loss, the larger the required heating system capacity. Design heat loss is not the highest heat loss that may occur, rather it is a reasonable maximum heat loss based upon design outside air temperatures. For this analysis, heat loss data will be used to compare the above grade, exterior wall systems of Campus Square, with the proposed prefabricated panels.

In order to determine heat loss through each wall assembly, the resistance (R-Value) of each material in the assembly must be identified. Resistance indicates how effective any material is an insulator. The R-Value is measured in hours needed for 1 BTU to flow through 1 $ft^2$ of a given thickness of material when the temperature difference is $1^oF$.

The U-Factor expresses the steady-state rate at which heat flows through architectural envelope assemblies. U-Factor is the overall coefficient of thermal transmittance expressed in terms of $BTU/hft^{2o}F$. U-Factors are calculated for a particular assembly by determining the resistance (R-Value) of each material, then adding these resistances to obtain a total resistance. However, it is important to realize that each material's U-Factor within the assembly is proportional to the overall square footage of the envelope system. Therefore, the U-Factor is the reciprocal of the sum of R-Values:

$$U=1/\Sigma R$$

Compared to other elements of the building envelope, wall U-Factors are fairly straightforward. There are minimal complications associated with computation such as ground contact, crawl spaces, or attic spaces. However, one of the largest impacts on wall analysis is incorporating thermal bridging; where framing interrupts insulation. Therefore, an averaged insulated value and uninsulated value must be obtained. This concept also applies to determining average values for wall penetrations such as windows and doors; compiling such values into an area-weighted resistance and U-Factor of the wall assembly.

The design sensible heat loss through all types of above-ground elements of the building envelope can be calculated as follows:

$$q=(U)(A)(\Delta t) \text{ for each element}$$

U= U-factor for a given envelope component
A= Surface area of the envelope component
$\Delta t$ = the design temperature difference between inside and outside air

*Existing Exterior Wall Assembly*

Through the use of the *Heating, Air and Moisture Building Science Toolbox* software (H.A.M), a cumulative R-Value of the exterior wall assembly could be obtained. This method had to be performed twice in order to compensate for thermal bridging. Therefore, an R-Value for both insulated, and uninsulated wall sections were calculated to be 20.51 and 3.86, respectfully. A dramatic difference between the two values can be attributed to the metal studs coming in contact with metal screws and other poor insulating material which adhere the layers of the assembly together. When poor insulators come in contact, they allow the outside temperature to flow through them, creating a thermal pathway in the assembly. Figure 25 below shows the calculated R-Value of the existing wall assembly.

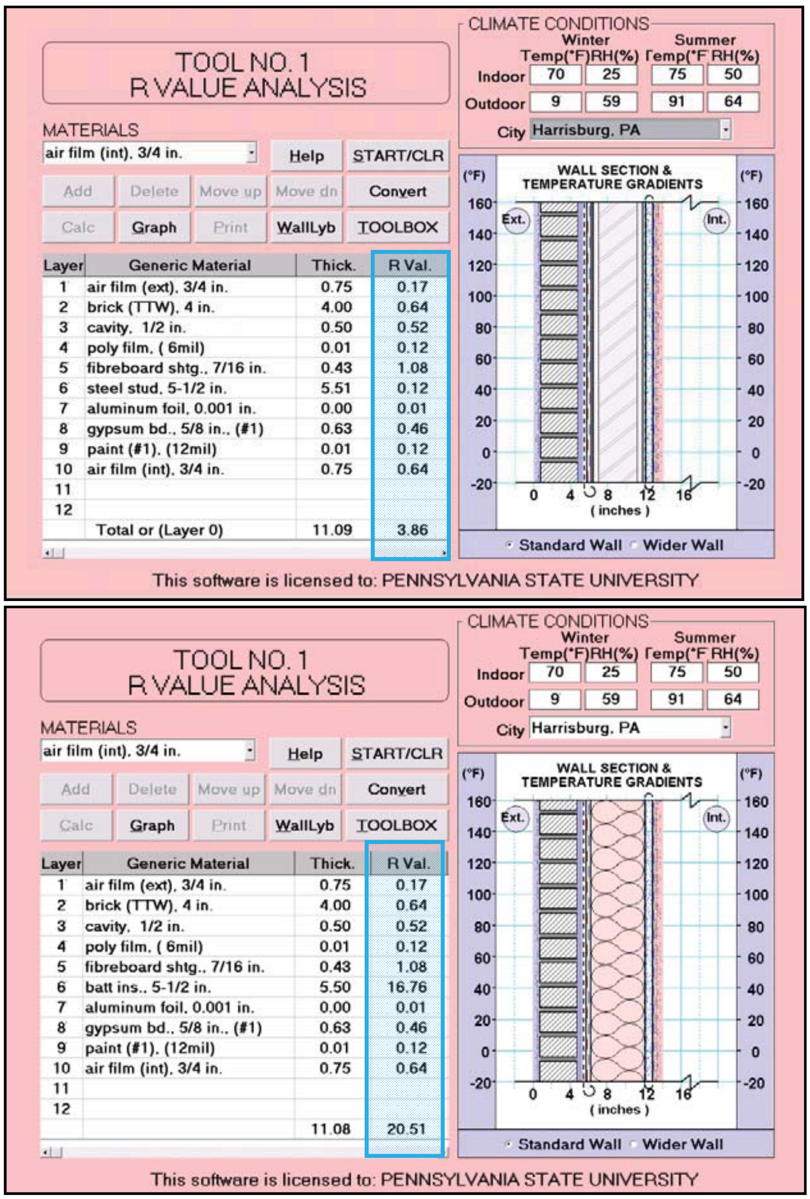


***Figure 25-Existing Wall Assembly R-Value Analysis***

Image produced using H.A.M. Toolbox software

*Glazing and Windows Analysis*

In order to correctly determine the heat loss through the exterior wall assemblies of Campus Square, a U-Value needed to be determined for the glazing used on the curtain wall system and the storefront windows and doors, as well as the Pella® windows. During the submittal process of preconstruction, performance results of the glass used were included. With these U-Values, the square footage of these materials was incorporated into the heat loss calculations in order to determine a total heat loss for all faces of the building. It was important to effectively determine these values due to the extensive heat loss through these particular materials. Figure 26 below highlights the test results obtained during the submittal process.

**PPG Industries Performance Glass Calculator Calculated *Center-of-Glass* Thermal and Optical Properties Based on NFRC 100-2001 Environmental Design Conditions**

| Details for Double Glazing as Specified | | | |
|---|---|---|---|
| Outdoor Glass Lite | 1/4" (6mm) Caribia | | |
| Gas Cavity Dimension | 1/2" (12mm) | | |
| Gas Fill | Air | | |
| Indoor Glass Lite | 1/4" (6mm) Sungate 500 on Clear (Surface #3) | | |
| Calculated Thermal and Optical Properties | | | |
| U-Values (K-Values) | Metric (Kcal/hr/m²/C) | Metric (W/m²/C) | English (BTU/hr/ft²/F) |
| Winter Nighttime | 1.69 | 1.97 | 0.35 |
| Summer Daytime | 1.71 | 1.98 | 0.35 |
| **Shading Coefficient** | 0.39 | | |
| **Solar Heat Gain Coefficient** | 0.34 | | |
| **Relative Heat Gain** | Metric (Kcal/hr/m²) 227 | Metric (W/m²) 264 | English (BTU/hr.ft²) 84 |

| Details for Monolithic Glazing as Specified | | | |
|---|---|---|---|
| Glass Lite | 1/4" (6mm) Clear | | |
| Calculated Thermal and Optical Properties | | | |
| U-Values (K-Values) | Metric (Kcal/hr/m²/C) | Metric (W/m²/C) | English (BTU/hr/ft²/F) |
| Winter Nighttime | 4.98 | 5.79 | 1.02 |
| Summer Daytime | 4.50 | 5.24 | 0.92 |
| **Shading Coefficient** | 0.93 | | |
| **Solar Heat Gain Coefficient** | 0.81 | | |
| **Relative Heat Gain** | Metric (Kcal/hr/m²) 541 | Metric (W/m²) 629 | English (BTU/hr.ft²) 199 |

***Figure 26 – Glazing Thermal Properties***

Table provided by Wohlsen Construction Company

*Proposed Prefabricated Wall Assembly*

Similar to the as-built wall assembly, the H.A.M software was utilized in determining a cumulative R-Value of the proposed exterior wall assembly. Likewise, this method had to be performed twice in order to compensate areas of metal stud and cavity space. Therefore, an R-Value for both metal stud, and cavity wall sections were calculated to be 19.79 and 20.66, respectfully. The proposed wall assembly implements an EIFS exterior finish which acts as an exterior insulator, which thermally outperforms the material currently used. Also, the manufacturing methods used to adhere the materials together mitigate thermal bridging through the metal studs. Because this is true, the proposed assembly has an improved, more balanced U-Value over the original design. Figure 27 below shows the calculated R-Value of the proposed prefabricated wall assembly.

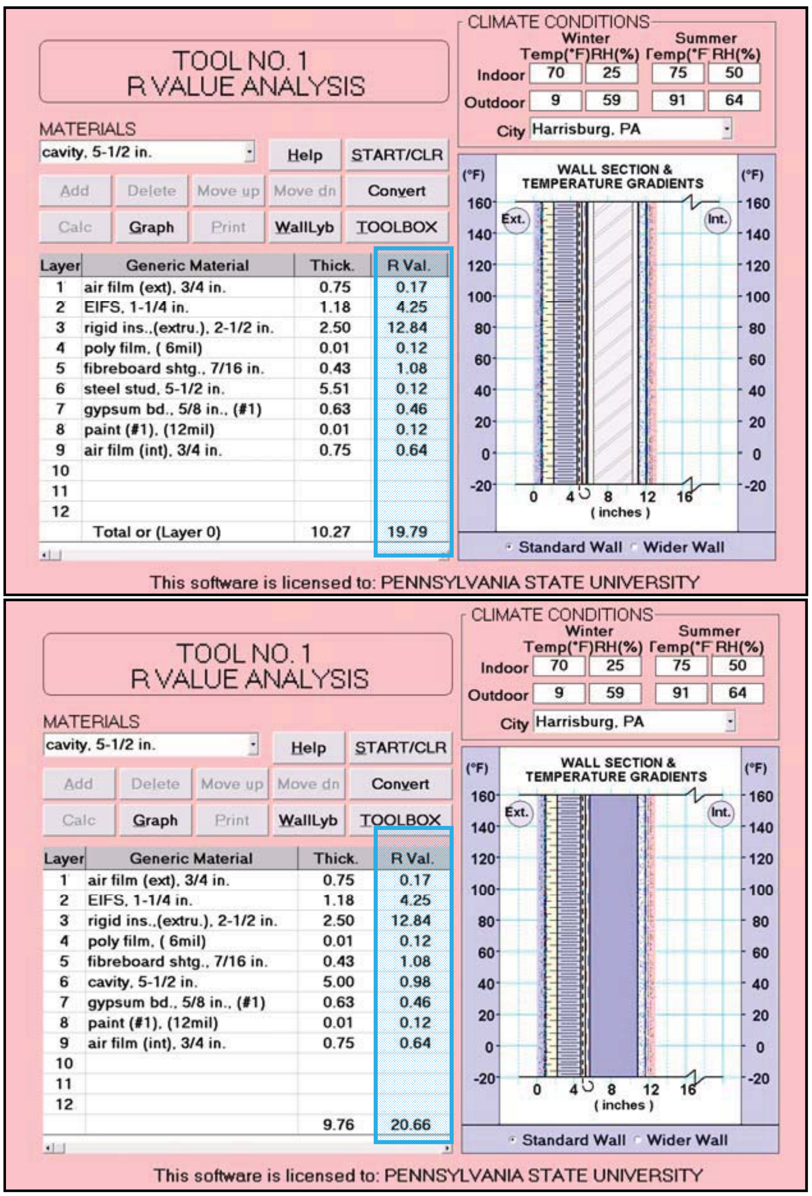


***Figure 27- Proposed Wall Assembly R-Value Analysis***

Image produced using H.A.M. Toolbox software

*Results*

Once the take-offs were tabulated, determining the square footage of each material used throughout the different exterior wall assemblies, the heat loss for Campus Square could be calculated using the heat loss equation mentioned earlier in this analysis section. As hypothesized, the prefabricated wall assembly thermally outperforms the as-built condition. This is attributed to better insulating materials, as well as a more effective wall assembly. As Figure 28 summarizes below, the prefabricated panels reduce the heat loss through the exterior wall envelope by 13.5% in the summer, and 13% in the winter. These values represent the inclusion of all exterior doors, windows, glazing, and brick/EIFS assemblies. The reduction in heat loss through the exterior walls will not only result in a more thermally efficient and sustainable building, but will also reduce operational costs in heating and cooling. The complete heat loss calculation data may be observed in Appendix D of this report.

| Exterior Wall Heat Loss (Q) Comparison Table | | | | | | | |
|---|---|---|---|---|---|---|---|
| As-Built (Q) | | Prefabricated (Q) | | Difference | | | |
| Summer | Winter | Summer | Winter | Summer Δ | % Summer | Winter Δ | % Winter |
| 90100.89 | 357092.64 | 77965.69 | 310827.18 | **12135.20** | **13.5%** | **46265.46** | **13.0%** |

***Figure 28 – Heat Loss Comparison Data***

*Value Engineering Impact*

As previously mentioned in the background information section of this analysis, GreenWorks and Wohlsen opted to eliminated a 3-story curtain wall system along the east side of the building. This was mainly done to reduce the façade square foot cost. However, savings can also be seen in the added thermal performance of the as-built assembly. Figure 29 below demonstrates the heat loss comparison of the proposed prefabricated panels with the originally proposed curtain wall system along Reily Street. A dramatic difference is observed in thermal performance if the curtain wall was added, compared to the proposed prefabricated panels. The data compares the heat loss differences between the as-built system and the prefabricated panels; as well as the difference between the prefabricated system and a curtain wall addition in the same region of the building.

| East Side Heat Loss Comparison of Prefabricated System & Curtain Wall Addition | | | | | |
|---|---|---|---|---|---|
| As-Built | | Prefabricated Panels | | Curtain Wall Addition | |
| Q (Summer) | Q (Winter) | Q (Summer) | Q (Winter) | Q (Summer) | Q (Winter) |
| 10719.10 | 40866.56 | 8613.93 | 32840.60 | 14602.24 | 61722.24 |
| **Percent Difference** | | **19.6%** | **19.6%** | **-69.5%** | **-87.9%** |

***Figure 29 – Heat Loss Comparison Data***

**Conclusions and Recommendations**

By comparing the heat loss data of the varied envelope systems used in the exterior wall assemblies, as well as the proposed system, it is evident that a prefabricated wall system is thermally advantageous over the as-built condition. The proposed assembly will assist in reducing operation costs throughout the year, as well as assisting in a quicker payback period due to the heating and cooling savings. Perhaps the most critical advantage of the prefabricated assembly is the implantation of EIFS on the exterior of the building. EIFS acts as an insulator, as well as accomplishes the aesthetic design considerations of Campus Square. When constructing exterior wall systems, it is important to avoid excessive glazing and/or wall penetrations, as these will reduce the thermal effectiveness of the envelope system. Furthermore, the proposed assembly mitigates thermal bridging through the wall, which is one of the larger contributors to thermal loss. A more in-depth study of the thermal properties, including heat gain analysis, may further demonstrate the advantages of implementing the proposed methods.