# COMPLEX FENESTRATION SYSTEM FOR ENERGY EFFICIENCY

Scientists at Eurac Research are using simulation to improve the energy efficiency of buildings and enhance visual and thermal comfort for people.

by **JENNIFER HAND**

Energy efficiency can save money for the operators, improve comfort for occupants, and reduce environmental impact, so it is a key consideration for any building and fenestration, the term applied to any opening in a building envelope. Components such as the frames, glass and shading attachments of windows, and doors and skylights make a significant contribution to energy efficiency. By controlling direct sunlight and heat gain, they minimize glare; distribute daylight comfortably; and reduce demand for heating, cooling, and artificial light.

The interplay of fenestration components can, however, have an unexpected influence, and this is not fully covered by ISO 15099:2003, which gives calculation procedures for determining the thermal and optical transmission properties of window and door systems. The standard does not, for instance, account for characteristics such as the complex geometry of shading systems or particular types of applied coatings, such as highly reflective ones.

"The main problem is that the standard method of calculation treats any shading system (for example, a blind that sits between two glass panes) as a parallel layer and not a 3D structure," explains Ingrid Demanega, junior researcher at Eurac Research in Bolzano, Northern Italy. "The slats of a blind are regarded as simple 1D openings through which air flows, even if the slats are curved as they are in a Venetian blind, and convective heat transfer is measured only in terms of pressure drop. The slats are also assumed to be ideal diffuse surfaces. This approach affects the accuracy of both the optical and thermal modeling" (Figure 1).

Led by Demanega, a team at Eurac Research, in collaboration with the research groups in building physics at the Free University of Bozen-Bolzano, set out to identify limits in the current approach to modeling and define a new approach by comparing simulation results with the physical testing of a commercial fenestration system installed at the Living Labs of the Free University of Bozen-Bolzano (Figure 2).

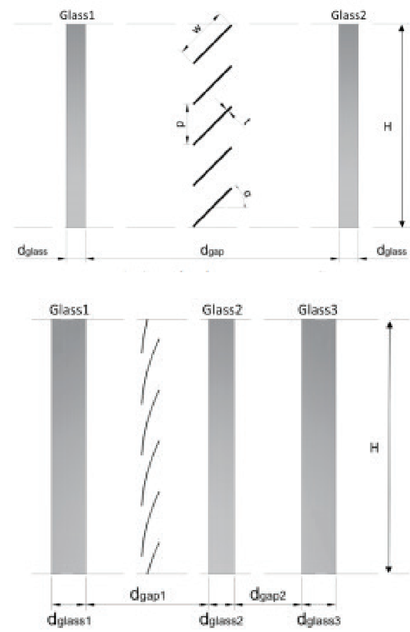


**FIGURE 1.** Standard (top) and complex (bottom) fenestration system.

## ⇨ CREATING A NEW OPTICAL MODEL

The on-site fenestration installation that the team set out to simulate is a triple-glazed system incorporating two sealed cavities with an integrated blind in the external cavity. This blind has curved slats that have a highly reflective coating designed to block solar radiation and provide comfort for people inside the

**FIGURE 2.** Setup at the Living Labs of the Free University of Bozen-Bolzano, including two heat flux plates, an in situ device designed by the University of Innsbruck to measure the overall heat flux, and several thermocouples for the surface and air temperature measurement.

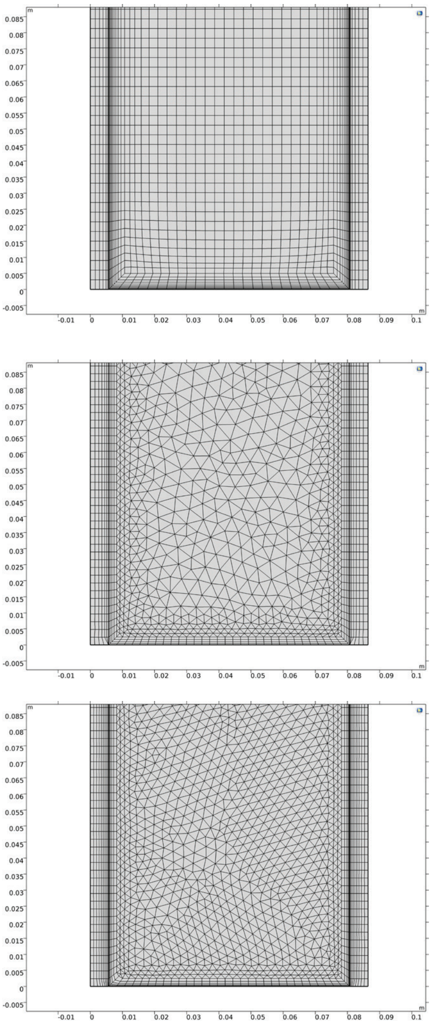

**FIGURE 3.** Mesh typologies for standard fenestration system without blinds: normal structured (top), coarser unstructured (middle), and normal unstructured (bottom).

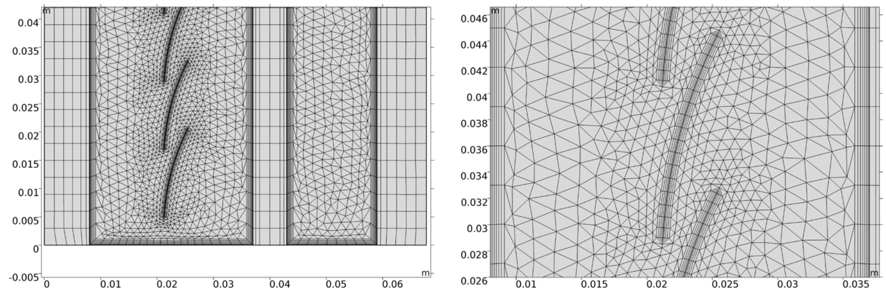

**FIGURE 4.** From left to right – glass pane, cavity containing blind, second glass pane, second cavity containing argon and air only, and third glass pane. In this case, the two cavities are sealed, not ventilated. Close-up image of the mesh around the blind and near the edges of the cavity.

building. The first step was to employ optical modeling to calculate the amount of solar radiation absorbed by the installation.

The main fenestration simulation tools, such as Window7, are based on ISO 15099 and the radiosity approach; however, it is possible to modify this by adding more detailed modeling data. Working with Radiance, the Eurac team used data based on the bidirectional scattering distribution function. This function describes how a solar ray splits and how its intensity changes as it passes through a surface so that it can be applied to complex geometries and highly reflective surfaces. Through ray tracing plus analysis of each pane of glass and each shading component, the team calculated the total amount of solar radiation absorbed by the glazing system.

## ⇨ MODELING HEAT FLUX AND FLUID FLOW

The absorbed fraction of solar irradiance was then transferred into COMSOL Multiphysics® for comprehensive thermal modeling. Demanega performed a mesh sensitivity analysis by modeling the fenestration system installed locally (Figure 3). In the preanalysis, she used the Boussinesq approximation and considered both incompressible flow with the Boussinesq approximation and compressible flow. "I noticed that, simulation time was much longer for a compressible fluid, but the results were similar, so I decided to use incompressible fluid," she explains.

To calculate radiation exchange, Demanega used the surface-to-surface (radiosity) method for long-wave radiation. She also created two radiation groups: one for the internal walls and blinds of the first cavity and another for all of the internal walls of the second cavity.

"After considering different approaches, I selected solving the fluid flow problem using the k-epsilon turbulence model with a low Reynolds number wall treatment. This led to a robust simulation with accurate results."

Using a triangular mesh in the center and a rectangular, mapped mesh at the boundaries, Demanega finalized the settings. "I altered the size until I could find no further improvement. In the end, the mesh was more or less 20,000 elements" (Figure 4).

## ⇨ SIMULATING STATIONARY CONDITIONS

Following standard National Fenestration Rating Council (NFRC) stationary boundary conditions for summer, the outside temperature was set at 32°C/89.6°F, with 24°C/75.2°F inside and a solar radiance of 783 W/m². The integrated blind was modeled in three separate positions: completely closed (75° angle), almost fully open (18°), and halfway between (37°) (Figure 5).

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The team members performed two types of simulation. They used Radiance for optical modeling to calculate the absorbed fraction of solar irradiance, then COMSOL Multiphysics for heat transfer and fluid flow; they also followed the standard method using Window7 with ISO 15099 calculations.

As a control, the team also modeled a standard fenestration system with and without a blind using stationary conditions. Simulation results showed clear correspondence between the two approaches for the system without a blind and nearly perfect correspondence for a standard system with a blind.

## ⇨ TIME-DEPENDENT CONDITIONS

For simulation of dynamic behavior, the team used data from the local weather station for input to the optical simulation and measured the surface temperatures of internal and external glazing as boundary conditions for the CFD simulation. These boundary conditions were implemented in COMSOL Multiphysics by importing a dataset with discrete temperature values and time steps of 300 seconds. These values were then interpolated with a polynomial function and assigned to the proper glazing faces. Simulation of heat flux on the internal surface of the window system was compared with measured heat flux on the same surface (Figure 6).

"We were very pleased to find correspondence between our simulation results and physical measurements for the blinds in a fully closed position, especially because conducting the simulation in two different environments meant that there was potential to fail in one or the other," comments Demanega.

## ⇨ A VERY USEFUL TOOL

The validation of a technique using Radiance and COMSOL® means that the Eurac Research team now has a very useful tool to accurately assess the temperature of components and the heat flow through a complex fenestration system.

According to Demanega, the results show the value of detailed optical modeling to understand primary solar radiation before thermal modeling in order to measure secondary heat gain caused by the absorption and re-emission of radiation.

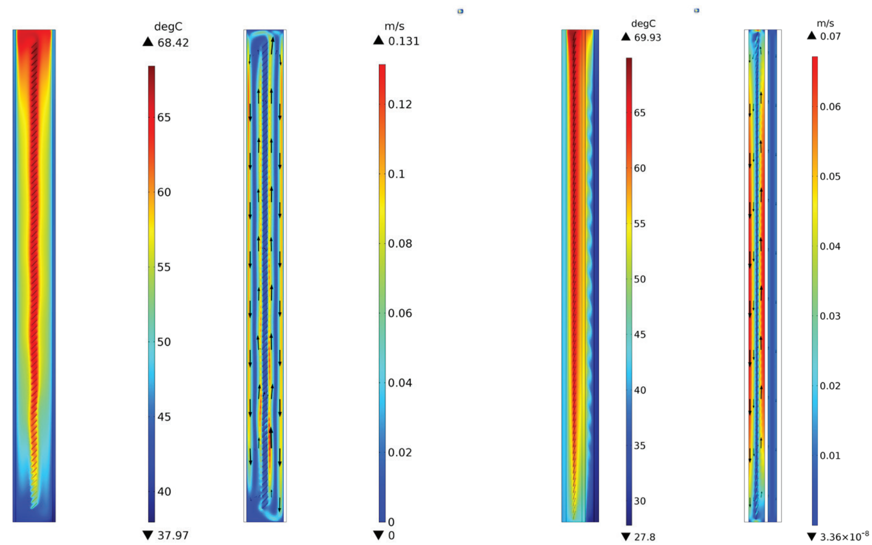


**FIGURE 5.** CFD results show how convection affects the temperature of a window in a standard (left) and complex (right) fenestration system.

"In particular, the standard approach does not account for the vertical distribution of temperature. It is important to learn more about the distribution of temperature from top to bottom of a cavity, pane of glass, and blind because component temperature influences both the structural integrity of a building facade and the comfort of people within."

With the knowledge gained, the team is now validating the approach for different blind positions and is looking forward to applying the approach to naturally ventilated cavities containing integrated blinds, often found in double-skin facades. The team is also looking at how to disseminate this information within the construction industry and is considering the feasibility of a simulation application that would enable modeling of complex fenestration systems to be more widely available to professionals. ❖


## ACKNOWLEDGEMENT

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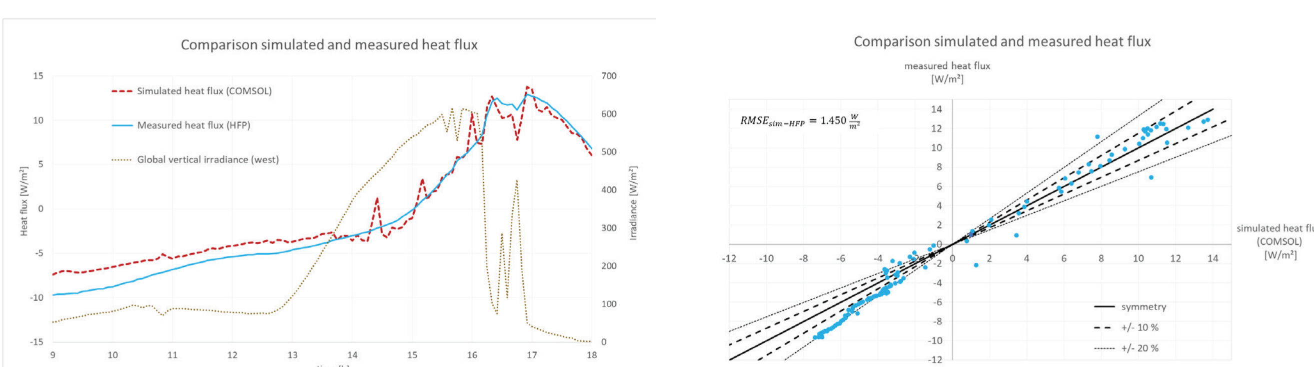


**FIGURE 6.** Correspondence between the time-dependent simulation of the commercial system at Free University of Bozen-Bolzano and physical measurements of heat flux on the internal side over the total height of window.