DOCKING STATE OFFICE BUILDING: REVISITING THE ENERGY PERFORMANCE OF THE MODERN GLASS TOWER

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ABSTRACT: The Docking State Office Building, a 12-story state office building immediately adjacent to the historic capitol building in Topeka, Kansas, was completed in 1957 as one of the region's earliest examples of tall, curtain wall glazed modern architecture. The Docking's glass curtain wall was innovative for its time, and the design exhibits an elegant composition of stone planes and glazed skin.

In recent years, the Docking Building has been thrust into limbo, with competing plans to demolish, renovate, or sell the building stalled in government gridlock. Problems with the buildings systems and glass facades have been cited in arguments to demolish the building. This paper examines the building's current and potential energy performance on a typical tower floor, analyzing the original curtain wall's thermal resistance and ability to use daylight. While it is believed that the building needs gutted and reskinned to be saved, the paper asserts that the original environmental hypothesis of the building is sound.

KEYWORDS: Curtain wall, envelopes, simulation, historic analysis

INTRODUCTION

The Docking State Office Building, completed in 1957 and designed by Kansas Architect John A. Brown in 1954, is more than simply a facsimile of other glazed office buildings. While currently threatened by demolition and deterioration, research presented here argues that the Docking's original thesis of broad, glazed walls and open floors is not only worthy of preservation, but remains tenable today given contemporary understanding of daylit office buildings and energy efficiency.

Architecturally, the Docking references the U.N. Secretariat Building, a monumental glass and stone-clad tower designed by Oscar Niemeyer and Le Corbusier and completed in 1950. Following the Secretariat by only a matter of years, Docking's architectural expression was still quite avant garde in 1957 and consistent with a paradigm described by Korn [translated in Yeomans 1998]: "…a new structural concept where all load-bearing elements are kept within the core of the building, leaving the outside wall to be nothing but a wrapping to enclose and allow light to penetrate." Like the Secretariat, the Docking building makes a statement by contrasting the lightness of a glazed curtain wall with crisp, stone-clad planes at its end walls – as opposed to wrapping the building homogeneously with glass. While the Secretariat stands monumentally against the Hudson River in New York, the Docking's 14 stories offer a more complex volumetric composition where two intersecting tower wings, a slightly projected stone-clad core, and a stretched three-story base come together to frame the southwest corner of the state capitol grounds (Figure 1).

The Docking's aluminium and glass skin was improvised from scratch as many early curtain wall systems were, with manufacturers "kite-flying" largely untested ideas on paper (Yeomans 1998). The Docking's aluminum and steel curtain wall were manufactured by the Benson Manufacturing Company of Kansas City, Kansas, whose prior business was in beer kegs. Thermopane, a pioneering manufacturer of double-glazing, provided double pane glass units (Griffin 2011). In the opaque portions of the curtain wall, Foamglas insulating blocks were used for their thermal efficiency and fire resistance.

Early glass buildings also presented significant environmental control problems. Reynor Banham credits Corbusier and air conditioning pioneer, Willis Carrier, side by side with the urban revolution marked by the U.N. Secretariat – a building only feasible because of huge fan rooms forcing air through heating and cooling induction units at the harsh perimeter environment (Banham 1969). The Docking's original approach was similar, yet different, using perimeter fan coil heating and cooling units instead of the remote fan rooms as in the Secretariat or most other tall glazed buildings at the time: these fan coils powered air flow and introduced fresh air locally at every unit.

Architecturally, the Docking made a powerful, forward-looking statement in a humble Midwestern capital city. Inside, the building's luminous and sweeping views of a capital city are complemented with beautiful original finishes that include carefully-selected stone, tile, and crisp aluminum ceilings. Fully occupied, the Docking hosted 1,500 workers in various state agencies while also providing an underground link to the capitol building.

Figure 1: The Docking State Office Building soon after it was constructed. (Source: Kansas Historical Society)

1.0 THE DOCKING BUILDING TODAY

1.1. Current Conditions

Sixty years after it was constructed, the Docking faces the prospects of either a costly renovation or implosion. Like other pioneering glass towers, its once-high-tech glass skin is entangled in larger questions about the building's viability. The U.N. Secretariat, for example, was 'reskinned' during a major renovation costing $2.3 billion (Gonchar 2012) and the 1952 Lever House in New York, had its glass skin replaced as part of a $60 million renovation in the 2000s (Stephens 2003). These buildings used single glazing systems that experienced widespread leaking and glass breakage. Aside from the decades-old sealant, the Docking's 60-year old façade appears to be in reasonable condition with little visual evidence of serious problems.

Comfort and energy consumption is another matter, and the 'poor' condition of official assessments cite poor performance of the original 1957 mechanical, plumbing, and lighting systems (Carlson 2007). Through the building's history, issues with comfort and energy use are evident. In 1965, forced air HVAC was added to each floor to supplement the struggling 2-pipe fan-coil units at the perimeter of the building (Steele 2016). According to building operators, complaints about comfort and the building's appearance grew as the building aged (Steele 2016); archival photos over various years show fabric curtains and blinds mostly closed, day and night.

By 2014, officials began publicly discussing the implosion of the building and state agencies were moving out (Marso 2014), leaving the building nearly vacant today. Most recently, estimates to extensively gut and reskin the building have grown to $84.5 million (C-J Editorial Board, 2016), while the state has 'mothballed' the building (Figure 2) rather than finance a costly demolition. While comfort and energy problems fit the stereotype of a recklessly glazed modern tower, this research examines the possibility that the risky – but innovative skin – may not be the root of the building's troubles. We know today that building performance is complex, the sum of many factors. If the Docking's fundamental design is sound, less expensive modifications may be able to update it to the efficiency and environmental quality of a modern building – or even a high-performance building, something of significant value for the State of Kansas.

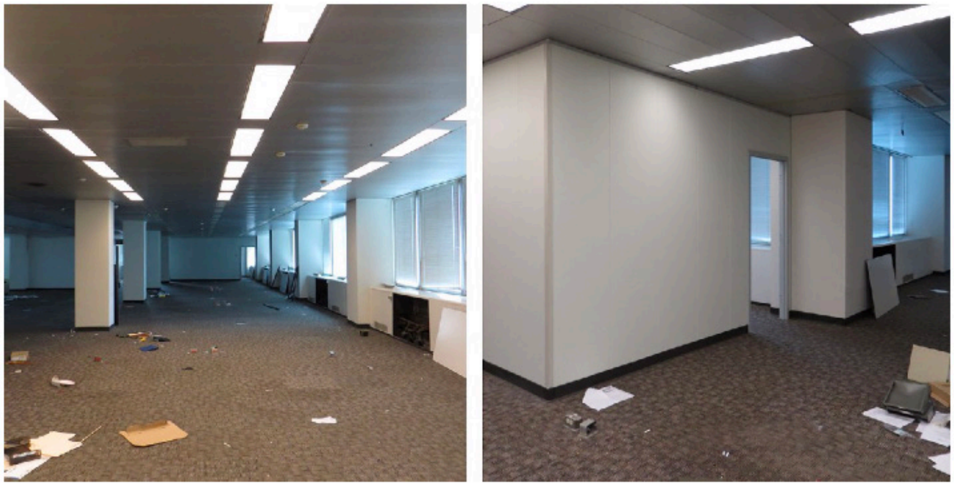

Figure 2: The Docking today, with vacant floor space. The image at right shows one of many private offices and perimeter rooms that partition the formerly open floors, blocking daylight and complicating environmental control. (Source: Author)

1.2 Description of the Wall Systems

The Docking Building is composed of a three-level base, with nine subsequent levels of 'tower' above, with an addition elevator machine level and penthouse level at the top. Two floors of underground mechanical space house boilers and chillers providing heating and cooling for six other major buildings in the capital complex. In total, of the roughly 368,000 square feet of building area above grade, 60% resembles the typical tower floor examined in this study (Fig. 3). On a tower floor, approximately 70% of gross wall area is curtain wall, with opaque spandrel panels giving the tower a window to wall ratio (WWR) of 33%: nearly compliant with the 30% minimum of current energy code (International Code Council 2014).

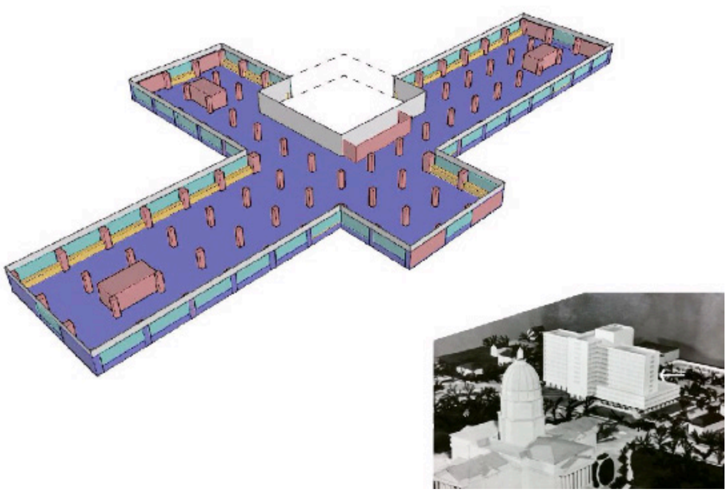

Figure 3: A typical floor in the tower, excluding the core containing restrooms, elevators, stairs, and mechanical space. Colors represent the planes of the thermal model, discussed later in the paper. The thumbnail at lower right shows the tower with the Kansas Capitol in the foreground. (Sources: Computer model – Author; photograph - Topeka Capital-Journal)

Apparently late in construction documentation, details were produced to bid the curtain wall system as an alternate, though earlier designs showed conventional masonry infill walls with ribbon glazing. Subsequently, the $4.5 million construction contract was awarded to a company who errantly bid the curtain wall alternate at a modest savings, but who admitted the company would "not relish" sourcing the more complex and exotic façade (No Author, 1954). Without surprise, construction didn't reflect the originally improvised details with enamelled steel skinned Foamglas panels for opaque sections of the curtain wall. Instead, the spandrels were solid granite (Figure 4) backed up with fireproof (and insulating) Foamglas block knee walls at the glazing sills. Glazing used Thermopane double glazed glass units with ¼" clear glass and air infill. Typical of early curtain walls, thermal breaks in the aluminum frames and mullions are absent. Structural loads are transferred to the building structure with continuous steel angles and tees. Though the sashes are bolted and sealed today, the drawings specified push-out awning windows for all glazing, worsening thermal performance.

The remaining end walls and exterior core walls (30% of wall area) are masonry block clad with limestone. No insulation in these masonry walls appears in the detail drawings, except for limited areas that placed thin fiberglass sheets in alcoves with fan coil units.

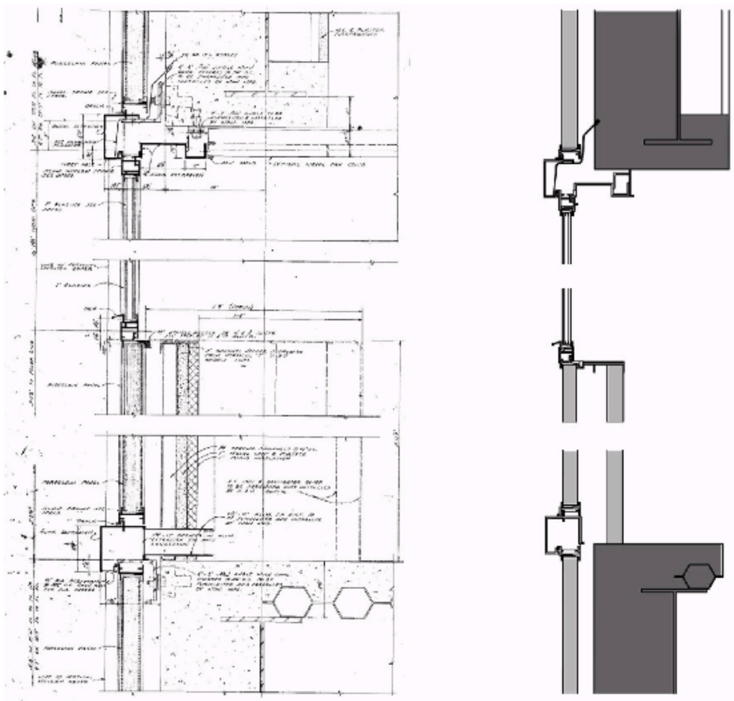

Figure 4: Shown are the details for a spandrel panel, glazing unit, and kneewall. The FCU surround is not shown in the detail at right, which was used for THERM analysis. At right, the spandrel is drawn as solid granite, and the knee wall is 2" FoamGlas block, representing the as-built condition. (Sources: Kansas State Office Building Construction Drawings; CAD drawing - author)

1.3 Mechanical Systems
By the 1950s, it was well established that aside from heating and cooling, commercial mechanical systems had to provide fresh ventilation air as well – one may imagine the ventilation problem in an office floor where over a hundred people are simultaneously smoking cigarettes. The Dockings peers, such as the U.N. Secretariat, distributed preconditioned ventilation air from central fan rooms where it received final heating and cooling in occupied spaces and, especially, in induction units along the climate-sensitive glazed perimeter (Banham 1969). Rather than use the more complex system of fan rooms and induction units for HVAC, the Docking attempted to use fan coil units (FCUs) exclusively for heating, cooling, and ventilation; a typical office floor has 84 FCUs, with an estimated 1,010 units in the building. Located at the base of each window (seen in Fig. 2) the FCUs brought in exterior ventilation air directly via a 2" by 24" duct connected to perforations in the floor-level curtain wall mullion on upper floors. Though this intake had a damper, for most of the building's life these intakes were probably left open [Steele 2016].

Environmental control by the FCUs posed several problems. The two-pipe water delivery system for the FCUs delivers hot or cold water to the units but not both, with the availability of hot and cold water determined uniformly for entire facades. A thermostat at each FCU controls water supply, while fans on the units operate continuously. Early in the Docking's life, it became clear that the FCUs could not provide all of the HVAC needs of the building and forced air was introduced in 1965, adding an air handling unit to each floor to service the central zones of office space.

1.4 Interior Components
The original perforated aluminum ceiling system used 48" two-lamp fluorescent fixtures throughout the office spaces. The ceilings have been largely preserved over time, while the original lighting fixtures were upgraded from T12 to T8 lamps and ballasts. The original beige vinyl floor tile was covered by dark carpeting in many offices and woven curtains were replaced by venetian blinds. More significant interior changes came when open plans were divided with floor-to-ceiling partitions on several floors, introducing private offices and other rooms against the perimeter.

2.0 EVALUATION AND ANALYSIS

2.1 Ventilation Rate

A ventilation test measured the outdoor ventilation rate of a typical FCU with the dampers open, as they were presumed to be for most of the building's life. The measured rate of unconditioned outdoor air was quite significant, at 102 CFM per FCU. For a floor of 84 units, the total ventilation rate would be approximately 8570 CFM, or 2.34 air changes per hour. Based on an average of 125 occupants per floor (as reported in Carlson, 2007), the code-required ventilation rate for a typical floor would be 2059 CFM, the equivalent of 0.56 air changes per hour – about one fourth of the ventilation rate from the FCUs. Fresh air is also provided by the air handling units in 1967 forced air system, further increasing the ventilation rate beyond what is necessary.

2.2 Lighting Loads

The second issue evaluated lighting loads. Each roughly 20 foot by 20 foot bay in the office space is illuminated by 12 original two-lamp luminaires with retrofit T8 ballasts and lamps that consume approximately 54 watts each; the original 1950s era lamps consumed 89 watts (Westinghouse 1946). With the T8 retrofit, the lighting power density (power per unit area) is 1.61 W/ft^2 for a typical tower floor. By today's standards – 1.0 W/ft^2 for ASHRAE 90.1 and 0.82 W/ft^2 for IECC 2015 – the lighting energy use in the building is high. This is significant because the heat gain from lighting energy increases cooling loads.

2.3 Daylight Analysis

The potential to use daylight in place of electric lighting was evaluated using analysis software (DIVA with Rhino). A typical tower floor was modelled with the complete exterior building mass in place to accurately shade, reflect, and obstruct sun and sky light. Curtains and shades were omitted from the model. Daylight evaluation used three methods: point-in-time illuminance with a cloudy sky, point-in-time illuminance per the LEED v.4 daylight credit (clear sky and sunny conditions), and climate-based simulation where the zone was evaluated through a typical year of sky conditions using Topeka climate data (following LEED v.4, USGBC 2016). The IESNA recommended office illumination levels were considered during this process, including 300 lux for task lighting (at desk surfaces), 150 lux for general lighting, and 75 lux for lighting in computer task areas.

Early daylighting design principles borrowed from Europe didn't consider direct sunlight. In cloudy sky conditions, the illumination in the Docking is evenly distributed, though relatively low: an average of 38.3 lux across the daylight zone, and 10.3% of the floor area within the useful range of 75 and 150 lux (Fig. 5). If the floor's reflectance is changed to 0.50 (versus the estimated 0.20 reflectance of dark carpet) much more daylight reaches the interior: an average of 88.1 lux is achieved, 33.5% of the floor area is between 75 and 150 lux, and 18.3% of the floor area reaches the recommended level of 150 lux for ambient office lighting (Fig. 6)

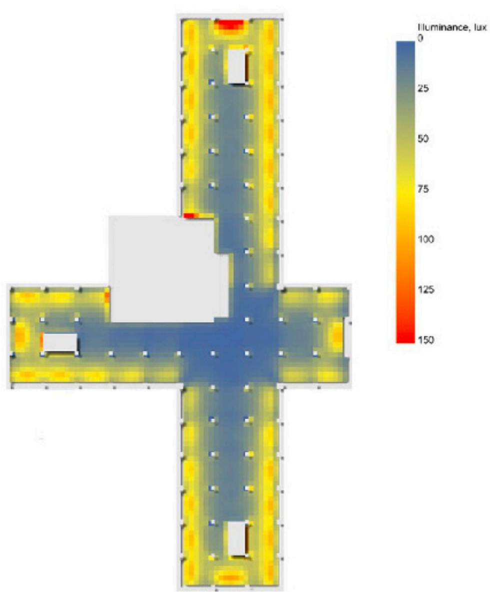

Figure 5: Illuminance levels throughout the typical floor, analysed with RADIANCE software and DIVA. The sky condition was overcast, and the model including the building volumes above and below. (Source: Author)

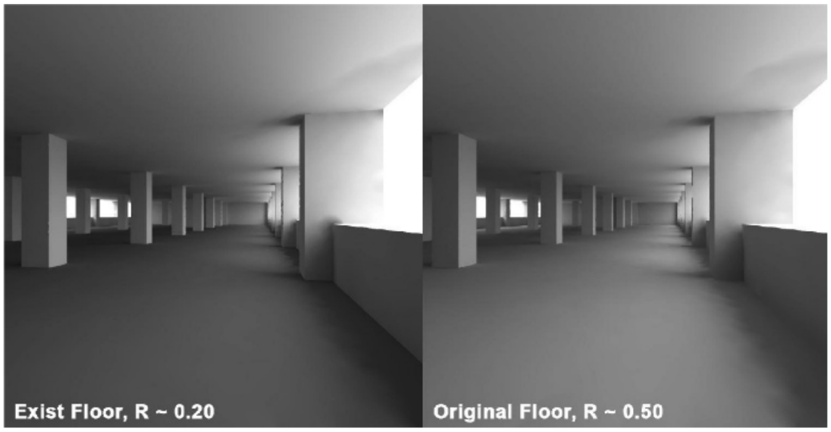

Figure 6: RADIANCE visualizations in a typical floor, without blinds. The image at left shows the existing floor, a dark carpet; the image at right shows a more reflective floor like that originally used in the building. The sky condition for the simulation was overcast. (Source: Author)

Next, a point-in-time illuminance analysis was done using a clear, sunny sky on Sept 21st at 9am and 3pm. The criteria for the current LEED v.4 daylight credit stipulate 75 to 90% of the floor area must be illuminated between 300 and 3000 lux: the lower end representing task lighting and the upper end representing a threshold where glare would become problematic. Results from the simulation show only 15.2% of the floor area in the 300 to 3000 lux range: too low to quality for the LEED credit. However, reasonable window sizes and deep surfaces around the windows result in only 7.9% of the floor at risk for glare

The climate-based simulation sought the amount of floor area where daylight would satisfy the 300 lux threshold (sDA300) for half of the occupied hours, while also measuring high solar exposures (ADE1000). The daylit floor area, defined in the LEED glossary, is a “regularly occupied” area where people “spend time…seated or standing as they work” (USGBC 2016). Thus for this analysis, the center bays were excluded in the daylit area as non-daylit circulation and support zones. Given this interpretation, the climate-based simulation results showed 47.2% of the daylit zone fulfilling the LEED sDA300 criteria: very close to the 50% minimum. Additionally, the ASE1000 simulation returned a 0%, satisfying that portion of the LEED credit.

2.4 Building Envelope Thermal Resistance

The thermal resistance of the curtain wall system was analysed with two-dimensional finite element analysis (via the computer software THERM) to determine and average the varying thermal resistances of glazing units, aluminum frames, granite panels with a variety of backing conditions, and their respective intersections. Following the simulation described for ‘site built fenestration products’ in the THERM NFRC User Manual (THERM 2013), analysis results from different typical curtain wall bay sections (shown in Figure 7) were averaged using an area-weighted method to produce ‘total product’ U-values. The U-values from simulation are shown in Table 1, with a typical bay averaging a U-value of 0.515 Btu/ F°*ft^2*hr. The energy code mandates a minimum fenestration U-value of 0.38 Btu/ F°*ft^2*hr for region 4. Thus the thermal resistance of the curtain wall as an aggregate is not terrible by today’s standards, but the effect of the aluminum mullions and frames is striking, increasing conductivity of the glazed areas by 44%.

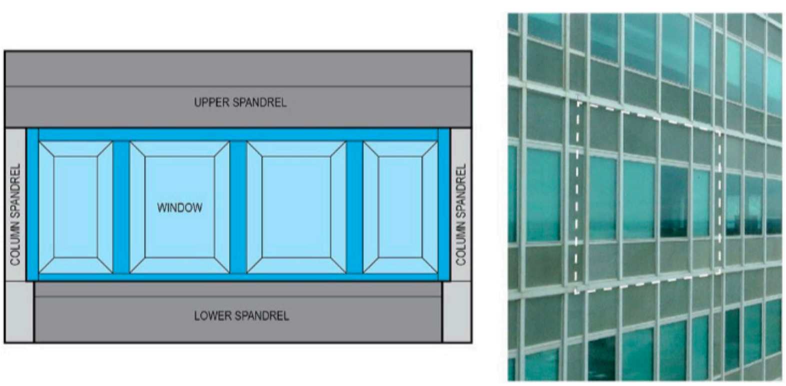

Figure 7: A typical curtain wall bay was divided as shown for determining an area-weighted average of the various conditions in the curtain wall. These averages are shown in Table 1. (Source: Author)

Table 1: (Source: Author)

Thermal Properties of Exterior Walls and Fenestration, Typical Tower Floor			
Component	% of Ext. Wall Area, Typ. Tower Floor	U-Value Btu/ F°*ft^2*hr	R-Value F°*ft^2*hr/Btu
Center of Glass, double-pane IGU, clear glass[1]	-	0.476	2.10
Window (glass, edges, and frames)	33%	0.796	1.27
Upper Spandrel	18%	0.297	3.37
Column Spandrel	7%	0.238	4.20
Lower Spandrel	15%	0.214	4.67
End Walls and Exterior Core Walls	25%	0.48	2.1[2]
End Walls at base of glazing, insulated	2%	0.22	4.6[2]

[1]Additional properties used for the glazing units: SHGC = 0.704, Tvis = 0.786, SC = 0.809
[2]Determined by summation and R-values of referenced materials.
Unless noted, values for thermal resistance shown here were determined using the software THERM.

Thermal resistance values for the end walls were determined by summation. In-situ observations with a heat flux sensor and thermal camera support the hypothesis that these walls, making up nearly as much exterior wall as the glazing, lack insulation. In summary, while the window areas (combining glass and frame effects) are the weakest components of the envelope, the better-insulated spandrels cover more wall area.

2.5 Annual Energy Simulation

Once ventilation, lighting, and envelope thermal characteristics were studied, the energy use of a typical tower floor (Fig. 3) was evaluated using EnergyPlus, with simulation inputs originating from the Grasshopper plugin Archsim and weather information for Topeka. The building volume above and below the floor were modelled to accurately shade the zone, and thermal properties from Table 1 were used in the simulation. The existing ventilation volume and lighting loads, derived from calculations discussed earlier, provided conditions for the initial baseline simulation along assumptions described in Table 2. Simulations were conducted with the floor as a single zone and without shading devices.

Following the initial simulation, a series of simulations were conducted in sequence to study simple modifications to the typical tower floor aimed at decreasing energy use. These variations are summarized in Table 2, presented in an order from least presumed cost to implement. The impact of these modifications to annual building energy use is shown in Figure 8, where results are displayed in terms of Energy Use Intensity (EUI, in annual energy units per square foot of floor area).

The first modification following the base simulation adjusted set points to the ASHRAE Standard 55 PMV Model, a prevailing climate-based comfort model. Lighting loads were then reduced to 0.40 W/ft2, representing the daylight as primary space lighting with low-energy lighting used for task lighting. The next simulation (number 3 in the sequence) reduced the infiltration rate from 2.34 to 1.1 air changes per hour (ACH). This number was derived from work by Emmerich et al which asserts that buildings like the Docking (over ten stories and double glazed) can be re-sealed to achieve infiltration rates of 3.3 cm2 per m2 of exterior wall area; using a reduction factor of 50% for a tall building (cited by Emmerich) and 10 mph of wind velocity, an infiltration rate of 0.55 ACH is reached. To this value, the 0.56 ACH minimum infiltration rate discussed earlier may be added to reach 1.1 ACH of approximate ventilation and infiltration. Further simulations were conducted with increased thermal resistance at the spandrels and end walls – using the equivalent of 1.5 inches of added polystyrene insulation to those assemblies. Lastly, a simulation was done with low-E glazing replacing the clear double pane glazing units.

Table 2: (Source: Author)						
			Energy Simulation Summary			
	Set Points[1] (H/C)	Lighting Loads W/ft2 [W/m2]	Ventilation Rate	End Wall R-Value h*ft2*F/Btu [K*m2/W]	Spandrel U-Value Btu/h*ft2*F [W/m2*K]	Glass U-Value[1] Btu/h*ft2*F [W/m2*K]
Base - 0	70F / 75F [21.1C / 23.9C]	1.61 [17.3]	2.34 ACH	See Table 1	See Table 1	See Table 1
1	**68.5F / 80.1F [20.3C / 26.7C]**	1.61 [17.3]	2.34 ACH	See Table 1	See Table 1	See Table 1
2	68.5F / 80.1F [20.3C / 26.7C]	**0.40 [4.3]**	2.34 ACH	See Table 1	See Table 1	See Table 1
3	68.5F / 80.1F [20.3C / 26.7C]	0.40 [4.3]	**1.1 ACH**	See Table 1	See Table 1	See Table 1
4	68.5F / 80.1F [20.3C / 26.7C]	0.40 [4.3]	1.1 ACH	**9.6 [1.69]**	See Table 1	See Table 1
5	68.5F / 80.1F [20.3C / 26.7C]	0.40 [4.3]	1.1 ACH	9.6 [1.69]	**0.10 [0.568]**	See Table 1
6	68.5F / 80.1F [20.3C / 26.7C]	0.40 [4.3]	1.1 ACH	9.6 [1.69]	0.10 [0.568]	**0.263 [1.49]**

1 No temperature setbacks were used.
2 Glazing in the base simulation was double pane glazing with properties as listed in Table 1. Glazing for simulation 6 was double pane, low-E glazing with a SHGC of 0.373 and VLT of 0.444

<u>Additional Configuration Notes – All Simulations:</u>

- Plug and equipment loads were 0.75 W/ft^2
- Occupancy was 125 people
- A typical office schedule of all-on, 8a to 6p, M-F was applied to lighting, occupancy, and plug and equipment loads
- Final EUI was based on ideal loads and did not model or simulation HVAC systems. For load conversion to energy consumption, the cooling COP was 2.7 and heating AFUE was 0.80.

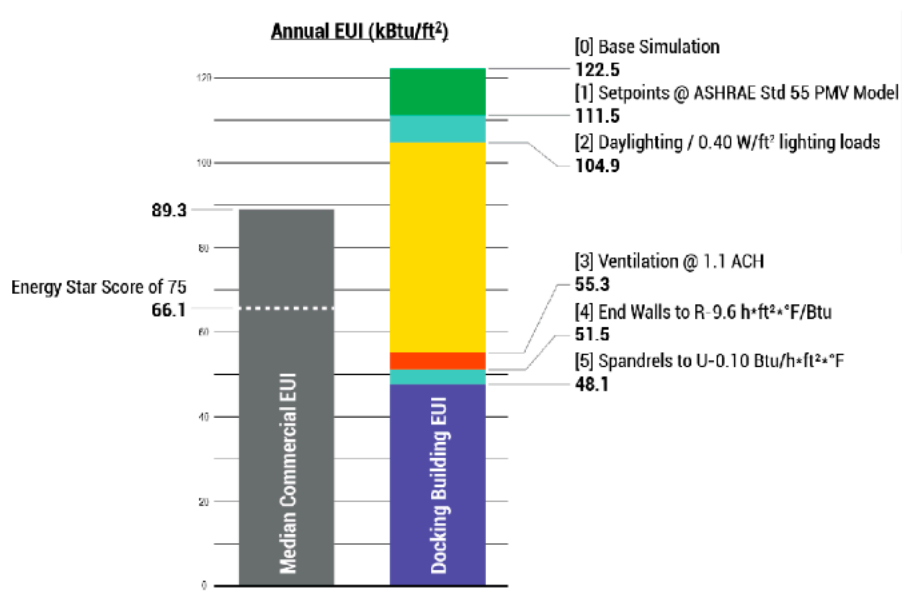

Figure 8: The resulting EUI of from various simulations, compared to median commercial EUI as estimated by Energy Star Target Finder. Simulation 6, using Low-E glass, *increased* EUI to 52.3 kBtu/ft2 thus is not shown. (Source: Author)

CONCLUSION

At the end of this detailed analysis, it may be argued, with evidence, that the basic architectural premise of the Docking State Office Building is quite sound. More importantly, its innovative curtain wall may be absolved as the source of energy and comfort problems. As results in Figure 8 demonstrate, efficiency gains from reducing lighting loads via daylighting may be greater than adding insulation to the curtain wall. Further, reskinning the building with Low-E glass appears to increase energy usage overall. Rather than an expensive reskinning, the Docking can take advantage of minor modifications (and preservation) to become an impressively efficient, passive office building – matching the performance of more advanced contemporary buildings. It should be no surprise, as the Docking fits the basic recipe for many of today's high performance commercial buildings: a resilient, high mass structure; narrow, open, and daylit floor plates; and appropriate amounts of double-pane glazing. One might contemplate the time and resources spent on new buildings pursuing benchmarks like Energy Star; the Docking offers this possibility for what could be a fraction of the cost.

Rather than pointing fingers at the Docking's facades, managing the building's ventilation and infiltration rate and more appropriately utilizing its open floors offer the biggest energy gains. With reduced cooling loads associated with daylighting and using existing fan rooms and duct spaces, it may be possible to retrofit the building to use modern forced air systems, distribution, and controls without the need for perimeter heat. Several sensible approaches can improve comfort while retaining the existing curtain walls. Modern window treatments can both admit diffused natural light while mitigating thermal issues. Primary work areas should take advantage of the open plan and occupy the perimeter daylit zones; though areas immediately next to windows, where comfort problems would be most acute, should be left to circulation or common. The center of the floorplate should be used for private offices and other rooms, rather than the obstruct daylight at the perimeter with these rooms. Interior partitions, if they are necessary, can be transparent to admit daylight.

Moreover, this paper serves to demonstrate a process of analysis and evaluation that may be used to counter vague criticism seizing upon comfort and energy problems of modern buildings. Such buildings may have more than historic significance – like the Docking, these building may also have latent environmental efficiency and environmental value, if the buildings are evaluated thoughtfully. The Docking Building is, in fact, an excellent work of architecture – not just for its modern lines and beautiful materials, but for the functional, modern, and elegant work environment it created for important state employees. It may be true that its 60-year-old systems need upgrading, that its limestone is stained with age, and the state has moved out of the building – but the building's purpose and potential as a modern office building hasn't expired at all. In many ways, the Docking Building was ahead of its time in bringing in natural light and using a long-lasted, serviceable curtain wall as its cladding: a soundly designed and built building that in many ways is superior to even today's buildings.

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