INVESTIGATION OF 3-D HEAT TRANSFER EFFECTS IN FENESTRATION PRODUCTS

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Abstract—

This research paper explains that windows, doors, glazed walls, and other fenestration products account for nearly 40% of the energy used in buildings in India. are the largest components of buildings' energy loss. It is essential to accurately evaluate the thermal performances of fenestration systems in order to improve product performance and predict the overall energy consumption of a building. Because 3-D analysis is a highly complex process that requires significantly more time, effort, and cost than 2-D analysis, it is typically used to evaluate their thermal performance. One more strategy for assessment for example actual test in a hotbox isn't feasible for every item as they are excessively costly. Fenestration products' effects on overall heat transfer must be investigated because heat transfer is a three-dimensional process. In contrast to the results obtained in two dimensions, this proposed thesis examined 3-D heat transfer effects in fenestration systems. In terms of 3-D modeling of windows that included all three types of heat transfer conduction, convection, and radiation, for example—no significant work has been done previously. For a wide range of fenestration products on the market that come in a variety of comprehensive 2-D and 3-D results were obtained. GAMBIT/FLUENT2 and Therm5/Window5 (for example, the current standard method for evaluating thermal performance) were used to obtain all 2-D and 3-D results, respectively. The heat transfer modeling included all three modes of the heat transfer mechanism. For current framing and glazing systems, the study demonstrated that the overall 3-D heat transfer effects are relatively small (less than 3%). 3-D effects were quite significant (10%) at the individual component level (such as sill, head, and Jamb), but when the overall fenestration system effect is calculated, they are cancelled by their opposite sign of variation. These three-dimensional cheat transfer effects are more pronounced in products of smaller sizes and for glazing and framing systems that are less convective or use less energy. The 3-D effects on heat transfer were not significantly affected by the space systems. 3-D effects on heat transfer, which may necessitate the development of specialized programs or the application of correlations to 2-D models, should be taken into account as the market shifts toward products with greater insulation and performance.

Keywords:3-D heat transfer, fenestration products, thermal performances, glazing systems

1. Introduction

In recent times, a renewed focus on the sources of carbon emissions around the world has resulted from global warning threats. People are realizing how important it is to conserve energy because the use of energy from non renewable sources directly contributes to the emission of carbon dioxide. New non-conventional and renewable energy sources have been investigated as a result. At the same time, one of the best ways to save energy is to make the systems that are already in place more energy efficient. Buildings (residential and commercial) use over 39 quadrillion kilowatt hours (roughly 40% of all energy used in India), making them the largest contributor to greenhouse gas emissions and global warming. The industrial and transportation sectors consume the remaining energy. Because they control cover 55% of the building’s energy loads, building envelop systems (walls, roof, and windows) have a significant impact on the building's overall energy performance.

Therefore, accurate thermal performance of the demonstration system is essential to the energy design of a building. The thermal design of a building has an impact on condensation resistance as well as the energy load and use of the building. The accurate performance of windows would also encourage product design innovation and enhancement. A non opaque aperture in the building envelope is known as a fenestration system. Sliding doors, traditional windows, roof monitors, and roof skylights are all examples of fenestration systems. The Latin word fenestra, which means "opening," is the origin of the word fenestration. Air, light, materials, and even people can move through them. They also give us a connection to the outside world, which has been shown to be important to our physical health because we spend more than 90% of our time inside. Designers like fenestration products because they give them a unique way to identify their buildings through the façade.

Products for fenestration must meet a variety of performance requirements, and Energy is one of them. When designing or selecting these products, designers of fenestration systems must also incorporate structural, acoustical, and durability performance requirements. Windows are the most frequently identified window products. Figure 1.1-1 depicts the three main components of a fenestration system: 1) Systems for framing; typically the mullions, dividers, or perimeter; (2) insulated glass units (IGU), a type of glazing system consisting of gas-filled layers of plastic or glass; and three, the spacer system that seals the edges of IGUs.

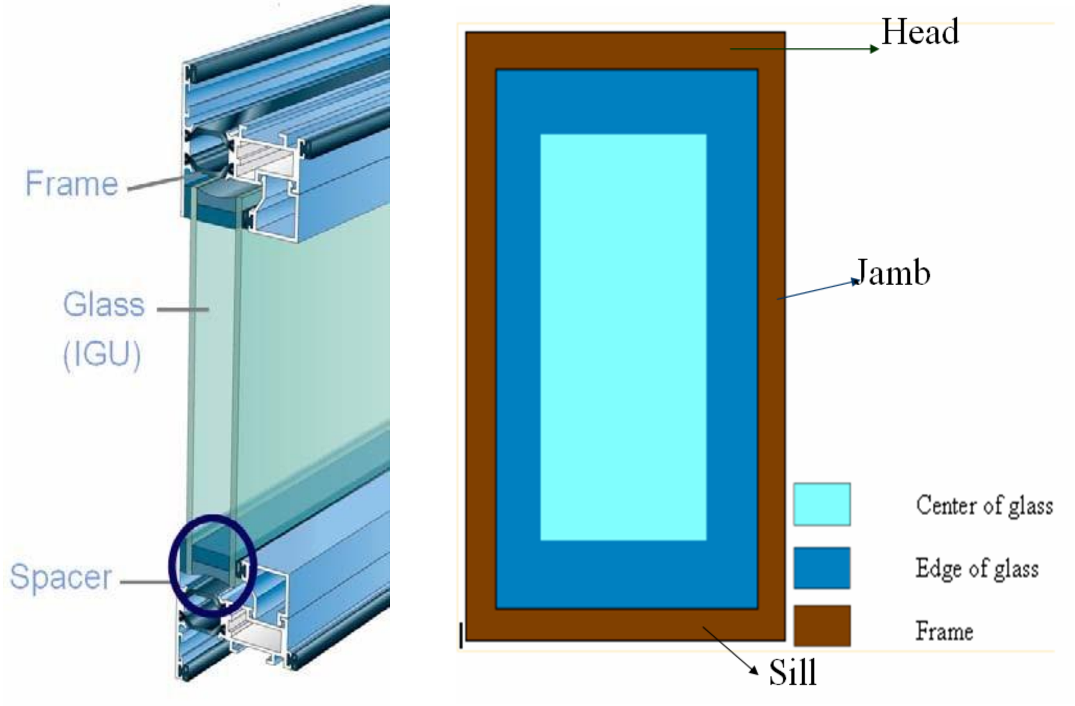

Figure 1: Terminology window (right) and window (left)

Outlines are usually produced using wood, aluminum, PVC, or fiberglass. The window frame's thermal transmittance is determined by its thermal conductivity and design. The majority of the glazing that is produced in North America takes the form of insulated glazing units (IGU), which offer superior thermal resistance. Multiple glass panes separated by gas spaces like air, argon, krypton, and so on makeup IGUs. In order to keep the glass panes apart, spacers and sealants are slid in between them. This prevents the passage of moisture, vapor, or gas through the seal.

The terms that are commonly used to describe various sections of a window, such as sill, head, jamb, edge of glass, and center of glass, are also depicted in Figure 1 above.

In this research paper section one contains the introduction, section two contains the literature review details, section III contains the details about the current performance evaluation, combined heat and power, section IV contains the result details,and section V describe the conclusion of this research paper.

2. LITERATURE REVIEW

2.1 Kevin Attonaty, 2019, with fenestration systems transfer of heat

Fenestration systems facilitate all three heat transfer modes: transmission through solid parts like the frame and spacer; convection inframe cavities, glazing cavities, and surfaces inside and outside and heat transfer by radiation on any surface that is exposed. The accuracy of the model as a whole and heat transfer in the fenestration system is largely dependent on how the convection part of the problem is solved. Figure 4 shows three significant kinds of energy flow going through windows.

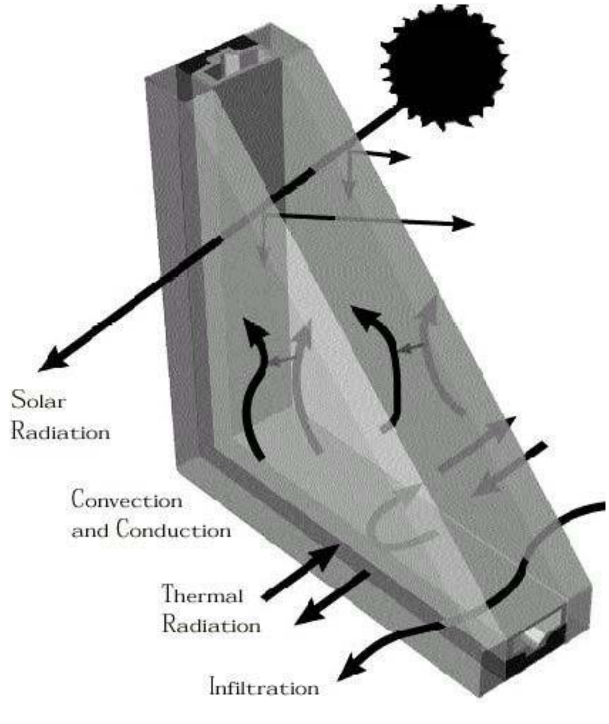

Figure 4: fenestration systemthrough Energy flow

Prior to the 1980s, only results from experiments were available. In these studies, the main approximation was to replace the air or other gases in the IGU with a solid material whose conductivity is the same as what happens when convective and radiative heat transfer are combined with the value of a still gas's conductivity. The effective thermal conductivity is the term for this. The set of boundary conditions is also simplified, with serving as an approximation. For instance, it failed to anticipate the situation in which the IGU's convective heat transfer results in asymmetric velocity and temperature fields, which in fact result in local variations in heat flux rates and temperatures. Because the effective thermal conductivity method creates a temperature field that is artificially symmetric in the edge of-glass region, the results are only useful for predicting overall U-factors, which may not fully account for localized effects.

Fenestration systems has been the subject of research since the 1990s, but most of it has been limited to 2-D modeling. Laminar heat transfer and radiation in a fenestration system and laminar convection in a vertical, rectangular slot were the subjects of two-dimensional numerical calculations by Wright (1990). In order to replicate the experimentalapparatus setup, Thetemperature difference and the cavity's size determine the definition of Ra, which can be found in Equation (2.1). Ra is primarily responsible for determining the heat flow rate for a particular window with a fixed aspect ratio. The fluid flow within the cavity will typically behave like a laminar flow when Ra is lower, but when Ra is higher, it is more likely to generate turbulence with a higher heat transfer rate.

Smith and others 1993) utilized the limited contrast strategy to demonstrate the convective and radiative intensity move in an IGU hole and the conductive intensity move in the glass sheets. Real frame sections were replaced with rectangular blocks on the top and bottom, where the conductive and convective heat transferswere modeled. Three fenestration systems were subjected to a variety of numerical calculations by Power (1998). Idealized one-dimensional conduction by

A segregated solution method was used in the numericalmethod for all fenestration system calculations. There were some differences in the edge of the glass regions, but overall, the numerical calculations of heat transfer through two fenestrationproducts and the measured data were well-matched.

In the past, it was prohibitively expensive to run 3-D models of heat transfer in windows due to the large computer system requirements and increased computational complexity. Rather than requiring a 3-D analysis, it may be less expensive to test thebuilding component in some instances. In any case, some 3-D effects may be minor enough to be ignored saving money and time. Some researchers have been studying 3-D window and component modeling since the 1990s.

The first researcher to take into account 3-D heat transfer throughout the entire fenestration system wasCurcija (1992). The convective boundary conditions for the indoor surface of a prototype window were based on these findings; heat transfer by laminar forced convection on the surface of the outdoor fenestration system; and making use of the findings regarding local heat flux as convective boundary conditions for the prototype window; numerical calculations for laminar heat transfer and radiation in a fenestration system in three dimensions as well as in two dimensions for both constant and changing boundary conditions. The 3-D numerical modeling produced a slightly higher edge of glass region U-factor (Ueg) as a result of the end effects of the 3-D glazing cavity, which is one of the important results. His research recommends modifying 2-D results. Despite the fact that it was unable to adequately describe the window at the time, it does offer a useful guide for subsequent work.

2.2 Heat transfer by radiation

According to Shapiro (1983), THERM makes use of the algorithm which is named radiation view, which is a fork of the free software program FACET. By directly modeling element-to-element radiation heat transfer this feature improves the accuracy of the program. This is especially important when products have self-viewing surfaces at temperatures different from the ambient air temperature. For surfaces that are subject tonatural convection, As a result, a building envelope component's overall U-factor and rates of surface heat transfer can be significantly impacted by significant variations in radiation heat transfer.

The correlations are used in WINDOW5 calculations to figure out the heat transfer for the glazing cavities. For simplicity's sake, frame cavities are modeled as a solid component, and their effective conductivity is used for modeling.

3. Current Performance Evaluation Options

A hotbox is depicted in Figure 2.

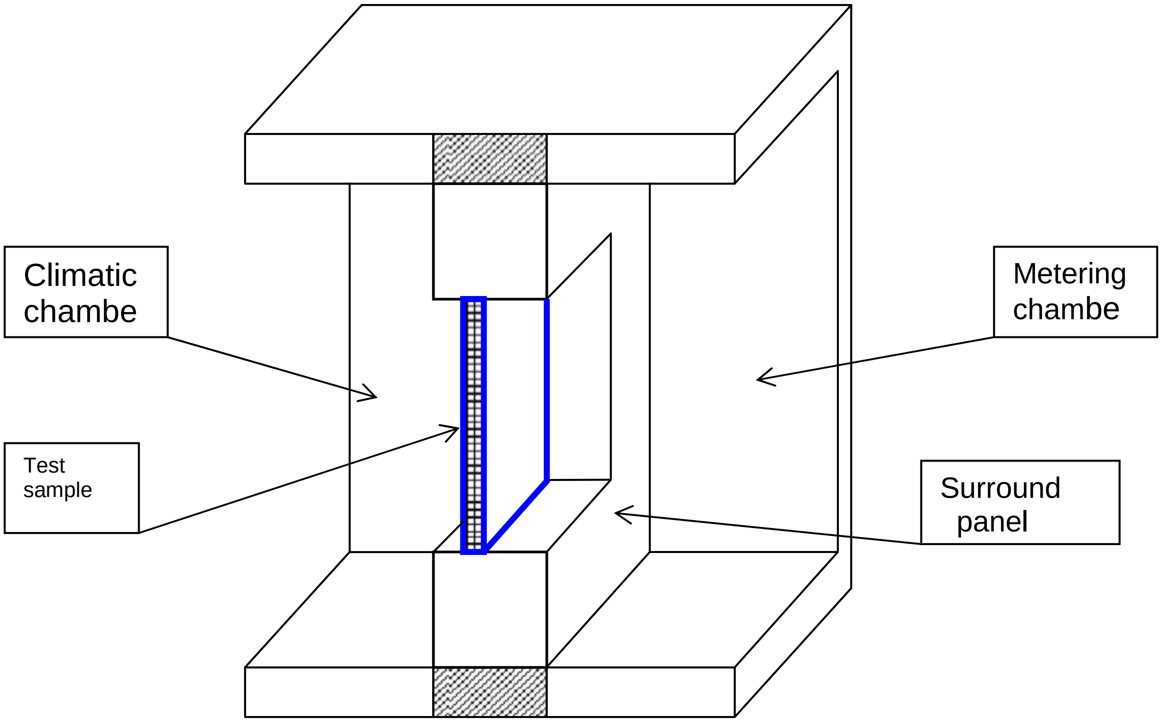

Figure2:Hotbox depiction

However, using a hotbox to measure windows' thermal performance is a costly endeavor. In addition to the high cost of laboratory testing, each windowmanufacturer typicallyoffers hundreds of distinct products each with distinct thermal performance characteristics. To test every kind of product will cost a lot of money for manufacturers.

The U-factor results can also be obtained through computer simulation. The use of simulation software to assess the thermal performance of building components like windows walls, and doors began in the 1980s. Software has the advantage of offering a less expensive alternative to testing for evaluating window performance as well as the capability of being utilized during the design phase to assist manufacturers in producing windows that will meet target specifications. But the big question is how closely these simulation results match the actual window performance and how reliable they are.Another Canadian software program, FRAME (Enermodal Engineering Ltd., 1991), calculates heat transfer in two dimensions.

Window5 and THERM5 are currently the standard, well-supported tools for evaluating fenestration systems' thermal performance. The standard for evaluating the thermal performance of fenestration products in the United States (NFRC 100) and in Canada both refer to these programs as the standard approach. The overview of the Winodw5 and Therm5 programs' calculation processes can be seen in Figure 3.

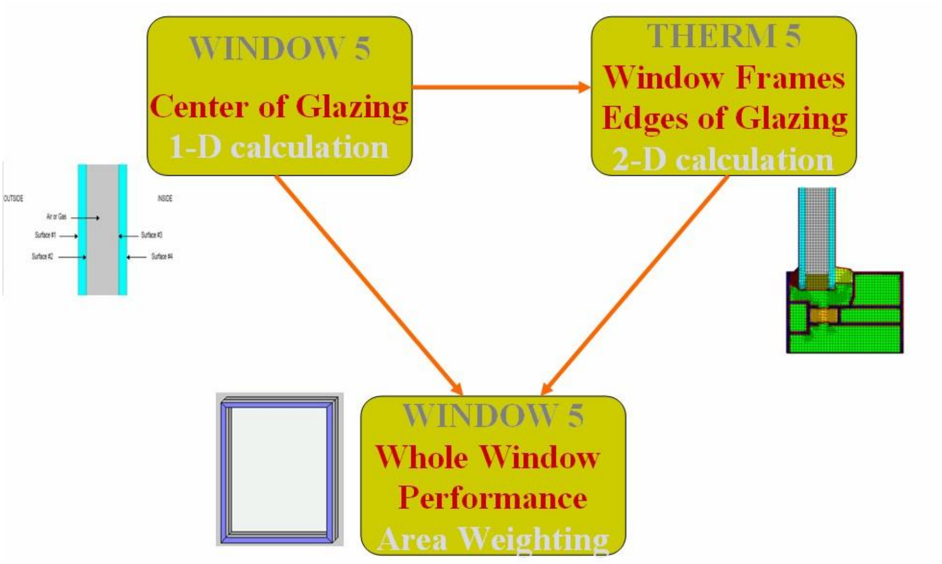

Figure3: Window5/Therm5 calculation overview

The U-factor of windows is calculated using one-dimensional heat transfer calculations for the center of the glass and two dimensional heat transfer calculations for portions in these prevalent simulation programs.

The product's total U-factor is calculated byarea weighting the center of the glass edge and the results of the frame, as depicted in Figure 3. The 2-D calculations show that even the window's corners have the same thermalperformance as the center of the frame. As a result, one and two-dimensional heat transfer can be thought of as an extension of the complex heat flow through a fenestration system.

This is a valid assumption for the majority of non-complex building components. However, unlike walls orinsulation products, where heat transfer is mostly one- or two-dimensional, windows may have significant three-dimensional effects that must be taken into account in order to obtain an accurate value for the total product U-factor.

4. RESULTSAND DISCUSSION

The process of obtaining results and the discussion surrounding those results are both depicted in this section. Both the 2-D models of THERM/WINDOW and the 3-D models of GAMBIT/FLUENT produced the heat transfer results for allof the window models. In order to effectively evaluate effects in three dimensions, FLUENT models were constructed in two dimensions and three dimensions. Before exporting to FLUENT, the geometry and mesh for each model are created using the pre-processor software GAMBIT. Prior to obtaining the results, all boundary conditions and material properties are defined in FLUENT. The effects of 3-D heat transfer were compared between the different models. The true "apples-to apples" comparison revealed 3-D effects and effectively removed any noise from the results, so this was done. Other than this 2-D model, the FLUENT and THERM /WINDOW results were compared to see how the conduction andconvection models differ.

4.1 WINDOW5 and TERM5 result

Warm outcomes were acquired first from THERM5 and WINDOW5 models for all the window models. The heat transfer calculation for a window's frame and edge parts is done by THERM, a two dimensionalfinite elementanalysis tool, while the WINDOW5 program calculates the center of the glass and the window's performance as a whole. The boundary conditions and geometry were used. The center of the glass is used by the THERM program when calculating the Frame and Edge of Glass performances. The WINDOW5 program imports these results; where the performance of the entire product is calculated using them and the glass center's performance.

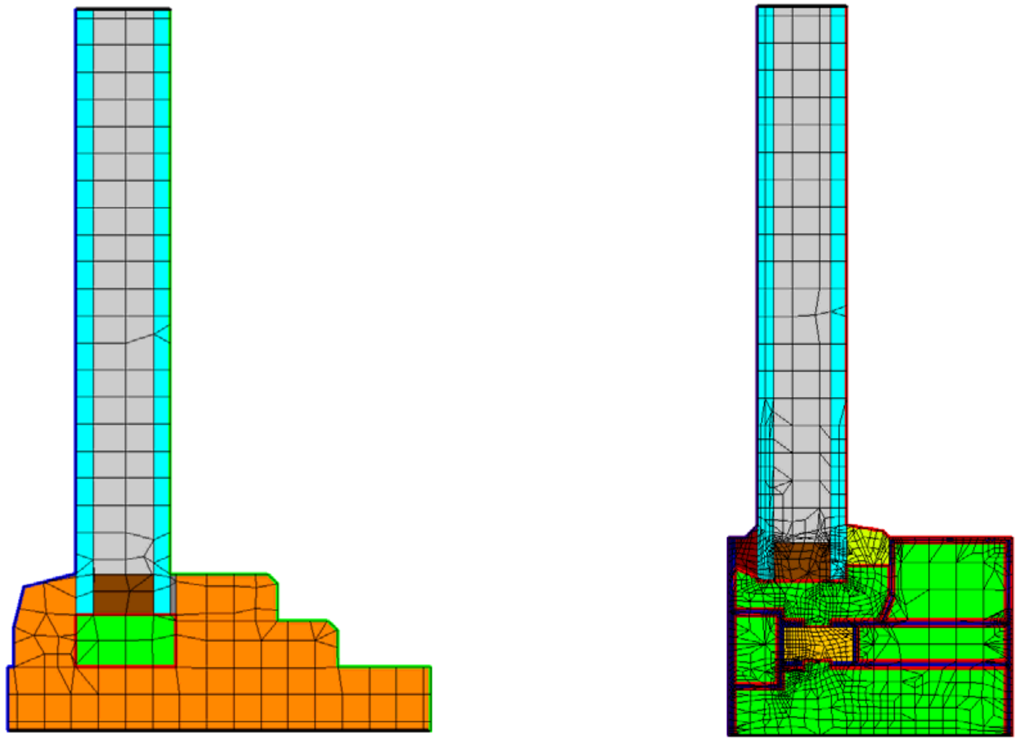

Figure5: WoodWindow(left) and AL window (right)

Here effective and conductivities of frame cavities and glazing cavities, obtained formTHERM /WINDOWmodels,were utilizedin FLUENT models.

4.2 GAMBIT creation of Geometry

It reduced computational and modeling time significantly. The closed planar loops were transformed into faces by applying a cross-section to the frame in the AutoCAD command region.

A mirror image of the meshed sill cross-section is used to construct the head section. They were joined to make parts for glazing and glass. Parts of the glazing matched. Both continuum entities and boundary conditions were defined. The two-dimensional model can now be exported to FLUENT for solution. The meshed view of the cross-section of the sill for the wood window is depicted in Figure 6.

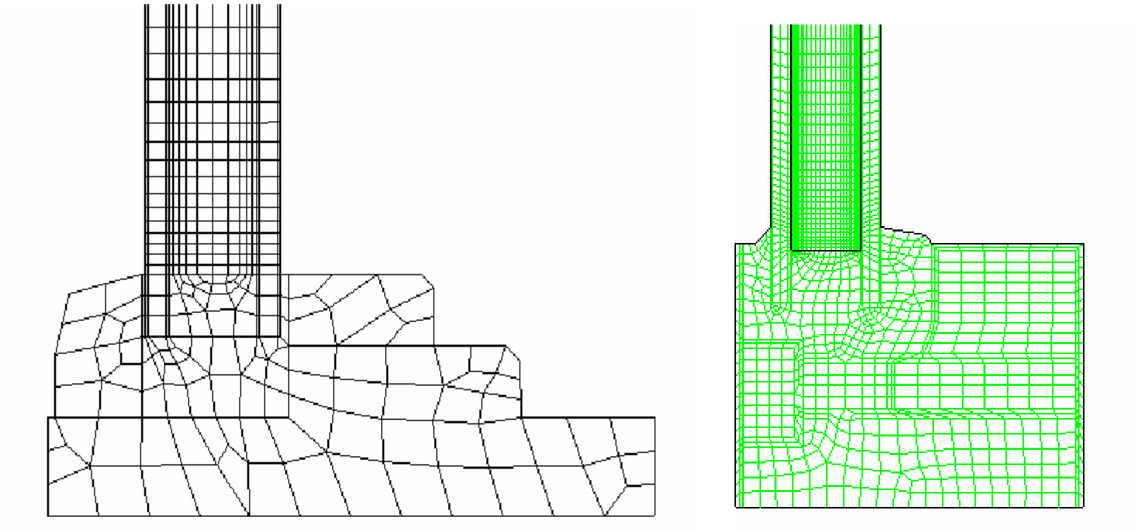

Figure 6: PVC window (right) and wood-window (left)

Each part sill, jamb head, and glazing unit must be created in order to create the 3-D model. There could be multiple ways of making. The ledge get area is moved throughout the z-course by 0.3 m to make the ledge volume. The sill-jamb end was then cut with a plane at 450 degrees. The portion of the sill that has one end planed at 450 is depicted in Figure 6. This part is coincided prior to continuing for effortlessness.

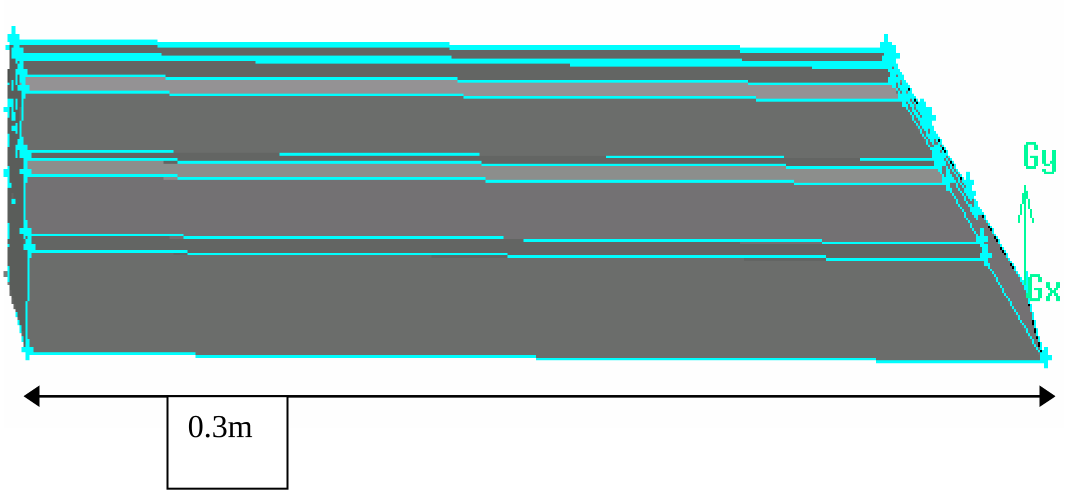

Figure7: Wood window 3d volume

One end cross-section is meshed using the "pave" meshing scheme after the sill edges were meshed for meshing. The "cooper" scheme is used to meshed the sill volume. Head, which is already meshed, is created by mirroring the meshed sill part at the required height. After that, joining the glazing components and the ends of the sill and head-formed jamb. The "cooper" scheme is used to mesh the jamb, while the "map" scheme is used to mesh the glazing components.

5. CONCLUSION

This is the first systematic investigation of 3-D corner heat transfer effects in fenestration systems. This study investigated and reported on four different glazing systems, which covered the entire range of current and future glazing designs, with the exception of single glazing. Three spacer types, which covered the entire range of current and future spacer materials and designs, were also taken into consideration. The study's first conclusion is that existing fenestration computer modeling tools can ignore 3-D corner conduction heat transfer effects for current frame. Spacer conductivity has no significant impact on the degree to which 3-D and 2-D conduction heat transfer models differ from one another. Therefore, the extent of 3-D effects is determined by frame and IGU performances, that is more pronounced and significant for frames and glazing with higher thermal resistance, and it exceeds 2% for smaller windows. Three-dimensional effects would need to be taken into consideration as the market shifts toward products for fenestration with higher performance. There were more 3-D effects in smaller windows with a higher frame to glass area ratio than in larger windows with a lower frame to glass area ratio. There were of greater magnitude, reaching 10%, at the individual component level. However, because the frame and edge of the glass sections typically has distinct signs in front of the differences, these distinctions would frequently cancel one another. The overall results do not reflect these significant differences. Right neighborhood data at part level would help in precise assurance of nearby temperature, buildup opposition, and nearby intensity motion. The local outcomes of the convection and conduction models were vastly distinct, despite the fact that their overall 3-D effects are comparable. It is prescribed to execute a convection model for 2-D investigation to accurately get temperature and intensity move result. For example, was used to determine the inside and outside surface boundary conditions in this study. In order to reveal the 3-D effects brought on by localized heat transfer effects, subsequent research ought to incorporate with moving structures.

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