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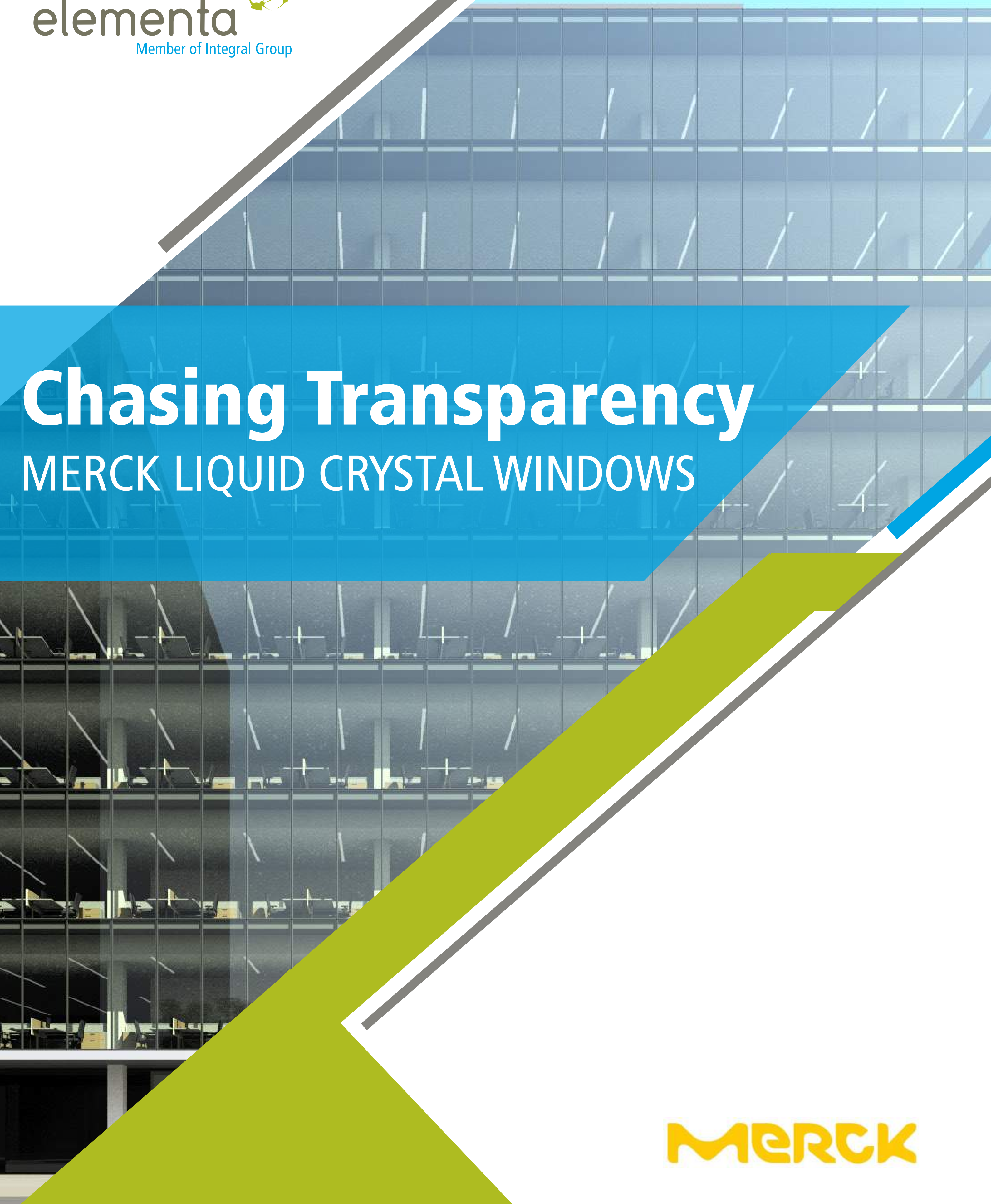
Chasing Transparency

MERCK LIQUID CRYSTAL WINDOWS



MERCK

CONTENTS

BACKGROUND

Climate change is one of the greatest challenges our global communities currently face, requiring a drastic reduction in carbon emissions to slow its effects. Buildings, which account for more than 30% of global carbon emissions, are a key component of the climate change mitigation solution and many cities around the world have committed to minimising the environmental impact of their new and existing building stock.

Carbon performance, however, is not the only consideration for building designers. With a renewed focus on occupants, buildings are now expected to enhance quality of life, improving health, wellbeing and productivity, both at home and in the workplace. The industry is now tasked with delivering efficient, low-carbon buildings that maintain a high level of occupant comfort.

The building's facade, which provides an interface between the indoor and outdoor environments, has become a crucial factor in the performance of today's buildings. There are well-established dichotomies of facade design, including the tensions between daylight penetration, solar control, glare mitigation and thermal comfort. The continuing architectural trend towards highly glazed buildings has spurred the advancement of facade technologies that seek to resolve these tensions while maximising facade transparency.

One such technology is dynamic, or "switchable" glazing, which has been ranked as #61 in the "100 solutions to reverse climate change", according to the recent publication Drawdown. By modulating the transmittance of light and thermal energy, dynamic glazing is able to provide a higher level of flexibility than static solutions, such as fixed-transmittance glazing with external shading devices. This flexibility derives from their capacity to adjust their optical properties in response to different types of stimuli, such as glass temperature in the case of thermochromic glazing, or voltage in the case of electrochromic glazing.

Dynamic glazing has increased in popularity in recent years, but is not without its limitations. These limitations have included slow switching speeds, where transitions may take up to 30 minutes, and colour rendering that produces an unwelcome yellow or blue effect.

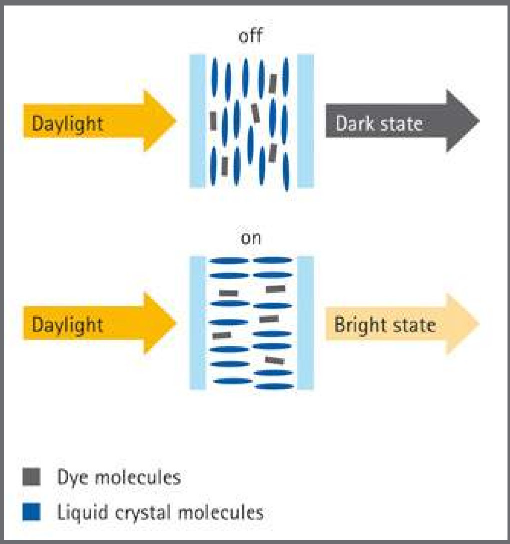
Merck Window Technologies B.V. has recently developed a dynamic glass product that uses liquid crystal technology to address these limitations and provide additional benefits. This report presents a joint research project between Elementa Consulting and Merck Window Technologies B.V., exploring the Merck Liquid Crystal Window (LCW) and its performance in relation to facade design challenges. Where possible, Merck's LCW is compared with established facade design solutions, such as closed-cavity systems, fixed external shading and solar control coatings, to establish how the technology fits within the industry's palette of options.

The report is presented in two chapters; the first chapter contains a collection of visual studies, while the second chapter focuses on integrated facade performance, including thermal comfort, energy efficiency and daylight availability.

Introducing Merck licrivision™

licrivision™ is the new technology that Merck's LCW product utilises. It is a transparent material comprising a mixture of dyes and liquid crystals and is applied between two panes of glass that have an invisible conductive coating.

As a voltage is applied to the licrivision™ layer, the crystals alter their orientation, thereby changing the position of the colour molecules. The position of these molecules determines the transparency of the system, which affects whether the glazing is perceived as bright or tinted.



Merck LCW is able to transition between tinted and bright states in less than a second, with continuous control for intermediate shading states. Control of the glass tinting can be achieved locally through user input, or centrally through a building management system.

02 APPROACH

Merck's LCW technology has been developed to meet the demanding performance requirements of today's facade designs. Aside from the inherent benefit of providing a dynamic solar control range, the technology has targeted neutral colour rendering, fast-response switching and customised coating placement as additional advantages.

To explore how these attributes could be realised in practice, and how they could affect the human experience of the built environment, a series of visualisations and environmental design analyses have been performed using best practice building physics techniques. These technical investigations have been assembled in two chapters within this report - Visual Studies and Integrated Facade Performance.

VISUAL STUDIES

This section of the report explores the visual performance of the Merck LCW in comparison with two alternative design solutions - a typical Double Glazed Unit (DGU) with solar-control coating and internal blinds, and a Closed Cavity Facade (CCF) system with interstitial shading fins.

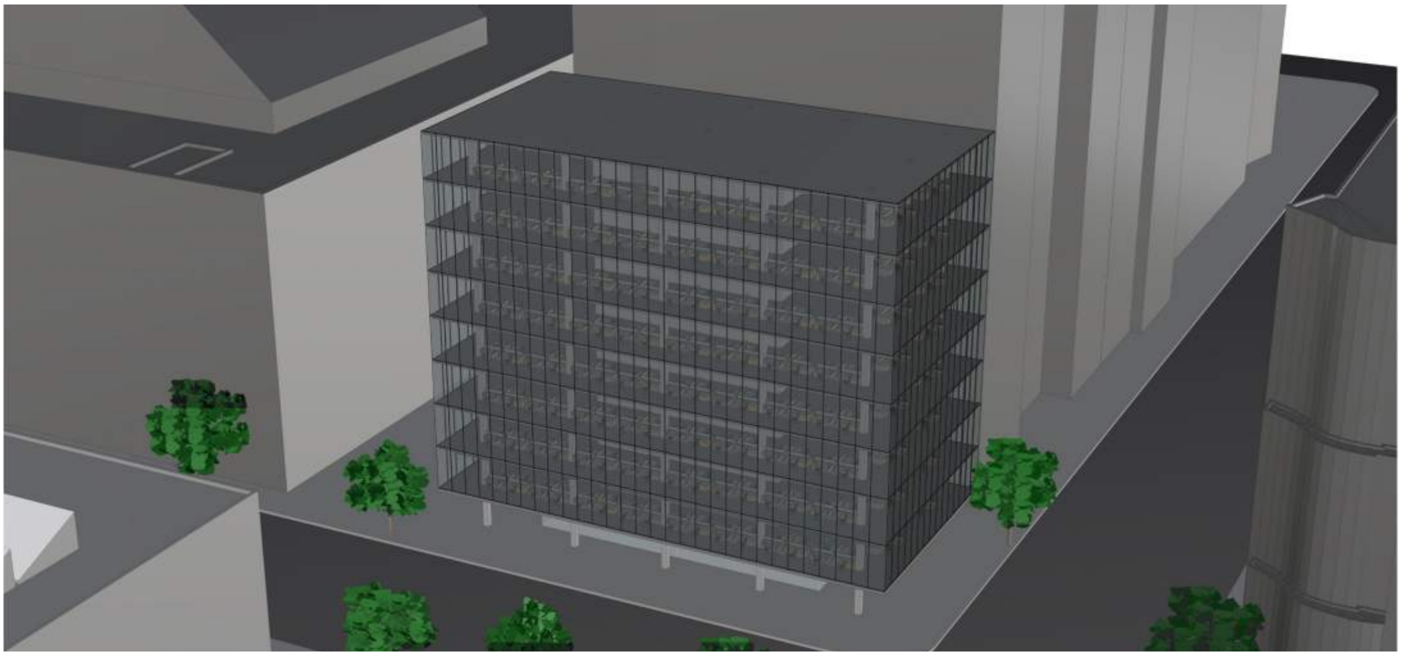
In order to compare the three design solutions, an illustrative eight storey office building has been created, placed within fictional surrounding context, and assumed to be located in the city of London. An image of the 3D model can be seen below, and additional details can be found in Appendix A.

An accurate representation of each facade design solution has been established, using technical data that describes how the optical properties of each glass surface vary across the visible spectrum. This has allowed physically accurate visualisations to be generated for a variety of scenarios, including clear-sky and overcast conditions.

These visualisations of the exterior of the building have been used to explore how the facade options contribute to the appearance of a glazed building, particularly in relation to the transparency, colour rendering and reflectivity of the glass, as well as the impact of each shading technology on the visual uniformity of the facade.

The impact on the indoor visual environment, however, is also a critical design consideration. The glare control capabilities of the Merck LCW in its tinted state is compared with the internal blinds of the double glazed unit and the interstitial fins of the closed cavity facade. The visualisations allow not only a quantitative assessment of glare risk, but also provide an understanding of how an occupant's connection with the outdoor environment is impacted by each shading measure.

The simulations have been conducted using Radiance in its native Unix form, a research grade simulation tool based on the physics of light and material properties. The simulation outputs are High Dynamic Range (HDR) images, with data rich pixel information containing both luminance (brightness) and colour data. These images have been processed with a tone mapping algorithm that uses HDR data to produce a rendered image which strongly correlates with human vision.



INTEGRATED FACADE PERFORMANE

The second chapter within this report focuses on the performance of the Merck LCW in relation to integrated facade design considerations, namely thermal comfort, energy efficiency and daylight availability.

Residential overheating is a topical design issue in London in 2017, and has been used as the contextual setting for this section of the report. A representative open-plan living space, with a single aspect south-oriented glazed facade, has been used to compare the Merck LCW performance against a baseline scenario (unshaded double glazing with a solar-control coating) and a typical design solution (fixed external shading).

The overheating risk during summer months has been assessed according to CIBSE's technical memorandum TM59: Design methodology for the assessment of overheating risk in homes, which provides a standardised methodology for predicting overheating risk in line with TM52: The Limits of Thermal Comfort: Avoiding Overheating in European Buildings. This approach has been used to establish the Merck LCW as a viable design solution before exploring its performance benefits in areas that stretch beyond regulatory compliance.

The potential of each facade option to reduce space heating demands has been explored by comparing passive solar gains during winter months. Climate-based daylight modelling (CBDM) has been used to evaluate and quantify the impact of each facade option on daylight penetration within the living space. Finally, the fast response time of the Merck LCW product and the consequential impact on transmitted solar heat gains has been analysed and compared to a typical dynamic glazing system with a slower response.

The dynamic thermal simulations have been conducted using IESVE (Integrated Environmental Solutions Virtual Environment), an industry-standard simulation tool widely used for advanced building performance analysis. Calculation of thermal comfort has utilised ASHRAE-55 standard methodologies for comfort analysis. Daylight calculations have been performed using Honeybee, a plug-in to graphical algorithm editor Grasshopper for Rhinoceros 3D, which uses Radiance as its calculation engine.

Performance Rating System

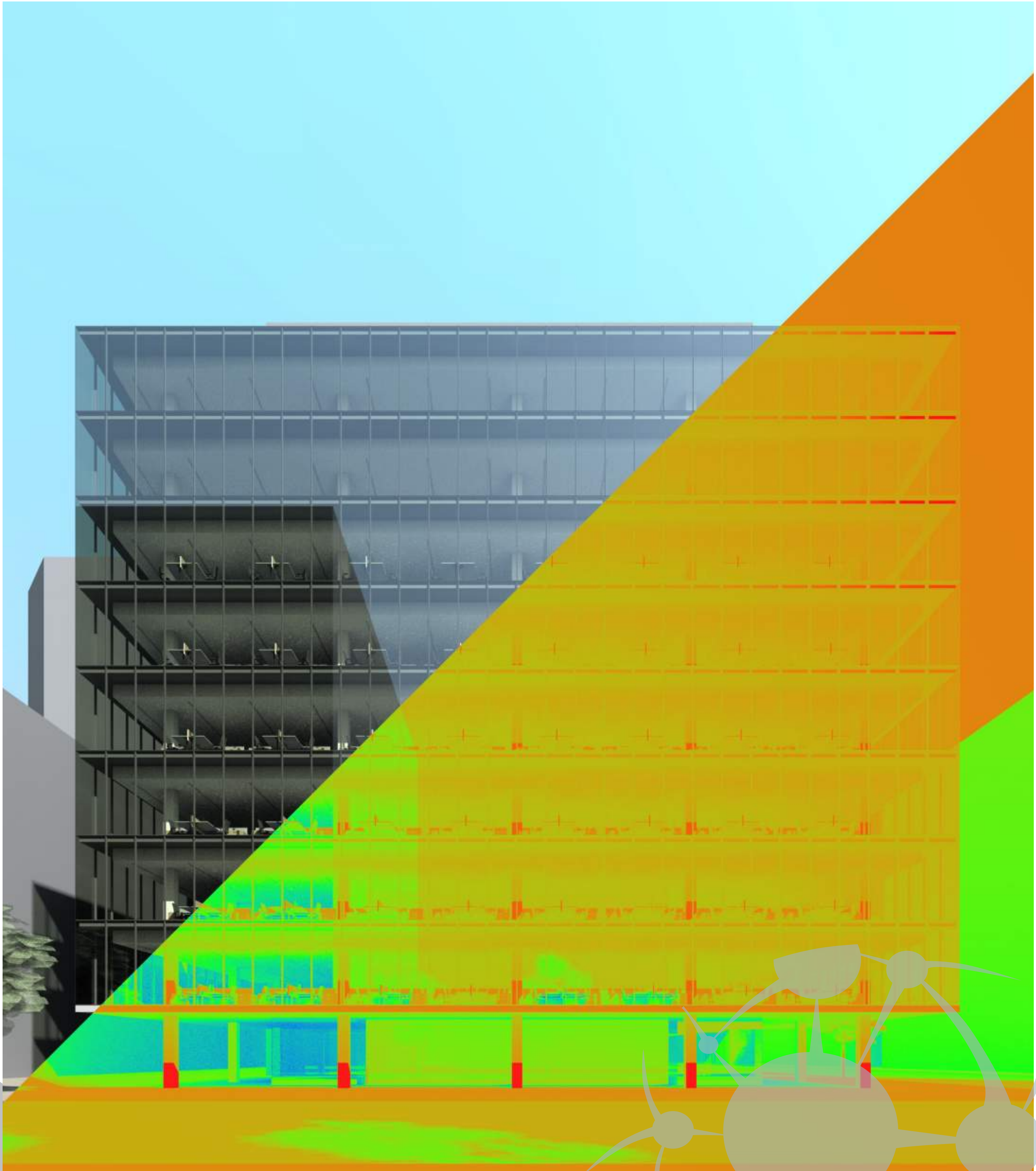
For each performance attribute that is explored in the Visual Studies chapter, a traffic light rating system has been used to indicate a relative scoring for the three design solutions. Icons are used to represent each performance attribute, and the green, yellow and orange colours of the icons indicate high, intermediate and low levels of performance, respectively.

Transparency

03

CHAPTER 1

Visual Studies



The Three Contenders

When deciding whether a physical glass sample is aesthetically suitable, it is often easier and more meaningful to view the glazing side-by-side with alternative options, rather than to view the glazing on its own. The same is true when virtually visualising glass products using computational renderings.

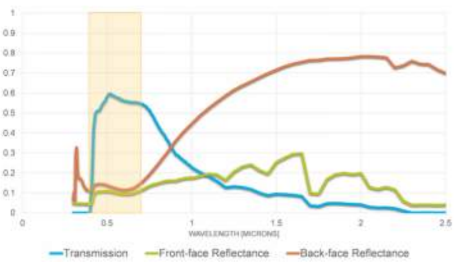
For that reason, this chapter presents a comparison of the Merck LCW with two alternative facade solutions. To establish a fair playing field, a common design scenario has been conceived, in which a hypothetical design team is tasked with meeting a particular performance threshold. In this case, the target is to achieve a Solar Heat Gain Coefficient of roughly 0.22, which is a reasonable benchmark for a building in London with a heavily glazed facade.

The alternative design solutions chosen for this study represent two ends of the design spectrum. The first is a double-glazed unit (DGU) with triple silver, high performance solar control coating on surface 2 and internal manually-operated blinds. The second is a more complex and costly closed-cavity facade (CCF) solution, with automated interstitial fins that can rotate to control solar penetration, and retract vertically to provide an unobstructed view.

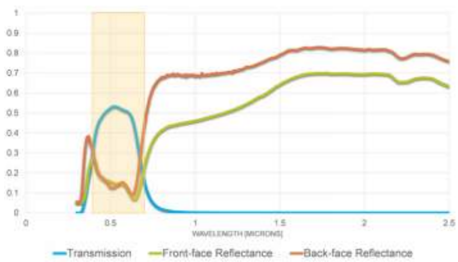
Each design solution, including the Merck LCW, has been modelled using the Lawrence Berkeley Laboratory's WINDOW and OPTICS software to create material definitions that accurately depict the spectral variation of light transmittance and reflectance. For the DGU and CCF options, the glazing build up was carefully selected based on current industry-available glass products that meet the design intent. These material definitions were then used to generate physically-accurate renderings from both external and internal views, for each of the facade alternatives.

The charts and tables below summarise the optical performance of the three design alternatives.

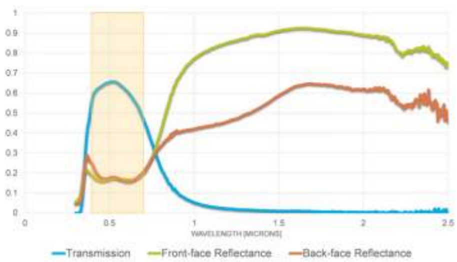
Merck Liquid Crystal Glass



High Performance Double Glazed Unit



Closed Cavity Facade



	22-12-6	Bright State	Tinted State
Visible Light	Transmittance, T(%)	57	11
	Front Reflectance, Rf(%)	10	8
	Back Reflectance, Rb(%)	12	12
Solar Energy	Transmittance, T(%)	36	18
	Front Reflectance, Rf(%)	14	13
	Back Reflectance, Rb(%)	32	32
	g-value (%)	43	22

	6-16-4	Blinds Up	Blind Material
Visible Light	Transmittance, T(%)	51	10 diff 0.5 spec
	Front Reflectance, Rf(%)	14	25 diff 0 spec
	Back Reflectance, Rb(%)	14	
Solar Energy	Transmittance, T(%)	19	
	Front Reflectance, Rf(%)	35	
	Back Reflectance, Rb(%)	48	
	g-value (%)	23	

	6-230-6-12-6	Fins Up	Fin Material
Visible Light	Transmittance, T(%)	64	0
	Front Reflectance, Rf(%)	17	35
	Back Reflectance, Rb(%)	17	
Solar Energy	Transmittance, T(%)	32	
	Front Reflectance, Rf(%)	46	
	Back Reflectance, Rb(%)	33	
	g-value (%)	44	

Performance data calculated in accordance with EN 410

What could it look like...
...on a clear sky day?

The aim of this section of the report is to provide readers with an understanding of the visual aesthetic of the Merck LCW under various conditions - to answer the question "What does Merck look like?".

This page focuses on the appearance of the three design alternatives under a clear, sunny sky. Under these conditions, it is possible to examine both the effective transparency and colour rendering performance of the glass.

The images to the right show the case study office building, rendered from three different external views - a corner perspective from the south-east and two elevations, south and east.

The first column illustrates the Merck LCW product in its bright state (visible light transmittance 57%). The images indicate a high level of transparency as well as a very neutral colour rendering, a result that is in accordance with the product's Colour Rendering Index of 97.

The second column illustrates the solar-control DGU option, which features a lower level of transparency and a noticeable blue-green hue that distorts the colours of the internal furniture and structure. This colour rendering issue is a common symptom when selecting glass with high visible light transmittance and solar control. If not considered during the design phase, this can lead to a surprising and unwanted visual appearance when constructed.

The third column illustrates the closed-cavity facade option, which derives much of its solar control from the isolated interstitial fins. In this way, it is possible to construct the CCF using ultra-clear glass materials, resulting in a high level of transparency and very good colour rendering when the shading is retracted.

Basis of Assessment

Time: 10am
Date: 8th September
Sky condition: Clear, sunny sky
Shading: None

Colour Rendering **Transparency**

Merck LCW

From top to bottom: Southeast, south and east perspectives of the Merck glazing option

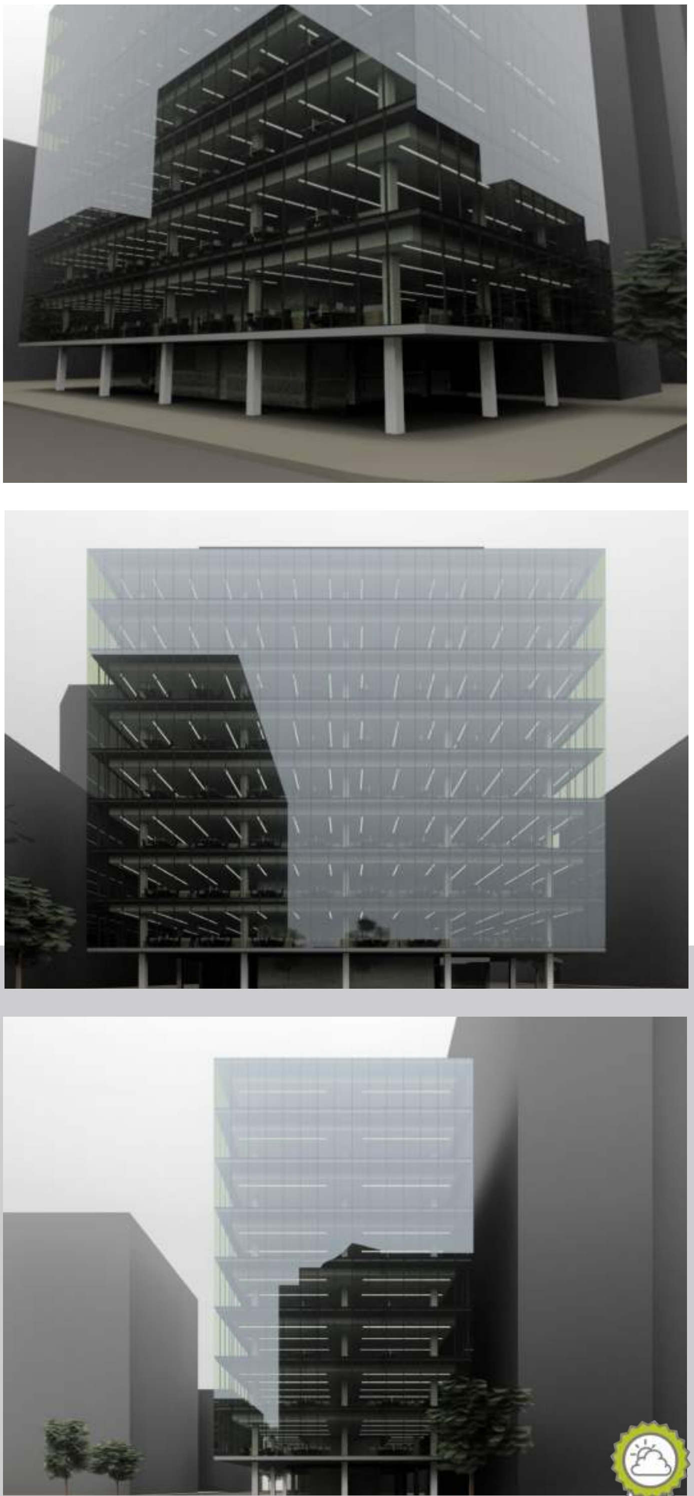
Double Glazed Unit

From top to bottom: Southeast, south and east perspectives of the double glazing option

Closed Cavity Facade

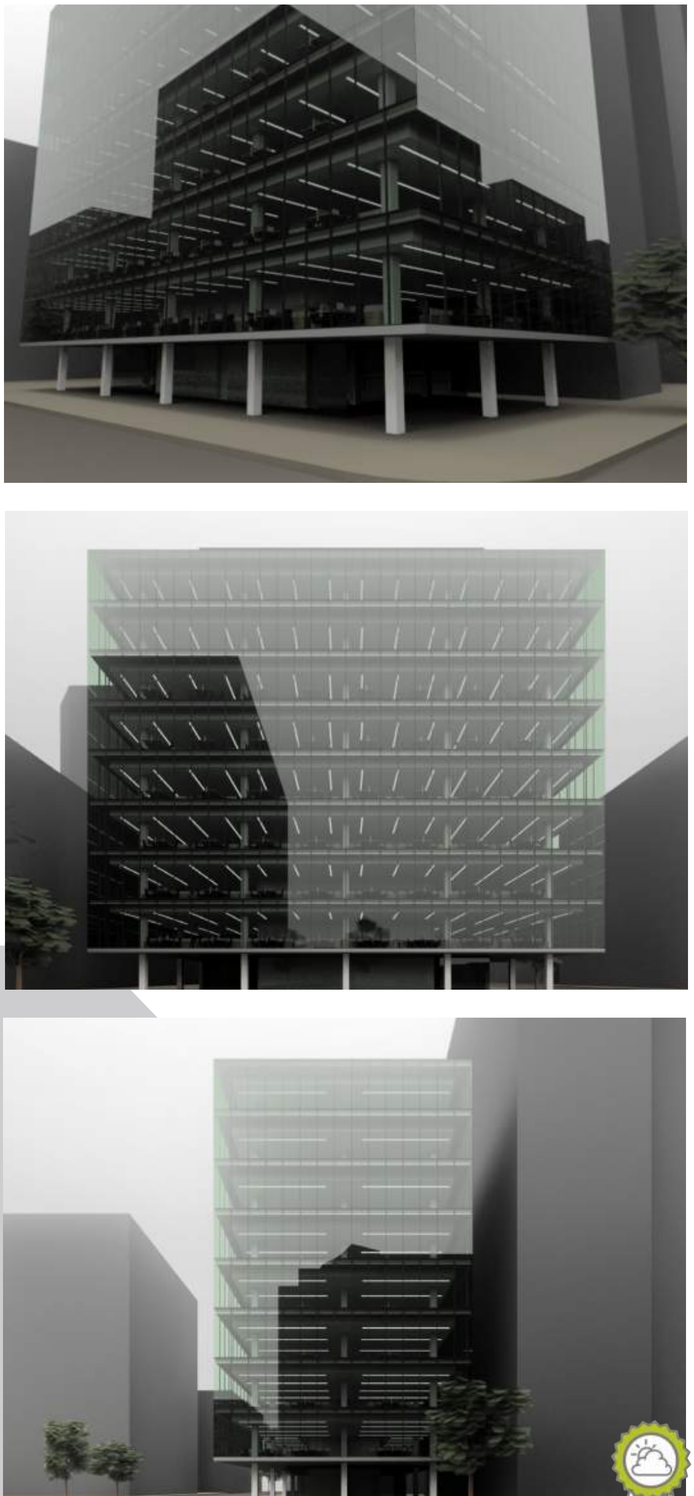
From top to bottom: Southeast, south and east perspectives of the closed cavity facade option

Merck LCW



From top to bottom: Southeast, south and east perspectives of the Merck glazing option

Double Glazed Unit



From top to bottom: Southeast, south and east perspectives of the double glazing option

Closed Cavity Facade

From top to bottom: Southeast, south and east perspectives of the closed cavity facade option

What could it look like...
...on a cloudy day?

This section of the visual study illustrates the facade alternatives under a very different condition - an overcast sky, generated in accordance with the CIE standard overcast sky definition. Overcast conditions are a useful setting for exploring the reflective properties of glass, which is an important consideration in many climates around the world. In comparison to the previous section, the images to the right show a different visual character in all three facade design alternatives.

By focusing on the internal furniture within the images, particularly within the portions of the elevation views that reflect the white sky, it is possible to assess the impact of glass reflectance for each alternative.

The images illustrate a similar level of visible reflectance in the Merck LCW and DGU facade options, while the closed-cavity facade glazing appears to exhibit a higher level of reflectance.

These comparisons are easier to make using larger images, and these have been included in Appendix B for reference.

Basis of Assessment

Time: 10am
Date: 8th September
Sky condition: Clear, sunny sky
Shading: None

Overcast Reflectance

What could it look like...

...when the shading is deployed?

A key aspect of pre-construction facade visualisation is predicting the appearance of the facade when the building is occupied. User behaviour, as well as automated building controls, can have a significant impact on the visual appearance of a building, particularly in relation to visual uniformity. This section aims to provide a comparison of how the facade alternatives may appear when solar control strategies are employed.

The setting for this assessment is an afternoon condition where direct sunlight falls on the predominant south elevation of the case study building and the east elevation is in full shade. The surrounding buildings have cast a trapezoidal shadow across the south elevation, which provides an interesting comparison of solar control and its impacts on visual uniformity.

The Merck LCW product has the potential to be controlled by occupants, but it has been assumed in this study that the tinting is controlled via an automated building management system. The internal blinds of the DGU option have been assumed to be manually-operated, while the interstitial fins of the CCF option have been assumed to be fully automated.

Two shading control scenarios have been modelled. The top row of images illustrates the results of a "whole-facade" shading control strategy, where sunlight exposure has triggered a tinted Merck state and a lowering of the CCF fins across the entire facade. The DGU option shows a randomised pattern of blind deployment, typical of many buildings that feature manually-operated blinds.

The second row of images illustrates a "bay-by-bay" shading control strategy, in which each bay of the Merck and CCF alternatives can be controlled in response to direct sun exposure. In this way, shaded portions of the facade can increase the level of daylight penetration for the benefit of occupants. Again, the DGU option shows a scattering of blind deployment, which is concentrated in the areas of direct sun exposure.

The third row of images shows the shaded east facade, which further highlights the potential uniformity of the Merck LCW and CCF options, in comparison to a DGU option showing some level of blind deployment, despite no direct sunlight.

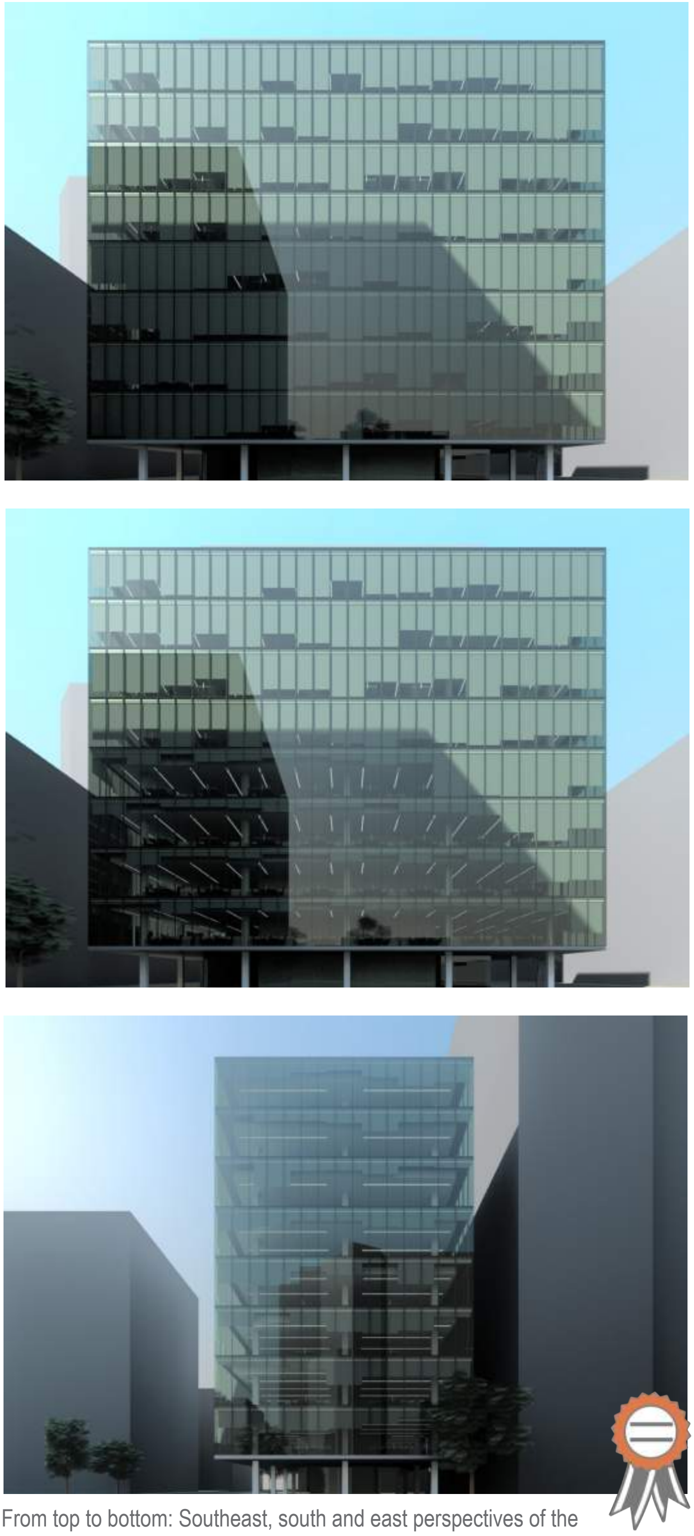
Merck LCW

From top to bottom: Southeast, south and east perspectives of the Merck glazing option

Basis of Assessment

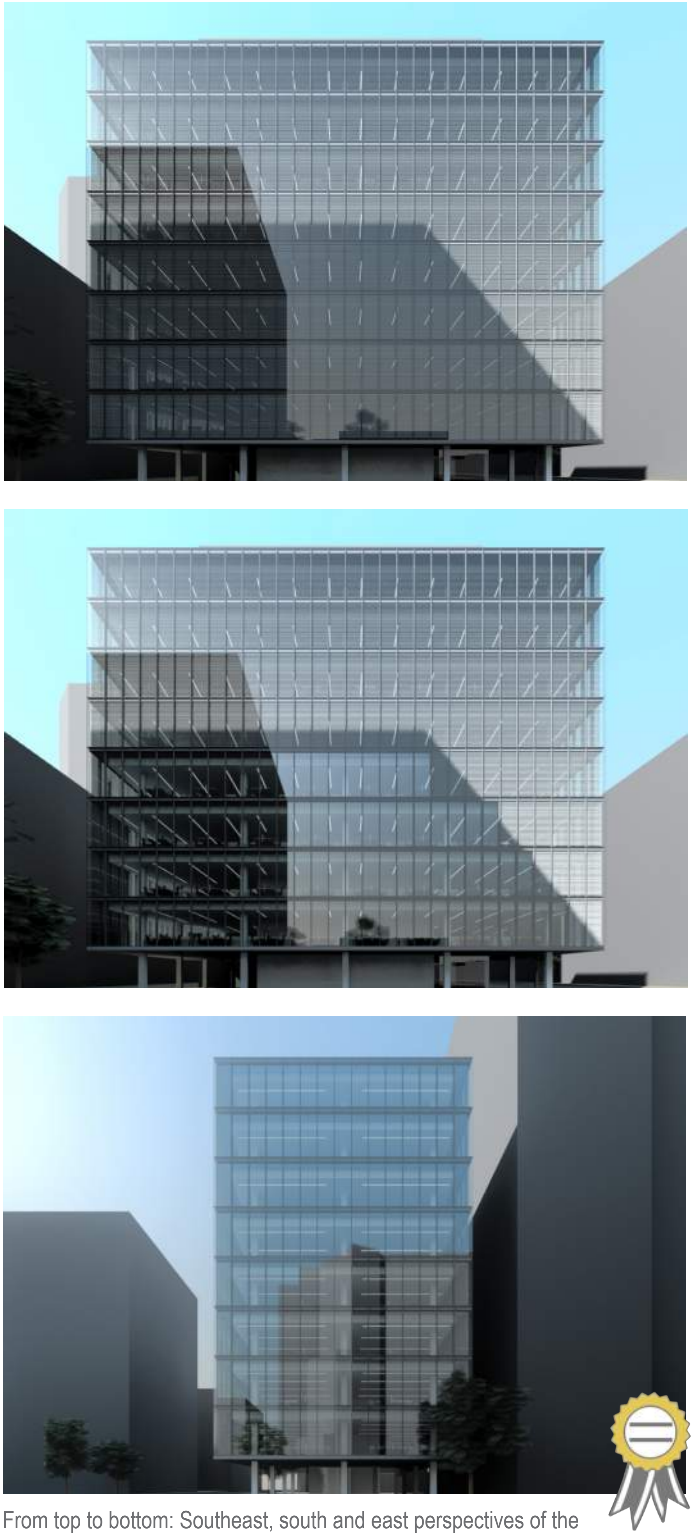
Time: 2pm
Date: 8th September
Sky condition: Clear, sunny sky
Shading: Deployed

Double Glazed Unit



From top to bottom: Southeast, south and east perspectives of the double glazing option. The DGU performance has been judged as poor based on the non-uniformity of occupant-controlled blinds.

Closed Cavity Facade



From top to bottom: Southeast, south and east perspectives of the closed cavity facade option. The CCF performance has been judged as intermediate based on the visual interruption caused by the interstitial fins.

Uniformity

Indoor Environment

Protecting Occupant Views

The impact of the facade on indoor environmental quality is a critical consideration when evaluating design solutions for any building typology. For an office space, such as our case study building, maintaining visual connectivity between occupants and the outside world needs to be balanced with providing an indoor visual environment that supports desk-based activities.

A common performance issue in highly glazed buildings is that of visual discomfort, often stemming from excessive daylight penetration causing a phenomenon known as discomfort glare. The risk of glare within many buildings is considered to be resolved through the implementation of internal blinds. However, this solution can lead to a visual disconnect between occupants and the external environment, not to mention the potential for manually-operated blinds to create a non-uniform facade aesthetic when observed from outside the building.

The studies presented in this section of the report illustrate the predicted internal visual environment of the three facade design alternatives, focusing not only on how the options perform in relation to glare reduction, but also how well they protect the occupant's external view.

The images on the following pages present rendered perspective and fisheye views, generated using the same software and methodology as the external renders of the previous section. For the purposes of the study, a clear and sunny sky has been simulated, and results are shown for both an unshaded and shaded condition.

The adjacent page shows the Merck LCW facade option. The left column of images depict the product in its bright state, while the right column depicts the tinted state. The perspective image at the top shows a view from the second row of desks, looking toward the south-east corner of the office. The middle image is a fisheye render from an occupant's seated position at the perimeter, looking toward the computer screen. The bottom image shows the same fisheye view with a falsecolour filter that provides a visual representation of the luminance, or brightness, of each surface in the field of view. Orange and red colours indicate surfaces that appear bright to the occupant, while blue tones indicate surfaces that are far less bright. For office environments, a higher level of luminance uniformity is often indicative of a visual environment that is more suited to desk- and computer-based activities.

The falsecolour luminance map has enabled the calculation of a glare metric, DGP, which indicates "intolerable glare" when the Merck LCW is in its bright state, and "imperceptible glare" in its tinted state. This indicates that the tinting action of the Merck LCW provides a suitable reduction in glare risk. It is important to note that the glare reduction is achieved without obstructing the occupant's view of the external environment.

In contrast, the following pages show the same renders for the DGU and CCF design alternatives. It can be seen that both alternatives successfully reduce glare risk to acceptable levels, but both achieve this glare reduction by obstructing the occupant's external view. The CCF option is considered to perform slightly better than the DGU option based on the potential for the interstitial fins to provide an intermittent view between the slats.

Basis of Assessment

Time: 10am
Date: 8th September
Sky condition: Clear, sunny sky
Shading: Deployed

Glare Reduction **External Views**

How is Glare Risk quantified?

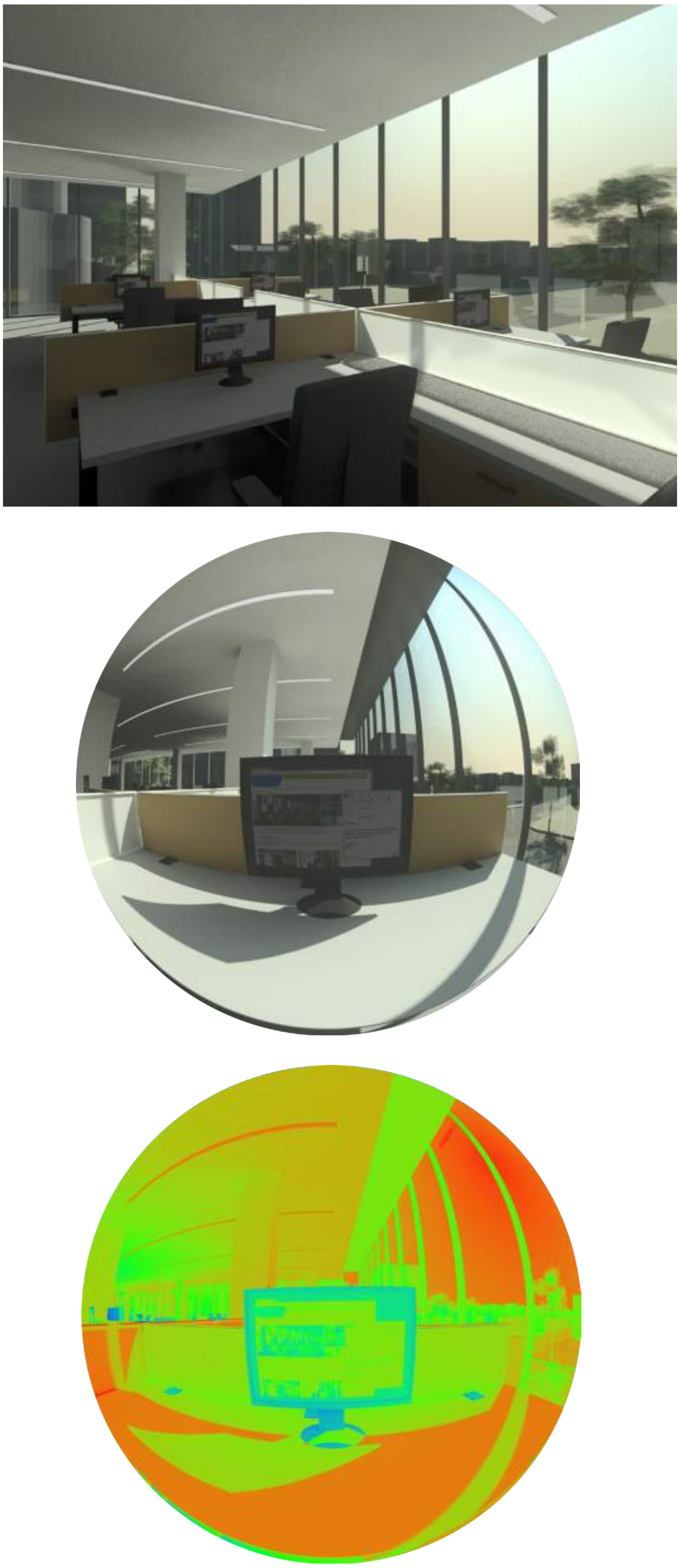
Glare risk has been quantified using the Daylight Glare Probability (DGP) metric, which was developed in 2006 based on empirical studies of subjects within a perimeter office space, and is considered a reliable method for assessing discomfort glare.

The metric predicts the probability that an occupant will be dissatisfied with their visual environment, based on the overall brightness of their field of view as well as the position and intensity of bright sources within it. The evalglare module within Radiance provides an opportunity to calculate DGP based on a fisheye render from an occupant's perspective.

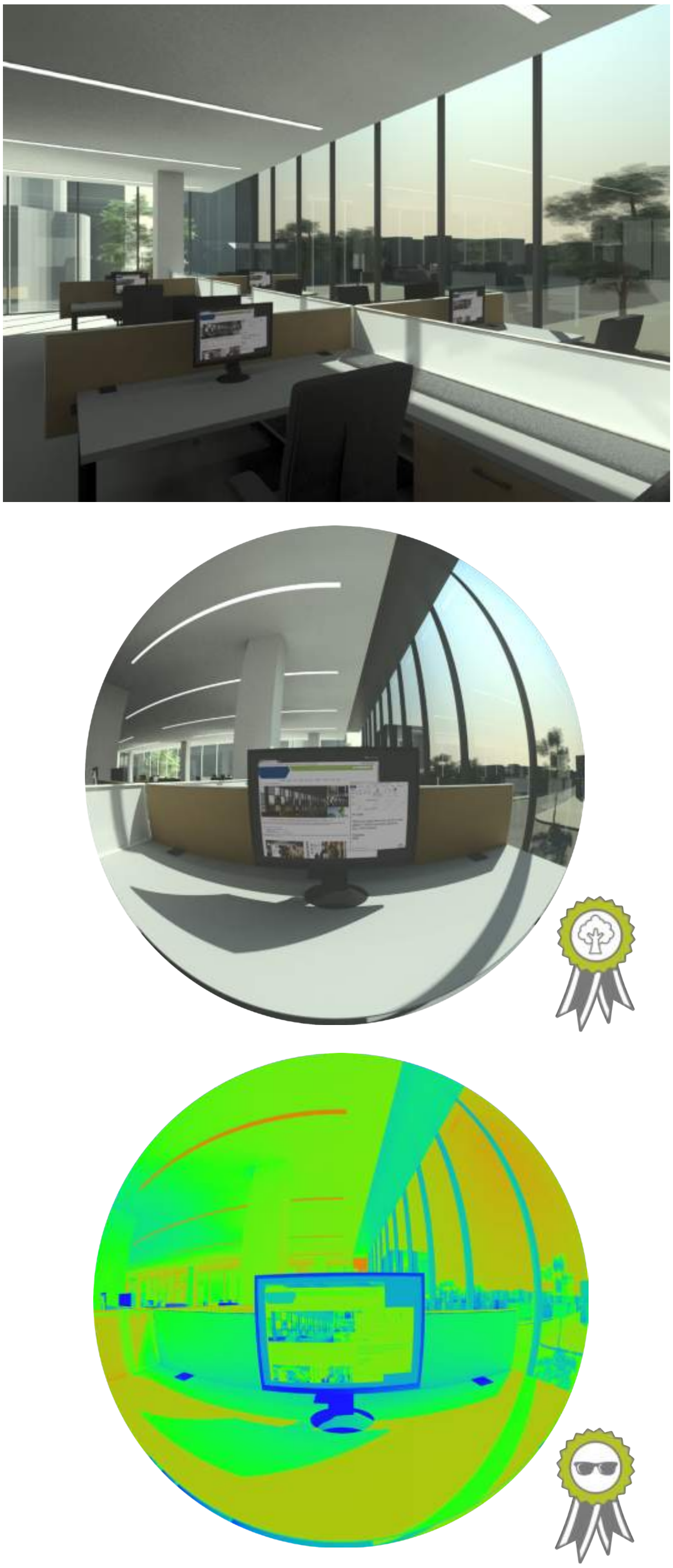
DGP values can be correlated to subjective glare ratings as follows:

DGP < 0.35	Imperceptible glare
DGP 0.35 to 0.40	Perceptible glare
DGP 0.40 to 0.45	Disturbing glare
DGP > 0.45	Intolerable glare

Merck LCW - bright state



Merck LCW - tinted state



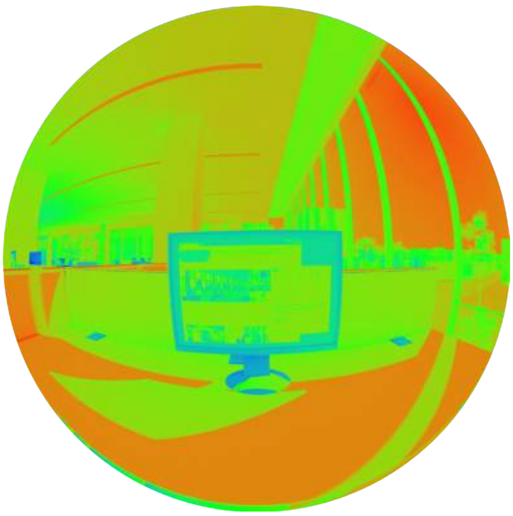
From top to bottom: perspective, fisheye and falsecolor images - unshaded

DGP 48%

From top to bottom: perspective, fisheye and falsecolor images - shaded

DGP 24%

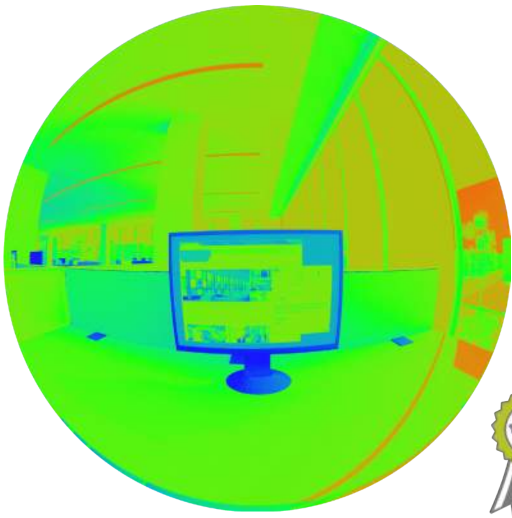
Double Glazed Unit - unshaded



From top to bottom: perspective, fisheye and falsecolor images - unshaded

DGP 43%

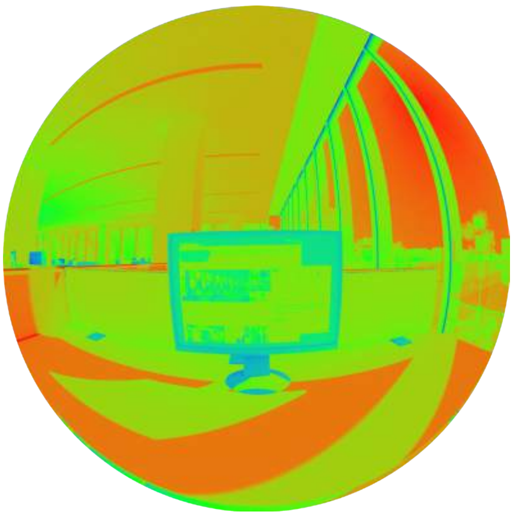
Double Glazed Unit - with blinds



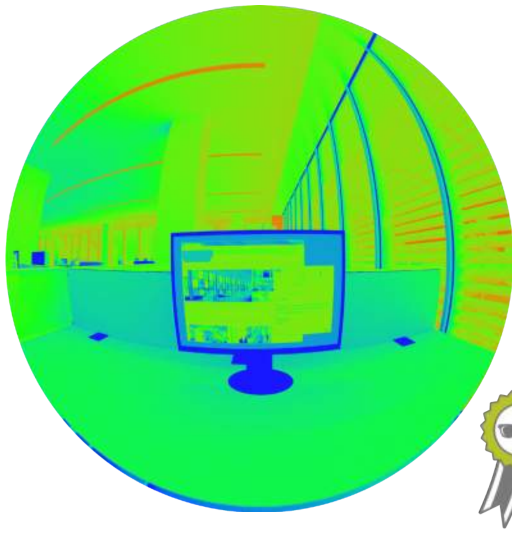
From top to bottom: perspective, fisheye and falsecolor images - shaded

DGP 24%

Closed Cavity Facade - unshaded



Closed Cavity Facade - with fins



From top to bottom: perspective, fisheye and falsecolor images - unshaded

DGP 45%

From top to bottom: perspective, fisheye and falsecolor images - shaded

DGP 22%

Custom In-Pane Zoning

Adapting to the seasons

An additional benefit of the Merck LCW product is the ability to customise the placement of the liquid crystal technology within the window module. It is possible to apply the dynamic control module to specific portions of a laminated glass sheet, in such a way as to create patterns, bands or even logos that can be controlled in the same way as a whole-sheet application. These custom patterns can be controlled individually, without the need to subdivide the window using framing elements.

One of many potential applications is the implementation of solar control that adapts as the position of the sun changes throughout the year. Applying the Merck LCW technology in several horizontal bands across each glazing module enables individual tinting control of each band. The images below explore how this might be used within the case study office building.

The top two images illustrate a winter scenario, in which the low-angle sun results in direct sun penetration at the occupant desks. By tinting the middle section of the glazing, this sun penetration can be reduced, without reducing daylight penetration through the top and bottom portions of the glazing.

Similarly, the bottom two images illustrate a summer scenario, in which direct sun penetration from a high altitude sun position can be reduced through the tinting of the top portion of the glass. Again, daylight penetration can be maximised, while minimising the impacts of unwanted sunlight.

This level of customisation has the potential to be used to optimise a building's performance, as a strategy to navigate the tensions of meeting daylight, glare, thermal comfort and energy efficiency aspirations.

Basis of Assessment

Winter Simulation: 21st December, 2pm
Summer Simulation: 21st June, 2pm
Sky condition: Clear, sunny sky
Shading: Customised

Custom Shading

Top row: Winter condition without (left) and with (right) zoned tinting; Bottom row: Summer condition without (left) and with (right) zoned tinting

Impact on Net Lettable Area

Maximising Yield

Another benefit of the Merck LCW is that it can be deployed within a standard window framing system. In contrast, the closed-cavity facade option requires a greater facade depth in order to house the interstitial fins. This internal space sacrifice is avoided when using the Merck LCW, while maintaining a similar level of solar control, as evidenced on the previous pages.

The dynamic tinting of the Merck LCW also presents an opportunity for the facade to be deployed without an internal blind. This approach is likely to be dependent on the local climate, selected tinting range, and landlord requirements.

The images below illustrate the typical facade depths for the three facade alternatives. The space sacrifice associated with the CCF alternative has been calculated to be equivalent to approximately €144,000 of annual rental yield in a typical London building.

Basis of Assessment

Merck LCW facade depth: 80mm
Closed-cavity facade depth: 250mm
Assumed rental yield in London: €900/m²

Space Sacrifice

Space Saving compared to closed cavity facade

20m² *per floor*

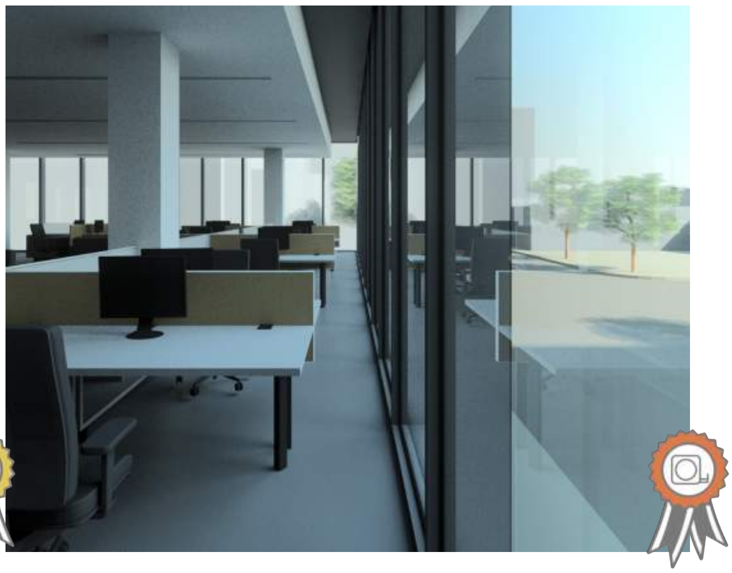
160m² *per building*

144,000 *rent per annum*

Merck LCW

Double Glazed Unit with blinds

Closed Cavity Facade



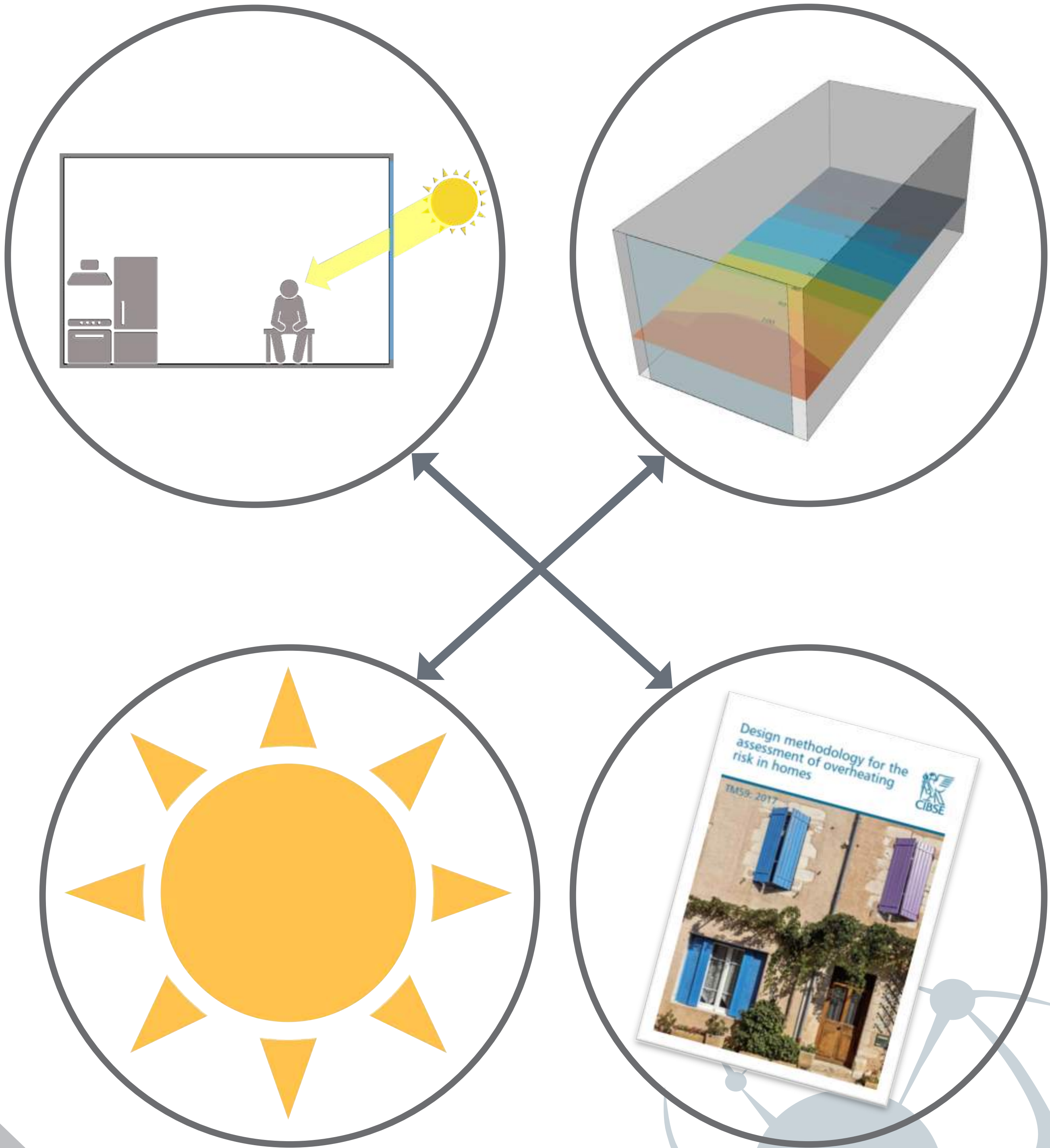
SCORING SUMMARY

	Merck LCW	Low-e Double Glazed Unit	Closed Cavity Facade
Transparency			
Colour Rendering			
Overcast Reflectance			
Uniformity			
Glare Reduction			
External Views			
Custom Shading			
Space Sacrifice			

CHAPTER 2

04

CHAPTER 2
Integrated Facade Performance



Testing Beyond Compliance

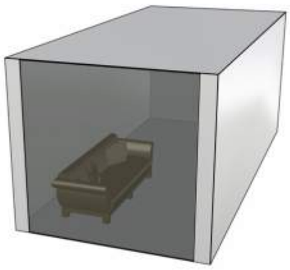
Facade performance can be evaluated and assessed in many different ways, but it is often the building typology, function and aspirations that will determine the performance goals. A common failure in building design is the assessment of facade performance characteristics in isolation. For example, glazing may be maximised to increase daylight penetration and external views without due consideration of thermal impacts on occupants and mechanical systems. An integrated approach to facade performance is necessary to establish a balanced performance, not only for the building's occupants, but for the benefit of the wider environment.

The design of residential buildings in London has recently garnered attention in relation to the risks of overheating during summer periods, particularly with increased focus on the impacts of climate change. The publication of CIBSE's TM59 memorandum, which provides a standardised methodology for assessing overheating, has spurred the industry's focus on overheating risk in dwellings, but has also resulted in the development of facade designs that consider overheating performance in isolation. This siloed approach to design can lead to facades that comply with codes and regulations during summer periods, but perhaps do not maximise their potential in relation to energy efficiency or daylight amenity in other portions of the year.

This chapter presents an integrated facade performance study, using a south-facing residential living space as a basis of assessment. The baseline design for this study assumes a high proportion of glazing, which is often an initial approach to maximising occupant views. This baseline is compared with a design that features fixed external shading and one that utilises the Merck LCW technology.

The design alternatives are first assessed in accordance with the current residential overheating standards in London, and then compared on the basis of several other performance characteristics, including an alternative thermal comfort assessment, and consideration of daylight and passive solar gains in winter. In the final section of this chapter, the fast-response switching of the Merck LCW is explored.

Baseline

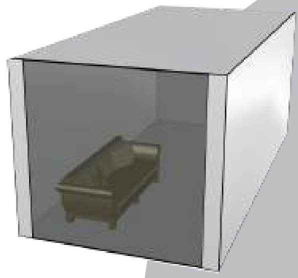


Double-glazed unit
Low-e coating on surface 2
SHGC: 0.41
VLT: 68%

Fixed External Shading

Double-glazed unit
External shading to 500mm
SHGC: 0.41
VLT: 68%

Merck LCW



Double-glazed unit
Merck licrivision solar 60/22
SHGC: 0.22 to 0.42
VLT: 11% to 57%

Is Merck a viable alternative?

Overheating risk

Compliance modelling is essential in ensuring the viability of a building's design within the constraints of any local or national regulatory guidelines. To maximise the overall performance of a building, however, compliance modelling needs to be integrated with what is often referred to as performance modelling, which seeks to evaluate design options against performance characteristics that fall beyond the reach of regulatory frameworks. This section of the integrated facade analysis explores the viability of each design alternative, in accordance with CIBSE's technical memorandum TM59: Design methodology for the assessment of overheating risk in homes, which provides a standardised methodology for predicting overheating risk in line with TM52: The Limits of Thermal Comfort: Avoiding Overheating in European Buildings.

The study assesses summer-time (May to September) overheating risk within the case study residential living space. This area of a dwelling is often the most critical space in terms of summertime overheating due to high glazing ratios and daytime internal gains.

The chart below shows the performance of each design alternative in terms of the percentage of hours during which the space operative temperature exceeds the threshold comfort temperature. The results indicate that the baseline, in which no solar control has been implemented, does not comply with the TM52 Criterion 1 requirements, while both the fixed external shading and the Merck LCW options both meet the requirements.

This compliance assessment establishes the Merck LCW technology as a viable alternative to a more common external shading solution when considering overheating risk. The Merck LCW may in fact be preferable in situations where articulation of the facade is considered undesirable.

CIBSE TM52 Criteria

The overheating risk during summer months has been assessed according to CIBSE's technical memorandum TM59: Design methodology for the assessment of overheating risk in homes, which provides a standardised methodology for predicting overheating risk in new and refurbished homes using a pass/fail approach focused on criteria based on operative temperature.

Basis of Assessment

Room assessed: Living room-kitchen
Orientation: South facing
Natural ventilation during daytime and night-time
Lightweight construction
85% glazing ratio (living room)
Weather file: Heathrow DSY1

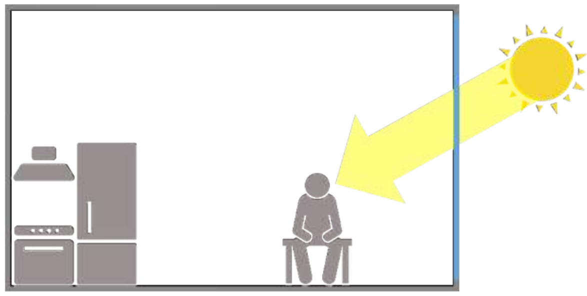
Thermal comfort at the facade

Assessing overheating risk in accordance with TM59 provides a reasonable level of understanding as to how often the threshold comfort limit is exceeded. For each space that is assessed using this methodology, a single comfort metric is calculated that represents the thermal performance of the entire space. This means that the spatial variation of comfort within the room is not considered. In operation, however, it is clear that an occupant's level of comfort is likely to vary depending on where the sun enters the space and how the surfaces of the room modulate in temperature.

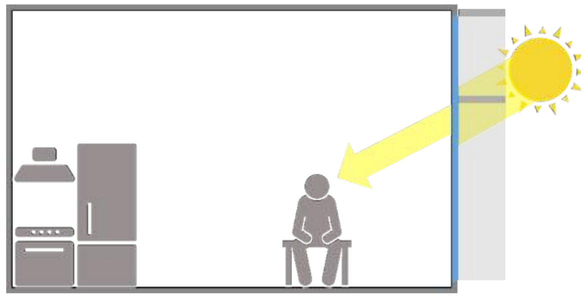
To address this, an additional thermal comfort calculation has been performed for an occupant sitting within a patch of sunlight, close to the facade. The calculation has been performed in accordance with ASHRAE Standard 55, and uses the results of a dynamic thermal model to establish air conditions, surface temperatures and solar radiation. The mean radiant temperature for the occupant has been calculated by considering the proportional contributions from surrounding surfaces as well as the uplift due to the exposure to direct solar radiation.

The results presented on this page show the Predicted Percentage Dissatisfaction (PPD) for each design alternative, taking into account how the facade solution reduces both glass temperature and transmitted solar radiation. The PPD value represents the proportion of occupants that would be dissatisfied with a particular comfort scenario, and a well established target for PPD is less than 10%.

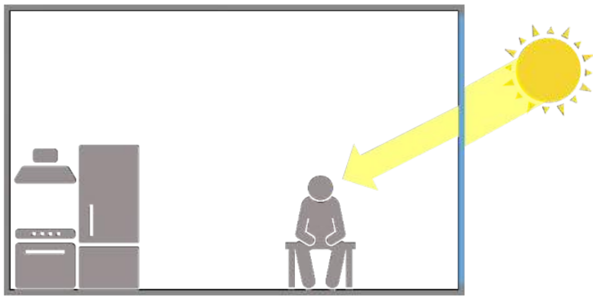
It can be seen that the baseline design results in a poor thermal comfort prediction, with PPD above 20%. This is due to the unshaded and expansive glazing and the associated radiant heating effect. In contrast, both the fixed external shading and Merck LCW options result in significantly lower glass temperatures and transmitted solar radiation. This results in a much more favourable PPD assessment, and aligns with the results of the TM52 overheating analysis.



PPD 21% - Slightly Warm



PPD 6% - Neutral



PPD 6% - Neutral

From top to bottom: thermal comfort results for the baseline, fixed external shading and Merck LCW options respectively

Quantifying Comfort

The physiological response of humans to their thermal environment is driven by a number of major factors, including air temperature, relative humidity, radiant temperature, air speed and their levels of physical activity and clothing.

ASHRAE Standard 55 sets out minimum thresholds for acceptable indoor thermal comfort based on these drivers, and allows a quantitative assessment of comfort using the Predicted Mean Vote (PMV)/Predicted Percentage Dissatisfied (PPD) model. This comfort analysis approach is widely used and has been adopted for the purposes of this study.

Basis of Assessment

Air speed 0.8m/s
Humidity 50%
Metabolic rate 1 met
Clothing level: 0.5clo
Thermal model based on Heathrow DSY1 weather

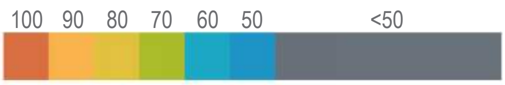
Beyond Compliance

Winter Daylight

The risks associated with isolated compliance modelling are no more evident than when considering the interaction between overheating risk and daylight amenity. Far too often facades are developed in response to overheating analysis alone, resulting in designs that successfully protect occupants from increased temperatures and solar radiation in summer periods, but provide poor levels of daylight availability during winter months when overheating is less of a concern.

The dynamic nature of the Merck LCW provides an opportunity to tune its performance in response to the environmental conditions. This allows the glass to control solar gains in summer, while maximising daylight in winter. In comparison, a fixed shading solution, which needs to be designed to meet summertime overheating requirements, does not have the ability to adapt in winter to allow higher levels of daylight penetration. To quantify this performance difference, a daylight analysis for the month of December has been performed using the daylight autonomy metric. The simulation for the Merck LCW assumes that the glass maintains a bright state until incident solar crosses a threshold of 100 W/m^2 at which point the glass increases its tint in line with increasing solar radiation, up to a maximum of 400 W/m^2.

The results clearly show that the ability of the Merck LCW to adapt its light and solar transmittance in accordance with incident radiation, allows for a higher availability of daylight within the space than the fixed shading solution.



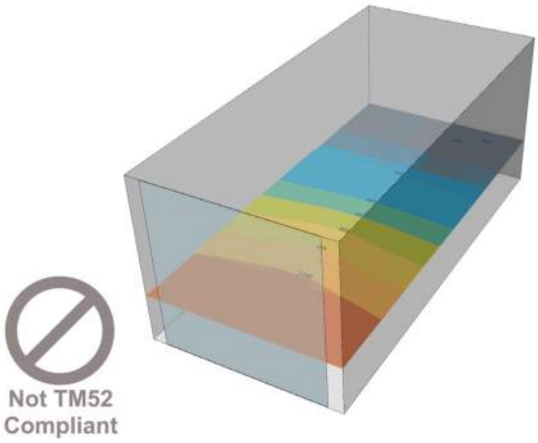
What is Daylight Autonomy?

Daylight autonomy was one of the first Climate-Based Daylight Modelling (CBDM) approaches, and considers the variation of daylighting performance of a space across a period of time. This is achieved by simulating the spatial variation of illuminance throughout the space, and calculating the proportion of time that a particular illuminance threshold is reached.

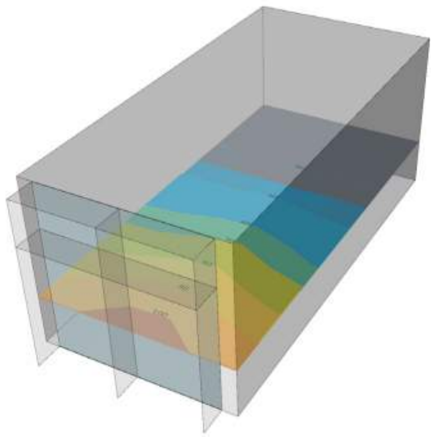
In the case of this assessment, a threshold illuminance of 100 lux has been used, as this is considered to be a useful level of daylight within a living room space.

The contour maps shown in the images on this page illustrate the percentage of time that the 100 lux threshold is exceeded across a desk-height plane within the living room.

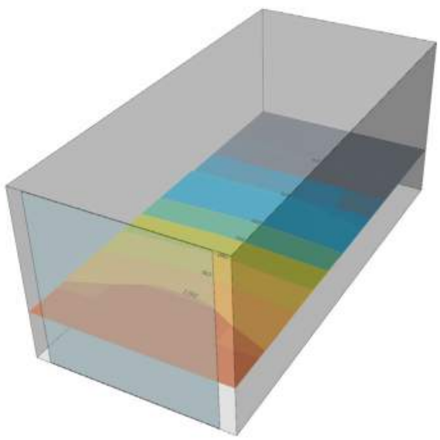
Baseline



Fixed External Shading



Merck LCW



Daylight autonomy results for a typical December period

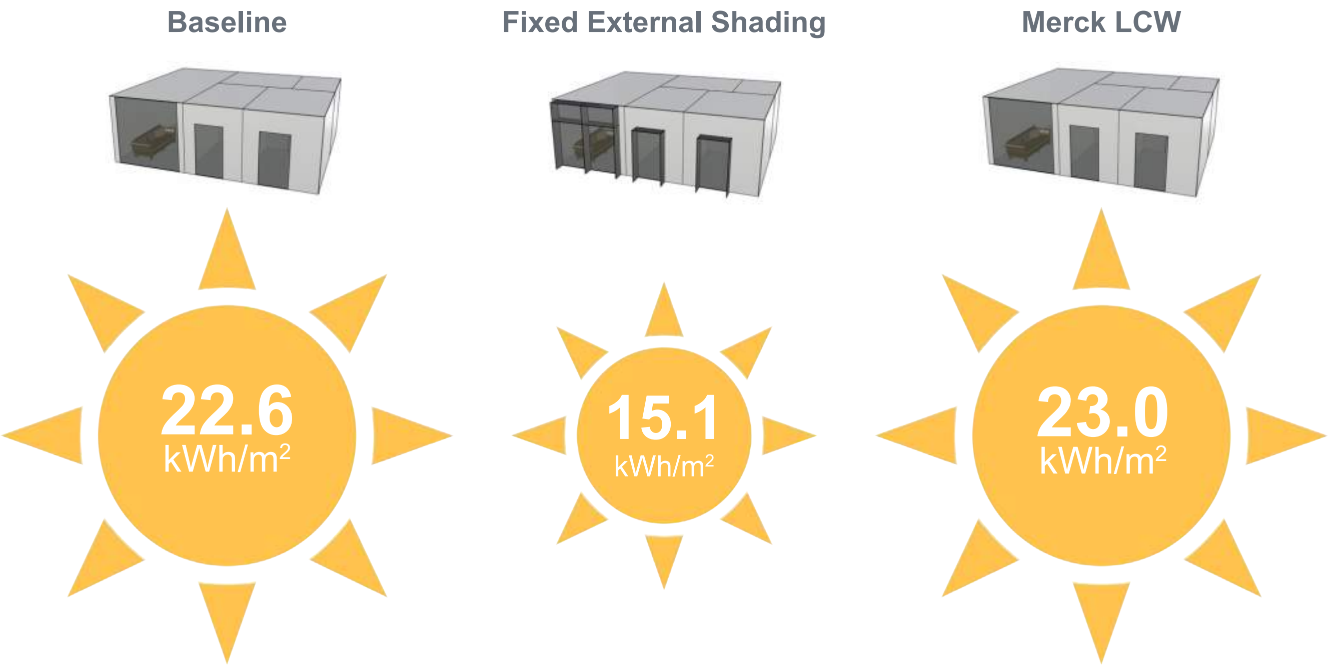
Passive Solar Gains

Access to passive solar gains is another performance characteristic that is often overlooked when considering summer overheating risk. During winter periods, solar gains can be beneficial in terms of maintaining thermal comfort while reducing heating demand within the dwelling.

Facades solutions, such as fixed external shading, that meet overheating requirements alone can result in designs that are unable to adapt between seasons. As per the daylight study, the Merck LCW provides an opportunity to tune the glazing in response to either a need for solar control, or a desire for increased passive solar gain.

To explore this performance aspect, the total transmitted solar energy between the months of October and April has been calculated for each facade alternative. The Merck LCW tinting control has been modelled as per the daylighting study.

The results presented below indicate that the fixed external shading results in far less winter solar gain than both the baseline design and the Merck LCW option. In comparison to the fixed shading solution, the Merck LCW could result in 52% more passive solar gain. If directly offsetting heating demand within the dwelling, this could be equivalent to a €29 reduction in winter heating costs.



Passive solar gain between October and April for each facade alternative

52 *more solar gain*

29 *heating bill savings*

Merck LCW compared to the Fixed External Shading solution

Basis of Assessment

Space assessed: Entire two bed apartment (65m2)
Orientation: South facing
Glazing ratio: 85% living rooms / 52% bedrooms
Apartment area: 65m2
Analysis Period: October-April
Weather file: London TRY

Fast Response Switching

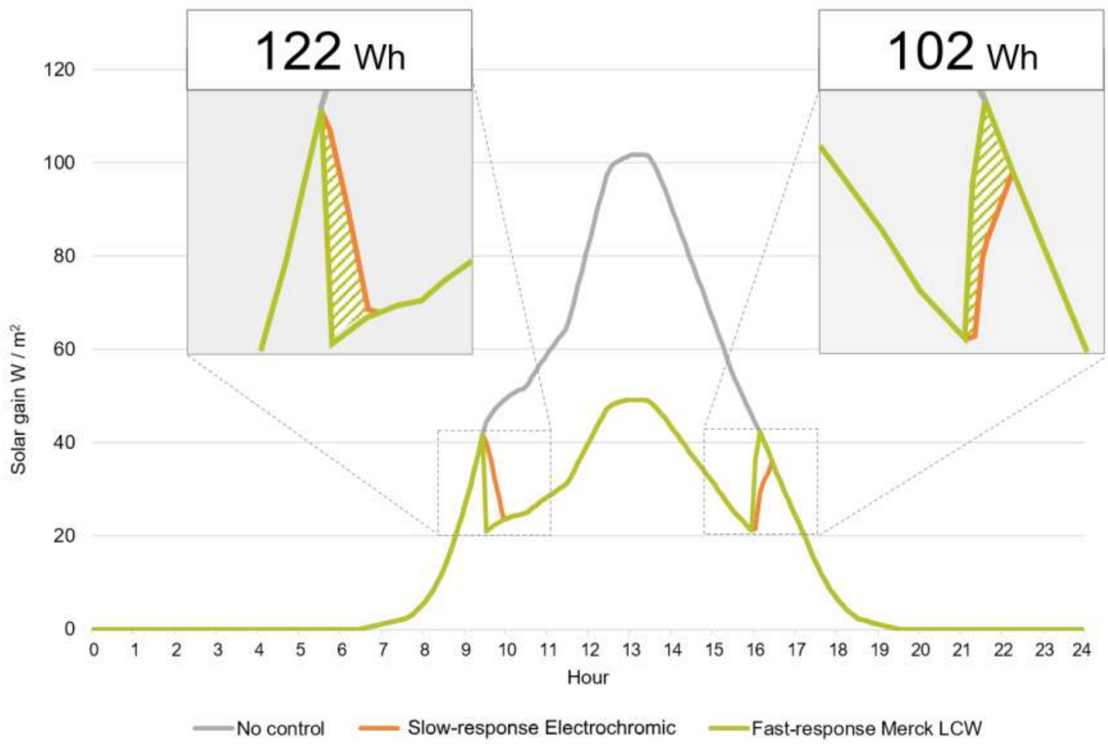
What you want, when you want it

One of the major benefits of the Merck LCW when compared with other dynamic glazing solutions is the speed of transition between bright and tinted states. It is possible for the Merck LCW to switch between opposite ends of its range in less than a second, which significant outperforms alternative products that may take up to 30 minutes.

This section of the report contains an exploration of the fast response switching in an effort to quantify the impact that the switching speed has on building performance. To do this, the case study living space has been simulated with the Merck LCW as well as an alternative electrochromic glazing that takes 30 minutes to transition when triggered. For the purposes of this study, the tinting is triggered when the incident solar radiation exceeds a threshold of 400 W/m^2.

The chart below shows the impact of switching speed both in the morning and afternoon. In the morning, when tinting has been triggered in an effort to reduce solar gains, the slow-response product allows an additional 122 Wh of solar energy to penetrate the living space. In the afternoon, the tinting is switched off to increase solar gains, perhaps in an effort to reduce heating demand. In this case, the slow response results in 102 Wh of beneficial solar energy being lost.

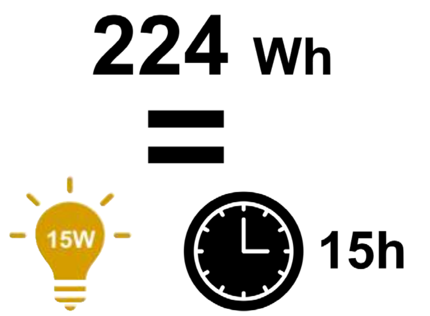
For this single day, in which the dynamic glazing has been used to control both welcome and unwanted solar energy, the net benefit of the Merck LCW is 224 Wh. This quantity of energy is equivalent to the electrical energy required to power a 15 watt lightbulb for 15 hours. Fast-response switching is expected to be even more beneficial on intermittently cloudy days, where changes of tinting state are frequently required.



A representative day in which two changes in tinting state show the benefit of fast-response switching

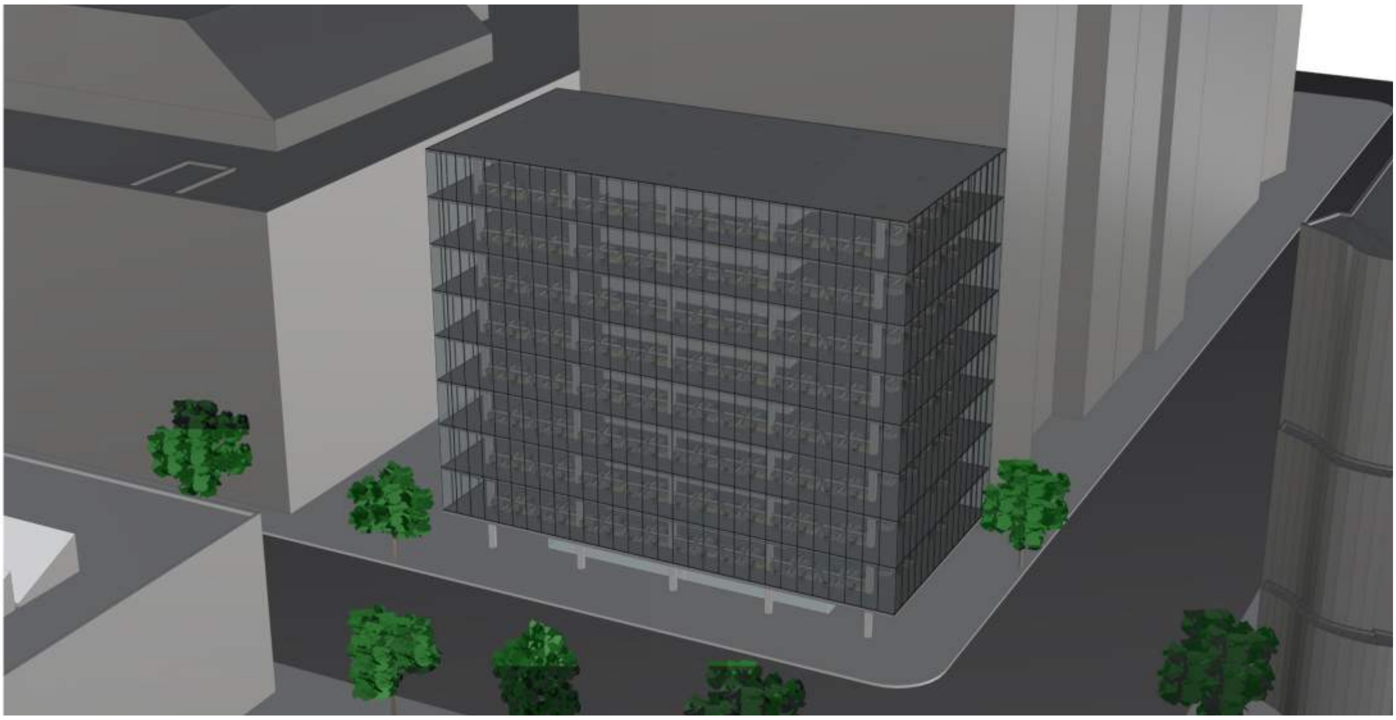
Basis of Assessment

Space assessed: Living/kitchen (25m2)
Orientation: South facing
Simulation date 19th September (peak solar gain)
Electrochromic changing status in half an hour
Switching threshold 400 W/m2 irradiation
Weather file: Heathrow DSY1



The net energy benefit for one representative day equates to 15 hours of light bulb power

Appendix A: Office 3D Model



BUILDING	Number of floors	8 (1st floor height at 3.7 m above ground)
	Width (South Elevation)	41.3 m
	Depth (East Elevetion)	20.7 m
	Height	35.7 m
FLOOR	Floor-to-Floor Height	4 m
	Floor-to-Ceiling Height	3.4 m (1m deep bulkhead at facade to maximise glazing)
GLASS PANEL	Width	1.36 m
	Height	3.95 m

Appendix B: Renders

Time: 10am
Date: 8th September
Sky condition: Clear, sunny sky
Shading: None
View: South
Facade: Merck LCW - Bright State

Time: 10am
Date: 8th September
Sky condition: Clear, sunny sky
Shading: None
View: East
Facade: Merck LCW - Bright State

Time: 10am
Date: 8th September
Sky condition: Clear, sunny sky
Shading: None
View: South
Facade: High Performance Double Glazing

Time: 10am
Date: 8th September
Sky condition: Clear, sunny sky
Shading: None
View: East
Facade: High Performance Double Glazing

Time: 10am
Date: 8th September
Sky condition: Clear, sunny sky
Shading: None
View: South
Facade: Closed Cavity Facade

Time: 10am
Date: 8th September
Sky condition: Clear, sunny sky
Shading: None
View: East
Facade: Closed Cavity Facade

Time: N/A
Date: N/A
Sky condition: CIE Overcast sky
Shading: None
View: South
Facade: Merck LCW - Bright State

Time: N/A
Date: N/A
Sky condition: CIE Overcast sky
Shading: None
View: East
Facade: Merck LCW - Bright State

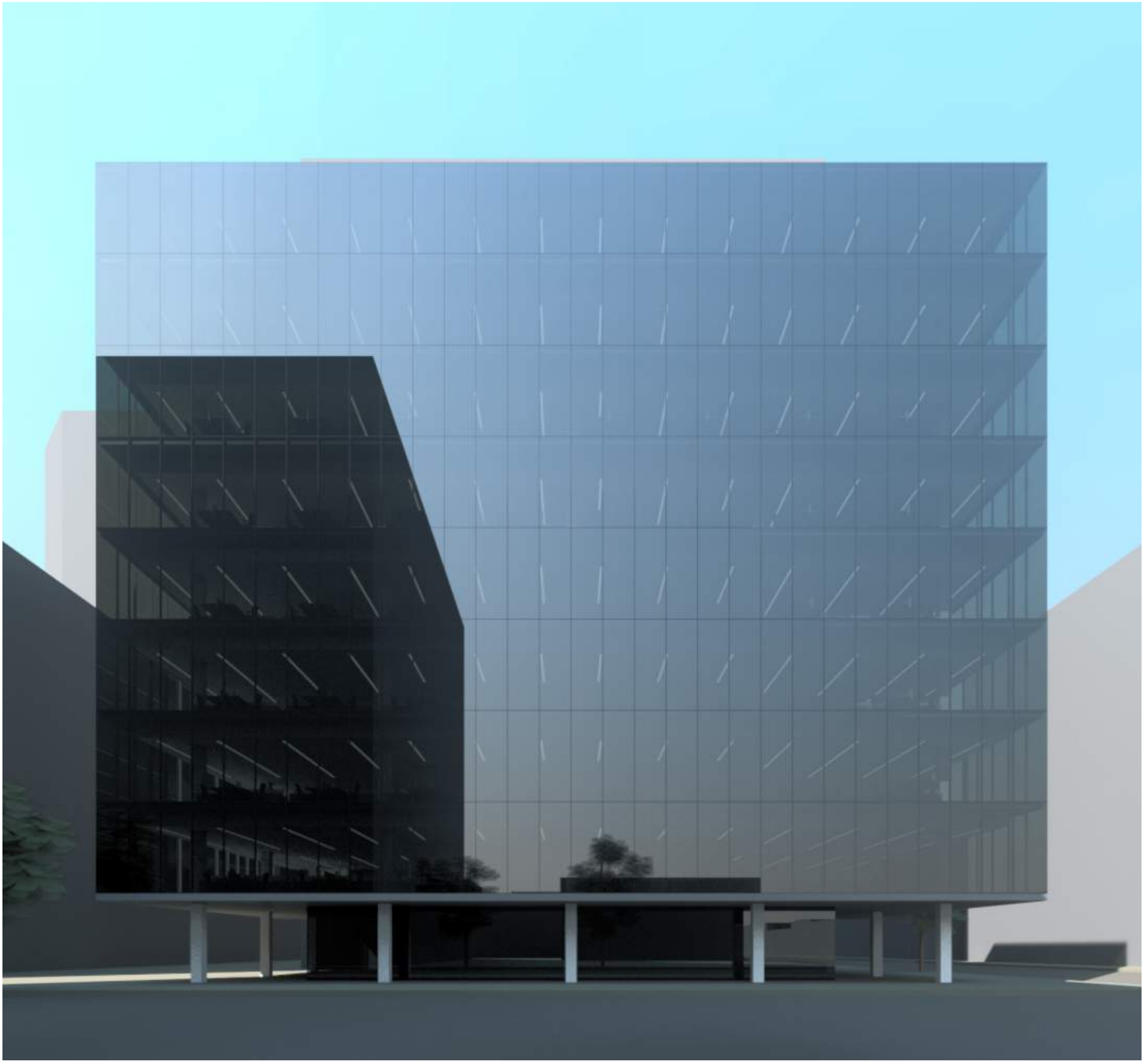
Time: N/A
Date: N/A
Sky condition: CIE Overcast sky
Shading: None
View: South
Facade: High Performance Double Glazing

Time: N/A
Date: N/A
Sky condition: CIE Overcast sky
Shading: None
View: East
Facade: High Performance Double Glazing

Time: N/A
Date: N/A
Sky condition: CIE Overcast sky
Shading: None
View: South
Facade: Closed Cavity Facade

Time: N/A
Date: N/A
Sky condition: CIE Overcast sky
Shading: None
View: East
Facade: Closed Cavity Facade

Time: 10am
Date: 8th September
Sky condition: Clear, sunny sky
Shading: Whole facade tinted
View: South
Facade: Merck LCW - Tinted State



Time: 10am
Date: 8th September
Sky condition: Clear, sunny sky
Shading: Select tinting on exposed panels
View: South
Facade: Merck LCW - Bright and Tinted States

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