Designing Green Buildings with Silicone Materials

Green Building Seminar - GlassTech
27 Nov 2014
Façades today

Creativity & Aesthetics

Transparency & Light
Façades today

Creativity & Aesthetics
Transparency & Light
Energy Efficiency

U-factor
Air Leakage
Structural Glazing

*silicone structural* glazing *supports* all these *trends*

Creativity & Aesthetics

Transparency & Light

Energy Efficiency
ARYA Residences

**Location:** BGC

**Architect:** AIDEIA

**Applications specified:** silicone structural bonding and silicone weathersealants

**Areas of use:** external glazing of the curtain wall facade, weatherseals for punch windows.

**Green Building Rating:** LEED GOLD, BERDE
The Zuellig Building

**Location:** Makati, Philippines

**Architect:** Skidmore, Owings and Merrill

**Applications specified:** silicone structural bonding and silicone weather sealants

**Areas of use:** external glazing of the curtain wall facade

**Green Building Rating:** LEED PLATINUM
Alphaland Tower

**Location:** Makati, Philippines

**Architect:** Wong & Ouyang

**Applications specified:** silicone structural bonding and silicone weathersealants

**Areas of use:** external glazing of the curtain wall facade

**Green Building Rating:** LEED GOLD
Globe Headquarters

**Location:** BGC

**Architect:** Aidea

**Applications specified:** silicone structural bonding and silicone weathersealants

**Areas of use:** external glazing of the curtain wall facade

**Green Building Rating:** LEED GOLD
More Projects....

• GT International Tower
• DC795 – Structural sealant
• DC791 – Weather sealant
• DC991 – Non-staining weather sealant.

• LKG Tower
• DC995 – Structural sealant
• DC791 – Weather sealant
• Two sided structural design curtain wall.
• Sealant glazing 1998.

• PBCom Tower
• DC995 – Structural sealant
• DC791 – Weather sealant
• Two-sided structural design curtain wall.
• Sealant glazing in 2000.
Why Silicone?

Silicone vs. Organic Products

Sand ➔ Silicon Mineral ➔ Silicone Polymer

- Silicone (polydimethylsiloxane) sealants are based on an inorganic silicon-oxygen (Si-O) polymer chain backbone

- Organic sealants such as polyurethane or polysulfide are based on a carbon-carbon (C-C) or carbon-oxygen (C-O) polymer chain backbone
Why Silicone?

- The bond length of the Si-O is longer and stronger than the carbon-oxygen (C-O) bond of organic sealants, which gives the silicone a unique resistance to UV.

\[
\begin{align*}
\text{Si-O} & \quad 452 \text{ KJ/mol} \\
\text{C-O} & \quad 357 \text{ KJ/mol} \\
\text{UV} & \quad \pm 400 \text{ KJ/mol}
\end{align*}
\]
Why Silicone?

• The rotation energy of the Si-O bond is lower than the C-C bond, giving inherent flexibility and elasticity to a silicone polymer, much like a spring.

• These unique physical properties remain unchanged when exposed to extreme temperatures (from -50°C to +150°C).
Princess Elisabeth Station Antarctica, the first ‘zero emission’ base
How do silicones enable greener buildings?

- Sustainable development
- Energy efficiency
- Facilitate green building designs
- Reduced maintenance
Designing Green Buildings with Silicone Materials

- Evergreen plant shield against sun and wind
- Double or triple pane low-e glazing
- Photovoltaic energy
- Rooftop planting
- Window Installation system
- Lower U façade values than mechanically fixed facades
- Weathersealants -> air tightness
- Automated ventilation control & lighting control using natural light
- Lighting control using motion detection sensors
- Higher energy efficiency with bonded doors and windows
Dow Corning Business & Technology Centre, Seneffe, Belgium
Architect: ELD Partnership (B)

Structural Silicone Glazing (SSG)
Structural Silicone Glazing (SSG) 
The Flexible Rubber Anchor

Load bearing bonding between glass and supporting metal frame using structural silicone sealant results in continuous thermal barrier and excellent air and water intrusion performance.

- Bonding must be dimensioned according to (thermal, live & dead) load requirements.
- SSG sealant carries loads and compensates movements.
- Higher performance requirements on IG edge seal regarding UV- and heat-resistance.
- IG edge seal must fulfill live and dead load-bearing function.
Early Structural Glazing History

• 1965 – First silicone SG projects using glass fin as structural support (Total Vision System)
• 1970 – First 2-sided SG project with mechanical fixation on two sides
• 1971 – First 4-sided SG project which used silicone (acetoxy) for full attachment of glass
Benefits of SG – Aesthetics

• Creative design possibilities
• Smooth, seamless façade
• Total vision system
Benefits of SSG – Outstanding Durability

- Water, Humidity
- Aggressive atmospheric gases, Ozon, SO₂, SO₃,
- Oxygen (O₂)
- UV radiation, Temperature aging
- Working loads
- Wind load, hurricane, bomb Blast, Relative movements
- Chemicals, Cleaning solvents, sealants
- Temperature differences
Benefits of SG – Upgrade Existing Facades

Before

And

After
Renovation Madou Tower Brussels

Architect: Robert Goffraux

Architects renovation: ASSAR & Archi2000
Benefits of SSG - Protective Design

Design protective facades for:
- Bomb blast resistance
- Earthquake
- Fire resistance
- Sound control
Benefits of SG – Energy Efficiency

Positive influence of:

- Structural glazing vs. mechanical fixation
- Wet sealing with silicone sealant vs. dry sealing with gaskets
- Gasfilled vs. airfilled IG units

SSG: 29.8°C
Dry: 40.0°C
Designing Green Buildings with Silicone Materials

- Lower U façade values than mechanically fixed facades
- Weathersealants -> air tightness
- Rooftop planting
- Photovoltaic energy
- Double or triple pane low-e glazing
- Double skin façade
- Active façade
- Automated ventilation control & lighting control using natural light
- Window Installation system
- Higher energy efficiency with bonded doors and windows
- Evergreen plant shield against sun and wind
Insulating Glazing
Insulating Glass Units - Definitions

IG  Insulating Glass
IGU Insulating Glass Unit
PIB Poly-Iso-Butylene = Butyl

Exterior
Interior

1  2     3      4
Butyl (PIB) Primary Seal
Spacer
Inter-pane Space
Desiccant (Mol. Sieve)
Secondary Seal
Function of an IG unit

**View Through – Light Transmission**
- Transmission Value (T in %)

**Durability**
- Expected life time >> 10 Years

**Specific requests**
- Noise control
- Protection against fire, bomb blast, earthquake, etc.

**Insulating properties and low heat transmission**
- Heat protection inside – out
  - U-Value winter / cold environment
- Sun protection outside – in
  - g-Value summer / warm environment
- Heat transmission at the edge - „warm edge“
Silicone Insulating Glass Units

- Ultimate UV resistance
- Longer life expectancy
- Colour flexibility (secondary seal)
- Energy efficiency
- Reduced condensation risk
- Resistance to temperature extremes
## Insulating Capability of an IG Unit

<table>
<thead>
<tr>
<th>Number of panes</th>
<th>Type</th>
<th>$U_g$-Value W/m²K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall</td>
<td>Insulated wall</td>
<td>0.3 – 0.6</td>
</tr>
<tr>
<td>Roof</td>
<td></td>
<td>0.15 – 0.3</td>
</tr>
<tr>
<td>Single pane</td>
<td>Monolithic float glass, 4 mm</td>
<td>5.2</td>
</tr>
<tr>
<td>Double pane</td>
<td>Float glass 2x4mm, air filled</td>
<td>2.8</td>
</tr>
<tr>
<td>Double pane</td>
<td>Float glass 2 x 4 mm, low-E coat, air filled</td>
<td>1.8</td>
</tr>
</tbody>
</table>
Gas Filling

- An insulating glass unit filled with Argon, Krypton or Xenon further reduces the heat transmission value (U value)

<table>
<thead>
<tr>
<th>Type</th>
<th>$U_g$-Value (W/m²K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>glass 2 x 4 mm, low-E coat, Air</td>
<td>1,8</td>
</tr>
<tr>
<td>glass 2 x 4 mm, low-E coat, Argon</td>
<td>1,3</td>
</tr>
<tr>
<td>glass 2 x 4 mm, low-E coat, Krypton</td>
<td>1,0</td>
</tr>
</tbody>
</table>
U Value

- U is the measurement of how much heat or energy will be lost or released from the unit via direct or indirect transmission.

- U Value is a measurement of how thermally efficient a unit or facade is.

- The lower the number the more efficient i.e. 1 is very good.
1. Where does the energy of the sun go when contacting the glazing?

1000 W/m²

- ENERGY TRANSMITTED DIRECTLY INSIDE
- ABSORPTION
- CONDUCTION
- AIR WARMED UP BY CONVECTION
- SECONDARY RADIATION OF WARMED UP GLASS
- OUTSIDE CONVECTION
- ENERGY REFLECTED
- up to 70-80 °C
REDUCTION OF INCOMING HEAT
SAVES A/C COST

In warm, sunny climates

- By reducing either:
  - direct energy crossing the glass
  - conduction and convection
  - secondary radiation of heated objects
Secondary Sealant

- Rigid seal reducing movements on primary seal
  - High modulus
  - Higher thickness, recommended 2nd seal thickness is 4-6mm. For structural IG edge a minimum 2nd seal thickness of 6mm is required
  - High elastic recovery reduces creep and will be an advantage
- Low volume increase under high humidity
- Low gas diffusion coefficient reduces gas loss ratio in case of leaking of primary barrier

Why Si-Sealed IGU Outperform Organic Sealed IG:
- Better mechanical properties: i.e. lower T°C dependency of Young’s modulus, elastic recovery
- Lower water pick-up (swelling) in high humidity micro-climates
- Si provide the best UV resistance and highest longevity for IGU. Only silicone can be used for structural IG
Case Study

- **Scientific Approach**
  - Descriptions of Glazing systems
  - Description of Curtain Wall systems
  - Description of Spacers

- **Results**
  - Comparisons of U-value, SHGC and Temperatures
  - Comparisons of Energy consumption and costs
  - Comparisons of CO₂ emissions

- **Conclusions**
Energy Efficiency and Sustainable Constructions: Hot Topic!

Drivers:
- Urbanization
- Energy and raw material prices
- Security of energy supply
- \( \text{CO}_2 \) emissions and Climate changes

Actions:
→ Necessity to reduce \( \text{CO}_2 \) emissions/energy consumption

-> "The largest cost effective savings potential lies in the residential and commercial buildings sector" and >20% could be saved by applying tougher standards on buildings" (Andris Piebalgs / EU Commissioner)

<table>
<thead>
<tr>
<th>Category</th>
<th>Percentage</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation</td>
<td>22%</td>
<td></td>
</tr>
<tr>
<td>Domestic</td>
<td>35%</td>
<td>&gt;50% energy use</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+/- 25% of global energy consumption</td>
</tr>
<tr>
<td>Industrial</td>
<td>43%</td>
<td>Production of CI related materials</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High energy vs low energy processes</td>
</tr>
</tbody>
</table>
- Western constructions consume 40% of total energy
- Built environment emits 25% of Western greenhouse gas (\( \text{CO}_2 \))
Challenge for Middle East: Dubai

- Urbanization & population increase
- Spatial expansion
- Economic growth
- Hot and humid climate
- Transparent façades

Gulf states have become one of the largest per-capita energy consumers in the world.

Projected CO2 emissions worldwide:
- Middle East
- OECD Europe
- United States

Factors contributing to CO2 emissions:
- Urbanization & population increase
- Spatial expansion
- Economic growth
- Hot and humid climate
- Transparent façades
Objectives:

Study the energy efficiency of commercial curtain wall systems in Hot climates

• Comparing dry glazed curtainwall systems to Structural Silicone Glazed Systems
• Comparing High performance glass to Standard Clear glass
• Comparing Silicone foam Warm Edge IG spacers to Aluminum IG spacers
• Comparison of Frame temperatures at exterior conditions at -16°C, 40°C, and 50°C+high solar load
• Comparison of U-values and SHGC
• Comparison of energy consumption for a whole building
• Comparison of CO₂ emissions for a whole building
Scientific Approach

- Calculate and Compare $U_{\text{façade}}$ value and SHGC of different generic curtain wall systems used in commercial construction
  - Glazing and frame system
  - THERM and WINDOW (LBNL) software

- Compare Energy Use of different curtain wall systems based on U, SHGC, air leakage:
  - EFEN software (CARLI)
Choice of Glazing Systems in Hot Climates

• Essential in order to:
  - Reduce incoming heat without losing light
  - Increase savings on aircon size and running costs
  - Increase comfort of inhabitants

• Sun energy = 50% visible range (light) + 50% IR range

  Reduce light: ↑ reflection (reflective glass),
  ↑ absorption (tinted, dark coatings),
  Combination

  Reduce IR: ↑ reflection (green glass, IR-reflect. Coat.),
  ↑ absorption (tinted, dark coatings),
  Combination

→ Compare Clear glass IG unit with high performance IG with increased IR absorption and high visible light transmission
Glazing systems

Calculate and Compare performance with WINDOW

- **Low performance:**
  - 6mm clear
  - 14mm air
  - 6mm clear

- **High Performance:**
  - 6mm Low-e3 coating on Face 2
  - 14mm air
  - 6mm clear

→ increase IR reflection and absorption + reduce indirect transmission
Structural Silicone Glazing Curtain Wall

8mm x 12 mm Structural silicone joint

15mm wide Silicone weatherseal

Foam backer rod

50mm x 100mm aluminum frame

8mm x 6mm Silicone foam spacer

Interior temp 21°C

Silicone Foam Warm Edge

6mm glass

Air space 14 mm wide

PIB Primary Seal

Desiccated Silicone Foam

Silicone Secondary Seal
Total Frame Results

Worst case: Dry glaze Curtain Wall System with low performance glass, Aluminum Insulating Glass spacer

ID # 101
Name Dry Glaze poor glass Al sp
Mode NFRC
Type Custom Dual Vision
Width 2400 mm
Height 2500 mm
Area 6.000 m²
Tilt 90

Environmental Conditions: NFRC 100-2001

Total Window Results
U-factor 3.167 W/m²-K
SHGC 0.665
VT 0.736
CR 39

Glazing System
Name 26mm clear on clear air Italian
ID 122
Ucenter 2.589 W/m²-K
Nlayers 2
SC 0.887
Area 2.369 m²
SHGC 0.693

Edge area 0.440 m²
Vtc 0.788
Total Frame Results:

Best case: SSG with high performance glass (low SHGC) and Si-warm edge Insulating Glass spacer

**Environmental Conditions**
- **ID #**: 105
- **Name**: SSG good glass Si spacer
- **Mode**: NFRC
- **Type**: Custom Dual Vision I
- **Width**: 2400 mm
- **Height**: 2500 mm
- **Area**: 6.000 m²
- **Tilt**: 5
- **Environmental Conditions**: NFRC 100-2001

**Total Window Results**
- **U-factor**: 1.798 W/m²-K
- **SHGC**: 0.281
- **VT**: 0.585
- **CR**: 58

**Glazing System**
- **Name**: Dubai Typical High performance
  - **ID**: 123
  - **Ucenter**: 1.609 W/m²-K
  - **Nlayers**: 2
  - **Area**: 2.376 m²
  - **SHGC**: 0.275
  - **Edge area**: 0.441 m²
  - **Vtc**: 0.623

**Frame**
- **Name**: Vertical meeting rail SSG good glass
  - **ID**: 59
  - **Uedge**: 1.663 W/m²-K
  - **Source**: 2
  - **Edge area**: 0.295 m²
  - **Ufactor**: 4.588 W/m²-K
  - **Area**: 0.123 m²
  - **Abs**: 0.500
Comparisons: U value, SHGC and Temperature

<table>
<thead>
<tr>
<th>System</th>
<th>spacer</th>
<th>glass</th>
<th>U value (W/m²K)</th>
<th>SHGC</th>
<th>Visible transmittance</th>
<th>Interior Mullion Temperature (exterior 50°C) high load 1120W/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSG</td>
<td>Si</td>
<td>LoE3/clear</td>
<td>1.80</td>
<td>0.28</td>
<td>0.59</td>
<td>29.8</td>
</tr>
<tr>
<td>SSG</td>
<td>Si</td>
<td>Clear/clear</td>
<td>2.72</td>
<td>0.68</td>
<td>0.74</td>
<td>31.4</td>
</tr>
<tr>
<td>SSG</td>
<td>Al</td>
<td>LoE3/clear</td>
<td>2.01</td>
<td>0.30</td>
<td>0.59</td>
<td>34.3</td>
</tr>
<tr>
<td>SSG</td>
<td>Al</td>
<td>Clear/clear</td>
<td>2.87</td>
<td>0.69</td>
<td>0.74</td>
<td>35.4</td>
</tr>
<tr>
<td>Dry</td>
<td>Si</td>
<td>LoE3/clear</td>
<td>2.19</td>
<td>0.27</td>
<td>0.58</td>
<td>40.0</td>
</tr>
<tr>
<td>Dry</td>
<td>Si</td>
<td>Clear/clear</td>
<td>3.07</td>
<td>0.67</td>
<td>0.74</td>
<td>41.0</td>
</tr>
<tr>
<td>Dry</td>
<td>Al</td>
<td>LoE3/clear</td>
<td>2.30</td>
<td>0.27</td>
<td>0.58</td>
<td>42.0</td>
</tr>
<tr>
<td>Dry</td>
<td>Al</td>
<td>Clear/clear</td>
<td>3.17</td>
<td>0.67</td>
<td>0.74</td>
<td>42.7</td>
</tr>
</tbody>
</table>

• **SSG** gives better (lower) U values than **Dry** systems in all combinations.

• **SSG** gives lower internal temperatures than **Dry** in all combinations.

• **Si** spacer provides a better (lower) U value than **Aluminum** spacer in all combinations.
Temperature Evolution for SSG system at 50°C, 1120W/m²:

- **High Performance Glass, Si Spacer**: 15.5°C
- **Clear Glass, Si Spacer**: 31.4°C
- **High Performance Glass, Al Spacer**: 34.3°C
- **Clear Glass, Al Spacer**: 35.4°C

+1.6°C, +4.5°C, +4.0°C, +1.1°C
Temperature Evolution for Dry system at 50°C, 1120W/m²:

- High Performance Glass, Si Spacer: 40.0°C (High Performance Glass, Al Spacer: 42.0°C) +1.0°C
- Clear Glass, Si Spacer: 41.0°C (Clear Glass, Al Spacer: 42.7°C) +0.7°C

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Temperature comparison between SSG and Dry system at 50°C, 1120W/m²:

- **SSG**:
  - Clear Glass: +10.2°C
  - High Performance Glass, Si Spacer: +7.3°C
  - Temperature measurement: 15.5°C
  - Temperature: 29.8°C, 35.4°C

- **Dry**:
  - Temperature: 40.0°C, 42.7°C

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## Comparisons for various temperature loads

<table>
<thead>
<tr>
<th>CW system</th>
<th>glazing system</th>
<th>spacer type</th>
<th>-16°C</th>
<th>40°C</th>
<th>50°C (1120W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSG</td>
<td>High performance</td>
<td>Si</td>
<td>15.5</td>
<td>24.2</td>
<td>29.8</td>
</tr>
<tr>
<td>SSG</td>
<td>Clear</td>
<td>Si</td>
<td>14.5</td>
<td>24.7</td>
<td><strong>31.4</strong></td>
</tr>
<tr>
<td>SSG</td>
<td>High performance</td>
<td>Al</td>
<td>12.5</td>
<td>25.7</td>
<td>34.3</td>
</tr>
<tr>
<td>SSG</td>
<td>Clear</td>
<td>Al</td>
<td>11.8</td>
<td>26.1</td>
<td>35.4</td>
</tr>
<tr>
<td>Dry</td>
<td>High performance</td>
<td>Si</td>
<td>9.1</td>
<td>27.6</td>
<td>40.0</td>
</tr>
<tr>
<td>Dry</td>
<td>Clear</td>
<td>Si</td>
<td>8.5</td>
<td>27.9</td>
<td><strong>41.0</strong></td>
</tr>
<tr>
<td>Dry</td>
<td>High performance</td>
<td>Al</td>
<td>8.0</td>
<td>28.1</td>
<td>42.0</td>
</tr>
<tr>
<td>Dry</td>
<td>Clear</td>
<td>Al</td>
<td>7.6</td>
<td>28.4</td>
<td>42.7</td>
</tr>
</tbody>
</table>

Temperature changes are more important for extreme climate

- Impact on temperature of system > spacer > glazing system

### Influence of:

<table>
<thead>
<tr>
<th>Conditions</th>
<th>-16°C</th>
<th>40°C</th>
<th>50°C (1120W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>1.1°C</td>
<td>0.5°C</td>
<td>1.7°C</td>
</tr>
<tr>
<td></td>
<td>0.9°C</td>
<td>0.5°C</td>
<td>2.0°C</td>
</tr>
<tr>
<td>SSG</td>
<td>3°C</td>
<td>1.5°C</td>
<td>4°C</td>
</tr>
<tr>
<td></td>
<td>2.7°C</td>
<td>1.4°C</td>
<td>4.5°C</td>
</tr>
<tr>
<td>Si</td>
<td>6.0°C</td>
<td>3.4°C</td>
<td><strong>9.6°C</strong></td>
</tr>
<tr>
<td></td>
<td>6.4°C</td>
<td>3.2°C</td>
<td>10.2°C</td>
</tr>
<tr>
<td>Al</td>
<td>4.2°C</td>
<td>2.4°C</td>
<td>7.3°C</td>
</tr>
<tr>
<td></td>
<td>4.5°C</td>
<td>2.3°C</td>
<td>7.7°C</td>
</tr>
</tbody>
</table>

- spacer: Si better than Al
- system: SSG better than dry
- glazing system: high perf. better than clear

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Potential Savings of Systems in a Hot Climate

Climate of Abu Dhabi

Door@north

3 floors

50m

50m

40 floors

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Scientific Approach

• Compare Energy Use (electricity for cooling and lighting and gas for heating) of different curtain wall systems based on:
  - EFEN software (CARLI)
  - $U_{\text{value}}$, SHGC: as calculated with THERM and WINDOW
  - Air leakage: from 0 (new gasket or SSG system) to 16.5 in order to simulate ageing of old gasket
  - Standard energy costs: 0.16$/kWh (electricity), 0.07$/kWh (gas)

• Calculate $\text{CO}_2$ emissions based on:
  - 1kWh electricity from a mixed generation = 0.480kg $\text{CO}_2$ emissions
  - 1GJ gas = 53.8 kg $\text{CO}_2$ emissions
Example of Results: Energy consumption

Reduced energy consumption with air infiltration rate:
~292GJ

Comparison of Total Energy use (GJ) between worse and best case

High performance glass, Si spacer
Low performance glass Al spacer

Reduced energy costs with air infiltration rate:
~9300$

Comparison of Total Energy costs ($) between worse and best case

High performance glass, Si spacer
Low performance glass Al spacer

Reduced energy costs with air infiltration rate:
~9300$
## Results: Energy consumption

- **Worst system:** Dry, aged gaskets (high infiltration), clear glass, Al spacer
- **Best system:** SSG, low infiltration, high performance glass, warm edge spacer
- Up to 292 GJ Energy savings between worst and best case: ~5% energy use reduction
- Up to 9300$ saved energy costs for a 3floors high building: ~7% of cost reduction

<table>
<thead>
<tr>
<th>system dry/wet</th>
<th>glass poor/good</th>
<th>spacer Al/Si</th>
<th>infiltration (m³/m²h)</th>
<th>total energy costs savings</th>
<th>total energy costs</th>
<th>total energy consumption (site) GJ</th>
<th>Total energy savings (GJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry poor Al</td>
<td>16.5</td>
<td>0</td>
<td>135671</td>
<td>6092</td>
<td>0.0</td>
<td>135671</td>
<td>6092</td>
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<td>Dry poor Si</td>
<td>16.5</td>
<td>5</td>
<td>135666</td>
<td>6091</td>
<td>1.0</td>
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<td>134285</td>
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Example of Results: CO\textsubscript{2} Emissions

- Calculate CO\textsubscript{2} emissions based on:
  - 1kWh electricity from a mixed generation = 0.480kg CO\textsubscript{2} emissions
  - 1GJ gas = 53.8 kg CO\textsubscript{2} emissions

Increase in CO\textsubscript{2} savings due to reduced energy consumption: \(~52.4\) tons
Results: CO₂ emissions

- Up to 52.4 tons CO₂ savings with 1 building of 3 floors high (between worst and best case) = -7%
- Annual CO₂ emissions from consumption and flaring of fossil fuels by UAE: 137.82 million tons
- Extend to all buildings in Dubai!

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7% energy savings
Conclusions

- Proper choice of glass is critical to performance.
- SSG Systems outperform the Dry Glazed systems
  - Lower U values when compared to each other all other items being equal
  - Frame temperatures are closer to interior ambient in both hot and cold climate
  - Lower energy consumption and CO₂ emissions
- Warm Edge Silicone spacers outperform Aluminum spacers
  - Lower U values when compared to each other all other items being equal
  - Frame temperatures are closer to interior ambient in both hot and cold climate
  - Lower energy consumption and CO₂ emissions
- A combination of both SSG and Silicone Warm Edge system provided the best results
- Air infiltration is critical to minimize energy consumption: durable systems should be preferred