Comparisons of Thermal Performance and Energy Consumption of Facades Used in Commercial Buildings

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Abstract
Concerns over the growth of emissions and global warming in the developed world have been rising steadily over the past few years. Buildings hold the key to obtain and maintain long term energy savings and sustainability, as the building sector accounts for a significant percentage of the energy usage today.

It is important to assess energetic performance of buildings in order to provide owners and specifiers economic data allowing the choice of an appropriate renovation program for an existing building or provide a comparison for systems selection for new constructions. Choosing energy efficient fenestration systems can play an important role in minimizing energy costs (heating and lighting) for the building.

This study investigates the energy consumption of commercial buildings with varying climatic conditions and materials. Fenestration systems evaluated are mechanically fixed glazed curtainwall systems compared to Silicone Structural Glazed system. Simulations are performed using Therm and Window software from Lawrence Berkeley National Laboratories and EFEN software from Carli Inc.

Results show that low U values in combination with low air infiltration rates provide the lowest energy consumption resulting in best performance.

Introduction

In today's economic situation, energy consumption and savings are more important than ever. Improvement of energy efficiency in all aspects of our lives will reduce costs and CO_2 emissions. In order to reduce energy consumption, countries all over the world focus on the design of energy efficient buildings. Buildings represent 38.9% of U.S. primary energy use (includes fuel input for production). Buildings are one of the heaviest consumers of natural resources and account for a significant portion of the greenhouse gas emissions that affect climate change. In the U.S., buildings account for 38% of all CO2 emissions. [1] The same startling statistics are reflected in the European Community through the European Commission Website. "The buildings sector accounts for 40% of the EU's energy requirements. It offers the largest single potential for energy efficiency". [3] There is a need for specialists in materials, construction professionals, and owner/occupant advocates to understand the advantages of Energy Efficient Whole Building Design approach from the start of a project.

Curtainwall assemblies are more attractive today than anytime in the past thanks to abundant use of glass in highly engineered glazing systems. The wide range of finishes offered by glass and aluminum increase the architectural appeal of commercial buildings. Efficiency is guaranteed through the use of insulating glass. Addition of a second (or third) piece of glass, inert gas filling, or use of glass coatings, are some of the latest developments in insulating glass units which improved significantly U-values (and therefore reduced energy consumption) down to values of 0.5-0.6W/m²K [4]. These values come close to (non-glass) wall U-values (~0.3-0.6 $W/(m^2K)$). However, the additional glass processing steps needed to obtain such low U-values, add extra costs to the façade resulting in increased payback time. Considering the continuous desire to increase the percentage of vision glazing systems and their relative inefficiency regarding thermal performance compared to non-glass walls, a lot of attention is still focusing on improving the thermal efficiency of the glazing systems. On the other hand, little is done to evaluate and optimize the thermal performance of frames and attaching systems. Considering the fact that frames are typically made of heat conductive metal (aluminum), a more intensive study of frame and attachment methods that show significant improvements in the efficiency is presented. Therefore, this paper compares the performance of two common methods of glazing attachment in combination with various air infiltration rates. Performances are compared through modeling by evaluating overall thermal transmittance and energy consumption of commercial facades using these systems in both hot and cold climates.

Methodology

Comparisons are made between two types of glazing systems that attach the glass to the frame, two different insulating glass configurations and two different insulating glass spacer systems. Comparisons are made the following ways.

1. Standard method versus structural silicone.
2. The use of an insulating glass unit with triple Low E high performance glass compared to a standard insulating glass unit using only clear glass
3. The use of an aluminum IG spacer compared to a silicone foam warm edge spacer.

Simulations

Therm 5.2 is a free computer program developed at Lawrence Berkeley National Laboratory (LBNL) for use by the public interested in two-dimensional heat transfer analysis to evaluate a product's energy efficiency. Boundary conditions corresponding to local temperature patterns can be input, therefore a direct relationship to problems with condensation, moisture damage, heat damage and structural integrity can be predicted or explained. [5]

WINDOW 5.2 is a publicly available computer program for calculating total window thermal performance indices (i.e. U-values, solar heat gain coefficients, shading coefficients, and visible transmittances) based on Therm's results. [6]

The THERM and WINDOW programs check the heat transfer through the frames and predict overall U values based on a designed window. THERM and WINDOW are not able to model energy use based on additional or excess air infiltration, this is done by EFEN, a program designed by DesignBuilder Software. Based on WINDOW results, EFEN evaluates and compares fenestration options in various types of commercial buildings, predicts the whole building energy use and the size of HVAC equipment. Evaluation takes into account location specific weather data and orientation to provide much customized results. It also allows the input of air leakage rates through fenestration systems, simulating the decreased energy performance with increased and unwanted air leakage. [7]

Boundary conditions

When applying the thermal modeling software, a heat transfer coefficient is calculated for the frame and also for the center of the glass. THERM calculates this based on the requirements found in National Fenestration Rating Council (NFRC) 100 method or other boundary conditions that are placed in the program. Changing boundary conditions allows one to track and compare the temperature gradients at various places within the system modeled. NFRC 100 specifies that the exterior temperature be set at -18°C. This temperature is not uncommon in the winter time in North America, Northern Europe and Northern China. These NFRC boundary conditions were used when studying cold climates. When modeling in a hot climate, THERM allows a solar loading and exterior temperature to be entered. The results in this study have used hot temperature condition of 50^{o}C exterior temperature with a solar loading of 1120 W/m^2. This condition comes from weathering requirements from the US military. [8]

Framing systems

Two different glazing systems were modeled in this paper. For sake of simplicity, a single aluminum framing system is explored. The basic frame is 50mm wide and 100 mm deep with a 3mm wall thickness. There is some slight difference in the frame depending on the type of attachment methods used.

The first standard thermally improved glazing system (Figure 1) uses pressure bars to mechanically attach the glazing to the façade. The exterior aluminum glazing stop is anchored to the interior frame every 236 mm with a steel bolt and a spacer of high performance plastic isolates the interior frame from the exterior frame. The glazing is allowed to move within the gaskets during thermal expansion and contraction and during movement due to live loading on the building. The gaskets take up the role of weatherseal. As an illustration, a similar non-broken system is shown on Figure 1. These systems have aluminum that is continuous between the interior and exterior. This type of system will typically be less expensive compared to other systems and is the most common in mild climates where there are minimum temperature differentials between inside and outside

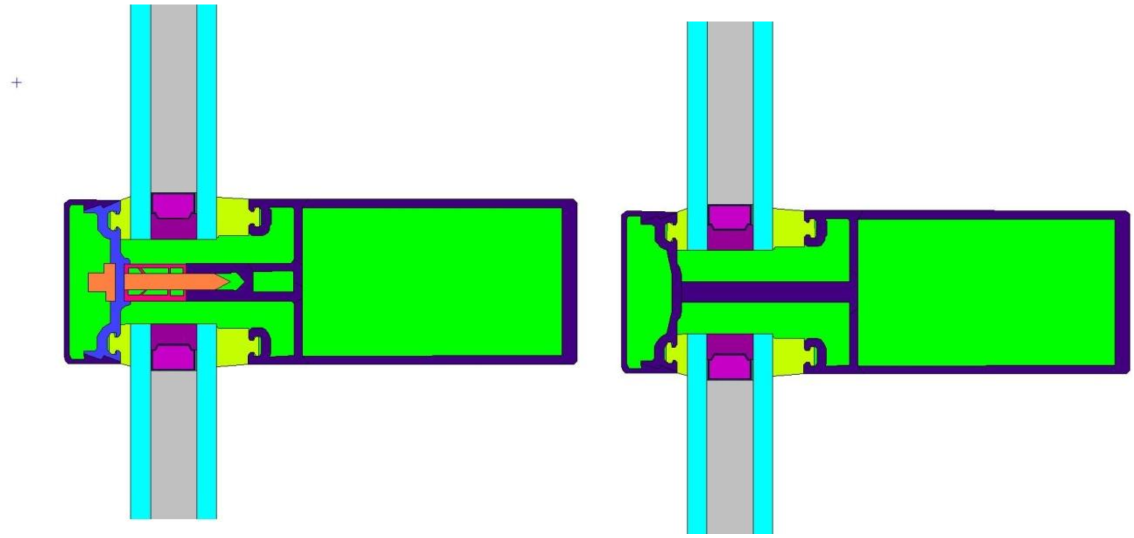

Figure 1: Dry glazed thermally improved system (left) and non-broken dry glazed aluminum system (right)

The second investigated glazing system (Figure 2) uses wet structural silicone sealant as an adhesive that continuously anchors the glass to the frame while sealing the glazing from air and water infiltration. The structural silicone absorbs differential movements between glass and frame experienced by thermal expansion and contraction and live load deflections from the building due to wind sway, seismic events, and occupant generated loads. This is a key attribute of the silicone structural glazing system. During these daily movements over many years, the silicone keeps the glazing in place and eliminates air and water infiltration.

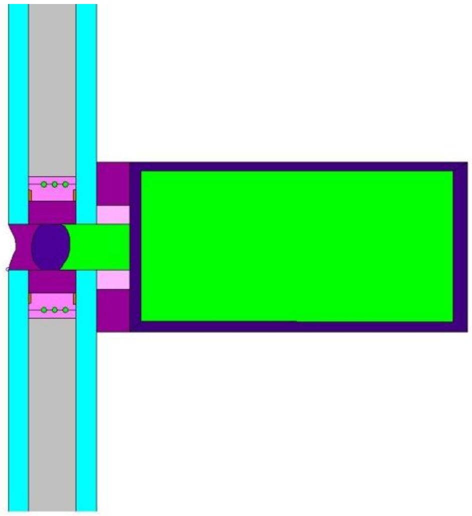

Figure 2: Silicone structural glazed system

Insulating glass units
The two insulating glass systems modeled each use 6mm glass with a 14mm airspace. The external pane is again clear glass for the first system, whereas the second system uses on the outboard a clear pane with a triple low E coating on the #2 surface. The properties of both insulating glass units, as modeled by WINDOW, are shown in Table 1.

Table 1: Overview of principal glazing characteristics for both investigated insulating glass units (as modeled by WINDOW)

Insulating glass Unit	U (W/m^2K)	SC (solar coefficient)	SHGC (solar heat gain coefficient)	Relative heat gain (W/m^2)	T_{vis} (visible transmission)	K_{eff} (W/mK)
Clear-Clear	2.676	0.810	0.702	532	0.786	0.0733
Low E^3 high performance	1.643	0.317	0.275	211	0.623	0.0331

Spacers
Two types of insulating glass spacers (Figure 3) are modeled to show the effects of different heat transfer rates of the spacers. One model uses an aluminum spacer filled with desiccant and the other model uses desiccated silicone foam. Both spacers use a polyisobutylene primary seal and a silicone secondary seal.

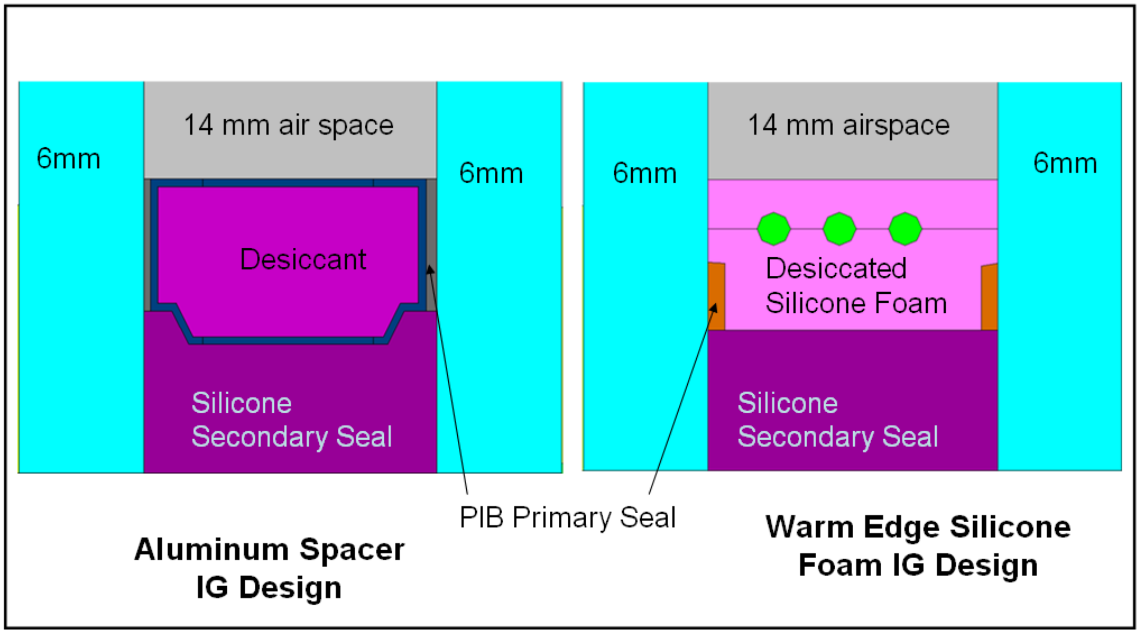

Figure 3: Configuration of the two types of insulating glass

Results and Discussion

We use results from Therm to record and compare the interior frame temperatures between systems or when the exterior environment is varied. Figure 4 and Figure 5 show the heat transfer in colors assigned by the Therm program for two specific combinations of façade, glass and spacer systems.

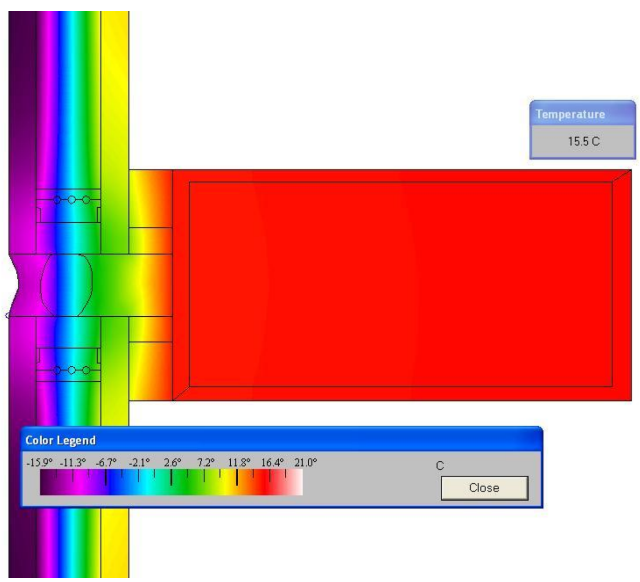

Figure 4: Therm Results for Structural silicone glazed system using high performance glass and a silicone foam warm edge IG spacer at -18C exterior and 21C interior noting a 15.5C frame temperature

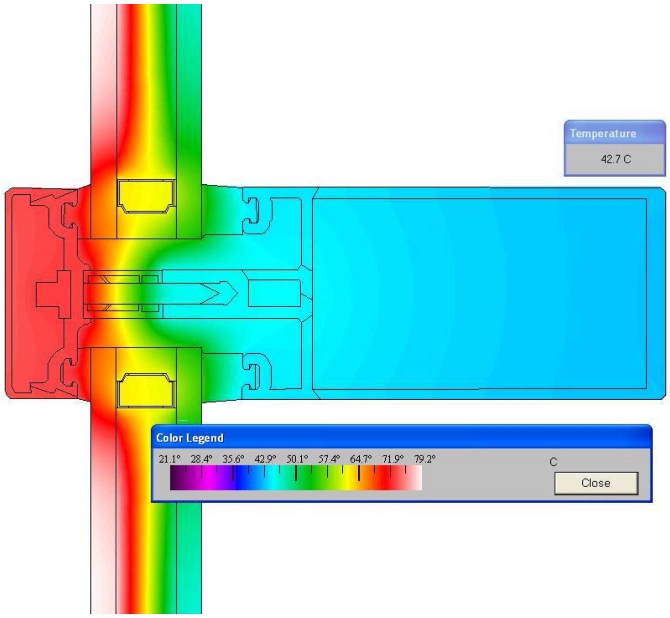

Figure 5: Therm results for a dry glazed system with clear insulating glass and an aluminum IG spacer at an exterior temperature of 50C and 1120 W/m^2 solar load noting a 42.7 C frame temperature

Tables 2 and 3 summarize the temperatures of the frames for the various glazing and frame models at a -18°C and 50°C exterior temperatures respectively. The temperatures are sorted in Table 2 numerically from highest value (which corresponds with highest performance for a cold climate) to lowest. The inverse order is used for hot climates. Note the first line item in Table 2 is represented in Figure 4 and the last line item in Table 2 is represented in Figure 5.

Table 2: Interior frame temperatures for various frame and glazing combinations at exterior conditions of -18^{o}C and 50C with 1120 W/m^2 constant heat flux solar loading.

Glazing System	IG Spacer	Glass	Interior mullion temp at -18C exterior temp	Interior mullion temp at 50C and 1120 W/m2 exterior conditions
SSG	Si	LoE3/Clear	15.5	29.8
SSG	Si	Clear/Clear	14.5	31.4
SSG	Al	LoE3/Clear	12.5	34.3
SSG	Al	Clear/Clear	11.8	35.4
Dry	Si	LoE3/Clear	9.1	40.0
Dry	Si	Clear/Clear	8.5	41.0
Dry	Al	LoE3/Clear	8.0	42.0
Dry	Al	Clear/Clear	7.6	42.7

From this modeling and the tables above, note that the SSG system with high performance glass and a silicone spacer system shows the least amount of thermal differential from exterior to the interior. This shows the advantage of the SSG system over the thermally improved dry glazed system (as shown in Figure 1 and Figure 2). We can also see the advantage of the silicone foam warm edge spacer. When looking at the data in Table 2, it should be noted that the highest performing systems are indeed in the same order for both types of external environmental conditions.

The results from THERM are then inserted in WINDOW where a full size window can be modeled and an overall U value for the glazing system is calculated, as well as the SHGC (solar heat gain coefficient) (Table 3). The windows were modeled to full size (1.2 x 2.5 meter) commercial fenestration units (insulating glass in a curtainwall system using the frame designs shown in Figure 1 and Figure 2). The results are sorted by the lowest U value at the top.

Table 3: Summary of overall U values from Window Program using 1.2 x 2.5 m glass in a curtainwall.

SSG or Dry	spacer	glass	glass size	U value overall W/m2K	Center of Glass U value W/m2K	SHGC	Visible transmittance
SSG	Si	LoE3/clear	1200 x 2500	1.798	1.609	0.281	0.585
SSG	Al	LoE3/clear	1200 x 2500	2.007	1.609	0.295	0.585
Dry	Si	LoE3/clear	1200 x 2500	2.185	1.609	0.266	0.584
Dry	Al	LoE3/clear	1200 x 2500	2.299	1.609	0.267	0.582
SSG	Si	Clear/clear	1200 x 2500	2.719	2.589	0.683	0.738
SSG	Al	Clear/clear	1200 x 2500	2.869	2.589	0.693	0.739
Dry	Si	Clear/clear	1200 x 2500	3.074	2.589	0.665	0.737
Dry	Al	Clear/clear	1200 x 2500	3.167	2.589	0.665	0.736

Table 3 is sorted in order of highest performance to lowest performance of the eight systems according to their overall U value. It is interesting to note that the top four systems are a result of the high performance glass. The center of glass U value has a large impact on the overall U value for this modeled system. We can note that the solar Heat Gain Coefficient (SHGC) and the visible transmittance ratings are directly related to the type of glass used. This ranked order is slightly altered compared to the order presented in Table 2. Here the model uses large pieces of glass to simulate commercial office building construction. When smaller glazing units are used, there is a larger ratio of frame area to glazing area. Increasing the frame area compared to the glazing area results in higher overall U values compared to the center of glass U value. This is logical when reviewing Therm results of the frame. This commercial system with relatively large pieces of glass has an overall U value that is impacted by the type of frame as noted in Table 3, however the impact is much less compared to the impact noted by the choice of glazing. Again we see the impact of high performance glass on the overall U value.

Two of these Window systems were then exported into EFEN, to analyze the energy consumption of a complete building using these fenestration systems. A model building was chosen, 9 stories tall with a rectangular footprint, 12.0 x 50.0 meters with a 4.0 meter floor to floor height. This configuration was chosen to maximize the façade area to building volume ratio with the expectation that differences in façade performance could be easily detected. A picture of this model is shown in Figure 6. This is modeled as a commercial office building using the assumptions previously published from Mahabir Bhandari. [9, 10]

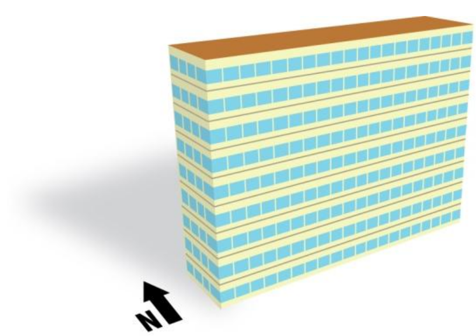

Figure 6: 12m x 50m x 9 story building model for energy analysis

The building was modeled to have a large south facing façade and had four chosen northern hemisphere locations, Hong Kong, Madrid Spain, Minneapolis, Minnesota USA, and Tampere Finland, representing hot and humid, hot and dry and cold climates respectively. For more specific US climates, Portland, OR, and Las Vegas, NV have also been added to the analysis. This 9 story building model could use the weather files from major cities around the world to obtain an energy use data set, a benefit offered by the Carli software. The modeled systems noted above incorporating insulating glass (Low E3 and clear IG), silicone structural glazed (SSG) system, and the Dry Glazed thermally improved (TI) systems were put into the EFEN model. The façade of this model contained no shading or setbacks.

This energy analysis program, EFEN, can perform simulations with various air infiltration rates affecting the fenestration system. The default rate for the program is 5.5 $m^3/m^2/hr$. Original specified glazing systems for the façade must maintain their integrity; however, infiltration rates vary from system to system. Air infiltration rates can increase over time if the original glazing materials are susceptible to degradation due to natural weathering. The thermally improved window/curtainwall system uses gaskets as the primary air seal on the wall. Typical gaskets technologies in use today are organic based and have a shorter lifespan compared to the silicone counterparts. One issue with dry glazed gasket sealed walls is the potential for gasket shrinkage allowing extra air into the façade during weather events. Weathered gaskets will allow unplanned air and water infiltration. Air infiltration will cause energy loss. Unwanted water infiltration that wets fiberglass or rock wool insulation in spandrel areas will decrease the insulation value. Spandrel areas that become wet also result in possible corrosion of anchors in a building and can result in structural problems with the façade. Excess air and water infiltration also result in tenant dissatisfaction.

On the other hand, wet sealed SSG facades have a long history of structural performance [11] due to the superior longevity of the structural silicone used as an adhesive/sealant in comparison to organic technologies. The SSG system offers a continuous flexible anchorage of glass to frame, a thermal barrier and a continuous air and water seal. When a building is wet sealed with a durable sealing material such as silicone, a reliable low air infiltration rate can be achieved. Dry Glazed systems that use silicone gaskets can maintain original air infiltration rates due to the thermal and weather stability of silicone gaskets compared to organic gasket materials.

Therefore, air leakages used in the simulations ranged from 0 to 16.5 $m^3/m^2/hr$ (0-3X default rates). The SSG designs were modeled at 0 and 5.5 $m^3/m^2/hr$ and the thermally improved dry glaze system was modeled at 5.5, 11, and 16.5 $m^3/m^2/hr$.

The data table for this modeling exercise is shown below in Table 4. The climate, type of glass, type of glazing system and air infiltration rates are simulated for energy usage using the building noted in Figure 6. When this table is studied closely it is noted that the data is sorted from lowest to highest total energy for each location. We will focus on energy use as opposed to energy costs as energy costs are location specific.

This building has also been modeled with no fenestration system and zero air infiltration. The zero fenestration simulation (color coded in Table 3 and Figures 7 and 8) was done to assess the amount of energy needed to operate this office building with regards to lighting and climate controls. It is surprising that the zero fenestration building is neither the best or worse case for energy consumption in three of the four climates. Commercial fenestration systems do indeed have positive impact on overall energy use in a building and the incorporation of high performance glazing systems are better than no glazing system at all.

Table 4: Energy and cost results for a the 9 story building in a 4 climates with two different glazing systems, two different fenestration systems, a zero fenestration facade and various air infiltration rates.

Glazing system SSG, or Dry TI	Low E3 or Clear	infiltration (m^3/m^2h)	Location	gas GJ	peak gas kW	gas cost $	electricity kWH	electricity GJ	peak KW	electricity cost $	Total Cost	total site GJ	total source GJ	Tons of CO2	Total Site GJ/10
SSG	Low E3	0 air	Hong Kong	**251**	177.00	2758.00	566703.09	**2040**	180.00	49194.00	51951.00	**2291**	6732.99	285.5	229.1
SSG	Low E3	5.5 air	Hong Kong	**297**	186.00	3262.00	574546.57	**2068**	187.00	49875.00	53137.00	**2365**	6872.18	291.7	236.5
SSG	Clear	0 air	Hong Kong	**229**	182.00	2517.00	593758.63	**2138**	169.00	51542.00	54060.00	**2367**	7017.76	297.3	236.7
dry TI	Low E3	5.5 air	Hong Kong	**296**	186.00	3259.00	575115.96	**2070**	187.00	49924.00	53183.00	**2367**	6878.37	292.0	236.7
SSG	Clear	5.5 air	Hong Kong	**271**	190.00	2983.00	598051.92	**2153**	170.00	51915.00	54898.00	**2424**	7112.64	301.7	242.4
dry TI	Clear	5.5 air	Hong Kong	**273**	190.00	3001.00	597873.96	**2152**	170.00	51900.00	54900.00	**2425**	7112.34	301.7	242.5
dry TI	Low E3	11 air	Hong Kong	**346**	195.00	3803.00	581876.87	**2095**	188.00	50511.00	54314.00	**2441**	7009.08	297.9	244.1
dry TI	Low E3	16.5 air	Hong Kong	**397**	204.00	4362.00	588188.12	**2117**	190.00	51059.00	55421.00	**2514**	7136.13	303.7	251.4
none	none	0 air	Hong Kong	**313**	180.00	3443.00	616998.06	**2221**	180.00	53560.00	57003.00	**2534**	7373.96	313.0	253.4
dry TI	Clear	11 air	Hong Kong	**317**	199.00	3483.00	616629.95	**2220**	183.00	53528.00	57011.00	**2537**	7373.70	313.0	253.7
dry TI	Clear	16.5 air	Hong Kong	**363**	208.00	3986.00	624523.68	**2248**	191.00	54213.00	58199.00	**2611**	7513.33	319.3	261.1
SSG	Low E3	0 air	Las Vegas	**908**	234.00	9983.00	465759.57	**1677**	150.00	40431.00	50414.00	**2585**	6294.50	272.4	258.5
SSG	Clear	0 air	Las Vegas	**797**	236.00	8766.00	509650.35	**1835**	151.00	53007.00	61773.00	**2632**	6674.86	287.5	263.2
SSG	Low E3	5.5 air	Las Vegas	**1103**	264.00	12123.00	464215.83	**1671**	149.00	40297.00	52420.00	**2774**	6487.88	282.1	277.4
dry TI	Low E3	5.5 air	Las Vegas	**1111**	265.00	12214.00	464485.82	**1672**	149.00	40321.00	52535.00	**2783**	6499.88	282.7	278.3
SSG	Clear	5.5 air	Las Vegas	**969**	267.00	10650.00	506861.36	**1825**	150.00	43999.00	54649.00	**2793**	6828.87	295.4	279.3
dry TI	Clear	5.5 air	Las Vegas	**975**	268.00	10721.00	506616.27	**1824**	150.00	43978.00	54699.00	**2799**	6833.08	295.6	279.9
none	none	0 air	Las Vegas	**1156**	254.00	12711.00	496971.26	**1789**	141.00	43141.00	55852.00	**2945**	6919.28	300.7	294.5
dry TI	Low E3	11 air	Las Vegas	**1280**	291.00	14072.00	463006.30	**1667**	149.00	40192.00	54264.00	**2947**	6666.21	291.1	294.7
dry TI	Clear	11 air	Las Vegas	**1134**	294.00	12466.00	504310.05	**1816**	150.00	43778.00	56244.00	**2949**	6978.80	303.1	294.9
dry TI	Clear	16.5 air	Las Vegas	**1277**	320.00	14039.00	497378.48	**1791**	150.00	43176.00	57215.00	**3067**	7054.86	307.4	306.7
dry TI	Low E3	16.5 air	Las Vegas	**1430**	318.00	15726.00	461968.03	**1663**	149.00	40102.00	55828.00	**3093**	6817.42	298.7	309.3
SSG	Low E3	0 air	Madrid	**1001**	274.00	11002.00	424691.89	**1529**	155.00	36866.00	47868.00	**2530**	5926.69	257.7	253.0
SSG	Low E3	5.5 air	Madrid	**1148**	312.00	12623.00	424208.78	**1527**	157.00	36824.00	49447.00	**2675**	6081.03	265.4	267.5
SSG	Clear	0 air	Madrid	**1014**	280.00	11149.00	463076.92	**1667**	156.00	40198.00	51348.00	**2681**	6378.89	276.8	268.1
dry TI	Low E3	5.5 air	Madrid	**1161**	313.00	12761.00	424378.66	**1528**	157.00	36839.00	49600.00	**2688**	6096.61	266.1	268.8
none	none	0 air	Madrid	**1037**	297.00	11403.00	465389.67	**1675**	156.00	40399.00	51802.00	**2713**	6430.25	279.2	271.3
SSG	Clear	5.5 air	Madrid	**1144**	318.00	12582.00	461611.01	**1662**	156.00	40071.00	52653.00	**2806**	6503.46	283.1	280.6
dry TI	Clear	5.5 air	Madrid	**1154**	318.00	12684.00	461295.42	**1661**	156.00	40044.00	52727.00	**2814**	6509.83	283.5	281.4
dry TI	Low E3	11 air	Madrid	**1298**	338.00	14276.00	424123.95	**1527**	157.00	36817.00	51092.00	**2825**	6242.99	273.4	282.5
dry TI	Clear	11 air	Madrid	**1275**	340.00	14022.00	460088.62	**1656**	156.00	39939.00	53961.00	**2932**	6628.06	289.5	293.2
dry TI	Low E3	16.5 air	Madrid	**1429**	359.00	15716.00	423993.04	**1526**	157.00	36806.00	52521.00	**2956**	6383.50	280.4	295.6
dry TI	Clear	16.5 air	Madrid	**1390**	359.00	15287.00	459090.85	**1653**	157.00	39852.00	55139.00	**3043**	6741.39	295.2	304.3
SSG	Low E3	0 air	Minneapolis	**3135**	476.00	34473.00	413655.77	**1489**	169.00	35908.00	70381.00	**4625**	8114.94	367.2	462.5
SSG	Clear	0 air	Minneapolis	**3083**	479.00	33902.00	444450.43	**1600**	164.00	38581.00	72483.00	**4683**	8409.74	379.2	468.3
SSG	Low E3	5.5 air	Minneapolis	**3532**	479.00	38836.00	414678.17	**1493**	171.00	35997.00	74833.00	**5025**	8556.83	389.1	502.5
SSG	Clear	5.5 air	Minneapolis	**3437**	479.00	37792.00	443917.14	**1598**	165.00	38535.00	76327.00	**5035**	8787.25	398.0	503.5
dry TI	Low E3	5.5 air	Minneapolis	**3555**	479.00	39091.00	414863.84	**1494**	171.00	36013.00	75104.00	**5049**	8584.00	390.4	504.9
dry TI	Clear	5.5 air	Minneapolis	**3452**	479.00	37949.00	443708.60	**1597**	165.00	38517.00	76466.00	**5049**	8800.35	398.7	504.9
none	none	0 air	Minneapolis	**3396**	479.00	37339.00	467529.76	**1683**	176.00	40585.00	77924.00	**5079**	9011.79	407.1	507.9
dry TI	Clear	11 air	Minneapolis	**3760**	479.00	41335.00	443562.68	**1597**	166.00	38504.00	79839.00	**5356**	9132.51	415.2	535.6
dry TI	Low E3	11 air	Minneapolis	**3897**	479.00	42843.00	415586.71	**1496**	171.00	36076.00	78919.00	**5393**	8962.22	409.1	539.3
dry TI	Low E3	16.5 air	Minneapolis	**4201**	479.00	46193.00	416200.34	**1498**	172.00	36129.00	82322.00	**5700**	9299.46	425.8	570.0
dry TI	Clear	16.5 air	Minneapolis	**3944**	479.00	43363.00	515404.83	**1855**	167.00	44741.00	88104.00	**5799**	10151.55	459.6	579.9
SSG	Low E3	0 air	Portland	**1970**	411.00	21664.00	401383.69	**1445**	153.00	34843.00	56507.00	**3415**	6712.17	298.7	341.5
SSG	Clear	0 air	Portland	**2011**	419.00	22111.00	429826.82	**1547**	156.00	37312.00	59423.00	**3558**	7080.53	314.5	355.8
SSG	Low E3	5.5 air	Portland	**2283**	444.00	25106.00	400743.29	**1443**	155.00	34787.00	59893.00	**3726**	7044.24	315.2	372.6
none	none	0 air	Portland	**2116**	433.00	23263.00	449032.62	**1617**	139.00	38979.00	62243.00	**3732**	7413.13	329.4	373.2
dry TI	Low E3	5.5 air	Portland	**2302**	445.00	25311.00	400897.44	**1443**	156.00	34801.00	60111.00	**3745**	7066.16	316.3	374.5
SSG	Clear	5.5 air	Portland	**2284**	450.00	25111.00	427920.36	**1541**	156.00	37146.00	62258.00	**3824**	7354.60	328.3	382.4
dry TI	Clear	5.5 air	Portland	**2298**	450.00	25261.00	427716.00	**1540**	156.00	37129.00	62390.00	**3837**	7367.08	328.9	383.7
dry TI	Low E3	11 air	Portland	**2584**	460.00	28405.00	400442.66	**1442**	156.00	34761.00	63166.00	**4025**	7366.05	331.2	402.5
dry TI	Clear	11 air	Portland	**2548**	463.00	28017.00	426163.84	**1534**	156.00	36994.00	65011.00	**4082**	7621.04	341.7	408.2
dry TI	Low E3	16.5 air	Portland	**2841**	471.00	31232.00	400327.72	**1441**	156.00	34751.00	65984.00	**4282**	7643.51	345.0	428.2
dry TI	Clear	16.5 air	Portland	**2670**	473.00	29360.00	495592.75	**1784**	156.00	43021.00	72381.00	**4455**	8545.05	381.6	445.5
SSG	Low E3	0 air	Tampere	**3028**	463.00	33295.00	388037.65	**1397**	146.00	33684.00	66980.00	**4425**	7706.78	349.2	442.5
SSG	Low E3	5.5 air	Tampere	**3400**	477.00	37384.00	387439.85	**1395**	145.00	33632.00	71016.00	**4795**	8103.04	368.9	479.5
SSG	Clear	0 air	Tampere	**3349**	465.00	36820.00	409170.87	**1473**	149.00	35519.00	72339.00	**4822**	8295.24	376.6	482.2
dry TI	Low E3	5.5 air	Tampere	**3437**	477.00	37788.00	387541.87	**1395**	146.00	33641.00	71429.00	**4832**	8144.07	370.9	483.2
SSG	Clear	5.5 air	Tampere	**3663**	477.00	40276.00	407916.95	**1469**	149.00	35410.00	75686.00	**5132**	8621.70	392.9	513.2
dry TI	Clear	5.5 air	Tampere	**3682**	477.00	40483.00	407739.23	**1468**	149.00	35395.00	75878.00	**5150**	8640.10	393.8	515.0
dry TI	Low E3	11 air	Tampere	**3771**	477.00	41460.00	387226.17	**1394**	145.00	33614.00	75074.00	**5165**	8502.48	388.7	516.5
dry TI	Clear	11 air	Tampere	**3967**	477.00	43615.00	407098.85	**1466**	149.00	35339.00	78954.00	**5432**	8941.57	408.8	543.2
dry TI	Low E3	16.5 air	Tampere	**4074**	477.00	44792.00	387285.57	**1394**	145.00	33619.00	78411.00	**5468**	8831.67	405.1	546.8
dry TI	Clear	16.5 air	Tampere	**4119**	477.00	45290.00	463336.16	**1668**	149.00	40221.00	85511.00	**5787**	9747.88	444.0	578.7
none	none	0 air	Tampere	**5116**	477.00	56253.00	432389.30	**1557**	140.00	37534.00	93788.00	**6673**	10475.94	482.8	667.3

As mentioned we will focus on the total energy use in gigajoules. Gas use is calculated and measured in gigajoules and electricity is measured in kilowatt hours. One gigajoule of energy is 277.8 kilowatt hours. These are standard energy conversions. The energy use for the site of the modeled 9 story building is plotted below in Figure 7 and Figure 8. The graphs are plotted starting with the lowest total energy on the left to the highest energy use on the right.

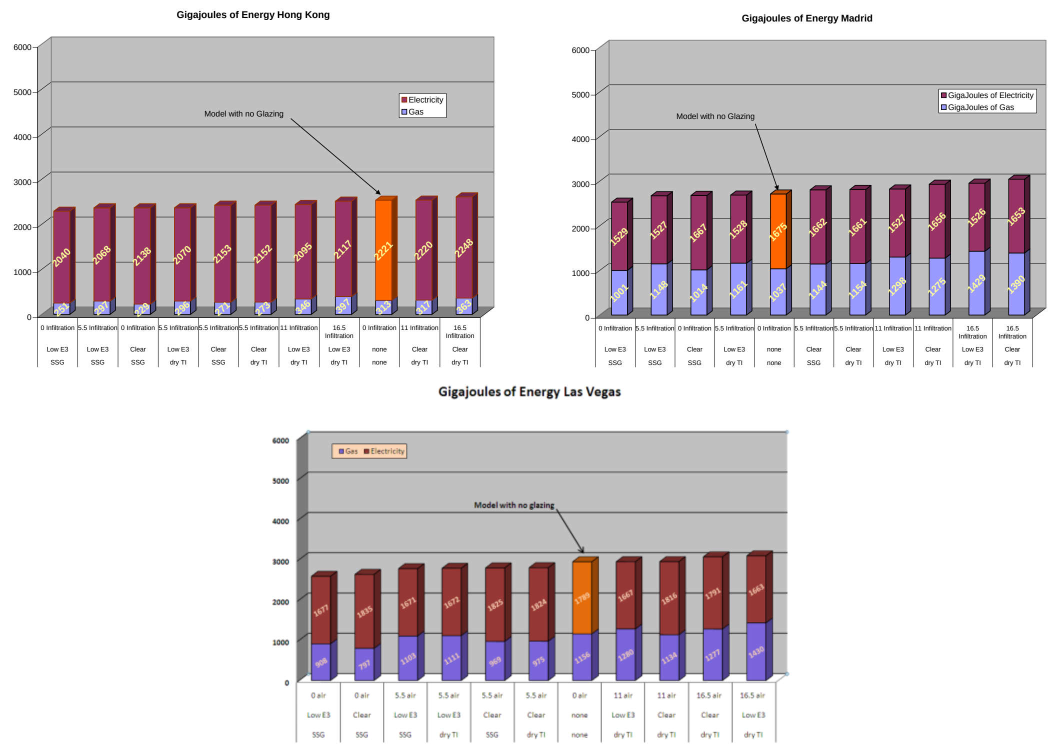

Figure 7: Energy Use of a 9 story building in a Hot Climate, Hong Kong, Madrid Spain and Las Vegas Nevada with variations on IG, system design and air infiltration rates

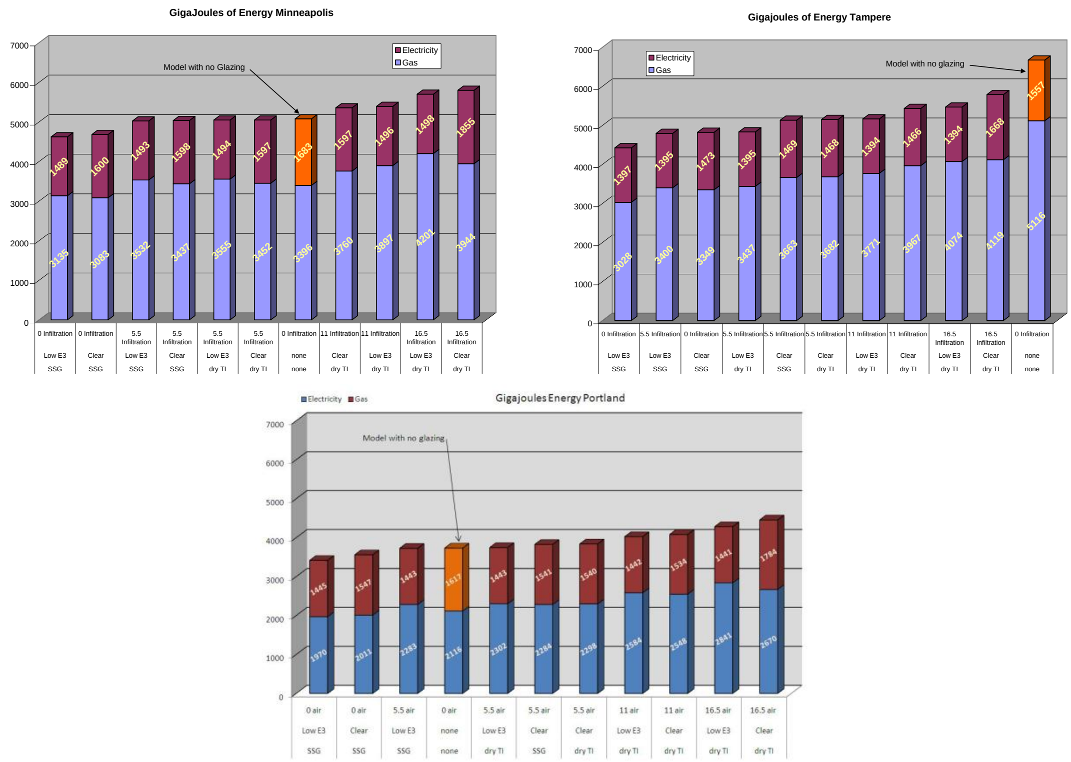

Figure 8: Energy Use of a 9 Story Building in a Cold Climate: Portland, OR; Minneapolis, MN and Tampere, Finland with variations on IG, system design and air infiltration rates

This energy model is calculated based on an annual use starting in January and ending in December using a typical weather year for that specific location. The above figures, 7 and 8, represent the total energy use for the building by adding the energy consumed in both gas and electricity. The building uses energy for electric lighting, heating water, heating and air conditioning, elevators and tenant appliances. The charts are color coded to identify a modeled building without any glazing incorporated in to the façade. The annual energy use is significantly impacted by the air infiltration rates. When the energy use at 5.5 $m^3/m^2/hr$, or default infiltration rates, is studied in Figure 7 and the trends observed from the Therm and Window results can be confirmed. Review the chart in Figure 8 for Minneapolis at an infiltration rate of 5.5 $m^3/m^2/hr$. The Low E3 SSG has a lower total energy consumption compared to the Clear SSG. However it should be noted that the Clear SSG entry actually uses less gas and more electricity compared to the Low E3 SSG. It is logical to conclude that the Clear SSG allows more heat gain into the building due to the higher Solar Heat Gain Coefficient of the glass and thus reduces the need for heating in the winter. Consequently this is offset by the heat gained in the summer and the air conditioning must work harder to cool the building.

It is possible to relate this energy use to local energy costs and CO_2 emissions. CO_2 emissions will vary depending on the energy sourcing of the local power supply, be it nuclear, coal, solar, hydroelectric and or gas. Some available sources calculate that electricity produced by a mixed generation of 40% gas, 40% coal, 11% nuclear, 6.6% renewable (wind), and about 2% of other technologies will result in:

1kWh electricity from a mixed generation = 0.480kg CO_2

Other more specific conversions are as follows

- 1kWh electricity from a coal-fired power station = 0.950kg CO_2
- 1kWh electricity from a gas-fired power station = 0.385kg CO_2
- 1kWh electricity from a oil-fired power station = 0.740kg CO_2

- 1GJ gas = 53.8 kg CO_2

If we apply these equivalences (1GJ gas = 53.8kg and 1kWh electricity= 0.48kg CO2) to the amount of electricity and gas consumed by the building, we can calculate how much CO2 the 9-floors high building emits annually, for each type of fenestration system. Of course, these emissions can be more accurately calculated when the exact energy sources are known. Figure 9 shows the total CO2 emissions for the building depending on the window type as indicated in Table 5. These are plotted in the exact order of Table 4 which represents the lowest to highest energy use for each site.

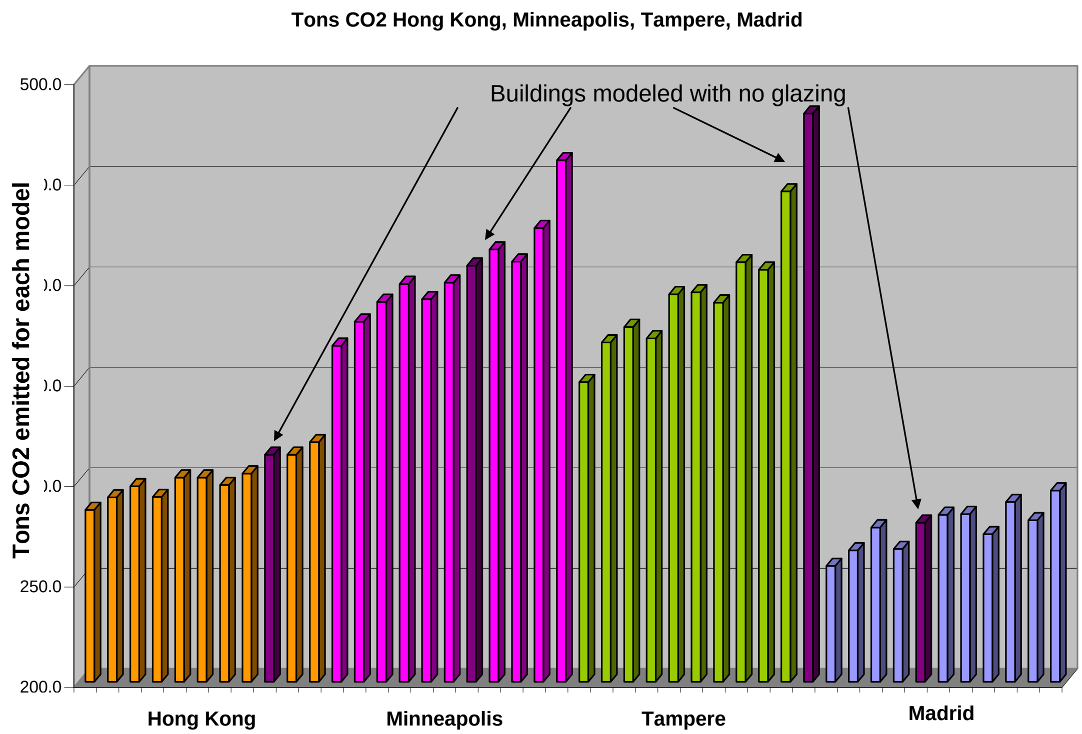

Figure 9: Total CO2 emitted by a 9 floor high building exposed to a various climate depending on the chosen fenestration system as noted in Table 4

From Table 4 and Figure 9 we can see that independently of the location, the lowest CO2 emissions are always obtained for the SSG system with Low E3 glass. The emissions are strongly influenced by the climatic conditions of the simulated location. As an illustration, within the cold climate of Minneapolis a difference of 92.4 tons CO2 is observed between worst and best modeled fenestration system. The savings in CO2 emissions presented here are obtained by choosing an appropriate curtain wall system for a single building of 9 floors height. This value may seem small in respect to overall emissions of the state of Minnesota but they concern only one building. These calculations can be extrapolated to all buildings (newly built or renovation) within the simulated geographic location. Results of these extrapolations estimate the overall energy savings and CO_2 savings that can be obtained when surrounding buildings at that location are brought up to higher performing standards.

A summary of the saving in CO_2 emissions between worse and best case for each simulated geographic area is shown in Table 5.

Table 5: summary of CO_2 savings between highest and lowest performing fenestration system for 9 floor high building in various climatic conditions

	Worse (tons CO2/year)	**Best (tons CO2/year)**	**Savings (tons CO2/year)**
Hong Kong	319.3	285.5	33.8
Minneapolis	459.6	367.2	92.4
Tampere	444.0	349.2	94.8
Madrid	295.2	257.7	37.5
Portland	381.6	298.7	82.9
Las Vegas	307.4	272.4	35.0

Conclusions

This paper provides a number of conclusions based on the thermal and energy models detailed above. These include

1. The SSG system provides the lowest heat transfer compared to a dry glaze thermally improved system, thanks to the absence of metal on the exterior of the façade channeling heat or cold to the interior.
2. The SSG system provides a better framing system compared to the thermally improved dry glaze system due to the structural silicone acting a continuous anchorage of glass to the frame and does not allow air and water infiltration.
3. Warm edge desiccated silicone foam insulating glass spacers are proven to be better spacer systems than aluminum spacers, due to a reduced heat transfer because the insulation values of silicone foam compared to aluminum.
4. Systems incorporating large pieces of glass will show a greater effect of high performance glass coatings introduced into a glazing system because the effect of the frame is decreased due to an increase of the glass area to frame area ratio.
5. The lowest U values are obtained for the SSG system incorporating high performance low E3 coated glass incorporated into an IG unit.
6. The overall energy analysis confirms the trends identified by THERM and WINDOW simulations and it highlights the real necessity for maintaining original specified air infiltration rates on the façade.
7. The building sector can contribute to reductions of CO_2 emissions by choosing an appropriate fenestration system that maintains a low air infiltration rate.

The authors wish to further convey that the gasket glazed systems such as the thermally improved system studied here are able to achieve reasonable low air infiltration rates when they are new. However, when gaskets shrink and pull out of the glazing pockets, excess unconditioned air enters the building and must be conditioned by the heating and air conditioning system, at a cost to the owners. It is suggested that durable gasket materials made of silicone should be used in lieu of organic alternatives. Energy consumption of a building must be considered for the long term, not just during the construction process to meet the existing code or specifications.

The modeling programs available allow the building engineers to model many different systems and alterations of each system. Many of the systems are interdependent on each other. From the experience gained by using the systems to compose this paper, it is clear that a general modeling direction can provide an estimate of costs and energy use based on an initial design. Continued refinements in glass design, gasket design, framing design, can easily be done after the experience is gained with the models before finalizing a design for new or renovation work.

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