Glazing Performance: A Vital Signs Resource Package for the Study of Architectural Glazing

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INTRODUCTION

The Vital Signs project has been spearheaded by Cris Benton of the Building Sciences Group at the University of California, Berkeley. Funding and support has been provided by the Energy Foundation, the National Science Foundation, the Department of Energy and the PG&E Energy Center. The development of the twelve current curriculum materials packages has involved eleven additional Universities, with the authors of this paper collaborating together on the production of two packages; the Glazing Package and a second on the concept of the Balance Point as a global measure of the environmental "fit" of a given building in its context.

Fig. 1. The Republic Newspaper Plant, Columbus, Indiana, Myron Goldsmith, SOM, 1971.

Consistent in general format with other Vital Signs packages, the Glazing Package includes a range of background material useful for both lecture preparation and class readings, a series of experimental protocols of varying levels of sophistication, and a series of appendices outlining sources for further information.

GLASS AND ARCHITECTURAL DESIGN

Glass as a material plays a large part in mediating the relation between inside and out, but until relatively recently the glass itself did not present a great variety of different possibilities to be sorted out in the design process. Glass, at least as far as its performance was concerned, was simple. It let in consistently high amounts of light and attendant solar heat, It blocked the passage of air from inside to out but otherwise provided little thermal insulation. It didn't screen enough UV to save the curtains from fading. It captured reradiant heat inside the space, for better or worse. Unwanted consequences of the use of glass were addressed by other means, such as architectural shading devices or HVAC systems dependent on cheap energy and a blind eye to the degradation of the planet. The desire for connection between inside and out, coupled with the limitations of glass, led either to energy wasteful design or to the elaboration of all of the other elements of the envelope in compensation.

Advances in glazing technology have now increased the control that the glazing itself can exert on the flows of energy between the inside and out. Coatings applied to glass can control the amount of light admitted, reflect away unwanted ultraviolet radiation and solar heat energy and reflect back into the room heat that would otherwise escape. Many such coatings are visually transparent and undetectable to the casual observer. Sealed multi-pane glazing units in conjunction with suspended films and inert gasses such as argon have increased the insulative values of typical windows from R-1 to R-3 and have made possible "superwindows" of R-7 and higher.

These advances turn window design on its head. They throw into question all of the balancing acts of past architecture and suggest that new forms of balance are possible. They have the potential to lead again to a dramatic rethinking of architecture similar to that which accompanied the availability of the first large sheets of glass at the beginning of the twentieth century. Understanding the thermal and luminous properties of glazing systems has become central to understanding the future of thermal and luminous design in general.

What is the image of this technology? Does it simply represent "getting it right this time," revisiting the 20th-century history of glass architecture without the associated environmental costs? What is the role of the rest of the envelope in enhancing the performance of these new glazings? How will the envelope as an integrated whole continue to evolve towards an ecologically sophisticated technology? And what new architectural expressions will emerge from the balancing act of juggling the demands of view, light and heat control as the rules continue to change? These are questions that cutting edge professionals as well as beginning students currently find worth pondering, making glazing a compelling focal point for teaching environmental technology.

OUTLINE OF THE GLAZING PACKAGE

The goals of this Vital Signs Glazing Performance package are to teach students 1) to understand the interrelationships of the design issues pertaining to the use of various glazings, particularly those issues relating to the thermal and luminous environments of buildings, 2) to identify the general types of glazings found in use and investigate their thermal and luminous performance characteristics, and 3) to be able to specify glazing with an eye towards optimizing a structure's thermal and luminous performance. As a compliment to these immediate pedagogical goals, the package provides a standardized format for collecting case study information; information that plays a direct role in other Vital Signs packages.

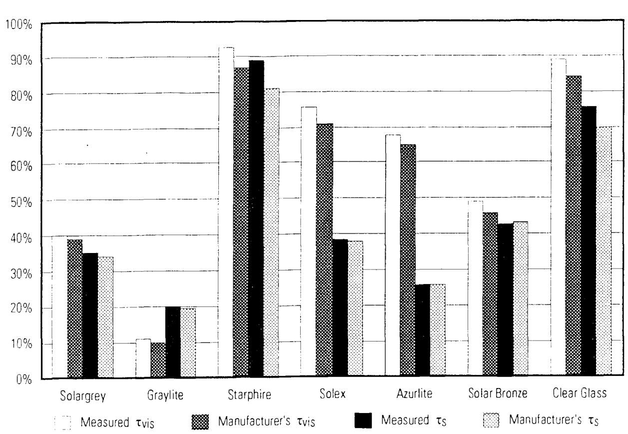

Fig. 2. Comparison of measured transmittance (visible and solar) with manufacturer's data for a variety of glass types. The manufacturer's data was drawn from the **WINDOW 4.1** database.

The background material includes an extended essay on the fundamental principles of solar radiation and thermal transfer applicable to glazing, an essay on the changing role of glazing in architectural design, a discussion of the codes, energy performance standards and incentives that might inform the architect's selection of a specific type of glazing, and other information that puts the package in perspective and suggests avenues of future development.

The experimental protocols of the Vital Signs Project are divided into three levels, based on their relative complexity. ***Level 1*** involves preliminary observations that can be made by an informed observer in a single visit and without special instrumentation. These are generally appropriate for introductory classes. ***Level 2*** involves short duration experiments that can be made with standard Vital Signs instruments on a single site visit. These are intended for more advanced classes. The ***Level 3*** experiments are more sophisticated and require longer term data gathering. Level 3 is appropriate for graduate level research, raising issues on the cutting edge of environmental performance modeling.

Also included in this package are two computer modeling exercises: one providing a general overview of the effects of glazing on energy flows in a building and the other models energy flows through specific glazing assemblies. These are meant to compliment and extend the field protocols and are provided free of charge with the package.

INNOVATIONS AND EXPERIENCES

The development of this teaching material has involved numerous small but original insights and contributions that we would like to call attention to in conclusion. At the same time, the limited experiences that we have had with it in the class room so far suggest a self critique.

As stated in the introduction, the Vital Signs project has been driven in equal measures by interest in process and product, and the Glazing Package for one has a great deal of redundancy as a result. The package is intended to be dissected and reassembled to suit the needs of whoever might use it. The package puts the emphasis on flexibility of process while a clear, concise approach to the case study as a product is only now beginning to emerge out of such exercises as the recent Vital Signs Case Study Competition. Our experience in both using the protocols in class and in coaching students in the competition has confirms this fact, hopefully for the better. Our recent introductory class producing entries for the competition did so without using any of the protocols directly, but the background materials were still useful in constructing alternative exercises to fit the given syllabus.

A second significant aspect of the Glazing package is the twenty pages of text and diagrams that we have devoted to introducing basic concepts of solar and thermal radiation transfer. While much of this material is gathered from other sources, here these concepts are introduced in the shadow of contemporary glass technology. We have found that keeping this "application" in the foreground has worked well to motivate discussion of the otherwise abstract physical principles that are the foundations for more general discussions of climate responsive design.

Even where material has been borrowed, we have made attempts to rework it for our own ends, elaborating on the material both conceptually and graphically. A simple example of this is taken from the discussion of center of glass and overall U-values. In an accompanying side bar illustration, ASHRAE U-value data is represented visually in a way that highlights the discrepancy between ideal and actual performance directly.

A time line of 20th-century glazing technology developments collects together disparate facts and statistics into a compelling narrative of the impact of this evolving technology on design. Did you know, for example, that between 1974 and 1994 the ratio of glass area to floor area in a typical U.S. house increased by 25%? Or that low-e coatings, which only became available in 1979, were present on one third of the residential windows sold in the U.S. in 1993? This list is one of the more open-ended aspects of the package, and one that we have openly encouraged students to contribute to, since the package is being maintained as an active site on the World Wide Web.

Finally, the technical challenge of the research was to devise methods of using the latest generation of inexpensive sensing and data logging devices to determine building performance characteristics in the field. These methods are required to be reasonably accurate and to be transparent

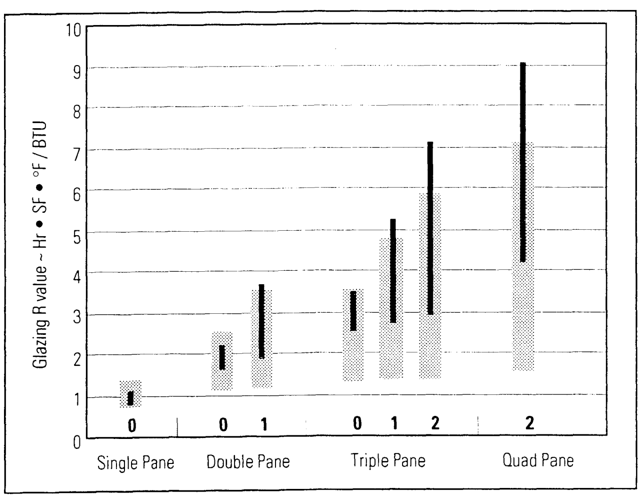

Fig. 3. Center of Glass and Overall Thermal Resistance for a Range of Fenestration Products in a Vertical Orientation. Adapted from data given in *ASHRAE Handbook of Fundamentals* (1993) Table 27.5. Thin *black lines* represent center of glass values. The low end of each line is characterized by 0.25" gap spacings and air filled gaps. The high end is characterized by 0.5" gap spacings and argon filled gaps. *Thick gray lines* represent overall unit values. The low end is of each line is characterized by aluminum frames without thermal breaks and standard metal edge spacers. The high end is characterized by insulated fiberglass/vinyl frames and insulated spacers. *Bold numbers* below each set of lines state the number of low-e coatings for each assembly.

enough in use that they are appropriately understood as surrogates. they are also required to be easy to use properly to assure the desired results.

Two of the protocols deserve special attention in this regard. Protocols 2a and 2c involve determining visible and total solar transmittances of first manufacturers' samples and then glazing in the field using hand held Li-Cor sensors. These measurements are shown through student comparisons to published data to be reasonably accurate for single and multiple layer glazing, glazing with low emissivity coatings and glazing with tints. The measurements are less accurate in dealing with glazings with visible metallic reflective coatings, a limitation of the sensor technology at this affordable price range.

Protocol 3A provides an experimental method for determining center of glass U-values in the field using single channel Hobo-Temp temperature data loggers. The resulting measurements are shown in our own published example to be sensitive enough to distinguish between hard and soft coat low emissivity coatings. This experiment requires time, some understanding of heat transfer mechanisms and a reasonable skill level with Excel.

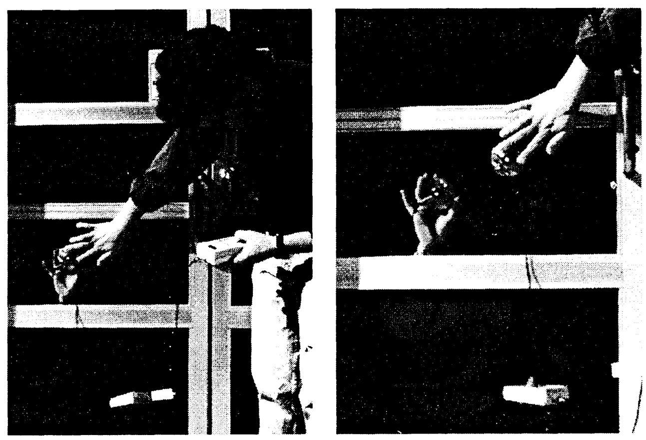

Fig. 4. Students measuring glazing transmittance in the field.

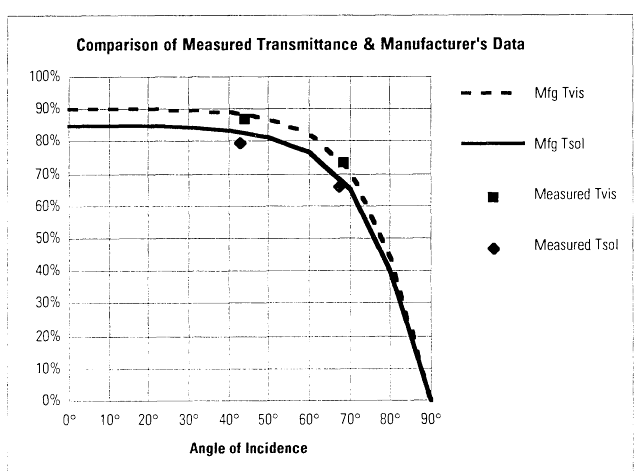

Fig. 5. Comparison of manufacturer's data and field measurements. The angle of incidence of solar radiation is accounted.

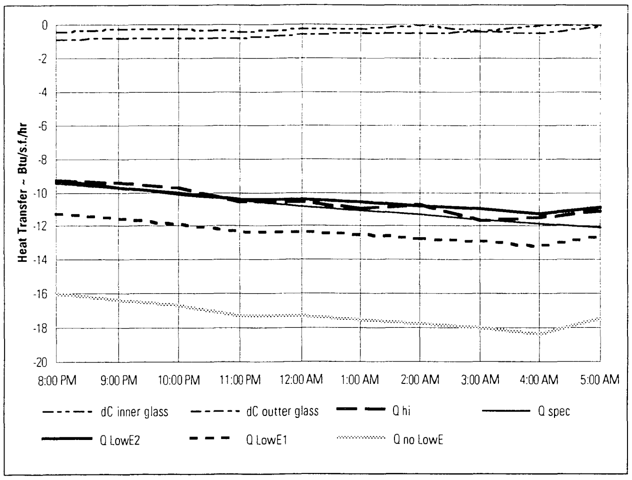

Figure 6: Heat flow across the glazing estimated from measured surface and air temperatures.

The heat released by the glass as its temperature drops as its temperature drops, dC inner glass and dC outer glass, are relatively small energy flows compared with the total estimated heat flow from building to environment. This suggests that the steady state assumptions used in the protocol are reasonable.

Finally, the package includes a number of Excel spreadsheet and macro templates which augment the field excercises and allow annual modeling of glazing performance. These worksheets are available on the world wide web (address: http://www.sarup.uwm.edu/JCI/vsg2.html).

This Glazing Performance package is offered as a starting point in the development of a curriculum covering glazing performance at a number of levels of sophistication. It is just that: a starting point and not the final word. In conclusion we would point to some of the directions that remain to be fleshed out and tested in the field. This list serves both as a way to put the current package into perspective and as a list

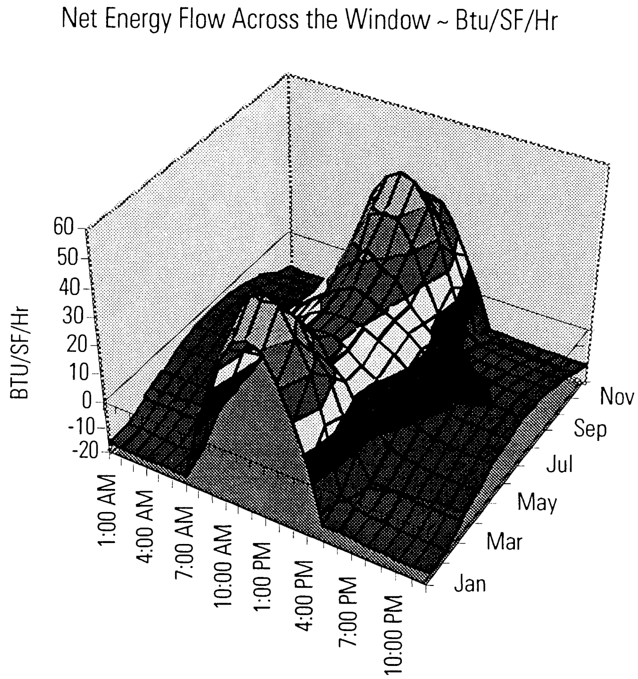

Figure 8: Average hourly heat flow across glazing for the year, an output graph from *Glazing.xlw*.

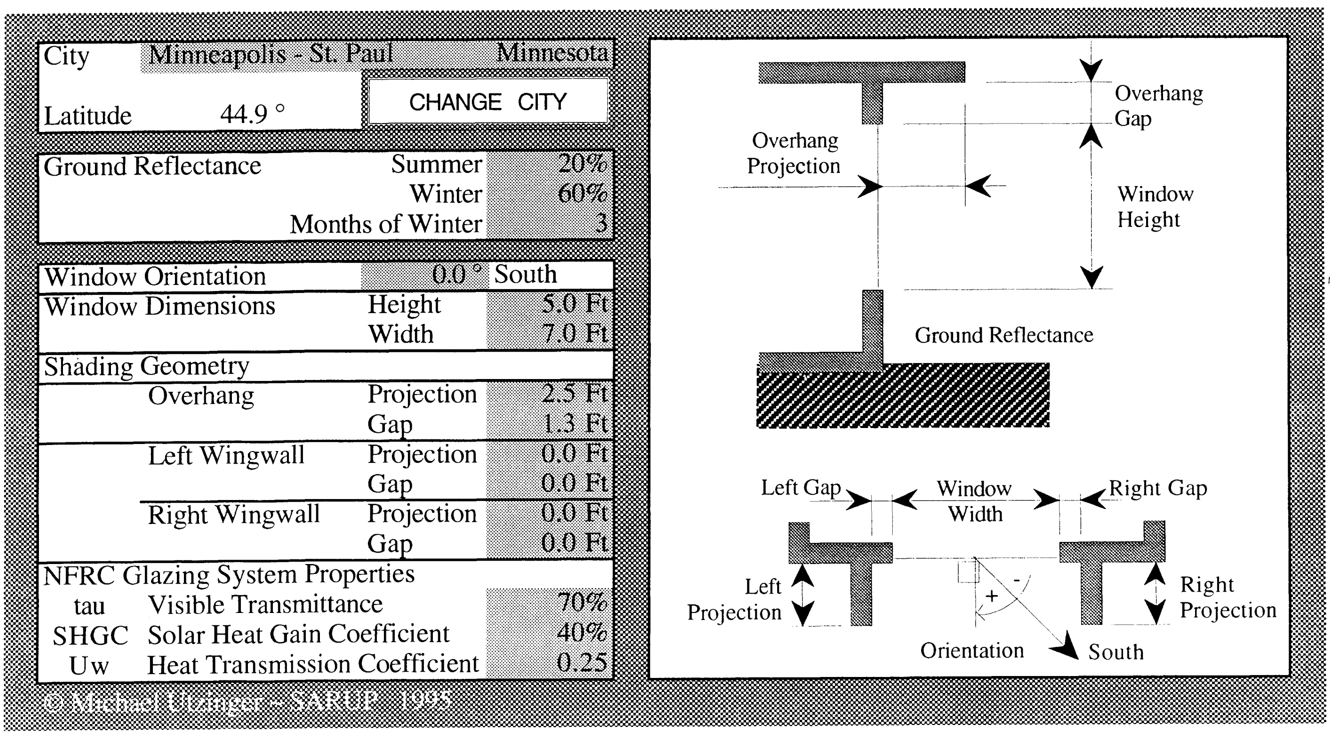

Fig. 7. Data entry page from Excel glazing analysis program *Glazing.xlw*.

of suggestions for independent student research. It is our hope that the package itself will continue to grow and develop along with the library of case studies that it aims to promote.

First, to reemphasize a point implicit in the protocols, the development of a school collection of glazing samples is one of the most helpful first steps towards introducing this topic in class. In our experience, having the samples on hand makes the use of even relatively dry numerical information such as found in *WINDOWS4.1* engaging. Subtle differences in coloration and other visual distinctions that are difficult to see in the field can be seen easily in the samples, and the dramatic performance features such as low-e coatings that can't be seen are more real when they can be tested in class. Samples can be obtained by either contacting the glazing manufacturers (listed in the Appendices) or local suppliers.

Several additional research topics could add to the depth as well as breadth of the package:

- The dynamic quality of interior daylight and the connection to the outside that daylight provides has both an aesthetic and psychological dimension that should be discussed.
- The degree to which color harmony with other facade materials dominates the choice of glazing in commercial work needs to be given its due, and the various strategies of integrating performance based selections into an aesthetic solution need to be identified and critiqued.
- A catalog of edge spacer designs by manufacturer and thermal performance could potentially be assembled as part of a field guide to glazing. In a multi-pane assembly, the edge spacer is one of the few distinguishing characteristics of the glazing that is visible. The question is whether different perforation and machining patterns could be used to identify the installed unit by manufacturer and date, and whether that information could be made useful in making educated guesses about performance.
- In conjunction with a field guide to edge spacer performance a protocol could be developed that would use an estimated edge U value with the *WINDOWS 4.1* program to arrive at a total U value. This in turn would allow estimates of net energy flows through the glazing assembly.
- The environmental impact of glass manufacture deserves serious attention. The *AIA Resource Guide* and Button and Pye (1993) (both reviewed in the bibliography) offer initial approaches to this topic, but neither is sufficiently critical to put the issue to rest. As glazing becomes more sophisticated, the materials and manufacturing processes of the coatings and gas fills needs as much examination as the actual glass manufacture. For example, Krypton, which is a high performance fill gas, is a scarce resource. What is the potential impact of using large amounts of Krypton in insulated glazing units?
- The development of a library of glazing specifications would be an invaluable addition to the package and a logical outgrowth of case study projects, where the case studies are conducted on buildings with complete construction records available. See Johnson (1991) for a good chapter on specifying low-e coatings. The Construction Specifications Institute (CSI) would be one professional organization that might be able to offer technical guidance.

We, the authors, will gladly act as a clearing house for any readers willing to build on this initial effort. See the acknowledgments page for information on contacting us.