Energy Implications for Glass in the Built Environment

There are millions of buildings in the United States and because of the physical, psychological and productivity benefits of glass, most buildings have many windows. The total number of windows is in the hundreds of millions. Many of these windows are single pane construction. These are not energy efficient. Typically they offer no protection from the heating effect of the sun's infra red rays in the summer. To compensate for the increased heat, the air conditioning in the building must be turned on. In the winter, these windows offer little protection for the loss of heat from inside the building. Consequently, the heating system must be turned on. Industry solutions to date for heat transmission loss through glass entail the use of cavity construction (i.e. double pane), low-e coatings and inert gas filling. These improvements have helped reduce energy loss in the built environment, e.g. doubling thermal resistance from an R-value of 1 to 2 and as much as 5 in some advanced constructions. These performance levels are far below that of standard wall construction with values in excess of R-19. Similar observations can be made for summer-time solar radiant heat, as measured by the solar heat gain coefficient (SHGC) through glass vs. other building materials. Glass performance improvements have leveled off for the last 30 years and new discoveries through R&D must be made to continue to reduce and eliminate energy wasted through building windows.

According to the U.S. Green Building Council:

- Buildings consume 70 percent of the electricity load in the U.S.;
- The primary use of this energy is to light, heat and cool these buildings, and half of that energy literally goes right out the windows;
- Buildings account for 38 percent of CO_2 emissions in the U.S. alone;
- As populations and economies grow significantly over the coming decades, approximately 15 million new buildings are projected to be constructed to meet demand, and glass will cover 80% of the building envelope;
- Buildings have a lifespan of 50-100 years during which they continually consume and waste energy, resulting in additional CO_2 emissions; and
- Over the next 25 years, CO_2 emissions from buildings are projected to grow faster than any other sector, with emissions from commercial buildings projected to grow fastest — 1.8 percent a year through 2030.

In response to these statistics the government has taken action with Federal and State energy mandates[i] to aggressively manage and reduce this wasteful drain on the economy, our ecology and our dependency on foreign oil.

Fixed Measurements for Dynamic Conditions

The three basic terms used to express thermal performance of a window, door or skylight are: *U-Factor, SHGC, and VT.*

- The U-Factor measures how well a product prevents heat from escaping from the room. U-Factors generally fall between 0.20 and 1.20; the lower the number, the better the performance. The reciprocal of the U-Factor is the more commonly understood R-Value. The U-factors noted provide a range of R-Values from 0.8 to 5.0 where now, higher is better.
- SHGC is the abbreviation for Solar Heat Gain Coefficient, which measures how well a product blocks heat caused by sunlight. SHGC is expressed as a number between 0 and 1; the lower the number, the lower the heat gain.
- VT is the abbreviation for Visible Transmittance, which measures how much light comes through a product. It is expressed as a number between 0 and 1; heavily tinted products have a lower VT.

These static measurements and values are used to model the energy performance of glass for a building to design a suitable HVAC system for human comfort. *ASHRAE Standard 55 defines thermal comfort as "condition of mind that expresses satisfaction with the thermal environment." With a* continually changing external environment, the goal of the HVAC system is to constantly adjust the building climate (via air conditioning or heating) to keep occupants in constant comfort.

Anyone who has sat near a cold window on a winter day recognizes that glass contributes to discomfort. Alternatively, sitting near a window on a hot sunny day forces people to move away from the windows. The limitation of ***static*** glass performance has amplified the growth of the solar reflective and solar absorbing coated glass industry. Further, keeping the blinding glare out of a building has increased the window blind market and led to innovations that turn windows into sunglasses. Unfortunately, static glass performance that optimizes U-Value or SHGC, compromises VT and causes building occupants to add lighting with its attendant energy implications.

Thus, there is a need of a "Thermal Comfort Rating System" that truly models optimum human comfort (thermal and visual) with a continuously changing external environment, and R&D programs that lead to innovative new products to achieve maximum ratings in an environmentally efficient manner.

Human Comfort

Thermal comfort is determined by air temperature, relative humidity, air movement, mean radiant temperature, the presence of direct solar radiation or insolation, and occupants' clothing and activity levels. Architectural glass affects human comfort in several ways.

During cold periods, exterior temperatures drive interior glass and frame surface temperatures down below the room air temperature. How low the glass temperature drops depends on the window's insulating quality (U-Value). If people are exposed to the effects of a cold surface, they can experience significant radiant heat loss to that cold surface and feel uncomfortable, even if the room air temperature is comfortable. The closer they are to a window, the more they feel its influence. The fact that this heat loss occurs on one side of the body more than the other is called radiant asymmetry, and this leads to further discomfort. A familiar example of radiant asymmetry is the experience of sitting around a campfire on a winter night. The side of the body facing the fire is hot, while the side facing away is cold. In the case of a cold window, a person may be cold in warm clothes in a 70 degrees Fahrenheit room air temperature if part of the body is losing heat to a cold window.

Drafts near windows caused by a convective loop are another major source of winter discomfort. Many people mistakenly attribute drafts to leaky windows when in fact they are the result of cold air patterns initiated by cold window surfaces. Air next to the window is cooled and drops to the floor. It is then replaced by warmer air from the ceiling, which in turn is cooled. This sets up an air movement pattern that feels drafty and accelerates heat loss. Cold-temperature-induced drafts occur at the same time as radiant discomfort. This emphasizes the need for insulating windows that maximize interior glass and frame surface temperatures under cold environmental conditions.

Similar observations can be made regarding solar radiant energy transmitted through a window (SHGC). The common experience to be noted in this case is that of sitting next to a window on a bright day. The part of the body facing the window will be at elevated temperature vs. the other side, causing asymmetry that creates discomfort despite a suitable room temperature.

Ultimately, building performance should be measured by occupant performance, which in part can be related to occupant comfort. Thus, a dynamic "Thermal Comfort Rating System" will stimulate product development to attain maximum occupant comfort and productivity.

Daylighting and Productivity

Buildings can be more productive places to work with improved comfort and natural daylight.

One way to look at productivity is to consider the total life-cycle costs of a workplace each year. In private sector offices, such costs are typically, in order of magnitude: $200 per square foot per year for salaries, $20 per square foot per year for amortized brick and mortar costs and $2 per square foot per year for energy.

In this situation, an additional $2 per square foot per year for brick and mortar costs—or providing more daylighting or better acoustical privacy—would pay for itself if it generated a modest 1 percent increase in salary "productivity." Therefore design strategies that increase user satisfaction and work effectiveness should be considered not as cost “extras”, but as productivity investments that enhance an organization's overall success, including recruitment and commitment.

Today’s Windows

Over the last 30 years, window performance has continuously improved, but it is now plateauing. High-performance, energy-efficient window and glazing systems are now available that can dramatically cut energy consumption. They have lower heat loss, less air leakage, and warmer window and frame 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 thermally improved frames. Some might include argon gas fill and warm-edge spacer. All of these features reduce conductive, convective or radiant energy transfer, thereby cutting the energy loss through windows and improving thermal comfort.

To properly specify a window system, an architect takes into account: window U-value, window solar heat gain coefficient, and glass visible transmittance. These static values are used to fine-tune and optimize glazing selections, but fail to maximize energy efficiency and human comfort. The solution for optimal environmental control is quite complex, and it is paramount that we understand and respond to these complexities.

From Basic Glass to Intelligent Devices

Our world has been transformed with an abundance of information. Glass contributes to the “information age” through its use as a computer display, a monitor or a television. Architectural glass, however, has lagged behind this information age in its ability to dynamically respond to changing external and internal environments.

Dual pane glass units, with static thermal and radiant performance have emerged as the product of choice for commercial buildings and have captured 80% of the window market. The fact that most of these units fail at some point during the typical life of a building has not affected its dominance. The most efficient thermal properties to date are found in glass units that have a vacuum between the two panes of glass, much like a thermos bottle. The product manufactured by only one glass maker has uniformly spaced pillars that keep the glass panes from collapsing and a tube to evacuate the air from the cavity. Unfortunately, this approach is extremely costly and traditional strengthened glass cannot be used in this assembly, limiting its value for the commercial building market.

All of the above static thermal units perform better with the addition of Low-E coating to one or both of the inside glass surface(s). Low-e coatings and other solar reflective coatings have recently been applied to plastic films and are now commercially available in “suspended film” dual pane units.

Architects are using more glass in commercial buildings, which raises the issues of glare and thermal comfort as well as energy efficiency and conservation. New technologies that allow glass to intelligently adjust for changing environmental conditions are beginning to be commercialized. Much fundamental work, however, needs to be done to make such products affordable and resolve problems specific to each of these early innovations.

The Smart Grid Cooperative

In the past, individual competitive advantage was the key ingredient for a financially successful company. Today’s complex and inter-related world requires synergistic relationships and collaborative efforts to insure sustainability of our environment. This “Green Movement” is generating a new paradigm in the way that we view glass. The next generation of glass must be a major, interactive contributor to the health of the building and the occupants it protects. Glass must become a part of the “Smart Grid Cooperative”.

Electronically controllable glass, working within the Smart Grid Cooperative can optimize grid efficiency by correlating the utility power supply to the adjustable efficiencies of the glazing. Each pane of electronically controllable glass may become part of a ‘mesh’ network of connected nodes. Such glass connected to intelligent mesh networks provide self-configuration, intelligent routing, secure networking, and remote network management via Web Browser or Mobile connected device. Future implementations may even become evolved enough for practical voice control.

A responsive product provides two-way communication with a variety of information systems in the Smart Grid ecosystem; Building Information Systems; Smart Grid metering infrastructure, data management software are examples. This is provided via interconnectivity to standards-based network protocols such as TCP/IP in wide use today.

The Smart Grid connectivity to the building envelope, may allow real-time energy usage, transfer, monitoring and control through the glass. This would be a faster and more direct method for controlling energy usage than waiting for the building’s air conditioning system to respond to manual inputs or via traditional air-based thermostats, which are not connected to the building envelope. Glass can be used as a sensor array to predict thermal loading and A/C on a massive scale if connected to the Smart Grid. Implementations by utilities have the potential to better manage energy supply to wide swaths of their subscriber base, providing benefits across the energy chain and creating new services that could be monetized.

Humidity and air flow within the building envelope can also be sensed by the glass and used to provide *very* localized weather analysis to further enhance forecasted energy needs and balancing. The Smart Grid can instruct the glass to allow more light or heat into a building as loads on the grid change. Service providers can monitor and control aspects never before known to add value, such as:

- Analyze usage data in real time
- Shift Loads
- Provide new forms of energy-peak shaving

With building integrated photovoltaics (BIPV) and the Smart Grid, localized energy production and usage analysis in real time could allow building operators to make better energy decisions by configuring each zone for optimal performance given the current environment.

Responsive is Responsible

The key solution is a failure resistant, highly isolative glass with "on demand" control of the natural sunlight promoting an interior environment that is safe and comfortable with minimal use of artificial lighting, heating or cooling systems. Architectural glass for the 21st century will be an adaptable device that controls the flow of energy with an integrated systems approach that leads to a significant reduction in both energy consumption and the corresponding pollution this consumption creates.

---

[i] ENERGY POLICY ACT, 2005, ENERGY INDEPENDENCE AND SECURITY ACT, 2007
The principal acts are the Energy Policy Act of 2005 (Epact 2005, Public Law No. 109-58) and the Energy Independence and Security Act of 2007 (EISAct 2007, Public law No. 110-140). These two acts define a broad mandate to develop Federal R & D that will enable commercial and residential buildings to be more efficient and sustainable to lower their impacts on the environment while improving occupant health and productivity.

NET-ZERO ENERGY COMMERCIAL BUILDINGS INITIATIVE
The goal of the initiative is to develop and disseminate technologies, practices and policies for the development and establishment of net-zero energy commercial buildings for the following: 1) Any commercial building newly constructed in the United States by 2030; 2) 50 percent of the commercial building stock of the United States by 2040; and 3) All commercial buildings in the United States by 2050.

-Source: EISA 2007. Title 4, Subtitle B, Section 422c