Glazing and Winter Comfort Tool

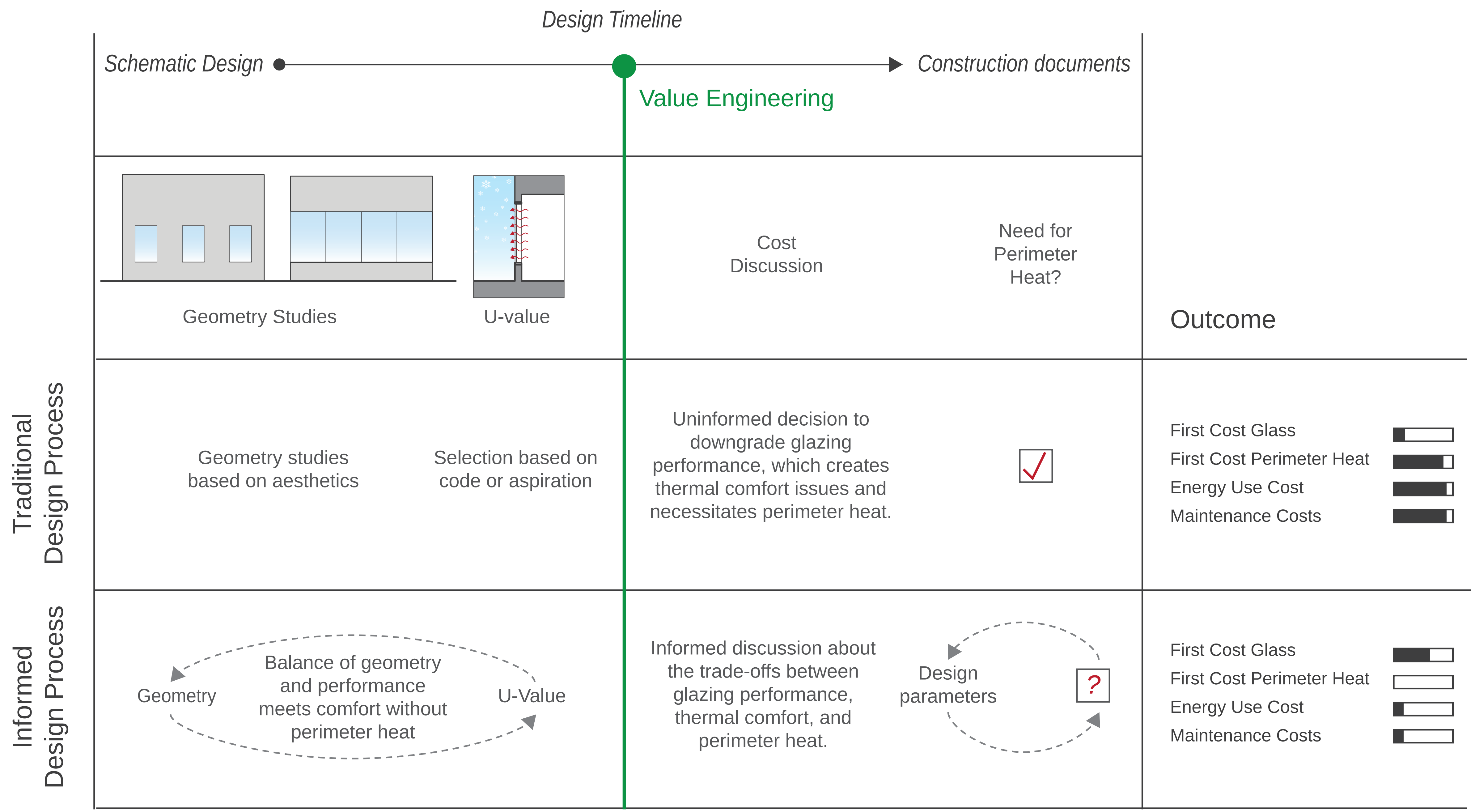
AIA / TAP Innovation Award 2016

GLAZING AND WINTER COMFORT TOOL

PROBLEM
In the developed world, mechanical systems, such as perimeter heating, compensate for shortcomings in envelope performance to provide a thermally comfortable environment. However, with an increased interest in maximizing energy efficiency and façade transparency as well as providing healthy spaces for occupants, this model is due for reconsideration. Currently, it is challenging for architects to quantify, early in the design process, how glazing performance and geometry affect the need for supplemental perimeter heating. This active system is often incorporated late in the design process, often leading to both aesthetic changes as well as increased operational and maintenance costs, which is a lose / lose situation for both the architect and the owner.

CHALLENGE
What if the design team could understand, as early as schematics, which façade properties negatively or positively impact occupant comfort? What if there was a way to avoid the use of perimeter heat by selecting the right glazing geometry and performance?

OUTCOME
To achieve this goal, our team of building scientists and designers developed the **Glazing and Winter Comfort Tool**. It is a web tool based on existing scientific research that aims to improve the design community's understanding of the triggers of thermal discomfort in the wintertime. It was developed to be simple and intuitive so that architects and engineers can design glazed façades that provide the desired levels of transparency, comfort and energy performance at an ideal cost.



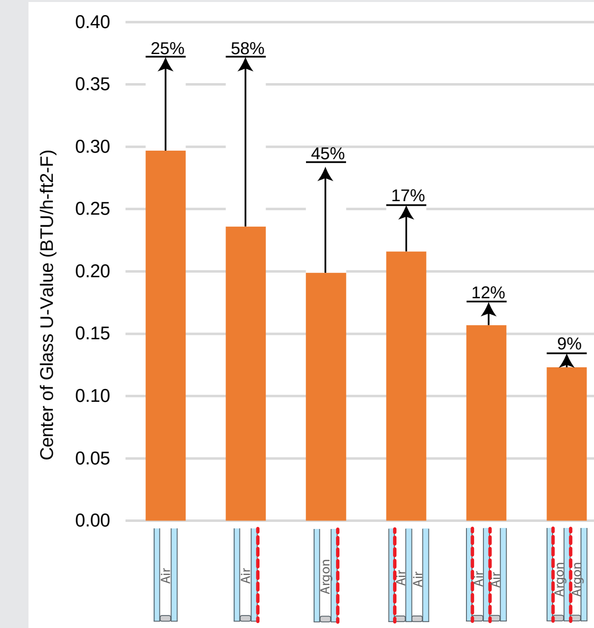
AVOIDING PERIMETER HEAT

Being thermally comfortable is one of the aspects that occupants value most in a building, research has found. And yet, mitigating localized thermal comfort is rarely a priority during the design process — it is always assumed that a mechanical system will guarantee it.

When it comes to glazing in the winter time, perimeter heat is the most common solution provided to avoid any potential discomfort. It is often used because it is thought to be cheaper than upgrading the thermal performance of the glazing. However, in the northeast US, this system has a first cost ranging between $250-$400 / linear foot, which we have found usually outweighs the cost of an upgraded envelope (between 5%–20% price increase to upgrade from double pane glass to triple pane).

The need for supplemental heat can be avoided by reducing the U-value of the window or by changing its geometry. Previously, the only way to understand to forgoing perimeter heat in favor of an improved window was to run a costly and time-intensive Computational Fluid Dynamics simulation.

The **Glazing and Winter Thermal Comfort Tool** was conceived to facilitate this decision-making process quickly and inexpensively early in the design.



PERIMETER HEAT AND ENERGY CONSUMPTION

The use of perimeter heating causes an instant degradation in the specified thermal performance of a window unit, by effectively heating the inner pane of glass. This leads to an increase of up to 58% in heat loss through the glass, significantly increasing the overall energy consumption of a building.

GLAZING AND THERMAL COMFORT

Glazing affects thermal comfort in two different ways: occupants can feel cold due to radiant losses to the glass or due to cold downdraft.

The **Glazing and Winter Comfort Tool** calculates the expected level of radiant and downdraft discomfort (expressed as Percent of People Dissatisfied, or PPD) for a given glazing geometry, performance, interior and exterior conditions.

RADIANT DISCOMFORT

When an occupant sits close to a cold window, radiant discomfort may be experienced. Radiant thermal discomfort is influenced by window height and width, the location of the occupant from the window, and the temperature if the inner windowpane. It is the U-value of the window and the temperature of the outside air that determine how cold a glass pane gets.

It is more likely that occupants will experience discomfort on a cold winter day due to radiant discomfort when standing close to a large (tall or wide) window, or to a window with poor thermal performance.

The emissivity of the interior glass surface also affects radiant heat loss. With the use of a room side low-e coating, radiant discomfort is greatly reduced.

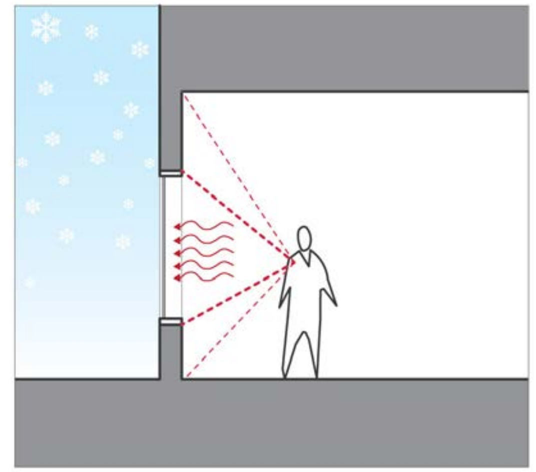
DOWNDRAFT DISCOMFORT

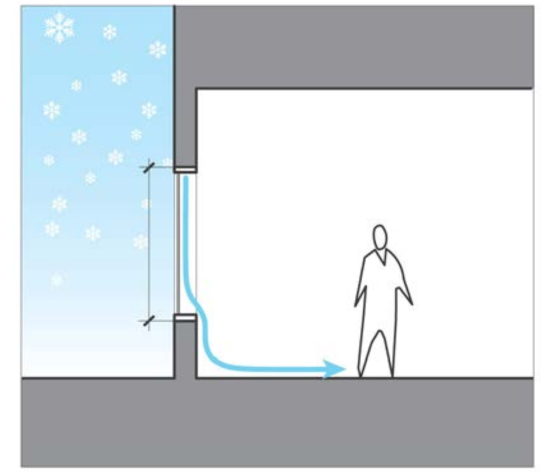
Cold convective currents occur when warm interior air hits the cold interior glass surface and falls due to negative buoyancy. This downdraft can cause occupant's hands or feet to feel cold, particularly when bare. Downdraft discomfort is primarily influenced by the height of the window and the temperature of the inner window pane.

It is more likely that occupants will feel an uncomfortable downdraft on a cold winter day when standing close to a tall window, or to a window with poor thermal performance.

The emissivity of the interior glass surface also affects downdraft discomfort. With the use of a room side low-e coating, the downdraft will be stronger and colder, increasing the potential for downdraft discomfort.

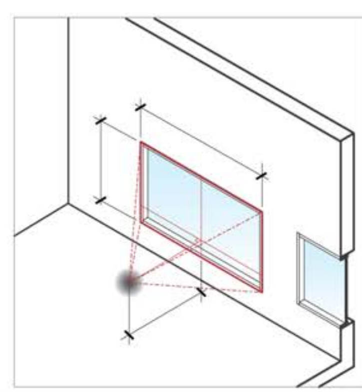
Type of Discomfort: **Radiant Discomfort** | **Downdraft Discomfort**

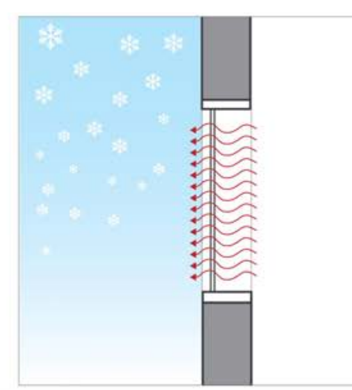


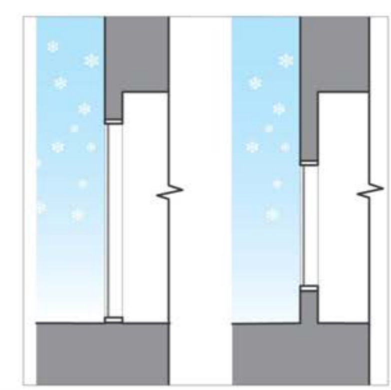


What to Measure: *Mean Radiant Temperature* | *Downdraft Speed & Temperature*

Function of: *View Factor* | *Interior Temperature of Glass* | *Window Height*





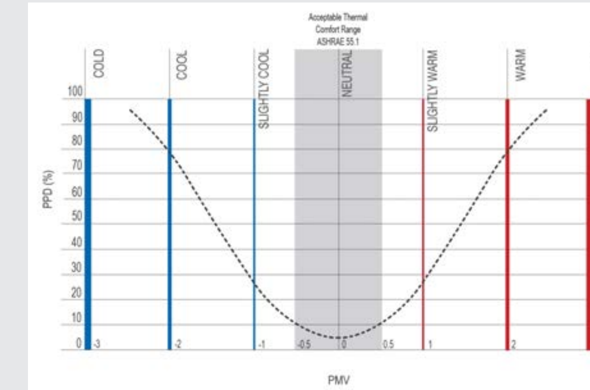


Variables:

- Window Height
- Window Width
- Occupant Distance to Window

- U-value of Glass
- Exterior Design Temperature
- Room-side low-e coating

- Window Height
- Mullion Projection



PERCENTAGE OF PEOPLE DISSATISFIED

Thermal comfort prediction models identify those situations when occupants may feel uncomfortably cold, and provide insight to the potential solutions to make a space more comfortable. Using these models to correlate comfort and glazing requires being able to quantify certain physical variables, such as temperature of the inner glass surface and the downdraft temperature and velocity at the occupant location.

P.O. Fanger proposed a metric to quantify comfort levels, and it is widely used to date (Fanger, 1973). It consists of a thermal sensation scale, known as Predicted Mean Vote (PMV), based on a 7-point scale from -3.0 (too cold) to +3.0 (too hot). This scale correlates a Predicted Percentage of Dissatisfied (PPD) value, which represents the percentage of occupants that may feel thermally dissatisfied under a given set of conditions. ASHRAE Standard 55 considers that an occupant will be thermally comfortable when the PPD in the space is of 10% or lower, while LEED allows PPD values of up to 20% in a space.

The **Glazing and Winter Comfort Tool** quantifies radiant discomfort by estimating the mean radiant temperature for the occupant's location with respect to the window, and then calculating the percent of occupant dissatisfaction (PPD) using Fanger's thermal comfort model. The tool quantifies downdraft discomfort by estimating the velocity and temperature of the downdraft at as a function of the occupant's perpendicular distance from the window, and then calculating the percent of occupant dissatisfaction (PPD) a model also developed by Fanger to quantify downdraft risk (P.O. Fanger, 1988).

Fanger, P.O., "Assessment of Man's Thermal Comfort in Practice." Occupational and Environmental Medicine, 30 (1973): 313-324.

Fanger, P.O., Melikov, A.K., Hanzawa, H., Ring, J. "Air Turbulence and Sensation of Draught." Energy and Buildings 12, no. 1 (1988): 21–39.

TOOL DEVELOPMENT

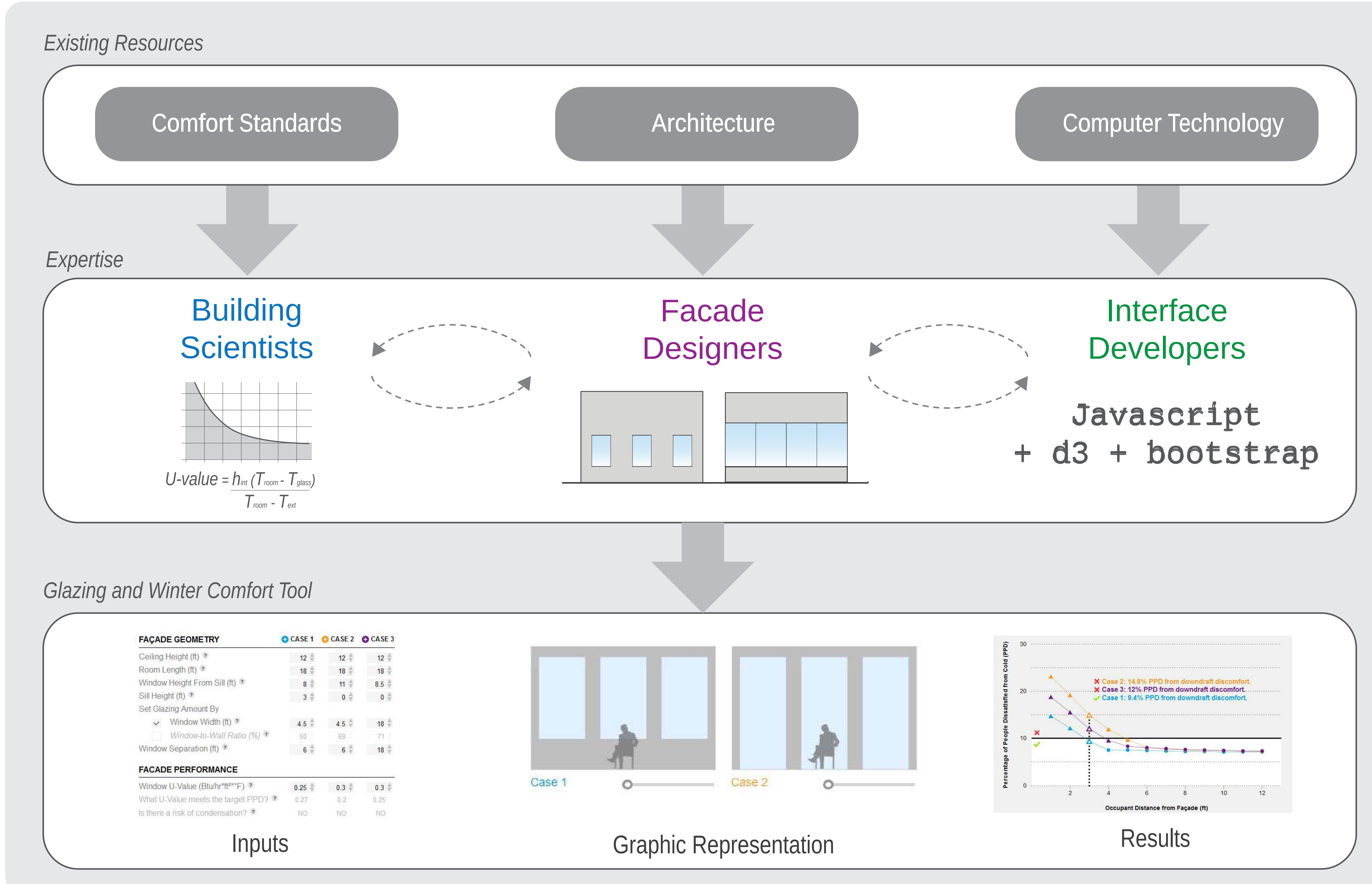
The tool was developed by an interdisciplinary team of building scientists, designers and software developers. The result is a powerful yet simple tool that is easily understood and used by the design community, leading to robust façade designs with lower building energy demands.

The collaboration of building scientists and designers resulted in a balanced process that ensured a rigorous research yet maintained real world applicability. The team reviewed and evaluated the relevance of current research to relate existing thermal comfort models to parameters known in early design, such as façade geometry, building material properties, outdoor climate, and other criteria.

While this collaboration provided the team with tools that could analyze one specific design at a time, the introduction of software development ensured that the research reached a larger audience through the online interface. A notable fraction of the tools' source code is taken from existing open software projects, including the Center for the Built Environment's comfort tool, and web libraries d3 and bootstrap. As a result, the tool is, by its nature, fully open source and freely in the domain of public knowledge.

Two rounds of testing helped shape the final tool interface. Testers with different background and levels of expertise helped find the right balance between ease of use and computational power.

As the product of such extensive collaboration, the **Glazing and Winter Comfort Tool** is accessible to a wide variety of professionals, ranging from designers to engineers to clients.



TOOL INTERFACE

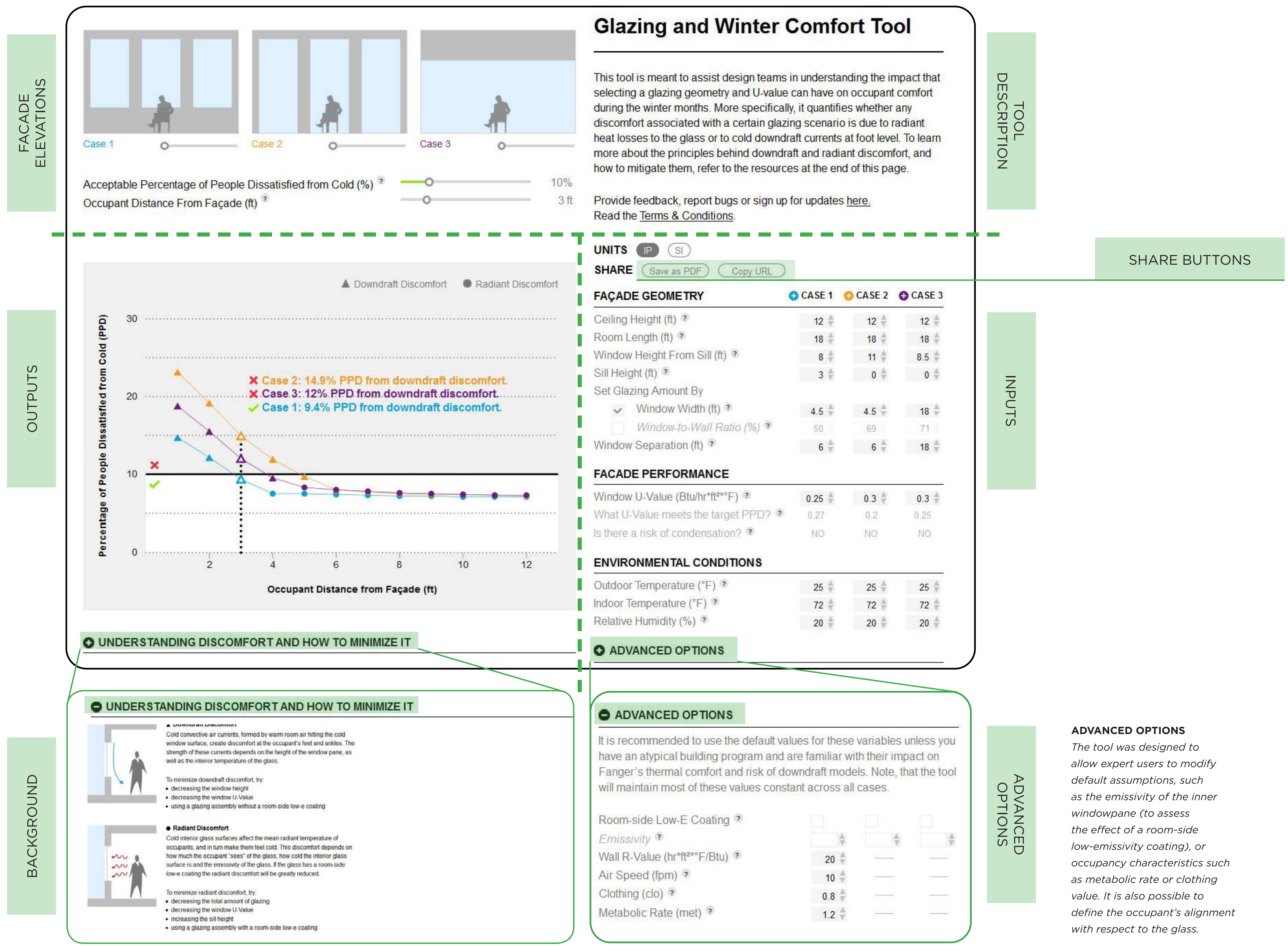
The interface was designed to be dynamic, simple and informative. The right side of the page displays all the inputs that have an impact on thermal comfort. These include window and room dimensions, window performance properties, indoor and outdoor conditions, and occupancy characteristics. Up to three scenarios can be compared, for which façade elevations (top left) are dynamically generated as values are modified.

The thermal comfort results are reported in graphical form on the left side of the page, as the variation of Percentage of People Dissatisfied (PPD) with occupant distance from the facade. A horizontal line indicates the maximum PPD threshold allowed by the user. Two different markers inform the user whether thermal discomfort is dominated by downdraft or low radiant temperatures.

While the user must enter a window U-value for each case, an automatic calculation provides the threshold value beyond which an occupant may feel uncomfortable.

The tool also indicates whether there is potential for condensation along the window, when the temperature of the inner pane of glass reaches the dew point of the indoor air.

All of the scenarios can be printed as pdf or shared though a unique link with the owner and consultants for a joint evaluation of the design.



ADVANCED OPTIONS

The tool was designed to allow expert users to modify default assumptions, such as the emissivity of the inner windowpane (to assess the effect of a room-side low-emissivity coating), or occupancy characteristics such as metabolic rate or clothing value. It is also possible to define the occupant's alignment with respect to the glass.

CASE STUDY:
IMPACT OF GLAZING GEOMETRY ON COMFORT

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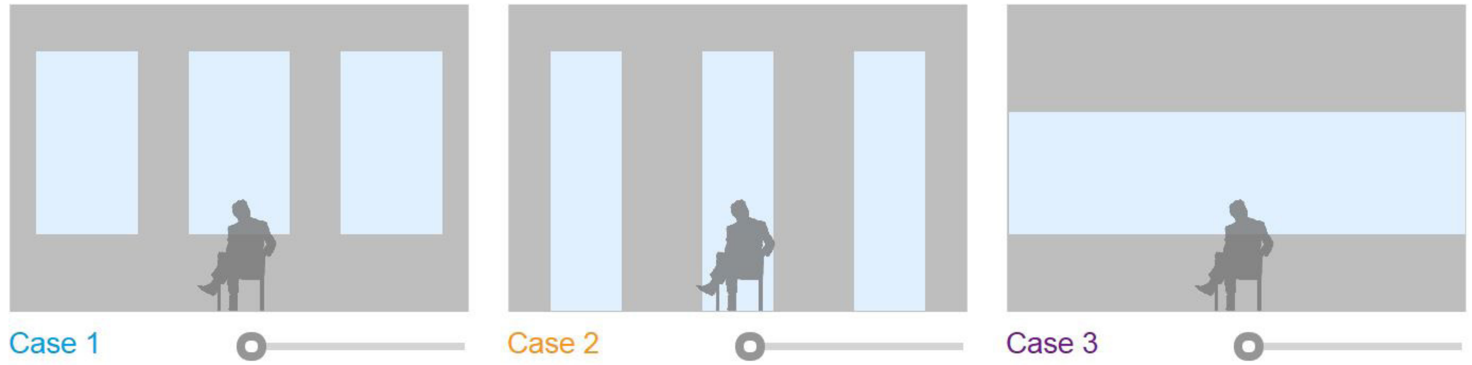
The design of a high performance building often involves setting a target glazing ratio. However, for the same glazing ratio, the possible glazing scenarios can lead to very different thermal comfort conditions.

This case study considers a project under design with a goal of 40% window-to-wall ratio, where the team wanted to avoid the use of perimeter heat in the offices. With the **Glazing and Winter Comfort Tool** we evaluated the impact of three very different glazing geometries on occupant thermal comfort. This was done assuming a design outdoor temperature of 15 F.

Short punched windows with a 3' sill (Case 1) are compared to tall windows without a sill (Case 2) and to ribbon windows with the same 3' sill (Case 3). For an occupant sitting 3' from the window, only Case 3 provides comfort levels below the goal (10% PPD).

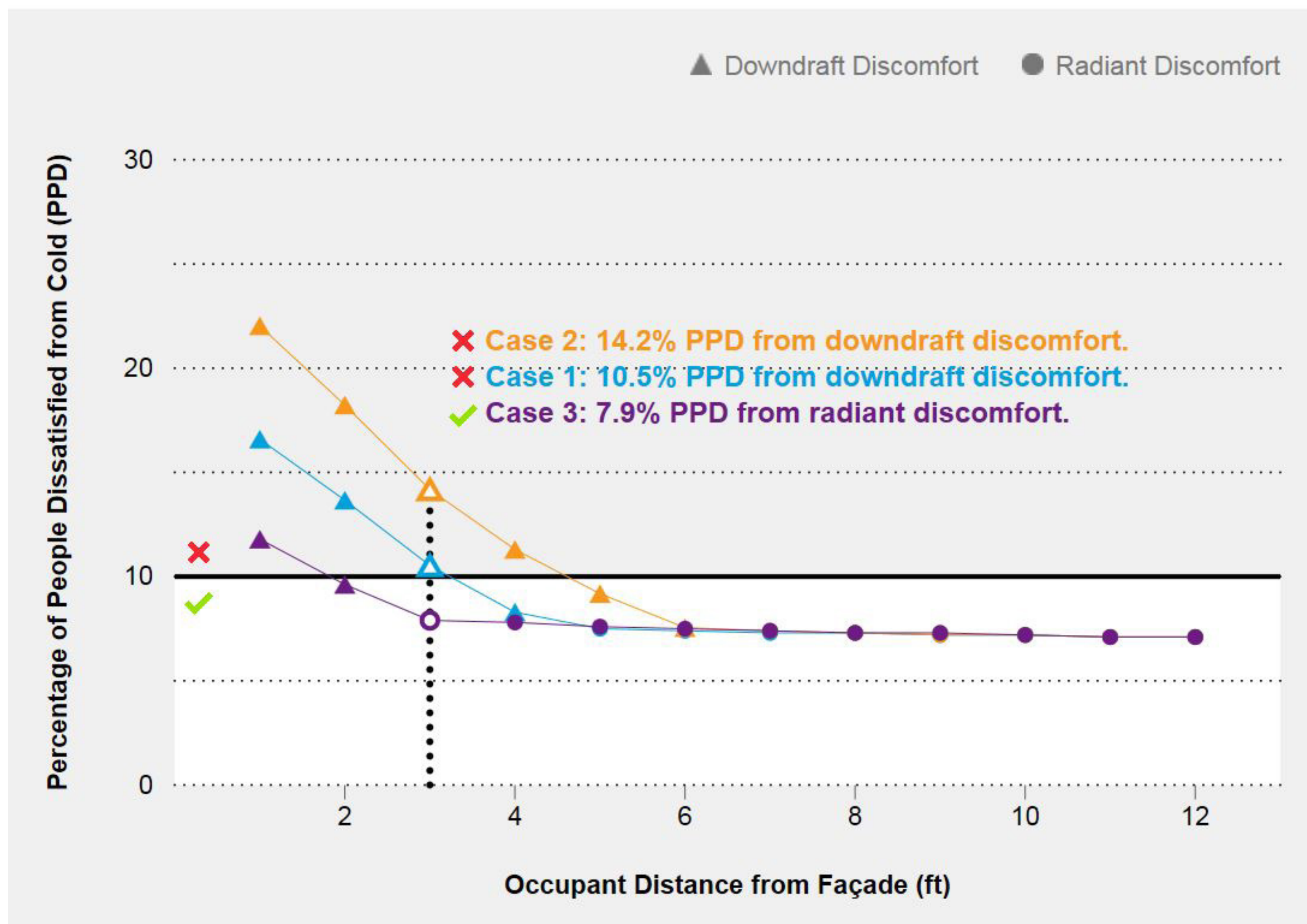
While both Cases 1 and 2 lead to occupant discomfort due to downdraft (▲), having a sill (Case 1) significantly reduces need for perimeter heat to the point that the conditions are close to the comfort threshold.

Ultimately the glazing configuration in Case 1 was selected as a compromise between thermal comfort and other design parameters such as daylighting and aesthetics.



Acceptable Percentage of People Dissatisfied from Cold (%) ? 10%

Occupant Distance From Façade (ft) ? 3 ft



FAÇADE GEOMETRY	CASE 1	CASE 2	CASE 3
Ceiling Height (ft)	12	12	12
Room Length (ft)	18	18	18
Window Height From Sill (ft)	7.2	10.2	4.8
Sill Height (ft)	3	0	3
Set Glazing Amount By			
Window Width (ft)	4	2.8	6
Window-to-Wall Ratio (%)	40	40	40
Window Separation (ft)	6	6	6
FACADE PERFORMANCE			
Window U-Value (Btu/hr*ft²*°F)	0.25	0.25	0.25
What U-Value meets the target PPD?	0.24	0.18	0.33
Is there a risk of condensation?	NO	NO	NO
ENVIRONMENTAL CONDITIONS			
Outdoor Temperature (°F)	15	15	15
Indoor Temperature (°F)	72	72	72
Relative Humidity (%)	20	20	20

CASE STUDY
IMPACT OF WINDOW U-VALUE ON COMFORT

CASE STUDY
IMPACT OF WINDOW U-VALUE ON COMFORT

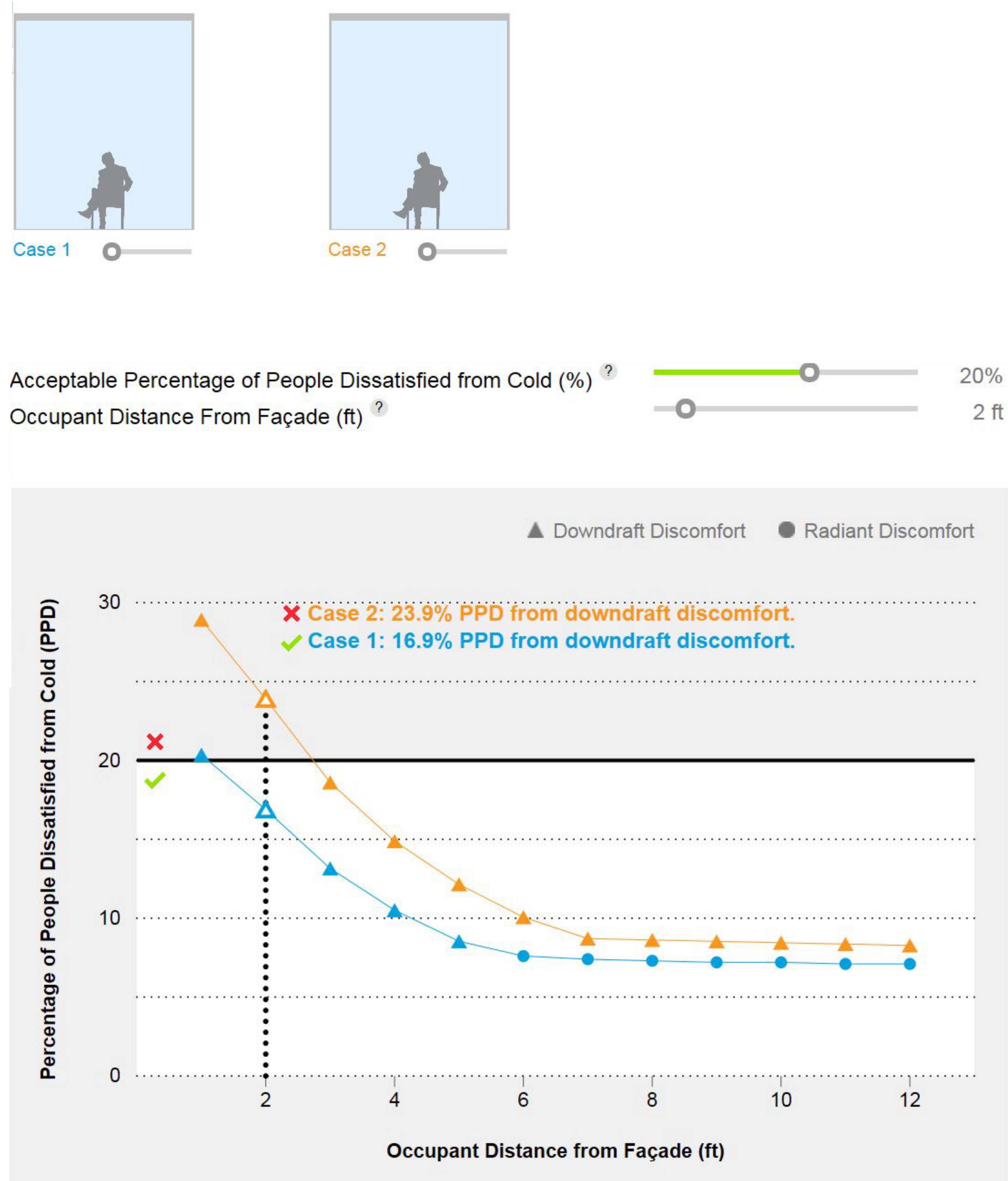
When a certain glazing geometry has already been chosen, the design team has the option of selecting the right U-value to ensure that occupant comfort is maintained.

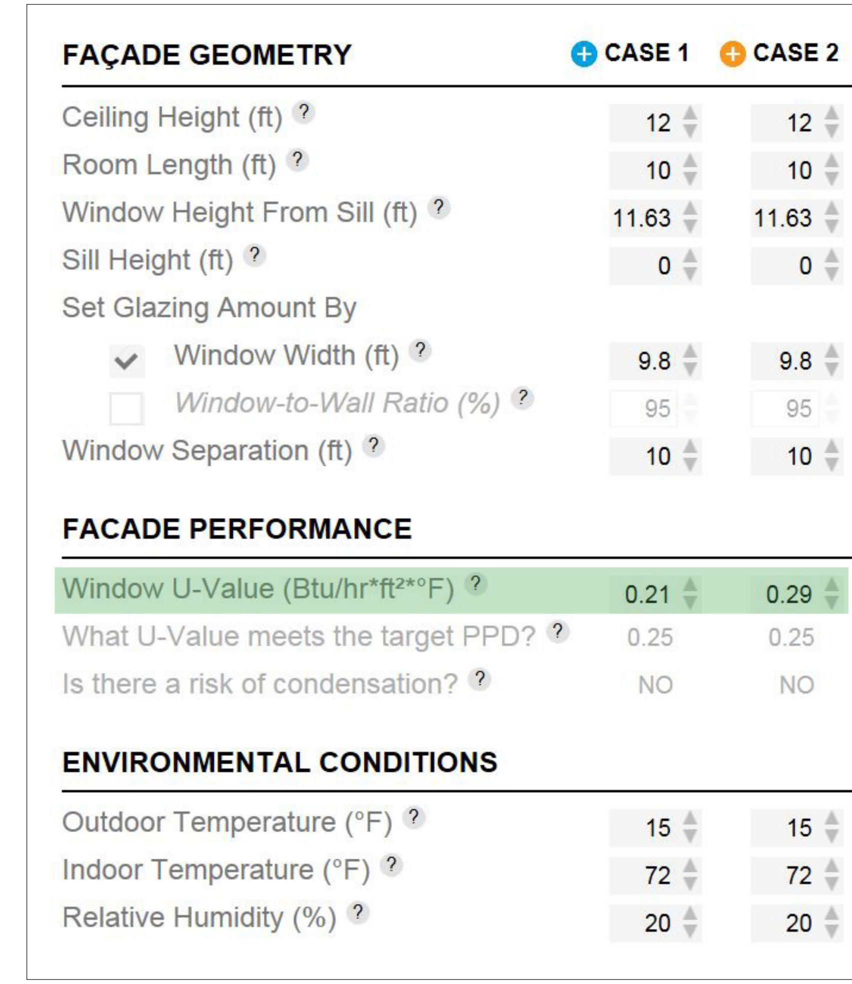
This case study considers a project, designed before the tool was developed, featuring an office building, with a 90% window-to-wall ratio that had originally specified triple pane windows for its façade (U-value of 0.21 Btu / h / sf F, Case 1). During the value engineering process, the team considered downgrading to a double pane unit (U-value of 0.29 Btu / h / sf F, Case 2).

To make a decision, consultants were hired to assess the need for perimeter heating under either condition and quantify the cost of this measure. A CFD analysis showed that only the double pane option would require perimeter heat, and that the cost for this active system was $450 / linear foot, while the added cost of using triple pane was $50 / linear foot.* This decision making process took several months and cost $12,500 in additional consulting fees, a luxury that not many projects can afford.

Had the team had access to the **Glazing and Winter Comfort Tool**, they could have compared these two scenarios in a manner of seconds. As results indicate, a double pane assembly (Case 2) will make occupants sitting 2 feet from the façade uncomfortable, while a triple pane window (Case 1) will not.

**In this case the premium to use triple pane windows was lower than is typically seen in the US, because the glass was being purchased in Europe, where triple pane glass is considerably cheaper.*





OVERALL IMPACT

In a world where most of our time is spent indoors and glazing is increasingly becoming a prominent design feature, it is critical that the practice views occupant thermal comfort with the same significance as transparency, daylight and energy use.

The **Glazing and Winter Comfort Tool** demonstrates its usefulness through the confidence it provides in selecting a glazing unit that will meet a specified comfort standard. It empowers the architect and engineer to make smart decisions early in the design process, and it enables the owner to know what to expect once their building is built and fully occupied.

> "The strength of glazing analysis tool lies in its ease of use; a valuable resource accessible to students or experienced professional alike. It synthesizes a lot of complicated factors under a user-friendly hood, and then helps you understand the results."

TESTER 1 (DESIGNER)

> "*The tool is a very valuable resource, particularly in the early stages of design iteration. The ability to rapidly establish boundaries is crucial at conceptual stages when the opportunity to integrate envelope and mechanical strategies is greatest. As a project develops, the tool also allows us to test our ideas with the proprietary products and systems that we work into our specifications. Even further in the process, it is useful to vet value engineering proposals and substitutions, allowing us to make sound recommendations to our clients.*"

TESTER 2 (DESIGNER)

> "This is a quick and user-friendly glazing comfort tool. It helps me understand the trade-offs with fenestration quantity, configuration, glass lay-up (and ultimately, cost of the fenestration) with comfort for the occupants of the building. The interface is well-thought-out and I appreciate how it all is laid out on a single page. The graphic output is quickly understandable and conveys the important results to decision makers who may be unfamiliar with much of the conceptual underpinning but recognize that comfort is key to occupant satisfaction. Having this tool available imposes quantitative rigor on comfort, which combined with quantitative daylighting analysis leads to a rational basis for fenestration design."

TESTER 3 (ENGINEER)