Enhanced Green Window Systems

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ABSTRACT

Some advanced window systems can provide insulation comparable to that of R-19 walls (Southwall Technologies, 2002) while others have the capacity to supply energy to a local power grid (Thoreau Center for Sustainability). This technology can improve the energy efficiency of residential buildings immensely because windows are currently the least efficient aspect of a home. However, designing a window that has a cradle-to-cradle life cycle is essential for minimizing environmental impact. The goal of this project is to design, build, and test a modular prototype window that represents the best in energy efficiency and has the most environmentally conscious production and consumption life cycle possible.

Photovoltaic cells, Heat Mirror® (Southwall Technologies, 2002), spectrally-selective coatings, low-e coatings, phase change materials, and gas filling were all initially investigated. Based on the initial research, four window technologies were selected for use in the final design. The selected technologies were photovoltaic cells, phase change materials, heat mirror technology, and thermal curtains.

The production of the prototype window will be made possible through collaboration with window manufacturers. The full-scale window mock-up and a control window will be tested at Miami University's Environmental Research Center in Oxford, Ohio during fall 2003 using Las Alamos-style passive solar test rooms. Temperature data will be collected and an overall U-value, a solar heat gain coefficient, and visible transmittance will be calculated. Software simulation using Window5 and PHANTASM Building Integrated PV will be completed for data comparison purposes.

INTRODUCTION

The Miami University Department of Architecture Energy Design Studio in the spring 2003 was conducted as an interdisciplinary studio involving students from several related disciplines including Architecture, Interior Design, Manufacturing Engineering, Marketing, and Environmental Engineering. In the studio, students learned to use energy analysis software and analytical protocols developed at Miami University's Center for Building Science Research to analyze the solar gains and heating and cooling loads for the buildings they design.

This studio was charged with designing a sustainable modular home for the future. Each team included members representing the disciplines needed to address the key project issues, from design to detailing, from marketing to manufacture. As an integral part of the design of the modular home, the teams were challenged to come up with new and innovative solutions for window designs. Team members from each discipline were involved in all phases of the preliminary design of the modular building and window components. Architecture and Interior Design majors completed design drawings for the modular homes that incorporated the alternative window designs their team developed. Students from the Manufacturing Engineering and Paper Science & Engineering departments continued the project by focusing on the detailing and design of the window units. The following paper presented by the engineering students describes the development of an energy efficient window system utilizing several window technologies.

The sections include (1) research pertinent to energy efficient windows; (2) the proposed prototype window; (3) discussion of testing and data collection; (4) software that will generate simulated data to compare to experimental data. The final design and data analysis will be completed by mid-December 2003.

WINDOW TECHNOLOGIES RESEARCH

As a gauge to compare windows with special treatments, an investigation was conducted on standard windows. This is a generic term; however it simply means that the window has no special glazing or treatments. These windows come in different shapes and sizes; have different casings, such as aluminum, vinyl or wood; and are operable. The R-value of non-glazed windows is around 1. These sections do not obstruct or detract daylight.

Window technology research was conducted to gain an understanding of the window market and products currently under development. Selections were made from this initial research based on the project goal of designing and testing an energy efficient modular window system. The selected technologies thermal curtains, heat mirror, phase change materials, and photovoltaic cells are discussed in this section .

Thermal Curtains

Insulated window curtains or thermal drapes are a product currently on the market aimed at reducing heat loss/gain through windows. Common window insulation systems consist of ordinary looking curtains or blinds, usually customizable to match the homeowner's interior, constructed in extraordinary ways. The fabric of these curtains is composed of four layers of special material designed specifically to accomplish the tasks described above. The four layers are described below (cozycurtains.com, 2003):

- The outside layer is composed of a lining with fabric protector.
- The second layer is a high density Dacron Holofil II.
- The third layer is a reflective polyethylene moisture vapor barrier.
- The last layer is metallicized Mylar with air trapping fibers.

Heat Mirror

The Heat Mirror® is a product developed by Southwall Technologies. It is a low-emissivity coated film product positioned inside panes of insulating glass. This gives a triple unit with two airspaces, while blocking 99.5% of ultraviolet light from the sun (Southwall Technologies, 2002). Compared to three panes of insulating glass, the heat mirror system gives superior insulating and shading while weighing much less. There are several different types of Heat Mirror coatings, ranging from low-reflectance, high-light transmittance mirrors to ones with maximum shading. Heat Mirrors can be used on almost any type of glass, including clear, heat absorbing, reflective, heat-strengthened, tempered, or laminated glass.

The manufacturing of Heat Mirror® requires several more steps than the manufacturing of a standard double pane window. The differences in materials for Heat Mirror® include 2 spacers and sealant. Additionally, this window type contains a soft low-e coating, which means that the low-e is printed on mylar film and the film is sandwiched between two panes of glass (Seimer, 2003). Other window types utilize a low-e hard coat, which is vacuum-baked onto the glass. The use of soft coat gives the window more potential for separation after the end of the useful life. Heat Mirror® durability must be ensured because they are used in office towers and therefore the seals come with a lifetime warrantee. The current practice at Stanek Windows, a manufacturer of windows containing Heat Mirror® technology, is to break glass that is not longer being used or that has defects. According to John Seimer (2003), it is impractical to reuse the windows and the company does not deal with reusability issues. A general shipping concern for windows is that they must be manufactured in the altitude where they will be used, or purge ports must be used because of the gas pressure issues related to window unit sealing.

These windows offer R values from 4.5-12.5 (0.19-0.33 U-values), which is double to six times higher than a standard window. The best Heat Mirror® systems approach that of a standard wall. These windows are especially effective because they maintain the visibility capability of a standard window while blocking 95% of UV rays and protecting furniture and other fabrics. These windows come in all of the standard sizes and designs, which make them more appealing to the residential market (Seimer, 2003).

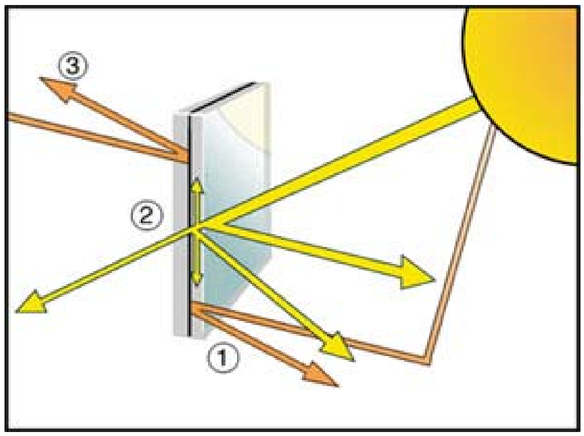

Figure 1 Reduction of solar gains by a Heat Mirror (Spring, 2002)
(1) External radiated heat is reflected.
(2) Incoming heat is reduced.
(3) Internal radiated heat is reflected.

Thermal Storage Walls and Phase Change Materials

Thermal storage walls are walls, usually made out of concrete, that are positioned so that they can absorb energy from sunlight. They store this energy and then release it when the surrounding temperature lowers. They do not cost much to install, as concrete is not an expensive material to put in near a window. Thermal storage walls do well to increase the heat gain of a home, but they do not contribute to daylighting ventilation. They also do not have a high aesthetic value. One way to improve the usefulness of thermal storage walls is to incorporate phase change materials into them.

Phase change materials (PCMs) are "latent" thermal storage materials, using chemical bonds to store and release heat. When a material changes from a solid to a liquid, or from a liquid to a solid, thermal energy transfer occurs. To accomplish this, the temperature of the solid rises as it absorbs solar heat. When it reaches its melting point temperature, it changes phase and absorbs large amounts of heat without getting hotter. As the surrounding temperature drops, the PCM becomes solid again, releasing its stored latent heat. PCMs stay at a nearly constant temperature while absorbing and emitting heat. Within a normal comfortable home temperature range of 68^o to 86^oF (20^o to 30^oC), latent thermal storage materials are very effective. They store 5 to 14 times more heat per unit volume than conventional storage materials such as water, masonry, or rock (US Department of Energy, 2002).

Phase change materials are generally more expensive and harder to ship and install than thermal storage walls (although new technology is lowering the initial cost). They do improve heat gain and insulation values, however. The other aspects of PCMs are similar to a normal thermal storage wall.

Photovoltaic Cells and their Application

Photovoltaic (PV) cells are a very promising renewable energy source yet they are not widely used. The technology is still increasing in efficiency, and the cost of a PV cell system is still too high for the general population to begin using it without some strong encouragement. Although the cost of PV-generated electricity is generally higher than that of conventional utility-supplied electricity, it has been reduced greatly over the last few decades to "less than one percent of what it was in the 1970's" (Starrs, 1999).

The application of PV cells into windows has been even more limited. There are no manufacturers currently producing PV cell-integrated windows but at least one application has been found. The Thoreau Center for Sustainability currently contains a skylight integrated with PV cells.

The mechanism by which a PV system creates electricity is the freeing of electrons that occurs because of interaction between sunlight and semiconductor materials in the cells. The electricity produced during this interaction is direct current (DC), whereas the type used in household appliances is alternating current (AC). For this reason an inverter must be included in the system to convert from DC to AC so that the energy can be used effectively in the home. The general overview of such a system is display in Figure 2 below (Starrs, 1999).

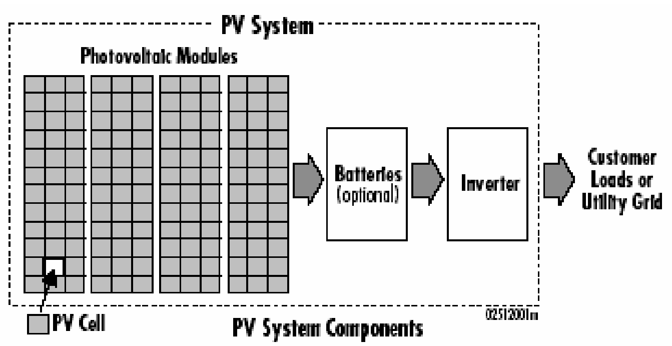

Figure 2 A general overview of a PV System (Starrs, 1999).

The main factors contributing to differences in PV unit are "your geographic location, the angle and orientation of your system, the quality of the components of your system, and the quality of the installation," (Starrs, 1999). Another issue to consider is saving your generated electricity using a battery because most of the power generation by a PV system occurs during the peak sunlight hours in the middle of the day when people may not be occupying the home. The cost of PV systems range from a single panel system of 75 watts at $900 to a two kilowatt system at $16000-$20000 installed to a five kilowatt system at $30,000-$40,000 (Starrs, 1999). These are the great upfront costs incurred, however the energy saving can be tremendous based on the efficiency and the incentives offered in the area where the home is located.

PROTOTYPE WINDOW

Using the technologies from the above discussion, a prototype test window was designed. This window has not yet been manufactured however an initial design concept is seen below. Dimensions are not yet established.

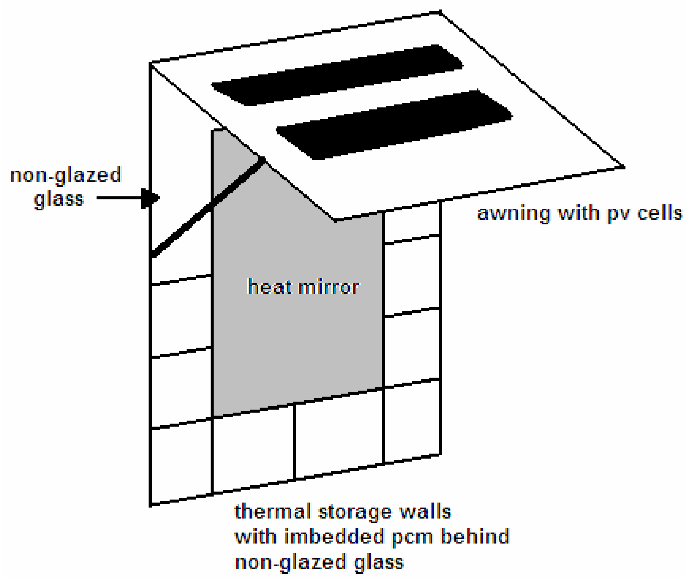

Figure 3 Prototype window

An awning will be built overhanging the window with photovoltaic integrated into the awning. A piece of non-glazed glass will adorn the outer part of the window with Heat Mirror® (Southwall Technologies, 2002) in the center of the window. In the bottom portion on the outer extents, thermal storage walls with imbedded phase change materials will be installed behind the non-glazed section. Finally, thermal curtains will be inside the test cell, drawn after sunset, to retain heat inside the cell. (This aspect is not shown in the figure.)

TESTING AND DATA COLLECTION

Experimental testing of the prototype window described above will be completed using the test cells pictured in Figure 4. Heat gains during the day, heat losses at night, and light gains during the day will be measured using both temperature and radiation sensors and data acquisition boards or data loggers. Final selection of data collection materials has not yet been completed.

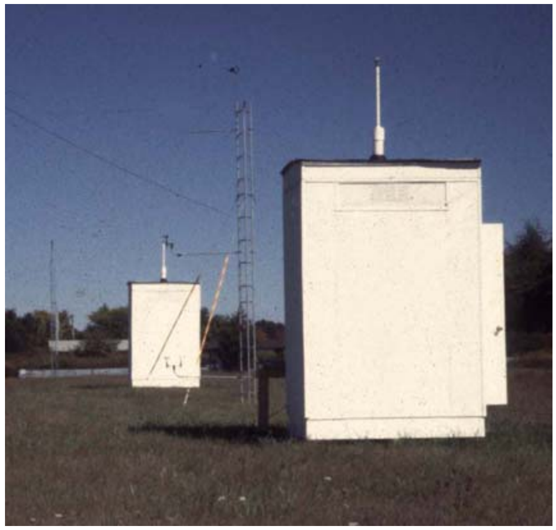

Figure 4 Test cells at Ecology Research Center. Photograph taken facing south. The windows face southward

Both test cells (see Figure 4) will be utilized in the experiment. Test cell 1 will be used as a control cell, containing a single- or double-paned “standard” window, with no efficiency glazing. Test cell 2 will house the prototype window described in the previous section.

Data will be logged over a 24-hour period, and downloaded to a laptop personal computer. The raw data will then be manipulated to determine window characteristics such as U-value and Solar Heat Gain Coefficient. A result comparison between the prototype window and the “standard” window will be conducted. It is anticipated that the comparison will reveal that the prototype exhibits substantial energy efficiency and light capacity improvements over the standard window. Furthermore, the experimental data from the prototype window will be compared and contrasted with data simulated in the software programs to be discussed in the following section. The programs enable the user to build a window and test such parameters as heat gains and losses.

SOFTWARE

A window analysis program created by the Lawrence Berkeley national Laboratories provides a method for calculating U-factor, solar heat gain coefficient, visible transmittance, and condensation index. This program, Window5, offers libraries for the inputs of glazing system, frame characteristics, divider characteristics, glass properties, gas properties, and environmental conditions. The libraries are extensive and include features such as creating new entries in the glazing library. The program accommodates modularity very well by allowing the insertion of dividers in any configuration desired (Mitchell, 1991). This feature will prove helpful in the analysis because of its focus on modularity. The software allows for the combination of modules with differing thermal properties. The results of software simulation of the design concept will be compared with the experimental results. Additionally, the software will be used to simulate proposed windows that were not experimentally tested.

In order to evaluate the photovoltaic array that is integrated into the window design, the PHANTASM: Grid Tied Building Integrated PV Simulation Program developed by the University of Wisconsin and the Thermal Energy System Specialists will be used. The inputs to this program include weather and location data, ground reflectance, utility rate, building type and floor area, PV array characteristics, economic issues such as prices and energy savings. The simulation provides economic results as well as energy outputs of the arrays (*PHANTASM*). This software was made available by a member of the Thermal Energy System Specialists team and is not yet commercially available. The results of the PV simulation will allow for the overall assessment of the window system design. The PV-integrated shading device will contribute to the energy needs of the home as well as provide shading to reduce unwanted heat gains. The following programs were used to calculate background data such as solar gains and energy savings based on window placement alone.

Solar Scott is a program designed by Professor Scott Johnston of Miami University based on *Solar Engineering of Thermal Processes* by John Duffie and William Beckman (1991). The program focuses on heat gains and losses through the building envelope. The windows, walls or roof can be specifically chosen and in the case of this project the window analysis is chosen. The various inputs for window analysis are day of year, climate variables: latitude of location, elevation, ground reflectance, and visibility; glazing variables: number of glazing covers, glass thickness, index of refraction, and extinction coefficient; design variables: glazing area (sq. ft.), glazing slope, window orientation, and room absorptance, and irradiated area by time of day (found using the heliodon). The outputs given based on these inputs are the altitude of the sun, the azimuth of the sun, previous inputs of irradiated areas, percent of the window that was irradiated, total BTUs per hour, diffused solar gains, and reflected solar gains. Architecture students used this program to create graphs of the total BTUs per hour for June 21 and December 21 for each climate (Solar Scott User's Manual). The results were used to analyze what needs existed in the building design for further reduction of heating or cooling loads. Additionally, this data can be used to determine the type of energy efficient windows that can be used to reduce heating and cooling loads in each climate.

The Energy 10 software package was also a key component of the architecture analysis. The project during which this software was created was titled Designing Low-Energy Buildings with Energy 10. The project was a collaboration between the US Department of Energy (DOE), the Sustainable Industry Council, the National Renewable Energy Laboratory (NREL), the Lawrence Berkeley National Laboratory (LBNL), and Berkeley Solar Group. The program is used to compare a reference home to a low energy home case. Inputs include a weather file for the location, floor area, surface area, volume, average U-value (inverse of the R-value), wall and roof construction including R-values, window construction including U-values, window shading, wall and roof areas, window area, glazing type, type of HVAC system, thermostat settings, daylighting used if any. The program outputs a yearly energy use based on an energy cost, shows how much energy is saved by daylighting, and splits up the energy requirements by lighting, heating and cooling, and water heating. Construction costs and life-cycle costs are also aspects of the output (Balcomb, 2002).

CONCLUSIONS

The architectural goal of a modular energy efficient home extended to many structural aspects. An under explored area of building efficiency is the window system. This project developed a concept for an energy efficient window system with consideration of manufacturing and reuse issues. Research of window technologies led to a selection of existing products that met the needs of the project. The modular prototype window system containing modules of photovoltaics, phase change materials, Heat Mirror® (Southwall Technologies, 2002), and thermal curtains was the final design selection. The experimental testing and simulation phases of this project will continue through December 2003. The project will conclude with recommendations to the window community on improving the energy efficient window system based on the result of the experimental research. These recommendations will consider manufacturing and reuse suggestions as well as energy efficiency in the broad sense. The main area for further progress in window systems is life-cycle analysis because although windows may increase energy efficiency of buildings, the energy usage of the manufacturing processes must be considered for the product to be considered truly efficient.

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