An unfair reputation

The energy performance of mid-century metal-and-glass curtain walls

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Abstract – The common argument that mid-century Modernist buildings with single-glazed, non-thermally-broken curtain wall systems are less energy efficient than modern buildings, often is used to justify demolishing these buildings or significantly altering their façades, many of which are significant examples of historic Modernist architecture. This belief does not consider the effect that the ratio of building enclosure area to volume has on energy use, nor does it consider the often poor efficiency of the existing older mechanical equipment’s effect on the overall energy profile. In some cases, the performance of the curtain wall contributes less to the overall building energy performance than heating/cooling, ventilation, and lighting. This paper presents an exploration of the energy use of historic curtain wall systems for two types of buildings and the return-on-investment (ROI) and effect on overall energy use of replacing/altering the curtain wall versus upgrading the mechanical systems.

Keywords – curtain wall; energy; Modernism; mechanical systems

1. INTRODUCTION

1.1 ENERGY CONSUMPTION AND COSTS

A building’s energy gain or loss (load) through the building envelope is a function of many things, including the envelope’s thermal performance characteristics, solar heat gain coefficients, interior and exterior climate, air leakage, the orientation of the façade, etc. Many mid-century curtain wall buildings (Figure 1 is an example) are taller buildings with relatively large floor plates.

Previous research shows that as a building’s surface area-to-volume ratio decreases, the contribution of the envelope load to the total building energy use also decreases, particularly for heating in colder climates.[1] In these cases, other loads, such as mechanical systems and lighting can have a much greater impact on the building’s energy profile, though lower envelope loads will lead to lower energy use for the mechanical system.

The United States (US) Department of Energy’s (DOE) 2011 Buildings Energy Data Book [2] provides analysis of overall US building energy consumption by end use. This data is not separated by building type, envelope, function, age, or location, but it is useful in that it shows that 50 % of US building energy use goes
to mechanical systems (heating, cooling, and ventilation) and 9% goes to lighting.

Other data published by the DOE [2] compares older buildings to contemporary buildings. For office buildings, which often have metal-and-glass curtain wall systems, the average energy use intensity (EUI) for buildings from pre-1959 through 1969 was 225 to 238 kWh/m²/yr (71.4 to 75.5 kBtu/ft²/yr), whereas the EUI for buildings constructed in 2000 through 2009 was 257 kWh/m²/yr (81.4 kBtu/ft²/yr). Also, the energy cost in 2009 for office buildings constructed from pre-1959 to 1969 was €37/m² ($2.5/ft²)[2,3], whereas the energy cost for buildings constructed in 2000 through 2009 was €32/m² ($2.1/ft²).[2,3] This data is not separated by building type, size, or location, but the available published energy consumption and cost data generally does not support the notion that newer must be more efficient or that older buildings will have higher energy costs than contemporary buildings. Instead, this data shows that the energy performance of older and newer office buildings is roughly equal.

We often consider a building’s site or end use energy consumption when discussing the global impact of building energy use, as it intuitively makes sense that lower site energy consumption must be better for the environment. However, considering energy in this way neglects the energy used to extract, process, transport, and transmit energy to the building (source energy). For example, natural gas can have extraction/piping losses of around 5% to 10%, as compared to electricity, which can have generation/transmission losses of up to 70%. These efficiencies affect the pricing of energy for the consumer, who pays for the raw source energy as well as for what is available to the building for use by the time it is delivered. Therefore, the building’s energy cost is a better indicator of the building’s energy impact on the environment. For this reason, site energy cost is used as the basis for comparison in most energy codes in the US. Since the efficiency of electricity will vary by generation type (e.g., a hydroelectric plant vs. a coal-fired power plant), using local energy cost data helps evaluate energy issues. However, note that the correlation between source energy and energy costs are not always direct, as energy costs also will be affected by generation type, demand schedules, market forces, government subsidies, regulations, etc. Also, building owners and managers likely will make their decisions for building improvements more on the building’s operational energy costs than on source
energy, as they are often concerned with the “payback period” on such upgrades. Consequently, we consider energy costs to be the main practical consideration in this type of analysis and use those metrics in our analysis. However, as discussed above, we also expect that the magnitude of changes in energy costs will be similar in magnitude to changes in source energy used, making energy costs a proxy for source energy use for the purposes of this study.

2. ENERGY MODELLING

2.1 ENERGY MODELLING APPROACH

One useful tool for evaluating ways to improve the energy performance of an existing curtain wall building (or any building) is whole-building energy analysis/energy modelling. Modelling can quantify the benefits of improvements to the building envelope, mechanical systems, and lighting systems in terms of the building’s energy consumption and energy costs. For all cases, it is important to note that the results of an energy model should not be seen as a prediction of actual future energy use for a building, but rather as an order of magnitude indicator of the change in performance associated with different building modifications.

To evaluate the changes to the energy performance from different modifications to mid-century curtain wall buildings, we created energy models of two different buildings: a four-story building and a twenty-story building. This exercise was theoretical to test assumptions and potential for energy improvements, rather than an analysis of specific existing buildings. The objective of our analysis was to evaluate the relative change in energy performance and cost from incremental improvements to the building envelope and mechanical systems. As a point of comparison, we also modelled a contemporary curtain wall building with modern systems, IGUs, and thermally broken aluminium framing. We do not consider analysis of these two building types to be representative of all mid-century curtain wall buildings; our purpose here is to test assumptions and provide a framework for analysing a mid-century curtain wall building’s energy profile that could be applied to other cases.

We used the DesignBuilder Version 3.2.0.067 and EnergyPlus Version 7.2.0.006 computer programs to calculate the total annual energy use for the two building types, including building enclosure, lighting, plug, and mechanical system loads. EnergyPlus is a whole-building energy simulation program developed and validated (using standards from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), American National Standards Institute (ANSI), and the International Energy Agency (IEA) by the US DOE that simulates and analyses energy consumption in buildings.

This study examines building performance in New York City using annual hourly weather data from John F. Kennedy International Airport from the US DOE. [4] For energy cost analysis, we used annual average commercial retail prices for electricity and natural gas rates in New York State from the US Energy Information Administration’s State Energy Data System.[5] We selected New York
City as the location for this study because it has a high volume of mid-century curtain wall office buildings and because it is in a climate that experiences all four seasons and a wide range of environmental conditions, including cold winters and warm humid summers. Note that buildings in different climates or in locations that have less urban density may have different results than those presented here.

We assumed internal gains for a typical office building. We kept occupancy rates and schedules, lighting, and plug and other loads constant for all cases to mitigate their effect on the relative change in energy performance between cases.

The modelled four-story building is mid-block with lot line walls, i.e., adjacent buildings on two sides, which often occurs in dense urban areas, such as New York City. The model includes shading on the sides (east and west facing elevations) and solar exposure on the front and back (north and south facing elevations). To be conservative, we assumed still exterior air conditions at the lot line walls, representative of a large gap between the adjacent buildings.

The modelled twenty-story building is standalone, i.e., no adjacent buildings to any side, so the model includes solar exposure on all four sides. While taller buildings, even in dense urban areas, typically will have at least some exposure on all elevations, they also will experience a great variety of shading from adjacent buildings or may share a lot line wall for part of their height. Rather than attempt to address the almost infinite variety of shading or lot line wall possibilities, we simplified the models by omitting shading and lot line walls for this case solely for comparison purposes.

In Table 1 we list the building component characteristics that varied between models. We based building envelope values on our experience with mid-century curtain wall and contemporary curtain wall buildings, and on typical US energy

<table>
<thead>
<tr>
<th>Building Component / Characteristic</th>
<th>Baseline</th>
<th>Improved Performance (New construction cases include all upgraded performance characteristics)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Roof</strong></td>
<td>U-factor: 0.568 W/(m²-K) 0.100 Btu/(ft²-hr-°F)</td>
<td>U-factor: 0.284 W/(m²-K) 0.050 Btu/(ft²-hr-°F)</td>
</tr>
<tr>
<td><strong>Lot Line Walls</strong> (only appears in four story building)</td>
<td>Type: Uninsulated three-wythe brick U-factor: 1.19 W/(m²-K) 0.209 Btu/(ft²-hr-°F)</td>
<td>Type: Insulated three-wythe thick brick U-factor: 0.590 W/(m²-K) 0.104 Btu/(ft²-hr-°F)</td>
</tr>
<tr>
<td><strong>Glazing</strong></td>
<td>U-factor: 5.837 W/(m²-K) 1.028 Btu/(ft²-hr-°F)</td>
<td>U-factor: 2.3 W/(m²-K) 0.50 Btu/(ft²-hr-°F)</td>
</tr>
<tr>
<td></td>
<td>SHGC: 0.76 (single-glazed, 3 mm (1/8 in.) clear glass)</td>
<td>SHGC: 0.40 (code-compliant dual-glazed insulating glazing system, based on 2011 New York City Energy Conservation Code)</td>
</tr>
<tr>
<td><strong>Central Chiller</strong></td>
<td>COP: 1 (assuming steam absorption chiller, common in historic buildings)</td>
<td>COP: 5.5 (modern electric chiller)</td>
</tr>
<tr>
<td><strong>Boiler</strong></td>
<td>75 % thermal efficiency (steam)</td>
<td>90 % thermal efficiency (hot water)</td>
</tr>
<tr>
<td><strong>Air Handlers</strong></td>
<td>90 % fan motor efficiency</td>
<td>95 % fan motor efficiency</td>
</tr>
</tbody>
</table>
code requirements for new buildings. We modelled a mechanical system with a central steam absorption chiller plant, a central steam boiler plant; constant volume forced air ventilation and cooling, and steam radiators and forced air in each zone.

2.2 FOUR-STORY BUILDING

As stated above, the four-story case is a mid-block building with lot line walls on its east and west elevations. Our analysis showed that the baseline four-story historic curtain wall building had a simulated EUI of 463 kWh/m²/yr (147 kBtu/ft²/yr), which is in general agreement with data published by the Lawrence Berkeley National Laboratory (LBNL) for older office buildings in the US. The majority of the energy consumption was for heating at 59%, with 14% for cooling and 9% each for lighting and ventilation (Figure 2). However, the energy cost results (using the New York State energy cost data cited above) showed that cooling had the highest percentage cost at 26%, despite its relatively low contribution to overall energy consumption for the building (on a site energy basis), with 20% for heating and 18% each for lighting and ventilation (Figure 3). The systems that use electricity (cooling, lighting, and ventilation) have higher energy cost due to energy losses from generation and transmission – exemplifying the need to look at source energy use and energy costs when evaluating global impacts from building energy use.

We reviewed a progression of upgrades to the building and its mechanical equipment, which we list in order here (Figure 4):

- Replacing the chiller with a modern electric chiller reduced the annual energy (operating) cost for the building by approximately 45%.
- Adding insulation to the lot line walls and roof had negligible effect.
- Replacing the steam boiler and radiator system with a modern efficient hot water system and installing new fan motors reduced the energy cost by approximately 7%.
- Replacing the historic curtain wall with a new thermally-broken and IGU system, but maintaining the existing boiler and fans, reduced the energy cost by approximately 15%.
The models showed that, for the four-story building, replacing the chiller with a modern chiller significantly can reduce the energy profile of the building, and has the greatest effect on the energy costs. As a point of comparison, the models show a new curtain wall building as having energy costs 36% lower than replacing the chiller only in an existing building. However, in terms of construction costs and the energy required to demolish the existing and manufacture and construct a new building, replacing a chiller would have a much lower initial cost (while published data for chiller replacement is difficult to find, we have found sources indicating a cost of around $250,000 to $400,000 for a 1930 to 2280 kW (550 to 650 ton) chiller replacement [7,8,9], a much more immediate ROI, and an arguably much lower overall impact on the environment than demolishing the existing building and replacing with new. Other incremental improvements could further reduce the energy cost of the existing building but, considering the reduction in costs ranges from almost nothing to 7%, we expect that the relative effort to implement these improvements (such as replacing a boiler and radiator system) would have a much longer ROI for these cases.

The models also showed that replacing the existing curtain wall with new would have relatively low effect on the building's energy profile after replacing the chiller (by a factor of one-third). Based on our project experience, we estimate a cost of $2200/m² to replace an existing curtain wall with a manufacturer’s standard system, not counting the operational costs due to tenant and building disruption. For an approximate 372 m² (4000 ft²) curtain wall area, the cost of replacing the curtain wall (approximately $800,000) is around two to three times that of
replacing the chiller, at one-third the reduction in energy costs (after replacing the chiller). And, we would expect that replacing the curtain wall would have a far greater impact on the environment (in terms of materials and embodied energy), not to mention the loss of historic fabric that is a main contributor to the building’s architectural significance and integrity.

Note that we expect these results would change in different climates or with different exposure or use for the building. However, these results show that a more in-depth analysis of an existing low-rise mid-century curtain wall building is warranted when assessing its energy performance, rather than just assuming that these buildings have irredeemably high energy consumption.

2.3 TWENTY-STORY BUILDING
As stated above, the twenty-story case is a standalone building, considering that taller buildings, even in dense urban areas, often have some exposure on all four sides. Our analysis showed that the baseline twenty-story historic curtain wall building had an EUI of 473 kWh/m²/yr (150 kBTU/ft²/yr), which again is in line with the data published by the LBNL for buildings in the US. [6] The majority of the energy consumption was for cooling at 59 %, with 14 % for ventilation, 10 % for lighting, and 8 % for heating (Figure 5). As noted earlier, as the building’s surface area-to-volume ratio decreases (compared to a shorter building), the contribution of heating to total load also decreases particularly in colder climates. The energy costs (using the New York State energy cost data cited above) follow the energy consumption for this case, with 64 % for cooling, 15 % for ventilation, 10 % for lighting, and only 1 % for heating (Figure 6), which is logical because the systems that use electricity (which has relatively high cost in New York) also have higher energy consumption.

We reviewed upgrades to the building and its equipment, which we list in order here (Figure 7):

- Replacing the curtain wall with a new thermally broken and insulated glazing system reduced the energy cost for the building by approximately 23 %.
- Replacing the chiller with a modern electric chiller, but maintaining the existing curtain wall, reduced the annual energy cost for the building by approximately 47 %.

20-Story Energy Use (energy based)  

Figures 5 and 6. Site Energy Consumption and Site Energy Costs Results for the Twenty-Story Building.
The models show that replacing the chiller alone can reduce the energy cost almost by half and that it has a much greater effect on the building’s energy profile than replacing the curtain wall, and likely at much lower cost and impact on the environment. Again, published data for chiller replacement is difficult to find, but we have found sources indicating a cost of around $1.3 to $2 million to replace chillers with a capacity of around 8800 kW (2500 tons).[7,8,9] By comparison, estimating $2200/m² to replace the curtain wall, for an approximate 7432 m² (80,000 ft²) curtain wall replacement, the cost would be approximately $16 million (again, not including the costs of tenant disruption for an occupied building). While the 23 % savings in energy cost from replacing the curtain wall is significant, it is half of the savings that would come from replacing the chiller but at approximately four times the cost, and it results in the destruction of historic fabric that typically is one of the main contributors to the building’s historic significance. Due to the small energy cost and use associated with heating, we did not model cases with a new boiler as there would be very low ROI and little reduction in energy use or cost.

![Annual Energy Cost for 20-Story Modifications](image)

Figure 7. Effects of Upgrades to Building and Systems on Energy Costs for the Twenty-Story Building.

Again, when comparing upgrades to the existing building to a new building, a new building would have energy cost 38 % lower than replacing the chiller only, but at a much higher initial cost and we expect a far greater impact on the environment.

Similar to the four-story case, we would expect these results to change with different exposure and in different climates. But, as with the four-story case, these results again show that assumptions about the poor energy performance of mid-century curtain wall buildings may not be founded in fact and that more rigorous analysis is warranted for any individual building.
3. CONCLUSIONS

The tendency to replace historic curtain wall systems with contemporary systems can be misguided in the absence of testing and analysis of the building. For the types of buildings in climates similar to those analysed here, replacement of single-glazed historic systems with thermally-broken contemporary aluminium-framed systems with IGUs likely will not result in as significant an ROI as other potential building improvements, though the results do show improvement in the buildings’ energy use and costs. While the demand on the mechanical system will depend in part on the thermal and air leakage performance of the envelope (and a better-performing envelope will lead to lower demand on the mechanical systems), in the cases modelled here, the older mechanical systems’ efficiencies contribute far more to the existing buildings’ energy use and cost than the curtain wall itself, and the taller the building the less effect the curtain wall has on the building’s energy profile. Building systems that require electricity have the greatest effect on the building’s energy cost and the environment due to the transmission losses involved in delivering the electricity to the site in these models. The greatest ROI in these cases, in terms of cost, is to replace older cooling equipment with modern, more efficient equipment. Note that this study was limited to two building types in one location and that local market forces, regulations, and energy sources will affect the costs of electricity, and the results of this type of modelling will vary depending on the location, exposure, and specific building systems. However, the results of this analysis demonstrate the potential dependence of energy use on a multitude of factors that are independent of the façade of the building, and the need for each building to be assessed on an individual basis.

Mid-century Modernist curtain wall buildings present a new type of challenge to the preservation community due to the scale and repetitive nature of their façades, and we consider the approach presented here to be valuable when assessing the energy performance of these types of buildings, both to assess the potential ROI of different improvements to the building, and potentially to help protect these buildings from the quick judgement that older is worse and cannot be improved, while newer is always better. Replacing the curtain wall with new would destroy the historic fabric that contributes to the building’s architectural significance, may have much lower ROI than other potential improvements that would not affect the contributing historic fabric, and possibly have a worse environmental impact.

4. REFERENCES


[6] Lawrence Berkeley National Laboratory. “Building Performance Database.” Internet: https://bpd.lbl.gov/ [October 2014]. Note, data in the original are in English units. We converted to metric units for this article.

