AC 2012-5014: GLAZING MADE SIMPLE: A DECISION SUPPORT SYSTEM TOOL USING MS EXCEL VBA

Mr. Asaad Mohamed, Auburn University

Asaad Mohamed has a diverse experience and holds several advances degrees in engineering and management. He is currently finishing up a master's in information systems management from Auburn University.

Ms. Emily Reynolds, Auburn University
Dr. Chetan S. Sankar, Auburn University

Chetan S. Sankar is the College of Business Advisory Council Professor of management information systems at Auburn University. He has received more than three million dollars from ten National Science Foundation grants to develop exceptional instructional materials that bring real-world issues into classrooms. He has won awards for research and teaching excellence from the Society for Information Management, NEEDS, Decision Sciences Institute, American Society for Engineering Education, American Society for Mechanical Engineering, International Network for Engineering Education & Research, Computer World, Campus Technology, and the Project Management Institute. He is the Editor-in-Chief of the Decision Sciences Journal of Innovative Education and the Managing Editor of the Journal of STEM Education: Innovations and Research.

Dr. P.K. Raju, Laboratory for Innovative Technology & Engineering Education (LITEE)
Mr. Nanda Kumar B.S.

Nanda Kumar B.S. is Assistant Construction Manager, Center of Excellence & Futuristic Development, Larsen & Toubro, Chennai, India.

Glazing Made Simple:

A Decision Support System Tool Using MS Excel VBA

Abstract

Larsen & Toubro (L&T) –being the largest construction company in India – realizes the importance of being able to offer the best glazing systems to its huge national and international customers. The architects at L&T select glazing systems based on three components: glass type, frame type, and shading. The glass type is chosen based on four sub-criteria: the color, solar heat gain coefficient, visible light transmittance, and U-value.

As part of a NSF International Research Experiences for Students (IRES) project a team of graduate and undergraduate students at a major U.S. university worked with L&T's design engineers at the Center for Excellence and Futuristic Design (CEFD) in conducting all the necessary calculations to determine the annual cooling loads for each of the glass-frame-shading combinations. The goal was to tabulate all the necessary values and calculations into an Excel spread sheet and then develop a simple interface –using Visual Basic for Applications (VBA) – for L&T's architects. The program accesses a hidden database that allows the architects to simply select their desired values for the glass type sub-criteria, frame type, and shading type, and then make a decision about which combination is ideal for their particular building design. The decision is based not just on aesthetics, but energy performance as well as some financial metrics such as additional investment and payback period. This results in a simplified decision-making tool with instantaneous consequence comparisons.

Through developing this interface, the project team learned the following:

- The culture and dynamics of working at an international company.
- Interacting and working with students from Indian Universities.
- Different aspects and properties of glass and their impact on the heating/cooling loading of a building.
- How to use data mining techniques to turn large data sets into a simple user interface.

Introduction

In architecture, glazing is the most sought-after technique when it comes to façade, whether it is commercial, governmental or even residential buildings. A welcome change from the mostly dull brick and mortar structures, these glass façades have brought in a near revolution in construction and architecture in the recent times due to their aesthetic appeal and higher natural light allowance. Glass manufacturers have capitalized on this trend –with the help of modern technologies – by offering wide ranges of glasses with different arrays of colors, thermal allowances, and other physical properties. During the mid-1980, the United States consumption of glass in commercial and residential construction was close to $2 billion, and the market for construction glazing systems has steadily grown even during times of housing recessions. [1]

Windows have long been used in buildings for day lighting and ventilation. Many studies have even shown that health, comfort, and productivity are improved due to well-ventilated indoor environments and access to natural light. However, windows also represent a major source of unwanted heat loss, discomfort, and condensation problems. In 1990 alone, the energy used to offset unwanted heat losses and gains through windows in residential and commercial buildings cost the United States $20 billion (one-fourth of all the energy used for space heating and cooling).[2]

The National Institute of Building Sciences states that in recent years, windows have undergone a technological revolution. The variety of glass types, coatings, and frames available for use in window systems has increased dramatically, as has the opportunity to fine-tune and optimize window selection on a project-by-project basis. High-performance, energy-efficient window and glazing systems are now available that can dramatically cut energy consumption and pollution sources: they have lower heat loss, less air leakage, and warmer window surfaces that improve comfort and minimize condensation. These high-performance windows feature double or triple glazing, specialized transparent coatings, insulating gas sandwiched between panes, and improved frames. All of these features reduce heat transfer, thereby cutting the energy lost through windows. [3]

Energy conservation is an important aspect of any building design not only during the construction phase, but also as a running cost. Façade Engineers from the Center for Excellence and Futuristic Development (CEFD) at the Chennai branch of Larsen and Toubro realize that with an extremely hot and humid climate in India and the huge choices of glasses, they needed to tabulate different glazing systems based on their energy performance and financial metrics (cost and Return of Investment). They needed a Decision Support System tool that will act as a database as well as aiding L&T architects in decision making during the design process.

As part of a NSF-IRES project, a team of graduate and undergraduate students at a major U.S. university worked with CEFD design engineers at L&T to conduct all the necessary calculations to determine the annual cooling loads for each of the glass-frame combinations from various domestic and international glazing suppliers. The goal was to tabulate all the necessary values and calculations into an Excel spread sheet and then develop a simple DSS interface –using Visual Basic for Applications (VBA) – for L&T's architects to use during the design process.

Background Info

a. Background of Larsen and Toubro

i. Founded in 1938 by two Danish engineers, Henning Holck-Larsen and Søren Kristian Toubro, L&T is one of the most successful businesses in the entire country of India and certainly a strong leader in the engineering and construction industry. They have an enormous list of accomplishments, such as constructing the world's largest coal gasifier, being a major contributor in India's mission to the moon, and constructing Asia's highest viaduct.

ii. L&T is India's largest engineering and Construction Company, with a dominant presence in India's infrastructure, power, hydrocarbon, machinery and railway related projects. In recent years, L&T has expanded its global presence. International projects contributed 9% of its overall order book for the 2010-11 periods. Considered to be the "bellwether of India's engineering sector", L&T was recognized as the Company of the Year in 2010. L&T has featured four times in Forbes Fab 50 list of the best public companies in the Asia-Pacific region.

iii. Joining the L&T family in 1944, their Engineering Construction and Contracts Division (ECC) is, in fact, the largest construction group in India. They are responsible for the research, design, engineering, and construction of buildings, pipelines, electrical systems, railways, transmission lines, and more. [4]

b. What is a glazing system?

i. Glazing systems are comprised of glass panes, structural frames, and a façade. The interface currently has only the glass panes and the structural frames. The façade, which provides shading from the sunlight, will be added later by Larsen and Toubro. It is important to note that even without the façade; the glass-frame combination performs in a slightly different way than the glass alone. A simple illustration of a glazing system is shown in Figure 1.

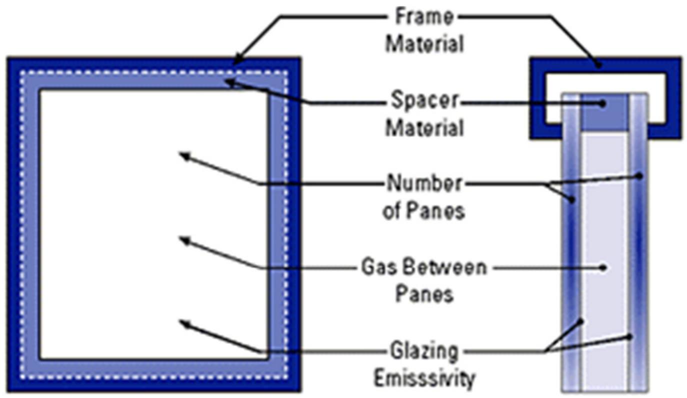


Figure 1: Parts of a Glazing System

ii. Types of glazing systems:

There are different types of glazing systems. [5] Some are listed below:

- *Framed Systems:*

Figure 2: Framed Systems

Framed systems (Figure 2) support the glass continuously along two or four sides. There are many variations of framed systems, most of which fall into two general categories. Conventional unitized curtain wall systems are seldom used with structural glass façades.

- *Stick:*

Figure 3: Stick-Built Glass Façade

Stick-built glass façades are a method of curtain wall construction where much of the fabrication and assembly takes place in the field. Mullions of extruded aluminum may be prefabricated, but are delivered as unassembled “sticks” to the building site. The mullion sticks are then installed onto the building face to create a frame for the glass, which is installed subsequently. Economical off-the-shelf stick curtain wall products are available from various manufacturers that may be suitable for application in structural glass façades, primarily on truss systems.

- *Veneer:*

Figure 4: Veneer Systems

Truss systems (Figure 4) can be designed with an outer chord of square or rectangular tubing, and may include transom components of similar material, presenting a uniform flat grid installed to high tolerances. Such a system can provide continuous support to the simplest and most minimal off-the-shelf glazing system, thus combining relatively high transparency with excellent economy. A veneer glazing system is essentially a stick-built curtain wall system designed for continuous support and representing a higher level of system integration with resulting efficiencies. Variations can include 4-sided capture, 2-sided capture, structurally glazed and unitized systems.

- *Panel/Cassette:*

Figure 5: Panel Systems

Panel systems (Figure 5) are typically constructed of a framed glass lite. The framed panel can then be point-supported by a supporting structural system, while the glass remains continuously supported on two or four sides. This also allows the panel to be stepped away from the support system - a practice that tends to visually lighten the façade. Panel systems can be prefabricated, benefiting from assembly under factory-controlled conditions.

Cassette systems combine properties of stick, veneer and panel systems. While variations exist, the predominant makeup of a cassette system is comprised of a primary structural mullion system, which is stick built. These provide the support and facilitate the attachment of the glass panels. The glass lites are factory assembled into minimal frames, which form an integral connection with the primary mullion system. A cassette system can be designed to be fully shop-glazed, requiring no application of sealant during field installation.

- *Frameless Systems:*

Figure 6: Frameless Systems

Frameless systems utilize glass panes that are fixed to a structural system at discrete points, usually near the corners of the glass panel (point-fixed). The glass is directly supported without the use of perimeter framing elements. The glass used in point-fixed applications is typically heat-treated.

- *Point-fixed Bolted:*

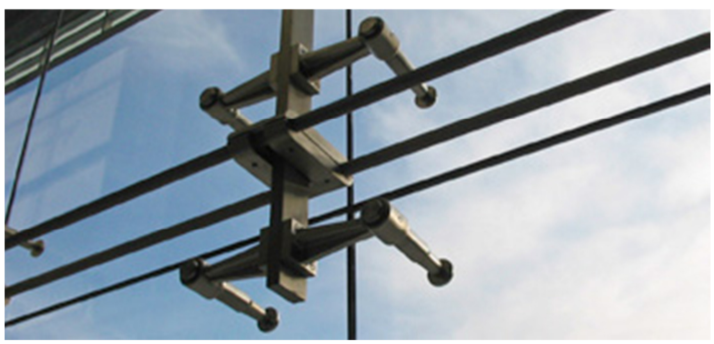


Figure 7: Bolted Glass Systems

The most popular glass system — and frequently the most expensive — for application with structural glass façades is the bolted version (Figure 7). The glass panel requires perforations to accommodate specialized bolting hardware. Specially designed off-the-shelf hardware systems are readily available, or custom components can be designed. Cast stainless steel spider fittings are most commonly used to tie the glass to the supporting structure, although custom fittings are often developed for larger façade projects. The glass must be designed to accommodate bending loads and deflections resulting from the fixing method. An insulated-laminated glass panel as required for overhead applications will require the fabrication of 12 holes per panel, which can represent a cost constraint on some projects.

- *Point-fixed Clamped:*

Figure 8: Clamped Systems

Point-fixed clamped systems (Figure 8) accomplish the point fixing without the requirement for perforations in the glass. In the case of a spider type fitting, the spider is rotated 45 degrees from the bolted position so that its arms align with the glass seams. A thin blade penetrates through the seam between adjacent pieces of glass. An exterior plate attaches to the blade and clamps the glass in place. The bolted systems present an uninterrupted glass surface, while the clamped systems expose the small exterior clamp plate. Some façade designers prefer the exposed hardware aesthetic. While the clamped systems have the potential for greater economy by eliminating the need for glass perforations, the cost of the clamping hardware may offset at least some of this savings depending upon the efficiency of the design.

- *Weather Seal:*

Figure 9: Weather Seal

The weather seal in most structural glass façade systems is provided by a field applied butt-glazed silicone joint (Figure 9). This technique provides a reliable and durable weather seal if simple procedures are followed during installation. An advantage of this sealing strategy is that any leaks, usually caused by installation errors, are easily detected and repaired. The joint design is critical, and is largely a function of the glass makeup and thickness. Compatibility between the field-applied silicone and the interlayer, if using laminated glass, or the edge seal in the case of an IGU, must be confirmed with the silicone material provider. The provider should also be consulted about the joint design. Craftsmanship is critical for the field application of the sealant to assure a visually satisfactory result.

c. The Project

i. The State of the System Initially

There are several companies that offer a wide range of glass varieties for windows and building walls. This provides architects great room for creativity in their designs. Yet, there are some constraints when it comes to making decisions based on initial and running costs and ultimately deciding which design would yield a better additional investment and payback period. The heating and cooling loads – which are a major portion of the financial calculations – make the glass comparisons even more tedious and troublesome. These calculations used to be done every time a new glass needed to be selected, thus the need for computerization. A database with most of the calculations for a generic building prototype already tabulated, combined with a simple user interface tool that helps architects make more informed decision, was vital to the architects' efficiency. The CEFD at Larsen and Toubro realized that need and assigned our team to work on building this database/tool.

ii. Calculations

1. <u>The Input Metrics</u>

The input metrics describe the heating and cooling properties of each glass. Based on the building project at hand, the architect will have certain desired values for these metrics, as well as glass color. He/she will use those constraints to find the appropriate glasses and then go on to choose a frame based on the output metrics, which are described in the next section. Here is a brief description of each of the input metrics:

a. SHGC – Solar Heat Gain Coefficient

SHGC indicates how much of the sun's energy striking the window is transmitted through the window as heat. As the SHGC increases, the solar gain potential through a given window increases.

- The SHGC is a ratio between 0 and 1. SHGC = 0 means none of the incident solar gain is transmitted through the window as heat and SHGC = 1 means all of the incident solar energy is transmitted through the window as heat.
- A window with a SHGC of 0.6 will admit twice as much solar heat gain as one with a SHGC of 0.3.
- Typically, windows with low SHGC values are desirable in buildings with high air-conditioning loads while windows with high SHGC values are desirable in buildings where passive solar heating is needed.
- The term "SHGC" is relatively new and is intended to replace the term "shading coefficient (SC)." While the terms are related, the shading coefficient of glass is defined as the ratio of the solar heat gain through a given glazing as compared to that of clear, 1/8 inch single pane glass.

b. VLT – Visible Light Transmittance

The VLT value indicates the percentage of the visible portion of the solar spectrum that is transmitted through a given glass product.

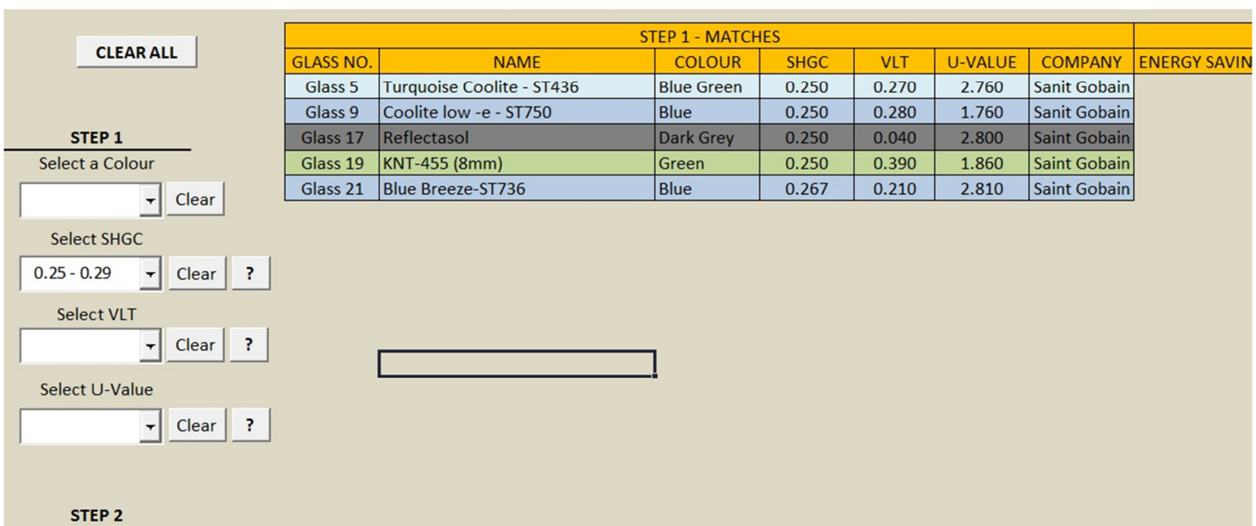
Sunlight is an electromagnetic form of energy exchange between the sun and the earth. It is composed of a range of electromagnetic wavelengths, generally categorized as ultraviolet (UV), visible, and infrared (IR) referred to collectively as the solar spectrum.

The short, UV wavelengths are largely invisible to the naked eye, but are responsible for fabric fading and skin damage. Visible light is made up of those wavelengths detectable by the human eye. This light contains about 47% of the energy in sunlight. Longer IR wavelengths are also invisible and contain about 46% of the energy in sunlight.

c. U-Value – Overall Heat Transfer Coefficient

- U-value indicates the rate of heat flow due to conduction, convection, and radiation through a window as a result of a temperature difference between the inside and outside. The higher the U-factor the more heat is transferred (lost) through the window in winter.
- The units of U-value are: BTUs per hour per square foot per °F (BTU/hr • ft² • °F)
- U-factors usually range from a high of 1.3 (for a typical aluminum frame single glazed window) to a low of around 0.2 (for a multi-paned, high-performance window with low-emissivity coatings and insulated frames).
- A window with a U-factor of 0.6 will lose twice as much heat under the same conditions as one with a U-factor of 0.3.
- Total (or net) window U-factors can be considerably higher than the center-of-glass U-factors. [6]

Figure 10 illustrates the sample metrics using the interface.



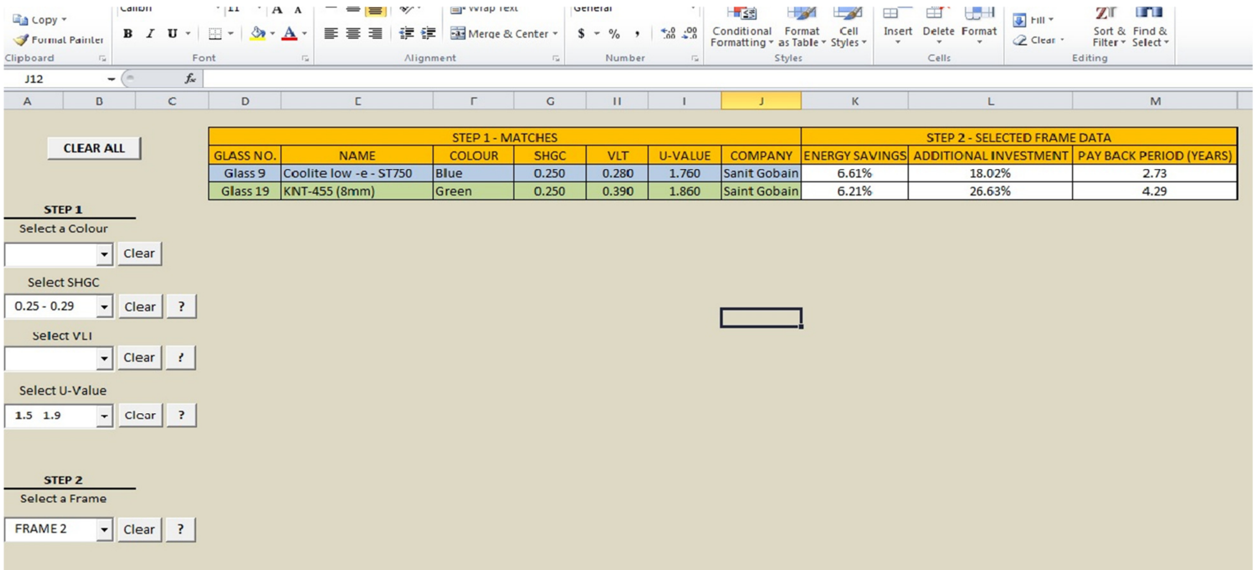
STEP 1 - MATCHES							
GLASS NO.	NAME	COLOUR	SHGC	VLT	U-VALUE	COMPANY	ENERGY SAVIN
Glass 5	Turquoise Coolite - ST436	Blue Green	0.250	0.270	2.760	Sanit Gobain	
Glass 9	Coolite low -e - ST750	Blue	0.250	0.280	1.760	Sanit Gobain	
Glass 17	Reflectasol	Dark Grey	0.250	0.040	2.800	Saint Gobain	
Glass 19	KNT-455 (8mm)	Green	0.250	0.390	1.860	Saint Gobain	
Glass 21	Blue Breeze-ST736	Blue	0.267	0.210	2.810	Saint Gobain	

Figure 10: Sample Input Metrics

2. <u>The Output Metrics</u>

While the input metrics narrow down the list of glasses, the best glass-frame combination is chosen based on the three output values: Energy Savings, Additional Investment, and Payback Period.

Figure 11 illustrates some of the output metrics.



STEP 1 - MATCHES							STEP 2 - SELECTED FRAME DATA		
GLASS NO.	NAME	COLOUR	SHGC	VLT	U-VALUE	COMPANY	ENERGY SAVINGS	ADDITIONAL INVESTMENT	PAY BACK PERIOD (YEARS)
Glass 9	Coolite low -e - ST750	Blue	0.250	0.280	1.760	Sanit Gobain	6.61%	18.02%	2.73
Glass 19	KNT-455 (8mm)	Green	0.250	0.390	1.860	Saint Gobain	6.21%	26.63%	4.29

Figure 11: Sample of Output Metrics

The output values are found by feeding the specific glass *input* values (SHGC, VLT and U-value) into the WINDOW Software database. Each glass is combined with an 8 mm clear glass with 12 mm air gap in between as a unit. The combined system's values are then calculated. Then these new values are fed into the THERM Software to get the *output* values for the combinations of that glass with each of the five frames. An assumption is made of a 15 °C temperature difference between the inside and outside environments (Chennai's design conditions).

a. Energy Savings

First, the cooling load for a whole year is calculated using DESIGN BUILDER Software. The overall U-Value, SHGC and VLT obtained from WINDOW Software are given as an input in DESIGN BUILDER with following assumptions:

- Typical building size of 50 m × 50 m× 4 m considered
- Window to wall ratio of 40% considered
- Orientation of the building – North
- 100% conditioned area assumed

These assumptions were provided by the CEFD at L&T as typical commercial building design that could be used as reference point for comparison between different glasses.

Then the energy saving is calculated as a ratio between the difference in cooling load of that glazing system compared to the clear double glazing system divided by the cooling load of the clear glazing system.

Example:

Cooling load for glass2frame3 = 104.363 KW

Energy Savings = (cooling load glass1frame1 – cooling load glass2frame3) / cooling load glass1frame1

= (116.482 – 104.363)/116.482

= 10.40%

b. Additional Investment

Additional Investment = (Cost of the Frame and Glass – Cost of the Base Frame and Base glass)/ (Cost of frame and glass)

Example:

Additional Investment for Frame3Glass3 = (6821.02-4891.37)/6821.02 =28.29%

c. Pay Back Period

Payback period = Additional Investment % /Energy Savings % (in years)

Example:

Simple Payback for Glass3Frame3 = 28.29%/7.56% = 3.74 Years

iii. Data Organization

After the calculations were made, they had to be organized. The list of glasses, list of frames, and each input and output metric was placed in its own worksheet in the Glazing Selection Tool workbook. It is important to remember that this is a user interface, which means that appearance is important – not just calculations! Every worksheet was made to have the same coloring, font style and sizes, etc.

iv. Creating the Program

After the data was organized, it was time to create the program! One of the things that are especially useful about VBA is that it is inside of/cooperates with Excel, so that any data you calculate can be print out to the Excel workbook in a very organized fashion. This is great because while not everyone understands programming languages, everyone *does* understand Excel.[7]

1. What the Program Does:

a. There is a large amount of data that goes into making these comparisons, so to make things very simple, the program hides all of the background data so that the architects do not have to worry about the calculations behind the parameters. The code adapts to changes in the data worksheets, so if the engineers in Larsen and Toubro's ECC division add any materials to the database or change any of the data, the interface will update itself and the architects will have the most up-to-date set of data from which to choose their glazing system.

b. How the Selection Process Works:

i. IMPORTANT: When the file is opened, if there is a warning displayed at the top of the Excel worksheet, click "Options" and then "Enable This Content." The program will not work if this is not done.

ii. Click the "Go To Glazing Selection Tool" button.

iii. A pop-up will explain the base of all the calculated values; Click OK to continue to the tool.

iv. There are three steps in the glazing system selection process: glass selection, frame selection, and shading. For the purposes of this project, we will only consider the first two steps.

a) In STEP 1, tell the program what color, SHGC, VLT, and/or U-Value you would like to have in your glass. Click the question mark beside any of the drop-down boxes for information about that parameter. You can leave any of them blank if you do not wish to specify a parameter, but at least one of the four must have a selection in order to move on to STEP 2. The program will list on the chart all of the glasses in the current database matching your selections.

b) In STEP 2, when you select a frame, the Energy Savings, Additional Investment, and Pay Back Period will be calculated for each glass listed from STEP 1 and displayed in the chart to the right. Selecting different frames will allow you to see the financial effects of different glass/frame combinations, which will help you decide which one is best for your specific requirements.

c) In STEP 3, you would ideally continue to the third step of the glazing selection process, shading. However, that part of the tool has not yet been developed. It will eventually lead you to an online selection tool. For now, base your glazing system selection on steps 1 and 2 only.

2. What the Glazing Selection Tool looks like:

Figure 12 provides an example of how the selection tool looks after the programming was done.

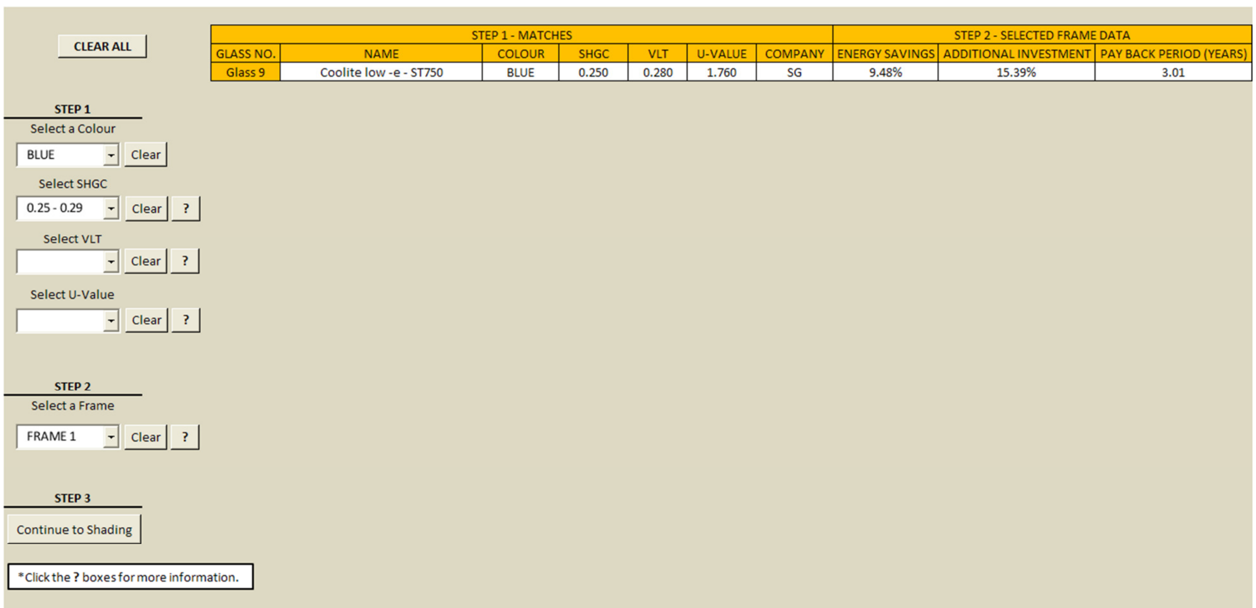


Figure 12: User Interface

The interface currently has only the glass panes and the structural frames. The façade, which provides shading from the sunlight, will be added later by CEFD engineers at Larsen and Toubro.

Student Participation and Cultural Aspects

Initially one Indian student intern was already working on the project. He has started identifying and tabulating some of the glasses that L&T architect could use from both domestic (Indian) and foreign glass suppliers. After selecting a few numbers of glasses, student interns were directed to start the calculation process using already available tools and software provided by CEFD engineers at L&T. During this process there was a learning curve to understand all the metrics involved and their impact on energy savings.

Afterwards the interns were directed to start the process of building the interface tool. One other US student intern already working in a different project for different client in Chennai India joined in because of her extensive knowledge in VBA programming. After several trials and iterations, the interface tool was developed and then tested according to the requirement set by CEFD engineers at L&T.

Throughout the development phase of this interface, the project team has a great opportunity to learn and interact with a different cultural work environment. L&T –being a large and very competitive company -represented a nice model for Indian work customs. While the hours are almost the same as any US company -9 to 5 every day and 5 to 6 days a week- the pace seemed to be less tense. Breaks were more frequent and a bit longer. Cooler conversations are still the same although in India they are Tea/coffee conversations. This is attributed to the fact the work has a more social element compared to the US. This enhances interaction and collaboration and improves productivity. There were several students who were working as interns at the company during the summer. Even though these internships were unpaid, students have to work very hard as these were mandatory requirement by curriculum of their universities. The company has integrated this system into their operational decisions and found interns projects to be useful to the architects.

Conclusion

The NSF International Research Experience for Students provides great opportunities for US students to travel, interact and work on viable projects at several Indian companies and universities. This provides US students with a great cultural as well as work experience that will enhance their learning capability, especially in global affairs. With a lot of companies forced to be more competitive in the global markets, these students will be more equipped with the multicultural experience and know-how compared to their peers.

Credits

The authors would like to thank the National Science Foundation (NSF#0966561) for funding this project. Great appreciation goes to Larsen and Toubro in Chennai, India, for facilitating our work on this project, especially Mr. Rajan Venkateswaran (Head of CEFD) as well as Mr. Nandakumar B. S. and Mr. Rajasekar Elangovan for their help and support.

Disclaimer:

The views and opinions expressed in this case study solely expressions of the authors and do not necessarily reflect the official policy or position of the National Science Foundation.

References

1. Webpage: http://www.referenceforbusiness.com/industries/Construction/Glass-Glazing-Work.html
2. Webpage: http://www.wbdg.org/resources/windows.php
3. Webpage: http://www.wikipedia.org/
4. Webpage: http://www.enclos.com/service-technology/glazing-systems/
5. Webpage: http://www.wbdg.org
6. Webpage: http://www.wbdg.org/resources/windows.php
7. Webpage: http://www.ozgrid.com/VBA/