

## Recent Technical Improvements to the WINDOW Computer Program

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### Introduction

The WINDOW series of computer programs<sup>1,2</sup> has been used since 1985 to model the thermal and optical properties of windows. Each succeeding version of WINDOW has brought its user base new technical capabilities, improvements to the user interface, and greater accuracy. Technical improvements to the current version, which will be released as version 5, are at first being released as stand-alone programs. This paper summarizes the capabilities and algorithms of two of these programs, THERM and LAMINATE. A third stand alone program, RESFEN, which calculates the annual energy effects of specific windows in a typical house throughout the US, will also be incorporated into WINDOW 5; because this program is already in use and documented<sup>3</sup>, it is not discussed in this paper. THERM allows the user to evaluate two dimensional (2-D) heat transfer effects through the solid elements of a window while LAMINATE determines the optical properties of an individual glazing layer with an applied film. Both of these programs are undergoing final development at the time of this writing and will be released as separate programs before they are incorporated into WINDOW 5.

### Modeling Two-Dimensional Heat Transfer with THERM

A 2-D heat transfer model is necessary to accurately model the heat transfer through a window frame or divider profile. While WINDOW 4.1 allows the user to use 2-D results from a stand-alone finite difference model<sup>4,5</sup> the process is only minimally integrated. Furthermore, the finite-difference computer code which interfaces with WINDOW is currently limited to a manual input of a rectangularized geometry with a fixed number of rectangles. THERM was therefore created in order to minimize the input time required of users to define a window and to offer the capability to model exact geometries without user simplifications. THERM was also created with a flexible user-interface and structure so that it can be used in the future to analyze other 2-D window (and non-window) heat transfer problems, such as a vertical section through a greenhouse window or a framing detail around a window. The remainder of this section summarizes THERM's capabilities and structure; more detail is found elsewhere<sup>6</sup>.

In keeping with current trends in personal computing, THERM makes use of a Microsoft WINDOWS based graphical interface to define a window cross section, perform the calculation, and analyze results. As shown in Figure 1, THERM is comprised of four modules: a drawing program, an automatic mesh generator, a finite-element solver, and an output display.

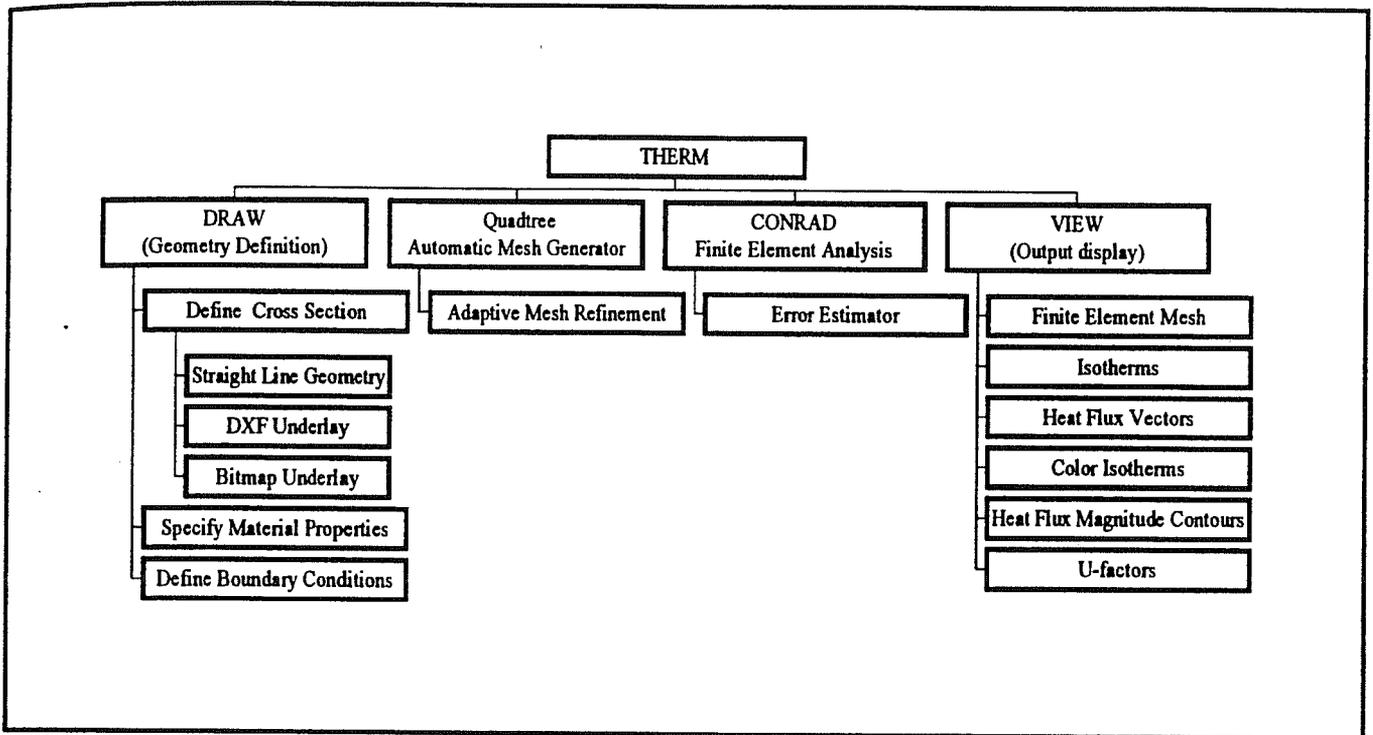


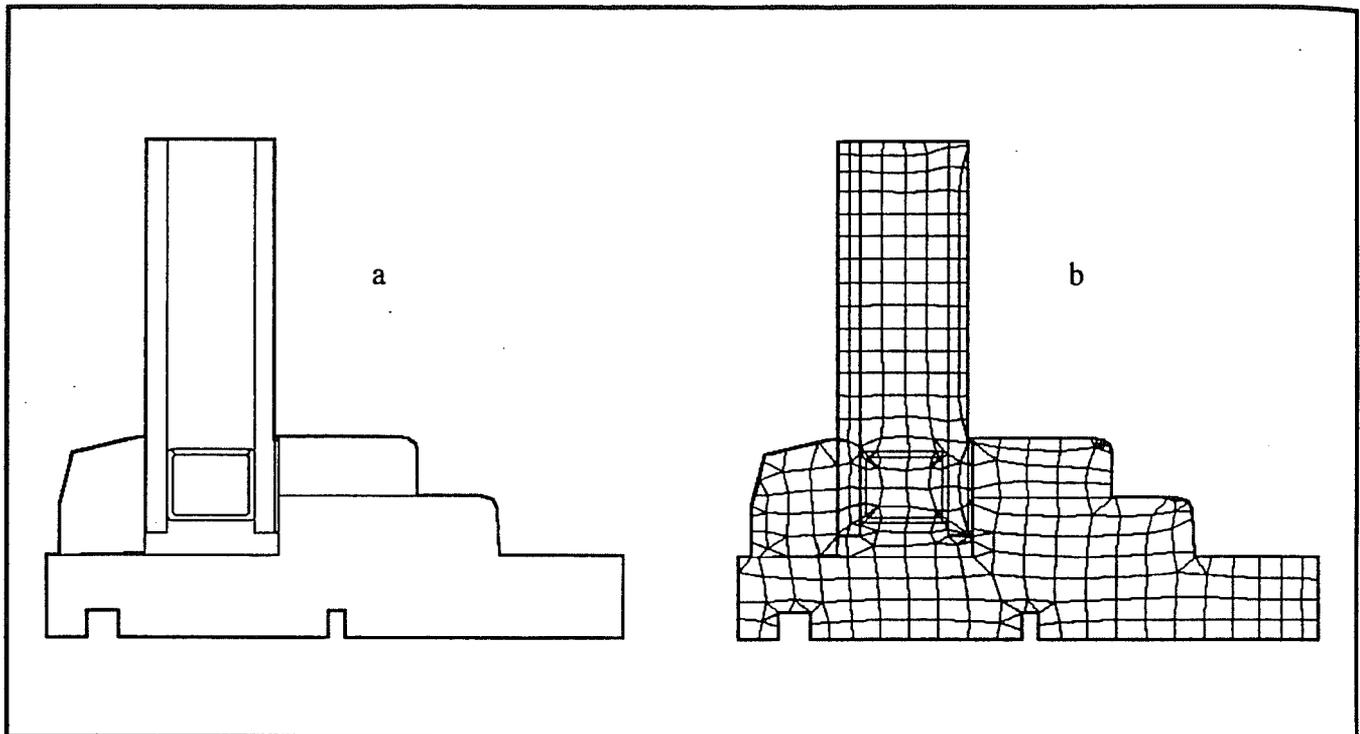
Figure 1: Schematic of the THERM Program.

To analyze heat transfer effects through a specific cross-section, it must first be graphically entered into THERM via the drawing module, DRAW. Cross-sections are defined by combinations of polygons. In the current implementation curved surfaces must be represented by combinations of straight lines, otherwise the geometric representation can be exact. A cross section can either be entered by mouse or cursor keys or by tracing over the image from an imported bitmap or DXF file. Once the geometry has been defined, materials and boundary conditions are specified.

Once the problem has been fully specified, it must be converted into a finite number of nonoverlapping subregions or elements (Figure 2). In the past, such grids had to be generated manually. Such a manual grid generation requires a sophisticated knowledge of the solution method and is an unreasonable requirement to impose on the typical WINDOW user. THERM therefore makes use of a state-of-the-art automatic grid generation algorithm, Quadtree<sup>7</sup>, to generate an element mesh suitable for the finite-element analysis (FEA) solver. Such a mesh generator requires no user decision making. Once the mesh has been generated, it is sent to the FEA solver.

Our FEA solver, named CONRAD, is a derivative of the public domain computer code TOPAZ2D<sup>8,9</sup>. The general FEA procedure is described in many texts<sup>10,11</sup>. The specific solution procedure is described elsewhere<sup>12</sup>. Once the mesh generated by Quadtree has been solved by CONRAD, an error-estimator automatically looks for regions of the problem domain which would benefit from a finer grid. These

areas are then remeshed by Quadtree, the new mesh is resolved by CONRAD, and the results are reevaluated by the error-estimator. The process is repeated until the error-estimator does not find any regions with a localized error beyond a pre-defined level.



**Figure 2: a) A window cross section created in DRAW using a DXF file underlay and straight line geometry drawing, b) The mesh generated by the Quadtree method.**

The final results of Quadtree and CONRAD can be displayed with VIEW, THERM's output processor. One sample output is shown in Figure 3. VIEW will display:

- the finite element mesh,
- isotherms
- color flooded isotherms,
- heat flux vector plots, and
- color flooded lines of constant flux.

Post processing routines will also calculate the U-values for any regions of the boundary which were tagged with DRAW. For window cross sections, this allows the user to easily calculate frame U-values, edge-of-glass U-values, or U-values for any arbitrarily defined regions.

### **Modeling the Effects of Applied Films with LAMINATE**

Applied films are a common solar control retrofit in both residential and commercial applications. Given that there are dozens of applied film products which could each be used with hundreds of glazing substrates, the number of film-substrate combinations is quite large. The LAMINATE tool was developed so that given the optical properties of an applied film and a substrate, the optical properties of the complete assembly can be calculated. The remainder of this section summarizes LAMINATE's

capabilities and structure; more detail is found elsewhere<sup>6,13</sup>. LAMINATE also has the capacity to extrapolate known properties for a given glazing to determine the properties at different thicknesses. This extrapolation can be done for coated or uncoated glass. Future versions of the LAMINATE program will extend its capabilities to the calculation of optical properties of laminated glazing layers (given the properties of both layers), and of coating layers (given the properties of a coated and uncoated substrate).

Recent experiments have shown that because the refractive index of the adhesive (used to apply the film to the glass) is essentially the same as the refractive index of glass, the adhesives have a negligible effect on the optical properties of the combined unit. Thus, only the transmittance and reflectances of the substrate and the applied film are needed; these are determined by measurements. From these, the substrate and film transmissivities and inter-facial reflectivities are determined as a function of wavelength. The transmissivities and reflectivities can then be combined to produce a system (substrate plus applied film) transmittance and surface reflectances<sup>13,14</sup>.

The system's spectral transmittance and reflectances can be viewed graphically. Average solar or visible properties, determined using the same procedures in WINDOW 4<sup>2</sup> are also displayed. The output files from LAMINATE can be imported into WINDOW 4.1 and combined to form glazing systems with other layers from the WINDOW 4.1 database.

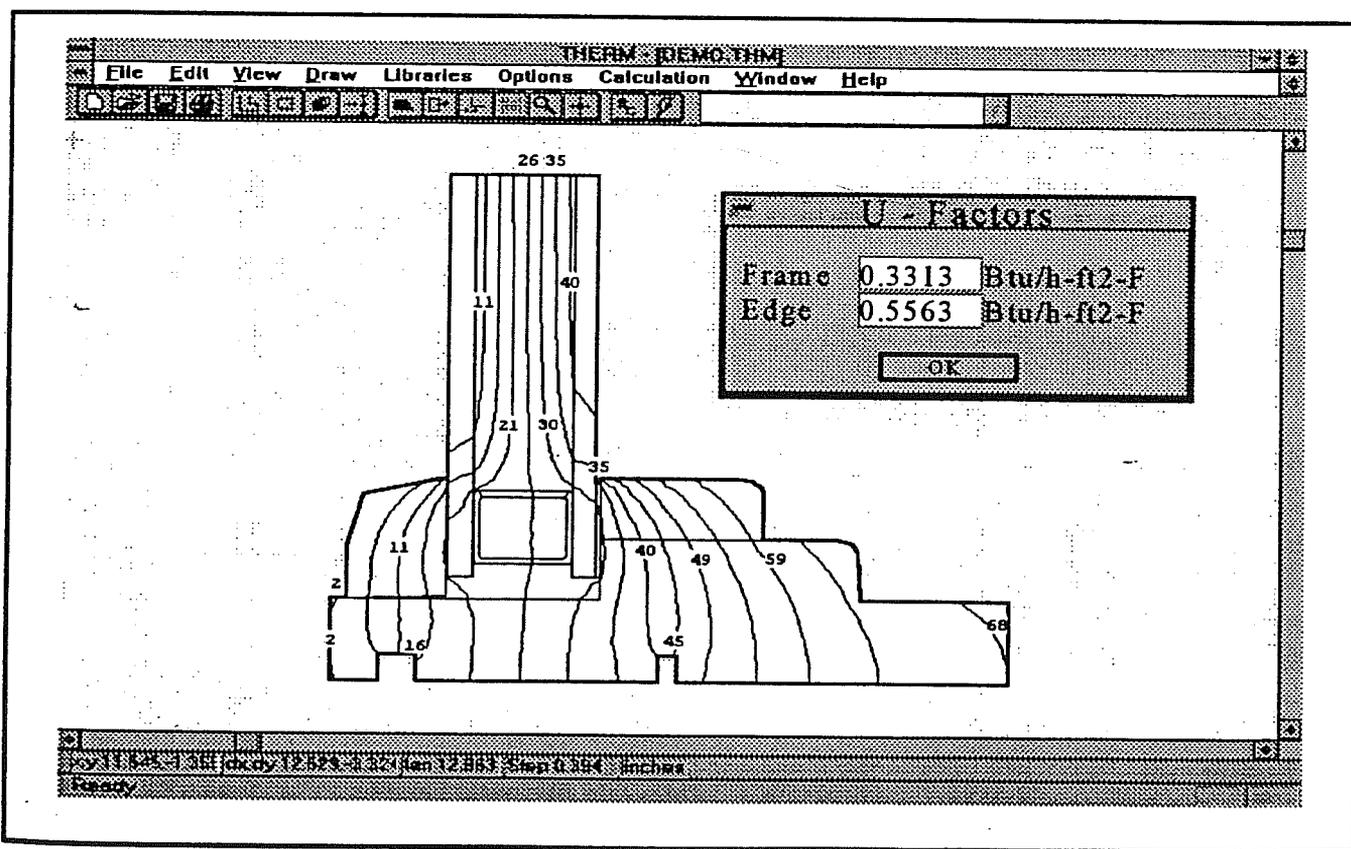


Figure 3: Sample output of a simple window cross section including isotherms and frame and edge U-factors.

## Conclusions

Two new stand alone tools, THERM and LAMINATE, add new technical capabilities to the analysis of the thermal and optical properties of window components. THERM allows the user to quickly model the two-dimensional heat transfer effects through opaque window components while LAMINATE allows the user to determine the solar optical properties of substrates and applied films, given the properties of the two individual components. When integrated into the WINDOW 5 program later this year, they will improve upon WINDOW's abilities to accurately characterize the thermal and optical performance of complete window systems.

## Acknowledgments

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Technologies, Building Systems, and Materials Division of the US Department of Energy under Contract No. DE-AC03-76SF00098.

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