Re-examining Glass Building Design

Exploring The Myths of Achieved Energy Savings

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Introduction

The City of Boston is particularly vulnerable to the future impacts of climate change. To reduce this risk, Boston in 2007 set goals of reducing emissions 25% by 2020 and 80% by 2050, relative to the baseline emissions from 2005. In an effort to meet those targets, Boston adopted both the Stretch Code and Article 37, which require energy savings relative to the American Society of Heating, and Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 90.1. By 2014 the goal was elevated to achieving carbon neutrality by 2050. In order for Boston to reach its ambitious 2050 goal, urban office buildings (new construction or major renovation) need to achieve a measured Energy Use Intensity (EUI)[1] of around 25 Btu/sf-yr[2].

Based on the 2017 Building Energy Reporting and Disclosure Ordinance (BERDO) reporting data, newly constructed office buildings – buildings that have been constructed since 2007 – demonstrate an average measured EUI of around 80 kBtu/sf-yr, which means that despite Boston's intent, its emissions goal is currently unreachable. The prevalence of glass enclosures among newly constructed buildings is evident. By honestly examining the myths and realities of glass-wrapped buildings, my SMMA colleagues and I hope to inspire the building community to prioritize performance and leverage the metric of EUI to define a new urban architecture that is both beautiful and responsible.

[1] EUI is measured in thousands of British Thermal Units per square foot per year

[2] An EUI of 25 kBtu/sf-yr is a typical design target for net zero buildings in cold climates for buildings such as offices and schools. While not every building will be able to achieve net zero status on its own, net zero can probably be achieved on a campus, district, or city scale with off-site renewables with this level of performance.

The Design Debate

Q: How can we design a truly sustainable glass building, one that optimizes energy efficiency and cost savings, while enhancing user environments?

This question, in varying forms, continues to vex the building industry as all-glass towers emerge across city skylines. Glass buildings evoke a certain modern cultural appeal, leading many to view floor-to-ceiling glass as a market necessity for attracting potential tenants. Proponents of highly-glazed facades often refer to the user benefits of additional daylighting and the energy savings from reduced dependence on electric lighting. This logic, while enticing, disregards the argument that all-glass buildings do not result in noticeable energy savings nor an improved indoor environment. Success stories exist, but are muddied by evidence where too much daylighting results in thermal and visual occupant discomfort and increased energy use.

These variances, we argue, can be traced to a flaw in our initial approach to sustainable design: the metrics adopted by the building industry and the design approach they enable. As the industry standard, Leadership in Energy and Environmental Design (LEED) and Stretch Code requirements are unreliable because they depend on relative metrics; both are measured against a hypothetical baseline building and rely on relative prices with varying dependencies. The danger of relative metrics is that they are more easily manipulated, and therefore easier to disregard during initial design decisions. This enables what we have termed, "Reactive Design," the industry standard of considering sustainability as a secondary measure to earlier design decisions such as the commercial inclination towards all-glass buildings.

To illuminate the deficiencies in a reactive design approach, we will first review the current preferred, reactive metrics and introduce EUI as an alternative. We will then provide a research overview explaining the difficulties behind designing all-glass buildings, both in terms of energy performance and employee productivity. In the third section, we review the results of typical reactions, or countermeasures, and discuss both their attributes and failings. Ultimately, we argue that relying on reactive rather than proactive approaches to sustainable building design will continue to prove ineffective.

Instead, we propose favoring EUI, an absolute metric that can not only be verified, but correlates with improved daylighting quality and thermal comfort. ***Our recommendation is to move away from considering performance through the isolated data sets stemming from reactive thinking – a limited approach that can be easily manipulated – and instead look through a more holistic lens. Identifying this holistic approach to sustainability metrics is the first step towards designing sustainable glass buildings. Without these metrics, our results will continue to be skewed, limited, and ultimately ineffective and costly.***

I. Flawed Metrics?

Satisfying Boston's Stretch Code and LEED certifiable requirements does not guarantee a building's sustainability. While these city requirements are aggressive, they rely on flawed energy performance metrics. The relative costs of energy sources – usually electricity or gas – skews energy cost savings, the metric for LEED certification. In the Northeast, a heating dominated environment, we see high energy savings from natural gas. However, since electricity prices are usually three to four times as costly as natural gas, energy cost savings gives electricity savings far more weight. This method then devalues the more effective source for energy savings. Energy cost savings can also be a misleading metric because it compares the design building to a hypothetical baseline building as defined by ASHRAE 90.1 Appendix G. This comparison makes it difficult to measure whether or not those hypothetical energy cost savings are actually achieved. Thus while Stretch code's metric, Energy Savings, removes cost as a factor, it fails because it is measured against this hypothetical "baseline" building.

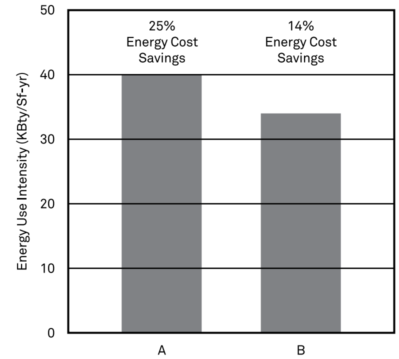

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Figure 1: Comparing energy and energy cost savings for two office building designs

In contrast, EUI speaks directly to a building's energy use. It is an absolute metric relative to zero, and it can be measured and verified once a building is operational.[3] For example, let's consider two LEED Core and Shell developer office buildings designed in Massachusetts.[4] Both were designed by the same firm, and were each approximately 250,000 gsf, and 8 stories in height. When modeled relative to ASHRAE 90.1-2007, Building A demonstrated a 25% energy cost savings and Building B demonstrated a 14% energy cost savings. Based on the LEED rating system, Building A would be awarded more "points" as a higher performing building with respect to energy use. However, Building A actually had a higher EUI, at 40 kBtu/sf-yr, while Building B had a modeled EUI of 34 kBtu/sf-yr. Thus, in respect to EUI, the energy cost savings data skewed the analysis of the buildings' design performance.

Pacific Northwest National Labs' (PNNL) 2013 study, "Analysis of Daylighting Requirements within ASHRAE Standard 90.1," also supports EUI's effectiveness as a measurement tool. The study evaluated the relationship between daylighting and energy performance of a hypothetical medium office building in Chicago. PNNL researchers found that increasing the prototype building's Window to Wall Ratio (WWR) from 30% to 50% – thus increasing the amount of glass – resulted in a 10% increased EUI (Athalye, Xie, Liu, & Rosenberg, 2013). This very real increase in energy use would not necessarily be apparent when comparing a proposed building design to an ASHRAE 90.1 Appendix G Baseline. Appendix G dictates that a baseline office building is modeled with the same WWR as the proposed office building, up to a maximum of 40%. Therefore, the energy penalty associated with increasing the proposed WWR from 30% to 40% (an approximately 5% increase in EUI based on the PNNL study) ((Athalye, Xie, Liu, & Rosenberg, 2013), would not be reflected in the percentage energy savings or energy cost savings between the baseline and proposed models. In both examples, we either wrongly assume savings or we miss out on potential savings when we disregard EUI.

II. True Cost of All Glass Buildings: Decreased Productivity and Comfort; Increased Costs

Understanding the costs of all glass buildings shows a need for different metrics.

Understanding the costs of all glass buildings – both in terms of energy performance and worker comfort and associated productivity – shows a need for different metrics, and is the first step towards considering possible alternatives.

II.a. Building Loads and First Cost

Glass building energy performance and associated costs have been well documented. In 2010, Building Green collaborated with Arup to evaluate how various factors – including building footprint, orientation, and glazing percentage– impacted building energy use and heating and cooling loads. This study demonstrated that, for a square building footprint in New York City, increasing the glazing percentage from 40% to 80% (with a double glazed low-e glazing type) increased cooling loads by 18% and heating loads by 35%. ***Thus, doubling the glazing results in significant costs for the building owner in terms of both first cost (in the sizing of the mechanical systems) and energy performance (Wilson, 2010).***

[3] A building's energy cost savings can also be verified once the building is operational by calibrating the energy model. However, this is still relative to a hypothetical baseline, and is therefore of limited value.

[4] This study is based on two projects, one that was recently constructed and one that is in design. Modeled energy use (rather than measured for the constructed project) based on the proposed design were used in this comparison. The building's names and owners have been omitted for privacy.

II.b. Daylighting Controls and Energy Performance

Energy savings from increased daylighting opportunities are also often misrepresented, a finding captured in multiple studies. In PNNL's study of the hypothetical medium office building in Chicago, supposed energy savings from daylighting are negated by the daylight and occupancy sensor requirements in ASHRAE 90.1-2013. Since the sensor requirements result in lower effective lighting power densities, increasing daylight with more glazing does not result in observable savings in energy.

Accordingly, "increasing the WWR of the Medium Office building in conjunction with daylighting controls resulted in an increase in energy consumption in all climate zones under all conditions (Athalye, Xie, Liu, & Rosenberg, 2013, p. 16)." Moreover, "increasing the VT [Visual Transmittance] did not change the trend of increasing energy consumption with increasing WWR (Athalye, Xie, Liu, & Rosenberg, 2013, p. x)." These findings show that the additional daylighting does not provide enough energy savings to offset the additional energy from increased heating and cooling loads. Studies have also shown that increased WWR does not positively impact Daylighting Autonomy (DA), a metric for daylighting quality. An east-facing office, with facades with greater than 25% WWR, did not demonstrate a measurable change in DA (Love, 2015). This confirms that successful daylighting can be achieved with a window-to-wall ratio of around 30%, which is reflected in the IECC 2015 prescriptive requirements for building enclosures. These requirements limit vertical fenestration to 30% of the gross above-grade wall area.[5]

II.c. Indoor Environmental Quality and Occupant Performance

Numerous studies demonstrate the benefits of natural daylight on overall occupant performance. The Heshong Mahone Group's highly cited study, *Daylighting in Schools*, found that "students with the most daylighting in their classrooms progressed 20% faster on math tests and 26% on reading tests in one year than those with the least (Heschong Mahone Group, 1999a, p.2)." Similarly, their study on daylight in a California retail chain, concluded that "all other things being equal, an average non-skylit store in the chain would likely have 40% higher sales with the addition of skylights (Heschong Mahone Group, 1999b, p.2)." However, natural daylight's benefits depend on daylight quality and not just quantity – they can be negated by exposure to excessive glare, which is much more difficult to control in highly-glazed buildings. Occupants encounter both visual discomfort from glare and thermal discomfort produced by all glass buildings. In these cases, businesses face an additional cost besides increased energy use: the costs from less productive occupants.

Important considerations for visual and thermal discomfort:

- Users experiencing visual discomfort from excessive glare are less productive. Glare from a primary view can decrease the performance of office workers by 15-21% (Heschong Mahone Group, 1999b)
- Overly cold or warm conditions are problematic. In addition to creating unusually cold conditions in the winter, highly-glazed facades also create the opportunity for excessively warm conditions in the summer because of unmitigated solar heat gain.
- Orientation matters: East and west facing glazing is subject to low angle sun that is difficult to control, while north facing glazing is subject to almost no glare conditions. South is easiest to control with shading devices, which we discuss in the third section of this article, relating to countermeasures.
- Temperature, the combination of mean radiant surface temperature and ambient air temperature, matters most. Of the five factors of thermal comfort – temperature, humidity, air movement, activity level and clothing – temperature is the most important and is easily affected by highly-glazed surfaces.
- Downdrafts matter too: A highly-glazed surface in a cold winter condition will reduce the mean radiant surface temperature and can also create downdrafts, affecting the ambient air temperature experienced by a nearby occupant.

[5] Up to 40% WWR is allowed if at least 50% of the building floor area (for buildings 2 stories or less) or 25% of floor area (buildings greater than 2 stories) is within daylight zone.

A case study on data entry personnel demonstrated that an increase in air temperature from 68F to 77F increased key stroke productivity by 150% while the error rate dropped 44%. This was equivalent to a $2/hour per worker savings in 2004 dollars (Tom, 2009). Relatedly, researchers from the University of Helsinki and Lawrence Berkeley National Labs reviewed several studies on the link between temperature and productivity and found an optimal range of 72F to 77F. Productivity decreased dramatically above or below this range (Tom, 2009). The link between thermal comfort and the design of the enclosure has costly implications for highly-glazed offices because they create an environment associated with thermal discomfort: sitting adjacent to a glazed wall in the winter creates uncomfortable conditions from both downdrafts and cold radiant surface temperatures, while too much exposure to the summer sun can be overly warm.

II.d. Thermal Performance of Building Enclosures

These disturbances take away from a building enclosure's main objective: to create a comfortable environment for building occupants by controlling heat transfer between the indoors and outdoors. Heat transfer across building envelopes is caused by either conduction, convection, or radiation,[6] the results of which are illustrated in Figure 1. Heat transfer across the building – from either conduction, convection, or radiation – depends on the thermal resistance of the building enclosure materials, the area of the material or assembly, and the difference in temperature across the assembly. The following equation illustrates the relationship between each of these variables, where Q is equal to heat transfer,

$$Q = (1/R) * A* (T_1 - T_2) \quad \text{or} \quad Q = U * A* (T_1 - T_2)$$ [7]

Where:
Q is heat transfer
R is thermal resistance
U is 1/R
A is area and
T1-T2 is the difference in temperature between indoors and outdoors.

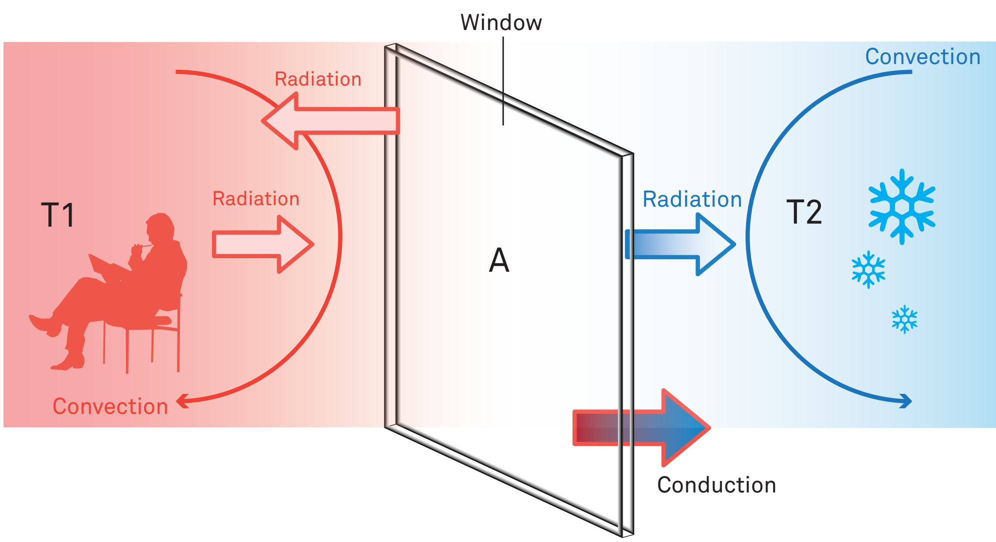

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Figure 2: Illustration of the three basic types of heat transfer

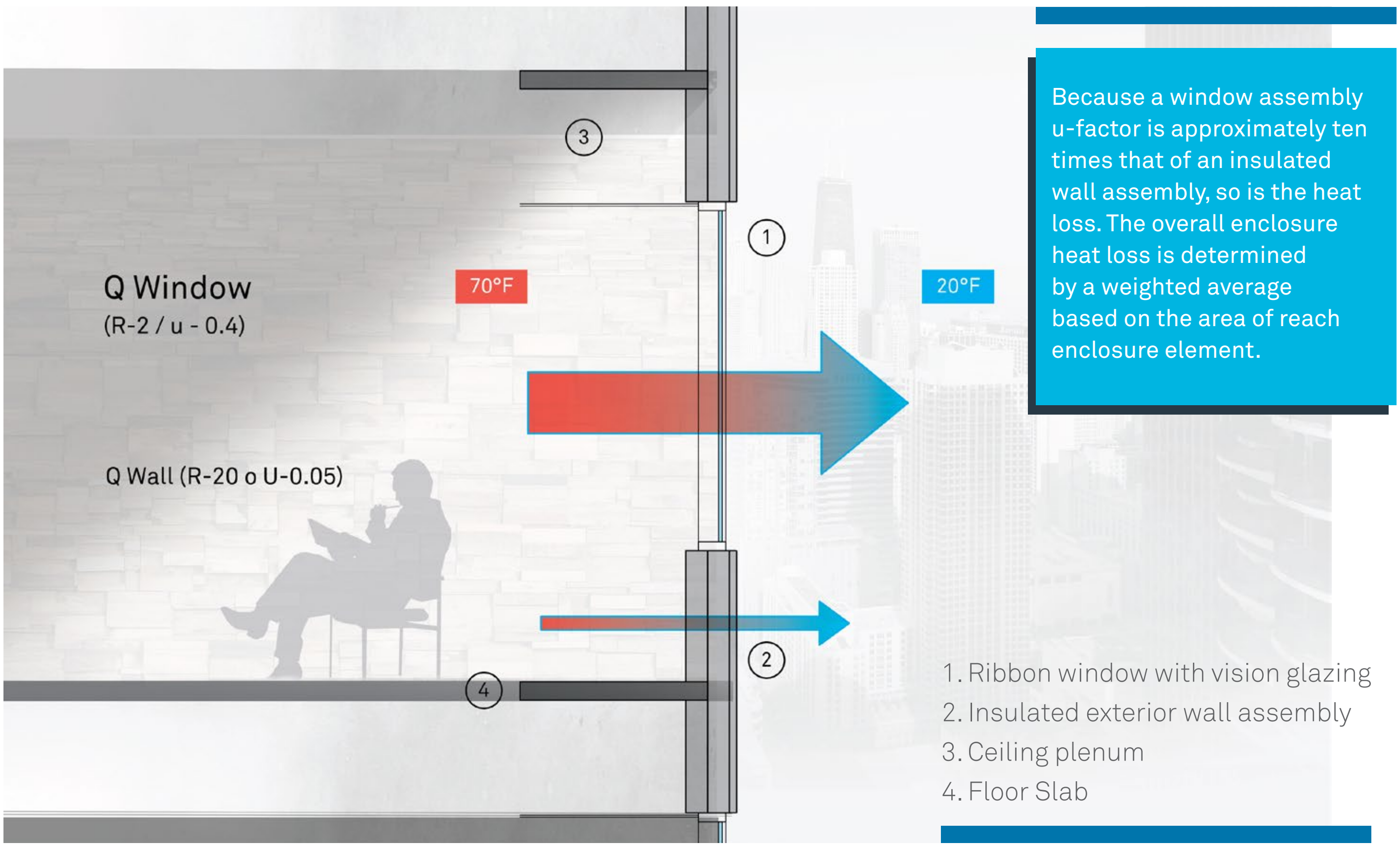
[6] There are three basic types of heat transfer, radiation, conduction, and convection. Conduction is heat transfer through a material, such as the transfer of heat across the warm side of a pane of glass to the cold side. Heat loss from convection occurs from a fluid, such as air, transferring heat as it moves past a warm or cold surface. Unlike conduction and convection, radiation does not require a medium for heat transfer, it can occur in a vacuum. All objects radiate heat waves depending on their temperature. Additional heat loss through building enclosures occurs through infiltration (air leakage) which is not specifically addressed here.

[7] The inverse, or U-factor, which is equal to 1/R, is also often used to compare the performance of enclosure elements. A more insulating building would result in a lower U-factor and higher R-value. This is represented in the equation, $Q = U * A* (T_1 – T_2)$

R is the thermal resistance, A is the area of the enclosure, and T1 and T2 show the difference in temperature across the assembly.

Heating dominated environments, such as those found in Boston, more heavily rely on thermal resistance for energy performance. There is a much larger difference in temperature on a cold winter morning, when peak heating loads occur, than during a summer day, when peak cooling loads occur. For example, consider a winter work day when it is 20°F outside. An office warmed to 70°F results in a 50°F difference in temperature across the enclosure (T1-T2). In comparison, a typical summer with an outdoor air temperature of 90°F and an indoor temperature of 75°F results in a 15°F difference in temperature. Therefore, in these situations, changing the R value is the most viable way to change Q and thus reduce the amount of heat leaving the building. The higher our R value, the more resistant our building. A more resistant building allows less escaped heat and thus reduces energy use.
A double glazed window assembly has a typical R-value of around 2, while a typical well-insulated wall assembly has an R-value of around 20. The result is a proportional difference in the magnitude of the heat transfer across the enclosure, as illustrated in Figure 2. Or simply put, the lower R value resulting from a double glazed window assembly, does not minimize heat flow and therefore increases energy use.

Figure 3: Comparison of heat loss through a window and well-insulated wall on a winter day ↓



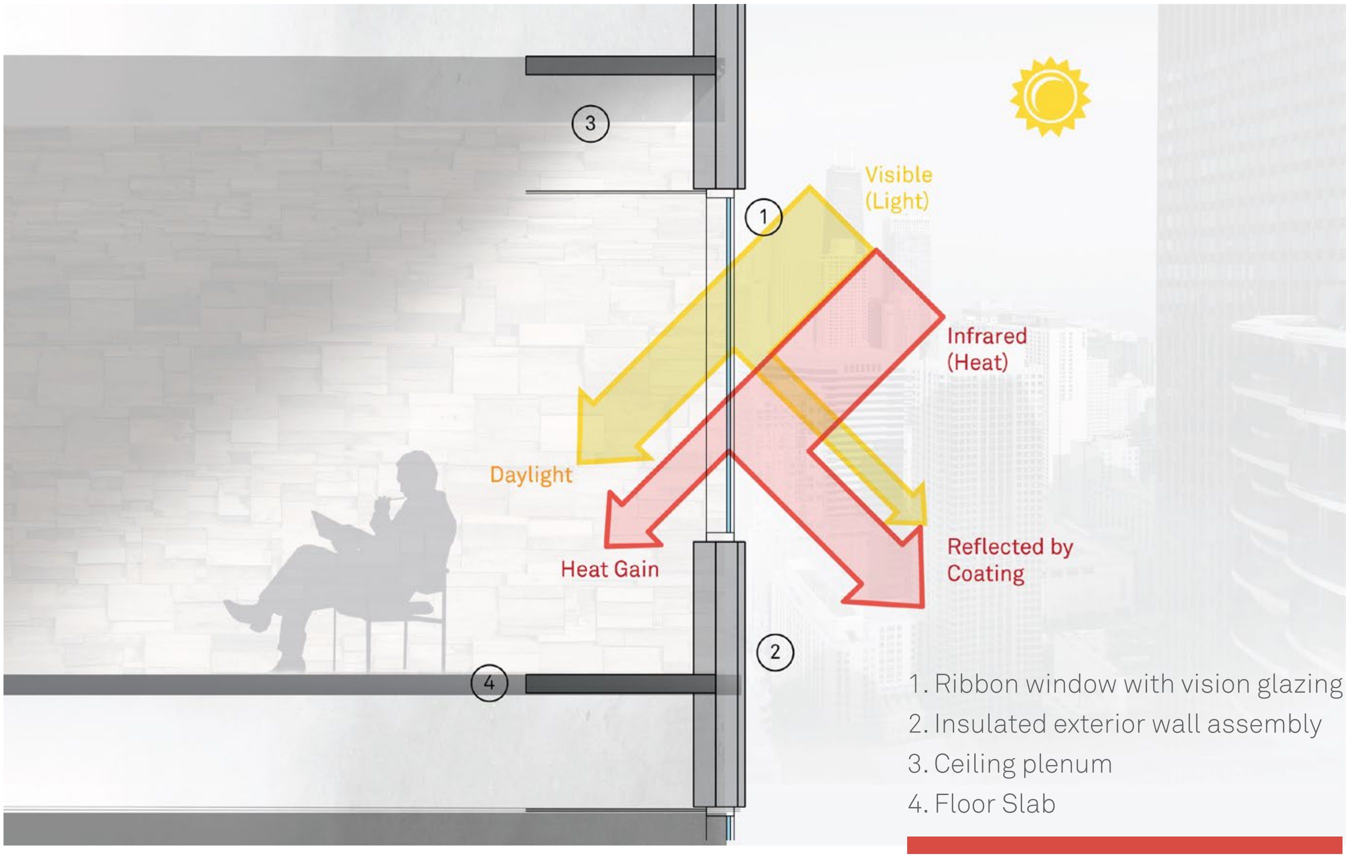


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Figure 4: Transmission of solar radiation through a window

As mentioned, enclosure design must also consider solar gain's impact on glazing assemblies. Direct solar radiation shining on a transparent glass assembly increases heat gain, as illustrated in Figure 4. In contrast, an optimal window balances light needed for visibility with heat control. Whether building occupants want to preserve or block heat depends on their climate, the time of year, and the indoor conditions they are trying to maintain.

A high performance, energy efficient enclosure then needs to provide the following:

- Visual and thermal comfort results
- High quality daylighting
- Limited heat transfer
- Controlled solar gain.

As we have discussed, all-glass facades cannot accomplish all of these measures. Compared to an opaque wall assembly, they have a relatively small R-value, which is bad for heating energy performance, and a relatively high solar heat gain, which is bad for cooling energy performance. All of these factors impact the occupant comfort and productivity.

III. The Costs of Counter Measures

Multiple solutions have been offered to mitigate these side-effects while still allowing for varying amounts of glass. Counter measures include manual shades, motorized blinds, double facades, glazing strategies, exterior shading, and a curtain wall design approach, with many used in tandem. However, each of these counter measures prove costly and ineffective. Many addressing only one side-effect or failing to perform as intended because of poor implementation. In the following paragraphs, we review each of these countermeasures and offer analysis into each's effectiveness in terms of sustainability. While none of these measures are ideal, we do note those that are preferable to mitigate the performance impacts of a glass enclosure.

III.a. Low-Emissivity Coatings

One of the most common strategies for improving thermal performance is to use a low emissivity or low-e coating on one of the inside surfaces of glass.

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Figure 5: Illustration of typical low-e coating placement

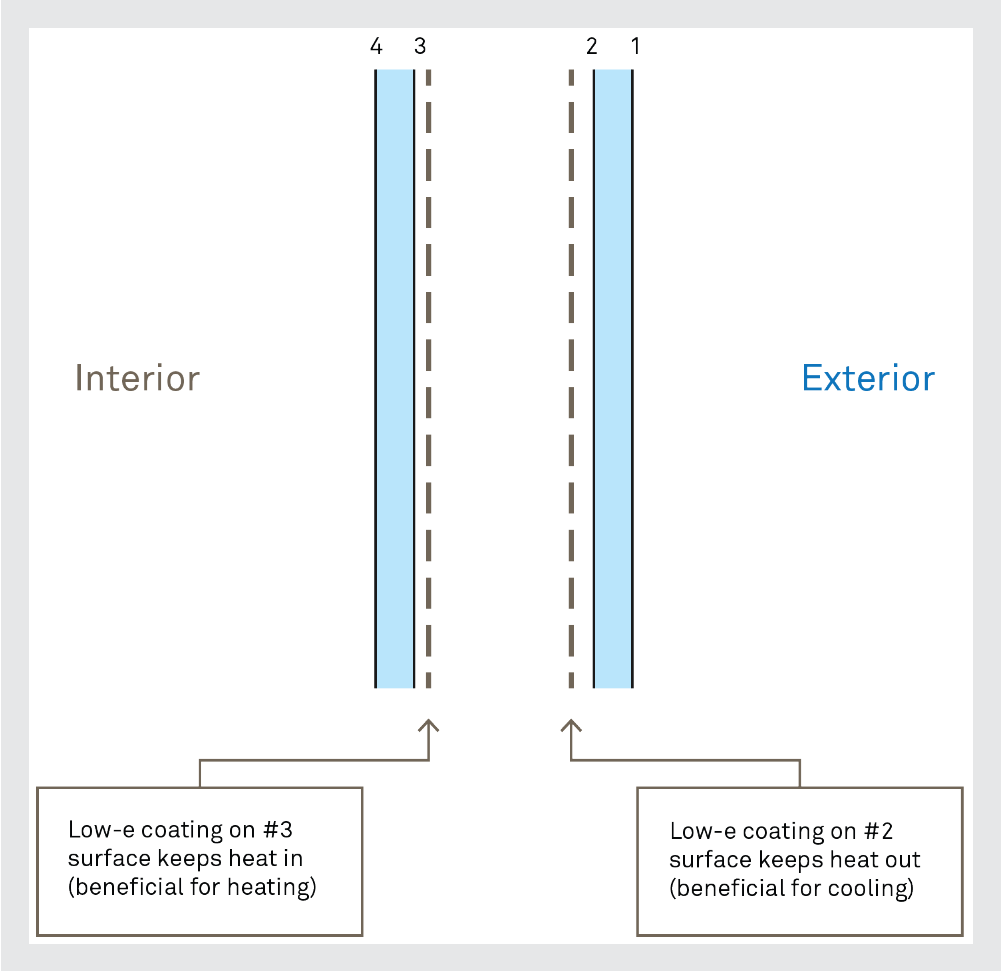

Figure 5 demonstrates the effects of this strategy. In warm climates, a low-e coating is placed on the #2 surface to "reflect" the heat back out, while in cold climates, a low-e surface is placed on the #3 surface to "reflect" heat back in. However, for highly-glazed buildings in Northern climates, the low-e coating is generally placed on the #2 surface in order to mitigate solar gain and reduce cooling loads. While this strategy limits solar heat gain, this can be counterproductive in the winter because it compromises potentially beneficial solar heat gain on south facing windows. Often the same glazing treatment is used regardless of orientation, although glazing could be specified to vary depending on its relationship to the sun.

III.b. Glazing Strategies

Additional glazing strategies for reducing cooling loads in highly-glazed facades include perforated exterior shading (in plane with window), fritted glass, and dynamic glazing. Each are used to reduce solar heat gain and control cooling loads. By blocking heat on the exterior of the glass, exterior shading prevents heat from passing through the assembly, and thus reduces heat gain. Glazing treatments such as frit and low–e coatings reflect a portion of the infrared heat from solar radiation away from the conditioned space. Dynamic glazing darkens automatically to reduce glare and solar heat gain when there is direct sun shining on it.

These glazing treatments and exterior shading are meant to minimize cooling loads and glare while preserving daylight and expansive views of urban environments. However, in practice, the additional glazing that these strategies are meant to justify does not actually improve daylighting or views. For example, consider a typical building with a 14 ft floor-to-floor height and a 10 ft ceiling height, with an opaque spandrel panel between the ceiling and the floor above (the plenum space). In this office, you achieve a 50% WWR if you have clear glazing from 30 inches above the floor to the 10 ft ceiling (see Figure 6). Therefore, moving beyond a 50% WWR would only change the amount of glass below the desk or above the ceiling, which would not actually enhance views. In most office environments, furniture blocks any view glazing below a typical desk height.

Figure 6: View glazing provided below a typical desk height does not contribute to quality daylighting or views. ↓

III.c. Fixed Exterior Shading

A more effective approach to controlling solar gain is the use of horizontal exterior shading. However, its dependence on specific and unyielding characteristics – the building's geometry and orientation and the location of the glazing – limits exterior shading's viability. For example, in the northern hemisphere, horizontal shading – including overhangs, light shelves, and louver systems – is most effective on southern facades. In June, when the sun is highest in the sky, the shading length can be adjusted to fully shade the glazing; similarly, it can allow full sun penetration in December when passive solar heating is beneficial, as illustrated in Figure 7.

Figure 7: Solar radiation is most effectively controlled with horizontal shading on a southern facade
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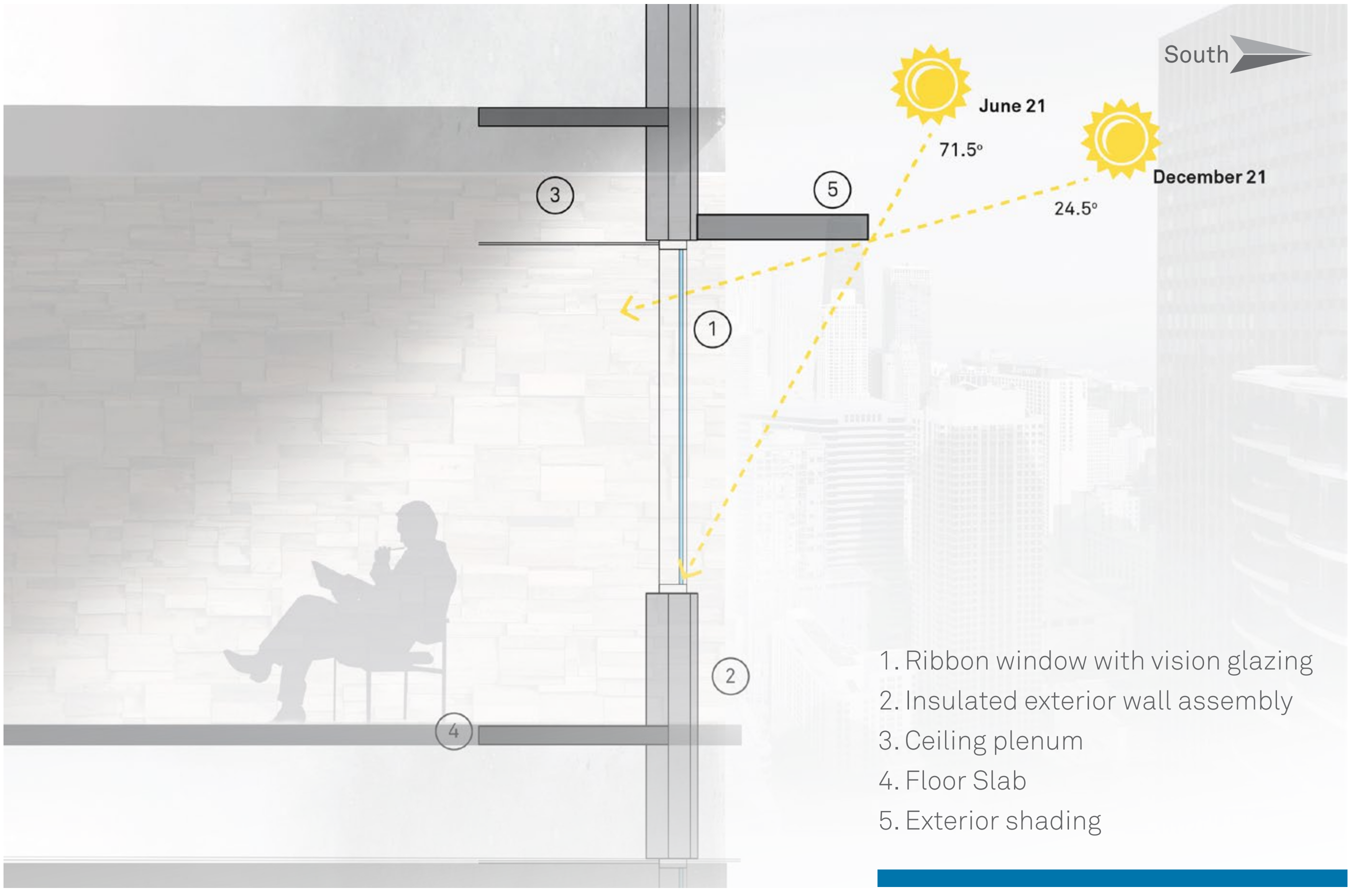

However, horizontal shading and other similar approaches, such as vertical glazing, are not effective on east and west orientations because the sun hits at a lower angle. Further, vertical fins[8] on these facades prevent passive solar heating during the winter months.

[8] Vertical fins are exterior shading perpendicular to the glass that runs up and down the façade rather than across.

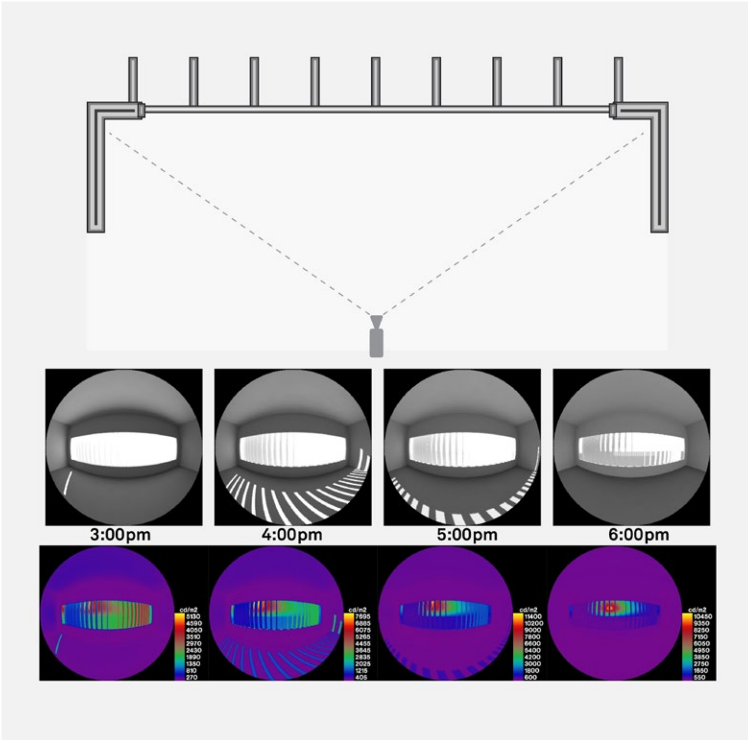

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Figure 8: Low angle afternoon sun with vertical louvers on a west facing window

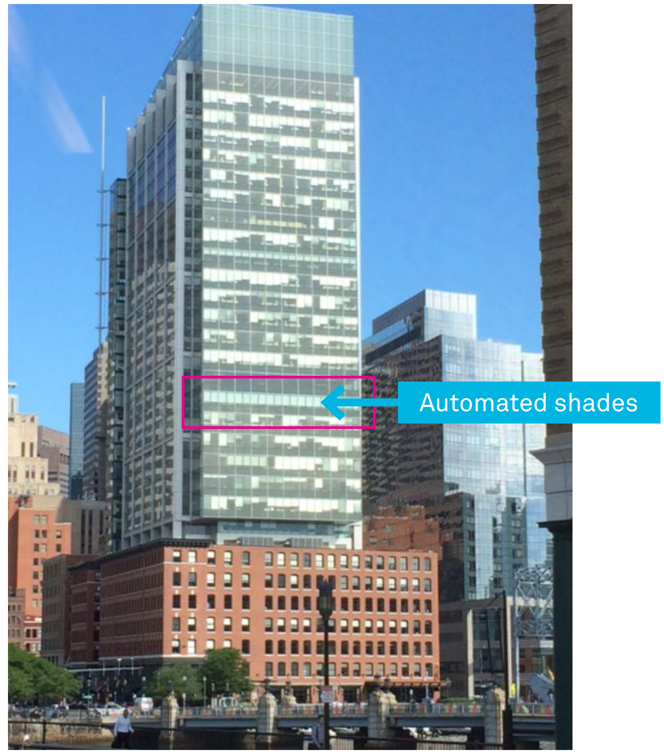

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Figure 9: Clean and consistent look of automated shades versus the disjointed appearance of manual blinds

III.d. Interior Window Treatments

Manual shades and blinds are another countermeasure against the user discomfort associated with highly-glazed facades. However, their susceptibility to human error creates a maintenance dilemma that compromises their effectiveness. A study presented at the 2016 Living Future Conference found that, on average, commercial and residential buildings with highly-glazed facades, have 59% of the total window area covered with interior blinds. Their study considered time of day, orientation, and building type. Regardless of these factors, the results remained the same: over 75% of the buildings sampled had more than half their window area covered by blinds or shades (Judah, Smith, Leung, 2016). Since the high levels of shading make much of the glazing functionally opaque, developers and designers need to consider whether they should prioritize thermal performance over the supposed marketability of all-glass buildings. Replacing at least a portion of the shaded area with a wall would provide greater thermal performance and offer occupants a similar level of daylighting.

Replacing at least a portion of the shaded area with a wall would provide greater thermal performance and offer occupants a similar level of daylighting.

Architectural renderings never depict manual blinds' messy appearance, which helps developers overlook their aesthetic drawbacks. The image above shows the contrast between the clean and consistent look of a floor with automated shades versus the disjointed appearance on the surrounding floors.

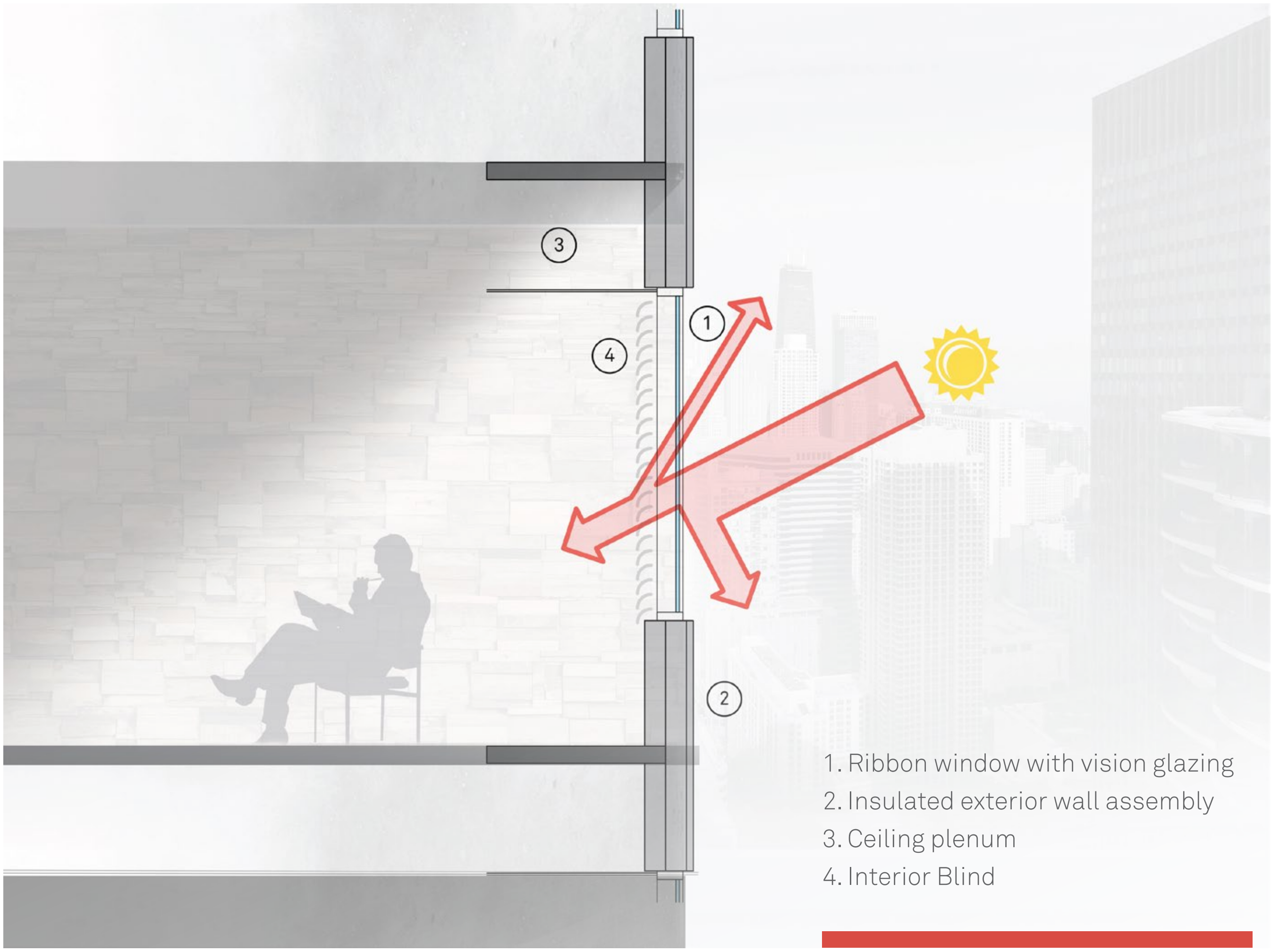

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Figure 10: While controlling glare, interior blinds do little to mitigate solar heat gain.

Motorized blinds can, in theory, counteract the human errors associated with manual shading. However, while they do address daylighting issues, they still have a limited effect on thermal performance. Motorized blinds are generally situated on buildings' interiors, which means they are susceptible to the same problems, in terms of thermal performance, as any other interior blind. Figure 7 showed how an exterior shade or louver can block the solar heat gain before it hits the surface of the glass. In contrast, an interior blind only reflects back a small portion, which allows significant heat gain into the conditioned space (Figure 10).

Since interior shades do little to mitigate cooling loads and occupant thermal discomfort, motorized blinds still represent a costly and ineffective solution.

III.e. Double Facades and Triple Glazing

Double facades can also improve both the heating and cooling performance of highly-glazed buildings. They typically consist of three layers of glazing, sometimes with a ventilated cavity or solar control devices between the outer two glazing layers. In Dr. John Straube's evaluation of the merits of double facades, he acknowledges their benefits – that they address the excessive energy, glare, and thermal comfort problems – but concludes that there are much less expensive ways to achieve the same performance (Straube, 2007). When it comes to cooling, heating, or acoustic performance, no glazed system performs nearly as well as an opaque wall assembly. A hypothetical office building in Toronto with a double façade and internal shading system would reduce cooling loads by approximately 44% relative to a 100% clear glass curtainwall with spectrally selective coatings. However an opaque wall assembly with double glazed spectrally selective punched windows (36% WWR) – in other words, one that is aesthetically appealing, occupant friendly, and performance responsible – achieves a similar performance (47% reduction in cooling loads) at undoubtedly lower cost. Double facades are nearly double the cost per square foot of an opaque wall assembly with punched windows. Since they also take up usable square footage, double facades remain a less than optimal alternative to an opaque wall assembly and a responsible WWR.

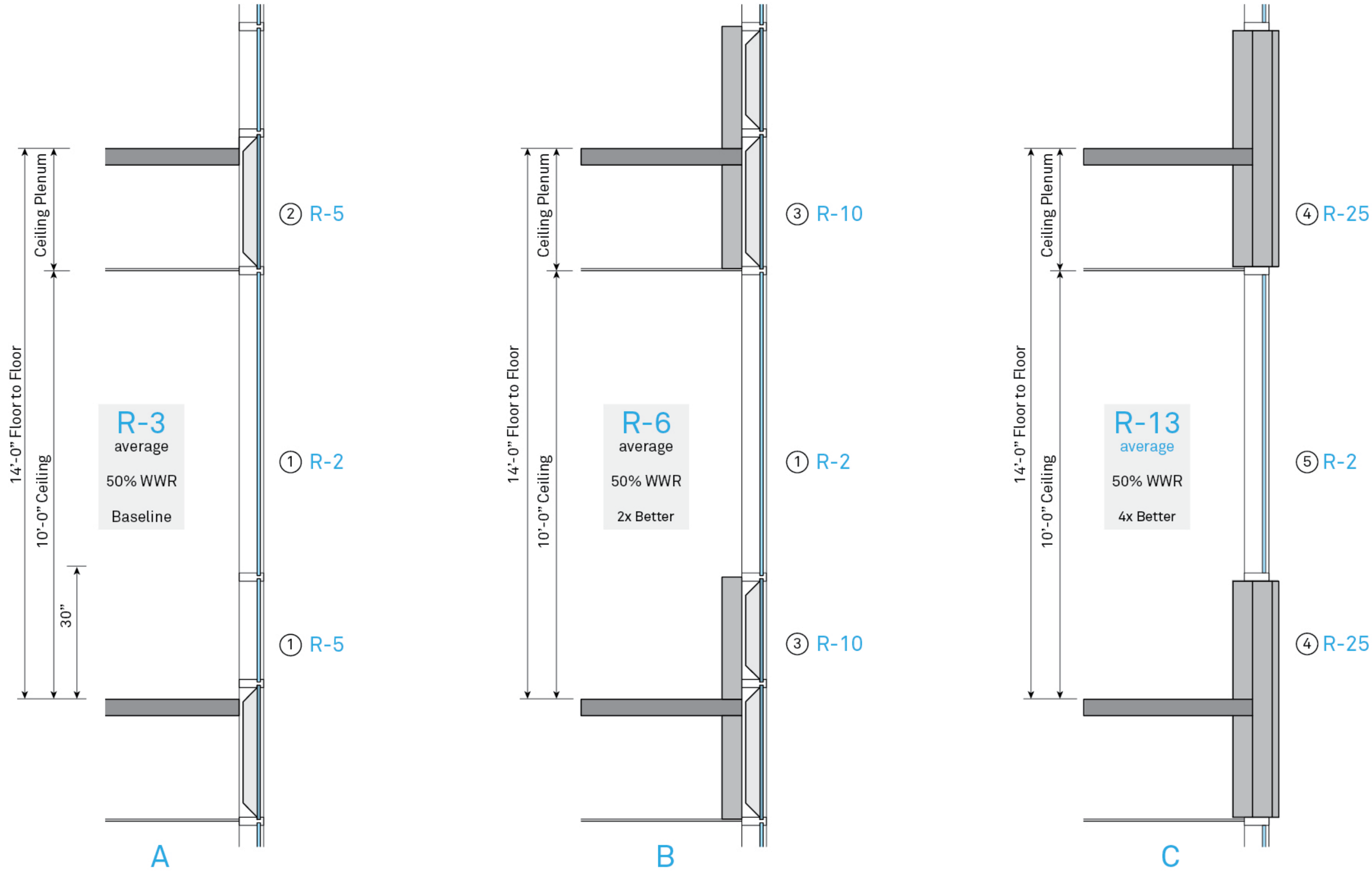
Triple glazing has a similar performance to a double façade without such significant loss of square footage or added maintenance expense. However, the performance costs associated with double facades are still prevalent in triple glazed buildings, making them a similarly less than optimal choice. Triple glazing also hurts quality daylighting, and at significantly higher first costs due to the curtainwall and the additional weight the structure must support.

Cambridge Public Library,
Double Façade

III.f. Opaque Spandrel

Last, we want to consider the use of opaque spandrel sections as part of a curtainwall design. This alternative offers the all-glass "appearance" without having full height clear glazing. Like other alternatives, its thermal performance is far from optimal. With a curtainwall, the vision glass can be reduced to a 6 or 7 ft band with opaque spandrel panels. An insulated stud wall is positioned behind the spandrel, either below the clear portion of glazing or above the ceiling as illustrated in Figure 11 (B). While the curtainwall mimics the appearance of an all glass building and improves cooling performance from reduced solar heat gain (SHGC of around 0.03 for spandrel instead of 0.3 for clear glass), it still compromises thermal performance: continuous exterior insulation in a wall assembly (C) has an effective R-value of 20 or 30, while this curtainwall assembly has an average R-Value of 5 to 10 (B) (Straube, 2007).

Figure 11. (Appendix B.9 High Performance Building Enclosures, John Straube, p. 267) ↓



1. Curtainwall with vision glazing
2. Opaque glass spandrel panel
3. Opaque glass spandrel panel with insulated back-up wall
4. Insulated exterior wall assembly
5. Ribbon window with vision glazing

III.g. The Minimal Use of Countermeasures

With the exception of low-e coatings and interior manual blinds, enclosure design rarely includes the countermeasures we have discussed because of two key factors: they have too great of a visual impact (in the case of frit or exterior in-plane shading) or come at too high of a first cost. Their minimal use, again, demonstrates the fundamental problem in our approach to sustainable design: our reliance on countermeasures as a "tack on" solution to an otherwise un-optimal design.[9] Because each countermeasures is flawed, a reactionary approach will always produce less than optimal results. Without prioritizing building sustainability at the outset of design, we can never achieve optimal performance that minimizes energy use and maximizes occupant comfort and productivity.

Conclusion

We believe it's time to recast current practices and adopt a holistic, evidence-based approach to the design of glass buildings.

The central problem, in our view, is a conventional tendency to evaluate incremental improvements rather than take a holistic approach to solving design and performance together. As this paper and its examples demonstrate, the current approach to sustainable design is to consider it a secondary measure or an additional layer that responds to earlier design decisions such as marketplace preference for highly-glazed buildings.

Achieving True Cost Efficiency: Goals and Benchmarking

The future of sustainable glass buildings, and genuine sustainable design, depends upon proactive rather than reactive thinking. Proactive thinking is driven by designs meant to create buildings that are energy efficient and provide an optimal working environment for the occupant, and therefore, ***are also highly cost effective.***

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The results we achieve depend on how we define our performance goals. Projects should begin with benchmarking their energy performance. Questions stakeholders should consider include: What is a typical EUI for a new office building in a cold climate? What is the lowest EUI of a similar building? Energy Star Target Finder and the BERDO website are great sources of data to begin analyzing these questions. Consider any specialty spaces in your building, such as a data center or food service, that might skew your design EUI relative to an average building. Once you identify these spaces, take time to explore what is possible for your performance goals.

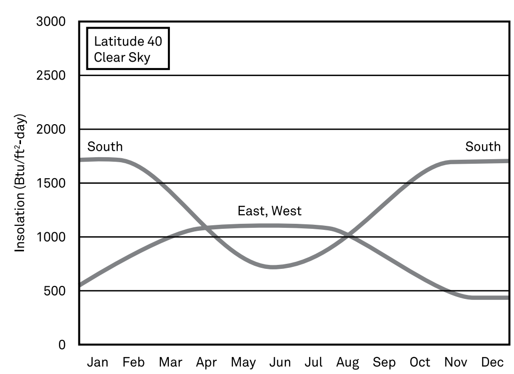

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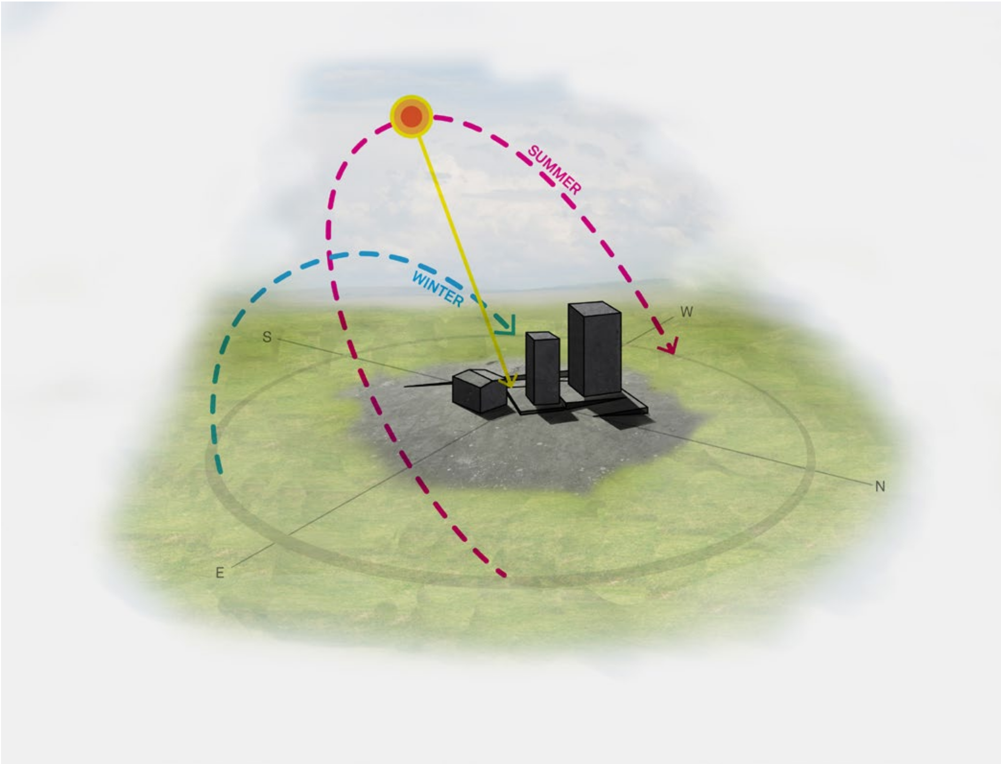
Figure 12: Monthly insulation on east, south, and west facing surfaces

The building performance experts at the Rocky Mountain Institute argue for setting a goal that reflects the theoretical minimum technical potential for energy savings – what's feasible given current technology (Harrington, Carmichael, 2009). Engage an integrated design team, including all the project stakeholders, and develop a plan to achieve that goal. This plan should first minimize loads and then meet those reduced loads with efficient systems. Prioritizing performance and setting aggressive goals based on EUI at the outset of a project would dramatically transform the design of the typical high-rise office building.

There have been steps taken that reflect a push towards a more proactive approach, notably designs that first optimize building geometry and/or glazing orientation. For example, an elongated double glazed low-e glass building (with 40% glazing area) with an east-west oriented axis (N/S facing glazing) had a 6% savings over a north-south oriented axis (E/W facing glazing) (Wilson, 2010). Not only are these savings achieved with no first-cost impacts to construction, orientation can actually improve some of the countermeasures we discussed, such as shading to effectively improve performance with respect to energy and occupant comfort. South facing vertical surfaces receive the most insolation in the winter months, when it can be beneficial, and the least, in the summer months, when it is not. Conversely, East and West facing vertical surfaces receive the most insolation in

[9] While countermeasures fall short, it is worthwhile to consider which are most effective. If the exterior appearance of a glass façade is necessary, the impact is best mitigated by orientation (a long east-west axis with primarily north and south facing glass), a curtainwall design with clear glazing limited to 40% of the enclosure, an insulated stud wall behind the remaining opaque portions of the curtainwall, and the use of automated interior shades.



→
Figure 13: Summer and winter solar paths

the summer, adding to cooling loads, and receive the least in the winter. As a result, the location and orientation of glazing can have a significant effect on heating and cooling loads, energy use, and visual and thermal comfort.

Yet, while orientation does represent a proactive design solution, it is rarely considered and not always possible. Instead, highly-glazed buildings continue to dominate the market and reactionary approaches are continuously favored. And as long as sustainability is only a response or a countermeasure, optimizing energy performance will remain elusive. We will continue to only target incremental measures, all of which are rarely persuasive because of their high costs and seemingly minimal impact on performance.

Moving Past the Flawed "Baseline" Model

This problem is compounded by our propensity to base performance on a hypothetical "baseline" building that does not exist in the built environment. The methodology behind this comparative analysis is designed to create an "apples-to-apples" comparison rather than being predictive of actual energy use. This hypothetical building again forces us to consider relative rather than absolute targets, which results in incremental and limited sustainability measures. It focuses on creating a building that is "less bad" rather than daring to imagine how a responsible building might look.

As long as we continue to only focus on minimizing first cost to comply with code requirements, we miss the opportunity to design a building that optimizes energy performance, reduces cost, and improves occupant well-being and productivity. We need to think bigger and look towards more comprehensive solutions, namely buildings that use less energy at a reduced first cost and enhance occupant health and productivity.

The Lasting Power of EUI

In this paper, we have argued that a reactive approach is very much a response to the metrics we currently favor. And, as we have demonstrated, this reactive approach has failed to produce sustainable design. Consequently, we need to reconsider those metrics. EUI is a preferable alternative because it does not repeat the failures of the favored metrics. Since it is an absolute metric that can be measured and verified, it is not skewed by relative prices or by being compared to a hypothetical building. Relative metrics that are measured as a percentage compared to a baseline are more easily manipulated. In contrast, it's not as easy to hide design elements that compromise true performance in EUI. Thus, instead of measuring building energy performance as a theoretical improvement relative to a minimally compliant code building, we need to focus on EUI and supplement these findings with daylighting quality and thermal comfort measures.

As with any metric, EUI is not perfect; it must be considered in context with other relevant information. For example, an office building with a higher than typical occupant density will also have higher than typical energy use because those people need more ventilation and an increased number of computers. But if increasing the occupant density allows a company to avoid constructing a second building for their employees, then overall energy efficiency has been achieved.

The comprehensiveness of EUI explains why the industry relies on it to best understand building's energy use. Moreover, it is the metric used by the Architecture 2030 Challenge, which has a goal of transforming the building industry from a major contributor to climate change to a source of solutions to create a carbon neutral future. If we are serious about our sustainability goals, we too need to adopt this metric and move towards a proactive approach to sustainable design.

We invite you to see this not as a sacrifice, but rather an invitation, to imagine and define a new and responsible urban architecture.

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