Role of Computer Simulation in Window Ratings and Design

Charlie Ćurčija, Ph.D.
University of Massachusetts
Center for Energy Efficiency and Renewable Energy
160 Governors Dr.
Amherst, MA 01003-9265

ABSTRACT

Before the advent of personal computers, modeling of heat transfer in building structures was primarily done in research laboratories using expensive mainframe computers and one of a kind numerical modeling programs. Architects and designers on one end, and manufacturers on the other end had to rely on the data obtained from full scale thermal testing, which was expensive and time consuming, and therefore only very limited number of products were evaluated. This was not only affecting designers and manufacturers, but also code officials and ultimately consumers, who had to settle for sporadic and unreliable data about the energy performance of fenestration, and other building products.

Not coincidentally was National Fenestration Rating Council born at the dawn of the introduction of first “user friendly” PC based computer programs for simulating thermal performance of windows (e.g., Rubin 1982, Rubin et al. 1985, Jonnson 1985). While first editions of these programs had very limited functionality, they represented a leap in convenience of use, consistency of results and even accuracy. This has created favorable conditions for the establishment of the national rating system that was sufficiently accurate and fair, while low cost and affordable. The United States and Canada started using computer modeling for its certification process little over 10 years ago, and the number of certified products had exponentially increased ever since. Today, more than 100,000 products have NFRC certified labels in United States.

While computer modeling had key role in the advancement of rating systems, it also had significant role in the improvement in energy efficiency of fenestration systems, through the use of computer modeling in the early stages of the design process. United States had invested significant public funds in the development of tools like WINDOW, THERM, RESFEN, and OPTICS and provided them at no cost to certification bodies, manufacturers, architects, etc. Further development and improvement of these tools in United States is continually funded until they achieve full functionality necessary to model majority of products on the market. Providing that products continually change, and that demands of certification bodies and manufacturers will increase as the sophistication of these programs and computer hardware increases, it is expected that some level of public funding in these tools will remain for years to come.

Today, the latest generation of computer tools (THERM 5.1, WINDOW 5.1, OPTICS 5.1, and RESFEN 3.1) offer significant improvement in accuracy, ability to model wider range of different products (e.g., projecting products, commercial systems, etc.), to provide new indices, like condensation resistance, and finally improvements in user friendliness and ease of use. It is

clear that continued and expanded use of computer modeling tools will continue and will be backbone of successful rating and certification system, and improvement in products design.

INTRODUCTION

Before the first energy crisis in early 70's there wasn't great concern about energy performance of windows and other fenestration systems. Very limited number of products were evaluated for their thermal performance and it was all done by testing. Even then, architects and designers were mainly concerned about comfort and liability in a case of premature failure of the installed fenestration system. Poor thermal performance didn't just mean higher energy bills but also meant condensation, mold, material deterioration, comfort complains, and other associated issues.

Due to high cost of thermal testing, limited number of products could be evaluated and it was up to a particular testing laboratory to establish quality criteria for the test. It wasn't unusual that thermal testing results coming out of these laboratories could differ by as much as 100%. During the first years of energy crisis, these same numbers were used to advertise "great" performance of somebody's products.

At that time, computer models were only used for research purposes and mostly in national laboratories and academia. These first computer models were used to better understand energy performance of windows and physics behind their thermal performance. Also, some of the early computer modeling research was used to develop simplified algorithms that were planed to be incorporated into the first generation of dedicated computer modeling tools. Advent of personal computers (PC) and lowering of cost of computing precipitated accelerated development of these tools.

About 20 years ago, first "user friendly" computer programs that were designed to calculate one-dimensional (1-D) heat transfer in insulated glazing units (IGU) only, were released to general public under the name WINDOW 1.0 (Rubin 1982, Rubin et al.1985). About 15 years ago, first dedicated computer program to calculate two-dimensional (2-D) heat transfer in frames and edge of glass was released in Sweden (Jonnson 1985). Initially, 2-D programs were utilizing finite difference method (FDM), and only simple rectangularized geometries, with very limited number of grid points, were allowed. Early versions of computer modeling tools had limited accuracy, but nevertheless brought consistency to the process of estimating energy performance of fenestration systems. The cost of computer modeling using personal computer was much lower than the cost of physical testing and it was possible to significantly increase the number of evaluated products.

TECHNICAL BASIS FOR SIMULATION PROGRAMS

The main philosophy incorporated in THERM and WINDOW suite of programs are outlined in a motto: *complexity is hidden behind ease of use*. Algorithms that represent the basis of these programs can be, and very often are very complex, but that complexity is hidden behind user friendly and convenient user interface. The programs were developed on the premise that accuracy does not need to be sacrificed, in order to create simple elegant computer modeling tools. This dream had been accomplished, and today THERM and WINDOW programs can be used by non-technical user and still achieve remarkable accuracy.

The algorithms incorporated in those programs are made fully available and are published in both North American (ASHRAE 2002) and international standards (ISO 2002). There are attempts to keep using methodologies more adapted to slide rule and hand calculations era (ISO/CEN 2000b), but the wider availability of more sophisticated computer tools that incorporate new sophisticated algorithms, like WINDOW and THERM, is changing that concept.

While present computer modeling tools had achieved very good accuracy and consistency, there are several areas where further improvements are needed. United States Department of Energy (US DOE) continually funds research that addresses needs for improvement of existing algorithms and new releases of computer programs. Several new indices and procedures to calculate them were developed in the past several years. Condensation resistance index (CRI) and UV fading resistance (FR) are planned for introduction into the rating system (albeit voluntarily in the initial period) in 2003. The new areas currently under development are; treatment of specialty projecting fenestration products (e.g., garden house windows, domed skylights, tubular daylighting devices, etc.), fenestration attachments, improved accuracy in estimating annual energy performance, treatment of laminates, etc. Future, longer term areas under development are; 3-D models, use of computational fluid dynamics in the treatment of convection heat transfer, multi-dimensional effects of solar heat gain, thermal-structural interaction analysis, acoustics analysis, durability analysis, etc.

APPLICATION OF SIMULATION TOOLS IN CERTIFICATION AND DESIGN

In early 90's, more powerful numerical methods, like finite element method (FEM), were introduced in fenestration computer models and first truly user friendly program, utilizing such method was released in 1995 under the name THERM. The program incorporated powerful drawing package which allowed for quick geometry preparation without simplifications. AutoCAD and scanned images could also be imported, significantly reducing preparation time. The simulation engine for THERM program is based on computer programs developed initially by United States government for military and space use (Shapiro 1983, Shapiro 1986). Now these tools are converted to peaceful use, helping reduce overall energy use and reduce pollution.

After initial validation studies showed that computer modeling tools can be reliably used for large number of fenestration systems, it opened the door for the establishment of low cost, but fair and credible certification procedure. Ten years ago United States and Canada pioneered the use of computer modeling tools in the certification and rating process. While in United States, there still is a requirement for at least one validation test per product line (acting as a reality check), in Canada it is possible to perform computer simulation only for the entire product line. Testing is used only in cases were manufacturers challenge simulation numbers.

Based on numerous studies done in the past ten years, it was concluded that for vast majority of fenestration products, computer simulation produces numbers that are within 10% of tested values. Providing that test methods are generally considered accurate to within 10%, it had been adopted that if the simulation and testing results are within 10%, the simulation is considered validated. For limited number of products like skylights, green house windows, certain types of curtain walls, etc., the discrepancy between computer modeling and testing can be higher, and in limited number of cases, in United States, testing only option needs to be used for these products.

The new version of THERM program, THERM 5.1 (LBL 2002) incorporates detailed radiation model (Arasteh et al.1998, Curcija, et al., 1998, Griffith et al., 1998), which allows for more accurate modeling of projecting and highly conducting products. Starting in January 2000, THERM had become an approved computer simulation tool at NFRC, and its detailed radiation model had been adapted as mandatory for projecting fenestration products. Starting in 2003, the use of detailed radiation model will be mandatory for all products. This will eliminate inconsistencies and will reduce non-validation. Current use of FDM based numerical models will be slowly phased out in United States certification program. Recently, THERM and WINDOW computer programs were adopted in Russian certification program (GOST 1999).

In addition to certification related use, new generation of computer modeling tools can be also used in the design of fenestration products. The availability of user-friendly and low-cost computer modeling tools for use by fenestration industry allows for the design and development of better and more energy efficient products while keeping R&D costs relatively low. The manufacturer's R&D team can now evaluate several proposed designs before ever building the actual product. Once the product design has been optimized, prototype can be built and its performance can be verified by means of physical testing.

WINDOW suite of computer programs are developed by United States government using public funds, and by the law these programs are free and publicly available. They are also made available internationally in an effort to improve overall energy efficiency and reduce pollution globally. The programs are available for download from the following web site: http://windows.lbl.gov. Other useful fenestration and energy efficiency related links are located at: http://www.nfrc.org, http://www.efficientwindows.org, http://eren.doe.gov.

CONCLUSIONS

- Computer modeling tools can reliably be used for estimating energy performance of fenestration products
- Computer modeling should become integral part of modern certification procedure
- Computer modeling can effectively be used in the design of energy efficient fenestration products
- Further developments of algorithms and computer programs will improve reliability of calculated numbers and increase the quantity of products that can reliably be modeled.

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Figure 1. NFRC Label

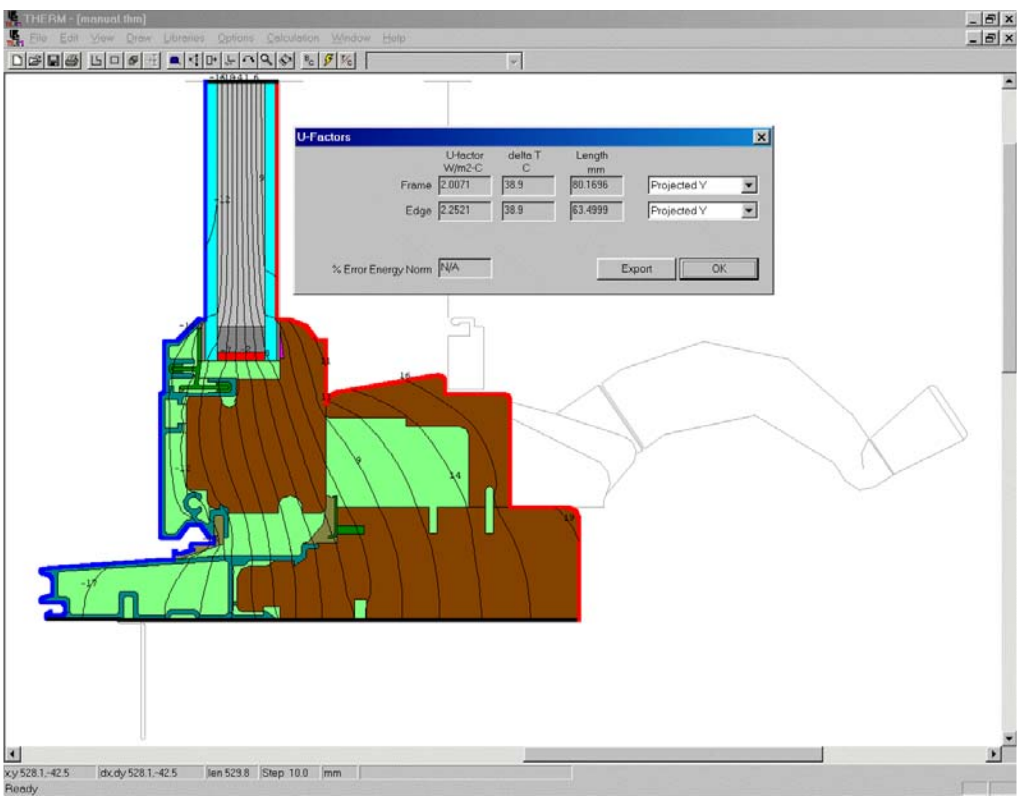

Figure 2. THERM Computer program

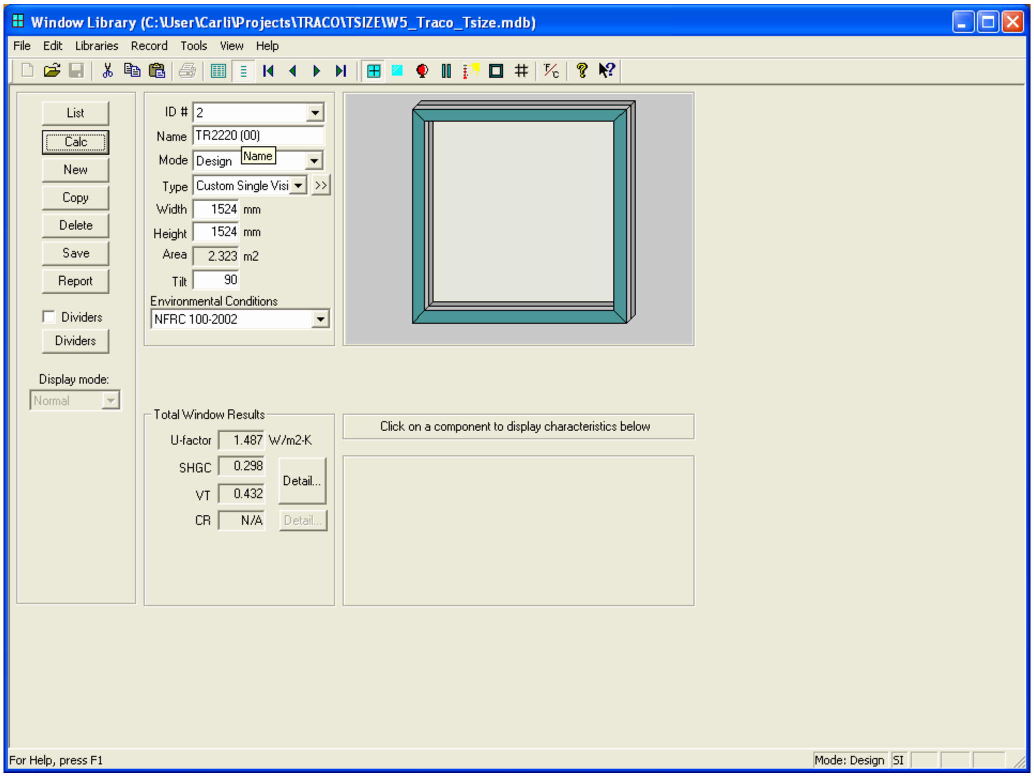

Figure 3. WINDOW Computer Program

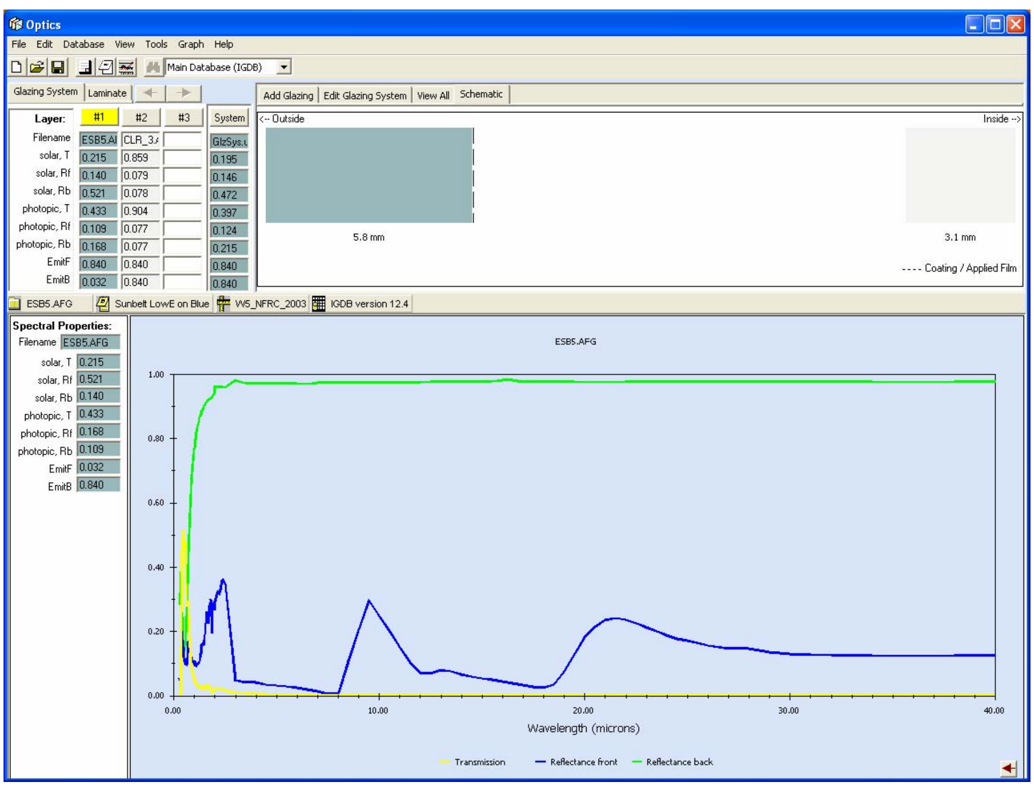

Figure 4. OPTICS Computer Program

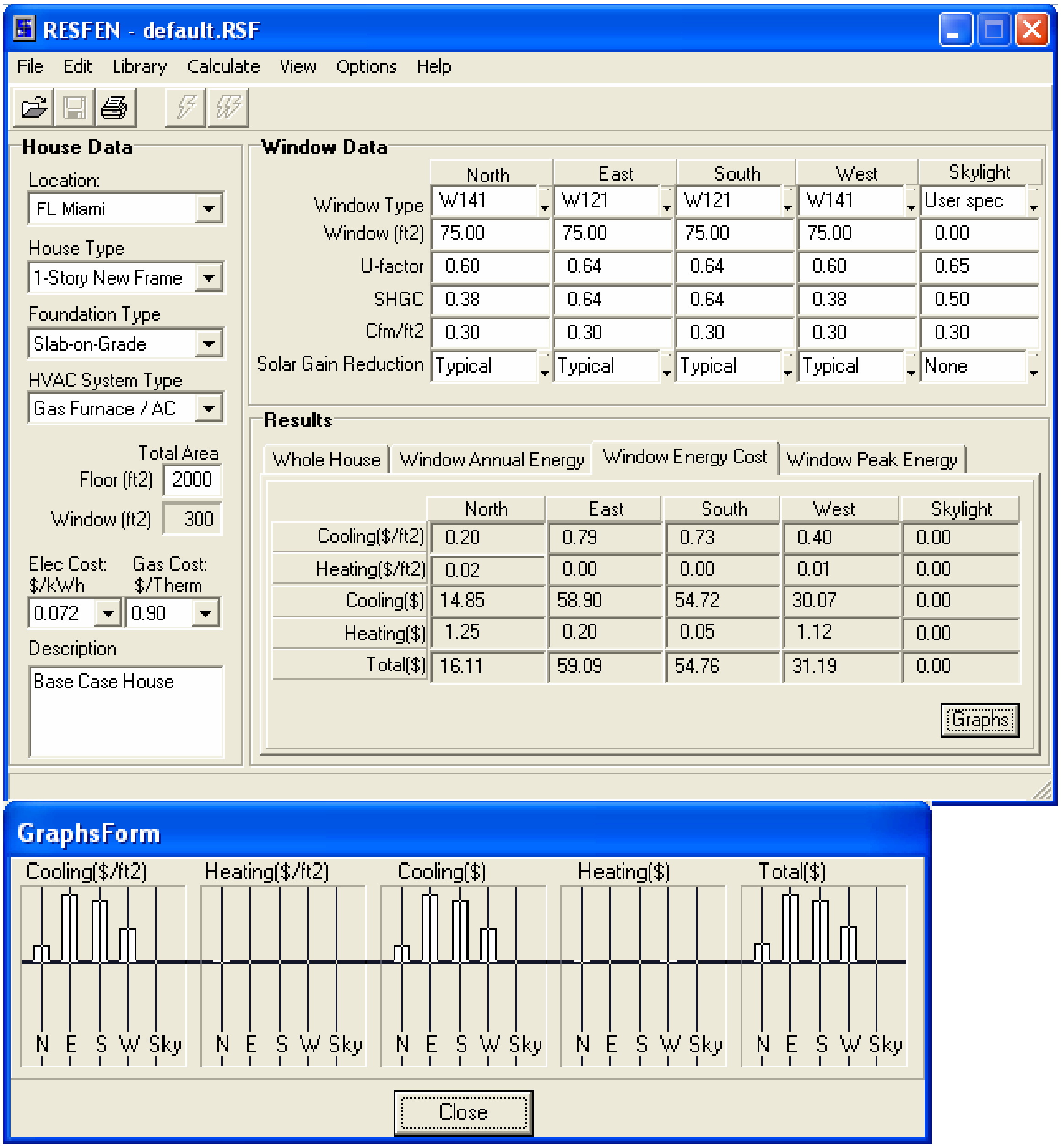

Figure 5. RESFEN Computer Program