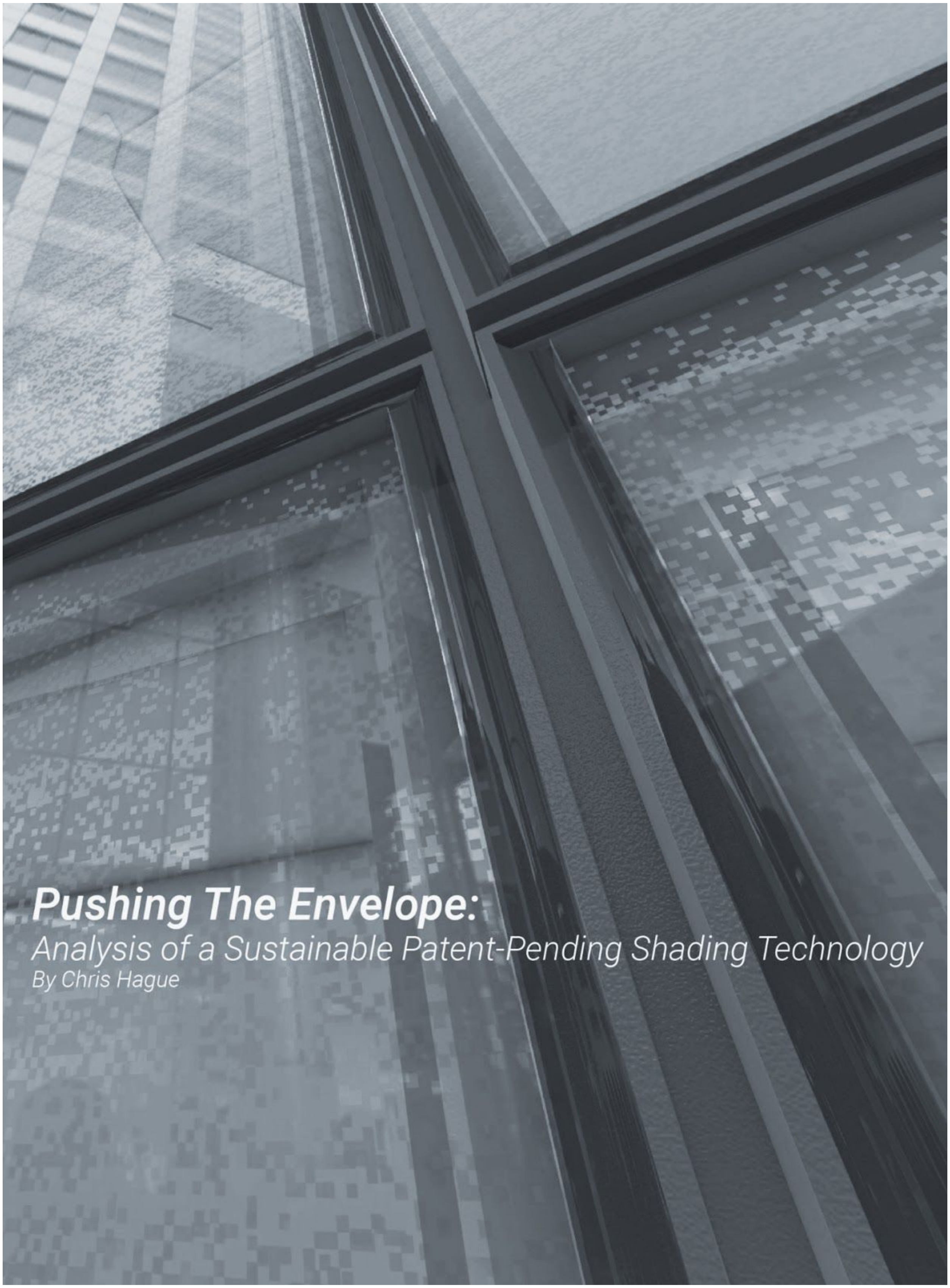


Pushing The Envelope:

Analysis of a Sustainable Patent-Pending Shading Technology

By Chris Hague

Fall 2019 Perkins&Will Innovation Incubator White Paper

Proposal Description

Perkins&Will is at the forefront of innovation and technology in Architecture, and to keep this trajectory we must look forward into market innovations and emerging technologies. The proposal is to analyze an emerging technology for its ability to increase performance of buildings in multiple locations in comparison to standard shading strategies. The energy, daylighting, and cost performance characteristics will be compared to existing systems, such as louvers and fins.

A patent-pending technology called “Multilayered Light Ray Moderator System” generally posits the idea of a simple, economic, and visually unobtrusive way to increase the performance characteristics of standard Insulated Glazing Units by utilizing multiple layers of frit on multiple glazing faces in very small project-specific non-intuitive patterns. An excerpt from the provisional patent application reads as follows:

...“a multilayer light moderator system that moderates light admission through a window glazing assembly by utilizing patterned layers of material that leverage their relative geometry to reject unwanted light ray vectors and admit wanted light ray vectors. The multiple light moderating layers work in concert to increase the assembly’s effective opacity thereby rejecting unwanted light rays, and [simultaneously] decrease the effective opacity thereby admitting wanted light rays from the source resulting in a moderated environment in the space that is separated from the Source-Side Environment. For a given set of impinging source light vectors, the optimal pattern of opaque moderating layers leverage each other’s pattern to reject unwanted vectors and admit wanted vectors.”

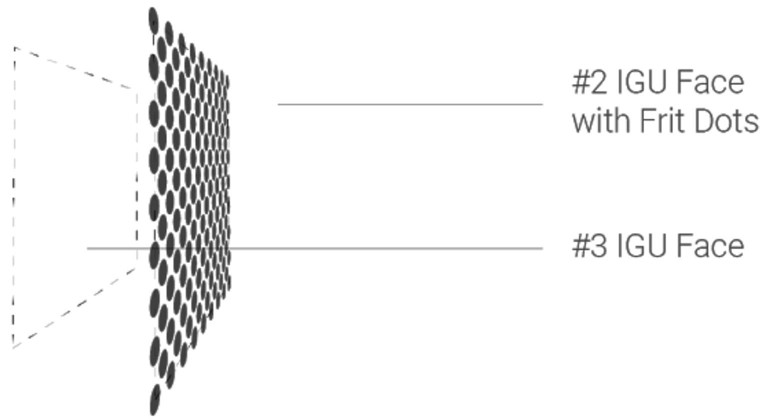
- (Multilayered Light Ray Moderator System, US Patent Application Number 62/868,910) [1]

Goals -

The goal is to position Perkins & Will at the forefront of architectural technology by analyzing novel innovations that can help decrease Energy Use Intensity of the Firm’s portfolio. The leverage that Perkins & Will can exert in the built environment is immense and with a small increase of performance to each square foot we design each year amounts to a large positive impact on the world.

Analysis Setup

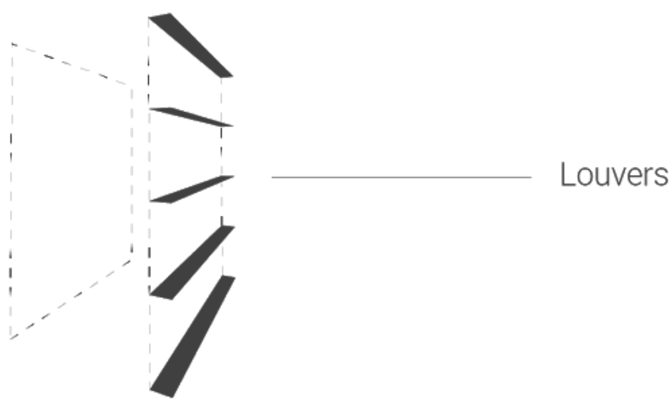
Test Articles:



Standard Frit

Standard Frit -

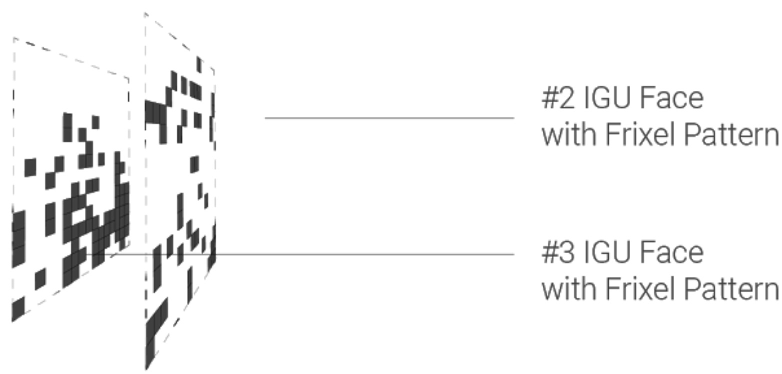
Industry standard frit patterns are a grid of dots or lines of opaque ceramic material baked onto the #2 or #3 face of an Insulated Glazing Unit (IGU) and provide a fixed percent coverage of the glass to provide shade year round to the interior of the building. Coverage typically varies from 10% for small dots to 100% for completely opaque spandrel panels. Since the shading geometry is two-dimensional, it cannot control the ingressing vectors from light sources such as the sun; it can only provide a fixed percent shade.



Standard Louver

Louvers/Fins -

Common fixed louvers/fins attached to the exterior of facades provide shade to the interior of buildings by leveraging their three-dimensional geometry to effect variable opacity in relation to a changing light source such as the sun. When the sun is high in the sky, it is generally warm outside (for most locations) and the louvers' collective geometry work in concert to provide more coverage to the glazing. Conversely, in Winter when the sun and the temperatures are lower, the louvers allow more direct light ingress. This simple geometry acts in a near-binary way, it is either shading, or it is not, depending on the relation of the louvers to the source. This approach provides significant advantages for shading in relation to the standard two-dimensional frit patterns, but it comes at a financial and aesthetic cost. The primary cost for louvers can be high, as well as the secondary structural costs due to the increased weight on the facade.



Multilayer Light Moderator

Patent-Pending Multilayer LIght Moderator -

This system provides the three-dimensional shading performance of louvers with the cost and aesthetics of frit. A fixed ceramic frit is applied to both interior layers of an IGU (faces #2 and #3) in a computationally calculated pattern that lets in specific vectors of light, and reject others, while providing adequate visibility and light transmission. The patterns are not limited to simple geometries like louvers, and thus can provide a more tailored approach to the local climate in relation to sun vectors. It can also be calculated to discreetly block specific points of glare or shade a particular area in a space, such as a reception desk in an all-glass lobby.

Calculation of the patterns is extremely intensive. The ideal system is two faces of the IGU where each face is a tessellated grid of modules, each module is broken into 256 frit-pixels, or "frixels" in a 16x16 grid. Each module has 2^256 possibilities, which is approximately equal to the number of atoms in the universe. Many nested methodologies have been employed to decrease the solution space size and the computation time.

Analysis Methodology:

Test bed -

All test articles were tested on the same digital test-bed and were given the same vector and temperature inputs for each location. Each Test Article was optimized for each of the following conditions: A) South Facing glazing in San Francisco, California, B) West Facing in San Francisco, California, and C) South Facing in Las Vegas Nevada. A and B were chosen to illustrate the performance differences due to direction (Azimuth), and C was chosen to illustrate differences in Climate/Location. In B and C, only one variable is changed in relation to A to retain maximum fidelity between analyses.

Analysis Goal -

Each sun vector for the particular location is tagged with a temperature differential from the human comfort zone and the test bed counts the hours that each vector is visible through the Test Article and multiplies the visibility count by the degree differential of that vector, thus creating a Degree-Day aggregate. “Hot vectors” are those above the comfort zone, and “Cold vectors” are those below the comfort zone.

There are three goals the Test articles try to achieve: maintain a 45% visible light transmission at minimum, maximize “Cold Vector” Degree-Days versus no Test Article (to passively heat during cooler hours of the year), and Minimize “Hot Vector” Degree-Days versus no Test Article (to passively block heat during warmer hours of the year). The values are tested against an empty Test Bed to create a baseline for each location to create ratios that are aggregated to produce a single number “score” to be minimized.

This is achieved through a Ladybug-Grasshopper script using standard EPW weather files, it does not produce an energy value like Honeybee, but rather provides a high-fidelity apples-to-apples comparison of geometrically different shading devices.

Optimization Methodology for Standard Frit -

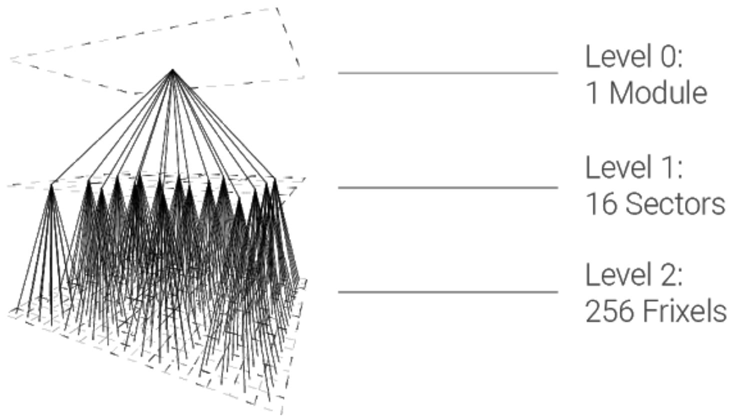
Each of the three conditions was given the choice of standard frit coverage percentages 10-50 in 10% increments. Solution space size of 5 is small enough to analyze all options.

Optimization Methodology for Louvers/Fins -

Each of the three conditions was given the choice of vertical fins or horizontal louvers, and spacing-to-depth ratio approximations of 1” increments from 2”-12” depth at 12” spacing. The solution space of 20 is small enough to analyze all options.

Optimization Methodology for Multilayer Light Moderator -

Each of the three conditions was given the choice of any number of 256 frixel locations in a binary sequence. The solution space is essentially infinite, but countable, at ~1x10^134. Right off the bat the second face can be reactionary and be deterministically found by analyzing the shading effect of the first layer onto the second layer, thus cutting the solution space in half to ~1x10^77. Also due to the caveat of minimum 45% visible light transmission, the first layer frixel coverage can hover around ~25%, decreasing the solution space to ~1.4x10^52. To evenly disperse and maintain ~25% coverage, the module is broken into 16 sectors, each with 16 possible frixel locations, to which only 4 are filled. There are 1820 options in a 25% coverage of a 16-cell grid; 16 grid sectors with 1820 options each is still too large to run all possibilities. An evolutionary algorithm can be used to find high-performing options with high-accuracy, but it can take up to several weeks of constant analysis to produce a suitable Article to test. A statistical analysis procedure was developed to calculate the most likely candidate for success against the analysis goals.



Data Tree

These 1820 options for each of the 16-sectors are plugged into a statistical analysis software to create a Design of Experiments (DOE) that outputs the minimum number of options to analyze in order to produce a Sensitivity Analysis. The Sensitivity Analysis will show which individual frixels on the front face are most useful in order to reach the goals. For each of the three conditions, 2048 options from the DOE that statistically represent the whole solution space are analyzed to produce a sensitivity analysis. Each option was transformed in a tree-structure from a 16-source system with 1820 options each, to a 256-frixel system with 2 options each (256-bit binary string), that is guaranteed to be equally dispersed and 25% coverage. This tree-structure simplifies the 256-bit solution space into only exactly what is needed for the goals but retains the fidelity of the DOE for sensitivity analysis. The sensitivity analysis provides the most sensitive 25% of the front face and produces one suitable Article to test.

There are limitations of the sensitivity analysis procedure and evolutionary solvers on their own due to the overwhelming size of the solution space, but if stacked they can augment each other's strengths. The stacking of the relatively quick sensitivity analysis with a moderate evolutionary algorithm run after immediately results in a higher performing specimen by approximately 5-10% in comparison to a sensitivity-only analysis, and approximately 90% reduction in compute time to an evolutionary algorithm-only analysis.

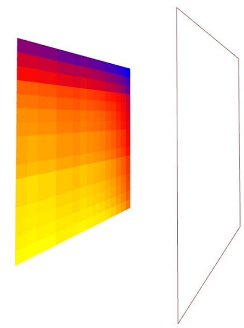
Analysis

San Francisco, California - South Facing:

Baseline Testbed:

- Test Bed Data: naked

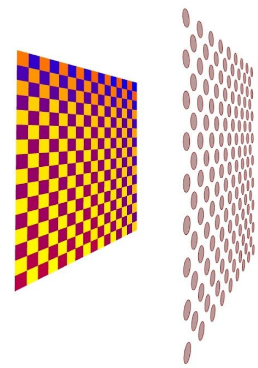
- Visible Light Transmittance: 73.0%
- VLT Differential (45%): 28.0%
- Hot Vector Degree-Day Ratio (min.): 1.000
- Cold Vector Degree-Day Ratio (max.): 1.000



Optimized Standard Frit:

- Frit coverage: 30.0%

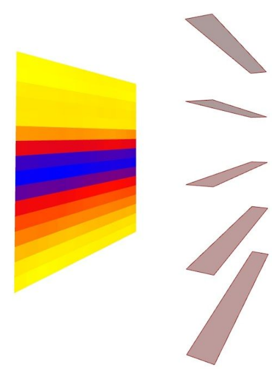
- Visible Light Transmittance: 51.6%
- VLT Differential (45%): 06.6%
- Hot Vector Degree-Day Ratio (min.): 0.70
- Cold Vector Degree-Day Ratio (max.): 0.71



Optimized Standard Louver:

- Louver Depth/Spacing: 4”/12”
- Louver Orientation: Horizontal

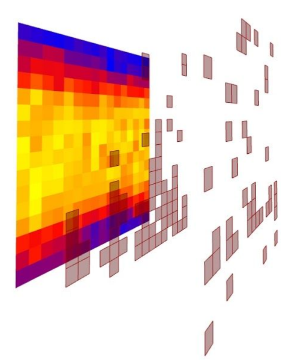
- Visible Light Transmittance: 47.2%
- VLT Differential (45%): 02.2%
- Hot Vector Degree-Day Ratio (min.): 0.28
- Cold Vector Degree-Day Ratio (max.): 0.75



Sensitivity Analysis-Only Multilayer Light Moderator:

- Front Pattern Coverage: 16.4%
- Rear Pattern Coverage: 25.0%

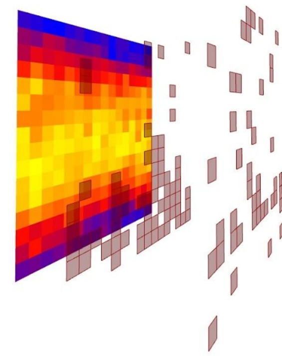
- Visible Light Transmittance: 45.0%
- VLT Differential (45%): 0.00%
- Hot Vector Degree-Day Ratio (min.): 0.61
- Cold Vector Degree-Day Ratio (max.): 0.64



Sensitivity Analysis+Evolutionary Algorithm Multilayer Light Moderator:

- Front Pattern Coverage: 16.8%
- Rear Pattern Coverage: 25.7%

- Visible Light Transmittance: 45.0%
- VLT Differential (45%): 0.00%
- Hot Vector Degree-Day Ratio (min.): 0.59
- Cold Vector Degree-Day Ratio (max.): 0.66

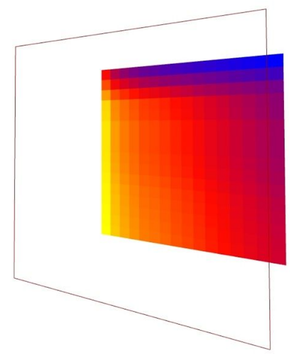


San Francisco, California - West Facing:

Baseline Testbed:

- Test Bed Data: naked

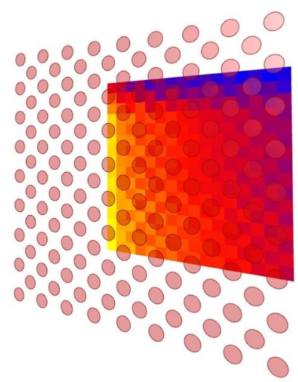
- Visible Light Transmittance: 73.0%
- VLT Differential (45%): 28.0%
- Hot Vector Degree-Day Ratio (min.): 1.000
- Cold Vector Degree-Day Ratio (max.): 1.000



Optimized Standard Frit:

- Frit coverage: 30.0%

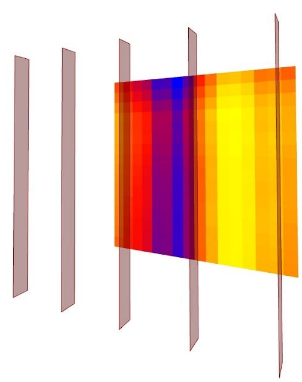
- Visible Light Transmittance: 50.6%
- VLT Differential (45%): 05.6%
- Hot Vector Degree-Day Ratio (min.): 0.69
- Cold Vector Degree-Day Ratio (max.): 0.69



Optimized Standard Louver:

- Louver Depth/Spacing: 6”/12”
- Louver Orientation: Vertical

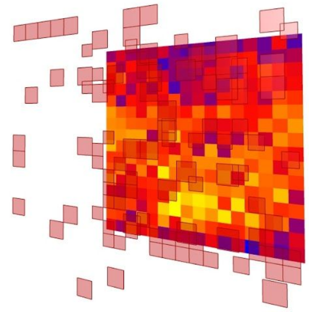
- Visible Light Transmittance: 54.0%
- VLT Differential (45%): 09.0%
- Hot Vector Degree-Day Ratio (min.): 0.80
- Cold Vector Degree-Day Ratio (max.): 0.71



Sensitivity Analysis-Only Multilayer Light Moderator:

- Front Pattern Coverage: 16.4%
- Rear Pattern Coverage: 25.0%

- Visible Light Transmittance: 45.3%
- VLT Differential (45%): 00.3%
- Hot Vector Degree-Day Ratio (min.): 0.61
- Cold Vector Degree-Day Ratio (max.): 0.64

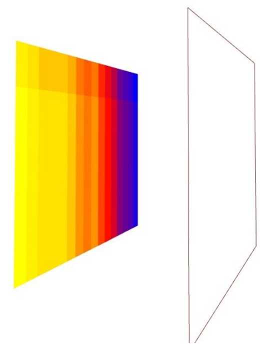


Las Vegas, Nevada - South Facing:

Baseline Testbed:

- Test Bed Data: naked

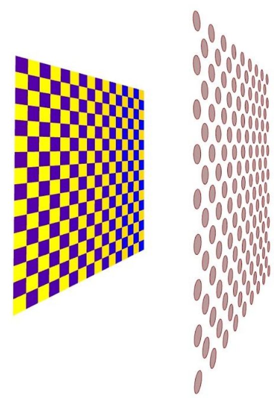
- Visible Light Transmittance: 73.0%
- VLT Differential (45%): 28.0%
- Hot Vector Degree-Day Ratio (min.): 1.000
- Cold Vector Degree-Day Ratio (max.): 1.000



Optimized Standard Frit:

- Frit coverage: 30.0%

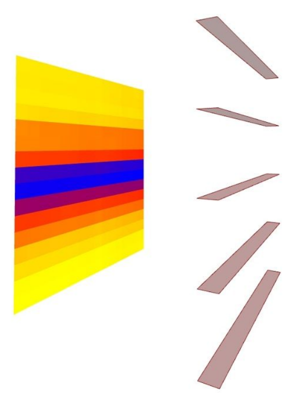
- Visible Light Transmittance: 51.0%
- VLT Differential (45%): 06.0%
- Hot Vector Degree-Day Ratio (min.): 0.70
- Cold Vector Degree-Day Ratio (max.): 0.70



Optimized Standard Louver:

- Louver Depth/Spacing: 3”/12”
- Louver Orientation: Horizontal

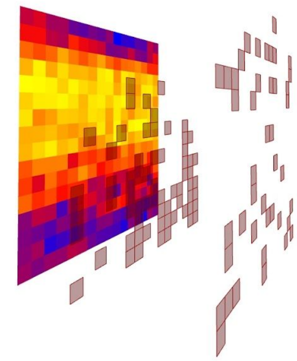
- Visible Light Transmittance: 47.5%
- VLT Differential (45%): 02.5%
- Hot Vector Degree-Day Ratio (min.): 0.38
- Cold Vector Degree-Day Ratio (max.): 0.86



Sensitivity Analysis-Only Multilayer Light Moderator:

- Front Pattern Coverage: 16.4%
- Rear Pattern Coverage: 25.0%

- Visible Light Transmittance: 45.0%
- VLT Differential (45%): 0.00%
- Hot Vector Degree-Day Ratio (min.): 0.60
- Cold Vector Degree-Day Ratio (max.): 0.63



Analysis Comparison

Analysis of Standard Frit -

Each of the three conditions tested with the standard frit patterns displayed similar effectiveness and an equal balance of Hot and Cold Vector Degree-Day attenuation. This is illustrative of the two-dimensional nature of the shading geometry itself, and its inherent inability to differentiate three-dimensional light source vectors.

Analysis of Louvers/Fins -

Each of the three conditions tested with the standard louvers provided different aspects of the geometry. The south facing louver system performed well, but when set to the west the performance suffered in a vertical or horizontal orientation. In the Las Vegas analysis, the louvers did very well due to the harsh summers and cool winter. Although in the San Francisco south-facing analysis, the more mild climate led to softer performance due to less differentiation between the solar path geometry and climate patterns.

Analysis of Multilayer Light Moderator -

Each of the three conditions tested delivered similar results due to the highly tailored nature of the computational patterns; the evenness of performance throughout climates and orientations is an advantage over standard frits and louvers. Although the south facing analyses produced mid-range results in between standard frit and louvers, the patterns were able to differentiate between hot and cold vector Degree-Day ratio unlike standard frits. When the evolutionary algorithm optimization is stacked on the sensitivity analysis there is a marked increase in performance with very little compute time; with more compute time, the trajectory projected a further increase of performance approaching that of louvers.

Conclusion

Relevance to Perkins & Will

Since Perkins & Will is one of the largest Architecture firms in the world, it has the agency to make a large impact, with the built-environment, on the health of the natural environment we all depend upon. If the Energy Use Intensity of each square foot that Perkins & Will designs could decrease by a small margin, it would have a large positive impact on the environment, but with current technologies, clients and gatekeepers have a hard time reconciling costs versus benefits. On the other hand, most designers have limited understanding on the performance and cost impacts of shading devices on the market. Analysis of emerging technologies' practical, sustainable, and economic implications within the built environment is imperative to the continuation of innovation within Perkins & Will, and to continue our path toward a sustainable future. This patent-pending technology is simple, economic, easily integrated, easily manufactured, and minimally impactful to formal design; it overcomes many of the hurdles that inhibit more sustainable design from the perspectives of clients, designers, contractors, and installers alike. This technology may be a step forward toward fully integrated, ubiquitous sustainable design and a healthier and happier built-environment.

Relevant Previous Work

I, Christopher Hague, am the holder and sole inventor of the novel technology represented in the Provisional Patent Application Number US 62/868,910 "Multilayer Light Ray Moderator System"[1], and reserve all rights of that license. As an employee of Perkins & Will and a grant applicant, I bring this as an opportunity for the Company to analyze the performance of a new patent-pending technology, and to gauge the technology's viability for future use within the built environment. Some drawings from the patent application have been included below.

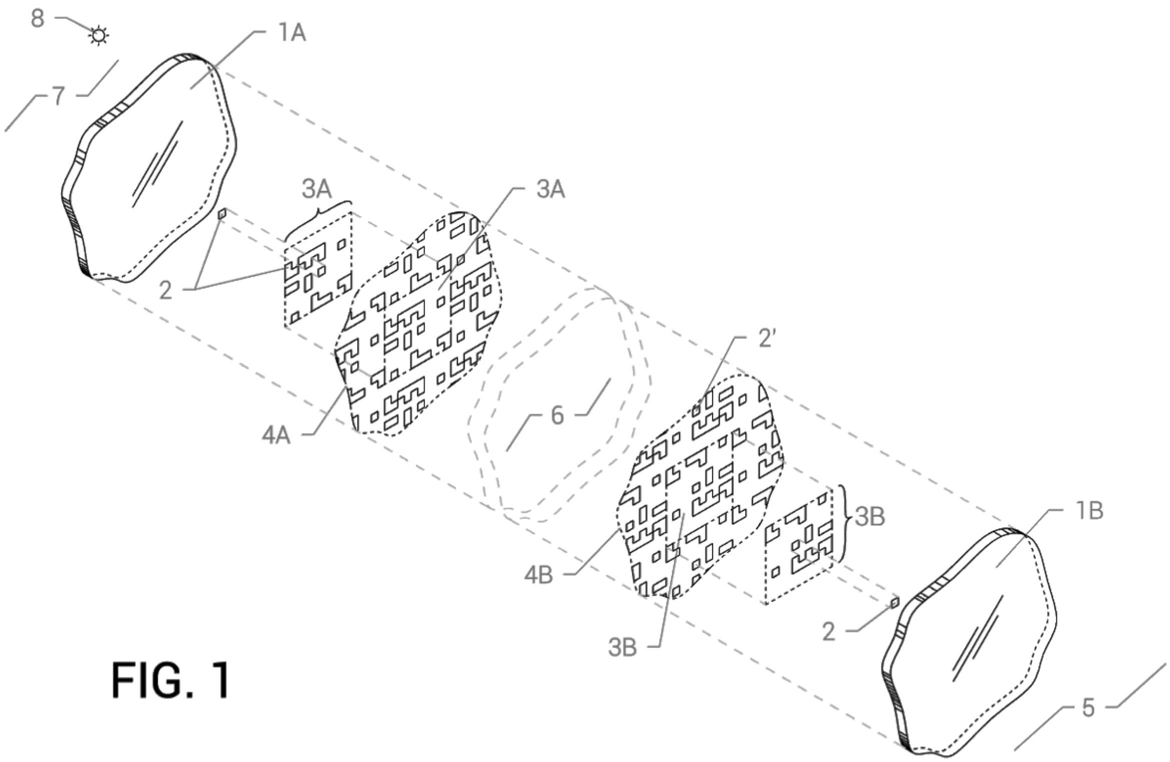


FIG. 1 [1]

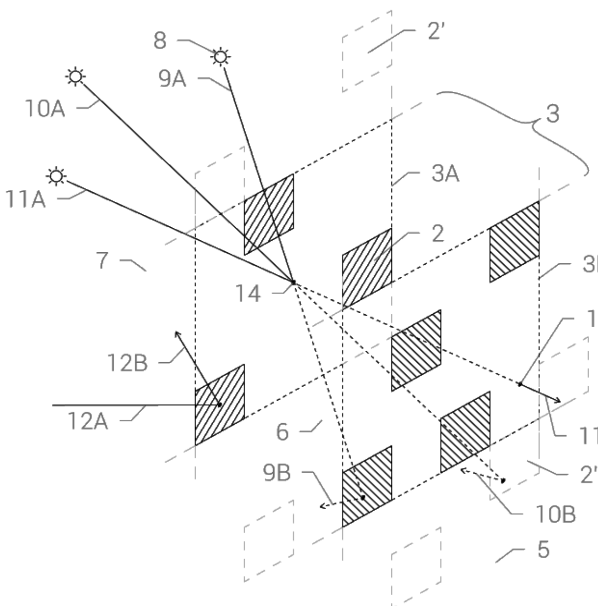


FIG. 2 [1]

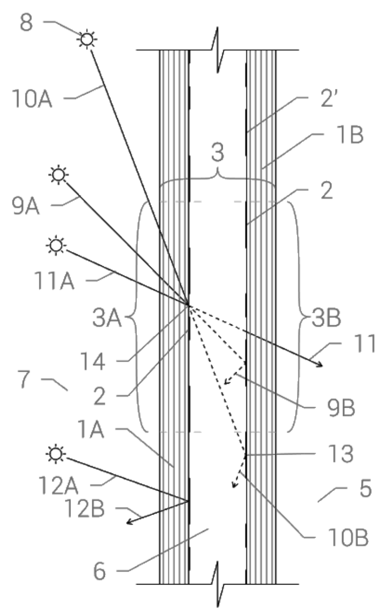


FIG. 3 [1]

Citations

1) US 62/868,910, 06/29/2019, Christopher Hague, Multilayer Light Ray Moderator System