# BUILDING ENVELOPE

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## Specifications

The building envelope performs various tasks, which includes protection from wind, rain, irradiation, heat and cold, visibility and glare protection, fire protection, noise protection, and physical security. At the same time, the building envelope must fulfill internal space requirements, which include thermal, acoustic, and visual comfort along with requirements for humidity conditions for both comfort, and mold and mildew growth prevention.

Thermal performance of the building envelope influences the energy demand of a building in two ways. It affects annual energy consumption, therefore the operating costs for building heating, cooling, and humidity control. It also influences peak loads which consequently determine the size of heating, cooling and energy generation equipment and in this way has an impact on investment costs. In addition to energy saving and investment cost reduction, a better insulated building provides other significant advantages, including higher thermal comfort because of warmer surface temperatures on the interior surfaces in winter and lower temperatures in summer. This also results in a lower risk of mold growth on internal surfaces.

There are several prescriptive sets of building criteria available to attain the thermal and comfort benefits specified above, and ASHRAE has published several of them. The ASHRAE Standard 90.1-2007 provides prescriptive requirements for building envelopes as a function of assembly type, climate zone, and building type are listed in Section 5.5 and Tables 5.5-1 to 5.5-8 in the Standard published by ASHRAE. This is a minimum code and when adopted by an enforcing jurisdiction this becomes the minimum code allowed by law. Figure 1 shows a map of the climate zones used in ASHRAE Standard 90.1-2007 and in the remainder of this document.

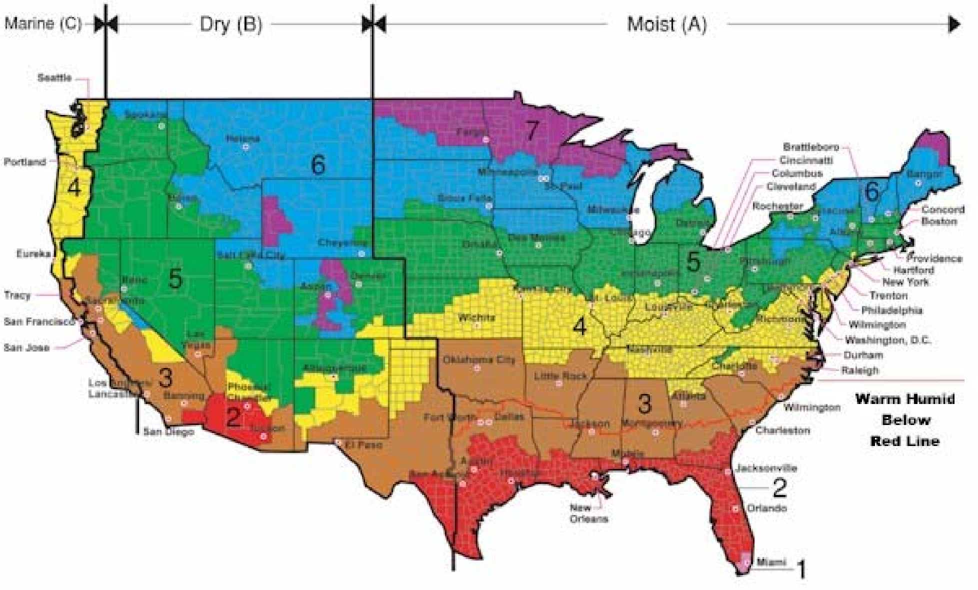

Figure 1. Climate Zones in ASHRAE Standard 90.1-2004.

To help designers with meeting above code goals or requirements for building several building types ASHRAE has published their Advanced Energy Design Guides. The building types that are currently available are small office buildings, small retail buildings, K-12 school buildings, small warehouses and self-storage buildings, and small healthcare facilities which give prescriptive requirements and energy conservation measures to achieve 30% energy savings over ANSI/ASHRAE/IESNA Standard 90.1-1999. These Advanced Energy Design Guides can be obtained from the ASHRAE bookstore or downloaded for free from the following website: http://www.ashrae.org/technology/page/938

Studies conducted by USACE in collaboration with DOE and ASHRAE resulted in prescriptive thermal properties (shown in Tables 1 through 7) of the building envelop components which shall be followed to meet the Section 109 of EPAct 2005 requirement for 30% over the ASHRAE Standard 90.1-2004 building energy performance. These requirements shall be met with all new construction and major renovation projects.

Table 1. Barracks – UEPH and Training.

| **Item** | **Component (1)** | **Climate Zones** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| **Roof** | Assembly Max U-value | U-0.0388 | U-0.0388 | U-0.0388 | U-0.0325 | U-0.0325 | U-0.0245 | U-0.0245 | U-0.0245 |
| | Insulation Entirely Above Deck | R-25ci | R-25ci | R-25ci | R-30ci | R-30ci | R-40ci | R-40ci | R-40ci |
| | Attic and Other | R-38 | R-38 | R-38 | R-49 | R-49 | R-60 | R-60 | R-60 |
| | Solar Reflectance (2) | High | High | High | High | High | Low | Low | Low |
| **Walls** | Assembly Max U-value | U-0.0676 | U-0.0676 | U-0.0676 | U-0.0676 | U-0.0512 | U-0.0373 | U-0.0373 | U-0.0373 |
| | Mass | R-13 | R-13 | R-13 | R-13 | R-19.5 | R-19 + R-3ci | R-19 + R-3ci | R-19 + R-3ci |
| | Steel Framed | R-13 + R-7.5ci | R-13 + R-7.5ci | R-13 + R-7.5ci | R-13 + R-7.5ci | R-13 + R-12.5ci | R-13 + R-18.8ci | R-13 + R-18.8ci | R-13 + R-18.8ci |
| | Wood Framed and Other | R-13 + R-3.8ci | R-13 + R-3.8ci | R-13 + R-3.8ci | R-13 + R-3.8ci | R-13 + R-7.5ci | R-13 + R-15.6ci | R-13 + R-15.6ci | R-13 + R-15.6ci |
| **Floors Over Unconditioned Space** | Assembly Max U-value | U-0.1067 | U-0.0739 | U-0.0739 | U-0.0521 | U-0.0521 | U-0.0377 | U-0.0377 | U-0.0377 |
| | Mass | R-6.3ci | R-10.4ci. | R-10.4ci. | R-16.7ci. | R-16.7ci. | R-25.1ci. | R-25.1ci. | R-25.1ci. |
| | Steel Joists | R-13 | R-13 | R-13 | R-19 | R-19 | R-30 | R-30 | R-30 |
| | Wood Framed and Others | R-13 | R-13 | R-13 | R-19 | R-19 | R-30 | R-30 | R-30 |
| **Slab-on-Grade** | Assembly Max U-value | F-0.730 | F-0.730 | F-0.730 | F-0.520 | F-0.520 | F-0.510 | F-0.510 | F-0.434 |
| | Unheated | NR (3) | NR (3) | NR (3) | R-15.0 for 24 in. | R-15.0 for 24 in. | R-20.0 for 24 in. | R-20.0 for 24 in. | R-20.0 for 48 in |
| **Doors** | Swinging | U-0.70 | U-0.70 | U-0.70 | U-0.50 | U-0.50 | U-0.50 | U-0.50 | U-0.50 |
| | Non-swinging | U-1.45 | U-1.45 | U-1.45 | U-0.50 | U-0.50 | U-0.50 | U-0.50 | U-0.50 |
| **Air Tightness** (4) | Max Leakage at ±75Pa Blower Test Pressures | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ |
| **Vertical Glazing** | Window to Wall Ratio (WWR) | 10% - 20% | 10% - 20% | 10% - 20% | 10% - 20% | 10% - 20% | 10% - 20% | 10% - 20% | 10% - 20% |
| | Thermal transmittance (Assembly Maximum) | U-0.45 | U-0.45 | U-0.45 | U-0.45 | U-0.42 | U-0.42 | U-0.33 | U-0.33 |
| | Solar heat gain coefficient (SHGC) | 0.25 | 0.25 | 0.31 | 0.31 | 0.39 | 0.39 | NR (3) | NR (3) |

Table 2. Tactical Equipment Maintenance Facility - TEMF

| Item | Component(1) | Climate Zones | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| **Roof** | Assembly Max U-value | U-0.0750 | U-0.0750 | U-0.0660 | U-0.0490 | U-0.0490 | U-0.0490 | U-0.0388 | U-0.0325 |
| | Insulation Entirely Above Deck | R-15ci | R-15ci | R-15ci | R-20ci | R-20ci | R-20ci | R-25ci | R-30ci |
| | Metal Building | R-13 + R-13 | R-13 + R-13 | R-19 + R-19 | R-19 + R-11 LS | R-19 + R-11 LS | R-19 + R-11 LS | R-19 + R-11 LS | R-25 + R-11 LS |
| | Attic and Other | R-19 | R-19 | R-19 | R-38 | R-38 | R-38 | R-49 | R-49 |
| | Solar Reflectance (2) | High | High | High | High | High | Low | Low | Low |
| **Walls** | Assembly Max U-value | U-0.1667 | U-0.1667 | U-0.1667 | U-0.1667 | U-0.0595 | U-0.0595 | U-0.0595 | U-0.0391 |
| | Mass | R-11.4 | R-11.4 | R-11.4 | R-11.4 | R-15.0 | R-15.0 | R-15.0 | R-11.4 + 3.0ci |
| | Steel Framed | R-13 | R-13 | R-13 | R-13 | R-13 + 12.5ci | R-13 + 12.5ci | R-13 + 12.5ci | R-13 + 18.8ci |
| | Metal Building | R-13 | R-13 | R-13 | R-13 | R-13 + 13.0ci | R-13 + 13.0ci | R-13 + 13.0ci | R-13 + 19.5ci |
| **Floors Over Unconditioned Space** | Assembly Max U-value | U-0.1067 | U-0.1067 | U-0.1067 | U-0.0739 | U-0.0521 | U-0.0377 | U-0.0377 | U-0.0377 |
| | Mass | R-6.3ci | R-6.3ci | R-6.3ci | R-10.4ci. | R-16.7ci. | R-25.1ci. | R-25.1ci. | R-25.1ci. |
| | Steel Joists | R-13 | R-13 | R-13 | R-13 | R-19 | R-30 | R-30 | R-30 |
| | Wood Framed and Others | R-13 | R-13 | R-13 | R-13 | R-19 | R-30 | R-30 | R-30 |
| **Slab-on-Grade** | Assembly Max U-value Unheated | F-0.730 ;<br>NR (3) | F-0.730 ;<br>NR (3) | F-0.730 ;<br>NR (3) | F-0.520 ;<br>R-15.0 for 24 in. | F-0.520 ;<br>R-15.0 for 24 in. | F-0.510 ;<br>R-20.0 for 24 in. | F-0.510 ;<br>R-20.0 for 24 in. | F-0.434 ;<br>R-20.0 for 48 in. |
| | Assembly Max U-value Heated | NA | F-0.900 ;<br>R-10 for 24 in | F-0.860 ;<br>R-15.0 for 24 in. | F-0.843 ;<br>R-20 for 24 in. | F-0.688;<br>R-20.0 for 48 in | F-0.688;<br>R-20.0 for 48 in | F-0.671;<br>R-25.0 for 48 in | F-0.671;<br>R-25.0 for 48 in |
| **Doors** | Swinging | U-0.70 | U-0.70 | U-0.70 | U-0.50 | U-0.50 | U-0.50 | U-0.50 | U-0.50 |
| | Non-swinging | U-0.50 | U-0.50 | U-0.50 | U-0.50 | U-0.50 | U-0.50 | U-0.50 | U-0.50 |
| **Air Tightness** (4) | Max Leakage at ±75Pa Test Pressures | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ |
| **Vertical Glazing** | Window to Wall Ratio (WWR) | < 10% | < 10% | < 10% | < 10% | < 10% | < 10% | < 10% | < 10% |
| | Thermal transmittance | U-0.56 | U-0.45 | U-0.45 | U-0.42 | U-0.42 | U-0.42 | U-0.33 | U-0.33 |
| | Solar heat gain coefficient (SHGC) | 0.25 | 0.25 | 0.37 | 0.39 | 0.39 | 0.39 | NR (3) | NR (3) |
| **Skylights** | Percent Roof Area | ≤ 2% | ≤ 2% | ≤ 2% | ≤ 2% | ≤ 2% | ≤ 2% | ≤ 2% | ≤ 2% |
| | Thermal transmittance | U-1.36 | U-1.36 | U-0.69 | U-0.69 | U-0.69 | U-0.69 | U-0.69 | U-0.58 |
| | Solar heat gain coefficient (SHGC) | 0.19 | 0.19 | 0.19 | 0.34 | 0.39 | 0.49 | 0.64 | NR (3) |

Table 3. Battalion HQ - BHQ

| Item | Component (1) | Climate Zones | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| **Roof** | Assembly Max U-value | U-0.0481 | U-0.0388 | U-0.0388 | U-0.0388 | U-0.0325 | U-0.0325 | U-0.0245 | U-0.0245 |
| | Insulation Entirely Above Deck | R-20ci | R-25ci | R-25ci | R-25ci | R-30ci | R-30ci | R-40ci | R-40ci |
| | Attic and Other | R-30 | R-38 | R-38 | R-38 | R-49 | R-49 | R-60 | R-60 |
| | Solar Reflectance (2) | High | High | High | High | High | Low | Low | Low |
| **Walls** | Assembly Max U-value | U-0.1242 | U-0.1242 | U-0.1242 | U-0.0676 | U-0.0676 | U-0.0676 | U-0.0512 | U-0.0373 |
| | Mass | R-6.5ci | R-6.5ci | R-6.5ci | R-13 | R-13 | R-13 | R-19 | R-19 + R-3ci |
| | Steel Framed | R-13 | R-13 | R-13 | R-13 + R-7.5ci | R-13 + R-7.5ci | R-13 + R-7.5ci | R-13 + R-12.5ci | R-13 + R-18.8ci |
| | Wood Framed and Other | R-13 | R-13 | R-13 | R-13 + R-3.8ci | R-13 + R-3.8ci | R-13 + R-3.8ci | R-13 + R-7.5ci | R-13 + R-15.6ci |
| **Floors Over Unconditioned Space** | Assembly Max U-value | U-0.1067 | U-0.0739 | U-0.0739 | U-0.0739 | U-0.0521 | U-0.0377 | U-0.0377 | U-0.0377 |
| | Mass | R-6.3ci | R-10.4ci. | R-10.4ci. | R-10.4ci. | R-16.7ci. | R-25.1ci. | R-25.1ci. | R-25.1ci. |
| | Steel Joists | R-13 | R-13 | R-13 | R-13 | R-19 | R-30 | R-30 | R-30 |
| | Wood Framed and Others | R-13 | R-13 | R-13 | R-13 | R-19 | R-30 | R-30 | R-30 |
| **Slab-on-Grade** | Assembly Max U-value | F-0.730 | F-0.730 | F-0.730 | F-0.520 | F-0.520 | F-0.510 | F-0.510 | F-0.434 |
| | Unheated | NR (3) | NR (3) | NR (3) | R-15.0 for 24 in. | R-15.0 for 24 in. | R-20.0 for 24 in. | R-20.0 for 24 in. | R-20.0 for 48 in |
| **Doors** | Swinging | U-0.70 | U-0.70 | U-0.70 | U-0.50 | U-0.50 | U-0.50 | U-0.50 | U-0.50 |
| | Non-swinging | U-1.45 | U-1.45 | U-1.45 | U-0.50 | U-0.50 | U-0.50 | U-0.50 | U-0.50 |
| **Air Tightness** (4) | Max Leakage at ±75Pa Blower Test Pressures | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ |
| **Vertical Glazing** | Window to Wall Ratio (WWR) | 10%-20% - East/West<br>10%-40% - North/South | 10%-20% - East/West<br>10%-40% - North/South | 10%-20% - East/West<br>10%-40% - North/South | 10%-20% - East/West<br>10%-40% - North/South | 10%-20% - East/West<br>10%-40% - North/South | 10%-20% - East/West<br>10%-40% - North/South | 10%-20% - East/West<br>10%-40% - North/South | 10%-20% - East/West<br>10%-40% - North/South |
| | Thermal transmittance (Assembly Maximum) | U-0.56 | U-0.45 | U-0.45 | U-0.42 | U-0.42 | U-0.42 | U-0.33 | U-0.33 |
| | Solar heat gain coefficient (SHGC) | 0.25 | 0.25 | 0.37 | 0.39 | 0.39 | 0.39 | NR (3) | NR (3) |
| | South Overhangs | Yes; Projection Factor = 0.4 | Yes; Projection Factor = 0.4 | Yes; Projection Factor = 0.4 | Yes; Projection Factor = 0.4 | Yes; Projection Factor = 0.4 | Yes; Projection Factor = 0.4 | Yes; Projection Factor = 0.4 | NR (3) |

Table 4. Central Operating Facilities - COF

| Item | Component (1) | Climate Zones | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| **Roof** | Assembly Max U-value | U-0.0481 | U-0.0481 | U-0.0388 | U-0.0388 | U-0.0388 | U-0.0388 | U-0.0325 | U-0.0325 |
| | Insulation Entirely Above Deck | R-20ci | R-20ci | R-25ci | R-25ci | R-25ci | R-25ci | R-30ci | R-30ci |
| | Attic and Other | R-30 | R-30 | R-38 | R-38 | R-38 | R-38 | R-49 | R-49 |
| | Solar Reflectance (2) | High | High | High | High | High | Low | Low | Low |
| **Walls** | Assembly Max U-value | U-0.1242 | U-0.1242 | U-0.0847 | U-0.0676 | U-0.0676 | U-0.0676 | U-0.0595 | U-0.0391 |
| | Mass | R-6.5ci | R-6.5ci | R-10 | R-13 | R-13 | R-13 | R-15.0 | R-11.4 + R-3.0ci |
| | Steel Framed | R-13 | R-13 | R-13 + R-3.8ci | R-13 + R-7.5ci | R-13 + R-7.5ci | R-13 + R-7.5ci | R-13 + R-12.5ci | R-13 + R-18.8ci |
| | Wood Framed and Other | R-13 | R-13 | R-13 | R-13 + R-3.8ci | R-13 + R-3.8ci | R-13 + R-3.8ci | R-13 + R-13.0ci | R-13 + R-19.5ci |
| **Floors Over Unconditioned Space** | Assembly Max U-value | U-0.1067 | U-0.1067 | U-0.0739 | U-0.0739 | U-0.0521 | U-0.0377 | U-0.0377 | U-0.0377 |
| | Mass | R-6.3ci | R-6.3ci | R-10.4ci. | R-10.4ci. | R-16.7ci. | R-25.1ci. | R-25.1ci. | R-25.1ci. |
| | Steel Joists | R-13 | R-13 | R-13 | R-13 | R-19 | R-30 | R-30 | R-30 |
| | Wood Framed and Others | R-13 | R-13 | R-13 | R-13 | R-19 | R-30 | R-30 | R-30 |
| **Slab-on-Grade** | Assembly Max U-value Unheated | F-0.730 ;<br>NR (3) | F-0.730 ;<br>NR (3) | F-0.730 ;<br>NR (3) | F-0.520 ;<br>R-15.0 for 24 in. | F-0.520 ;<br>R-15.0 for 24 in. | F-0.510 ;<br>R-20.0 for 24 in. | F-0.510 ;<br>R-20.0 for 24 in. | F-0.434 ;<br>R-20.0 for 48 in. |
| | Assembly Max U-value Heated | F-1.020;<br>R-7.5 for 12 in | F-0.900 ;<br>R-10 for 24 in | F-0.860 ;<br>R-15.0 for 24 in. | F-0.843 ;<br>R-20 for 24 in. | F-0.688;<br>R-20.0 for 48 in | F-0.688;<br>R-20.0 for 48 in | F-0.671;<br>R-25.0 for 48 in | F-0.671;<br>R-25.0 for 48 in |
| **Doors** | Swinging | U-0.70 | U-0.70 | U-0.70 | U-0.50 | U-0.50 | U-0.50 | U-0.50 | U-0.50 |
| | Non-swinging | U-1.45 | U-1.45 | U-1.45 | U-0.50 | U-0.50 | U-0.50 | U-0.50 | U-0.50 |
| **Air Tightness** (4) | Max Leakage at ±75Pa Blower Test Pressures | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ |
| **Vertical Glazing** | Window to Wall Ratio (WWR) | < 15% | < 15% | < 15% | < 15% | < 15% | < 15% | < 15% | < 15% |
| | Thermal transmittance (Assembly Maximum) | U-0.56 | U-0.45 | U-0.45 | U-0.42 | U-0.42 | U-0.42 | U-0.33 | U-0.33 |
| | Solar heat gain coefficient (SHGC) | 0.25 | 0.25 | 0.25 | 0.39 | 0.39 | 0.39 | 0.45 | NR (3) |
| | South Overhangs | Yes; Projection Factor = 0.4 | Yes; Projection Factor = 0.4 | Yes; Projection Factor = 0.4 | Yes; Projection Factor = 0.4 | Yes; Projection Factor = 0.4 | Yes; Projection Factor = 0.4 | Yes; Projection Factor = 0.4 | NR (3) |

### Table 5. Child Development Centers – CDC

| Item | Component (1) | Climate Zones | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| **Roof** | Assembly Max U-value | U-0.0481 | U-0.0388 | U-0.0388 | U-0.0388 | U-0.0388 | U-0.0325 | U-0.0245 | U-0.0245 |
| | Insulation Entirely Above Deck | R-20ci | R-25ci | R-25ci | R-25ci | R-25ci | R-30ci | R-40ci | R-40ci |
| | Attic and Other | R-30 | R-38 | R-38 | R-38 | R-38 | R-49 | R-60 | R-60 |
| | Solar Reflectance (2) | High | High | High | High | High | Low | Low | Low |
| **Walls** | Assembly Max U-value | U-0.1242 | U-0.1242 | U-0.0847 | U-0.0676 | U-0.0676 | U-0.0676 | U-0.0595 | U-0.0391 |
| | Mass | R-6.5ci | R-6.5ci | R-10 | R-13 | R-13 | R-13 | R-15.0 | R-11.4 + R-3.0ci |
| | Steel Framed | R-13 | R-13 | R-13 + R-3.8ci | R-13 + R-7.5ci | R-13 + R-7.5ci | R-13 + R-7.5ci | R-13 + R-12.5ci | R-13 + R-18.8ci |
| | Wood Framed and Other | R-13 | R-13 | R-13 | R-13 + R-3.8ci | R-13 + R-3.8ci | R-13 + R-3.8ci | R-13 + R-13.0ci | R-13 + R-19.5ci |
| **Floors Over Unconditioned Space** | Assembly Max U-value | U-0.1067 | U-0.1067 | U-0.0739 | U-0.0739 | U-0.0521 | U-0.0377 | U-0.0377 | U-0.0377 |
| | Mass | R-6.3ci | R-6.3ci | R-10.4ci. | R-10.4ci. | R-16.7ci. | R-25.1ci. | R-25.1ci. | R-25.1ci. |
| | Steel Joists | R-13 | R-13 | R-13 | R-13 | R-19 | R-30 | R-30 | R-30 |
| | Wood Framed and Others | R-13 | R-13 | R-13 | R-13 | R-19 | R-30 | R-30 | R-30 |
| **Slab-on-Grade** | Assembly Max U-value Unheated | F-0.730 ;<br>NR (3) | F-0.730 ;<br>NR (3) | F-0.730 ;<br>NR (3) | F-0.520 ;<br>R-15.0 for 24 in. | F-0.520 ;<br>R-15.0 for 24 in. | F-0.510 ;<br>R-20.0 for 24 in. | F-0.510 ;<br>R-20.0 for 24 in. | F-0.434 ;<br>R-20.0 for 48 in. |
| | Assembly Max U-value Heated | F-1.020;<br>R-7.5 for 12 in | F-1.020;<br>R-7.5 for 12 in | F-0.860 ;<br>R-15.0 for 24 in. | F-0.843 ;<br>R-20 for 24 in. | F-0.688;<br>R-20.0 for 48 in | F-0.688;<br>R-20.0 for 48 in | F-0.671;<br>R-25.0 for 48 in | F-0.671;<br>R-25.0 for 48 in |
| **Doors** | Swinging | U-0.70 | U-0.70 | U-0.70 | U-0.50 | U-0.50 | U-0.50 | U-0.50 | U-0.50 |
| | Non-swinging | U-1.45 | U-1.45 | U-1.45 | U-0.50 | U-0.50 | U-0.50 | U-0.50 | U-0.50 |
| **Air Tightness** (4) | Max Leakage at ±75Pa Blower Test Pressures | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ |
| **Vertical Glazing** | Window to Wall Ratio (WWR) | < 20% | < 20% | < 20% | < 20% | < 20% | < 20% | < 20% | < 20% |
| | Thermal transmittance (Assembly Maximum) | U-0.56 | U-0.45 | U-0.45 | U-0.42 | U-0.42 | U-0.42 | U-0.33 | U-0.33 |
| | Solar heat gain coefficient (SHGC) | 0.25 | 0.25 | 0.37 | 0.39 | 0.39 | 0.39 | 0.45 | NR (3) |
| | South Overhangs | NR (3) | NR (3) | NR (3) | NR (3) | NR (3) | NR (3) | NR (3) | NR (3) |

Table 6. Dining Facilities - DFAC

| Item | Component (1) | Climate Zones | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| **Roof** | Assembly Max U-value | U-0.0634 | U-0.0634 | U-0.0481 | U-0.0481 | U-0.0481 | U-0.0388 | U-0.0388 | U-0.0388 |
| | Insulation Entirely Above Deck | R-15ci | R-15ci | R-20ci | R-20ci | R-20ci | R-25ci | R-25ci | R-25ci |
| | Attic and Other | R-19 | R-19 | R-30 | R-30 | R-30 | R-38 | R-38 | R-38 |
| | Solar Reflectance (2) | High | High | High | High | High | Low | Low | Low |
| **Walls** | Assembly Max U-value | U-0.1242 | U-0.1242 | U-0.0847 | U-0.0676 | U-0.0676 | U-0.0676 | U-0.0676 | U-0.0391 |
| | Mass | R-6.5ci | R-6.5ci | R-10 | R-13 | R-13 | R-13 | R-13 | R-11.4 + R-3.0ci |
| | Steel Framed | R-13 | R-13 | R-13 + R-3.8ci | R-13 + R-7.5ci | R-13 + R-7.5ci | R-13 + R-7.5ci | R-13 + R-7.5ci | R-13 + R-18.8ci |
| | Wood Framed and Other | R-13 | R-13 | R-13 | R-13 + R-3.8ci | R-13 + R-3.8ci | R-13 + R-3.8ci | R-13 + R-3.8ci | R-13 + R-19.5ci |
| **Floors Over Unconditioned Space** | Assembly Max U-value | U-0.1067 | U-0.1067 | U-0.0739 | U-0.0739 | U-0.0521 | U-0.0377 | U-0.0377 | U-0.0377 |
| | Mass | R-6.3ci | R-6.3ci | R-10.4ci. | R-10.4ci. | R-16.7ci. | R-25.1ci. | R-25.1ci. | R-25.1ci. |
| | Steel Joists | R-13 | R-13 | R-13 | R-13 | R-19 | R-30 | R-30 | R-30 |
| | Wood Framed and Others | R-13 | R-13 | R-13 | R-13 | R-19 | R-30 | R-30 | R-30 |
| **Slab-on-Grade** | Assembly Max U-value Unheated | F-0.730 ;<br>NR (3) | F-0.730 ;<br>NR (3) | F-0.730 ;<br>NR (3) | F-0.520 ;<br>R-15.0 for 24 in. | F-0.520 ;<br>R-15.0 for 24 in. | F-0.510 ;<br>R-20.0 for 24 in. | F-0.510 ;<br>R-20.0 for 24 in. | F-0.434 ;<br>R-20.0 for 48 in. |
| | Assembly Max U-value Heated | F-1.020;<br>R-7.5 for 12 in | F-1.020;<br>R-7.5 for 12 in | F-0.860 ;<br>R-15.0 for 24 in. | F-0.843 ;<br>R-20 for 24 in. | F-0.688;<br>R-20.0 for 48 in | F-0.688;<br>R-20.0 for 48 in | F-0.671;<br>R-25.0 for 48 in | F-0.671;<br>R-25.0 for 48 in |
| **Doors** | Swinging | U-0.70 | U-0.70 | U-0.70 | U-0.50 | U-0.50 | U-0.50 | U-0.50 | U-0.50 |
| | Non-swinging | U-1.45 | U-1.45 | U-1.45 | U-0.50 | U-0.50 | U-0.50 | U-0.50 | U-0.50 |
| **Air Tightness** (4) | Max Leakage at ±75Pa Blower Test Pressures | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ |
| **Vertical Glazing** | Window to Wall Ratio (WWR) | < 20% | < 20% | < 20% | < 20% | < 20% | < 20% | < 20% | < 20% |
| | Thermal transmittance (Assembly Maximum) | U-1.22 | U-1.22 | U-0.57 | U-0.42 | U-0.42 | U-0.42 | U-0.33 | U-0.33 |
| | Solar heat gain coefficient (SHGC) | 0.25 | 0.25 | 0.37 | 0.39 | 0.39 | 0.39 | NR (3) | NR (3) |
| | South Overhangs | NR (3) | NR (3) | NR (3) | NR (3) | NR (3) | NR (3) | NR (3) | NR (3) |
| **Skylights** (Dining and Servery) | Percent Roof Area | ≤4% | ≤4% | ≤4% | ≤4% | ≤4% | ≤4% | ≤4% | None |
| | Thermal transmittance (Assembly Maximum) | U-1.36 | U-1.36 | U-0.69 | U-0.69 | U-0.69 | U-0.69 | U-0.69 | NR (3) |
| | Solar heat gain coefficient (SHGC) | 0.19 | 0.19 | 0.19 | 0.34 | 0.39 | 0.49 | 0.64 | NR (3) |

Table 7. Army Reserve Center - ARC

| Item | Component (1) | Climate Zones | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| **Roof** | Assembly Max U-value | U-0.0388 | U-0.0388 | U-0.0388 | U-0.0388 | U-0.0388 | U-0.0325 | U-0.0245 | U-0.0245 |
| | Insulation Entirely Above Deck | R-25ci | R-25ci | R-25ci | R-25ci | R-25ci | R-30ci | R-40ci | R-40ci |
| | Attic and Other | R-38 | R-38 | R-38 | R-38 | R-38 | R-49 | R-60 | R-60 |
| | Solar Reflectance (2) | High | High | High | High | High | Low | Low | Low |
| **Walls** | Assembly Max U-value | U-0.0847 | U-0.0847 | U-0.0847 | U-0.0676 | U-0.0676 | U-0.0676 | U-0.0595 | U-0.0391 |
| | Mass | R-10 | R-10 | R-10 | R-13 | R-13 | R-13 | R-15.0 | R-11.4 + R-3.0ci |
| | Steel Framed | R-13 + R-3.8ci | R-13 + R-3.8ci | R-13 + R-3.8ci | R-13 + R-7.5ci | R-13 + R-7.5ci | R-13 + R-7.5ci | R-13 + R-12.5ci | R-13 + R-18.8ci |
| | Wood Framed and Other | R-13 | R-13 | R-13 | R-13 + R-3.8ci | R-13 + R-3.8ci | R-13 + R-3.8ci | R-13 + R-13.0ci | R-13 + R-19.5ci |
| **Floors Over Unconditioned Space** | Assembly Max U-value | U-0.1067 | U-0.1067 | U-0.0739 | U-0.0739 | U-0.0521 | U-0.0377 | U-0.0377 | U-0.0377 |
| | Mass | R-6.3ci | R-6.3ci | R-10.4ci. | R-10.4ci. | R-16.7ci. | R-25.1ci. | R-25.1ci. | R-25.1ci. |
| | Steel Joists | R-13 | R-13 | R-13 | R-13 | R-19 | R-30 | R-30 | R-30 |
| | Wood Framed and Others | R-13 | R-13 | R-13 | R-13 | R-19 | R-30 | R-30 | R-30 |
| **Slab-on-Grade** | Assembly Max U-value<br>Unheated | F-0.730 ;<br>NR (3) | F-0.730 ;<br>NR (3) | F-0.730 ;<br>NR (3) | F-0.520 ;<br>R-15.0 for 24 in. | F-0.520 ;<br>R-15.0 for 24 in. | F-0.510 ;<br>R-20.0 for 24 in. | F-0.510 ;<br>R-20.0 for 24 in. | F-0.434 ;<br>R-20.0 for 48 in. |
| | Assembly Max U-value<br>Heated | F-1.020;<br>R-7.5 for 12 in | F-1.020;<br>R-7.5 for 12 in | F-0.860 ;<br>R-15.0 for 24 in. | F-0.843 ;<br>R-20 for 24 in. | F-0.688;<br>R-20.0 for 48 in | F-0.688;<br>R-20.0 for 48 in | F-0.671;<br>R-25.0 for 48 in | F-0.671;<br>R-25.0 for 48 in |
| **Doors** | Swinging | U-0.70 | U-0.70 | U-0.70 | U-0.50 | U-0.50 | U-0.50 | U-0.50 | U-0.50 |
| | Non-swinging | U-1.45 | U-1.45 | U-1.45 | U-0.50 | U-0.50 | U-0.50 | U-0.50 | U-0.50 |
| **Air Tightness** (4) | Max Leakage at ±75Pa Blower Test Pressures | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ | 0.25 cfm/ft$^2$ |
| **Vertical Glazing** | Window to Wall Ratio (WWR) | < 15% | < 15% | < 15% | < 15% | < 15% | < 15% | < 15% | < 15% |
| | Thermal transmittance (Assembly Maximum) | U-0.56 | U-0.45 | U-0.45 | U-0.42 | U-0.42 | U-0.42 | U-0.33 | U-0.33 |
| | Solar heat gain coefficient (SHGC) | 0.25 | 0.25 | 0.31 | 0.39 | 0.39 | 0.39 | NR (3) | NR (3) |
| | South Overhangs | Yes; Projection Factor = 0.4 | Yes; Projection Factor = 0.4 | Yes; Projection Factor = 0.4 | Yes; Projection Factor = 0.4 | Yes; Projection Factor = 0.4 | Yes; Projection Factor = 0.4 | Yes; Projection Factor = 0.4 | NR (3) |

Notes:

1. **U-values and R-values** for assemblies and their definitions, requirements, and determinations can be found in ANSI/ASHRAE/IESNA Standard 90.1-2007, Normative Appendix A.
2. **High/Low Surface Reflectance**: Light colored and Cool Roofs reflect and emit the sun's heat back to the sky instead of transferring it to the building below. "Coolness" is measured by two properties, solar reflectance and thermal emittance. Both properties are measured from 0 to 1 and the higher the value, the "cooler" the roof. For details, please see “Roofs” section.
3. **NR** means there is no requirement or recommendation for a component in this climate zone.
4. **Increased Building Air tightness**. Building air leakage (measured in cfm/ft$^2$) is the average volume of air (measured in cubic feet per minute) that passes through a unit area of the building envelope (measured in square feet) when the building is maintained at a specified internal pressure (measured in Pascals). The air tightness requirement adopted by the U.S. Army for new construction and major retrofits requires that the leakage rate must not exceed 0.25 cfm/ft$^2$ at 75 Pa. For details, see Attachment 12, “Building Air Tightness and Air Barrier Continuity Requirements.”

## Exterior Wall Insulation for Renovation Projects

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In retrofit projects, older buildings can be insulated from the outside (Figure 2 [left]) or the inside (Figure 2 [middle]). The best way to insulate a building wall is on the outside of the structure since this minimizes problems with thermal bridges and does not reduce the usable floor area. With sufficient exterior insulation the dew point temperature should not occur within the wall cavity, thus reducing the risk of condensation. With current technologies, external insulation offers different color and texture options and improves the look of the façade.

**Figure 2. Retrofitted Army barracks with exterior insulation (left), interior insulation of the retrofitted administrative building at the Rock Island Arsenal (center, right).**

However, with some buildings (e.g., historic buildings) external insulation may not be approved, therefore internal insulation shall be used when necessary. In these cases, improving the wall insulation must be done internally. The interior of the wall structure can be insulated with fiberglass (blown or batts), mineral wool, foam, or other insulating materials. Insulation can also be applied to the interior surface of the walls, or a combination of wall cavity insulation and interior surface insulation may be used. The choice of techniques and materials depends on the wall structure, building use, current furnishings and need to preserve interior space, etc.

While the energy savings of a specific increase in wall R-value (with proper vapor barrier and sealing of wall openings) will be the same whether the insulation is applied externally or internally, the costs of internal insulation can vary widely depending on product, materials, requirements for interior finishing, and costs of accessing the wall from the interior. Insulating the wall from inside will also entail more inconvenience for the building's residents and disruption of activities. Internal insulation reduces usable floor area and may have poorer aesthetics. Because the technology choice and cost of internal wall insulation is so building-specific, this technology fact sheet will focus on EIFS (Exterior Insulation Finishing System) only. However, the energy savings estimates for EFIS can be applied to projects where internal insulation is being considered.

EIFS (Exterior Insulation Finishing System) increases a building envelope's R-value by about R-3.85 per inch. Typically, 1, 2, 4, 6 or 8 inch (2.54, 5.08, 10.16, 15.24 or 20.32 cm) thicknesses are installed. Up to 40 cm insulation can be glued and anchored to the wall. Sometimes, anchor systems limit the thickness of insulation. For each thickness of insulation, there are two alternative installation types. The less expensive option is known as a “face-sealed system,” where the outermost layer of the exterior facade is sealed to help repel moisture. Alternatively, a more expensive “drainage system” option avoids moisture buildup within the wall by installing a barrier behind the actual insulation (Figure 3). This barrier is able to remove any moisture that penetrates the outer layer, thereby preventing mold or fungal growth, corrosion of the building wall and/or freezing in winter. Such events could lead to separation of the EIFS from the building wall, creating a path for more moisture intrusion. Differences in the two installation methods have negligible effect on the energy performance of the building; however, the difference is reflected in the cost of installation and prevention of water damage.

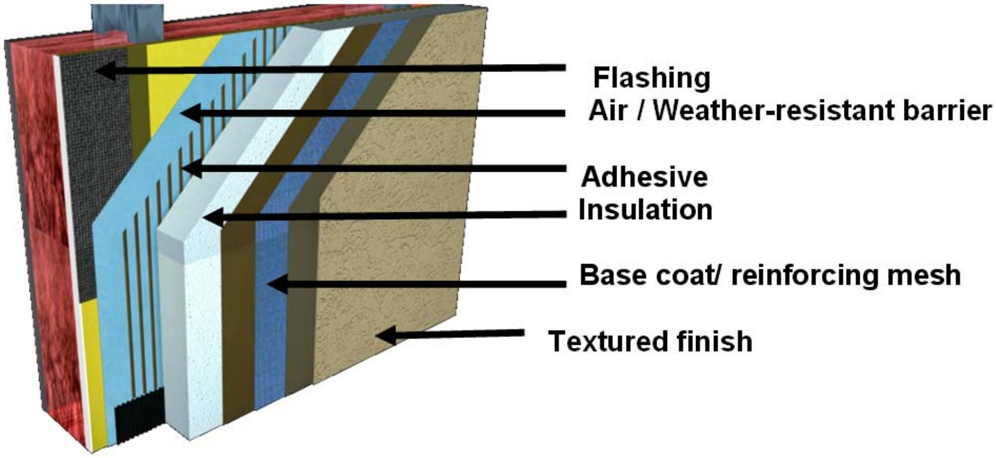

**Figure 3. EFIS Construction.**

The reduced thermal conductivity from retrofitting a building with EPS typically results in 10% to 40% energy savings, depending on the initial level of insulation and the climate. Energy savings tend to taper off quickly beyond two inches of insulation in warmer climates, but colder climates often benefit significantly with additional thickness of insulation, because protection from a larger temperature differential is needed. Therefore, thicker insulation layers are most cost effective to install in colder climate zones. In addition to energy saving and investment cost reduction (from being able to install smaller sized HVAC equipment), a better insulated building provides other significant advantages, including higher thermal comfort because of warmer temperatures on the interior surfaces in winter and lower temperatures in summer. This also results in a lower risk of mold growth on internal surfaces.

EIFS also offers benefits during construction of new buildings. For instance, the system offers significant savings on construction costs, compared to a brick veneer system. The light weight of EIFS could also offer potential savings in the building’s structural steel as the weight of the façade is reduced. In addition to contributing to energy cost savings, decreased infiltration improves air quality inside the building by keeping much dust, pollen, and car exhaust from entering. Also, reduction in drafts, noise and humidity contribute to the comfort of individuals inside the building.

The effect on annual energy use and costs of retrofitting an existing barracks with improved exterior wall construction is examined in this analysis. To estimate the achievable savings, a number of pre- and post-retrofit year-long simulations were performed using the EnergyPlus 3.0 building energy simulation software, which models heating, cooling and ventilation flows through buildings, among other criteria.

The baseline building is assumed to be an existing barracks, dormitory or multi-family building built either to meet the minimum requirements of ASHRAE Standard 90.1-1989 (ASHRAE 1989) by climate zone (Baseline 1) or to have been built prior to 1960, using typical construction practices of the time with little or no insulation (Baseline 2). The barracks are three stories high with an area of 30,465$ft^2$ (2,691 $m^2$) and include 40 two-bedroom apartment units, a lobby on the main floor and laundry rooms on each floor. The barracks were assumed to be unoccupied during the hours of 8 AM – 5 PM Monday through Friday. Further details on the barracks and the baseline heating, ventilation, and air conditioning (HVAC) systems used are included in [5]

The application of EIFS was evaluated for 15 U.S. locations The U.S. locations were selected as representative cities for the climate zones by the Pacific Northwest National Laboratory [4]. Flat utility tariffs were assumed for each location (i.e., no energy demand charges are included). The U.S. energy costs are based on Energy Information Administration (EIA) 2007 average data for commercial rates in each state and may not reflect the utility rates at a specific location (EIA 2008). The climate characteristics, energy costs and building details and construction parameters of all simulations are in [5].

Several different systems were modeled, each summarized in Table 8. Along with the added insulation, improvements in the air tightness of the barracks were modeled. The air tightness improvements ranged from the baseline of 1.00 cfm/$ft^2$ at 75 Pa to 0.85 cfm/$ft^2$ at 75 Pa. Proper installation of the EIFS on the walls and around windows and doors is expected to reduce infiltration to some extent. The full 15% reduction (to 0.85 cfm/$ft^2$ at 75 Pa) modeled might require some additional work to seal the barracks, which is not included in the cost estimates. Best practice is to improve the building's airtightness at the same time as the EIFS installation, using the same construction crew; the additional costs for ensuring proper window and door frame sealing are minimal while the EIFS is being installed. Therefore, the 15% reduced infiltration is assumed in all the analyses presented here.

Table 8. U.S. Scenario Descriptions

| Building Walls Tested | Baseline | Wall Construction | Additional Insulation ($ft^2$-hr-°F/Btu) | Air Leakage (cfm/$ft^2$ @ 75 Pa) |
|---|---|---|---|---|
| Baseline 1 | - | Wood framing with fiberglass insulation and brick facade | - | 1.00 |
| Baseline 2 | - | Same as Baseline 1, but pre-1960 construction | - | 1.00 |
| 1" EPS | 1 | Baseline with 1 inch EPS | R-3.85 | 0.85 |
| 2" EPS | 1 | Baseline with 2 inch EPS | R-7.70 | 0.85 |
| 4" EPS | 1 | Baseline with 4 inch EPS | R-15.4 | 0.85 |
| 6" EPS | 1 | Baseline with 6 inch EPS | R-23.1 | 0.85 |
| 8" EPS | 1 | Baseline with 8 inch EPS | R-30.8 | 0.85 |
| 1" EPS | 2 | Baseline with 1 inch EPS | R-3.85 | 0.85 |
| 2" EPS | 2 | Baseline with 2 inch EPS | R-7.70 | 0.85 |
| 4" EPS | 2 | Baseline with 4 inch EPS | R-15.4 | 0.85 |
| 6" EPS | 2 | Baseline with 6 inch EPS | R-23.1 | 0.85 |
| 8" EPS | 2 | Baseline with 8 inch EPS | R-30.8 | 0.85 |

Two baseline scenarios were used when studying the U.S. locations to describe potential existing conditions of barracks prior to a retrofit:

Baseline 1: This baseline accounts for pre-retrofit barracks with exterior walls consisting of wood framing with fiberglass insulation and brick façade meeting the minimum requirements of ASHRAE Standard 90.1-1989.

Baseline 2: This baseline also accounts for pre-retrofit barracks with exterior walls consisting of wood framing and brick facade. However, in this scenario, the existing building is assumed to have been built using pre-1960 typical construction practices with no prior insulation incorporated.

Table 9 lists the cost estimates for each type of insulation. Recommended practice is to use the drainage system. In humid climates, any flaw in the vapor barrier, either from mistakes in installation or post-installation penetrations of the vapor barrier or façade, can result in condensation within the wall. Because of the prevalence of this type of problem, provision for drainage is essential in warm, humid climates. In colder climates, face-sealed EIFS (i.e., without the drainage) is prevalent. However, even in cold climates, penetrations in the vapor barrier or façade can allow moisture intrusion in summer or winter. Unrepaired, this can result in significant moisture-caused damage or fungal growth. Government buildings and public housing (i.e., not privately-owned residences) are more likely both to experience damage from careless usage or vandalism and to not have such damages repaired promptly.

Table 9. U.S. Retrofit Costs for External Insulation ($/sq ft).

| System Thickness | 1” | 2” | 4” | 6” | 8” |
|---|---|---|---|---|---|
| Face-Sealed | 7.00 | 7.20 | 7.60 | 8.00 | 8.40 |
| Drainage | 8.00 | 8.20 | 8.60 | 9.00 | 9.40 |
| Insulation Only | 0.20 | 0.40 | 0.80 | 1.20 | 1.60 |

Figure 4 demonstrates the HVAC energy savings achievable with various thicknesses of insulation in selected U.S. locations. These energy savings can also translate to reduced HVAC system capacity required to heat or cool the building. Baseline 1 assumes the building meets ASHRAE Standard 90.1-1989; such buildings will already have some insulation in cold climates but little to no wall insulation in warm climates. For cold climates, the EIFS in Baseline 1 yields up to about 10% to 15% reduction in peak HVAC energy use (for 8 inch EIFS compared to the baseline). Such savings would usually result in a negligible to small capital cost savings for the HVAC system. For hot and humid climates, on the other hand, a 20% to 40% HVAC peak energy savings can be expected (for 8 inch EIFS compared to the baseline, which is typically an uninsulated building); this could represent a significant capital cost savings if the building’s HVAC system is renovated along with the building’s envelope.

The EIFS installed in Baseline 2, which is applied to pre-1960 construction with no insulation, results in much greater savings in HVAC energy use in cold climates (approximately 40% savings). Baseline 2 scenarios in hotter climates typically see savings ranging from 20% to 40%, since Baselines 1 and 2 for these climate zones are usually identical or very close.

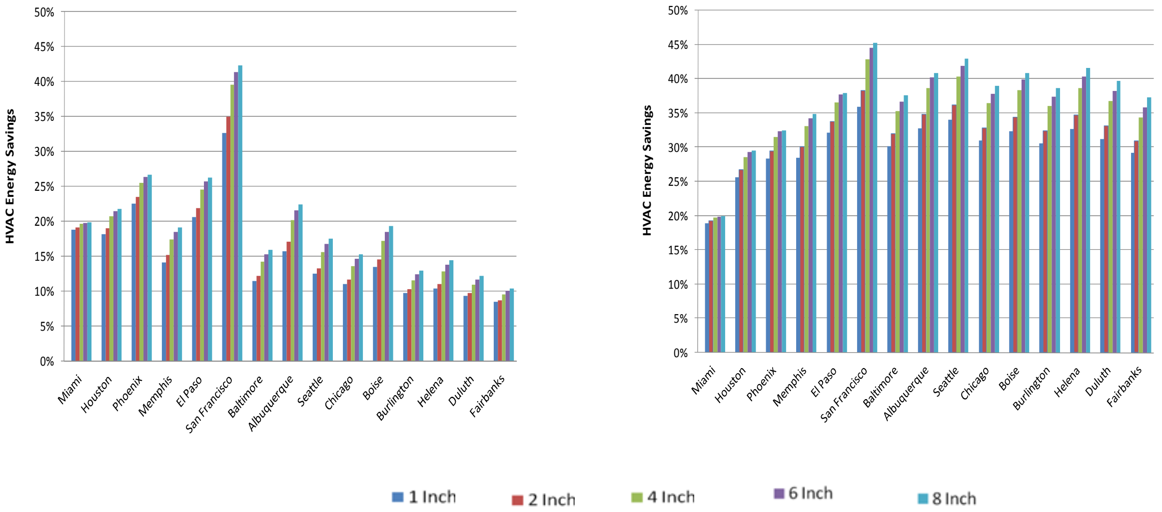

**Figure 4. HVAC Annual Percentage Energy Savings for Baselines 1 (left) and 2 (right).**

Figure 5 shows the expected annual energy cost savings for U.S. locations in Baselines 1 and 2. When comparing to the Baseline 1 building, warmer climates (e.g., Miami, FL) see average savings between $0.15-0.30 per sq. ft. depending on the EIFS thickness; however, these buildings are not as likely to see significant increases in savings beyond a 1- to 2-inch layer of insulation. Colder climates (e.g., Boise, ID), however, see average savings of only $0.10-0.20 per sq. ft. for the first inch of EIFS because the building already is insulated (ASHRAE 90.1-1989). Such buildings in colder climates do tend to benefit from additional insulation thickness. This can be seen when comparing to the Baseline 2 building with no pre-retrofit insulation. The warmer climate buildings exhibit similar cost savings as in Baseline 1, because the Baseline 1 buildings have little wall insulation. The greatest savings are seen in colder climate zones since they have the largest temperature differential to overcome, and unlike Baseline 1 (which already has appropriate levels of insulation for specific climate zones), Baseline 2 cold climate buildings have little insulation.

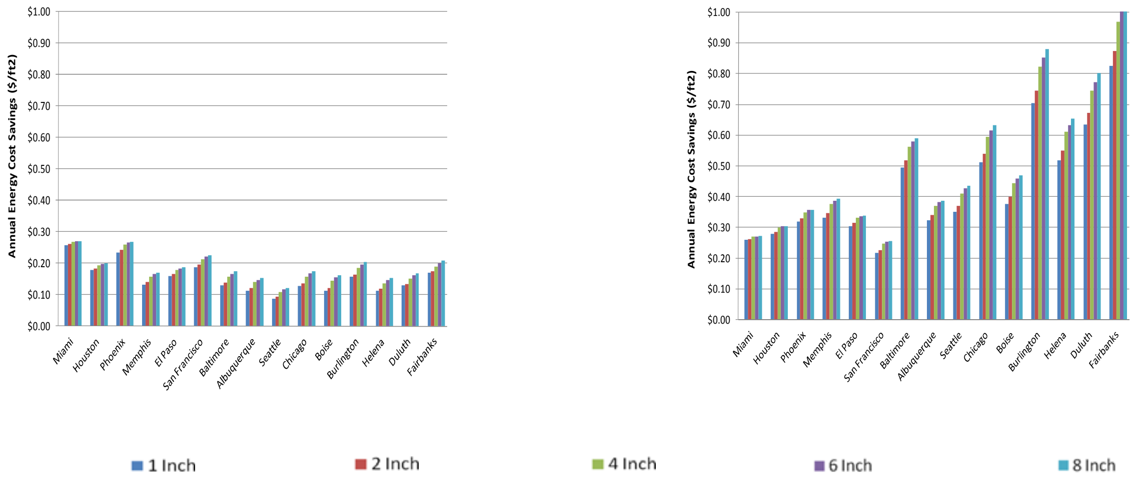

**Figure 5. Annual Energy Cost Savings for Baselines 1 (left) and 2 (right) for U.S. Locations.**

A rough indicator of the economic feasibility of EIFS is the ratio of capital cost to annual energy savings, sometimes referred to as “simple payback” (SPB). (The simple payback period for the U.S. locations is calculated based on the annual energy cost savings combined with estimates of the retrofit cost. Interest and inflation are neglected.) As previously mentioned, results from only the drainage EIFS are presented. Figure 6 shows SPB for Baseline 1 and 2, respectively. The SPB period is much shorter in Baseline 2 because more significant energy savings are realized due to there being no prior insulation. Furthermore, Figure 7 shows that Baseline 1 buildings have similar SPB since insulation installed in accordance with ASHRAE 90.1-1989 is designed to match the climate zone. Overall, buildings with no prior insulation are much better candidates for external wall insulation, especially in colder climates.

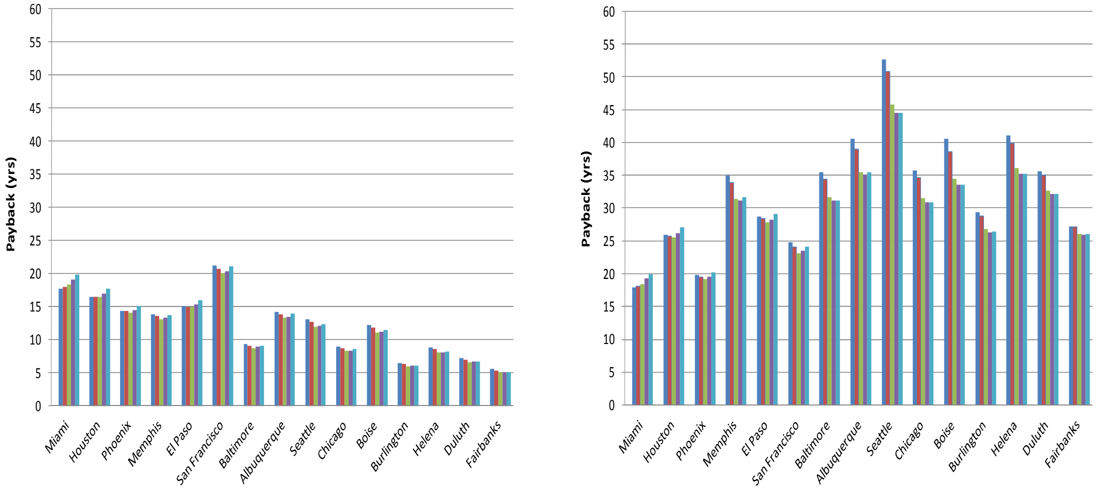

**Figure 6. SPB Period for Baselines 1 (left) and 2 (right) with Drainage System Installation.**

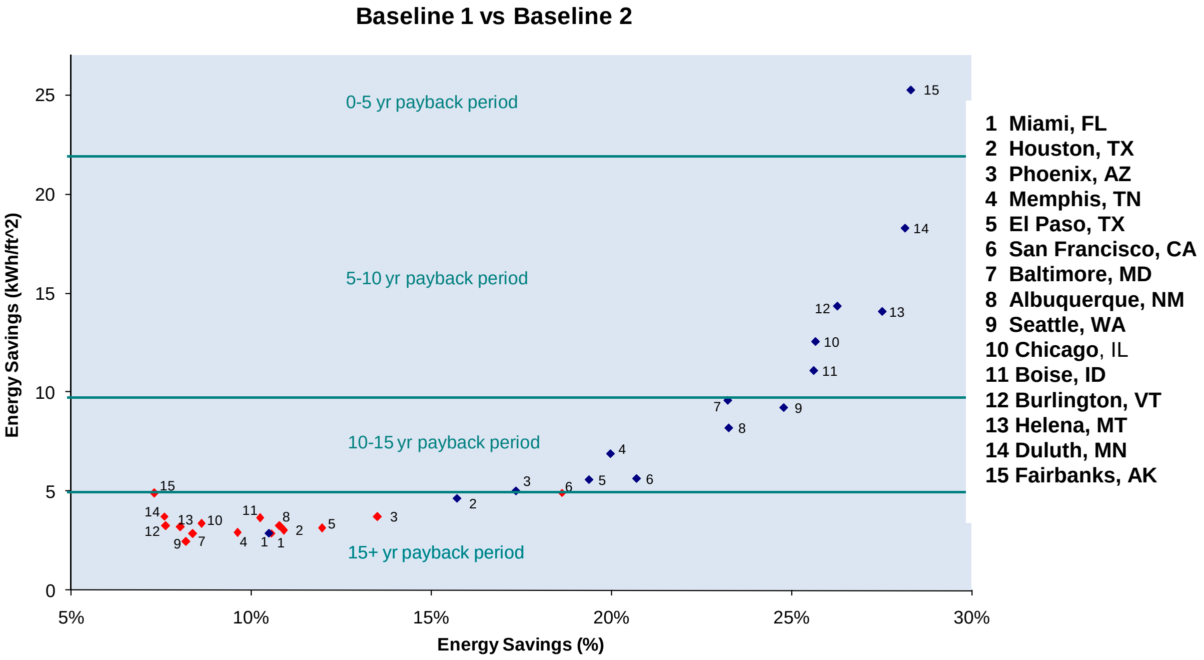

**Figure 7. Comparison of SPB Periods for Baselines 1 (Red) and 2 (Blue) with 4” Thickness – U.S. Locations**

Wall insulation is most cost-effective in cold climates. Buildings in hot climates buildings will also benefit from increasing wall R-value, but the benefit per inch of insulation tends to be less than in cold climates because the temperature differential between the building interior and ambient air is greater in cold weather (e.g., ∆T of about 15 – 25 °C, about 30 – 40 °F) than in hot weather (e.g., ∆T of about 10 – 15 °C, about 20 – 30 °F ). Existing buildings in warm climates are likely to have little to no pre-existing wall insulation. In colder climates, they are likely to already have been insulated to some extent. While adding insulation to a warm or moderate climate building may result in appreciable energy reduction in terms of percent, the magnitude of energy saved is smaller, and therefore the cost savings are smaller. The primary costs of EIFS are the initial set-up (project preparation, scaffolding, etc.) and the façade. Therefore, if a building's façade needs repair or replacement, adding insulation though EIFS is strongly recommended. The cost of the insulation itself is small compared to the rest of the project. For new construction, insulation to the extent possible should be included when constructing the walls. For a retrofit project requiring a new façade, it is recommended to install the maximum amount of insulation physically possible.

While the cost of additional insulation is small compared to the cost of the wall or façade, it is not negligible. The "optimal" level of insulation based on life cycle costs can be determined from building energy simulation models. For retrofit projects in moderate climates, an additional layer of 5 cm (2 inches) of insulation of may be sufficient (adding R 8), and 4 inches (R 15) should be considered in hot climates. For cold or very cold climates, additional insulation thickness (up to 20 cm or 8 inches, R 30) is usually justified.

## Windows

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For new designs and major retrofits windows will be selected to improve visual and thermal comfort and provide an opportunity for energy savings. While window replacement for energy conservation reason only is typically not cost efficient, energy efficient windows for new construction and major retrofit projects which include window replacement requirement is cost efficient and shall be specified. The selection of windows for cold climates shall be based on a window's ability to retain heat inside the building and reduce infiltration, whereas in warm climates, on the capacity to block heat gain from the sun and reduced infiltration. The main energy related parameters of a window are its insulation value, transparency to solar radiation, and air tightness.

Recommendations are provided in this section, but the prescriptive requirements are shown in the Tables 1 – 7 for all climate zones and 8 building types.

The U-factor expresses a window's insulation value, its resistance to heat flow when there is a difference between inside and outside temperature. The U-factor is measured in Btu/hr-sq ft-°F (W/sq m-°C). The lower the U-factor, the greater a window's resistance to heat flow.

A window's transparency to the heat carried by solar radiation is expressed in the solar heat gain coefficient (SHGC). The SHGC is the fraction of solar heat admitted by the window on a range of 0 to 1. A window’s transparency to visible light is expressed as its visible transmittance (VT) on a range of 0 to 1.

The air-leakage (AL) rating of a window indicates its air tightness. It expresses the rate of air-leakage around a window at a specific pressure difference in units of cubic feet per minute per square foot of frame area (cfm/sq ft) or cubic meters per minute per square meter of frame area.(cmm/sq m).

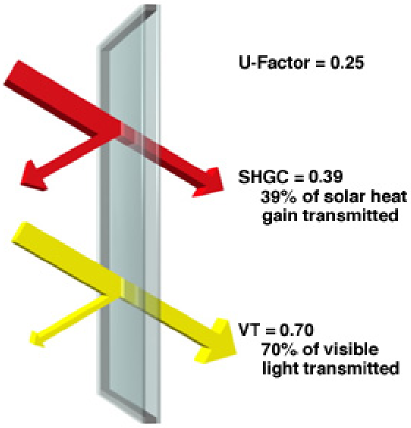
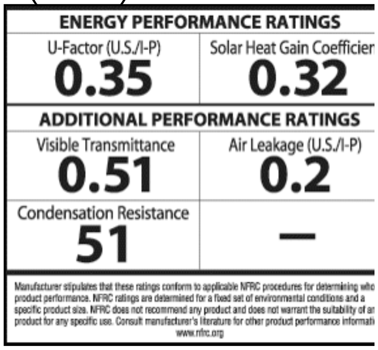


**Figure 8. Critical window performance parameters.**

Figure 9 shows an example of the label verifying that the energy properties of windows are rated according to nationally accepted standards and certified by the National Fenestration Rating Council (NFRC).



ENERGY PERFORMANCE RATINGS

| U-Factor (U.S./I-P) | Solar Heat Gain Coefficier |
|---|---|
| 0.35 | 0.32 |

ADDITIONAL PERFORMANCE RATINGS

| Visible Transmittance | Air Leakage (U.S./I-P) |
|---|---|
| 0.51 | 0.2 |
| Condensation Resistance<br>51 | — |

Manufacturer stipulates that these ratings conform to applicable NFRC procedures for determining who
product performance. NFRC ratings are determined for a fixed set of environmental conditions and a
specific product size. NFRC does not recommend any product and does not warrant the suitability of an
product for any specific use. Consult manufacturer's literature for other product performance informati
www.nfrc.org

**Figure 9. Example of the window label with energy performance ratings according to nationally accepted standards certified by the National Fenestration Rating Council (NFRC).**

Table 10 shows a range of window options used in barracks located in different climates and their energy-related characteristics. Window options I and II are conventional windows typically used in new construction and retrofit projects with only minimal energy-efficiency, whereas the other options (A through F) provide different energy-efficiency benefits in different climates.

Table 10. Window options with Default Values for Barracks Buildings.

| Window Option | Glazing type | Frame type | U-factor (imp./metric) | SHGC | VT | AL (imp./metric) |
|---|---|---|---|---|---|---|
| I | 2-pane, tinted | Aluminum | 0.76/4.3 | 0.56 | 0.51 | 0.2/0.06 |
| II | 2-pane, uncoated | Non-metal | 0.49/2.8 | 0.56 | 0.59 | 0.2/0.06 |
| A | 2-pane, low-solar-gain low-E | Aluminum, thermal break | 0.47 / 2.7 | 0.33 | 0.55 | 0.2 / 0.06 |
| B | 2-pane, low-solar-gain low-E | Non-metal | 0.34 / 1.9 | 0.30 | 0.51 | 0.2 / 0.06 |

| Window Option | Glazing type | Frame type | U-factor (imp./metric) | SHGC | VT | AL (imp./metric) |
|---|---|---|---|---|---|---|
| C | 2-pane, high-solar-gain low-E | Non-metal | 0.36 / 2.0 | 0.49 | 0.54 | 0.2 / 0.06 |
| D | 3-pane, low-solar-gain low-E | Non-metal | 0.26 / 1.4 | 0.25 | 0.40 | 0.1 / 0.03 |
| E | 3-pane, high-solar-gain low-E | Non-metal | 0.27 / 1.5 | 0.38 | 0.47 | 0.1 / 0.03 |
| F | 3-pane, high-solar-gain low-E | Non-metal, insulated | 0.18 / 1.0 | 0.40 | 0.50 | 0.1 / 0.03 |

A study conducted by the USACE Engineer Research and Development Center (ERDC-CERL) in collaboration with National Renewable Energy Laboratory (NREL) using EnergyPlus software to simulate energy use of a representative three story Army barrack building in 15 U.S. climate locations with the commonly used new and replacement window practices and advanced window options listed in Table 10. According to these studies improved window technologies will achieve annual site energy use savings in all climates with the most significant impact in the colder climates (Figure 10).

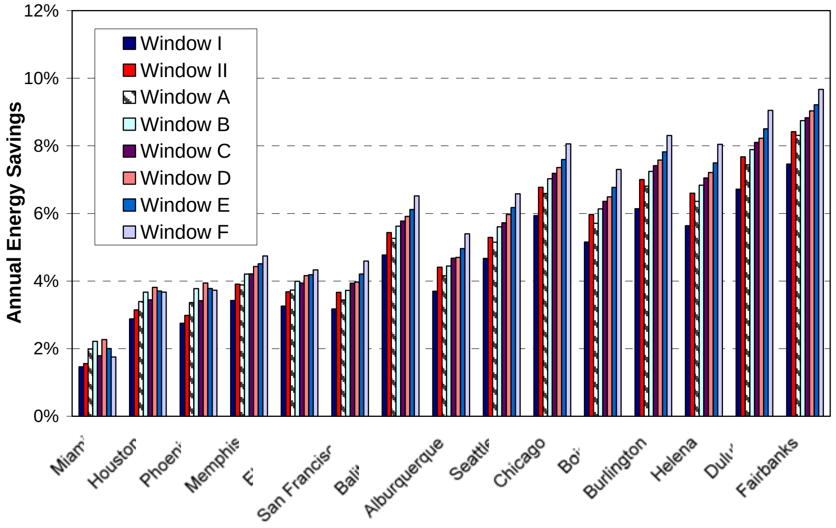


**Figure 10. Annual energy savings for U.S. cities representing different climates (Compared to baseline windows)**

When windows replacement is planned as an energy conservation projects, it is important to determine if a basic window replacement project using current baseline window technologies will save enough energy to offset the project costs and achieve a reasonable payback. Figure 11 shows the modeled payback for replacement of the ASHRAE 90.1-1989 windows with currently available baseline windows. Window I (aluminum frame) was chosen as the baseline replacement window for Climate Zones 1A, 2A, 2B and 3A because the additional strength of an aluminum frame is warranted in hurricane susceptible areas, Window II is a typical replacement window for Climates 3B-7 and Window C is a typical replacement choice for climate 8. Based on the results shown in Figure 11, an energy conservation window replacement project in Zone 3C (San Francisco) is not viable while a window replacement project in Zone 3B (El Paso, TX) would be considered to be marginally viable. In other climate zones, a simple back ranges between 1 and 8 years.

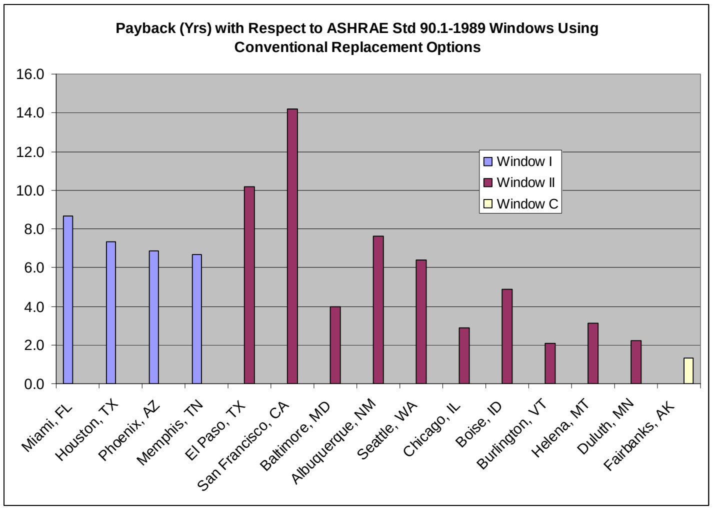


**Figure 11. Modeled payback results of an energy conservation project using current baseline quality replacement windows.**

For new construction and major building renovation projects or projects to replace failed or failing windows, one can assume that the cost of replacing the existing windows with currently available conventional replacement windows is a sunk cost. For these projects, one should conduct an analysis to determine if the additional cost of premium replacement windows rather than conventional replacement windows can be justified.

The marginal installed cost ($C_{premium}$ minus $C_{conventional}$) is divided by the marginal annual energy savings ($S_{premium}$ minus $S_{conventional}$) to arrive at the payback for the investment in premium quality replacement windows. Note that although a window replacement project in Zone 3C (San Francisco) is not justifiable for an energy conservation project, for a major renovation or repair project; we assume that the original windows will be replaced anyway. As a result, installation of conventional replacement windows is a sunk cost. Therefore, even in Zone 3C, one should perform an analysis to determine if premium quality windows can be justified.

The results of an engineering analysis for renovation/repair projects in the fifteen climate zones are shown in Figures 12, 13, 14 below. One can see that for each of the climate zones, there are at least two high performance replacement window options that satisfy the assumed ten year payback criteria. Table 11 lists several premium quality replacement windows options recommended for each of the fifteen U.S. climate zones which satisfy the ten year payback criteria, while in moderate and cold climates the payback is under 4 years.

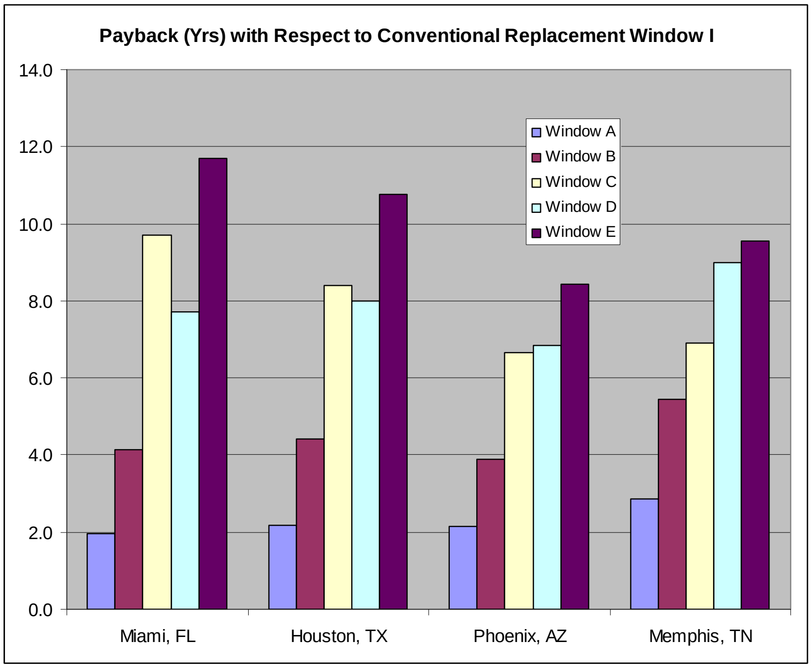


**Figure 12. Modeled payback results of upgrading to premium quality replacement windows from current baseline quality replacement windows (Zones 1A, 2A, 2B, and 3A) for new construction and a major renovation or repair projects.**

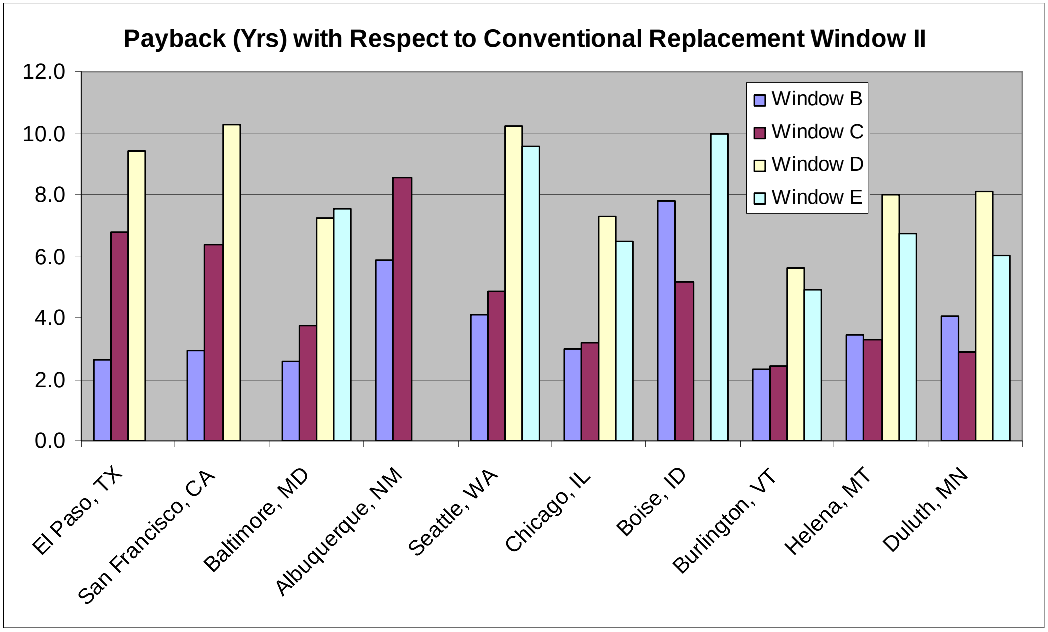


**Figure 13. Modeled payback results of upgrading to premium quality replacement windows from current baseline quality replacement windows (Zones 3B, 4A, 4B, 4C, 5A, 5B, 6A, 6B and 7A) for new construction and a major renovation or repair project.**

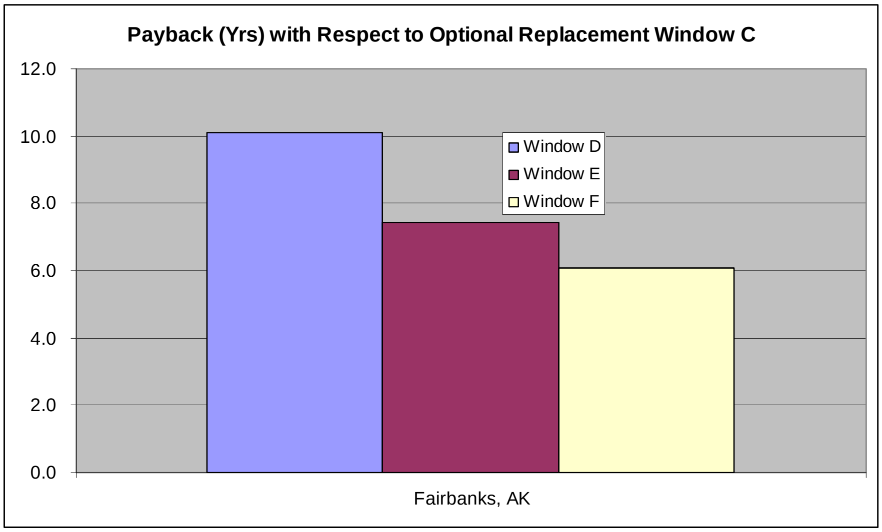


**Figure 14. Modeled payback results of upgrading to premium quality replacement windows from current baseline quality replacement windows (Zone 8) for new construction and a major renovation or repair project.**

Table 11. Window recommendations for barracks located in different U.S. climates.

| Zone | Climate | Efficient Window Options |
|---|---|---|
| 1A | Very hot | A, B |
| 2A,B | Hot | A, B, |
| 3A,B,C | Warm | A, B |
| 4A,B,C | Mixed | B, C |
| 5A,B | Cool | B, C, D, E |
| 6A,B | Cold | C, D, E |
| 7 | Very cold | C, E, F |
| 8 | Subarctic | E, F |

Operable windows provide building occupants with a connection to the outdoors and can serve to provide additional natural ventilation (under appropriate outdoor conditions) if the mechanical systems are shut down because of problems or servicing. Operable windows shall not be used in hot and humid climates (Zones 1a, 2a, and 3a) to prevent mold problems.

The ventilation characteristics of a window that provides a modest connection to the outdoors are different from a window that can provide a portion of the cooling requirements for the interior space. The ventilation function of an operable sash must be incorporated into the total fenestration design. It may not be feasible or necessary to make all windows operable in office or commercial buildings. A small awning or sliding window below a fixed window can provide the desired effect. All operable windows must have appropriate switches to disarm air-conditioning systems controlling sensible load (DOAS controlling latent load shall be operated all the time).

Table 12 shows a range of window options (A through D) and their energy related characteristics for administrative buildings which provide energy-efficiency benefits in different climates.

Table 12. Window options with Default Values for Administrative Buildings.

| Window Option | Glazing type | Frame type | U-factor (imp./metric) | SHGC | VT | Incremental cost ($ per ft²) |
|---|---|---|---|---|---|---|
| A | 2-pane, reflective coating | Aluminum, thermal break | 0.54 / 3.1 | 0.17 | 0.10 | $1.25 |
| B | 2-pane, low-E, tinted | Aluminum, thermal break | 0.46 / 2.6 | 0.27 | 0.43 | $1.75 |
| C | 2-pane, low-E | Aluminum, thermal break | 0.46 / 2.6 | 0.34 | 0.57 | $1.50 |
| D | 3-pane, low-E | Insulated | 0.20 / 1.1 | 0.22 | 0.37 | $8.00 |

Table 13 lists window options for administrative buildings that shall be considered in different climates. Efficient window options are recommended based on the climate-specific considerations —a low SHGC for warm climates and a low U-factor for cold climates. Aluminum-framed window A is among the recommended options for regions where hurricane considerations might require the sturdiness of aluminum (1A, 2A, 2B, 3A).

Table 13. Window recommendations for administrative buildings located in different U.S. climates

| Zone | Climate | Efficient window options |
|---|---|---|
| 1A | Very hot – humid | A, B |
| 2A,B | Hot | A, B |
| 3A | Warm -humid | B |
| 3B,C | Warm (dry, marine) | B, C |
| 4A,B,C | Mixed | B, C |
| 5A,B | Cool | B, C |
| 6A,B | Cold | B, C, D |
| 7 | Very cold | C, D |
| 8 | Subarctic | C, D |

## Roofs

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Roofs are vulnerable to solar gain in summer and heat loss in winter. Dark, non-reflective roofing surfaces create heat island effects by absorbing energy from the sun and radiating it as heat. Solar reflectance is the fraction of solar energy that a roof reflects. Thermal emittance is a measure of the roof’s ability to radiate any heat absorbed back into the air, rather than the building below. Both properties are measured on a scale of zero to one; the higher the values, the cooler the roof.

High-reflectance and high thermal emittance roofs (often referred to as “cool roofs”) can reflect heat instead of absorbing it, thereby reducing the building’s interior temperature and the running time of the air conditioning system. In winter “cool” roofs might have a negative effect on the building energy consumption by increasing load on the heating system compared to standard roofs.

Cool roofs are typically white and have a smooth surface. Commercial roof products that qualify as cool roofs fall into three categories: single-ply, liquid-applied, and metal panels. For roofing products, the values for solar reflectance and thermal emittance shall be determined by a laboratory accredited by a nationally recognized accreditation organization, such as the Cool Roof Rating Council CRRC-1 Product Rating Program, and shall be labeled and certified by the manufacturer.

In order to be considered a cool roof, a solar reflectance of 0.67 when tested in accordance with ASTM C1549, ASTM E903, or ASTM E1918 and, in addition, a minimum thermal emittance of 0.75 when tested in accordance with ASTM C1371 or ASTM E408, or a minimum Solar Reflective Index of 78 when determined in accordance with the Solar Reflectance Index method in ASTM E1980 where standard white is SRI = 100 and standard black has SRI = 0. An SRI can be determined by the following equations:

$$\mathrm{SRI} = 123.97 - 141.35(x) + 9.655(x2)$$

where

$$x = \frac{20.797 \times \alpha - 0.603 \times \varepsilon}{9.5205 \times \varepsilon + 12.0}$$

Where $\alpha$ is the solar absorbance (= 1 – solar reflectance) and $\varepsilon$ is the thermal emissivity, which were derived from ASTM E1980 assuming a medium wind speed.

Cool roof options exist for most traditional roofing materials. Each cool roof product offers a different level of reflectance and emissivity, as well as different costs. For flat-roofed buildings, metal roofs, coatings and membranes are feasible options. For sloped roofed buildings, metal roofs, reflective tiles and architectural shingles are feasible and more aesthetically pleasing (Figure 15).

**Figure 15. TEMF building at Fort Bliss with a reflective white metal roof.**

Metal Roofs: Several metal roof products have earned the ENERGY STAR® label, thanks to the development of pigments that make metal roofs highly reflective. Cool metal roof products are extremely durable and, at a cost of approximately $2 per square foot, are generally less expensive than reflective tiles.

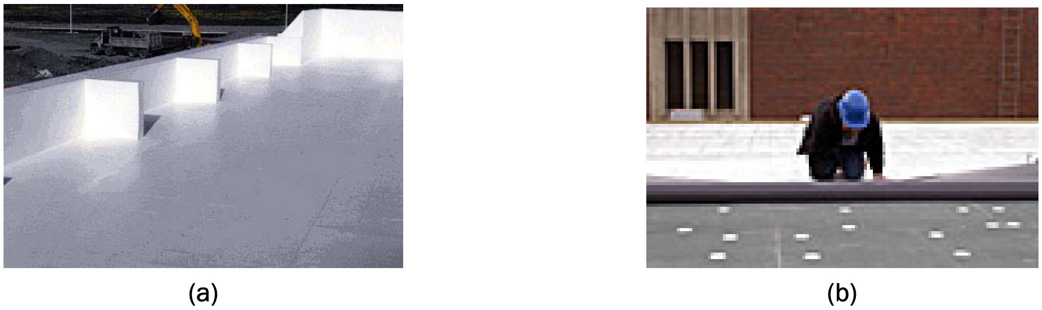
Membranes (single-ply): These flexible or semi-flexible pre-fabricated sheets consist of EPDM (ethylene-propylene-dieneterpolymer), PVC (polyvinyl chloride) or TPO (thermoplastic polyolefin). They can be applied over existing low-slope roofs using heat-sealed seams or caulk. Some are self-cleaning and mold resistant. The cost of single-ply roofing varies from $1.50 to $3 per square foot, including materials, installation and reasonable preparation work (Figure 16).

**Figure 16. Duro-Last Cool Zone® roofing system with a single-ply, 40 mil membrane roofing material and a polyvinyl chloride polymer blend demonstrated through the Navy Technology Validation (Techval) Program.**

Coatings: There elastomeric, polyurethane or acrylic liquids are the consistency of thick paint. They can be applied over existing low-slope roofs with a roller or power sprayer and last from 10 to 20 years. Cool roof coatings may cost between $0.75 and $1.50 per square foot for materials and labor (Figure 17).

Reflective Tiles: Clay or concrete tiles can incorporate special pigments that reflect solar energy while mimicking traditional colors, including green, brown and terra cotta. These tiles are extremely durable and especially suitable for new homes or for construction projects where a white roof might be aesthetically unacceptable (Figure 18). They cost approximately $3 per square foot.

Architectural shingles: These products resemble traditional roofing shingles but have the reflective properties characteristic of other cool roof materials. The shingles are available in a variety of colors, and the difference in cost between architectural shingles and conventional asphalt shingles is minimal (Figure 18).



(a)

(b)

**Figure 17. Reflective roof coating (a), and reflective roof membrane (b).**

(a) (b) (c)

**Figure 18. White metal roof (a), roof tile coatings (b), and architectural shingles (c) (http://www.elkcorp.com).**

Reflective "cool roofs" which reduce the building cooling load, are available in many colors besides white, though roof color, has an impact on energy usage. Table 14 lists the reflectance and emittance values by roof type and color for new and aged roofing materials (ORNL).

Table 14. Characteristics of reflective roofing materials.

| Roofing Type | Color | New Solar Reflectance | Aged Solar Reflectance | New Thermal Emittance | SRI (ASTM E1980 |
|---|---|---|---|---|---|
| Roof Coatings | White | 0.70 – 0.85 | 0.50 –0.65 | 0.85 | 84 – 106 |
| Roof Coatings | Grey or Tan | 0.70 | 0.50 | 0.85 | 84 |
| Roof Coatings | Terra Cotta or Brown | 0.40 | 0.30 | 0.85 | 43 |
| Roof Coatings | Aluminized | 0.50 | 0.40 | 0.50 | 42 |
| Metal Paint | Red | 0.25 | 0.25 | 0.83 | 22 |
| Metal Paint | Terra Cotta | 0.35 | 0.35 | 0.83 | 36 |
| Metal Paint | Bright Red | 0.35 | 0.35 | 0.83 | 36 |
| Metal Paint | Beige/Off White | 0.55 | 0.55 | 0.83 | 63 |
| Metal Paint | Tan | 0.45 | 0.45 | 0.83 | 49 |
| Metal Paint | Dark Blue | 0.25 | 0.25 | 0.83 | 22 |
| Metal Paint | Medium to Light Blue | 0.32 | 0.32 | 0.83 | 32 |
| Metal Paint | Dark Brown | 0.25 | 0.25 | 0.83 | 22 |
| Metal Paint | Medium to Light Brown | 0.32 | 0.32 | 0.83 | 32 |
| Metal Paint | Dark Green | 0.25 | 0.25 | 0.83 | 22 |
| Metal Paint | Medium to Light Green | 0.32 | 0.32 | 0.83 | 32 |
| Metal Paint | White | 0.65 | 0.65 | 0.83 | 77 |
| Metal Paint | Bright White | 0.70 | 0.70 | 0.83 | 84 |
| Metal Paint | Black | 0.25 | 0.25 | 0.83 | 22 |
| Metal Paint | Dark Grey | 0.25 | 0.25 | 0.83 | 22 |
| Metal Paint | Medium to Light Grey | 0.35 | 0.35 | 0.83 | 36 |
| Metal Paint | Pearlescent Colors | 0.35 | 0.35 | 0.75 | 32 |
| Galvalume | Unpainted | 0.65 | 0.55 | 0.05 | 45 |
| Copper Metal | Unpainted | 0.85 | 0.18 | 0.03 | 89 |
| Galvanized Steel | Unpainted | 0.40 | 0.20 | 0.50 | 26 |
| EPDM Membrane | Black | 0.05 | 0.10 | 0.85 | 0 |
| TPO Membrane | White | 0.80 | 0.60 | 0.85 | 99 |
| TPO Membrane | Grey | 0.50 | 0.40 | 0.85 | 57 |
| PVC Membrane | White | 0.80 | 0.60 | 0.85 | 99 |
| PVC Membrane | Grey | 0.50 | 0.40 | 0.85 | 57 |
| Asphalt Shingle | Dark Color | 0.10 | 0.10 | 0.85 | 4 |
| Asphalt Shingle | Light Color | 0.25 | 0.25 | 0.85 | 23 |
| Modified Bitumen Cap Sheet | Dark Color | 0.10 | 0.10 | 0.85 | 4 |
| Modified Bitumen Cap Sheet | Light Color | 0.25 | 0.25 | 0.85 | 23 |
| Modified Bitumen Cap Sheet | White | 0.50-0.60 | 0.40 – 0.45 | 0.85 | 57 - 71 |

Studies conducted under the IEA ECBCS Annex 46 showed that “cool roofs” are cost effective over air-conditioned spaces only for buildings located in climate zones 1-5. In these locations, a minimum of 75% of the entire roof surface not used for roof penetrations, renewable energy power systems (e.g., photovoltaics or solar thermal collectors), harvesting systems for rainwater to be used on-site, and buildings shall be covered with roofing products that comply with one or more of the following:

1. Have a minimum initial SRI of 78 for a low-sloped roof (a slope less than or equal to 2:12) and a minimum initial SRI of 29 for a steep-sloped roof (a slope of more than 2:12).
5. Comply with the criteria for the USEPA’s Energy Star Program Requirements for Roof Products – Eligibility Criteria.

For industrial buildings with only heating and ventilation, cool roofs can improve the comfort conditions (and hence productivity) in the space.

In colder climates (DOE Zones 6-8), the amount of energy cost savings for a cool roof may be significantly less than in warmer climates and can be offset by increased energy use for heating.

In the case of industrial ventilated and heated, but not air-conditioned buildings, “cool roofs” reduce indoor air temperature during the hot part of the year and therefore improves worker’s comfort and productivity and is cost effective in all climates.

Typically cool roofs are only installed during new construction or planned re-roofing projects. The cost of a cool roof versus a standard roof depends on the type of cool roof selected. Some cool roof products, e.g. metal roofs or membrane roofs, cost about the same as their traditional counterparts while others cost slightly more.

For specific projects use the Department of Energy’s Cool Roof Calculator to calculate savings associated with cool roof technologies. List of the Energy Star “cool” roofing materials and manufacturers can be obtained from the following websites:

http://www.energystar.gov/index.cfm?c=roof_prods.pr_roof_products.

Also, a list of cool roof manufacturers and suppliers can be obtained from the Cool Roofs Rating Council Web site at:

www.coolroofs.org.

## Hygro-Thermal Requirements for Building Envelopes

**Ray Patenaude**
*The Homes Agency*

**Hygro-Thermal Control.** The exterior wall not only provides a structure that keeps the building from falling down, it also separates the outdoor elements of temperature and moisture from the interior of the building. To do this the wall assembly must exclude rain, air, vapor and heat or cold. If these environmental conditions cannot be controlled then moisture will form within the wall assembly or the interior surface of the wall. Accumulation of moisture will increase the risk of mold and mildew contamination.

Hygro-thermal control is accomplished with the use of four principal control layers, in order of importance:

- Rain control layer consisting of a water barrier
- Air control layer consisting of an air barrier
- Vapor control layer consisting of a vapor barrier
- Thermal control layer consisting of insulation.

These control layers are placed against the outside of the structure of the building to protect the structure and the interior of the building.

The control layers are protected from ultraviolet and rain by use of a cladding system installed on the exterior of the building. Between the cladding and the control layers a drainage gap is installed to allow drainage of rain water which gets past the cladding system. It is important to provide flashing within the drainage gap to drain accumulated water out and away from the building. Of course, the flashing should terminate above the grade of the soil outside the building.

It is important to provide an interior wall finish such as a latex paint, textured finish or some other material which will allow moisture to pass thru it into the conditioned space which has a permeability of greater than 15 perms. Vinyl wall coverings should not be used on exterior walls.

The interior conditioned space should be conditioned with an HVAC system which provides relatively dry air at or below 55° F dew point. In addition the interior spaces should be positively pressured to assure that any outdoor air will not penetrate the air barrier control layer. This can be accomplished with the use of a dedicated outdoor ventilation air system (DOAS). The DOAS should provide more ventilation air then is exhausted from the building. In addition, ventilation air should be dried by the DOAS to assure a space condition at or below 55° F dew point. This resultant interior air will help control moisture condensation on interior spaces which will reduce the risk of mold and mildew contamination.

**Mold Detection Technologies for Building Interiors.** Suspected mold or mildew contamination within the interior spaces can be tested using one of the following testing methods:

1. <u>Spore Trap Mold Testing.</u> Spore trap testing is the oldest and most frequently used and least expensive mold test method, although it has limitations in being able to detect hidden mold. This mold test collects a large volume of air and deposits the particles on a glass slide containing an

adhesive. The slide is viewed microscopically to differentiate between mold types and determine the quantities of mold spores present with a sensitivity of 13 spores/cubic meter.

2. Mold Volatile Organic Compounds (MVOCs) Testing. Metabolic by-products are produced during the growth of the mold. As mold "consumes" its food, the chemical reactions of enzymes, substrates and mold growth produce carbon dioxide, water, and volatile organic compounds (VOCs). Since these compounds are volatile, they will diffuse through walls into living or office areas where they can be detected. Testing for MVOCs is accomplished by using vacuum cylinders to obtain samples of the air with laboratory analysis using gas chromatograph/mass spectrometers. This method does not differentiate between different types of mold; however, it is very sensitive, and has the advantage of detecting hidden mold.
3. Lateral Flow Immunoassay/Polymerase Chain Reaction (PCR) Detection. The lateral flow immunoassay is a presumptive field test for mold. A sample containing an unknown suspected biological contaminant is placed on the strip where it reacts with the dye-labeled antibodies. As the dye-labeled antibody-contaminant complex binds to contaminant-specific antibodies attached further down the test strip, a visible sample line forms along with the control test line. In the absence of target contaminants, only the single control line forms. To enhance the sensitivity of detection, an electronic reader can report the intensity of the faint line barely visible to the naked eye within 15 minutes. The test only indicates that one or more of 24 of the 26 Group 1 molds (associated with health problems) may be present in the solutionized sample. It does not identify which mold is present. Positive identification of the mold type must still be accomplished by PCR, a type of DNA testing. PCR can be used to identify individual genera/species accurately and fairly quickly. PCR methods have been used in other venues since the early 1980's, however, the method was only recently customized by the Environmental Protection Agency (EPA) as a screening tool to evaluate the potential risk of indoor mold growth. This test can identify and quantify the unknown mold from among 36 species of mold known to produce mycotoxins. It can differentiate between different types of mold, based on as little as a single strand of DNA from 1 mold spore.
4. Fluorometric Mold Detection. The Fluorometric detection method determines the activity of a fungal enzyme. Although it does not differentiate between the types of mold, it has high sensitivity. In the lab, samples taken from a mold contaminated surface are washed to transfer the mold into a solution, which is put into a dish that contains the nutrients that molds need to grow. After being incubated, the organisms in the solution that are alive will form visible colonies in the dish, which can be quantified.

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