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PROTECTIVE GLAZING STUDY

for

National Preservation Center

Dr. Mark Gilberg, Research Coordinator

by

Inspired Partnerships, Inc.

Chicago, Illinois

March, 1996

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INTRODUCTION

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March, 1996

PROTECTIVE GLAZING STUDY BACKGROUND

Inspired Partnerships, a not-for-profit organization based in Chicago, IL received a $34,320 grant from the **National Preservation Center** in October 1994 to investigate the virtues and liabilities of various protective glazing installations over stained glass. The study was conducted over an 18-month period from October 1994 to April 1996 and addresses energy, security, sound and light transmission, aesthetic, and conservation issues surrounding the use of protective glazing. Although some aspects of this research are applicable to all protective glazing, the study concentrated on the virtues and problems associated with installations over stained glass in houses of worship. Churches and temples have specific energy, maintenance, and security concerns which tend to be unique to their function, management and operation.

"Protective glazing" (PG) is defined as a secondary layer of sheet glass or plastic on the exterior of a stained glass window. PG is also described as "storm", "double", "outer" and "secondary" glazing and these terms are used interchangeably throughout the study. "Stained glass" pertains to all types of leaded glass. In addition to research, the study included: 1) a stained glass studio survey; 2) a field survey of one hundred PG installations in four different U.S. regions; 3) in-situ testing of two protective glazing installations; 4) an energy model of an intermittently heated building, and; 5) the alteration of ten PG installations.

Inspired Partnerships first assembled a **Protective Glazing Advisory Committee (Committee)** that included the following people: **Rolf Achilles**, Art & Industrial Historian (Chicago, IL); **Arthur J. Femenella**, Stained Glass Consultant with Femenella & Associates (Annandale, NJ); **Dr. Mark Gilberg**, Research Scientist with the National Preservation Center; (Nachitoches, LA), **Thomas Harboe**, Director of Preservation with McClier (Chicago, IL); **Barbara Krueger**, Stained Glass Artist and Historian (Hartland, MI); **Richard Pieper**, Restoration Consultant (New York, NY); **Andrew Rudin**, Energy Consultant (Melrose Park, PA); **Dr. Wayne Simon**, P.E. (Evergreen, CO); and **Neal A. Vogel**, Director of Technical Services with Inspired Partnerships (Chicago, IL). Several Committee members served as authors and editors as well.

Susan Reilly, P.E. of EnerModal Engineering, Inc. was also commissioned by the National Preservation Center to report on the energy value of protective glazing over stained glass. Many other people provided assistance for this study but are far too numerous to mention. However, those who deserve special recognition include: **Susanna Aulbach**, German Translater; **Matthew Bellocchio,** Roche Organ Company; **Chris Botti** and **Mike Smoucha,** Botti Studio of Architectural Arts; **Janice H. Chadbourne**, Curator of Fine Arts, Boston Public Library; **Richard Cieminski**, Jon-Lee Art Glass; **Marit Eisenbeis** and **Charles Kiefer**, Inspired Partnerships; **Betty Kirpatrick**, Hermosa Mountain Studio; **Gabriel Mayer** of Franz Mayer'sche Hofkunstanstalt, Munich, Germany; **Virginia Raguin**, Holy Cross College; **Jack and David Sussman**, J. Sussman, Inc.; **Susan Tunick**, Friends of Terra Cotta; **Theodore Von Gerichten; Kirk D. Weaver**, Pittsburgh Stained Glass; and **David Wixon**, Wixon & Associates. **Inspired Partnerships** would also like to thank the numerous stained glass studios provided assistance by completing questionnaires and reporting past experiences with protective glazing.

PG research in the United States cannot be discussed in context without having a firm understanding of subsequent 20th century research in Europe, spearheaded by the **Corpus Vitrearum Medii Aevi (CVMA)**. The **CVMA**, an international research organization dedicated to scientific work concerning medieval stained glass, has held biannual seminars since its inception in 1952. In 1962, a committee within the **CVMA** was formed 1) for research on materials and techniques used in medieval stained and painted glass, and 2) to establish principles and guidelines for conservation and restoration of these (*ed. - stained glass*) endangered works of art.[1]

Although the **CVMA** initially consisted of mostly art historians, membership now includes conservators, restorers and scientists. Some time ago, a **CVMA** newsletter stated that *"protective glazing is the most effective instrument of conservation (ed. - of stained glass) known at present."* Much of this research during the 1970s and 1980s can be attributed to Roy G. Newton who authored The Deterioration and Conservation of Stained Glass: A Critical Biography (1982), which remains among the most important sources on glass conservation to this day. It is important to note that the **CVMA** and its research are only concerned with medieval stained and painted glass. The question is whether these same circumstances apply to stained glass manufactured and painted since the Industrial Revolution.

When the Corpus Vitrearum was formed in Europe in 1952, some U.S. museums were interested, as medieval stained glass was found in most, if not all, of the more prominent American museums. For obvious reasons, academic art historians involved in teaching medieval art, architecture and literature were also interested in research carried out by the **CVMA**. A subsequent survey of medieval stained glass in the United States and the formation of a group involved in the survey, **The Census of Stained Glass Windows in America (CSGA),** was the vehicle by which European research findings about PG became more widely known.

Stefan Oidtmann's recently published dissertation, Die Schutzverglasung - eine wirksame Schutzmaßnahme gegan die Korrosion an wertvollen Glasmalerieien, Technische Universiteit Eindhoven (December 6, 1994), is the most extensive resource on protective glazing to date. Unfortunately, as a dissertation, only a very limited edition has been published in German. The table of contents, appendices, and Chapter III *Construction-related Physical Measurements* were translated for **Inspired Partnerships** to aid this study. This book provides an excellent summary of conservation work at various European cathedrals but is generally limited to medieval stained glass conservation as related to moisture problems.

Nearly all European research has concentrated on moisture related conservation issues and has generally surmised that "isothermal" PG installations are the only way to protect medieval stained glass from deterioration. Such applications are fundamentally and economically impractical for the vast majority of post industrial stained glass in America **[see Section V].**

[1] Corpus Vitrearum Newsletter 45, Bacher 15.

PROTECTIVE GLAZING PROJECT SCOPE

***PROJECT GOAL:* To record and publish a national protective glazing research project to promote higher industry standards for the proper use and installation of protective glazing the United States.**

In order to accomplish the project goal, the **Committee** developed a list of claims to address the myths, facts and hearsay surrounding PG (see the chart on the following page). The **Committee** also developed the following project objectives:

1. **Perform an international literature search on PG over stained glass.**
2. **Provide a historical overview of the development of PG in America.**
3. **Inspect & evaluate a cross section of PG installations in America.**
4. **Create PG models addressing energy performance and interspace conditions.**
5. **Prepare manuscripts to publish for professional/preservation/lay audiences.**
6. **Disseminate the study through the building, preservation & religious networks.**
7. **Identify additional research and testing to be undertaken.**

An international literature search on the history, development and current usage of protective glazing has been undertaken to provide background information for field investigation and the final study. This includes written correspondence to preservation organizations and stained glass professionals in the U.S. and Europe, and an extensive library search **(see Bibliography)**. A stained glass studio questionnaire was also published in Stained Glass Quarterly and mailed directly to 200 professionals and studios. Trade literature from manufacturers and promotional literature from stained glass studios was collected to explore how protective glazing is promoted to both the stained glass industry and the consumer.

A field survey of 100 PG installations from four different climatic regions of the U.S. was performed to establish a representative pool of examples. Three primary aspects were evaluated in the field survey: 1) the effects of condensation; 2) heat build-up, and; 3) aesthetics. Ten PG installations in Chicago were removed, modified or replaced to determine the effect of PG over time; to determine changes that occur when unvented PG is vented or removed altogether, and; to experiment with various installation methods. These “case studies” were evaluated further for deterioration, light and sound transmission, and installation methods in collaboration with professional contractors and stained glass studios in Chicago **[see Section VI.].**

The research results are incorporated in this final study to the **National Preservation Center (Natchitoches, LA).** It includes: the history, development, use and promotion of protective glazing; its prevalence in America; its advantages and disadvantages; data and photos of the 100 installations inspected during the field survey; detailed case studies of ten PG installations; final analysis and general specifications for PG installations, and; supplemental materials. The intent of this study is to develop publishable manuscripts from the study for professional, preservation, and lay audiences after peer review.

The **Committee** developed the following list of perceived pros & cons in order to separate the myths from facts regarding protective glazing:

PROTECTIVE GLAZING PROS	PROTECTIVE GLAZING CONS
Protects from physical impact (vandalism, storm damage, weather/exposure)	Increases deterioration by condensation and thermal expansion/contraction
	Installation costs
Reduces maintenance of window surround	Negative effect on exterior/interior aesthetics (hazing, frames, conceals tracery, shadow lines)
Saves energy and increases comfort (heat gradient)	Physical damage to frame when poorly installed
Reduces sound transmission	Adds weight to ventilators affecting operation (piggyback)
Alters light transmission (controlled intentionally)	Eliminates natural ventilation
	Breeds complacency towards window maintenance
Filters ultra-violet light (to protect adhesives in glass repairs)	Increases comfort expectations (raising thermostat settings)
Stabilizes glass	Causes air pressure on high windows from wind suction (venturi effect on wayward side of building)
Reduces air conditioning load	
	Reduces light transmission and can mute stained glass colors (hazy, cloudy--particularly plastics)
Reduces insurance premiums (possibly required for insurance)	
Decreases air (and dirt) infiltration (reducing cleaning)	Increases impact damage (spreading bullets, entire panel knocked into stained glass)
	Prevents emergency ventilation of fires
Economic benefit to stained glass and manufacturing industries	Increases air conditioning load
Strengthens a weak window frame (acting as a diaphragm)	Weakens some windows
Keeps moisture & dirt out of plated windows	Environmental impact of manufacturing materials
	Postpones installation costs for another generation
Postpones high restoration costs	Typically not historic
Can be historic	

Protective glazing for stained glass has been used in America since the late 19th century, however, it did not become popular until after W.W. II by filling the void caused by a waning stained glass industry. The civil rights demonstrations of the 1960s, and energy crisis of the 1970s acted as catalysts, and protective glazing evolved into a multimillion dollar industry.

Many stained glass studios and window contractors endorse the use of PG in their trade literature while manufacturers of laminated and tempered glass, acrylics and polycarbonates promote the advantages of their products. Yet, PG may be causing serious damage to many stained glass windows across the country by increasing condensation and heat build-up in the air space and by preventing maintenance.

There are conflicting opinions among stained glass contractors as to the merits, potential problems, and proper installation of PG. While theories and opinions abound, American studies to develop and perform scientific field surveys and tests to separate myth from fact have not been initiated until now. This project frames the debate about protective glazing, dispels many of the misconceptions regarding its usage, and recommends the appropriate installation methods when it is required.

Inspired Partnerships has been documenting PG installations since 1991. Some installations appear to cause no harm, while others appear to cause serious harm. Basic factors such as the age of the installation, window orientation, installation details, humidity, and lighting measurements were recorded during field inspections to develop baseline data. However, because of weather and installation variables, these efforts were too limited to establish clear patterns and accurate information. While most of the stained glass industry, professionals and tradespeople agree that PG should be vented in some manner, it rarely occurs in the field.

The intended audience -- primarily owners of historic churches, synagogues, mausoleums and civic buildings in America -- are the target of numerous claims encouraging PG. Vandalism, street noise, energy losses, and unusual deterioration circumstances all play a role in its use, yet data is unavailable to make an educated judgment for the specification or application of protective glazing. Meanwhile, PG is often installed improperly... threatening America's stained glass treasures.

This research project may save stained glass stewards countless dollars in needless PG installations and premature repair costs and restoration when installations cause or contribute to deterioration. The study may also help eliminate the practice of using protective glazing in place of proper stained glass conservation measures. Most importantly, a published record backed by hard facts may convince owners to protect stained glass properly for future generations, with or without PG. This information, collectively authored and presented here for the first time, will be invaluable to preservationists, stained glass studios, and architects in advising and specifying PG. The continued practice of installing improperly ventilated PG is creating a myriad of preservation problems. The result is the potential loss or replacement of many important historic stained glass windows.

PROMOTION AND USE OF PROTECTIVE GLAZING

The ever-changing face of religion (less active members), architecture (less complex designs), art (less ornamentation) and economy (less money) since the 1960s has resulted in greater competition for fewer stained glass installations. In order to stay in business, many stained glass studios and other window contractors have fully endorsed the use of PG as *"The only economical method of halting water seepage in an old window is to install permanent protective Lexan® or storm glass."*[2] The installation of PG has become a lucrative aspect of the glazing industry across the country. Stained glass studio literature collected since the 1960s reveals that most studios used at least some of the following reasons to promote PG to consumers including: vandalism, security, energy savings, comfort, conservation, weather damage, sound barrier, and less maintenance.

The results of this study show that claims of saving 50% on energy bills or quadrupling the life of stained glass by using PG are simply false advertising **[Appednix XX].** No reliable studies substantiate such claims, including this one. The continued efforts of many stained glass professionals and preservation experts are effecting how PG is promoted in studio advertisements, videos and brochures. This study encourages professional presentation of what storm windows can and cannot do for stained glass.

Most studios have mentioned PG in advertisements and company brochures over the past several decades which provided an opportunity to review how PG is represented in company literature. The following sampling provides an array of promotional methods:

A contracting bid (not public information) from an Indianapolis stained glass studio lists the following advantages of using *Lexan®* as PG: *"reduce heating costs, reduce cooling costs, protect wooden millwork and eliminate need for continual repainting, protect valuable windows from vandalism.., can quadruple your stained glass window life expectancy and save your congregation money every day."*

Lamb Studios (Philmont, NY) wrote an article based on a lecture to the Energy Task Force Workshop of the **Episcopal Urban Caucus,** Louisville, Kentucky in 1983 that was printed in the Journal of the Interfaith Forum on Religion. Art & Architecture. It claims *"by covering a stained glass window a church can save about 50% of the energy-- either heating in winter or cooling in summer."* The article further notes *"neither of the products (Lexan® from **General Electric** and Tuffack® from **Rohm and Haas**) will yellow over time."*

Shenandoah Studios (Front Royal, VA) advertised in Faith and Forum (IFFRA) in 1989 that *"Stained glass can be insulated for energy savings, remain watertight and weather resistant. . . concerns about weathering, vandalism, burglary or accidents are a worry of the past."*

[2]First United Methodist Church, Ypsilanti, MI proposal by Hauser Studios, 1973.

Willet Studios (Philadelphia, PA) developed a full-color brochure that recommends the use of Lexan® as an overglaze. *"Meets or exceeds the strictest building code regulations for safely glazing. . .your church will be better insulated with . . .Lexan® sheet. . . can reduce heat loss and lower fuel consumption by as much as 25%"*

Bovard Studio's (Fairfield, IA) 1991 newsletter provides a comprehensive view of PG: *"Benefits of PG are energy conservation, protection... from vandalism protection of stained glass, leading and frames from deterioration caused by weathering, hailstones, and pollution. But beware, improperly vented PG can create more damage than vandals throwing rocks... If condensation and humidity are not alleviated by proper air circulation, the leading and metal frame deteriorate to the point where structural integrity of the window is lost. .PG alone is not a restoration technique or an alternative to proper maintenance of stained glass.*

Rohlf's Stained and Leaded Glass, Inc. (Mt. Vernon, NY), self-described as *"America's Foremost Stained Glass Conservators,"* printed a brochure that states *"Clear float, safely or tempered glass should be used for PG. Acrylic or polycarbonate should only be used in areas of severe vandalism, due to yellowing, frosting and not allowing the wood to breathe"*

David Wixon & Associates (Glen Ellyn, IL) printed a newsletter entitled "Stained Glass Technical Advisory" that reads *"DANGER ALERT!"* and contains three pages dedicated to the problems associated with improperly installed double glazing.

CONSUMER DEMAND FOR PROTECTIVE GLAZING

A series of events in the 1960s and early 1970s greatly intensified the use of PG in the United States. Civil unrest throughout the South and large northern cities motivated a number of congregations to cover their stained glass windows with PG in fear of vandalism. One church in Savannah, Georgia, revealed that the all-white congregation had PG installed during the early 1960s in direct response to verbal threats of destruction for their segregated philosophy. A Detroit church installed PG in response to bullet holes in their stained glass during the 1967 riots. Fear over vandalism and theft, whether justified or not, remains a powerful motivator for PG, especially in gang-infested inner-city neighborhoods. The 1973 oil embargo greatly increased the cost of fuel oil convincing many churches to add secondary glazing to conserve energy. In the January/February 1976 issue of Your Church magazine, a total of 338 persons responded to the property management survey. The survey asked whether the church had protective glass over the stained glass. Of the 70% who answered the question, 41% said their churches either had some form of PG or they were thinking about it. Field surveys by **Inspired Partnerships** estimates that 90% of the stained glass in Northeast, Midwest, and Rocky Mountain churches is covered with PG, and 70% of the stained glass in Southeast, South and West Coast churches is covered with PG.

Perhaps even more important than the fear of vandalism, or the concern over fuel bills is the financial inability of many congregations to fund stained glass restoration. The enormous popularity of stained glass in America between the Civil War and World War I has resulted in countless large stained glass installations between 80 and 130 years old. Incidently, the life span of most leaded glass windows falls into this time span. Many dwindling congregations housed in large old churches are faced with the reality of expensive restoration costs and choose to defer the expense of restoration -- meanwhile buying the PG alternative over restoration. Regardless of the aesthetic or conservation impact on stained glass, PG stops leaks and drafts through deteriorated stained glass and postpones the inevitable restoration costs for someone else. Procrastination has been the decision of thousands of congregations across the country and today a vast majority of U.S. churches with stained glass have some type of PG. In recent years, a greater sense of stewardship, increasing professional criticism of PG and a growing "restoration" market is prompting the question, "Do we need protective glazing... or do we really need restoration?"

AWARENESS OF PROTECTIVE GLAZING PROBLEMS

British stained glass expert, Roy G. Newton, was among the first to rejuvenate the century-old concerns over PG in a **CVMA** Newsletter in April 1975. Lawrence Lee followed suit and included a brief mention of PG and its associated problems in his book entitled Stained Glass (Crown Publishers, New York) in 1976. Lee noted that *"experts recommend that for important windows, protective plain glass should be inserted into the window openings with the precious ancient glass remounted a little way inside."* This book, first published in England, generally refers to medieval glass. Nevertheless, Lee discusses condensation and aesthetic concerns as well as isothermal installations. This was the first time PG problems were mentioned in a U.S. publication.

An article in Stained Glass Quarterly (Winter 1983/84) discussed venting PG to the interior but is restricted to museum settings. This and subsequent issues discussed how PG might be damaging to stained glass windows. Julie Sloan boldly asked *"Protective Glazing: Is it Necessary?"* in her February 1987 article in Professional Stained Glass. Many important observations were presented in this review, however, the only research Ms. Sloan cited was The Deterioration and Conservation of Stained Glass: A Critical Biography by Roy G. Newton (London: Oxford Press) published in 1982. While the **CVMA** was not mentioned specifically, most of the information cited came directly from their research findings. Ms. Sloan did not perform or cite any additional tests or research to further support her position.

In 1988, The Census for Stained Glass Windows in America, published a booklet entitled Conservation and Restoration of Stained Glass: An Owner's Guide. Geared toward the caretakers of our nation's stained glass-- ministers, church custodians, and church lay committees -- the booklet contained a short discussion on PG. *"PG systems, when correctly installed, may greatly increase the longevity of historic glass, and may decrease the overall energy requirement of the buildings. When incorrectly installed, PG may detract from the aesthetic beauty of the windows and the building, and may set up conditions which may actually destroy the glass..."* It is significant that leaded, laminated and tempered glass with venting was encouraged while acrylics, polycarbonates without venting were discouraged.

Stained Glass Quarterly, Glass Art, Old House Journal, Traditional Building, The Clergy Journal and several not-for-profit preservation newsletters such as Common Bond, Inspired, and Amazing Space have printed articles since the mid 1980s detailing the hazards of PG. Many of these articles were reprints or reviews of previous publications. These articles were backed by personal experience and observations but lacked American research data to contradict unsubstantiated claims made by PG manufacturers and installers.

SGAA Reference & Technical Manual. A Comprehensive Guide to Stained Glass. The 1988 manual had an article (reprinted from Stained Glass, Summer 1982) by Viggo B.A. Rambusch where he stated that *"protective glass or acrylic plastic is very important. . . care should be taken in selecting the framing system.. .note that plastic is not flat but is rather wavy.. .weep holes or other venting systems (are necessary) for the air pocket between the stained glass and the protective element."* Several articles with references to PG were reprinted for the 1992 manual. However, even the most comprehensive book (785 pages) on stained glass in America, contains contradicting statements on PG installations pertaining to venting the air space. Nevertheless, it includes several important points regarding PG: 1) it is not a substitute for repair, restoration or maintenance; 2) the airspace should be vented to allow for any condensate to evaporate; to equalize air pressure; and to minimize the temperature gradient; 3) ventilation methods, and; 4) if plastic glazing is used, adequate provision must be made for significant expansion/contraction.

Copyrighted in 1993, Conservation of Stained Glass in America. A Manual for Studios and Caretakers, by Julie L. Sloan was not printed until January, 1995. Prior to the **Inspired Partnerships** study, Ms. Sloan's manual was the most extensive American resource on PG. Much of the text is taken from previous articles by the author in Professional Stained Glass and other publications, while the entire last chapter is dedicated to PG. As with many of her articles, there are few references cited. Ms. Sloan notes that unlike medieval glass, most types of 19th and 20th century glass are virtually impervious to most atmospheric pollution (as researched by Roy G. Newton). She also noted that energy conservation measures, such as lowering thermostats, are more cost effective than applying PG (although no data was included). Ms. Sloan further wrote that rain, in and of itself, actually washes a window of hygroscopic dirt. It is when condensation is trapped and allowed to collect on glass, surrounding lead cames, and metal or wood frames that deterioration to glass, paint, and frames will take place.

Sloan further notes that it is imperative for PG to have adequate ventilation to allow full air circulation and continuous exchange within the air space. She describes a number of conditions that influence whether PG should be vented to the exterior or interior including climate, building materials, and window orientation. She defines two categories of PG, plastic or glass. Acrylic and Lexan®, upon ageing will become less shatterproof and will scratch from air-blown particles. Sloan promotes laminated glass as the ideal PG. In terms of aesthetics, she suggests the use of leaded clear glass, either diamond leading or following the lead lines of the stained glass. This is expensive, and shadow lines can be seen from the inside, this method avoids a highly reflective surface created by large sheets of glazing. All plastics and plate glass must be installed in full sheets that are highly reflective and detract from the stained glass. She notes that framing materials must be compatible with the existing stained glass frame, and architecture.

The **Stained Glass Association of America's Restoration and Repair Committee** recently published Standards and Guidelines for the Preservation of Historic Stained Glass Windows (copyright, February, 1995). In reference to PG, this resource summarizes:

- Promotion of PG to save money due to energy conservation is not correct.
- Majority of American windows fabricated after 1850 do not need PG
- Exceptions are windows containing fragile paint, window composed of large, very thin pieces of glass, and some plated windows with irregular exterior plating that may encourage the infiltration of water between the plates.
- Primary purpose of PG is to protect the window from vandalism, and severe weather conditions.
- The interspace must be vented with screens, preferably to the exterior at the extreme bottom and top of the PG to encourage the movement of air through the interspace.

In recent years, the voices of numerous stained glass and preservation professionals have begun to congeal into a solid message that PG is not a substitute for restoration, and when improperly installed, can detract from the building's aesthetics and accelerate deterioration. This message is greatly strengthened by 1) SGAA Reference & Technical Manual. A Comprehensive Guide to Stained Glass; 2) Conservation of Stained Glass in America. A Manual for Studios and Caretakers; 3) Die Schutzverglasung - eine wirksame Schutzmaßnahme gegan die Korrosion an wertvollen Glasmalerieien; 4) Standards and Guidelines for the Preservation of Historic Stained Glass Windows; 5) Preservation Brief #33: The Preservation and Repair of Historic Stained and Leaded Glass; 6) Stained Glass in Houses of Worship, and; 7) this study for the **National Preservation Center**-- all seven resources were written in the past four years!

PROTECTIVE GLAZING QUESTIONNAIRE

Inspired Partnerships solicited input from the stained glass industry as part of this study through a questionnaire published in the Winter 1995 Stained Glass Quarterly which has a circulation of 5,000 copies. A similar questionnaire survey was mailed to the Studio and Artist/Designer members of the SGAA, various known stained glass artists who are not SGAA members, and non-profit religious and preservation organizations who will benefit from the study. Some questionnaires were sent to European individuals involved in PG concerns over the years. Approximately **200 questionnaires** were mailed or faxed (180 to stained glass practitioners and 20 to other interested parties) yielding 40 responses, all from stained glass studios. Disinterest, and reticence over taking a position before the final results of the study are published, ostensibly reduced the number of responses.

However, the 40 studios who responded literally represent hundreds of PG installations per year, and thousands of PG installations over the life of their companies: Some questions involved multiple responses while others were answered by short essays. Moreover, some respondents chose not to answer certain questions. Therefore, the final results are not scientific, but a general representation of the U.S. stained glass community. The geographic distribution included 17 states, Canada, England and Yugoslavia.

Over 62% responded *"always or nearly always recommend the use of PG "*, with about the same number doing the actual installation. The decision for or against PG was almost equally made by the client or the studio. Reasons for encouraging PG ranged from 75% citing vandalism, 50% citing hail/high winds, and 50% citing energy savings, which represent the most common reasons expressed by congregations. Another 35% cited security or protection from glass deterioration. The top three reasons cited for discouraging the use of PG included: 35% negative impact on aesthetics, 25 % condensation in the air space, and 25 % heat build-up in the air space.

Nearly half of the respondents noted that they ALWAYS vent their PG installations. However, the national PG field survey strongly contradicts this response *{See Protective Glazing Field Survey}*. Half of the studios which responded do not offer any guarantees on their PG installations; only 18% offer a guarantee over five years. Polycarbonates (e.g. Lexan®) are used most often for PG, while standard sheet or plate glass were next. All materials considered, the use of glass and plastic products were equally divided among the respondents. The controversy involving venting in literature and seminars is a concern of many respondents. The source of industry information about PG indicates that nearly 85% of the respondents glean their information from stained glass publications or commercial glazing publications. Others rely on "word of mouth."

Very few respondents answered all the questions, choosing instead to ignore those questions which involved something other than simply checking a box. One respondent who declines the use of the firm's name in this study stated that the firm doesn't really recommend PG…they just do it to make money. *"When a church calls and wants it done, they are going to have someone do it and it might as well be us."*

Several firms discourage the use of plastic materials, unless vandalism is a major problem. Eventual yellowing, clouding and scratching were the reasons stated. One respondent from Florida felt that *"acrylics hold their clarity much better than polycarbonates when exposed to intense Florida sun."* Of the three respondents from Florida, two always vent (to the exterior) while one never vents; however this studio is waiting for more definitive research on American stained glass. All three are SGAA members. The one Canadian respondent (Saskatchewan) only vents to the inside, to prevent condensation; early experiments with outside venting resulted in condensation. Both studios from California and Washington feel venting is not necessary in their particular climates.

Most of the respondents started installing PG since the 1970s. Another 20% were installing PG in the 1940s-50s-60s, while only three of the respondents installed PG prior to 1940. The vast majority of the respondents were small studios of less than five people working full time. It was disappointing that only one of the ten largest studios in America responded to the questionnaire. Nevertheless, it was little surprise since these studios tend to rely on larger contracts which include more storm glazing -- they also tend to promote PG more in studio literature and have voiced more opposition to this study.

Protective Glazing Questionnaire

Inspired Partnerships recently received a 1995 National Preservation Center Grant to investigate the virtues and liabilities of various storm window ("protective glazing") installations over stained glass. This study will include analysis of deterioration, energy loss, security and aesthetic issues among other factors. The objective is to develop sound data to address the concerns and/or virtues of storm windows over stained glass. The goal is to publish the research data to help set industry standards for proper storm window installations over stained glass. This is a challenge to all those interested in improving industry standards, and in the preservation of both new and old stained glass. We hope you will help us in this important endeavor. **Please complete the questionnaire and mail or fax to:** Neal Vogel, Inspired Partnerships, 53 W. Jackson Blvd. Chicago, IL 60604 (312)-294-0085 FAX.

Firm Name (optional)__________ Geographic Location__________ Date Firm Established__________
Earliest PG installation of Firm______ Is it Still in Place (where)?______,______ Have you replaced this PG at any time?______

How Often Do You Promote the Use of PG?
15__Always
10__Nearly Always
12__Specific Conditions Only
2__Rarely
__Never

How long are PG installations guaranteed?
19__No guarantee offered
4__1-5 years
5__5-10 years
2__10-20 years
__Over 20 years
(1 - we stand behind all our work)

What PG materials are used?
17__% Standard Sheet Glass (10-90%)
13__% Laminated Glass (5-100%)
12__% Tempered Plate Glass (5-90%)
21__% Polycarbonates (5-90%)
7__% Acrylics (5-100%)
__% Screens
4__% Other (thermalpane)
(1 - leaded lights 60%)

When Do You Vent PG installations?
18__% Always Vent (regardless of location)
7__% Never Vent
__% South Elevation
__% West Elevation
__% East Elevation
__% North Elevation
(3 - rarely or depends)

Reasons You Encourage PG?
30__Protects from Vandalism/Accidents
14__Protects from Glass Deterioration
5__Protects from Paint Deterioration
23__Protects from High Winds/Hail/Weather
14__Security
10__Sound Barrier/Acoustics
7__Prevents drafts/dirt infiltration
2__Required by Church Insurance Company
21__Energy Savings
__Temporary Solution to Restoration
__Improved Appearance
10__Specified by Architect/Consultant

Who generally installs your PG?
24__% Our company
10__% Outside contractor

What guarantees, if any, are offered?
3__ Wind damage
2__ Vandalism
4__ Energy Savings
1__ Less noise transmission

Typical Depth of Airspace (installed)?
3__¼"
8__½"
12__1"
3__1½"
7__2"+
(5 - 3/4")

Reasons You Discourage PG?
9__Condensation in Air Space
10__Heat Build-up in Air Space
1__Minimal Energy Benefit (poor payback)
4__Cost of Installation
1__Elimination of Natural Ventilation
6__Historic/restoration authenticity
8__Discoloration
2__Discourages Window Maintenance
__Fire Dept. Barrier (for venting fires)
__Specified by Architect/Consultant
14__Aesthetic impact on exterior
4__Aesthetic impact on interior (shadows)

Decision for/against PG generally made by?
13__% Our company
17__% Church (client) committee
__% Insurance Company
__% Outside Contractor
__% Other (__________)

Which kind of PG do you use?
18__% Single storm
7__% Double glazed (thermalpane)
1__% Triple glazed
__% Thermally broken
__% Non-thermally broken

Source of industry information on PG
20__ Stained glass publications
14__ Commercial glazing publications
13__ Word of Mouth
7__ Other (experience, seminars)

Thank you for your time and input. Please respond to these additional questions on the back, if possible.

1. Please identify the oldest PG installation you have seen and its location. (mostly unanswered)
2. Please identify any insurance company which requires PG for stained glass coverage. (NONE)
3. Please describe how you vent. (7) holes/screens; (5) gaps; (2) screened louvers; (3) no putty; (2) to the inside
4. Please describe the framing materials you typically use and how they are installed in the opening.
5. Please discuss any situation which caused you to change from one PG material to another. (abrasion of plastics)
6. Why did you **first** recommend PG for stained glass? (11-vandalism, 8-weather, 6-insulation, 3-protect st. gl)
7. Does your company retrofit PG on your older installations, or those of others? (mostly unanswered)
8. Please identify industry problems/concerns about PG which you have observed.(Discussion about venting, use of plastics)
9. Has your position changed on the use or venting of PG installations over the years.(mostly unanswered)
10. Which local, state or national industry associations do you belong to? (mostly unanswered)

LOCATION OF RESPONDENTS
AR (2), AZ (2), CA (1), FL (3), IL (2), KS (1), ME (1), MI (5), MD (1), NC (2), NJ (1), OH (2), OK (2), PA (3), TX (2), WA (1), WI (3).
CAN (1), ENG (2), YUG (1)

PROTECTIVE GLAZING FIELD SURVEY

Inspired Partnerships performed a field survey of 100 PG installations from March, 1995 to March, 1996. The **Committee** suggested four regional areas to be surveyed based on their climate, concentration of PG installations, and potential for minimizing travel costs. These included: **Portland-Tacoma-Seattle** in the Northwest (temperate/wet); **Tucson-El Paso-Albuquerque-Phoenix** (hot/dry) in the Southwest, **Chicago** in the Midwest (cold/wet), and **Savannah-Charleston** in the Southeast (hot/wet). Each area provided valuable insight on PG installations, and collectively gave a strong national perspective on the PG industry which is summarized in this section. In addition, five of the nine members of the **Advisory Committee** have considerable professional experience in the Northeast and Mid Atlantic areas as well, including Boston, New York City, Philadelphia, and Washington, D.C.

The **Committee** developed the following criteria for selecting PG installations in the field:

1. **Variety of window settings (wood, masonry, steel)**
2. **Variety of stained glass (painted glass, plated windows)**
3. **Variety of PG (acrylics, polycarbonates, glass)**
4. **Variety of aesthetics (good, bad, mediocre)**
5. **Variety of installations (vented, unvented, fixed)**

The **Committee** also established the methodology to use during the field survey of the 100 PG installations using a survey form developed by **Committee** member, Arthur J. Femenella:

1. **Surface temperature of glass & lead (when feasible)**
2. **Outside and inside ambient temperature**
3. **Outside and inside ambient humidity**
4. **Relative humidity in air space (when feasible)**
5. **Description of installation and general conditions**
6. **Expanded visual inspection/comments on condensation**
7. **Date and time measurements were taken**
8. **Orientation of window**
9. **Document and photograph all installations**
10. **Note weather conditions**

SUMMARY OF 100 INSTALLATIONS:

Although various aspects of the PG Field Survey installations are drawn upon throughout this study, particularly in **SECTION III**., all 100 installations are collectively evaluated here. An effort was made to select PG installations at random, which was a necessity due to limited travel costs in every region but Chicago. Most installations were selected on a first-seen basis, while trying to adhere to the selection criteria developed by the **Committee**. The 25 installations in Chicago, however, were essentially hand-picked from the thousands of available installations based on the selection criteria.

In terms of window orientation, the survey was concentrated on the east (31 %), south (40%) and west (27%) windows, since north windows are not effected by solar gain in the Continental U.S. **[FIG 1.]**. Among the windows surveyed, 40% are a simple rectangular or round-arch window, while 60% are gothic-arch or rose windows with tracery **[FIG 2.]**. Window height from the ground was recorded since improved security is often cited to warrant protective glazing; 22% are within five feet of the ground, 30% are between five and ten feet above ground; and 48% are over ten feet above ground (up to 40 feet) **[FIG 3.]**. The exact type of PG material was recorded when it could be determined, otherwise it was simply grouped into plastics (23%) or glass (27%). The breakdown of PG materials employed is: polycarbonates (31%); acrylics (14%), tempered glass (3%), laminated glass (1%), and fiberglass (1%). Therefore, as a group, plastic products accounted for approximately 70% of the windows surveyed. The age of the installation was also recorded when known.

In terms of their condition, over half of the installations (both glass and plastic) appeared "dirty." Usually the dirt was found on the inside surface of the PG. Nearly all of the plastic installations are discolored, scratched or hazed and church members are displeased with their appearance **[FIG 4.]**. About 15% are too discolored to see the stained glass at all. The few (5%) of the plastic installations that are not discolored, scratched or hazed are less than two years old. Approximately half of the installations are set into a sub-frame, typically aluminum, which clashed with the building's historic materials and aesthetics. Another 23% prevent the window ventilators from operating.

Ironically, although response to the questionnaire signify that most studios vent their PG installations, only 4% of those surveyed in the field were intentionally vented **[FIG 5.]**. Another 19 have self-vented over time due to deteriorated sealants or broken glazing **[FIG 6.]**. The depth of the air space varies greatly and is usually contingent upon the window frame and ease of installation, over 75% are set more than 1" from the stained glass. Condensation is unquestionably a problem with PG installations as evidence of condensation was found in nearly 70% of the windows; while 10% of the windows were too obscured to see at all. As expected, the Southwest installations, that are located in regions where the average relative humidity is below 20%, generally had little or no evidence of condensation. Glass temperatures, measured in direct sunlight were always higher than ambient indoor or outdoor temperatures, averaging between 18°F and 21°F higher. The temperatures varied depending on the color of the glass, wind speed, and how long the window had been exposed to direct sunlight at the time of testing.

Despite recorded heat and condensation problems, the stained glass and glass paints were in good condition overall, while the leading, bracing and frame of the windows were deteriorating. However, a number of these windows have been repaired or braced (many *in situ*) over the past 20 years. These conditions seem to correlate with the quality of the window's construction. High-quality windows by reputable American studios and imported windows (primarily English and German) were in better condition than generic windows. Their superior condition can be generally attributable to better bracing, leading, and design. Low-end generic windows with thin (1/8"), flat lead cames, were deforming the worst. Although their internal condition is unknown, none of the plated windows revealed any serious deterioration on the surface.

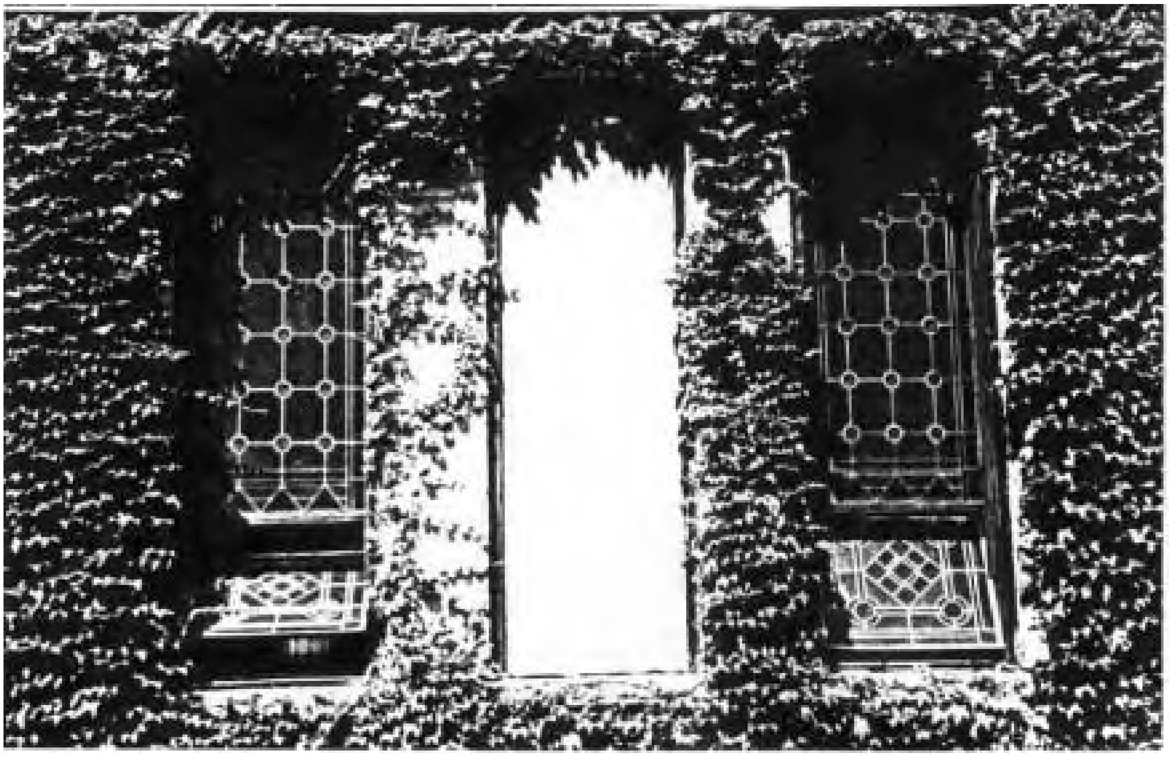

Fig 1. Most of the windows were tested in direct sunlight.

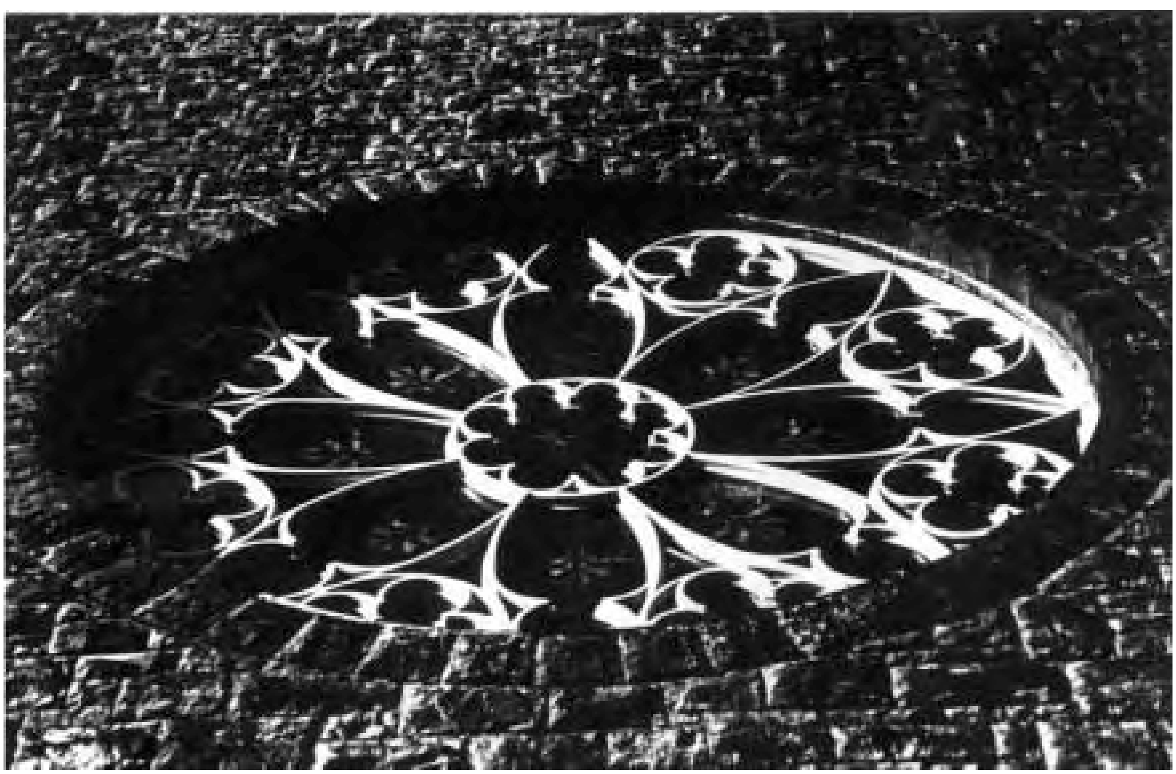

Fig 2. Approximately 60% of the windows surveyed had intricate tracery.

Fig 3. Security was not an issue for most of the windows.

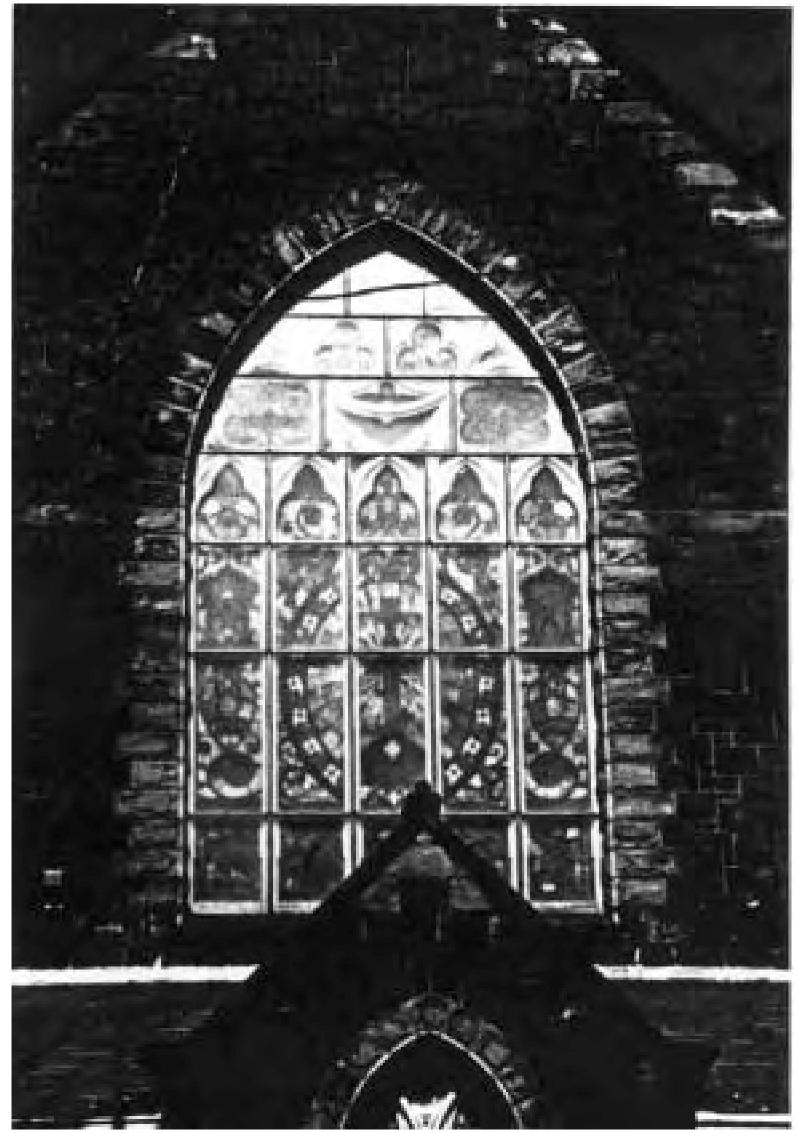

Fig 4. Nearly all plastics have badly hazed and yellowed.

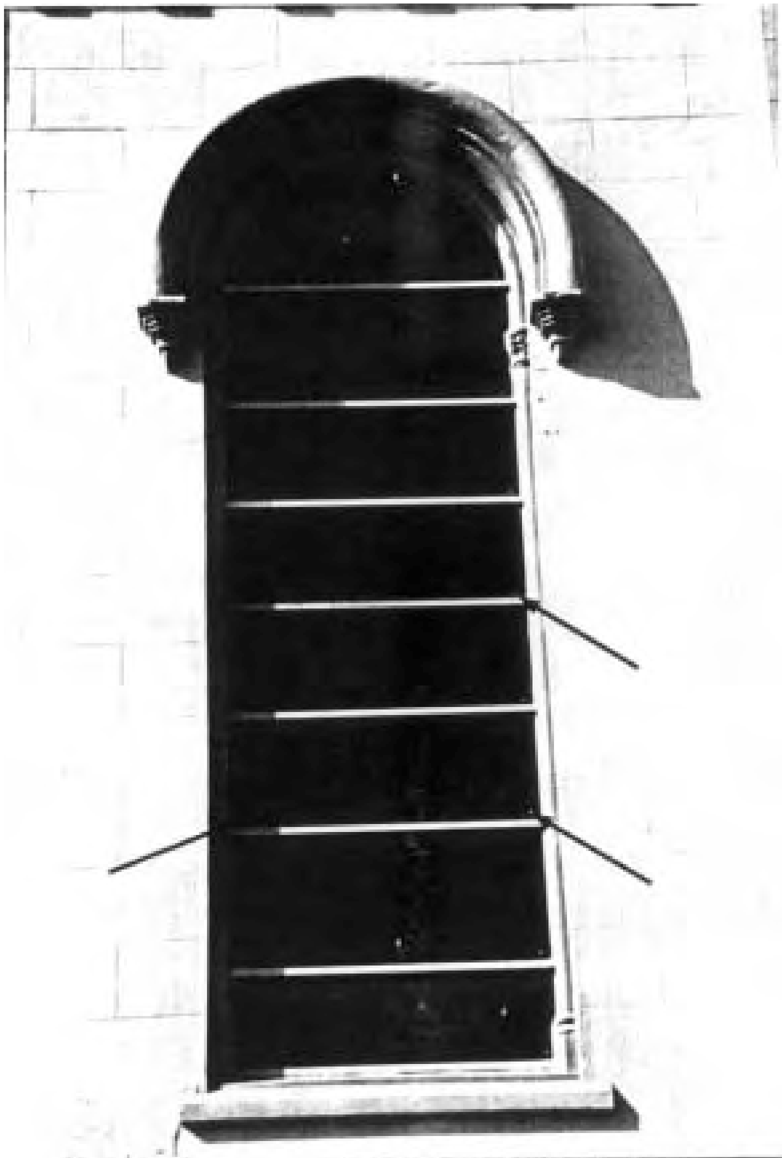

Fig 5. Only 4% of the PG surveyed was intentionally vented.

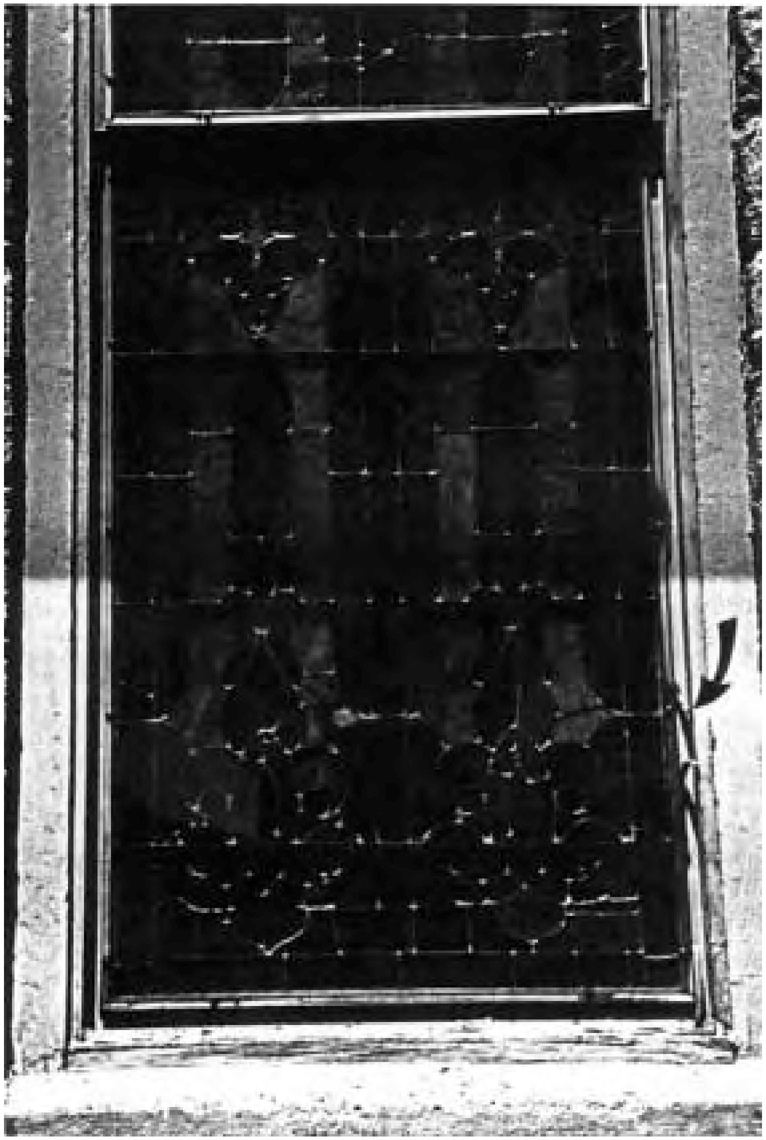

Fig 6. Many windows have self-vented as sealants breakdown.

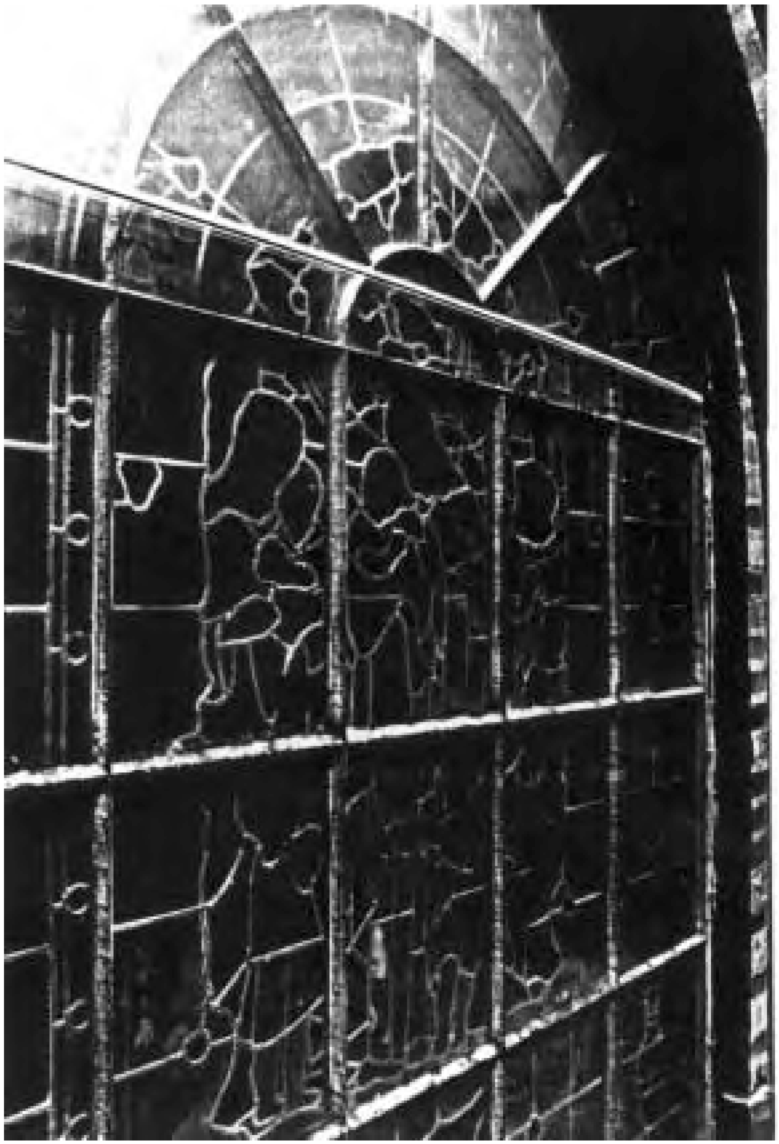

Fig 7. Glazing sealants and frames often deteriorate behind PG.

Fig 8. PG can be integrated with the original tracery.

Nevertheless, the waterproofing (cement) was missing in areas on 40% of the windows and had completely failed on another 22% -- regardless of their quality. Moreover, the perimeter sealants had partially or totally failed on half of the PG installations. The PG definitely prevents proper window maintenance; approximately one-third of the windows surveyed required maintenance to the metal or wood frames, which were not accessible due to the PG **[FIG 7.].**

GROUP A, PACIFIC NORTHWEST (surveyed in April, 1995):

There are fewer pre-W.W.II churches in the Northwest compared to other areas in the country and, perhaps due to limited sunshine, there are comparatively few stained glass installations. This area took several weeks to survey since sunshine was sparse, yet necessary to test for heat build-up and surface temperature of the stained glass. One of the oldest PG installations found in the Northwest was located at the Congregation Beth Israel synagogue and appears original to the 1927 construction. Despite the mild Northwest climate, most of the stained glass is covered with protective glazing. Due to predominately mild temperatures, ventilators are only found on 25 % of the stained glass windows so PG has less impact on church ventilation than many other regions in the U.S. None of the churches surveyed had air-conditioning. The most obvious problem with PG in the Northwest was the creation of an interspace which traps moisture in a very damp climate. Evidence of moisture was readily apparent on 80% of the installations and over 20% of the frames had some degree of corrosion or rot.

GROUP B, SOUTHWEST (surveyed in June, 1995):

Protective glazing installations were difficult to find in the Southwest which required an 800k mile trek through Arizona, New Mexico and southern Colorado. Most of the installations were found in older Southwest towns and cities such as Albuquerque, NM, El Paso, TX, Bisbee and Prescott, AZ, and Durango, CO. The extremely dry climate revealed fewer problems with condensation. When present, condensation seem to be related to air conditioning or evaporators known as “swamp coolers.” As expected, approximately 80% of the churches surveyed had air conditioning. The Southwest churches also generally had lower roofs with wider overhangs that shaded the side walls and stained glass from direct sunlight. However, the intense sunlight on exposed windows, particularly plastic materials with high coefficients of expansion/contraction, was consistently causing failure of perimeter sealants. Despite the blistering daily temperatures, often over 90°F during the field survey, few of the windows surveyed had deformation problems. Unfortunately many of the windows were installed or restored after *1950.* Many Southwest congregations have the resources to keep their buildings well maintained.

GROUP C, CHICAGO-LAND (surveyed between March 1995 and March 1996):

There are literally thousands of protective glazing installations in the Chicago area, yielding the greatest variety of installations to select from. Crime and vandalism rates around the third largest city in the U.S., coupled with brutal winter weather, has encouraged the vast majority (over 90%) of churches to cover their stained glass with PG. Most of the stained glass in Chicago was installed during the late 19th and early 20th century and is, therefore, between 80 to 100 years old. PG installations also tend to be older in the Chicago area than the other three areas surveyed with installations dating back to the early 20th century. The condition of stained glass in Chicago, whether covered by PG or not, is also worse than the other three regions surveyed. Demographic shifts and suburban flight have left many inner city churches in despair with very limited resources. Expensive stained glass restoration is often near the bottom of their building priorities. Here, more than any other region surveyed, PG is sought as a temporary solution to buy time and postpone restoration while the congregation struggles to find new growth and financial independence. Unfortunately, this common lack of resources is coupled with the most severe weather conditions of the four regions with the highest seasonal temperature and humidity swings and freeze-thaw conditions. The combination of these cultural, economic and environmental conditions motivate many urban churches to install PG. Unfortunately, the PG layer becomes another aspect of the window to maintain on top of its first-investment cost.

GROUP D, SOUTHEAST (surveyed in July, 1995):

Charleston, SC, and Savannah, GA were selected for their concentration of historic churches, strong preservation movement, good church documentation, and vulnerability to hurricanes. Surprisingly, several of the churches without PG suffered no stained glass damage from Hurricane Hugo in 1989. Other windows covered with PG actually had the entire window (frame and all) blown out of the window opening. Exposed stained glass is very resistent to wind pressure, but is vulnerable to flying objects. The vast majority of stained glass damage resulting from Hurricane Hugo was caused by flying roofing and siding materials, branches or debris hurled into the windows as opposed to wind or rain from the storm itself. All but one of the Southeast churches were air conditioned, and most of air conditioning systems were on during the field survey. Combined with high relative humidity, which averaged between 50% and 60%, the air conditioned interiors were causing the worst condensation problems observed anywhere. Congregations located in strong preservation communities like Charleston and Savannah, tend to integrate PG more carefully within the original window frame and tracery **[FIG 8.].**

SECTION II:

HISTORY OF PROTECTIVE GLAZING

Written by

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&

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March, 1996

HISTORY OF PROTECTIVE GLAZING IN EUROPE

The **Corpus Vitrearum Medii Aevi** (CVMA) in Europe records the earliest important protective glazing (PG) installation known, based on reliable documentation; the application of external diamond-pane leaded glazing over the "Five Sisters" window at York Minster Cathedral, England, in 1861. This medieval window dates from the third quarter of the 13th century and contains approximately 1,250 square feet of glass. More PG was installed over the west and east windows the following year. The York Minster installations are well documented and therefore an extremely important case study in the history of PG. Records show that the same energy, aesthetic and conservation concerns prevalent in America today were debated over the York Minster protective glazing a century ago!

> The Yorkshire Gazette of June 29, 1861 has an article on the heating of York Minster. Twelve stoves were expected to guarantee a temperature of 50°F at York but the great expanse of glass made this difficult to achieve. *"The Dean and Chapter have determined to glaze the outside of 'the five sisters' window, in the North Transept, with plate glass, to obviate the great draught of cold air through (sic) that expanse of glass; this work will also have the additional advantage that it will protect the beautiful stained glass which in heavy gales from the north is in danger of sustaining considerable damage."*
>
> In the York Herald on July 17, 1862, a letter to the Editor complained about *"the covering of the Five Sisters and the Great West Window with plate glass which takes away the depth of slay of the mullions and richness of effect,.. .besides forming a space for dust to lodge in."*

Subsequent mention of this early PG installation occurred in 1906 and 1907 in papers concerning the restoration of York Minster. Large plates of 'Hartley's rough patent glass' had been used as the 1861 PG, but these plates had been fastened with iron bars, which, due to expansion and contraction, had broken the PG and split the stone mullions. These broken plates were to be replaced with a 'complete skin of clear crown glass in diamond quarries, similar to work already done at the Chapter House.' In 1921, the **Society for the Protection of Ancient Buildings** suggested venting the external glazing over York Minster's windows, *"especially on the south side, to leave opening in the clear borders of the internal glass at the top and bottom of each light. These openings should be filled with copper wire gauze to keep out insects... The object of this is to provide ventilation between the glasses and to minimize the effect of condensation produced by changes of temperature in an unventilated space,"*[2] Seven years later, the Society changed its opinion to *"no protection be put to the glass unless it is very certain that there is real risk of damage happening for want of it."*[3] According to Mr. Peter Gibson, the former stained glass conservator at York, *"the current English view is to install protective glazing only when necessary and to vent it to either the inside or outside, just vent it."*

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[1]CVMA Newsletter 13, February 21, 1975, Peter Gibson.

[2]CVMA Newsletter 14, April 21, 1975.

[3]Ibid.

During the 1970s, Gibson researched the history of several other English protective glazing installations which are recorded in CVMA newsletters:

1. A church in Cothele, Cornwall, is known to have had PG removed in 1880. It is not known when the PG was installed, but the quarries produced a diamond-shaped corrosion pattern on the outside of the medieval window. The 1480 window was possibly "altered" between 1535 and 1540. Unfortunately, this building was demolished when the CVMA printed this information.[4]

2. The William Peckitt Commission Book at the York City Art Gallery contains an entry which refers to glazing on a William Peckitt window at Audley End in Essex. The entry, dated March 1782, records the purchase of nine panes of strong glass for fixing behind the painted glass in the frame for the panel made for Sir John Ramsden, High Sheriff at Byram Hall, near Ferrybridge, Yorkshire.[5] Unfortunately, this building had also been demolished. Further discussion about Peckitt's work indicates that he often mounted stained glass in suspended frames, therefore the "strong glass" may have only served to strengthen an autonomous panel or "sun-catcher" of sorts, rather than the role of "PG" in terms of this study.

3. As initially reported in the British Society of Master Glass Painters (#8, 408) communications, the Collins-Martin window at Redbourne, Lincs. had outer glazing in iron frames, set before 1845.

Several other 19th century PG installations were documented elsewhere in Europe and reported by Stefan Oidtmann in his published dissertation entitled Die Schutzverglasung - eine wirksame Schutzmaßnahme gegan die Korrosion an wertvollen Glasmalerieien (December, 1994).

4. The great northeast windows at the Orvieto Cathedral, Orvieto, Italy, were covered with PG sometime between 1826-1886. Unfortunately, this 19th century installation is not well documented but deserves to be recognized.

5. In 1897, the windows of the small Romanesque church of Lindena (Mark Brandenburg, Germany) were protectively glazed by Dr. H. Oidtmann, Linnich, Germany; the installation was probably installed to protect the window from environmental deterioration.

6. Gabriel Mayer of Franz Mayer'sche Hofkunstanstalt, Munich recalled his father and grandfather mentioning, though he has no documentary evidence since the company records were destroyed in 1944, that 19th century Mayer & Co. and F.X. Zettler (Munich) installations sometimes included large sheets of clear glass for protective purposes.

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[4]CVMA Newsletter 13, February 21, 1975.

[5]CVMA Newsletter 13 & 14. February 21, and April 21, 1975.

Given the abundance of stained glass in Europe, and the few PG installations recorded, it is readily apparent that the usage of PG during the 19th century in Europe can only be described as rare at best. Its limited use continued until W.W.ll. Then the perceived value of PG changed drastically. For most of their history, the major cathedrals throughout Europe had established restoration programs, but few had pressing concerns regarding the deterioration of stained glass from atmospheric pollution and moisture. When these great windows were systematically removed for protection from aerial bombing, a unique opportunity to document them arose. Upon reinstallation, the resulting photo survey showed enormous damage to the paint and glass caused by damp storage below ground. As a result of this new awareness, many windows such as those at Cologne, Regensberg, and Munich were automatically covered with protective glazing upon reinstallation after the war.

Further studies of medieval glass corrosion caused by acid rain since W.W.II have strongly influenced the Europeans to cover their windows with PG. In Germany, protective glazing became common with the repair and restoration of churches since the mid l950s. Since then, protective glazing has become common throughout Central Europe and in Austria as well as the Netherlands. Gabriel Mayer, a principle of the **Franz Mayer'sche Hofkunstanstalt**, Munich concurred with this observation and noted that his company reinstalled many windows with protective isothermal glazing in Germany in the l950s. Most of these installations were reportedly vented. The Canadian studio that responded to the questionnaire always installs PG while the European studios from Hungary and England indicated that they only promote its use under specific conditions. France has only recently begun to use protective glazing. Considerable scientific study of European PG installations and their effect on stained glass, particularly medieval glass, has been undertaken since W.W.II. This research is covered in ***Section V.***

HISTORY OF PROTECTIVE GLAZING IN THE U.S.

Stained glass was installed on a very limited basis in America before the l830s and was not commonly used until the l860s. Prior to the l860s, most of the stained glass in the U.S. was imported from England, Germany, Holland, France and other European countries. Imported plate glass was available in America by the late l830s but it was expensive. Like Europe, the use of protective glazing in the United States during the 19th century was extremely rare. Additional "strong glass" to fill a window opening with a second layer could not be justified when the stained glass already served to keep the weather out. Glass making technology in the U.S. evolved throughout the mid 19th century and eventually inexpensive domestic plate glass was available for use as protective glazing.

Several attempts to manufacture plate glass in the U.S during the 1850s ended in failure, and the first "truly successful" plate glass enterprise, the **New York Plate Glass Company**, was not established until 1880 in Creighton, Pennsylvania; the company changed its name to the **Pittsburgh Plate Glass Company** in 1883.6 Although defined as an "infant" industry in 1879, new technology reduced manufacturing costs and the cost of plate glass to the consumer dropped

[6] Glass Incorporated. The Miracle of Glass, 1939. pg. 22.

by 50% between 1879 and 1884.[7] As American ingenuity spread through the glass industry, the domestic output of polished plate rose to 82% by 1890, while rough plate (more commonly used for PG) rose to 97%. 8 Further, domestic plate glass production tripled from 1,055,224 s.f. in 1890 to 3,342,573 s.f. in 19l9.[9] This growth is attributable to technological improvements in plate glass manufacturing. A U.S. patent for tempered glass was issued on December 15, 1874; tempered glass is stronger and more difficult to fracture than ordinary glass. In 1897, the **Marsh Plate Glass Company** in Floreffe, Pennsylvania, installed the first continuous lehr for annealing plate glass, *"to anneal plates by means of the old-type oven required about three days; the continuous lehr reduced this time to three hours.* **"**[10] With these developments and others, American machinery was being sought abroad. Electric-powered grinders and polishers also played a significant role by 1900.

Until the first World War, however, plate glass was produced almost entirely by the "casting" method, both in the U.S. and Europe. Glass was melted in regenerative pot furnaces. The pots were removed from the furnaces by a crane, skimmed, and partly inverted over a flat, cast iron casting table which was covered with fine sand to prevent the glass from sticking or chilling to quickly. The molten glass was poured in a continuous stream just ahead of an enormous water cooled cast-iron roller. The roller was lifted and the glass removed to a series of lehrs. It was now rough-rolled glass. Polishing the rough-rolled glass was costly. Various pieces of rough glass were fitted onto a plaster bed, on a circular table up to 30 feet in diameter **[FIG 9.]**. The table was transferred to a grinding frame where large iron disks, supporting smaller iron disks, were spun on the sheets with increasing pressure. First coarse sand and water, then finer sand, and finally emery and water were fed to the grinding surfaces, gradually wearing away irregularities. The process took about one hour. The table was used again for polishing, using felt wheels and a finer abrasive, rouge (iron oxide) and water. Upon completion of the grinding and polishing, the rough plate was half its original thickness.

Prior to 1889, it took nearly ten days to produce a piece of polished plate glass from the raw materials. Max Bicheroux of Germany developed a new type of rolling machine shortly after the first World War. His machine produced sheets of predetermined length in a semicontinuous process. In 1922, U.S. automaker Henry Ford introduced continuous rolling in the manufacture of autoglass and revolutionized the American glass industry-- soon to be the largest producer of plate glass in the world. Making the blank, grinding and polishing were now automatic and continuous, just as an assembly line. This process was adapted by **Libby Owens Ford Glass Co.** in 1925. By the pot casting and continuous rolling method of 1922, it took just 54 hours,

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[7]Pittsburgh Plate Glass Company: Glass, pg. 31.

[8]Scoville, Warren C. Revolution in Glassmaking. pg. 52.

[9]lbid. pg. 70.

[10]Scoville, Warren C. Revolution in Glassmaking. pg. 335.

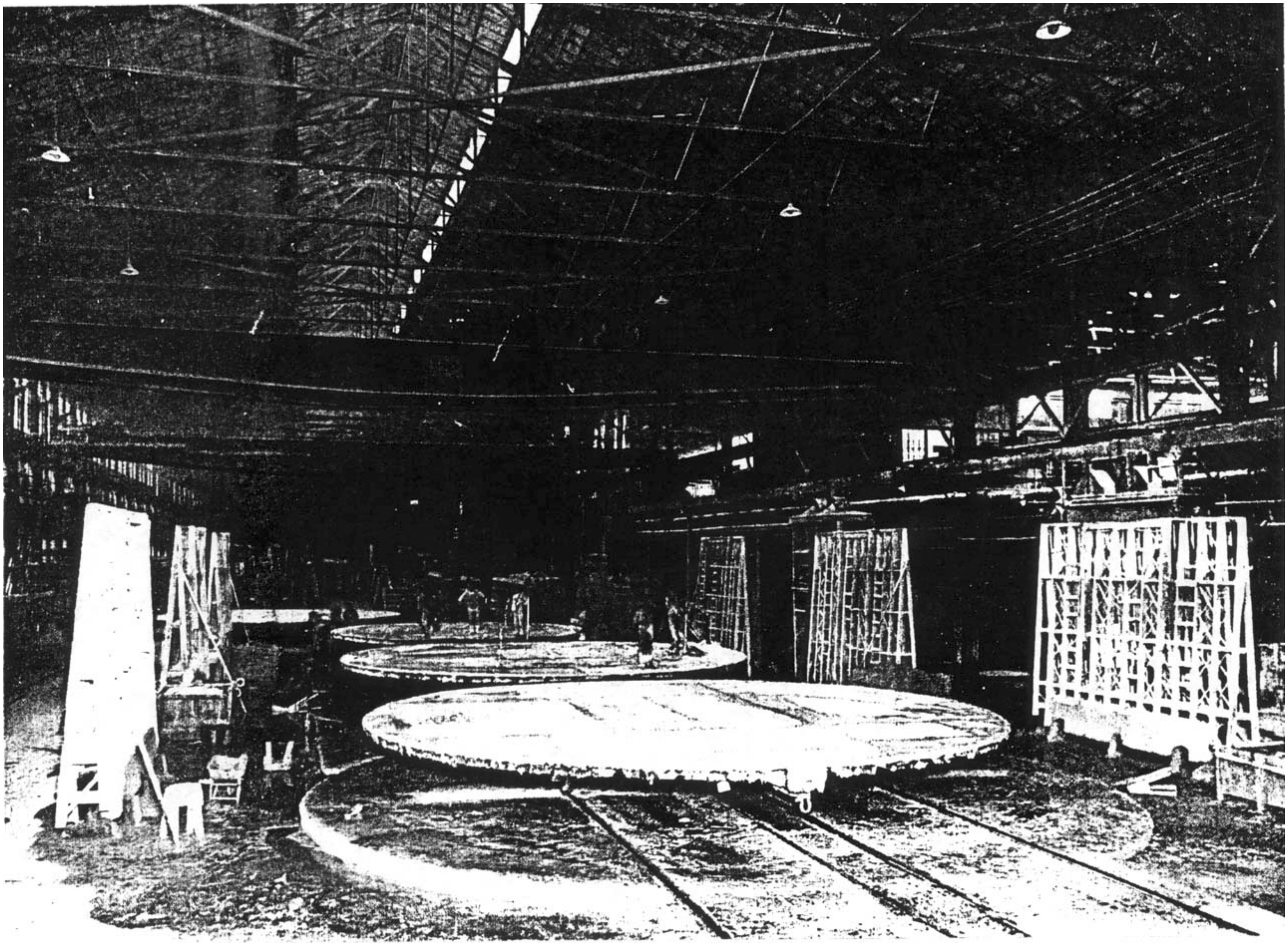


Fig 9. Workmen tramp sheets of rough glass into wet plaster for grinding.

while the semicontinuous method of 1925 further cut production time to only 22 hours! With the introduction of ever larger sheets of glass through ever increasing technical efficiency, resulting in ever lower costs, double glazing became ever more common.

The American development of plated opalescent windows by John LaFarge, Louis Comfort Tiffany and their followers may have lead to the earliest use of protective glazing in the United States. Plated opalescent windows, consisting of several layers of glass, inherently called for the use of large outer glass plates to keep dirt and moisture out of the window interspaces. The exterior plate(s), integral with the window, effectively served as PG. Many plated windows were installed throughout the country by the early 1890s, but most are not representative of the typical PG installation **[Fig 10.].** Within a decade, plated windows were sometimes covered with a full back-plate of rough (unpolished) or ribbed plate glass. A recent restoration of 1902 plated windows found at Old St. Paul's in Baltimore, and made by Maitland Armstrong (a Tiffany colleague), appear to have had original "textured" protective glazing. This exterior glazing was set in an iron frame and bolted to the angle-iron sash holding the stained glass.[11]

Fig 10. A large piece of glass is removed from a plated Tiffany window.

[11] Diane Roberts, "A Portrait of Maitland Armstrong," PSG's Glass Artist, April/May, 1995 p.16.

There are reports of domestic ribbed plate glass installed over German imports from the late 19th century in the Northeast. However, Theodore C. Von Gerichten, whose grandfather founded **Von Gerichten Art Glass Company** (Columbus, OH) in 1893, does not recall any practice of installing PG over their domestic windows or those they imported from Munich, Germany. A search through hundreds of 19th century and early 20th century photos of Chicago churches uncovered no examples of PG over stained glass.

Only two examples of protective glazing in the United States prior to 1900 have been substantiated as part of this study. Both examples represent the usual concept of PG as a separate layer over traditional (single layer) stained glass. St. Thomas Episcopal Church in Taunton, Massachusetts was severely damaged by fire in January 1898. An article in the parish magazine in September 1898 listed repairs and improvements as a result of the fire and noted "*…the rose window guarded against leaks by storm sash."* The Second Church of Christ in New York City has original PG from 1899.

A number of documented PG installations have been identified from the first quarter of the 20th century. The art glass at Wellington Avenue Congregational Church, constructed in a bustling Chicago neighborhood in 1910, was installed in hollow-core steel window frames behind wire safety glass. Crammed into a small site on a residential block, the use of PG may have been motivated by building codes designed to limit the spread of fire rather than any concern for "protecting" the simple art glass. Plated Munich style windows at St. Mary's Church in Beaverville, Illinois, were covered with plate glass provided by the Pittsburgh Plate Glass Company in 1911. Today, several types of plate glass, mostly ribbed, are found on the church.

The **C.J. Connick Collection** at the **Boston Public Library** provides valuable insight on how one of the most prolific American stained glass studios, **Connick Associates**, handled the use of PG in the early 20th century. Although the studio was formed in 1912, protective glazing was not mentioned in company contracts during the first few years in business. However, the Collection contains dozens of references to PG installations starting around 1920 when Hyde Park Baptist (Union) Church in Chicago paid an extra $100 for protection glass in an outside frame. A mausoleum in Rosehill Cemetery, Chicago, was to have *"protection glass furnished by the donor. …. installed by Temple Art Glass Company,"* an indication that PG was sometimes subcontracted to local glaziers. March 1930 correspondence from the Levere Temple in Evanston, IL to Connick reads *"we have set aside, with protection on the outside, the sum of $5,000, complete, set up."* By the late 1920s, job records in the Connick Collection often indicate whether "protection glass" was ordered or not.

Other early American PG installations include a stained glass window by Willet Studios in Calvary Church, Chestnut Hill, Pennsylvania that was covered with plate glass for $250.^{00} in 1915. The Chapel of St. James of Quigley Seminary in Chicago has ribbed plate glass PG from 1917, while Buena Memorial Presbyterian Church in Chicago has leaded diamond-pane PG from 1922 **[Fig 11.]**. Both of these installations, as apparent with many others around the country, became a protective layer by default. Once available, stained glass was simply inserted behind external glass rather than replacing it. An August 1925 parish monthly from St. Mary of the

Fig 11. 1922 diamond-pane windows became PG for stained glass installed later.

Immaculate Conception (Michigan City, IN) states that the imported F.X. Zettler windows installed from 1925-1927 *"will all be protected against the weather by storm glass."* PG was a frequent option by 1925, the year Mr. Henry Hunt spoke on "Setting Storm and Leaded Glass" at the **National Ornamental Glass Manufacturers Association** conference held in Pittsburgh.

PROTECTIVE GLAZING AND THE BUILDING INDUSTRY

As protective glazing became common to the stained glass industry, it began to attract attention from the architectural community and manufacturers. Good Practice in Construction: Part II, published in 1925 by **The Pencil Points Library**, illustrates a leaded glass window in a stone wall with double glazing and notes *"Extra glass affords protection to the expensive Leaded Art Glass from the weather and possible exterior damage, Also gives added heat insulation"* **[Fig 12.]**. No venting of the air space is indicated. The same illustration also describes a *"double double type"* ventilator. **J. Sussman, Inc.**, Jamaica, New York has been making steel windows for churches since 1906 and Jack Sussman believes his father, the company founder, made double-glazed ventilators from the start. A 1926-27 Sweet's Architectural Catalog listing for **The Philadelphia Supplies Co., Inc.** has sectional views of a double glazed window with a 3/4" air space between the storm and leaded glass, and *"double, double"* ventilators **[Fig 13.]**. No venting of the air space is indicated. The company manufactured all-metal window frames and pivot window ventilators and promoted *"fully weatherproof, all-metal ventilators for masonry construction made for double glazing."* Blueprints for Blessed Sacrament Church in Chicago (1937) denote the installation of double glazed windows with a 1" unvented airspace made by **Rossbach Manufacturing Co.,** Chicago **[Fig 14.].**

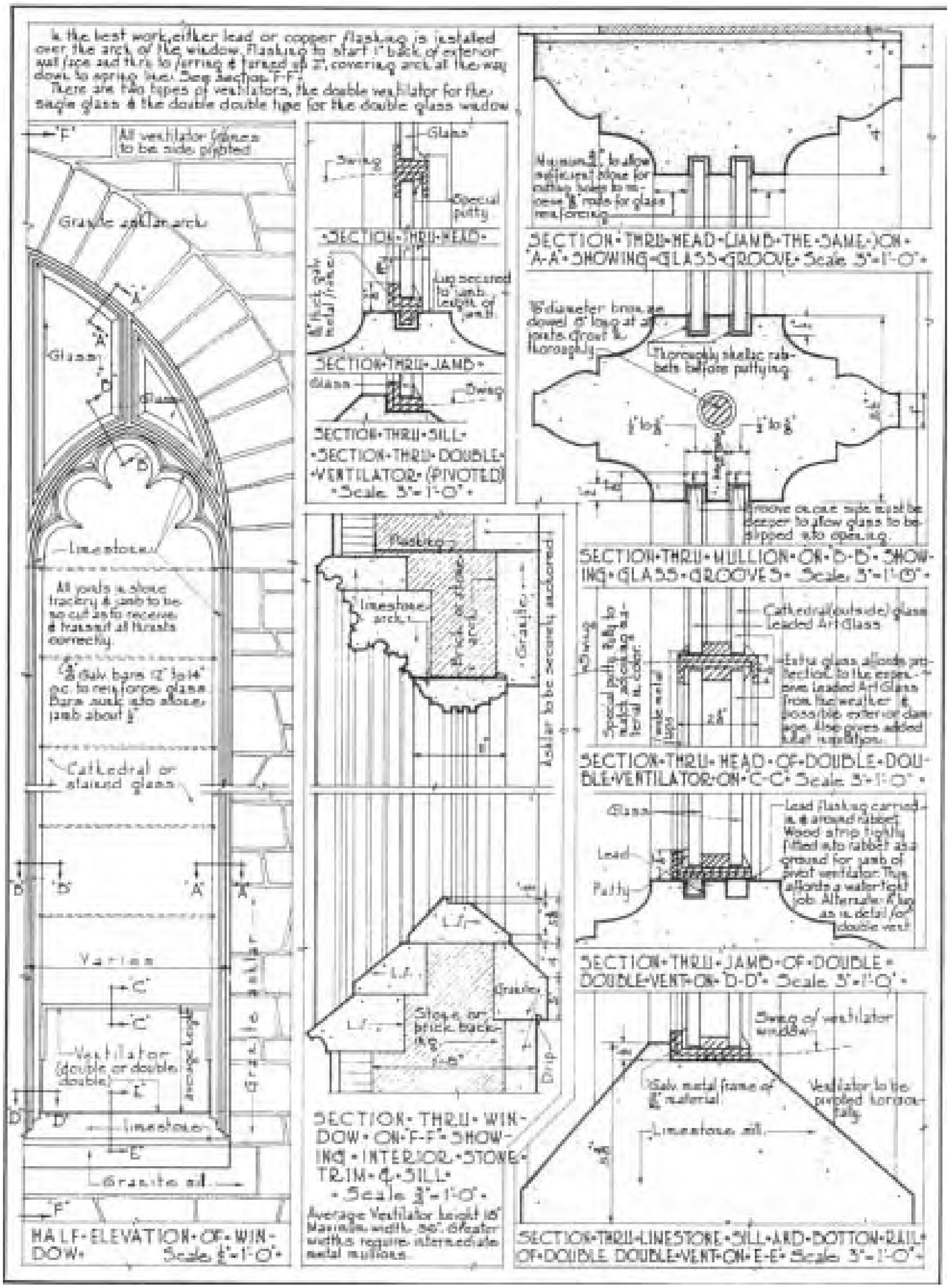


Fig 12. An illustration by The Pencil Points Library (1925) clearly shows double glazing.

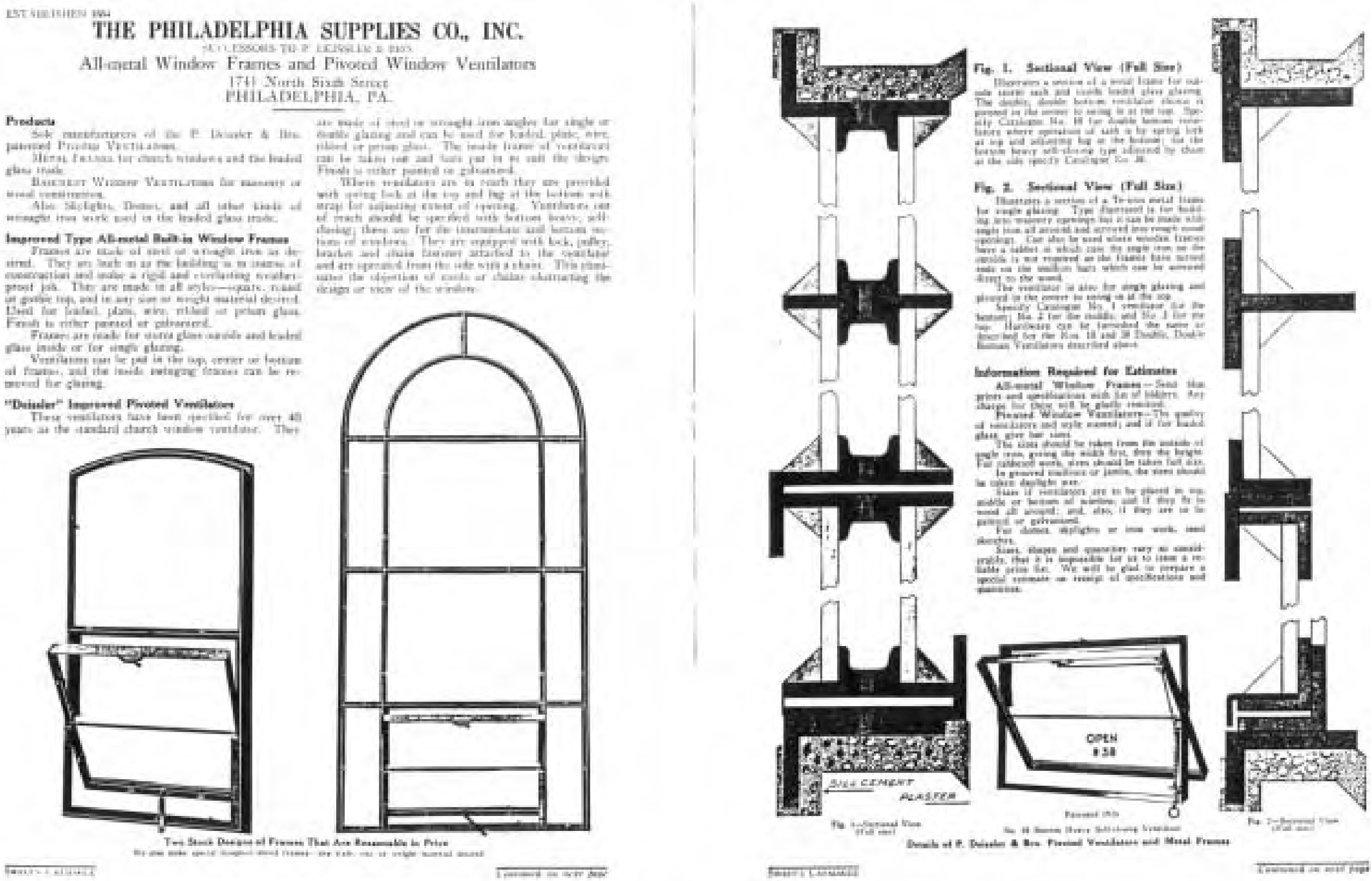
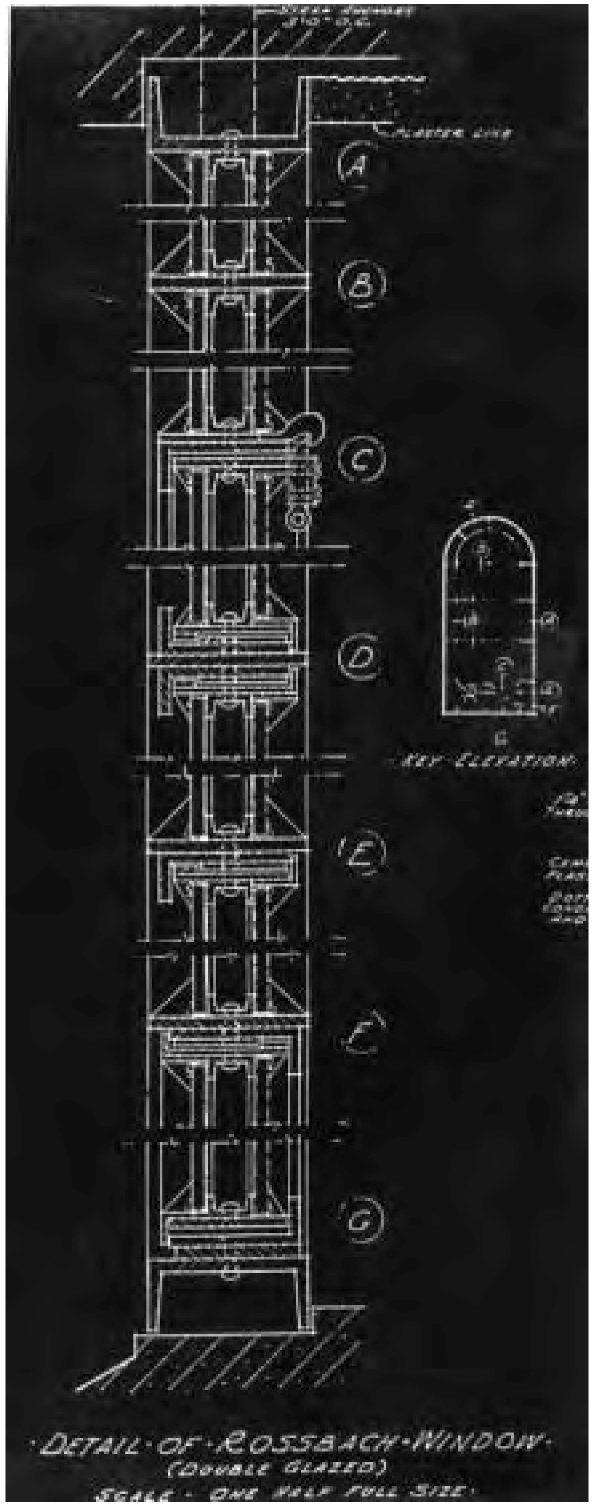


Fig 13. The Philadelphia Supplies Co., Inc. advertised double glazed windows in <u>Sweet's</u> catalog (1926-27).



Blessed Sacrament Church, Chicago

May, 1937

From Blueprints by McCarthy, Smith & Eppig

Fig 14. Double glazing was occasionally specified for churches by the late 1930s.

Stained glass has always served a specialized market, complicating the research for double glazing. **The Philadelphia Supplies Co.** was the only one out of 15 steel window companies listed in the 1926-27 Sweet's to promote double-glazing. Most of the manufacturers targeted the industrial market which had little need for PG. The Great Depression brought church construction to its knees which further limited the demand for decorative luxuries, like stained glass. Although PG was becoming more readily accepted in the U.S., it still remained the exception rather than the rule before W.W.II.

In residential construction, the notion of glass storm windows as "double glazing," did not become popular until after the Civil War. Storm sashes are regularly available in sash & blind company catalogs by 1900. The catalogs tout the benefits of storm windows in terms of energy savings, greater comfort, and the ability to prevent illness. **Noelke-Lyon Manufacturing Co.** (Burlington, IA) asked *"Why should any one be without these items (storms) that easily save their cost in a few seasons* **"**[12] **[Fig 15.]**. Early residential storms were often installed on hooks or hinges for easy seasonal installation and removal; they, usually had elliptical holes on the bottom rail that served as hand-holes and vents during unseasonably warm weather. By the l920s, extruded rubber weatherstripping led to double insulated steel casement windows featured in the 1924 Audel's Carpenters and Builders Guides. But these windows had limited success as single-pane steel windows remained prevalent until the 1950s.

The architectural firm of Keck & Keck (Chicago) designed the first thermalpane window as a sealed unit in 1935 to alleviate condensation and dirt. By 1941, double-hung and casement thermalpane windows were commercially available in wood or steel. *"By building a wall of captive air, the inner pane is kept comparatively warm even though the outer pane may be very cold. This greatly decreases the heat transmission through the window and simultaneously, eliminates foggy windows and dripping sills."*[13] Energy tests at that time indicated a savings of 23% to 36% for double-glazing. Further studies in the *Architectural Forum* and *American Builder* revealed that in many cases *"double glass insulation pays for itself in 2 years or less, in fuel savings alone.*[14] " These studies were likely developed for houses (24-hour occupancy) and it is important to note the reference to double glazing in such emphatic terms. Without any published concerns for how intermittently-used buildings (e.g. churches, synagogues, auditoriums) should be heated, someone reading this in the 1940s might conclude that if double glazing is so effective in terms of energy, it should be used everywhere ***{see Section IV}***. Regardless, the value of double-glazing was further advanced during the 1940s in residential and commercial building markets, which traditionally lead the building industry as a whole.

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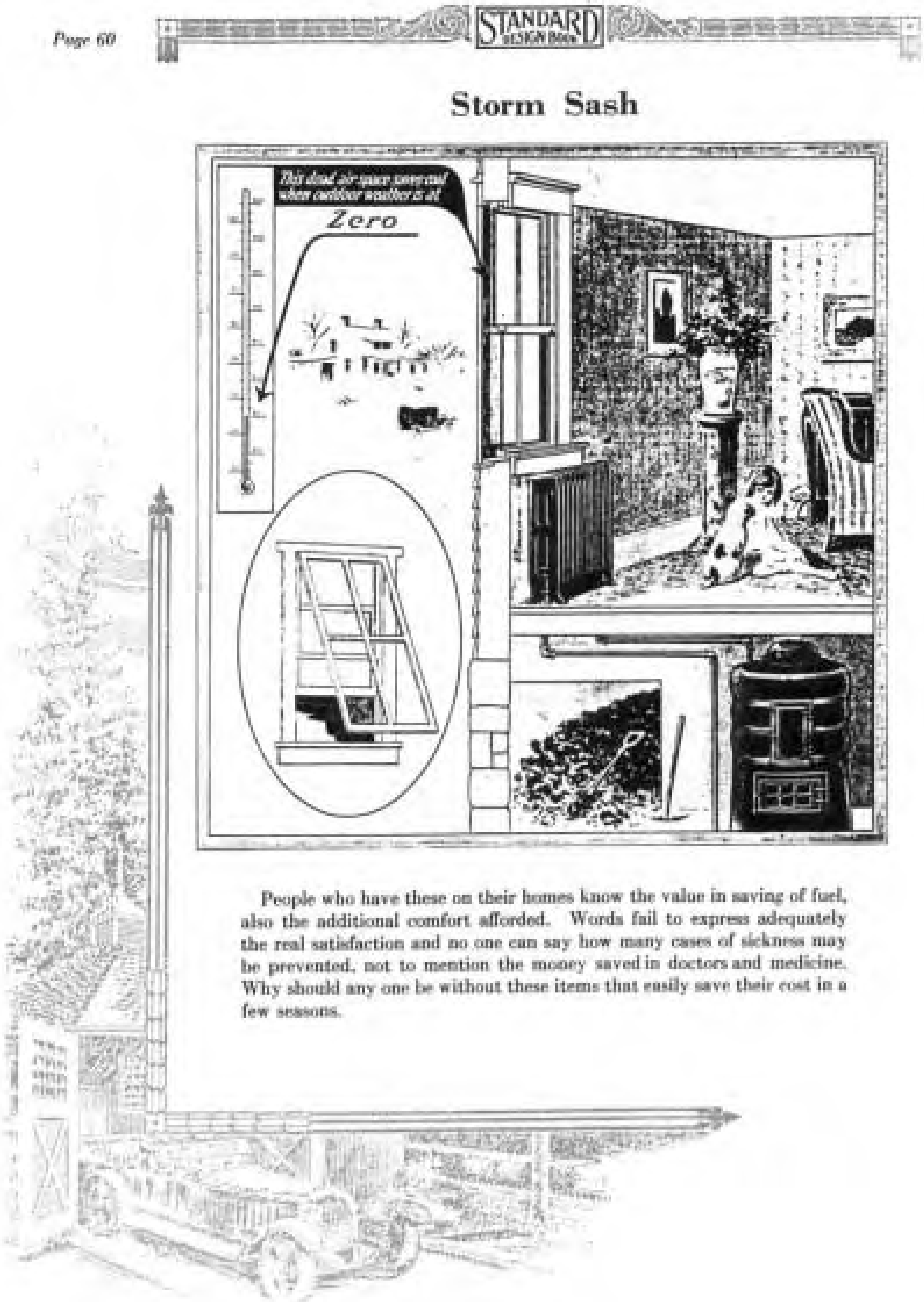
[12]The Noelke-Lyon Manufacturing Co. Catalog, May 1919. pg 60.

[13]C.J. Phillips, Glass: The Miracle Maker, pg. 252.

[14]Ibid, pg. 253.



Storm Sash

People who have these on their homes know the value in saving of fuel, also the additional comfort afforded. Words fail to express adequately the real satisfaction and no one can say how many cases of sickness may be prevented, not to mention the money saved in doctors and medicine. Why should any one be without these items that easily save their cost in a few seasons.

Fig 15. A 1919 storm sash advertisement for residential windows.

Methods of producing stronger glass evolved in the years leading up to, during, and immediately after W.W.ll. Even leaded glass was not spared as super stained glass, called “Dalle De Verre,” was developed in France in 1937. Eventually dubbed “faceted” or “slab” glass in America, such windows can be more than 1” thick and were originally set in a hard cement matrix (now epoxy). Generally less expensive and much stronger than leaded glass, slab glass has grown in popularity since its introduction in the U.S. in the l940s. Ironically, despite its wall-like strength, PG has been installed in recent years over several slab glass installations in the U.S. **[Fig 16.]!**

Fig 16. PG was installed over slab glass in 1993 on this church in Phoenix, AZ.

A tempered polished glass advertisement for **Libby Owens Ford (LOF)** appears in the 1950 Sweet's catalog. Sold under the trade name of *Tuf-flex®,* it was made by a process of reheating and sudden cooling, yielding an outer glass surface in a state of high compression which is highly resistant to breakage. Glass treated in this way is three to five times stronger than regular plate glass in sustaining windloads, three times more resistant to thermal shock, and five to seven times more resistant to impact. Tempered glass, like *Tuf-flex®,* shatters if cut and must be made to size specifications before it is tempered-- a purchasing and scheduling hurdle for glazing contractors looking for greater strength and job site flexibility.

The l950s saw the introduction of glass alternatives for protective glazing. Alternatives included translucent fiberglass sheets, lead by *Kalwall* in 1955, and a barrage of sheet plastics to follow, which greatly simplified PG installations.

More and more window manufacturers recognized the rapidly changing market after W.W.II and began designing frames to accommodate double glazing. A terra cotta rose window detail by the **Architectural Terra Cotta Institute** from around 1950 shows two pre-formed glazing grooves, one for stained glass and the other for storm glazing **[Fig 17.]**. A **National Metallic Sash Company** (Chicago) brochure illustrates a window sash for double glazing manufactured in brass, bronze, aluminum, steel and stainless steel. According to a company brochure, the **Twin Beam Corp.** (Easton, MA) was incorporated in 1925, but its "twin beam" section was not designed until 1950 and then specifically for churches. *"Sections can be formed in gothic, round-head, square or any other shapes. On church windows,* ***it*** *is possible to reuse the present stained glass, often with minor changes."* The Series 100 was double glazed, 2½" deep **[Fig 18.]**. The outer glass is plain, the inner glass leaded. *"The system is considered highly protective, highly efficient in reducing heating and air-conditioning loads, in reducing transmission of street noise."*

A company brochure for **J. Sussman's** steel windows from the early 1950s shows double glazing in a stone and wood setting. A later catalogue illustrates the 300 Series, an aluminum double glazed church window that Sussman has produced since 1959. The 300 Series *"is specially designed to receive protective glass on the exterior and stained glass on the interior.. This 'Double Glazing' protects the stained glass from vandalism while also insulating from the heat and cold and reduces outside noise infiltration. The insurance and fuel costs can be substantially lower….either glass can be installed without disturbing the other. The exterior glass can be installed at time of erection to close up the building and the stained glass installed at a later date at the churches own convenience."* None of these manufacturers vented the air space.

The commercial availability of sheet acrylics drastically changed the glazing industry and created new opportunities for less-skilled, even unscrupulous, contractors to enter the PG business, increasing competition and sales. Dominating the PG market during the l960s and early 1970s, the research of acrylic actually dates back to Otto Rohm who initially investigated the polymerization of acrylic for his doctorate in 1901! However, he did not pick up this research again until 1920, seeking to expand his business in the race against similar work in progress at

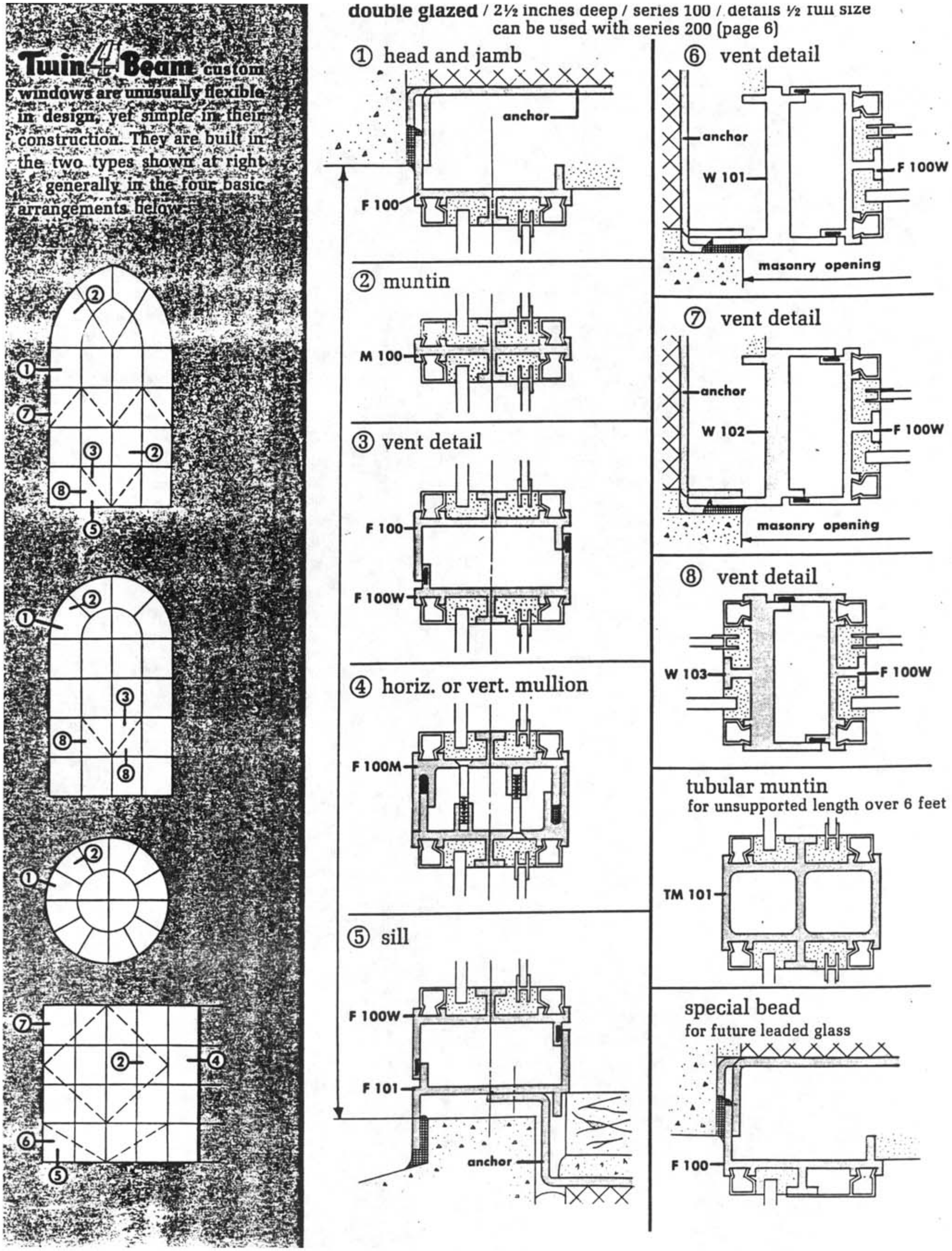


Fig. 18 A Twin Beam catalog illustrating double glazing ca. 1950.

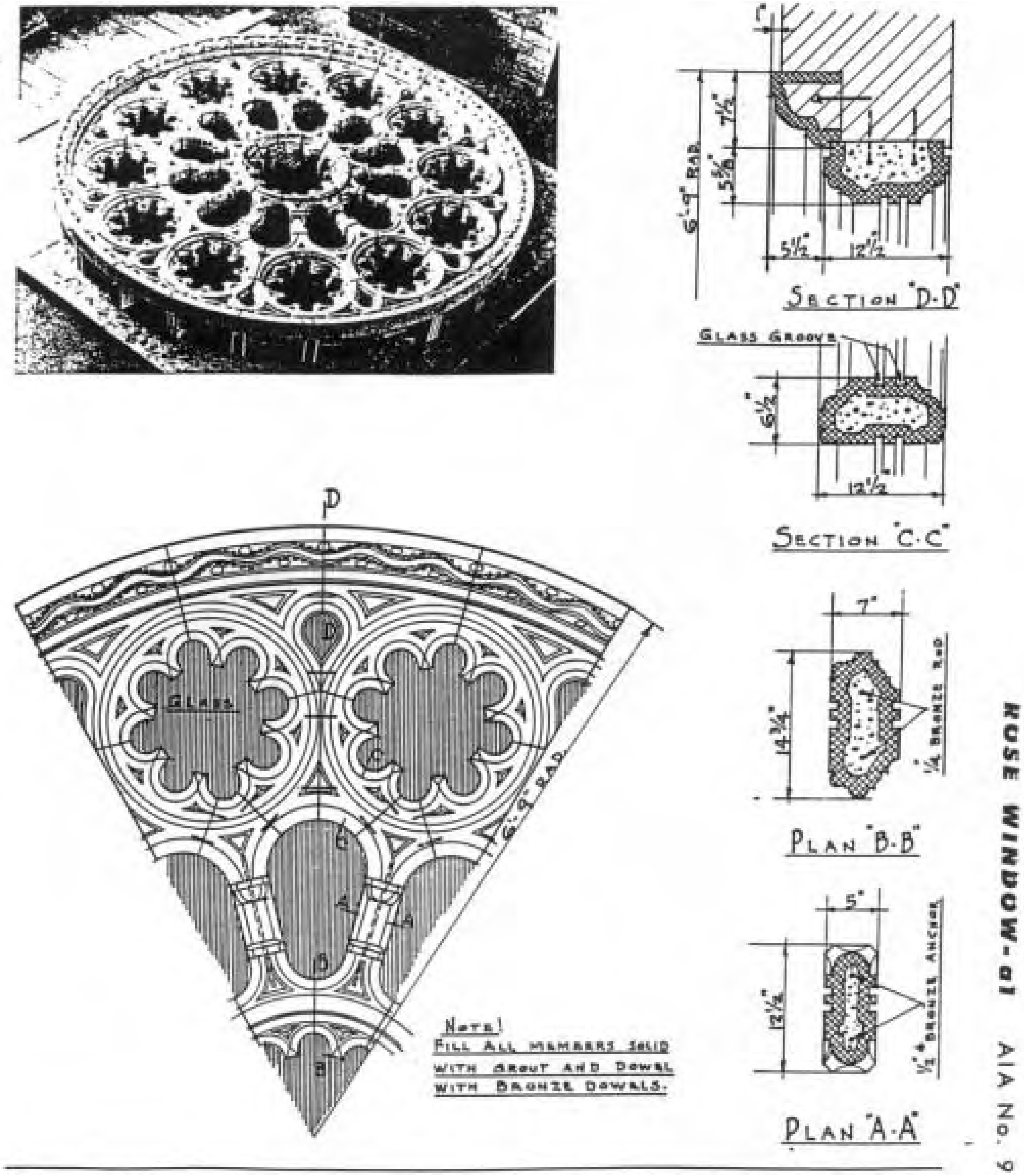


Fig 17. Terra cotta units designed for double glazing (ca. 1947-1959).

Imperial Chemical Industries (ICI) in Britain and at **Du Pont Laboratories (Du Pont)** in the U.S. Eight years later, Rohm and his associate Walter Bauer developed a polymethyl acrylate interlayer for safety glass that was marketed by a U.S. firm as ***Plexigum®*** in 1931. It was better than celluloid, which yellowed, or cellulose acetate, which became brittle at low temperatures, but it could not compete with polyvinyl butyl, introduced in 1936.[15]

Bauer and Rohm continued experimenting and came up with polymethyl methacrylate, a transparent, glass-like substance that could be sawn, machined and cast in sheets. They also discovered that polymerization occurred through exposure to light. So instead of cementing two sheets of glass together as with *Plexigum®,* this polymer separated cleanly from the glass in a strong sheet. The new material became known as ***Plexiglas®*** and was commercially available in both Germany and the U.S. in 1936![16]

Du Pont and ICI meanwhile continued their own research as well and focused on casting and molding acrylic into rods, tubes and blocks. With the commercial introduction of acrylics looming, and a joint desire to forestall patent litigation, all three companies agreed to an intricate set of cross-licensing agreements in 1936. First, Rohm announced *Plexiglas®,* followed by **ICI** in Great Britain with ***Perspex®*** and then, **Du Pont** with *Pontalite®, "a new, water-clear plastic, strong as glass, flexible and non-shattering.* "[17]

Bauer and Rohm's American sister firm, **Rohm and Haas**, obtained a license for casting acrylic sheet from the German firm in late 1935 and in January of 1936 sent Donald S. Frederick to Darmstadt for two months to familiarize himself with acrylic sheet manufacture and fabrication. Frederick then demonstrated *Plexiglas®* to the U.S. Army Air Corps and won a decree stating that polymethyl methacrylate was the only plastic sheet material approved for use in military planes. **Du Pont** did not know exactly how Rohm was casting large acrylic sheets until 1939, but a new license granted **Du Pont** half the annual sheet capacity of **Rohm and Haas**. The name *Plexiglas®* implied a flexible improvement over glass, while **Du Pont's** *Pontalite®* did not. Shortly after its introduction, **Du Pont** dropped the name *Pontalite®* in favor of a new name, *Lucite®;* and soon thereafter, **Du Pont** controlled the U.S. acrylic market.[18]

Laminated glass incorporates both glass and plastic technology. Developed by Bernard Carsten in 1912, it was manufactured by the **Progressive Windshield Company** of Chicago which later became the **Chicago Bullet Proof Equipment Company (CBP)**. The Prohibition era accelerated the need for laminated glass, first for get-away-cars, then for the police, and finally

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[15]Jeffrey L. Meikle, American Plastic: Molding a Culture of New Materials. Rutgers U.P., 1995.

[16]lbid.

[17]lbid.

[18]lbid.

for banks and currency exchanges. **CBP's** specialized line of glazing protects people from people. They also protect stained glass from people-- and natural disasters. Variations of this high impact glazing have found their market in hurricane prone areas, such as Florida.

Laminated glass is comprised of a tough, flexible interlayer of plastic sandwiched between two or more lites of glass. According to the **Glass Association of North America**, laminated glass is made by one of three methods today: 1.) plasticized polyvinyl butyral (PVB) sheet, which includes **Monsanto's** *Safelex*®, **Du Pont's** *Butacite*®, and **Sekisui's** *S-Lec*®; 2.) aliphatic urethane (AU) sheet which includes **JPS Elastomerics** *Stevens*®, and **Deerfield Urethane's** *Dureflex*®; 3.) ultraviolet cured acrylic resin (UV-CAR) which includes **UCB Radcure's** *Uveko*®.[19] PVB and AU are placed between two or more lites of glass and bonded by heat and pressure (PVB can be either clear or tinted). UV-CAR is a liquid laminating system which crosslinks and bonds to both plastic and glass when exposed to ultraviolet light.

In the late 1980s, **Du Pont** began to mass market a *Butacite*® family of advanced composite glazing products with names such as **Du Pont** *Sentry* ***Glas*®, Du Pont** *Spallshield*® and Du Pont *Butacite*® interlayer. According to company trade literature, these glazing types offer the same natural light and viewing characteristics of conventional window glass, while able to sustain the impact of a nine-pound 2"x 4" traveling at 34 mph, or a 26 pound cinder block at 40 mph. Each of these glazing products feature a *Butacite*® PVB interlayer.

Softer, less brittle, and stronger than acrylics, polycarbonates were first developed as a resin in the 1960s and manufactured in sheets in 1970 by **General Electric Plastics. GE** dubbed their product *Lexan*® and its popularity and trade name has become so widespread in the PG industry that many consumers and installers generically refer to any plastic sheet material as "lexan" regardless of the actual product. Although it weighs about the same as acrylic products, the impact resistance of *Lexan*® is said to be 30 times greater than acrylic and 250 times greater than standard glass. Upon installation, the clarity of *Lexan*® is almost that of glass but it will yellow and haze over a few years. **GE** continues to develop new variations such as *Lexan*® *XL*® which is coated with an acrylic non-yellowing ultra-violet protective surface. It has been subject to a three year exposure test and was observed that it tends to bleach, resulting in a clearer product with slightly higher light transmission and less yellowing. *Lexan MR5*® is coated with a silicon abrasion resistant coating called *Margard*® to reduce scratching. Polycarbonates have been the most prevalent material used for PG since the mid l970s, but chronic aesthetic and technical problems are changing the perception of this incredibly strong material.[20]

Today, protective glazing technology has evolved to the point of triple-glazing! The concept of triple-glazing for stained glass was developed in the wake of triple-glazing for residential and commercial windows by the mid 1980s. Triple-glazed windows were developed in response to

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[19]**Glass Association of North America**, Laminated Glass Design Guide, 1994. pg. II-1.

[20]GE Plastics trade literature on Lexan.

long periods of time -- which is not typical of most worship spaces surrounded by stained glass.

Nevertheless, some consider triple-glazing the “cutting edge” of protective glazing. The Mormon Church, considered to be among the best builders of energy-efficient churches, is reportedly specifying triple-glazed window units on all new Mormon churches. **J. Sussman** currently offers two triple-glazed window types, the 5200 Series and the 5600 Series **[see Section III]**. The 5600 Series is incorporated into a 3½” thermally broken frame and *“can accommodate 1” protective insulated glass with another 5/8” inch minimum air space between the an glass to maximize the protection and insulation of the an glass... The separation of an glass and protective glass is achieved by a channel that is an integral pan of the extrusion (not an add-on piece). This channel acts as a condensation gutter and helps prevent air and water infiltration.”*

Custom made triple-glazed units are also being fabricated today where the stained glass is sandwiched between (not behind) outer glass layers. These triple-glazed units are discussed in further detail in **[see Sections III & V].**

SECTION III

ARCHITECTURAL IMPACT

PROTECTIVE GLAZING

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March, 1996

Aesthetic Impact of Protective Glazing

During the field survey, church and temple administrators and clergy were asked how they liked the way protective glazing looked on their building today...73% said they did not like the way it looked. None of those who had purchased plastic PG materials were happy with their appearance today. Although the glazing industry has claimed many advantages for PG, no one claims that it will actually make the stained glass look better. Windows that are not covered with PG look the best **[Fig 19., 20. 21. & 22.].**

The design, materials, and installation of secondary glazing can have a serious aesthetic impact on the stained glass windows as well as a building's architectural design. The exterior appearance of many stained glass windows is nearly as important as their interior appearance. This is particularly true of ecclesiastical architecture. Virtually all Gothic revival churches rely on pointed-arched window frames and delicate window tracery to accentuate the vertical emphasis of the design **[Fig 23.]**. When a conventional grid is installed over the original frame, this crucial design feature is lost and the building's architectural character is severely compromised **[Fig 24.]**. American churches, temples and mosques designed in Byzantine, Romanesque and Renaissance revival styles often feature deeply recessed window openings to punctuate their heavy architectural massing. When PG is installed several inches forward or flush with the outer molding, or large when sheets of PG create surface reflections, the window no longer reads as an aperture and the architectural effect is lost **[Fig 25. & 26]**. With the exception of leaded PG which follows the original stained glass design, all protective glazing systems obscure the leading pattern and texture of the stained glass windows, which are important to the perception of the building from the exterior.

Color & Light: Although the color of stained glass is mostly viewed through transmitted light (from inside), some stained glass -- particularly opalescent glass -- is nearly as beautiful when viewed from the exterior **[see Figs 21. & 22.].** Most glass products today are very stable and will retain excellent clarity over the years. However, it is important to consider how light will play off the glass surface. Reflections and glare can be very disconcerting when PG is viewed from an angle **[Fig 27.].** Some historic and contemporary PG systems have used leading, either figurative or geometric, to break up the broad expanse of glass or sheeting and mitigate the glare. On primary facades, and where leading and texture are of great importance to the perception of the building, this can be a worthwhile approach. Leaded PG is expensive however, typically costing over $100 per square foot.

Plastics are also susceptible to glare but their primary downfall is that when exposed to sunlight and weather, over time all plastics will cloud and yellow. Cloudy PG appears almost opaque, more like a painted surface than a window. Out of 60 plastic PG installations surveyed, only those installed in the past few years still had reasonable clarity. Manufacturers recognize this chronic problem and do not warranty their products beyond a few years. Plastics are also difficult to clean since they scratch easily. **In terms of aesthetics, all plastic products are a poor investment.** The appearance of a plastic installation is certain to decline in a relatively short period of time.

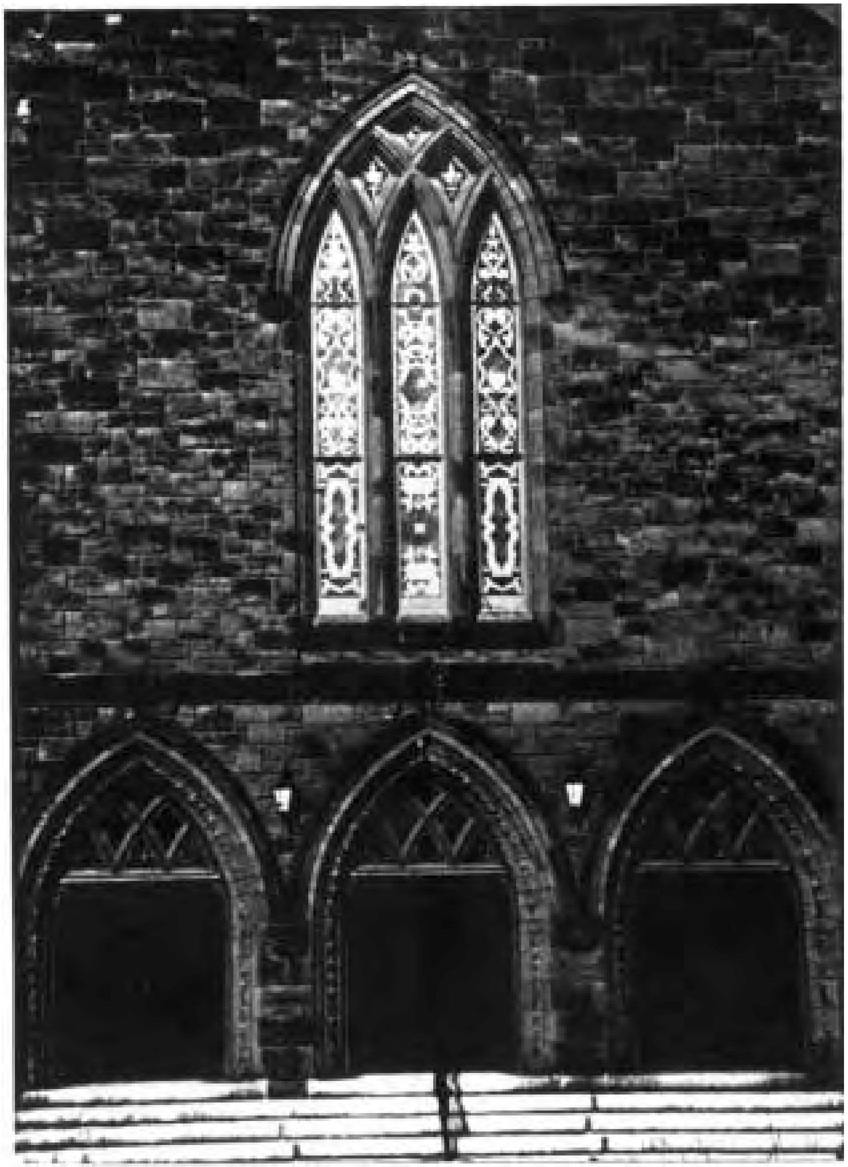

Fig 19. The stone and glass harmonize without PG.

Fig 20. Crisp details and texture can be seen without PG.

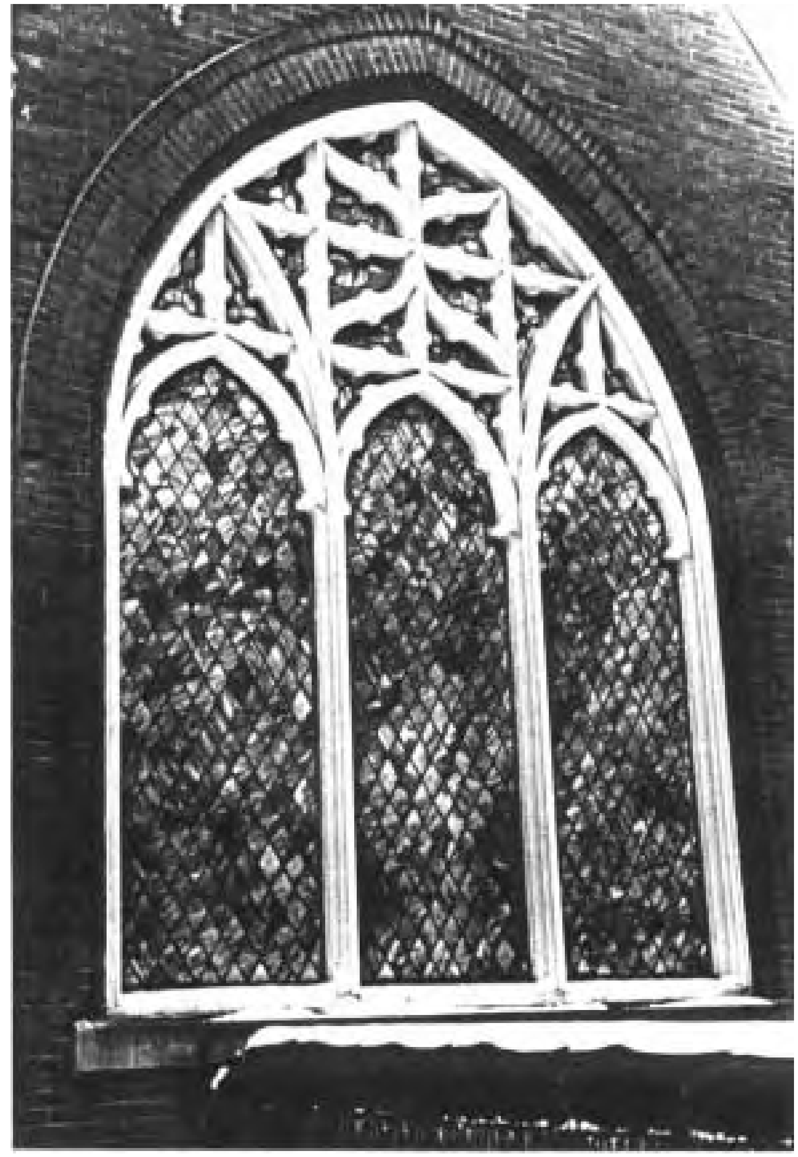

Fig 21. Opalescent glass adds color to the exterior.

Fig 22. Even simple art glass looks better without PG.

Fig 25. Romanesque Revival churches rely on the shadow effect of deep, recessed windows.

Fig. 26. Due to cloudy PG, these windows no longer read as apertures in the wall.

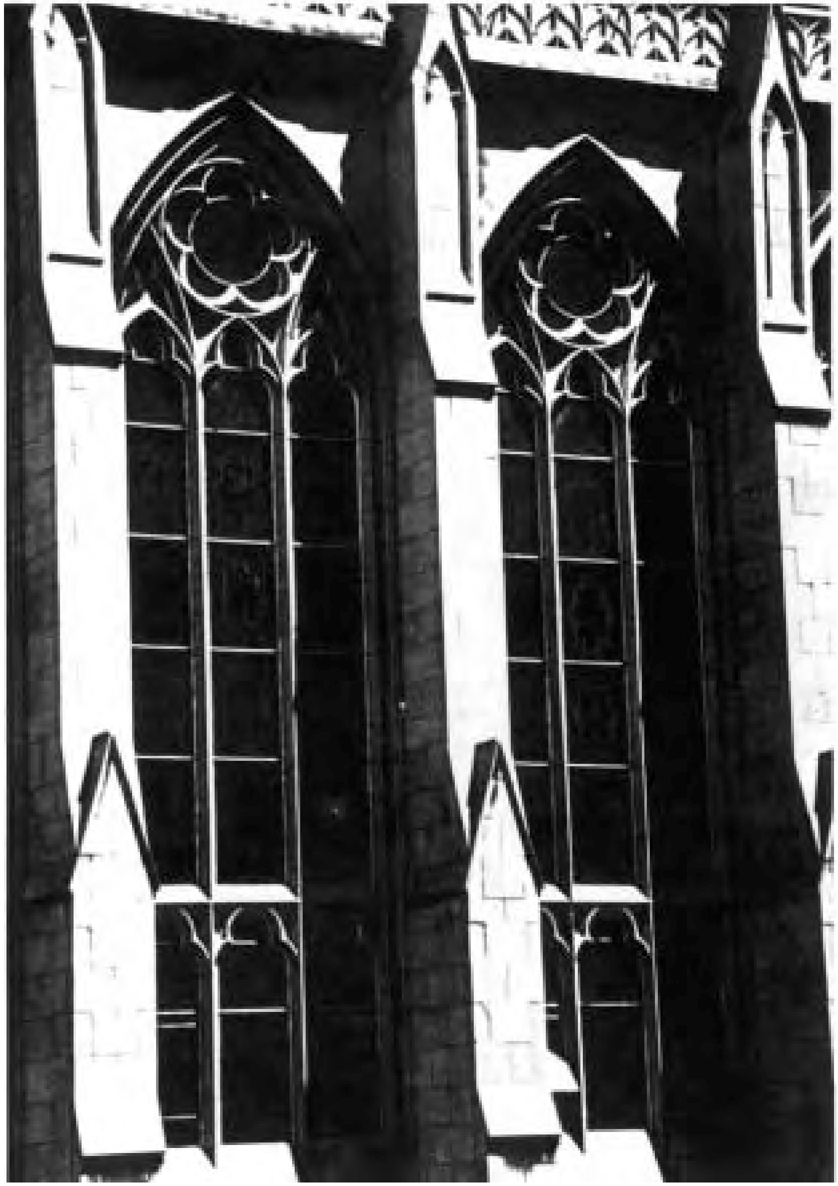

Fig 23. PG over the tracery would alter these windows.

Fig 24. The delicate tracery of this window is completely hidden

Fig 27. The art glass in this installation is blurred by glare and textured PG.

Window Framing: The design of the PG framework should be compatible with the design, materials and color of the original stained glass window frame. Installations in which the glazing is cut to fit within the existing mullions or conform to the tracery are visually most successful **[Figs 28. & 29.].** Linear frames or grids are faster, easier and cheaper to install than curvilinear frames and have become a popular method of installing PG. Of the 100 installations randomly surveyed, 64% had PG frames which did not conform to the original window frame; most of the remaining 36% had simple shapes without any interior framing. Moreover, the color of the PG frame clashed with that of the stained glass window frame in 42% of these installations. An advantage of wood and steel PG frames is that they can be painted to match or compliment the original frame and surrounding trim. Aluminum frames do not hold paint well but are available in anodized colors, typically ranging from silver to bronze to black **(see Appendix B).** Materials should be selected carefully to enhance rather than detract from the windows and architecture; aluminum or silver metallic colors should generally be avoided.

A subtle but important factor in the design of secondary glazing systems is the extent to which the installations reduce the apparent depth of the window opening. Because PG frames are often set against outer moldings, or the PG is merely screwed directly into the frame, it may be nearly flush with exterior wall surfaces **[Fig 30.].** The window is no longer perceived as an aperture or an opening, and the building appearance may be dramatically altered. It is therefore important to install PG within the window opening, maintaining at least a 1” interspace between the PG and the stained glass.

Fig 28. This PG needs maintenance, but the muntins conform to the tracery.

Fig 29. Another PG installation on the same building disregards the tracery.

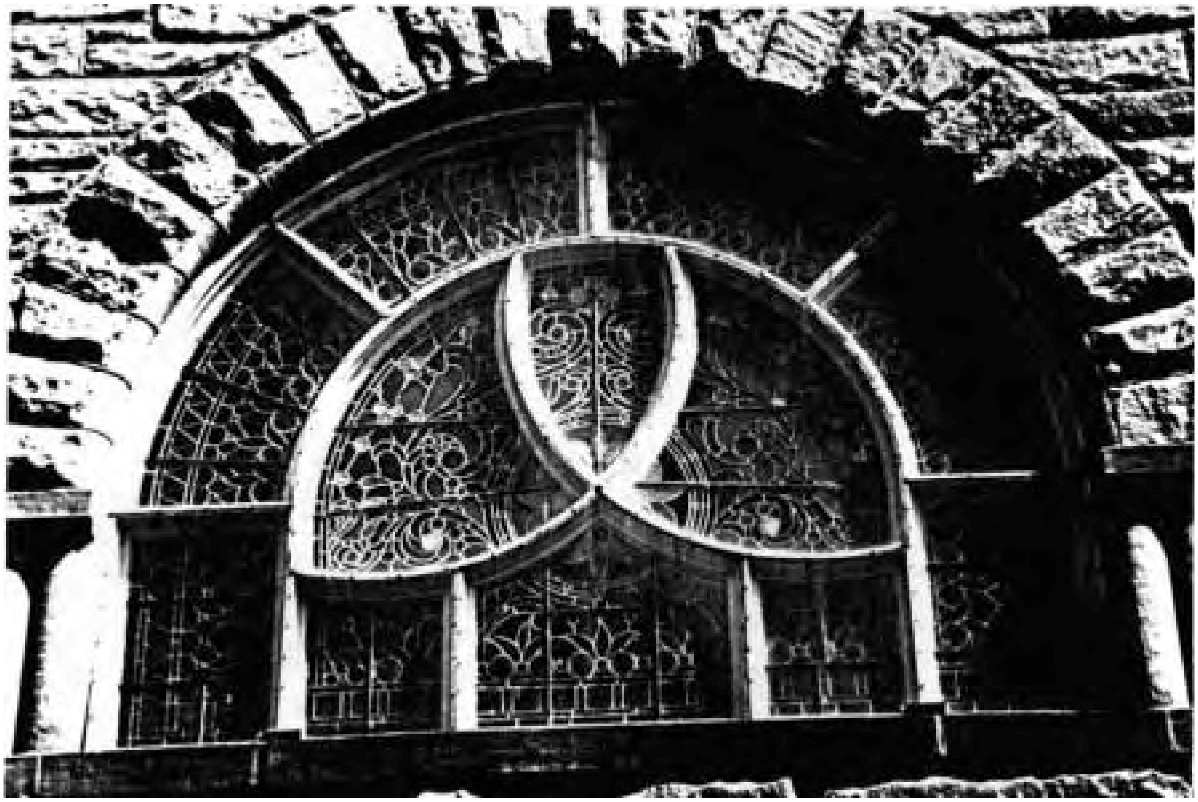

Fig 30. Only a few years old, this PG will haze and obscure the window reveal.

Maintenance and Protective Glazing

Protective glazing is often promoted to alleviate window maintenance. Unfortunately, the field survey revealed that PG is typically installed in a fixed position as a barrier to window maintenance. Paints and sealants (and the materials they protect) continue to deteriorate from ultra-violet light and moisture that inevitably gains access before exterior sealants are renewed. Moreover, it is readily apparent that PG gives building owners a false sense of security; and that annual window maintenance is often overlooked as a property management responsibility. Even if failing paint and deteriorating wood become apparent, congregations are reluctant to remove a system that was installed at significant cost, because removal and remounting may be difficult and time consuming. Frame problems concealed behind cloudy secondary glazing are "out of sight and out of mind" and maintenance is neglected.

Leaks behind PG can cause serious deterioration of the window frame supporting the leaded glass. New PG installations often remain watertight for several years before deterioration begins. Typically the contractor warranty has expired and the owner must pay to have the PG removed temporarily or permanently in order to maintain the very window it was installed to protect! In addition to raising moisture levels, accelerating deterioration, and preventing maintenance, secondary glazing prevents normal window operation. Almost all churches require some ventilation during various seasons, and permanently mounted secondary glazing often immobilizes original stained glass ventilators. It is common to see secondary glazing systems where panels have been removed to expose ventilators, allowing them to operate.

Polymer sheets, such as acrylic and polycarbonate, have a much greater coefficient of thermal expansion than glass, and sheets may bow and break sealant joints if the secondary glazing is improperly installed **(see Fig 6.)**. Even when PG is properly mounted in a removable sash, leakage behind the sash is likely to be a recurring problem. Small cracks in the sealants allow a surprising amount of water to collect behind the glazing in areas subject to runoff or wind-driven rain. Unvented PG does not allow water to drain or evaporate, and trapped moisture leads to condensation and high humidity in the interspace. Protective glazing, whether vented or not, alters the drip details at the window sill, sometimes creating a dam for ponding water unless weep holes are added to drain water away.

If sealant integrity could be maintained, condensation would not occur. Unfortunately, due to the nature of leaded glass, and the high expansion/contraction of lead came, it is impossible to hermetically seal stained glass with secondary glazing alone. A triple-glazed installation, with the stained glass in the middle, or an isothermal installation is required **(see Section V).**

Wooden tracery of Gothic windows is most at risk. Laminations and joinery in woodwork readily admit water once the paint and sealants fail. Unvented windows, where humidity and temperatures are high may exhibit rot or delamination in only a few years. Metal and masonry surrounds are not immune to damage. Iron frames or mountings often rust more quickly in high humidity conditions beneath "protective" glazing systems than if exposed to the weather. Pack rusting of window supports may deform glass and crack masonry. Severe rusting and loss of metal in iron mountings can necessitate frame replacement. While stone tracery is generally more tolerant of improperly installed PG, damage often occurs through the use of impermeable sealants and inappropriate anchors. When sealants are placed directly on the stone surface, they may trap moisture within the stone and cause it to weaken and deteriorate beneath and adjacent to the sealant. The sealant is disfiguring as well, and periodic replacement requires mechanical removal with a chisel or grinder, which can cause further damage. Not infrequently, glazing systems are mounted against masonry with mild steel or electrogalvanized fasteners which are susceptible to rust. Rusting fasteners can stain, or worse, spall the stone or brick.

Light Transmission and Protective Glazing

All secondary glazing, whether glass or plastic, reduces the light to the stained glass in some degree. For most types of glass and plastics that are not hazed or yellowed, the light reduction is relatively insignificant. Clear/clean ¼" polished float glass reduces light transmission only 3%, while clear/clean ¼" *Lexan*® reduces transmission about 16%. Admittedly, the amount of daylight varies constantly for all stained glass depending on the time of day, cloud cover, shading from trees and buildings, etc; however, when dirt builds up on the inside surface of the PG, and when plastics are yellow and haze over time, the effect can be dramatic. These conditions not only reduce the amount of light, they change the color of light passing through the stained glass. **Inspired Partnerships** measured the change in light levels for the case study windows and found that the light level always went up; increasing from as little as 17% up to 103%! For examples, see case studies in **Section VI.**

Sound Transmission and Protective Glazing

All secondary glazing, whether plastic or glass, reduces sound transmission through the stained glass to some degree. This can be very beneficial under certain circumstances where excessive street traffic, airport or industrial noise negatively effects the worship service. Sound transmission qualities vary considerably between different PG materials and frequency of sound involved. Monolithic (single layer) plastics generally reduce sound transmission better than standard glass. Laminated glass, particularly laminated insulating glass however, is superior to monolithic glass or plastics in reducing sound transmission. When tested, these materials receive a "sound transmission class" (STC) rating depending upon their sound transmission loss over 16 frequency bands. For instance: ¼" float glass has an STC rating of 27; ¼" *Lexan*® has an STC of 31; '4" laminated has an STC of 39 (depending on the interlayer); and ¼" laminated insulating glass has an STC of 48 (depending on the interlayer).

In practical applications, the true sound reduction value also varies depending upon the depth of the air space between the PG and the stained glass. The deeper the interspace, the greater the sound reduction (although there are negative drawbacks in trying to vent a deep interspace, **see Section VI.)**. **Inspired Partnerships** measured the sound transmission of (generally) low frequency street traffic through the stained glass before and after PG was removed from the ten case study windows. Depending on the location of the church from the street, the amount of traffic, and the PG installation, sound levels ranged between 50 to 100 decibels. Under normal circumstances, the change in sound transmission with or without PG, was negligible (less than 3%). The highest sound transmission increase measured when the PG was removed was recorded at Covenant United Methodist Church (Evanston, IL) which had a 5½" interspace. Here, the average sound level increased from 87 decibels to 95 decibels (14%). Triple glazed units were not available for testing but would probably reduce sound transmission significantly and could be very effective under abnormal conditions.

Installation Guidelines for Protective Glazing

The owner should obtain a complete condition report of the windows to be covered prior to installing protective glazing. It is important to recognize that PG does not fix deteriorated stained glass, it only covers it up. There are instances where recurrent vandalism, stained glass conditions, or stained glass value warrants a "protective" glazing system. Conservation of the stained glass itself should of course be the overriding consideration for any installation. "Isothermal" protective glazing which remounts the stained glass on the inside of insulated glass, and vents the space between the two glazing systems, may be the best method in many instances for conservation of the stained glass. Even isothermal installations and properly vented systems may have an unacceptable architectural impact unless they are properly designed, however. When designing the installation details of a protective glazing system, the following issues must be considered: the existing condition of the window and its surround; the effect on the aesthetics of the window and the building; the appropriate materials to use; the venting of the interspace; and the ease with which the system can be maintained. The following factors should also be considered in the installation of any protective glazing.

1. **Framework Configuration:** Successful PG installations mimic the shape of the tracery or mullions which support the stained glass. Installation of a grid or a series of horizontal muntins will almost always have an unacceptable architectural impact. If a window is placed high in a wall or clerestory, muntin placement should consider the viewing angle to avoid shadows on the glass when the window is viewed from the interior.

2. **Texture, Leading & Framework Color:** In buildings where the glass texture and leading pattern are important to the exterior perception of the building, large sheets of PG are an unacceptable compromise. Similarly, windows with opalescent glass or other glass which has a distinctive appearance in reflected light may not be appropriate candidates for PG.

3. **Depth of Window Opening:** Installations which maintain a reasonable setback from the plane of the adjacent wall surfaces are generally more successful than those which do not. It is generally more successful to have the window moldings engage the PG, rather than to set it against them. Assuming that proper provisions can be made for expansion/contraction, installations which are set within existing tracery are typically more successful than those which "piggy back" new frames on top of existing window supports.

4. **Glazing Attachment Method:** The attachment of PG is extremely important, especially when plastics are used. PG should never be attached directly to the existing frame, even where a bead of sealant is provided to seal it in place. The PG should be attached within the frame surrounding the stained glass and be securely anchored. It should not just hang on the existing frame of the stained glass. Thermal expansion of plastic glazing, especially with large glazing panels, will break sealant joints and leak. Glazing should be placed within sashes or reglets to allow expansion/contraction. All fasteners should be nonferrous.

5. **Frame Material:** In general, frame components should be fabricated of the same material (either metal or wood) as the original window surround. Metal muntins are rarely acceptable on a wood window. Bronze or anodized aluminum are acceptable, but mild steel will rust should not be used. In strong salt conditions (near coastal areas) special coatings or alloys may have to be specified so that the aluminum does not corrode.

6. **Glazing Material:** Tempered and laminated glass are durable, resistant to breakage, and do not have the expansion or discoloration problems that plastic sheeting does. Glass products are heavier, but are not more expensive to install than plastics when either material is installed properly. For the most part, plastics are more resistant to impact than all of the glass options. Plastic can be cut into complex shapes without risking its integrity. There are numerous tradeoffs for this increased strength. Plastics tend to bow and distort however, especially in large sheets. While the degree to which they are effected varies depending on individual composition, all plastics are subject to scratching.

In the advanced stage, the plastic becomes cloudy, restricting light transmission. The two most common generic types used are acrylics and polycarbonates. Both types have relatively high coefficients of expansion that must be accounted for during installation. The plastics field is one of constant research, developing new products all the time. New improvements are expected, however, any claim that manufacturers are not willing to put in writing should be ignored. Specific considerations for materials are as follows:

Plate or Float Glass. Large sheets of standard plate glass offer the most economical glass solution, but have the least impact resistance with the exception of leaded glass.

Leaded Glass: If glass is cut and leaded together to form an exterior protective glazing, it is often the most aesthetically successful type of PG system. Dramatic impact resistance can also be gained by tempering the glass before leading. This method is very popular in European Cathedrals, for whom it was developed. The disadvantage of this approach is its cost which can range well over $100 per square foot.

Tempered Glass. Glass can be tempered by heat or hardened by a chemical process. The result is that the glass becomes up to ten times more resistant to impact than annealed glass (the transparent barriers on professional hockey rinks are tempered glass). Tempered glass maintains all of the glass attributes discussed in **Section III.** The greatest disadvantage is that tempered glass cannot be cut once its tempered. Therefore, the glass must be measured accurately, often necessitating templates (since windows are rarely perfectly square), which translates into a greater expense and attention to design. In addition, tempered glass (material only) cost approximately 70% more than plate glass, which increases total installation costs almost 20%.

Laminated Glass. This glass is composed of two sheets of annealed glass that have been laminated with a polyvinyl butyral interlayer. While the individual glass sheets are still subject to breakage, the strong interlayer will prevent most projectiles from passing through thereby protecting the stained glass. It is tricky to cut laminated glass in the field, but it is possible. Custom shapes can be fabricated in the shop, and they are only as limited to the skill of the cutter. Certain interlayers, such as Monsanto's Safeflex, will block 99.9% of the ultra-violet light, while maintaining total clarity. This is important if the use of epoxies has been specified in the restoration of the stained glass. Laminated glass (material only) is approximately twice as costly as standard plate glass which increases installation costs around 35%.

Acrylics *(Plexiglas®):* Acrylics have a harder surface than polycarbonates, and tend to be less flexible but are more resistant to scratching. They are effected by sunlight however, tending to yellow and become brittle with age.

Polycarbonates *(Lexan®):* Polycarbonates are softer than acrylics, and thereby more subject to scratching. They are also more flexible, which contributes to their greater resistance to impact. If used in the correct thickness and installed correctly, polycarbonates are virtually unbreakable. The owner should inform the local fire department whenever polycarbonates are installed on windows; it is very difficult to break through polycarbonates in order to vent a fire.

7. **Venting Protective Glazing:** The interspace formed by protective glazing must always be vented. There are three primary reasons for venting: to allow any condensate to evaporate and leave the interspace; to equalize the pressure in the interspace with that of the local atmosphere; and to minimize the temperature gradient for the leaded glass. Where and how the glazing is vented depends on the type of installation and the local environment. In a northern temperate climate, such as found in much of Europe and the United States, the interspace should generally be vented to the exterior of the building. This theory has been supported by testing in many European countries. In hot, humid sections of the United States, venting to the interior should be considered if the building is air-conditioned throughout most of the year. The venting needs of particular windows may vary greatly. The amount of venting required is dependent on the micro-environment that the window is subject to based on climate, orientation, and the depth of the interspace. Venting can be accomplished as follows:

Frames: If applied frames are used to support the PG, holes can be drilled through the members of the frame to allow air movement. The holes must be at the top and bottom of the window, placed in such a way as to discourage the infiltration of rain water.

Plastic: When plastic glazing is used, holes can be drilled through the plastic. Place them at the top and bottom of the lancet, and angle them up to prevent rain from coming in.

Glass: If the exterior glazing is leaded, vent panels (stainless steel screens) can be glazed into the window during fabrication. if laminated glass is used, the corners can be cut off (or the top three inches of a Gothic Head) and a hooded vent screen comprised of glass, stainless steel screening and lead came, can be fitted to the system.

It is better to not apply protective glazing, than to apply it improperly. The most common result of improper installation is condensation. Moisture gets trapped between the glazing and condenses on the stained glass, framing members, and the surrounding window. The moisture promotes corrosion of the glass and the metals, rots the wood, and may contribute to spalling of the masonry. Even the lead of the window may be attacked by organic acids produced my micro-organisms that live in the condensed water. Unvented interspaces can also be subject to extreme temperatures as solar radiation is absorbed throughout the day. The absorbed heat is transferred directly to the window, augmenting the deleterious effects of the expansion and contraction cycle **(see Section VI.)**

SECTION IV

ENERGY BENEFITS OF PROTECTIVE GLAZING

Written by

Andrew Rudin
Energy Management Specialist

Energy Analysis of Protective Glazing Report

Written by

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ENERGY BENEFITS OF PROTECTIVE GLAZING

The concept that double glazing over stained glass would improve comfort and reduce energy needs dates back to at least 1861. The Dean and Chapter at York Minster Cathedral in England *"determined to glaze the outside of 'the five sisters' window, in the North Transept, with plate glass, to obviate the great draught of cold air through (sic) that expanse of glass."* The American glazing industry has promoted the use of protective glazing to save energy since the 1920s. The practice grew rapidly after World War II and again after the oil price shocks in the 1970s. Other technical, cultural and economic events added to the interest in double glazing. For further description, see **Sections II & III** of this study.

Today, energy savings remains among the three most popular ways to promote protective glazing, in addition to vandalism and weather protection. **Sealmaster** Magnetic Interior Insulating Windows claims savings of 25% or more of heating costs and up to 16% of cooling costs. **General Electric** claims improvements of energy efficiency up to 68% for one of their polycarbonate products. Such estimates may assume 24-hour occupancy and unnecessarily high interior temperatures, neither of which is common to houses of worship. Unfortunately, promotional literature from stained glass studios adopts these claims verbatim from the manufacturers. While promotional literature for PG often lists the energy benefits, the savings has been anecdotal or derived from technical formulae. The following report by **Enermodal, Engineering, Inc.,** developed for this study, is the first to measure the savings with a computer model and weather data.

ENERGY AND INTERMITTENTLY-USED BUILDINGS

Worship spaces enclosed with stained glass are usually heated intermittently. To heat the worship space continually is very expensive. Typically, the ceilings are high, the walls are thick, the attics are uninsulated, the doors are drafty, and the stained glass windows-- originally conceived to be a single layer -- are made with many pieces of glass. When new, the stained glass windows were cemented on the inside and outside face which made them nearly as tight as a sheet of glass. However, over time the sealants and putties break down, the windows begin to buckle and bow, and gaps emerge throughout the window.

Since 1990, **Inspired Partnerships** has surveyed 160 houses of worship in Chicago. In 97% of the buildings, the worship space is zoned separately from the rest of the building. Heating systems installed prior to World War II are zoned with manual valves. More recent systems have electric valves controlled by thermostats. Church boilers are usually big, designed to heat large spaces quickly. Their heating capacity is typically over 100 BTUs per square foot regardless of where the building is located in the U.S. They are sized to quickly raise the temperature in the worship space to comfortable conditions, not for maintaining continuous interior temperatures.

There are large radiators under the windows to counter heat loss. The systems are usually steam heat, leaving practically no water to freeze on outside walls when temperatures are cold. Often, the systems were originally designed to be hand-fired by coal, with no plans to heat the buildings continually. In short, the systems were designed to heat quickly and then go off, letting the temperature of interior spaces drift very low without harm to organs, paint, plaster or wood. Other zones in the building might have been heated more hours each week.

Adding a layer of PG reduces heat loss from a window. To reduce conduction of heat, each layer of glass provides two air films, each with a resistance to heat flow. To reduce infiltration, PG is usually installed tightly. While the intent of PG is to reduce the rate of heat loss, there is little benefit in holding heat in an empty space. A comparison of the cost of living index to the cost of energy index back to the early 1900s shows that the cost of energy and the cost of living rose in somewhat parallel fashion. In other words, the prices of *$5* per ton of coal and a nickel for a loaf of bread in the early 20th century are relatively the same as $100 per ton and $1 per loaf today. Architects and builders traditionally understood the intermittent use of churches and realized that additional construction costs to improve the thermal shell of the building would have very long paybacks. Therefore, they redirected funds into big boilers (for short term heating), lighting, acoustics, and works of art.. .including stained glass.

QUANTIFICATION OF ENERGY SAVINGS

In order to understand the energy benefits from protective glazing, the **National Preservation Center** contracted **Enermodal Engineering Inc.** to create a computer model of a typical church. Enermodal has had considerable experience with measuring and rating glazing systems. They used the most advanced software available, DOE 2. 1E, to analyze the energy used by St. John United Church of Christ in Evanston, Illinois. With 7,600 square feet of floor area, St. John is smaller than many urban churches, but is typical of many suburban and rural churches across the country. St. John Church has a fairly typical schedule of use. The sanctuary is used about ten hours per week. The offices are open about thirty hours per week, and the other major spaces are used about twenty hours per week.

Enermodal entered data on the walls, roofs, windows, air leakage, doors, and the outside weather in order to simulate the energy use at St. John. The estimates were then fine-tuned to match the actual energy use utilizing weather data from Chicago. Once a reasonably accurate match was made, the components of the building, thermostat settings, or the weather data could be changed to analyze the effects on the energy bills.

In 1982, the congregation spent $7,544 (about $19 per square foot) to install protective glazing over five large stained glass windows. According to the computer model, the resulting savings was only $183 per year if the interior temperature was “lowered” to 68°F during unoccupied periods. **Inspired Partnerships** advises such temperatures to be as low as 45°F. With lower temperatures during unoccupied periods, the savings would be even less. And the savings would be lower yet if the PG was installed over plated stained glass windows consisting of several layers of glass.

If the church were "moved" to Toronto, the payback would be shortened to about 36 years. In Phoenix, the payback period would be extended to over 1,500 years! In short, the "minimum" payback period for any continental U.S. church would be decades, and represents a lower return on investment than an equal investment in a savings account. **Even** the energy savings claimed for protective glazing over <u>residential</u> or continuously occupied buildings is questionable, since this study endorses ventilating the air space to avoid window deterioration **{see Section V}.** Additionally, the PG at St. John has become cloudy, requiring additional artificial light to maintain interior light levels. Moreover, the glazing has become an eyesore when viewed from the outside.

Enermodal concludes *"The results show that the energy savings from protective glazing for an intermittently occupied church do not warrant the expense of installation,"* *Therefore, the manufacturers or installers of PG have greatly exaggerated its value in energy savings when applied over stained glass in churches and synagogues. There are far better investments which congregations can make to lower their energy bills, such as programmable thermostats and zone valves. For further information, see their analysis following this introduction in **Section IV** <u>Energy Analysis of</u> <u>Protective Glazing</u>.

ENERGY ANALYSIS OF

PROTECTIVE GLAZING

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ENERGY ANALYSIS OF PROTECTIVE GLAZING

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INTRODUCTION

Churches around the country have installed protective glazing over single-glazed stained glass windows to protect the glazing and to reduce the energy loss through the windows. Single glazing is not a good insulator; however, the actual energy and cost savings from a double-glazed system depends on building occupancy patterns and climate.

This study quantifies the potential energy savings from unvented and vented protective glazing installations in a church located in Evanston, Illinois. The energy savings are also calculated for this church in Toronto, Ontario; Seattle, Washington; Phoenix, Arizona; and Savannah, Georgia.

For this intermittently occupied church, the annual cost savings are as great as $200 for Toronto. The cost of the protective glazing was $8000 over 10 years ago, and this translates into over a 40 year simple payback. The results show that it is much more cost effective to use temperature setback and properly insulate the ceiling where it is accessible.

METHODOLOGY

The DOE-2.1E building simulation program (LBL 1995) was used to predict the energy use in the church. The church, St. John UCC, is a 7,584 square foot, brick church (Figure 1) and is located in Evanston, Illinois. The energy performance of the church is also simulated in Toronto, Ontario; Seattle, Washington; Phoenix, Arizona; and Savannah, Georgia. For Evanston, Chicago weather data is used.

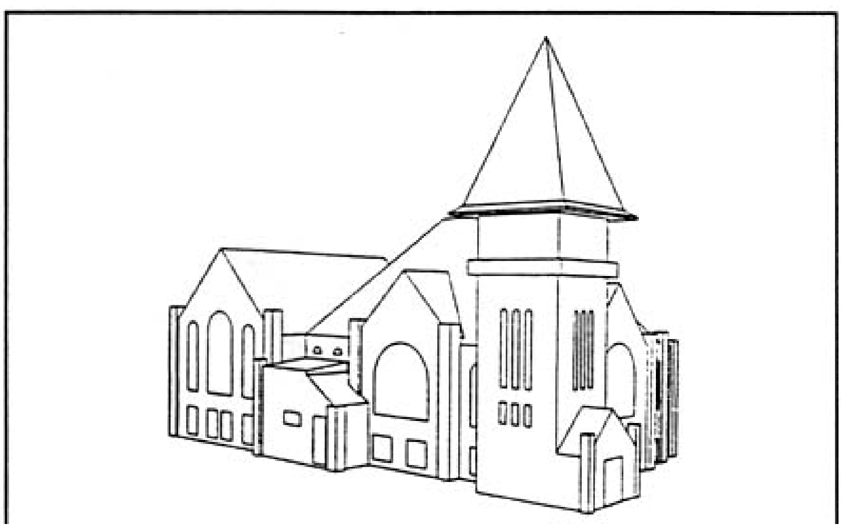


Figure 1 Isometric drawing of St. John UCC, Evanston, Illinois

The church was built in two phases: the rear section dates back to 1898 and is 2,688 square feet; and the main section dates back to 1908 and is 4,896 square feet. The main floor, or sanctuary/hall, is above a full, conditioned basement with a dropped ceiling. The basement has offices that are occupied from 9 a.m. to 3 p.m., Monday through Saturday. The rest of the basement is used as a classroom from 7 a.m. to 2 p.m. on Sundays, and from 9 a.m. to 5 p.m. on Wednesdays. The sanctuary/hall is used from 7 a.m. to 2 p.m. on Sundays, and from 4 p.m. to 10 p.m. on Thursdays. The thermostat setpoint is 72T during occupied periods and 68'F during unoccupied periods.

For lighting, the church has a mixture of incandescent and fluorescent lights inside. There is a total of 5 kW of lighting on the main floor, 1.4 kW in the basement, and 0.8 kW of miscellaneous lights. There is one 150 W mercury vapor lamp outside.

The section constructed in 1898 has 2x6 walls that are uninsulated with 1 inch lath and plaster and 1 inch furring on the inside and 2 inch wood sheathing and a 4 inch brick veneer on the outside. The roof is constructed of 240 pound asphalt shingles over 15 pound felt on 3/8 inch plywood decking installed on top of' 1x6 nailers with 1 inch gaps. The ceiling is 5/8 inch lath and plaster and the space between the ceiling and roof is not insulated.

The section constructed in 1908, has walls that are 13 inch masonry walls (12 inch brick and 1 inch mortar) with 1 inch lath and plaster and 2 inch furring on the inside. The roof has the same construction as the 1898 roof, except the attic is insulated with 6-inch fiberglass batts. The sanctuary ceiling has four vents and three of them have been covered with boards. To adjust for the vents in the ceiling above the sanctuary, the insulation value is down-graded from a nominal 6 inches to a nominal 4 inches.

Windows

The church has 1153 square feet of windows. Five of the windows are stained glass windows (379 square feet) and have protective glazing. The average cost per square foot of window area for the protective glazing was $21. The remainder of the windows are a mixture of single-glazed (338 square feet) and double-glazed (436 square feet) windows. For the double-pane windows and the windows with protective glazing, a 3 to 4 inch gap is assumed between the glazing layers. -

For this study, three glazing options are considered for the stained glass windows:

I) Single glazed: green glass;
2) Unvented protective glazing: clear glass (or acrylic) on the outside and green glass on the inside; and
3) Vented protective glazing: clear glass (or acrylic) on the outside and green glass on the inside.

Table 1 summarizes the thermal properties of the stained glass window options. The properties were determined using the WINDOW 4.1 computer program (LBL 1994) for calculating the thermal and optical performance of window systems. The U-factor (or U-value) is a measure of the heat loss through the window and does not account for solar gains. The shading coefficient is a relative measure of the solar heat gain through a window. The solar heat gain coefficient is the fraction of incident solar radiation that comes through a window. (Multiply the shading coefficient by 0.86 to determine the solar heat gain coefficient.) The solar transmittance is the fraction of incident solar radiation the is transmitted through a window. The shading coefficient and solar heat gain coefficient include the transmitted and absorbed components that come through a window. -

The glass temperatures are center-of-glass temperatures of the inner glazing layer. We assumed ASHRAE Summer Design Conditions which specify 248 Btu/hr-ft^2 of directly incident solar radiation, an 89^{o}F outside air temperature and a 75^{o}F room temperature. The "no wind" case is the worst case.

Table 1 - Stained Glass Window Properties

Properly	*Single*	*Unvented*	*Vented*
U-Factor (Btu/hr-ft2-F)	1.09	0.50	0.64
Shading Coefficient	0.73	0.70	0.63
Solar Heat Gain Coefficient	0.63	0.60	0.54
Solar Transmittance	0.51	0.36	0.36
Glass Temperature (7.5 mph wind)	106^{o}F	119^{o}F	119^{o}F
Glass Temperature (no wind)	108^{o}F	120^{o}F	120^{o}F

The glass temperatures show that the protective glazing increases the inside glass temperature by 12^{o}F. The calculations in WINDOW 4.1 are based on glazing systems that are unvented, so the results do not show that venting the glazing lowers the glass temperature. The glazing temperature for the Vented option will be between the Single and Unvented options and closer to the Unvented condition.

To simulate the vented glazing option, natural convection is assumed between the glazing layers to determine the U-factor. The solar heat gain coefficient is the average of the contribution of absorbed solar heat gain from the Single and Unvented options added to the solar transmittance. The absorbed solar heat gain is the difference between the solar transmittance and the solar heat gain coefficient.

The remainder of the glazing area is a mixture of single glazed, clear units and double-glazed units. The majority of the windows in the basement are double-glazed, while the majority of the windows in the sanctuary and the main hall are single glazed.

Heating, Ventilation and Air Conditioning

The church has baseboard heat that is served by a gas-fired, hot water heater. The boiler has an input rating of 600,000 Btu/hr and an output rating of 480,000 Btu/hr and is well maintained.

The church has 3 zones, each with its own thermostat: 1) sanctuary/hall; 2) basement (school area); and 3) offices. There is a total of 0.4 hp circulating pumps serving the zones. The office also has a 2500 W window air conditioning unit. The same system is used for the analysis in Seattle and Toronto. For Phoenix and Savannah, three 5-ton electric heat pumps provide heating and cooling.

Electricity and Natural Gas Costs

The average cost for energy in Evanston is $0.10/kWh and $0.42/therm. Utility bills for electricity and natural gas usage for May 1994 through April 1995 were provided for the church, and the model was tuned to match the usage. For the other locations, the cost for electricity is $0.1/kWh and for natural gas is $0.5/therm.

RESULTS

The DOE-2.1E building simulation program was used to predict the energy savings froth the unvented and vented protective glazing as compared to the single-glazed window. The simulation model was tuned to match the monthly utility data to within 5% of the annual energy use. Figures 2 and 3 compare the predicted energy use with the actual energy use for each month. The greatest deviation in the monthly natural gas usage occurs in August and September when the usage was estimated by the utility. On the electricity usage, the model predicts within 5% of the annual usage; however, the monthly values show greater deviation, especially in the summer months. The model overpredicts electricity usage in the summer. This difference can be attributed to- weather conditions, and less frequent use of lights and other equipment in the summer.

The actual energy use between May 1994 and April 1995 at St. John UCC was 5941 kWh and 5407 therms. The electricity cost $605, and the natural gas cost $2271. Although space heating accounts for over 90% of the energy used at the church, the cost for natural gas is only 79% of the total energy costs.

Figure 4 gives a breakdown of the energy use within the building in Evanston. A similar graph is given for Phoenix in Figure *5.* For the other climates, graphs are included in Appendix A. In Evanston, Seattle, and Toronto over 90% of the energy used is for space heating. In Phoenix and Savannah, space cooling accounts for the majority of the energy use.

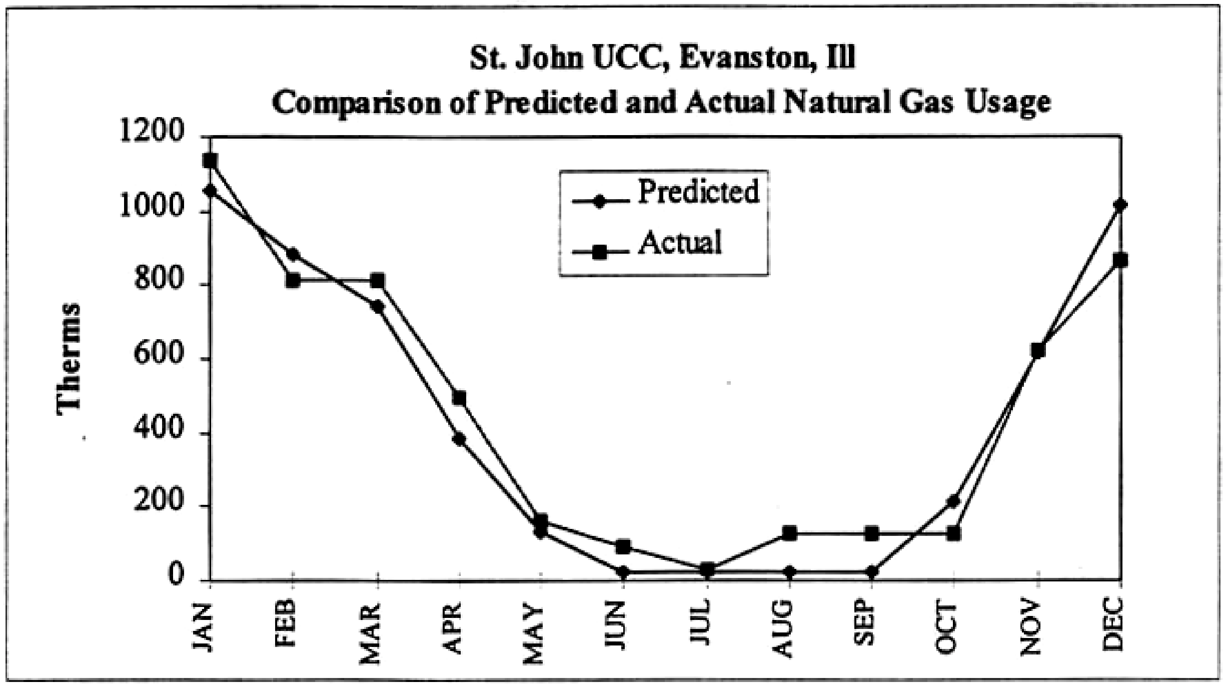


Figure 2 Comparison of actual and predicted natural gas usage in Evanston, Illinois.

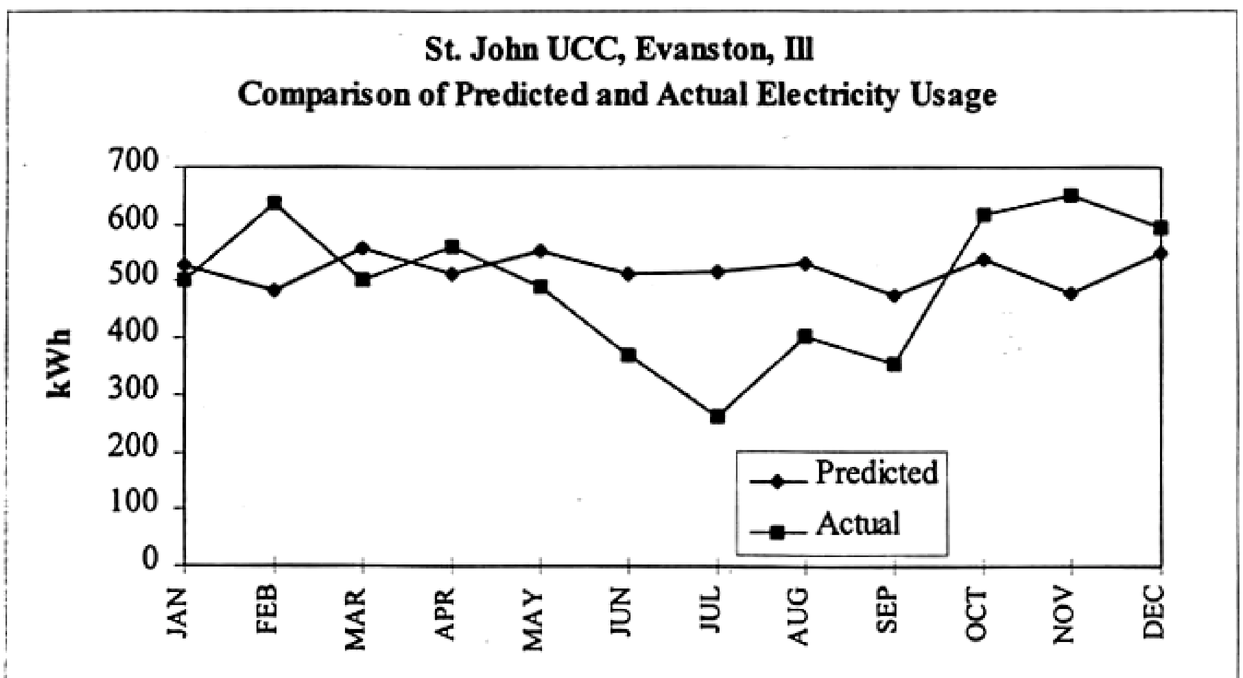


Figure 3 Comparison of actual and predicted electricity usage in Evanston, Illinois.

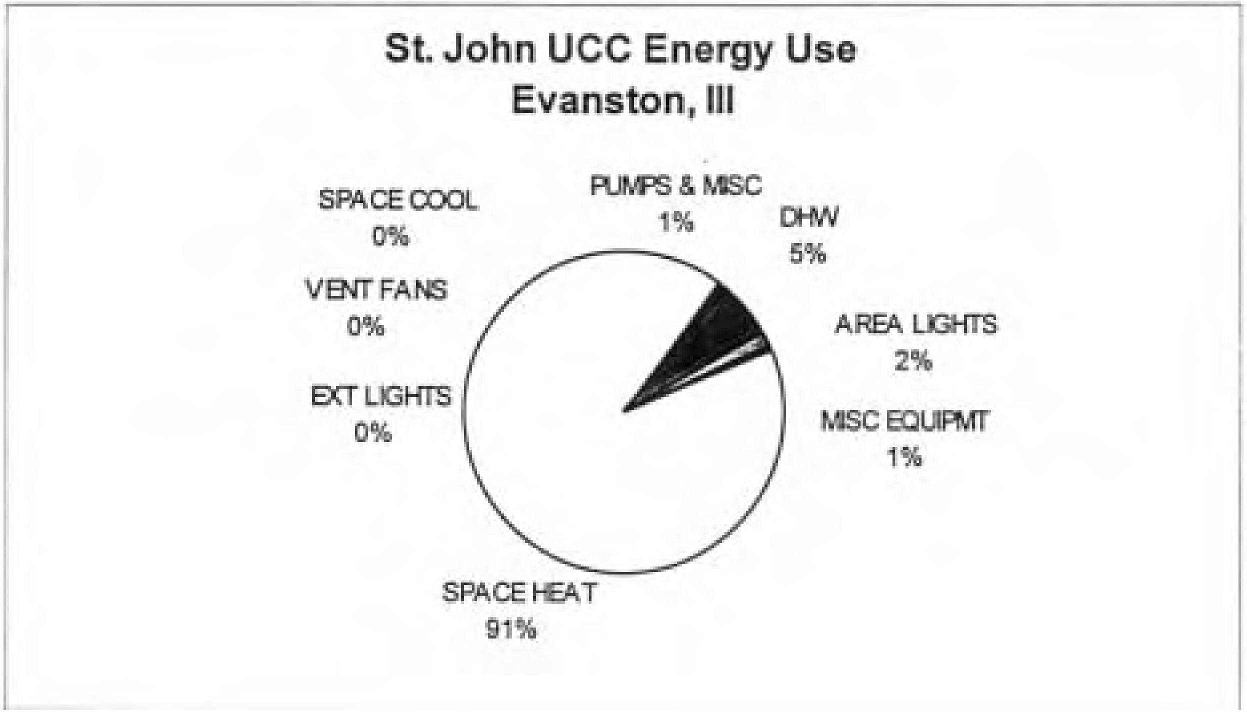


Figure 4 Breakdown of energy use at St. John UCC.

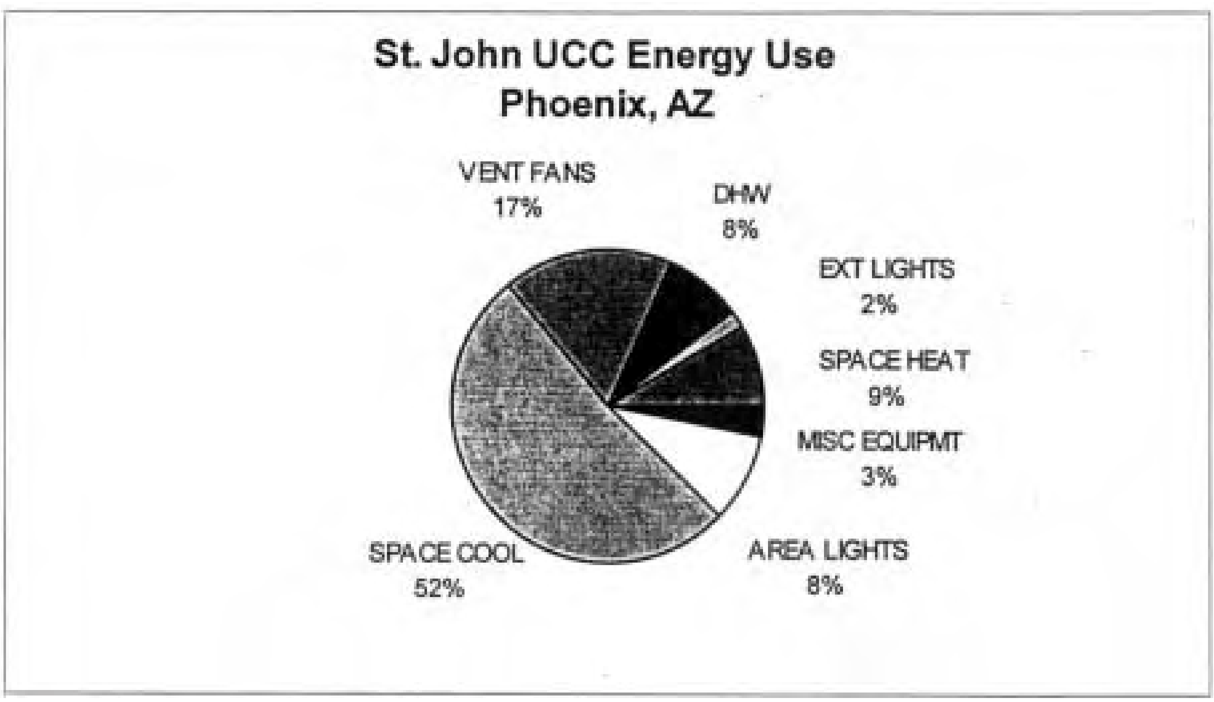


Figure 5 Breakdown of energy use in church in Phoenix, Arizona.

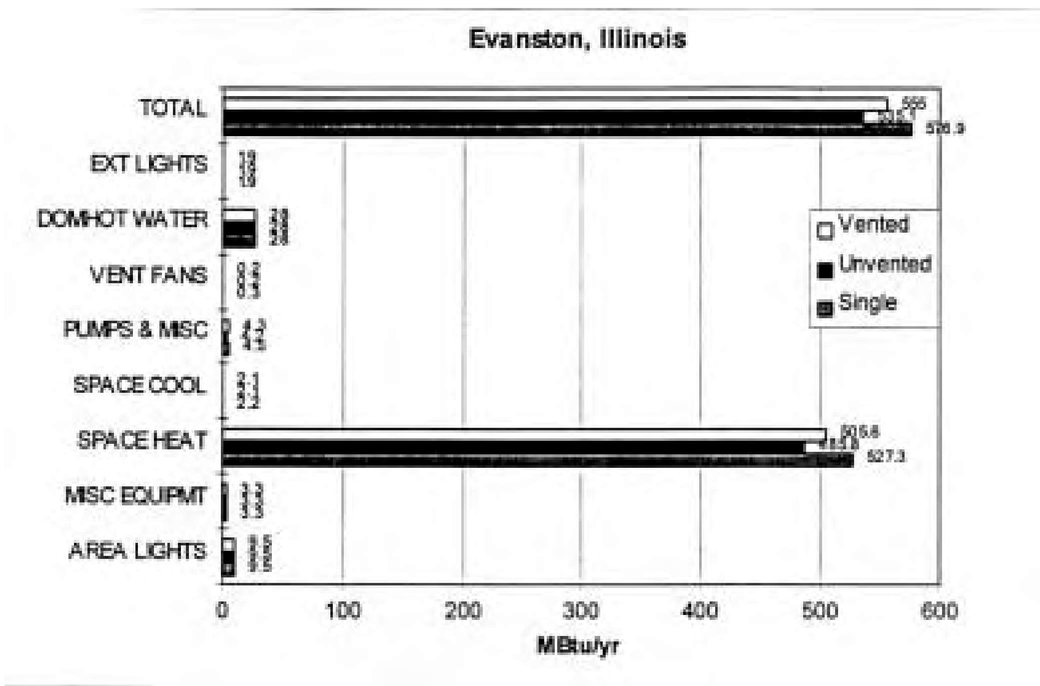


Figure 6 Comparison of end use categories for Single, Unvented, and Vented glazing options in Evanston II

Figure 6 compares the energy use for all end-uses for the single, Unvented, and Vented glazing options in Evanston. The Unvented and Vented glazing options reduce the space heating requirements by 8% and 4% respectively and have a minimal impact on the other loads. The graphs for Seattle and Toronto are similar, and are given in the Appendix. Figure 7 gives the same information for Savannah, except the difference in annual energy use for the options is less than 1%. The results for Phoenix are similar to Savannah and the graph is also included in the Appendix.

Figure 8 shows the annual energy cost for the three glazing options and Figure 9 shows the annual energy cost savings in Evanston predicted by DOE-2.1E. In Evanston, Seattle, and Toronto, the unvented protective glazing affords the greatest energy savings. The colder the climate is that greater the cost savings are. The annual costs savings are $136 in Seattle, $183 in Evanston, and $209 in Toronto. If the installation of protective glazing costs 21 per square foot, the simple payback ranges between 20 to 30 years. This does not account for costs to replace the protective glazing, which has a 10 to 20 year life.

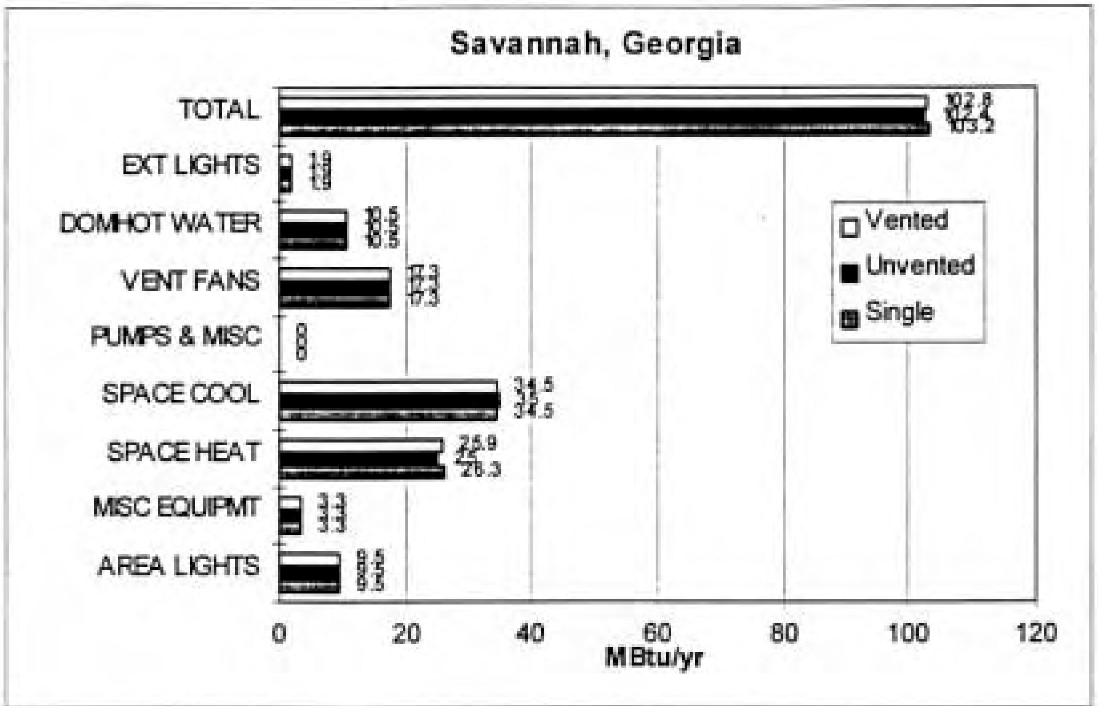


Figure 7 Comparison of end-use categories for Single, Unvented, and Vented glazing options.

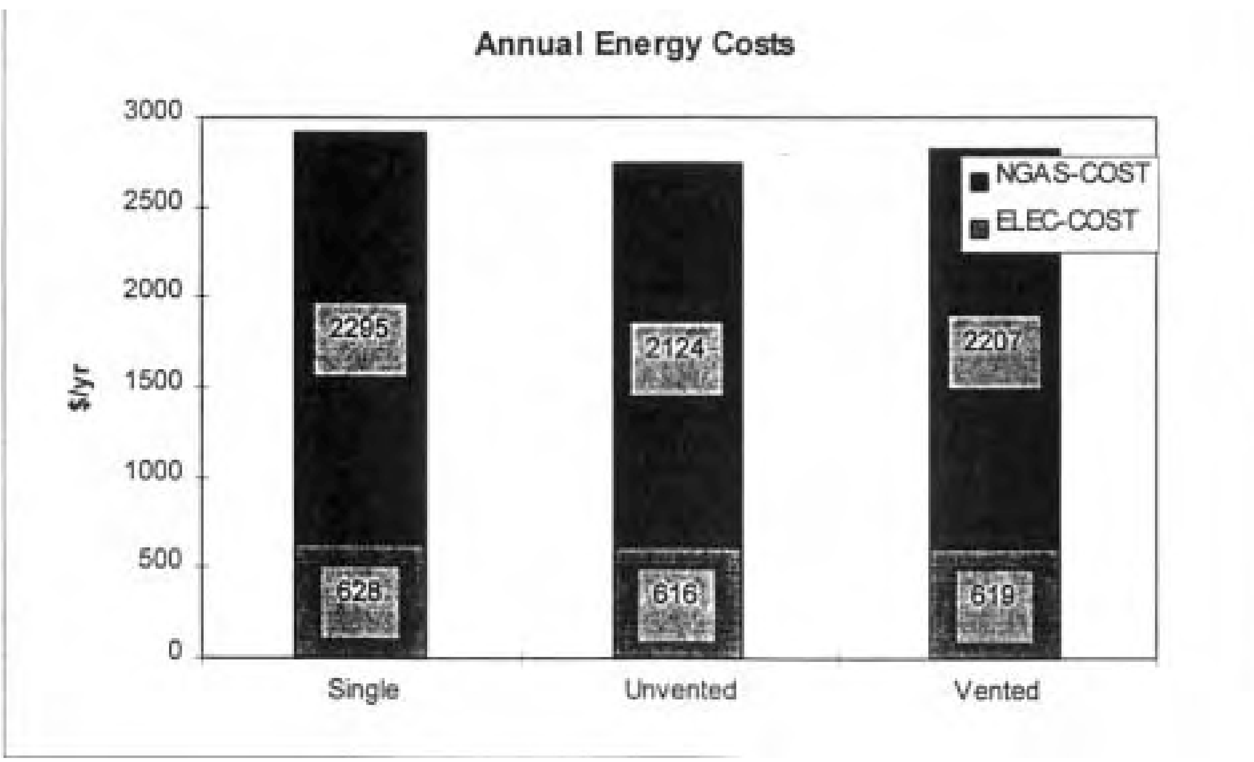
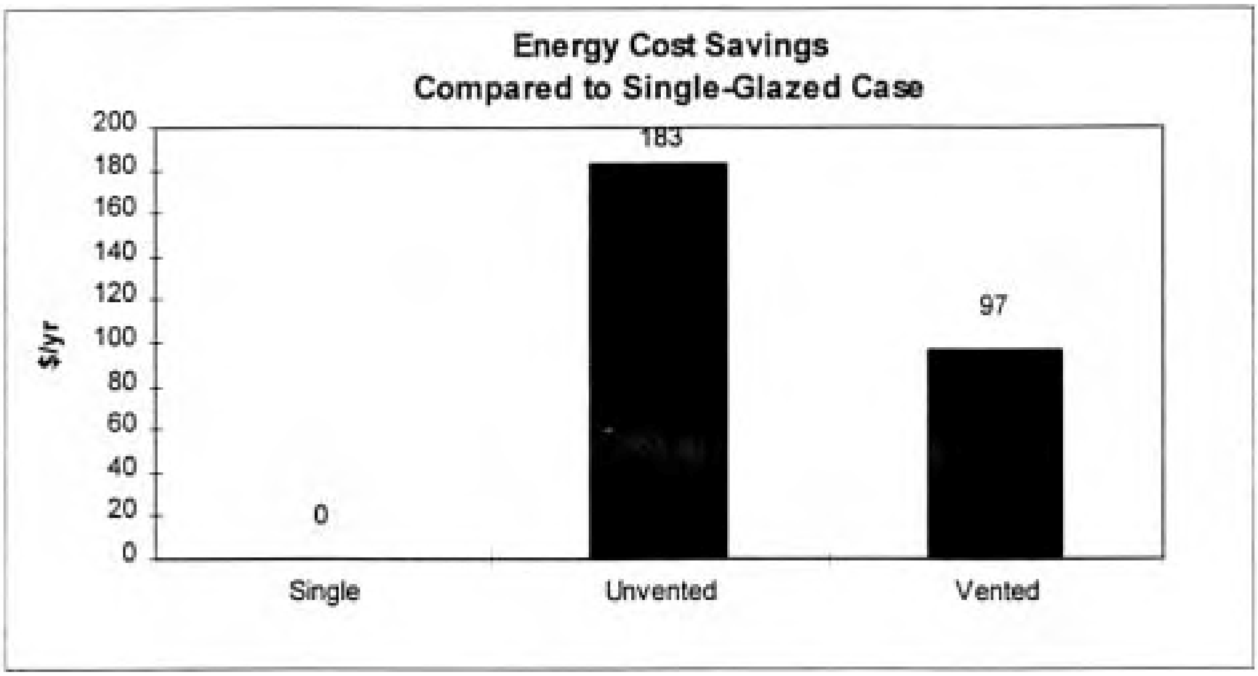


Figure 8 Annual energy costs for St. John UCC in Evanston, Il.



Annual energy cost savings from the Unvented and Vented glazing options for St. John UCC in Evanston, Il.

In Phoenix and Savannah, the annual cost savings are $8 and $23 respectively. In Phoenix, the vented option outperforms the other two options because there is almost no heating requirement. In Savannah, the unvented option outperforms the other two options because heating accounts for *25%* of the energy use. Graphs showing annual energy costs and savings are shown for all locations in the appendix.

A secondary goal of this study is to identify energy conservation measures which are the most cost effective. This part of the analysis focuses on the Evanston location. Table 2 describes the 6 cases which are considered. Note that Case 1 represents St. John UCC with protective glazing over the stained glass (Unvented glazing option). The energy savings from Cases 2 through 6 would be greater as compared to the Single glazing option.

Table 2 Description of Cases for the Additional Energy Conservation Measures

Case	**Description**
1	Base Case, Temperature setback = 68°F
2	Base Case, Temperature setback = 62°F
3	Base Case, Temperature setback = 52°F
4	R-l 1 insulation above old roof, Temperature setback = 68°F
5	R-l 1 insulation above old roof, Temperature setback = 62°F
6	R-l 1 insulation above old roof, Temperature setback =52°F

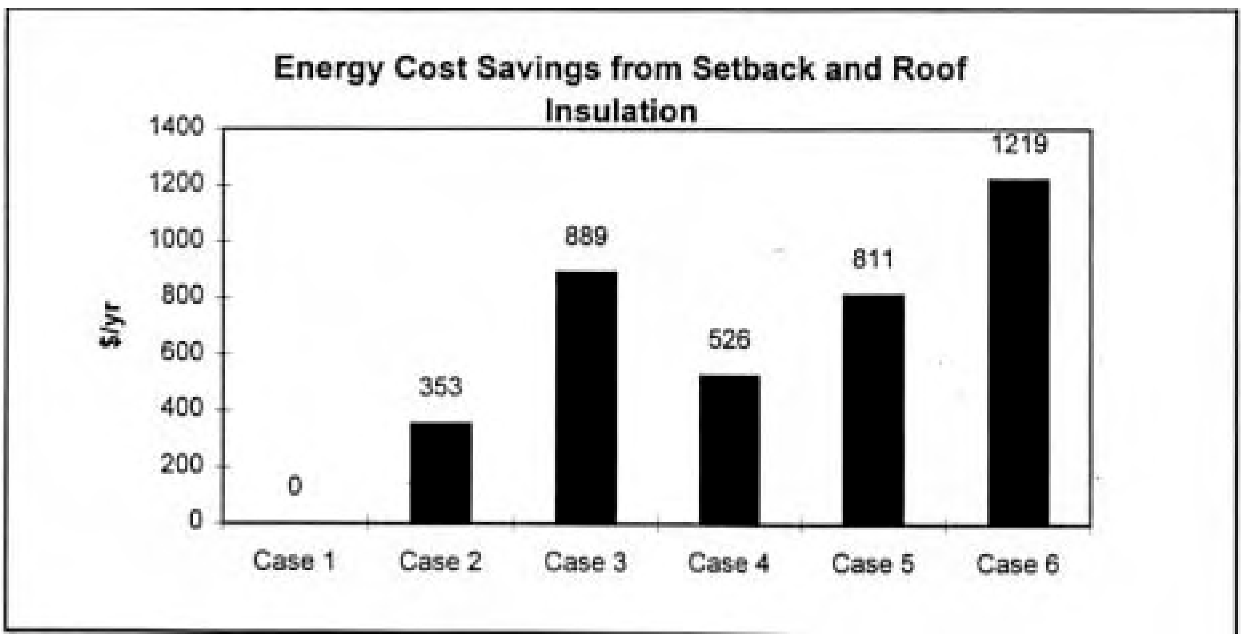
Of greatest interest is the effect of setting back the thermostat during unoccupied periods.

Because the church is occupied fewer than 40 hours per week, this is a very cost effective action to take. Currently, the thermostat is set back from 72°F to 68°F during unoccupied periods. Cases 2, 3, 5, and 6 consider setting the thermostats back to 62°F and 52°F. In addition, Cases 4 through 6 consider the addition on insulation over the ceiling in the hall (1898 section).

Figure 10 shows the costs saving for Cases 2 through 6 as compared to the base case, Case 1. The energy savings and costs savings are substantially higher with thermostat setback and adding ceiling insulation than with adding protective glazing. Programmable thermostats would pay for themselves in 1 year by setting the temperature back to only 62°F. The ceiling insulation does not have as fast of a payback as the thermostats; however, the simple payback is less than 3 years with or without the programmable thermostats.

The results from Evanston are extrapolated to Seattle and Toronto in Table 3. The estimated savings are based on the percent reduction in space heating energy use in Evanston. The graph showing the energy use by category for Evanston is included in the Appendix. For Seattle and Toronto, an average cost per therm of $0.5 is used. This same extrapolation could not be made for Phoenix and Savannah because of the difference in heating fuels and heating systems.

Figure 10 Energy cost savings from temperature setback during unoccupied periods and ceiling insulation in the



hall in Evanston.

Table 3 Estimated Energy Cost Savings for Seattle and Toronto

Location	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Evanston	-	353	889	526	811	1219
Seattle	-	338	856	476	747	1143
Toronto	-	528	1339	744	1169	1788

CONCLUSIONS

The results show that the energy savings from protective glazing for an intermittently occupied church do not warrant the expense of the installation. The cost savings are much greater from thermostat setback and from insulating ceilings in cold climates, and these energy conservation measures have simple paybacks of one to three years. In hot climates, sheltering the building from the sun through shades and landscaping are effective means of reducing the energy -use and affording greater comfort in the church.

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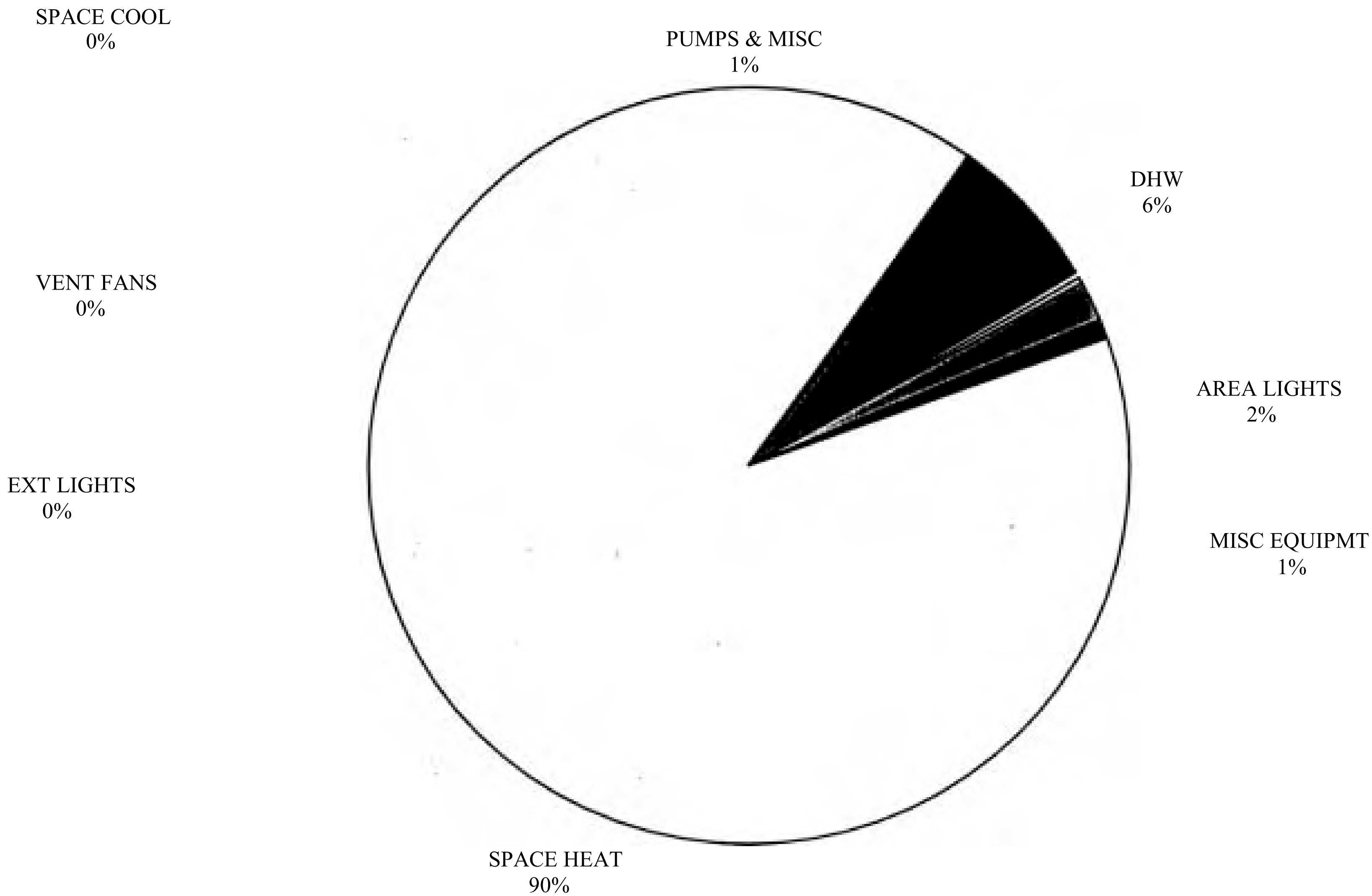
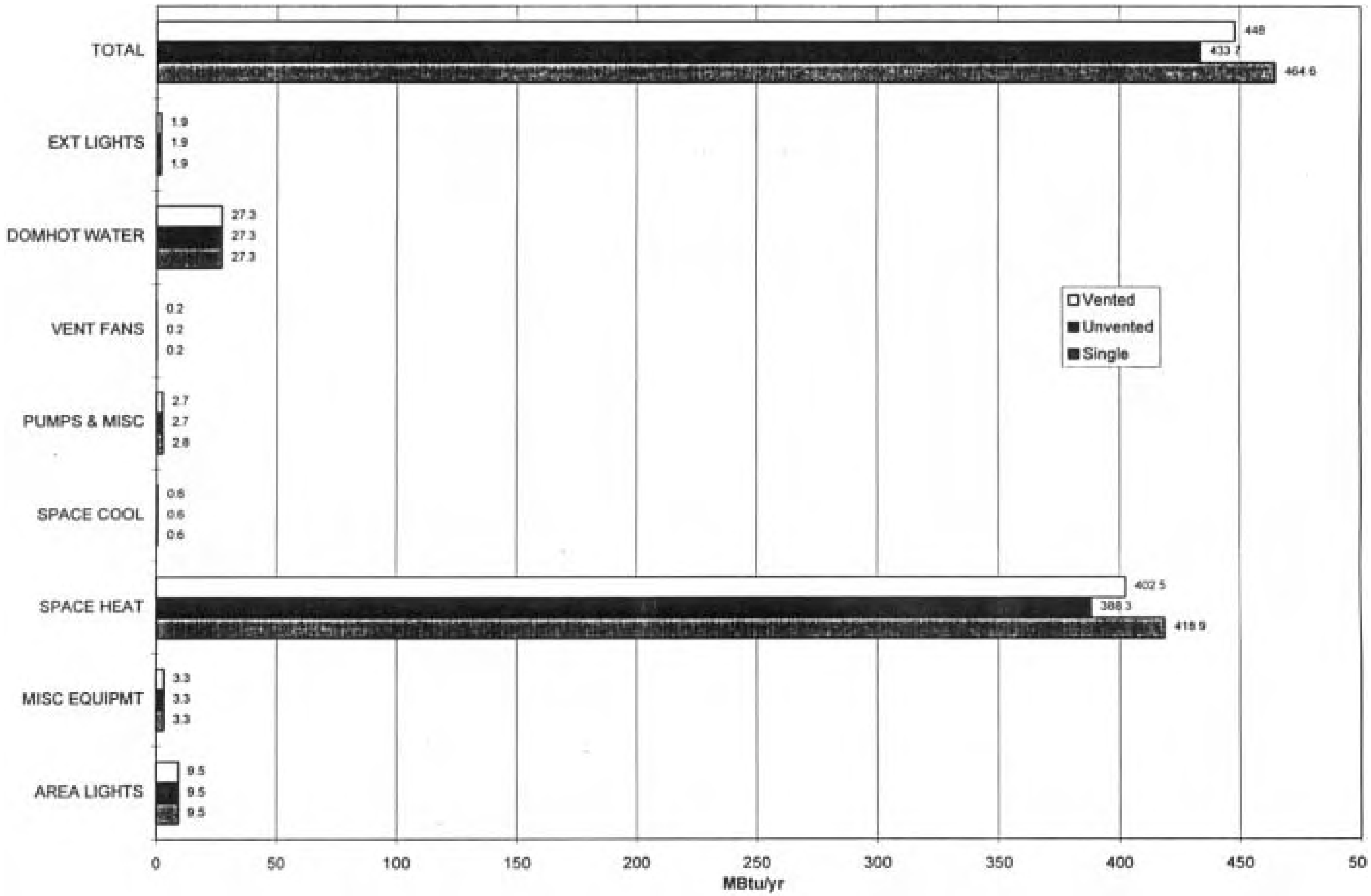
APPENDIX

St. John UCC Energy Use
Seattle, WA



Seattle, WA

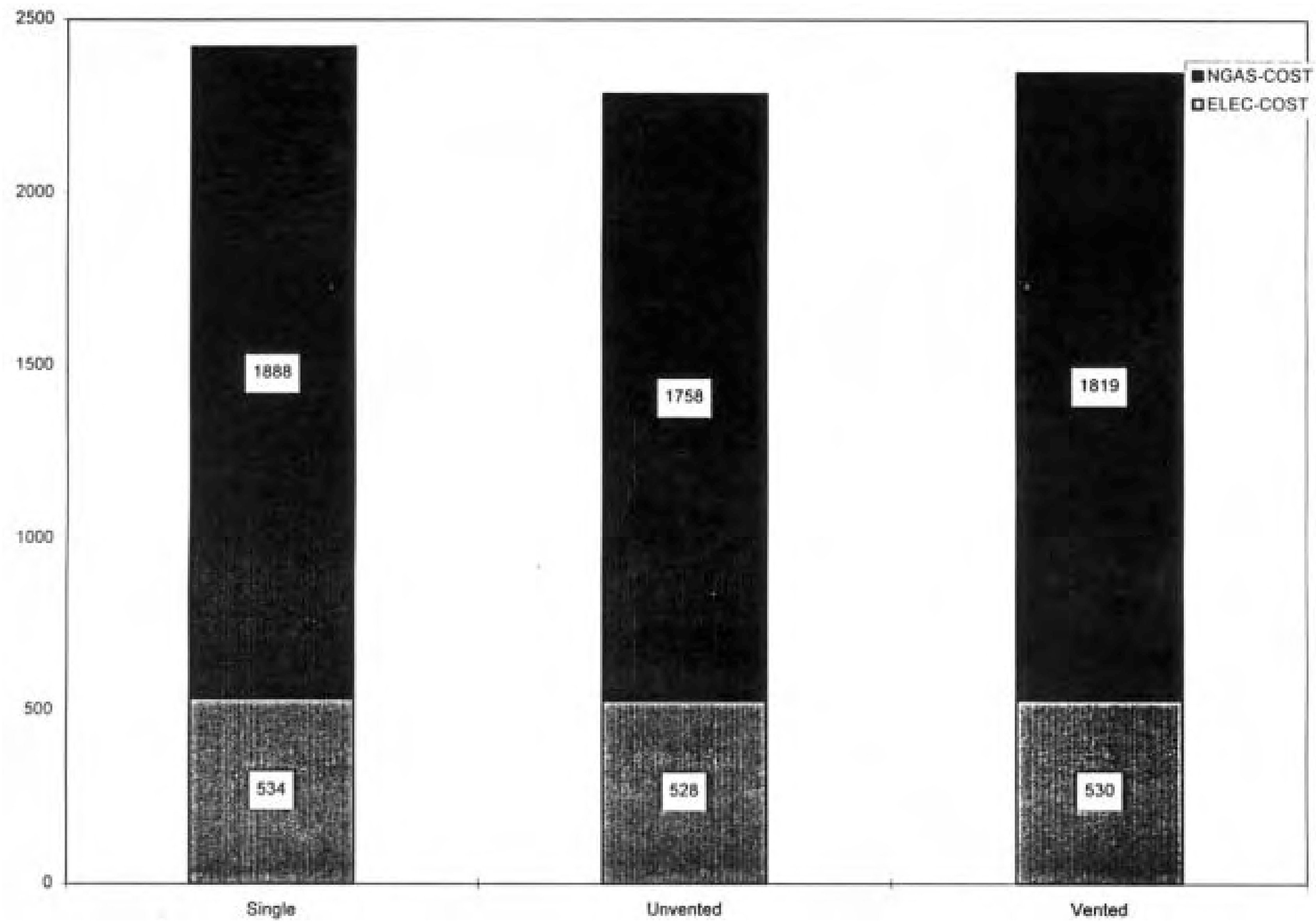
Comparison of Energy Use



St. John UCC

Seattle, WA

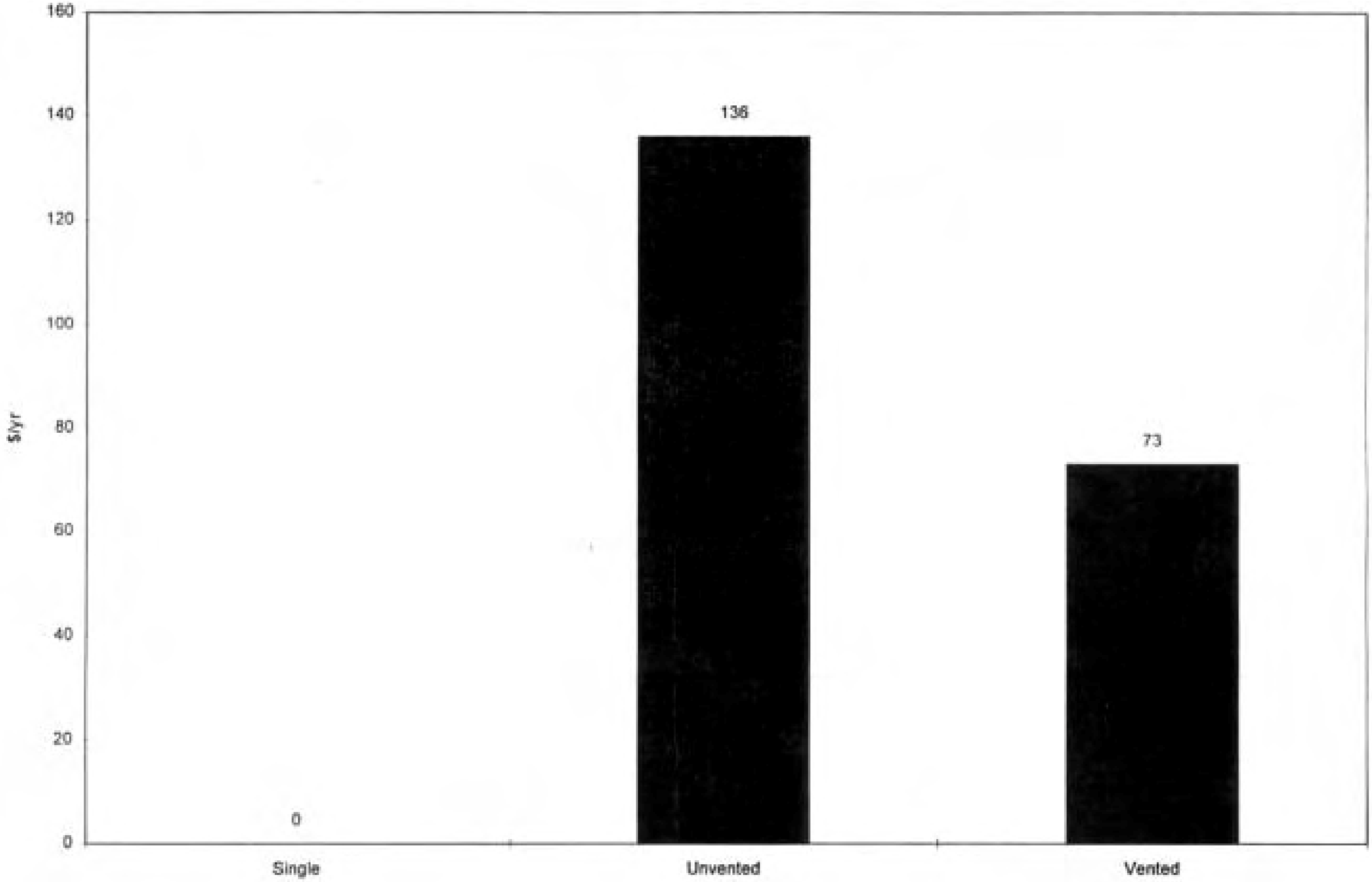
Annual Energy Costs



St. John UCC

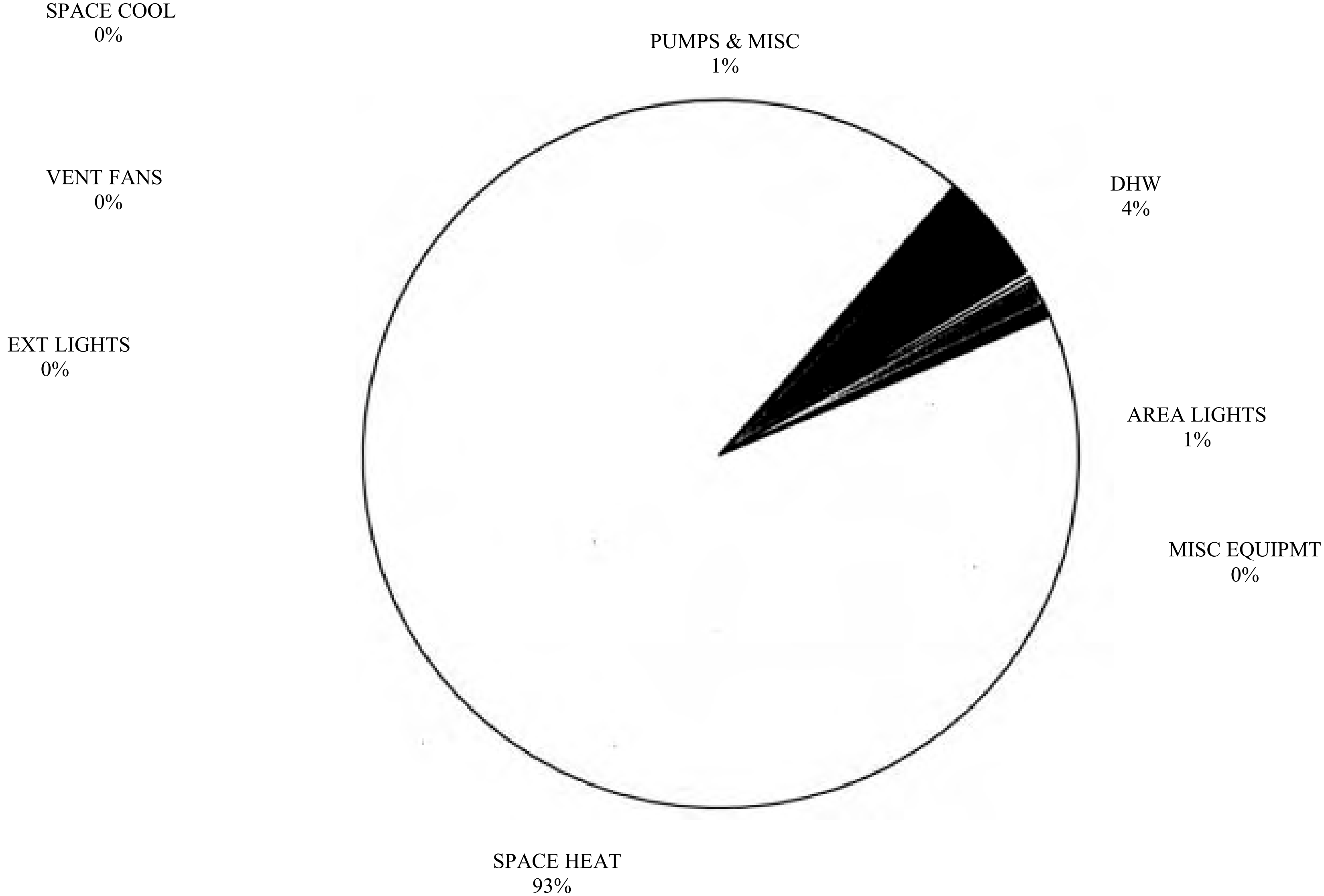
Seattle, WA

Energy Cost Savings
Compared to Single-Glazed Case



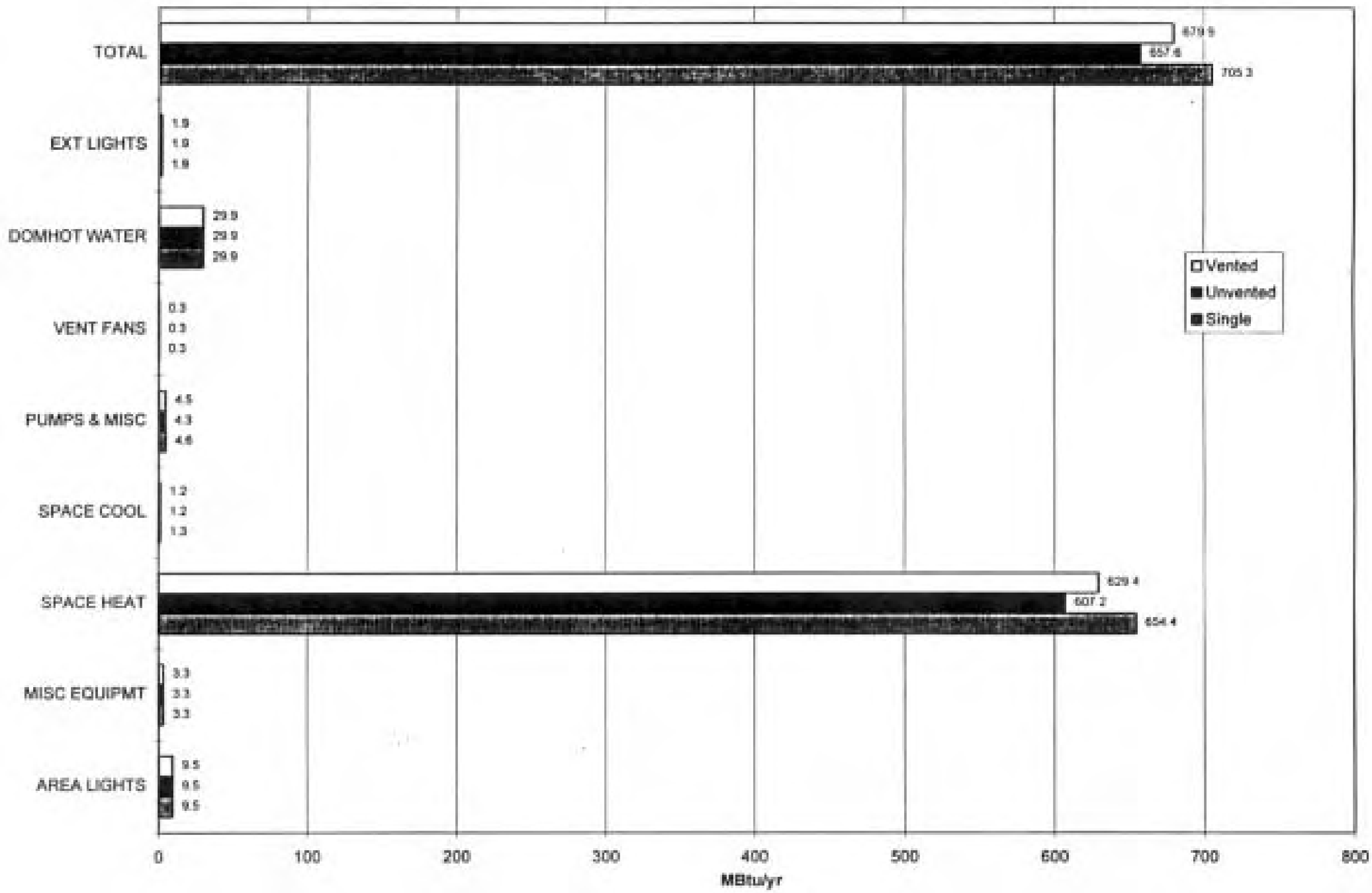
St. John UCC

St John UCC Energy Use
Toronto, ON

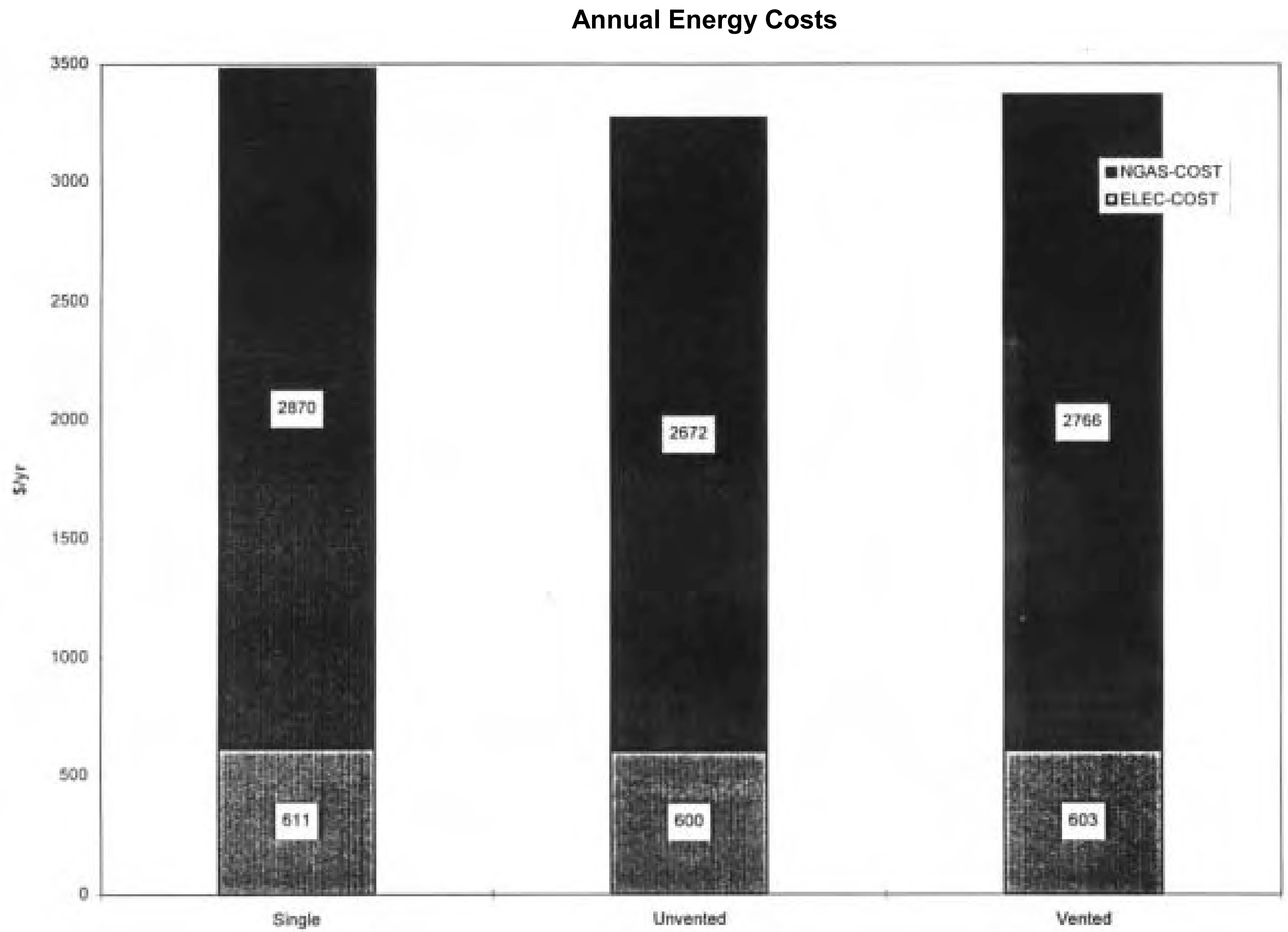


Toronto, ON

Comparison of Energy Use



Toronto, ON



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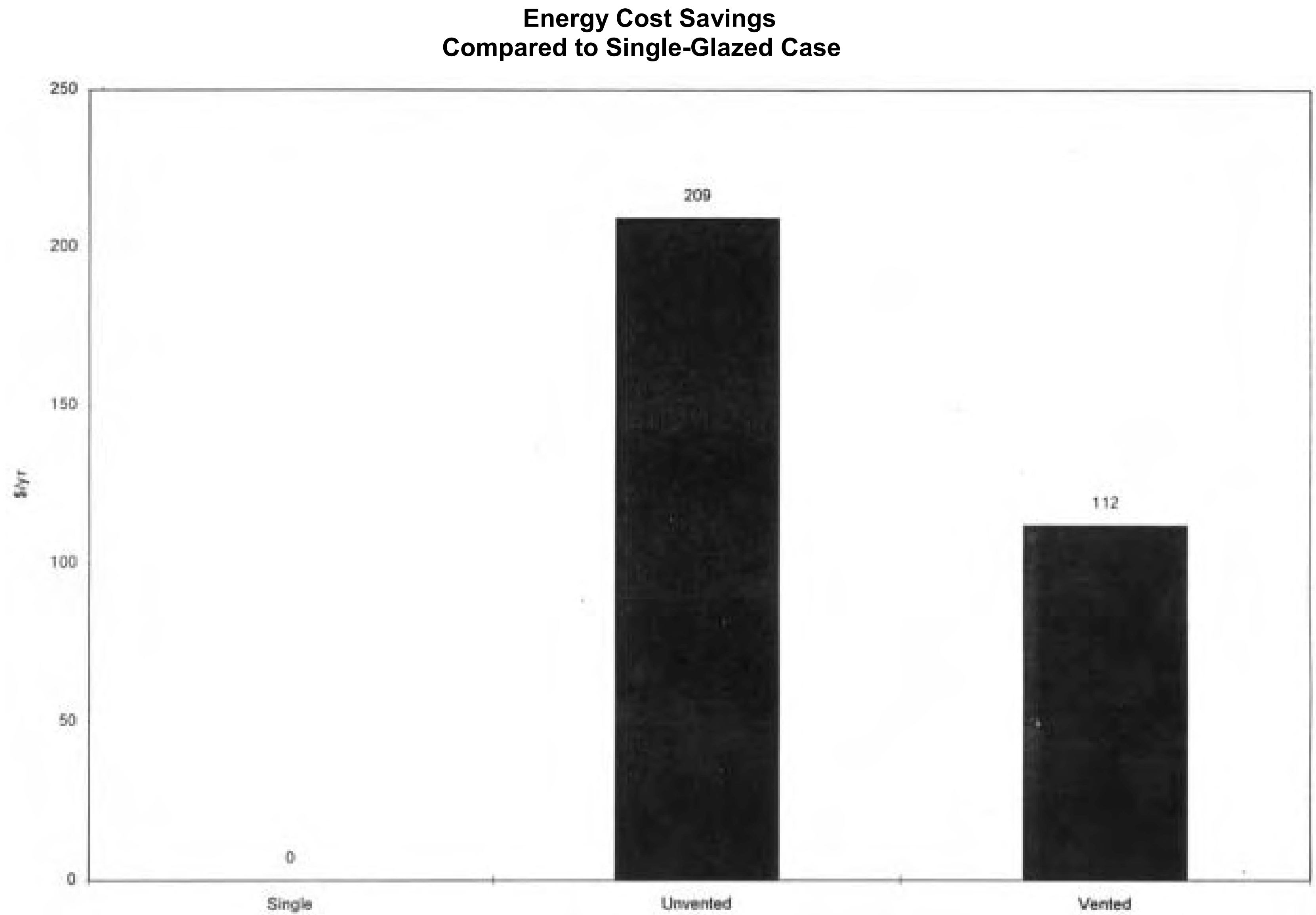
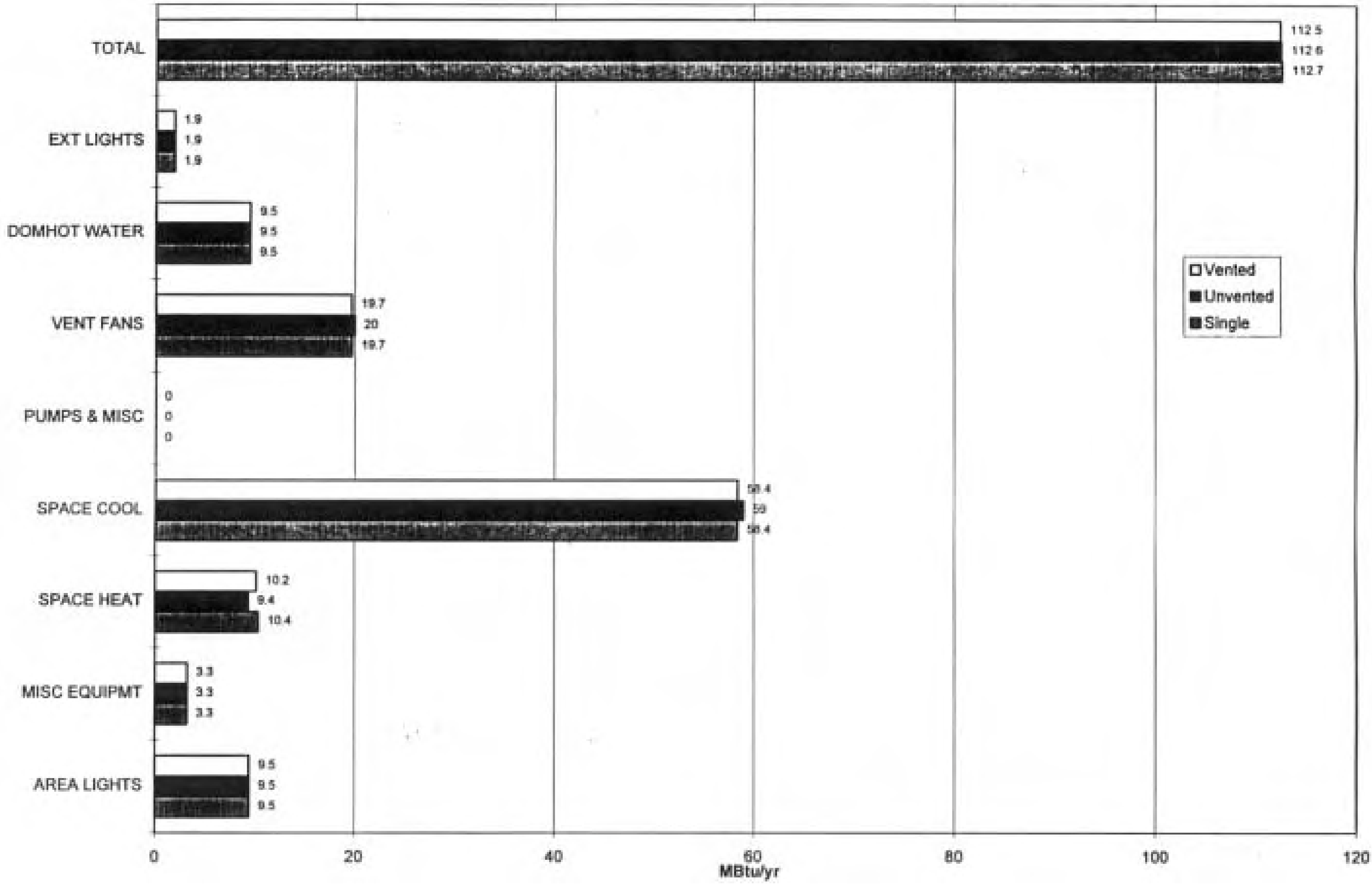
Toronto, ON



St. John UCC

Phoenix, AZ

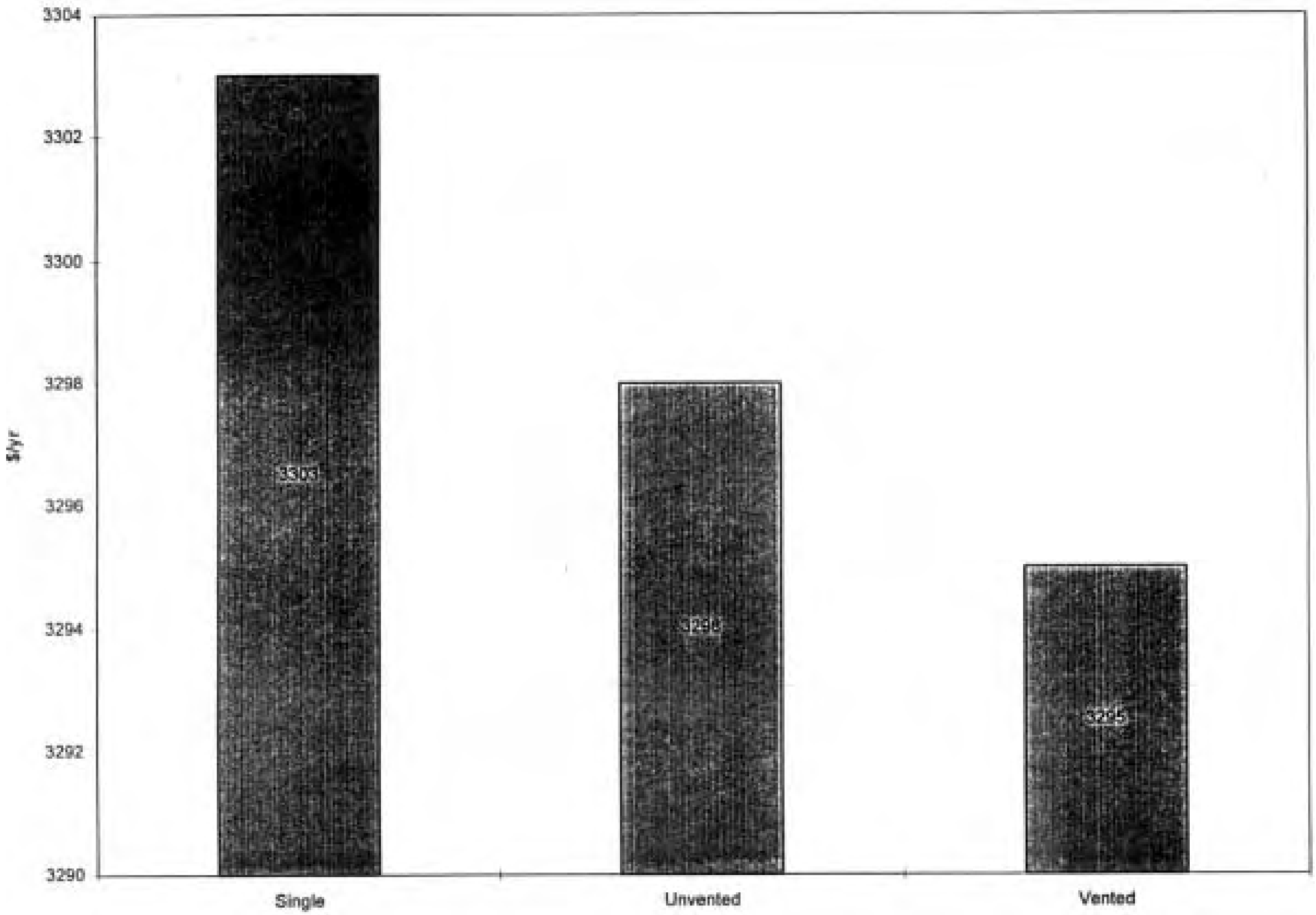
Comparison of Energy Use



St. John UCC

Phoenix, AZ

Annual Energy Costs
All Electric

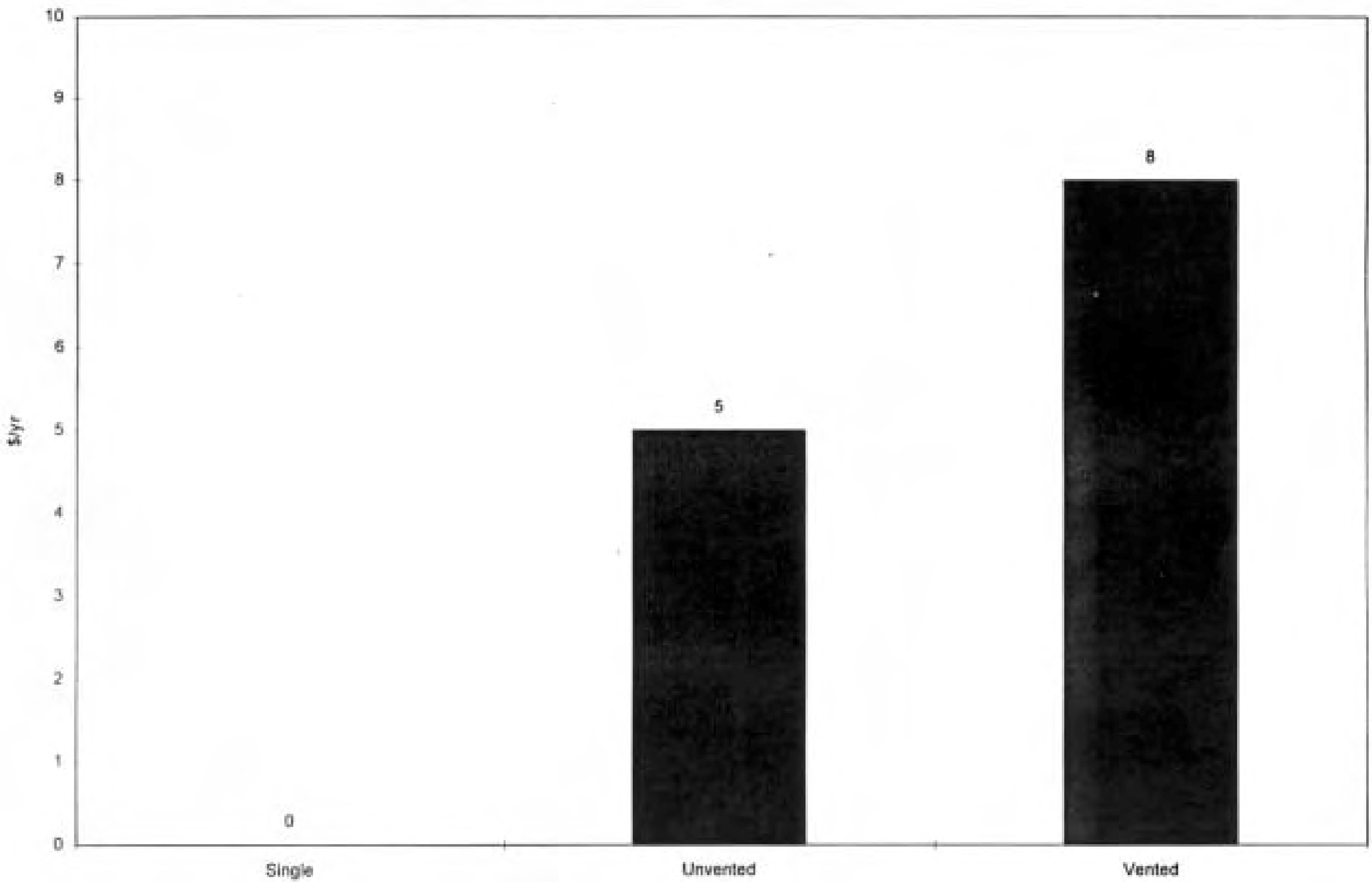


St. John UCC

Phoenix, AZ

Energy Cost Savings

Compared to Sinqle-Glazed Case



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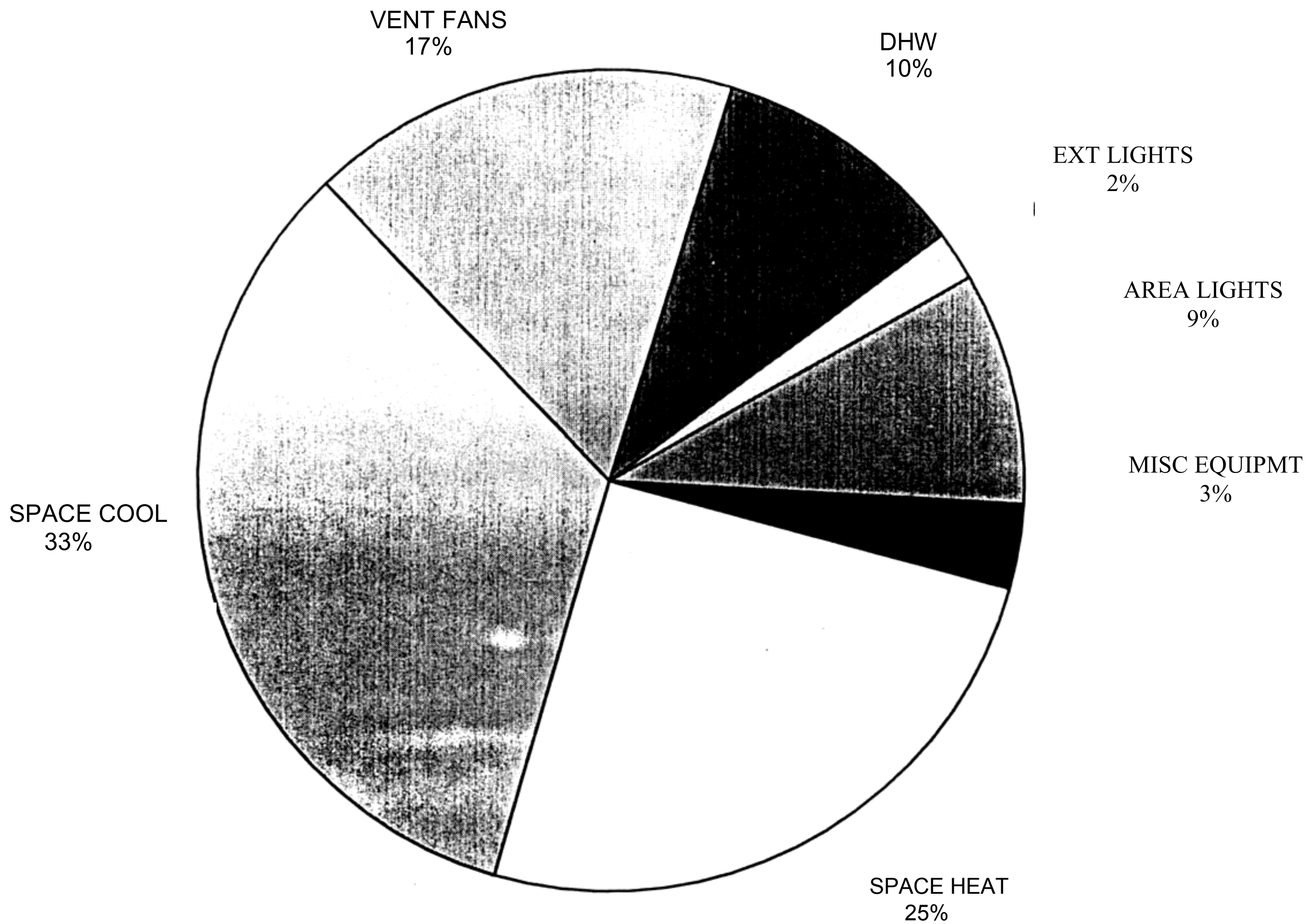
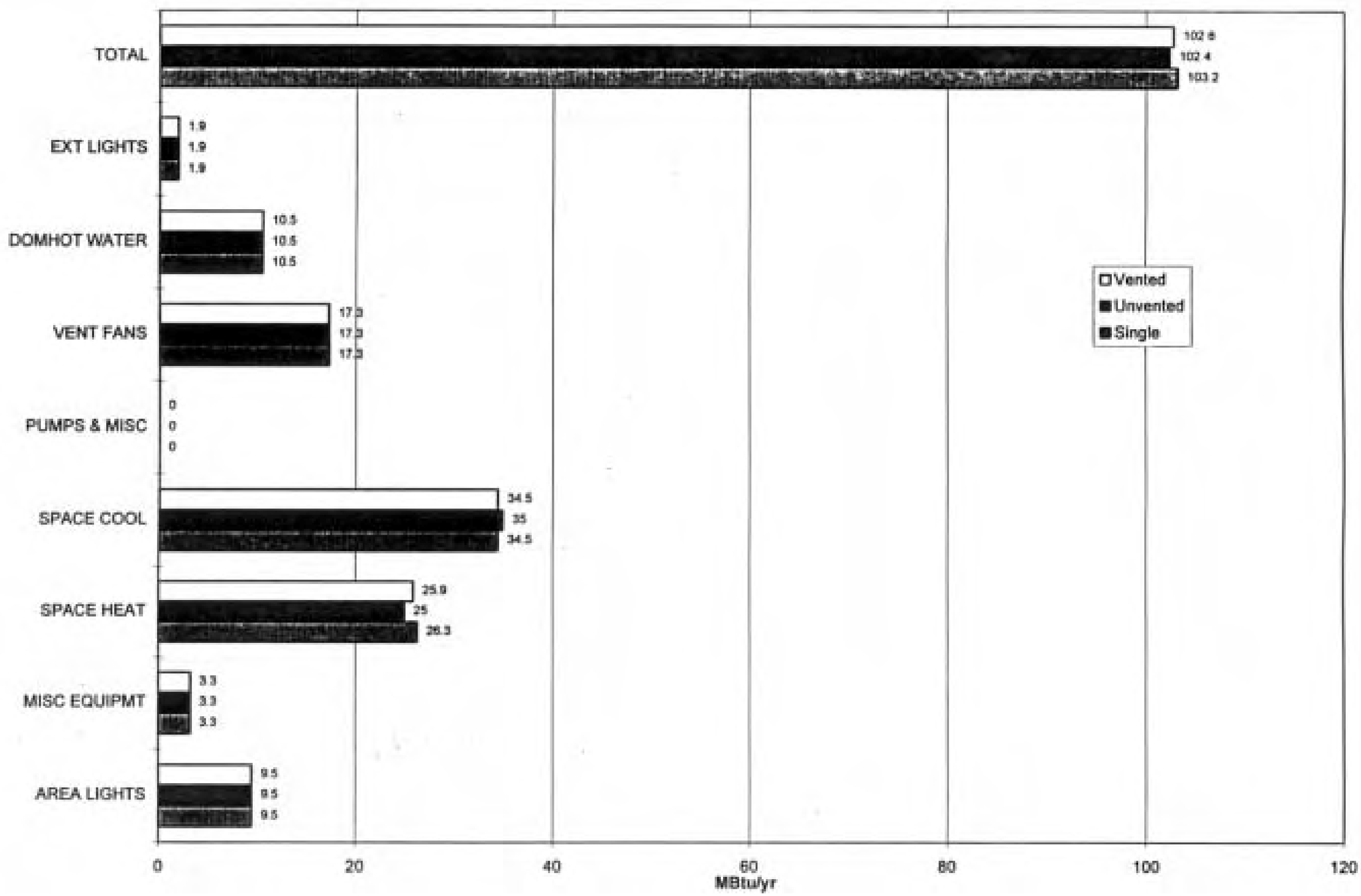
St. John UCC Energy Use
Savannah, GA



Savannah, GA

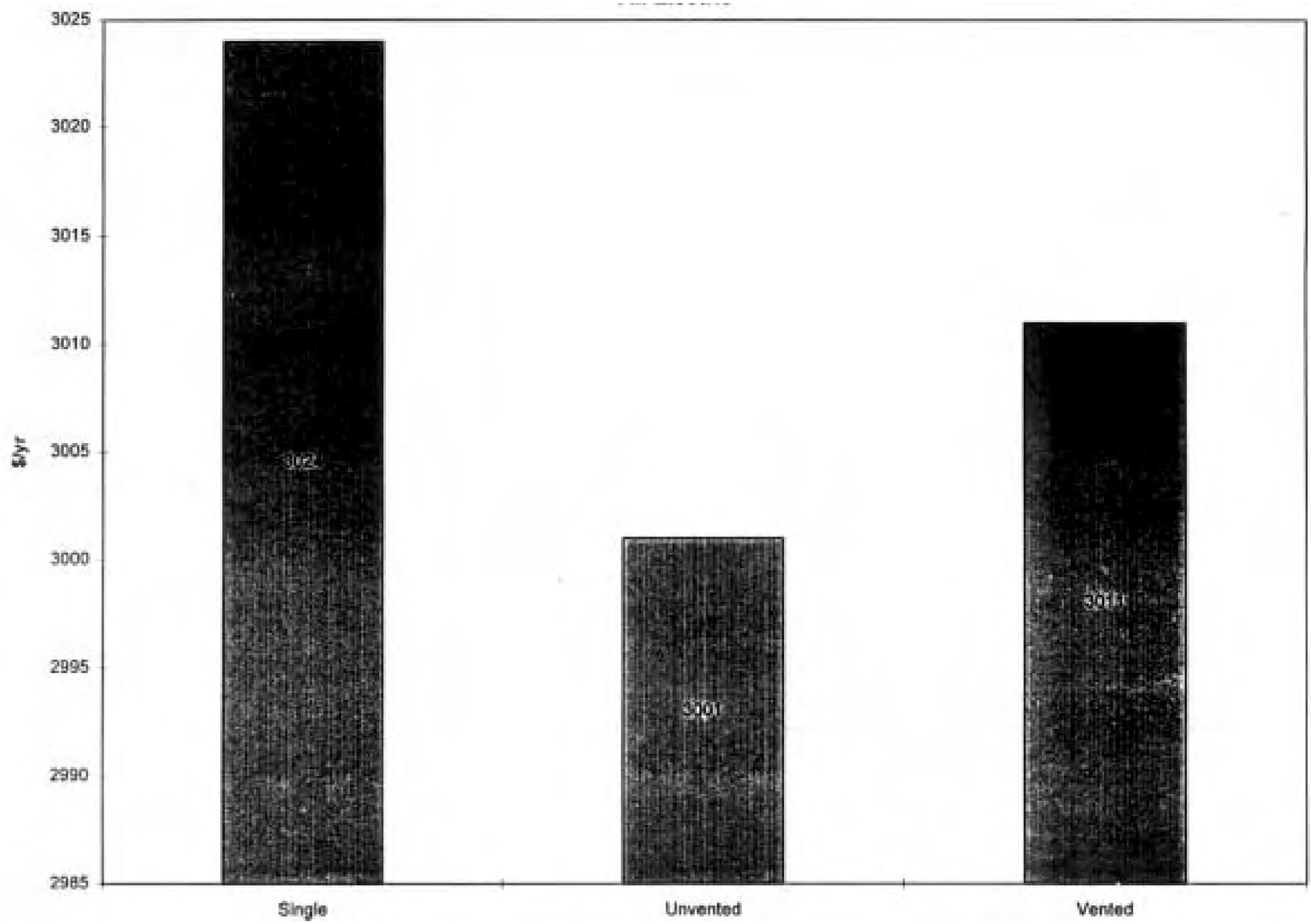
Comparison of Energy Use



St. John UCC

Savannah, GA

Annual Energy Costs
All Electric



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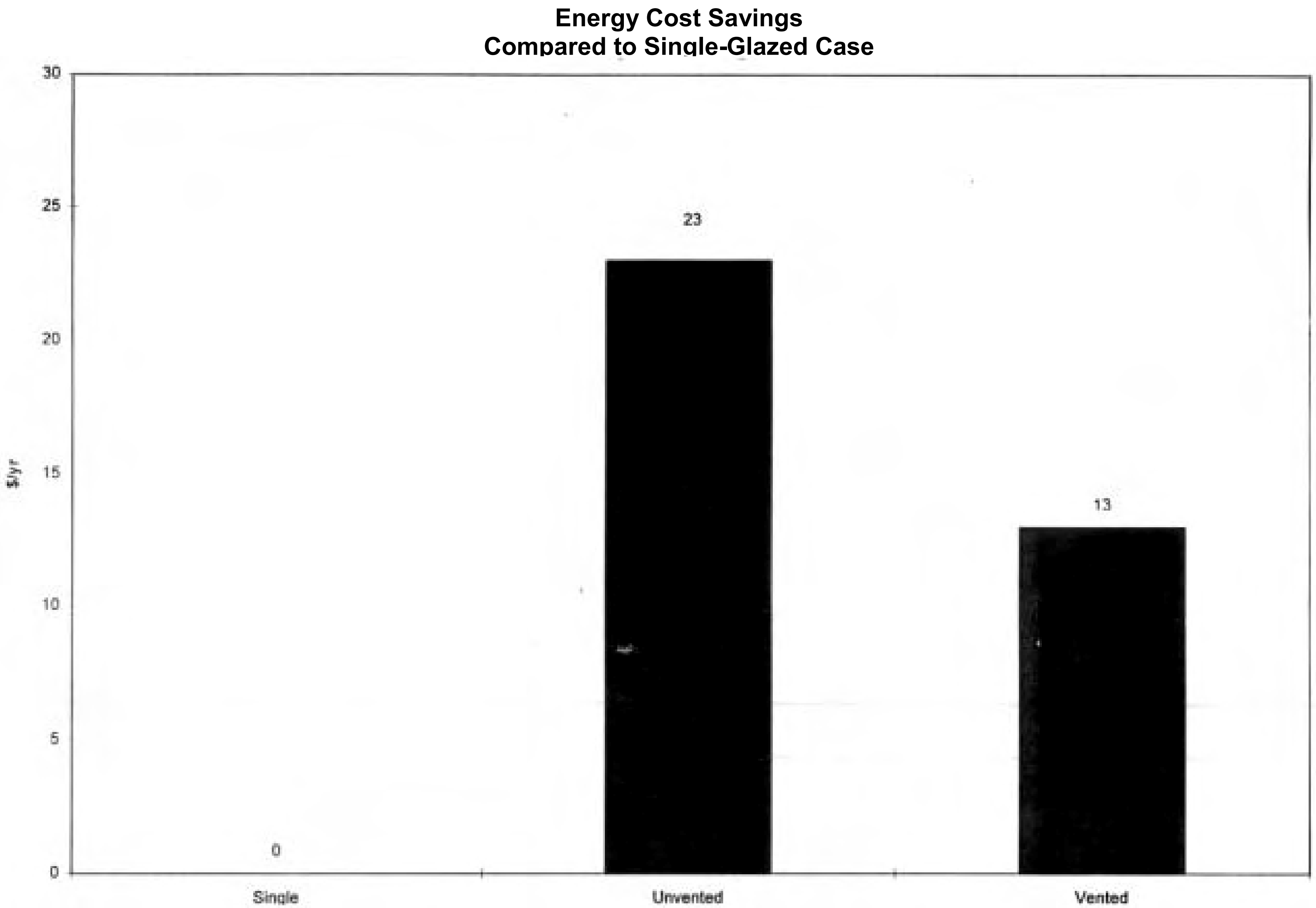
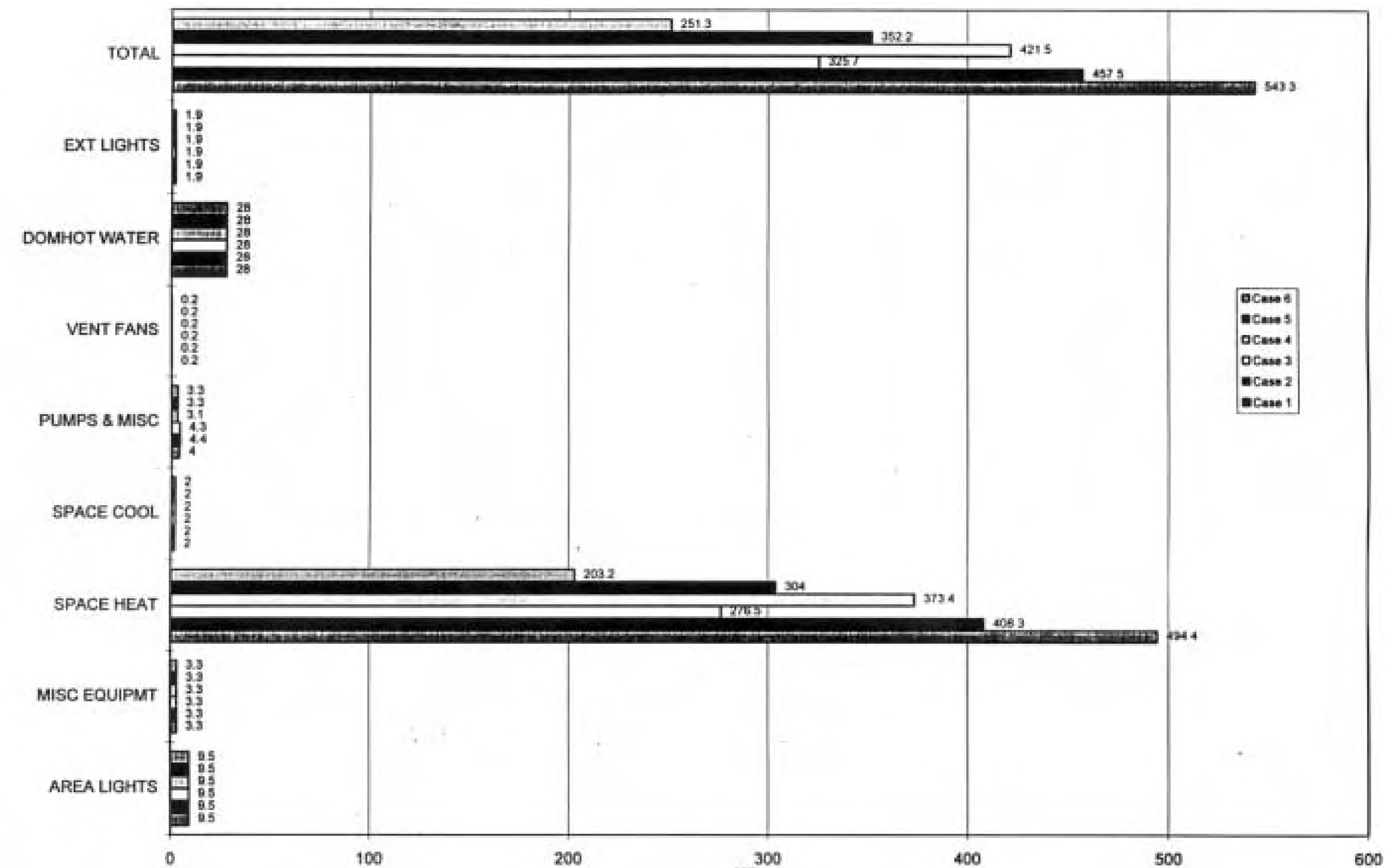
Savannah, GA



St. John UCC

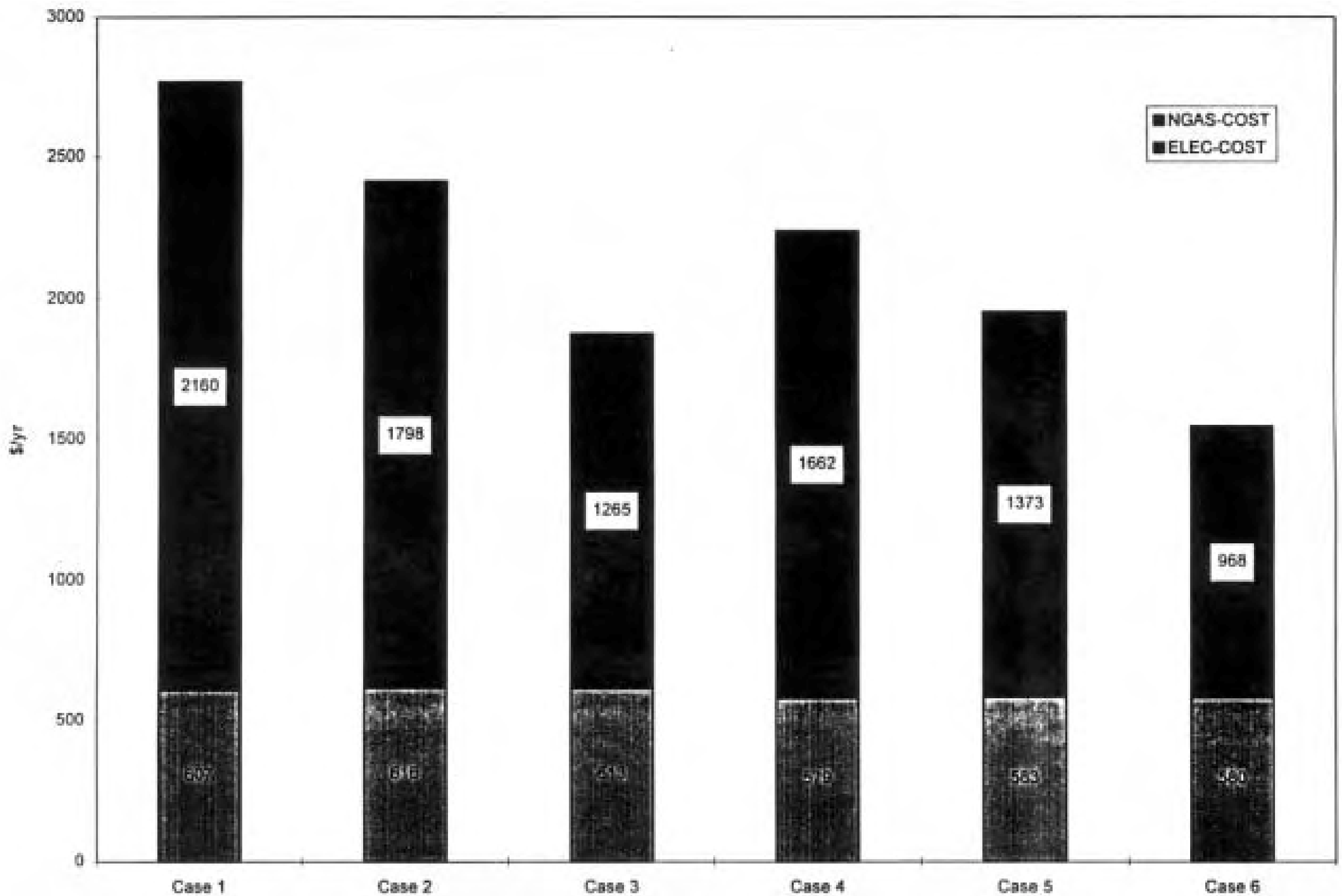
Evanston, IL

Energy Use



St John UCC

Evanston IL
Annual Energy Costs



St. John UCC

SECTION V

CONSERVATION ISSUES OF PROTECTIVE GLAZING

Written by

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&

Dr. Wayne Simon
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March, 1996

PRESERVING STAINED GLASS WITH PROTECTIVE GLAZING

Stained glass windows are installed for the purpose of elevating the human spirit and beautifying our manmade environment. They are designed to be appreciated for color, line and texture. Beyond the possible conservation problems that inappropriate protective glazing may cause, it can dramatically detract from the aesthetic of the windows. It is critical to the success of any protective glazing system that aesthetic, structural and conservation issues are all fully addressed.

Protective glazing (PC) is not a substitute for repair, restoration or continued maintenance. In fact, incorrectly installed, it can actually accelerate the deterioration of the leaded glass, supporting frame and surrounding architectural elements. If the installation is not properly designed, it can prevent or inhibit the regular maintenance of the window and the frame. All forms of PG inhibit or prevent entirely the beneficial effects of rainwater periodically washing the exterior surface of the window. Beyond the positive aesthetic result of cleaner windows, rainwater removes the surface layers of dust and dirt that may adhere to the surface of the glass and often becomes hygroscopic. This moist layer of dirt can create a micro-environment that can be quite detrimental to the glass, lead and framing materials of the window.

PG is too often prescribed for the wrong reasons. Many stewards of stained glass in this country hear of the myriad problems air pollution and acid rain may cause the medieval windows of Europe. An important distinction must be drawn between these ancient windows and our relatively modem stained glass. The glass found in stained glass windows has three basic components: silica, alkali and metallic oxides. In medieval glass, the alkali was provided by adding potash to the glass mix, resulting in a glass high in potassium oxide. This glass is very susceptible to corrosion through attack by air born pollutants and moisture. To conserve this glass, it is important to separate it from the exterior environment. Modem glass, fabricated after the early to mid-l9th century, derives its alkali from a soda lime mixture. This results in a glass high in sodium oxide, a much more durable material. There is no need to protect this glass from air born pollutants.

Most stained glass windows in the United States do not need to be protected from the elements. The rare exceptions are the following: windows with very large panel sizes and an insufficient support bar system, thereby susceptible to damage from wind-loading; glass with fragile or unstable fired paint; glass with cold (unfired) paint or unstable glass; and plated windows with irregular, exterior plating levels that may encourage the infiltration of water between the plates.

It is crucial to identify the real cause of damage to the windows in question before determining how to protect them. Is the damage manmade or natural deterioration? Is the source a permanent condition or one that is temporary and can be rectified? The first step should always be to remove the cause of the damage rather than to treat the symptoms of the disease. However, in this unfortunate age of wanton destruction, it is sometimes necessary to take extraordinary precautions to protect our treasured artworks from misguided people. In this capacity, protective glazing serves an important role. Correctly installed, this PG can maximize the protection of the stained glass while having a minimal impact on the window’s aesthetic.

CONSERVATION WITH PROTECTIVE GLAZING IN EUROPE

It should be noted that in most European countries, the government is a partner in varying degrees to the conservation Of historic buildings and stained glass. Various governments provide funding, some significant, for research, actual conservation and restoration of stained glass. For his dissertation research, Oidtmann conducted in-situ tests in the following medieval churches:

Altenberg, Dom (Cathedral)
Breinig, St. Barbara
Keyenberg, Heilig Kreuz
Koln, Dom (Cathedral)
Lamersdorf, St. Cornelius
Marburg, Elisabethkirche
Monchengladbach, Munsterkirche
Monchengladbach-Hardt, St. Nikolaus
Monchengladbach-Hermges, St. Josef
Rheydt-Giesenkirchen, St. Gereon

He concludes that venting to the inside is best. He makes no distinctions in the quality of protective glazing material.

In the early 1950s the Franz Mayer'sche Hofkunstanstalt, as part of the overall restoration of the war damaged Cathedral in Munich, reinstalled the medieval windows with isothermal glazing under the supervision of Dr. Heinz Merten, the noted German glass expert of the time. During the restoration, a crated pair of windows from the Cathedral were found in the basement of a tower. These windows had been removed from the church in 1830, during an earlier restoration, and replaced by then modem windows. Important for preservation and deterioration research, was the nearly mint condition of these windows. They proved a 110 year old control group, when compared to the weathered and deteriorated condition of the in situ windows. In 1980 the isothermal glazed windows were again studied and found not to have suffered any more in the past. Other medieval windows in Munich that had not been protectively glazed suffered markedly in those 25-30 years of Germany's economic miracle.

Around 1960, notice was made of *new* general deterioration of medieval stained and painted glass. Conservation personnel were consulted and the Corpus Vitrearum formed their special study committee; the general consensus was that the corrosiveness of *air pollution* was the culprit. From this situation, Roy C. Newton has written numerous articles and a book citing scientific evidence relative to air pollution damage on glass, how moisture interacts with glass to form corrosion, weathering of medieval glass, and deterioration and conservation of painted glass. His were the first scientific responses to the deterioration of medieval stained glass. In 1980 Newton gave a lecture at a conservation seminar in which he discussed the results of interspace temperature monitoring at Canterbury Cathedral, on both externally and internally vented stained glass windows. He discussed why Relative Humidity figures could be misleading and why the Dew Point figures were more useful as an indication of the wetness of the air.

ISOTHERMAL GLAZING

As reported in the February 1975 CV Newsletter #13, the British Building Research Establishment and the British Department of the Environment concluded, as a result of an experiment on a simulated cathedral, "isothermal" glazing (the temperature on both sides of the stained glass is the same) is much more efficient than had been previously thought because air velocities in the interspace have sometimes exceeded 1 meter per second, corresponding to 600 changes of air per hour in the cavity." Additional unspent money from the contract was to be used for a similar experiment at York Minister, using a window on the south choir aisle which already had external protective glazing in position. Some adjustable external ventilation of the interspace was going to be introduced so that several conditions could be studied - thermal, air - flow and humidity conditions. Five kinds of sensors were to be used. At the time, an Air Flow Tester Kit manufactured in Germany was obtained from Draeger Safety Limited, with the German makers being DRAGERWERK AG, Lubeck, Germany. In one case at York Minster where the ventilation gap was only 2mm wide, a stream of smoke was introduced at the bottom of the window, travelled up for about 1 meter and then went down again to come out at the bottom, but at a different point. This exercise revealed that air flows are difficult to predict.

The CV NEWSLETTER 41/42, 1988 has an article discussing that beneficial effects of isothermal glazing have "proved to be the most important method for the protection and conservation of stained glass", due to the following reasons:

1. Protection against 'mechanical' damage (stones, storms, hail, wind, sonic boom).
2. Protection against weather (rain, snow, dew, damage of air pollution).
3. Stained glass is no longer the barrier between inside and outside climate.
4. Prevention of condensed water on the painted inner side of glass painting.

However, it is pointed out that the protection of double glazing can only be effective when its installations has certain guarantees, such as:

1. The outside glazing is wind and rain proof.
2. The outside glazing resists mechanical damage.
3. The dimension of the interspace guarantees a free circulation of the air (necessary openings on top and bottom and both sides, if necessary).
4. Construction should be planned so that alterations are possible, as the state of knowledge about the subject changes.

Various European countries shared their experiences/experiments with each other, especially through the CV Newsletter. Some of their findings are listed below.

* **Inside** ventilated protective glazing is preferred, subject to additional research
* PG should be easy to execute and as cheap as possible
* Aesthetically, solutions can be geometrical patterns, simplified lead lines, unreflecting panels. Interior light openings are ease to hide.

The need for long-term data was recognized, in order to obtain accurate knowledge about the effectiveness of the various PG systems. Measurements of PG needed to address temperature, relative humidity of the atmosphere and airstream speed in the interspace. It was suggested that measuring instruments be put together by experts which could be made available on an international level.

In England, for fear of spoiling the aesthetic appearance of architecture, isothermal glazing systems have not been used. Also due to results and recommendation from Roy Newton's Cathedral experiments. After some years, the use of isothermal glazing began to have its proponents, as it became apparent that non-vented exterior PG allowed condensation to collect, The cost of future maintenance of glass, frames and architecture seemed minimal compared to isothermal glazing.

According to S. Oidtmann in his recent doctoral thesis, there have been various experiments involving condensation and internal venting vs. external venting at York Minster, Sheffield and Canterbury since 1972. Varying conditions were observed: time of day of measurements, amount of time in sun/shade at time of measurements, differing spaces between the glazings, differing size of ventilation openings, diamond glazed leading and some full sheet PG, and heated/unheated churches. Due to the varying conditions, there did not seem to be conclusive results (see "Reported Results of Isothermal Glazing").

Keith Barley, a glass restorer at York Minster received a Churchill Fellowship in the mid-1980s to travel to the continent and investigate long existing systems. He returned to England and with cooperation of commercial manufacturers developed special manganese bronze frames so that isothermal glazing could more easily be accomplished. (CVMA Newsletter 45, July 1994, p. 26). Barley spoke of his findings and solutions in Philadelphia at the 1994 International Seminar on Stained Glass of the 19th and 20th Centuries; this seminar was co-sponsored by the Society of Architectural Historians and The Census of Stained Glass Windows in America.

A report in the 1993 Autumn/Winter periodical British Society of Master Glass Painters discusses a symposium conducted on conservation of stained glass in Britain. Keith Barley discussed methods of PG with ample illustrations; recognized the "enlightened attitude of the Church of Ireland in commissioning Dr. David Lawrence to make an inventory of windows… which contrasts with the attitude of the British Council for the Care of Churches who ignore these for some form of training in the care of historic buildings for those such as vicars charged with such care".

Dr. David Lawrence, advisor to the Diocese of Chichester, has drawn up guideline for architects working in that diocese. (Sarah Brown, by letter, 2/24/95). In subsequent communication with Dr. Lawrence, he sent his guidelines on window-protection which use information from English Heritage, the Council for the Care of Churches, the Corpus Vitrearum, and views of ecclesiastical architects and other stained glass conservators. The guidelines are summarized on the following page.

Diocese of Chichester, England protective glazing guidelines:

1. Double glazing is useful in the protection of medieval glass, provided that the ventilated system known as *isothermal glazing* is used.

2. Isothermal glazing is not normally used for modem glass, although is some cases it may be applicable.

3. There must be a good-sized aperture both at the top and bottom to allow air to flow.

4. Unventilated systems are positively harmful.

5. Stained glass within any double glazed system, vented or not becomes much hotter in sunlight than unprotected glass. Wide swings in temperature cause the stained glass panels to buckle.

6. Where double glazing encloses adjoining stonework, this is harmful to the stone.

7. Double glazing is not a substitute for restoration of stained glass.

8. The additional groove needed for PG often is cut into the mullions and jambs, which can weaken the structure.

9. Mullions will have to carry twice the weight for which they were designed; this may weaken the structure.

10. Sheet glass is not easy to remove to give access for inspection and maintenance.

11. Because double glazing is itself breakable, it cannot be seen as an effective guard.

12. Stainless steel wire guards, powder-coated wire guards or in special cases polycarbonate guards, provide the most effective protection against attack.

13. Double glazing has a bad aesthetic affect on the appearance of any building.

14. It is displeasing when joins in the sheet glass are determined only by the stock size of the sheet, without considering the architecture or the stained glass and the frames across the glass so as to be visible from the inside of the building.

EFFECT OF PROTECTIVE GLAZING ON CONDENSATION

Venting a PG system is complex but critical to successful protection without negative side effects. As just mentioned, the are numerous studies in Europe investigating the correct method of venting the interspace between the stained glass and the PG. There are four possibilities: to the exterior, to the interior, isothermal to the interior and no venting at all. The only absolute upon which all of the European studies agree, is that no venting is the worst possible alternative. All studies indicate that not venting the interspace results in increased levels of glass corrosion.

There are three primary reasons for venting: to allow any condensate to evaporate and leave the interspace; to equalize the pressure in the interspace with that of the local atmosphere; and to minimize damage to the lead came matrix due to metal fatigue induced by the increased expansion of the lead from the greater range of temperature experienced by unvented windows. The data gathered during this study in the United States confirms these facts.

The data becomes less conclusive as to the best method to vent the interspace. As stated earlier, it is important to determine the cause of the deterioration before a PG system can be designed to protect a window. Most of the studies done in Europe focus on medieval stained glass. Much of this glass derives its alkali from potash thereby making a glass very susceptible to corrosion from the weather and air borne pollutants. The primary concern of the scientists and craftsmen working to solve the *best method* in Europe is to keep condensation, precipitation and the exterior air from coming in contact with the fragile medieval glass, thereby inhibiting the process of corrosion. A secondary concern is the protection from impact damage, be it natural or man-made in origin. Two other factors appear to act as filters in their decision making process. First, the medieval glass is irreplaceable. It could be replicated to a degree, but the original glass is inherently valuable from both an artistic and historic point of view. Second, there is a limited number of windows left, therefore, a limited number to protect.

In America, the problem is quite different. Less than 1 % of the stained glass in this country is as susceptible to corrosion from the elements as is the medieval glass. There are additional windows, possibly 5% of the total extant, that have unstable paint. As mentioned earlier, there are a small number of windows that should be covered for other technical reasons. The balance and overwhelming preponderance of the windows in the United States only need to be protected from the misguided actions of destructive people. The sheer volume of windows in this country dwarfs the number of medieval windows found in Europe. While many of our windows are important, only a small percentage of them approach the high inherent value found in the medieval panels.

The *best method* for protecting European windows may also be the *best method* for American windows, from a strictly scientific point of view. However, when other important components are considered, such as the possible alteration of historic facades and interiors, or the cost of the PG system, an alternative design may provide a better solution to the site specific needs of the stained glass windows to be protected. America can benefit greatly from the studies performed in Europe, but this should not translate into the blind acceptance of their chosen PG systems.

Based on the work completed in Europe, the consensus opinion for the best method of venting the interspace is an isothermal installation vented to the interior of the building. In this type of setting, the glazing material is set into the groove or rebate originally intended for the stained glass. The framing members of the window are then adjusted, or a new frame is built and installed on the interior of the building, to support the stained glass. The original setting type (i.e. individual panels on stout T bars or lead came to lead came meeting joints) and the perimeter shape of the window openings (i.e. rectangular, Roman arch, Gothic head with tracery, etc.) determine the complexity and extent to which the original frame must be altered to accommodate the isothermal setting.

The advantages of this system are twofold. First, the stained glass is completely separated from the exterior environment. Second, when properly installed, this system also minimizes the temperature differential that the stained glass experiences because the interspace is heated (or cooled) by the interior air. The interior volume of air always experiences a reduced temperature differential when compared to the air within the interspace of a window that is vented, but not isothermally. The level of protection from impact damage is the same as windows vented in other ways. It is determined by the glazing material installed on the exterior.

An isothermal installation should not be confused with simply venting the interspace to the interior, a correct installation is much more complex. The opening to allow for proper venting is quite substantial. A basic understanding of the forces at work is necessary to effect a proper design. The relative humidity (RH) of the interior air is often much lower than the RH of the exterior air. However, R.G. Newton in his studies in English cathedrals, illustrated that the RH is not always the best indicator of the likelihood of condensation forming on the windows. The low RH of the interior air is more a function of its higher temperature, and not an absolute measure of the amount of moisture it is carrying. The dew point (DP), the temperature at which a given volume of air will condense, is a much more reliable indicator. The DP of the interior air is often higher (thereby more likely to condense) than that of the exterior air. Newton's data indicates that for the coldest period in January, the RE of the exterior air was substantially higher (10% to 40%) than the RH of the interior air. However, for the corresponding times and RHs, the DP of the exterior air was lower (less likely to condense) than the interior air. This study was done in an unheated English cathedral. In heated American churches, the effect would be similar, but with a greater disparity between the DP of the interior and exterior air masses due to the increased capacity of the warmer air to hold moisture**.**

Where and how the glazing gets vented depends on the type of installation and the local environment. A key scientific premise to understand is that of relative humidity. Relative humidity (as opposed to moisture content) is not a finite measurement of the amount of moisture in a given volume of air. It is a ratio of the actual moisture content of a given volume of air divided by the maximum possible moisture content of an equal volume of air at a given equal temperature. The relative humidity of a given volume of air is inversely proportional to the temperature of the air. As the temperature of the air increases, its ability to hold more water increases.

If the interior air with the higher dew point is introduced into the interspace at a slow or restricted volume, it will cool. This can often lead to condensation between the stained glass and exterior glazing. A setting can only be considered isothermal when the velocity and volume of air moving through the interspace is sufficient to maintain a temperature close to that of the interior air. The spacing between the stained glass and the PG and the size of the vent openings at the top and bottom of the interspace determine the success or failure of the system. There are varying opinions as to the correct spacing and size of the vents. The thoughts on adequate spacing vary from 3 cm as posed by Alfred Fisher FMGP of Chapel Studio, Kings Langley, Great Britain in the CVM Newsletter of July, 1994; to 5 to 8 cm as posed by Dr. Jütte during a talk at St. Ann & the Holy Trinity in 1995.

There are similar disparities in regard to the size and relationship of the vent openings. One school of thought posits that the depth of the interspace is directly proportional to the width of the openings. Another presumes a more complicated relationship, and places greater dependence on the size of the openings than the width of the interspace. A convergence of these two opinions occurs when the position and effect of the openings is discussed. The openings should only occur at the top and bottom of the interspace. The ideal airflow through the interspace should be .5 m/sec, and a minimum of .4 m/sec., to maintain an isothermal situation. To get the full picture, one must also understand the insulating effect of boundary layers and the hydrodynamics of the air column moving through the interspace.

There a number of challenges to successfully achieving an isothermal installation. Very few installations in American churches easily convert to isothermal situations. Most often, the historic facade or interior window surround must be substantially altered, at great expense, to accommodate an isothermal setting of the PG. The cost factor can be three to five times more than an exterior-applied exterior-vented system. In the few situations where important, fragile, historic glass must be protected from any possible incidence of condensation and/or thermal expansion kept to an absolute minimum, the expense and possible architectural compromise of an isothermal system may be warranted. However, in the vast majority of U.S. installations, the isothermal approach would appear to be an overly protective solution. Further, the high cost of these systems can severely deplete the resources of the owner. The money would be better spent on other, more cost-effective conservation procedures.

It is clear from all of the studies that the interspace must be vented. If isothermal venting is overly protective, what is the more appropriate method for windows with stable glass and paint? J.M. Bettembourg of the Laboratoire de Recherche des Monuments Historiques (LRMH), Champs sur Marne, France presented a paper at the Ottawa Congress in September of 1994. The data of his study indicated virtually no difference between interior and exterior venting in the probability of condensation occurring on the interior surface of the stained glass in a PG installation. His data does indicate a higher probability of condensation occurring in the interspace when the system is vented to the interior. This supports the earlier findings of R.G. Newton in his study of English cathedrals. In a number of the papers written by the Europeans, even when an isothermal system is installed, it is often recommended to provide additional venting to the exterior to remove moisture from the interspace.

Where and how the glazing gets vented depends on the type of installation and the local climatic conditions. Exact specifications as to the amount of venting do not yet exist. It is clear that the best system is one that can be easily modified to allow for a greater or lesser airflow. Each site must be examined before determining the exact method of venting. There may be differences within the same building when moving from one elevation to another, or one micro-environment to another. Suggestions of how to vent are given below.

A northern temperate climate, as found in much of the United States and Europe, calls for venting of the interspace to the exterior of the building. As Bettemborg states, it may be necessary to increase the venting on the Southern elevation of the building to counteract the solar gain from sunlight. This is more important if the glass chemistry is such that it absorbs more heat from the sun, as many medieval glasses are wont to do. Newton found that excessive shade from a nearby tree, or projecting bit of architecture, can greatly alter the micro-climate of a window. Newton also found that if the bottom vents are made close to the material forming the window surround, the air drawn into the interspace is preheated by captured heat radiating from the mass of the building.

Exterior venting can be accomplished in several ways. If applied frames are used to support the protective glazing, holes can be drilled through the members of the frame to allow air movement. The holes must be at the top and bottom of the window, placed in such a way as to discourage the infiltration of rain water and insects. If plastic glazing is used, holes can be drilled through the plastic. Place them at the top and bottom of the lancet, and angle them up to prevent rain from coming in. If the exterior glazing is leaded, vent panels (stainless steel screens) can be glazed into the window during fabrication. If laminated glass is used, the corners can be cut off (or the top three inches of a Gothic Head) and a hooded vent screen made from glass, stainless steel screening and lead came, can be fitted to the system. The hood is a projecting piece of metal or glass that prevents water from entering the interspace.

A southern temperate climate, such as the hot, humid sections of the Southeastern United States may call for different venting methods. Here, venting to the interior should be considered if the building is constantly air-conditioned. This may demand a minor alteration of the frame, or setting the stained glass on blocks and allowing the air to pass beneath the bottom panel and over the top panel.

As stated earlier, the venting needs of particular windows may vary greatly. The amount of venting required is dependent on the window's micro-environment. Whenever possible, install one window as a test installation. Monitor all installations throughout the year and inspect for evidence of condensation, such as moisture trails on the interior surface of the stained glass or PG. Presently, there are no set specifications to determine the exact amount of venting. One must use common sense, and be willing to constantly review the results of past work. In general, larger vents are better than small ones. If there was no evidence of condensation before the PG was installed, it is unlikely that it will occur after an externally vented PG system is installed. As Bettemborg states, the likelihood of condensation lessens as the thermal resistance of the stained glass window is increased.

It is better to not apply protective glazing, than to apply it improperly. The most common result of an improper installation is condensation. Churches are notorious for neglecting maintenance, particularly on high windows; paints and sealants nearly always fail before they are renewed causing leaks into (often) unvented PG. Moisture is trapped between the glazing and condenses, on the stained glass, PG, framing members and surround of the window. Moisture promotes corrosion of the glass. Condensate accelerates glass corrosion all the more due to its chemical purity. The condensate corrodes metals that may be part of the window system. As steel or iron rust, they expand in size. This expansion can put substantial pressure on the stained glass window, often resulting in deflection of the panels or breakage of glass. If the oxides produced dissolve in additional condensate, they can migrate, resulting in staining of the glass or the window surround.

Water can leach organic acids from certain types of wood. The organic acids oxidize the lead cames, turning them to a fine white powder. Water encourages wood rot. The rot usually begins at the sill of the window, or within sections of the tracery where water can collect. As the wood rots, it loses its rigidity. This allows the window to compress and settle into the damaged wood frame. This can result in deflection or glass breakage.

Humid and wet conditions within the interspace can encourage the growth of micro-organisms. The micro-organisms trap minute amounts of water close to the surface of the stained glass, where it does the most damage. Micro-organisms may excrete it organic acids than can attack the lead cames. As the micro-organisms respire in the interspace, carbon dioxide is released. This mixes with the water vapor and forms an organic acid which attacks the lead came.

Less prevalent in the United States, but critical to a complete understanding of the problem, are the effects of an improperly vented system on fragile paint. In depth studies of paint failure in this country do not exist, however, once again we can take advantage of studies from Europe. At Orvieto cathedral in Orvieto, Italy medieval glass with fragile paint was studied. The glass had PG installed approximately 100 years ago. Potash as well as soda lime glasses were found in the windows. The causes of paint loss as found at the Orvieto in a study by M. Marabelli, P. Santopadre & M. Verità are: separation due to a difference in the coefficients of expansion of the substrate glass and the ground glass of the paint; absence of elemental inter-diffusion (the paint never quite fused with the glass substrate) between the substrate and the glass paint (more common in the soda lime glass due to higher softening temperature); in some of the potash glass, the corrosion had occurred in the glass beneath the paint; possible presence of stress generating organic films deposited for restoration purposes.

The writers concluded that the external protective glazing has a protective effect, as it attenuates thermohygrometric variations, and separates the glass from the weather. The separation of paint is due to the chemical composition of the paint and the glass substrate, resulting in differing coefficients of expansion and melting temperatures, and that the primary bond between the two is a physical one. The increased temperature differential caused by an improperly vented window will exacerbate the separation of paint from the substrate. Condensation that may form will accelerate the corrosion that may occur beneath the paint, thereby hastening its loss. If organic films have been employed to consolidate fragile paint, the extreme temperature differential can cause the films to expand and contract at different rates, possibly lifting the paint the films were designed to protect, resulting in permanent loss.

A late arrival to the field of PG systems is the process of placing the stained glass panel within a triple-glaze,d insulated unit. A sandwich comprising clear glass, the stained glass and a second layer of clear glass is fabricated. The edges are sealed and the interspace is partially evacuated or filled with an inert gas such as argon. The early prototypes of this system quickly failed due to edge sealant failure. The sealant on the edge was not compatible with the waterproofing compound used on the stained glass panel. Once the integrity of the seal is breached, the panel quickly fogs up due to condensation. The use of space-age technology employing materials that are more compatible and purported to last longer, has resulted in an increased longevity for panels fabricated with this system.

The benefits of this system are the increased energy efficiency of the panels and the separation of the stained glass from collecting dirt and smoke deposits from the environment. Laminated or tempered glass can be used to provide maximum protection from impact. The panels are protected from impact on both sides. However, the drawbacks are numerous. While longer lasting than the early prototypes, the insulated unit is destined to fail well before the stained glass panel will. This will necessitate expensive maintenance of the system, entailing the removal and remaking of failed units. The added weight of the second piece of plate glass may accelerate the deterioration of the supporting frames. The system cannot be installed into stone tracery or surrounds without a major alteration of the stonework, or a resizing of the original stained glass panels resulting in a permanent loss of historic glass. The spacing available between the leaded glass and the plate glass is too small to provide space for adequate support barring on large panels. If round bars are used, they will not tie into the supporting frame and there fore will provide little or no support.

No studies have been done to measure the surface temperature of the lead came matrix trapped within this PG system as the panel is heated and cooled during a typical daily cycle. In the absence of such testing proving otherwise, this system must be treated as a non-vented system. The one consistent fact from all of the studies is that this is the worst condition to put stained glass in. The reflective surface of the applied clear glass will interfere with the appreciation of the stained glass from both the exterior and the interior. Encasing the stained glass in a triple-glazed, insulated system may be desirable for small windows used in a residential or a commercial space. This PG system, due to the many drawbacks described above, does not appear appropriate for ecclesiastical installations.

All PG systems add to the solar gain absorbed by the stained glass throughout the day. If the interspace is improperly vented, the temperature differential can be quite dramatic. Lead has a high coefficient of thermal expansion and a low modulus of elasticity. For a given change in temperature, the lead came will expand along its length. When it cools, it does not return to its original size and shape like steel does. The pressure generated by this expansion is enormous. The pressure causes the window to deflect from its original design plane. An unvented interspace can be subject to extreme temperatures as solar radiation is absorbed through the day. The absorbed heat is transferred directly to the window augmenting the deleterious effects of the expansion and contraction cycle. If plastic glazing is used, adequate provisions must be made for the high degree of expansion they experience (up to 1/8” per lineal foot). Deep glazing grooves and flexible caulk must be used in these applications. If not allowed for, the expansion of the plastic will tear the existing framing apart.

EFFECT OF PROTECTIVE GLAZING ON HEAT BUILD-UP

Unvented protective glazing has a “greenhouse effect” on the air space between the stained glass and the secondary storm glazing. Solar radiation is absorbed by the protective glazing, stained glass and frame and converted into heat. In America, this effect only occurs on unshaded east, west and south elevations. Naturally, the south elevation gets the longest exposure to direct sunlight and therefore normally registers the highest temperatures. The west elevation typically registers higher temperatures than the east since the ambient air temperature on a sunny day normally increases throughout the day. Wind speed and direction can have a significant effect on reducing glass and air space temperatures. However, some of the greatest discrepancies between air space temperature and outdoor temperature occur during the winter months when the sun is low in the sky (low angle of incidence) and shines more directly on southern windows. Finally, the color and type of glass also effect temperatures significantly, light opalescent windows absorb less heat than traditionally darker “medieval-style” windows.

During the Protective Glazing Study, Inspired Partnerships measured the surface temperature of 100 windows under various environmental conditions but nearly always under direct exposure to sunlight. The surface temperatures ranged from a low of 72^{o} to a high of 118°. Moreover, dataloggers were installed in the air space of two unvented south-facing opalescent windows of medium color density at St. John’s Church near Chicago. These dataloggers monitored daily air space temperature and humidity every twenty minutes from May 1995 to May 1996. While the outdoor temperature varied between a low of -15°F and a high of 120°F, and the indoor temperature generally ranged between 55°F and 75°F, the air space temperatures varied between a low of 4°F and a high of 165°F! Perhaps more important than the temperature peaks and valleys recorded is the exaggerated temperature swings in unvented PG installations. On November 19, 1996, a sunny day, the outdoor temperature fluctuated 14°F and indoor only 13°F, but the air space fluctuated 88°F!

Although few people question the effect of heat build-up, some people question whether it is relevant to the deterioration of stained glass. The Europeans have paid less attention to heat build-up but rather concentrated on moisture and pollution issues which they have correctly identified as causing the most serious deterioration of <u>medieval</u> glass. However, Inspired Partnerships’ field survey revealed that some American windows are having problems which seem related to heat build-up; southern windows are generally in worse condition than other facades as typical of roof and wall materials with southern exposure. Moreover, southern windows covered with unvented PG appeared to be deforming (sagging and buckling) more than windows that were not covered.

It is interesting to note that few imported windows, plated windows, windows made with ¼" or larger came, and higher quality windows made by the most reputable American studios show few signs of heat-related deterioration. However, temporary or "catalog" windows, particularly those produced around World War I or fabricated with narrow 1/8" came, were seriously effected by heat build-up. In other words, the increased heat caused by unvented PG does not seem to be a significant factor for well designed and fabricated stained glass. It does seem to accelerate the deformation of lesser quality windows. Unfortunately, this process occurs over years, sometimes decades, and is difficult to demonstrate under real weathering conditions (as opposed to accelerated laboratory tests).

All building materials have a "coefficient of thermal expansion" (COTE) which represents their measurable change in size depending on their exposure to various temperatures. The higher the COTE the more the material moves from thermal changes. Some building materials, particularly metals, have a high COTE and must be designed to accommodate considerable expansion-contraction movement. Lead and zinc came for instance, have a COTE of .0000183 and .0000174 respectively, compared to .0000067 for steel, .0000047 for glass, and .0000021 for wood, all typical materials found in stained glass windows. Therefore, the expansion-contraction of lead and zinc came from thermal changes is approximately three times that of steel, four times glass, and seven times wood!

The process that results in deformation of stained glass panels is a consequence of the creep characteristics of lead came. The controlling parameters of this process include: 1) panel size, 2) shape and size of the glass pieces in the panel, 3) lead came size, profile and strength, and 4) placement and attachment of reinforcement. This makes the actual calculation of deformation and extremely formidable task. However, it is possible to make statements about the long term deformation of stained glass based on an equation for the creep characteristics of lead as a function of load and temperature.

An equation for the creep of lead has been developed based on some theoretical considerations and a set of creep measurements for "commercial lead." More accurate determination of the constants could be made with creep measurements on modern came which was not uncovered, but this data is sufficient to demonstrate the nature of the conclusions which may be made. The equation for lead creep is shown on the following page.

The first term in this equation is the elastic response of lead to stress. The magnitude of this term is very small and is included only for completeness. The second term in the equation is the plastic response of lead to stress. This plastic response is usually called the first stage of creep. Its magnitude is much larger than the elastic response, but is small compared to the long term effects of second stage creep (the third term in the equation). Second stage creep is the actual flow of the metal. It continues indefinitely, coming to an end only when the lead fractures. This is the reason viscosity appears in the third term. The units of viscosity are unconventional (usual units would be ft-lb/sec-see) but are convenient in this application.

$$CREEP(\sigma,t) = \left[\frac{\sigma}{E} - \left(\frac{\sigma}{Pl}\right)\cdot e^{\frac{T-70}{Tc}}\cdot\left(1 - e^{-\frac{t}{tc}}\right) + \left(\frac{\sigma\cdot t}{\mu}\right)\cdot\left(\frac{\sigma}{E}\right)^{2}\cdot e^{\frac{T-70}{Tc}}\right]\cdot 100$$

t := time(hours)

σ := stress$\left(\frac{lb}{in^2}\right)$

E := modulus_of_elasticity$\left(\frac{lb}{in^2}\right)$

Pl := modulus_of_plasticity$\left(\frac{lb}{in^2}\right)$

Tc := characteristic_temperature_effect(degrees_F)

tc := characteristic_time_effect(hours)

μ := viscosity$\left(\frac{lb\cdot hours}{in^2}\right)$

The value of E (modulus of elasticity) was taken from the literature, but the four other constants were determined by data reported in: Mechanics of Engineering, H.F. Moore and M.B. Moore, McGraw-Hill, 1953. If creep data on lead came exists in later literature, the constants could be revised. The purpose of this work is simply to make inferences with respect to deformation of stained glass panels as affected by temperature. The relationship of time and temperature on lead creep is shown in the following chart.

$$CREEP(\sigma,t) = \left[\frac{\sigma}{E} - \left(\frac{\sigma}{Pl}\right)\cdot e^{\frac{T-70}{Tc}}\cdot\left(1 - e^{-\frac{t}{tc}}\right) + \left(\frac{\sigma\cdot t}{\mu}\right)\cdot\left(\frac{\sigma}{E}\right)^{2}\cdot e^{\frac{T-70}{Tc}}\right]\cdot 100$$

t := time(hours)

σ := stress$\left(\frac{lb}{in^2}\right)$

E := modulus_of_elasticity$\left(\frac{lb}{in^2}\right)$

Pl := modulus_of_plasticity$\left(\frac{lb}{in^2}\right)$

Tc := characteristic_temperature_effect(degrees_F)

tc := characteristic_time_effect(hours)

μ := viscosity$\left(\frac{lb\cdot hours}{in^2}\right)$

Appendix 1 presents a MathCad Plus 6 program which compares calculated creep as a function of stress and time with measured values, all at 70°F. The agreement is quite good. Appendix 2 presents a second MathCad program which computes on year creep at three temperatures and compares the calculations to measured data. Again, the agreement is quite satisfactory.

Computation of the deformation of a stained glass panel as a function of its geometry and reinforcement is currently beyond the state of the art. However, from the equation and experimental data, it is clear that the flow temperature term in the equation is dominate at long times. This makes is possible to evaluate the effect of temperature on stained glass deformation as a factor of time. If a leaded glass panel is going to deform, it will deform more rapidly when exposed to higher temperatures. The preceding graph presents this relationship. For instance, deformation will proceed twice as fast at 118°F (the highest surface temperature measured during the survey) than at 70°F. It is presumed that the surface temperature of the came facing an unvented air space is higher yet with temperatures potentially reaching 150°F. In this case, deformation could occur up to three times faster than uncovered windows during the period it is exposed to direct sunlight.

It appears that leaded glass in unvented installations is somewhat self-relieving. That is, panels deform from the initial heat build-up, but the deformation creates gaps between the came, putty and glass that allow the window to vent itself. This is particularly true of new, or recently releaded windows installed with weathertight, unvented PG. These supertight new or restored windows produced the highest temperatures. Therefore, deformation is accelerated on the front end of the window's life which is the least desirable.

The service life of a stained glass window, at least one that is particularly susceptible to deformation due to inferior design, fabrication, or materials, could be reduced by years due to unvented PG. Unfortunately, there are far too many variables between stained glass windows and ever-changing weather to accurately estimate the accelerated deformation as a direct result of heat build-up from unvented (or under-vented) PG. Further studies are required into creep characteristics, exposure, and the thermal effect of sunlight on uncovered stained glass.

Three general approaches are employed to minimize thermal expansion-contraction: 1) reduce the thermal exposure; 2) select materials with lower coefficients of expansion, or 3) design expansion or control joints to allow for movement and prevent binding or buckling. Alternative materials and control joints are not viable options for stained glass, but removing, or at least venting PG to reduce thermal exposure and temperature swings is always an option.

One of the two St. John windows were vented during the study to determine the impact on heat build-up. The Lexan® panel measured 33" x 76" (2,508 square inches). In this panel, three ¼" holes were drilled at the bottom and top totaling .294 square inches (.0001% of the total area); later this was doubled to .589 square inches (.0002%). The holes were kept small to minimize the aesthetic impact, however, the overall results on relieving heat build-up were disappointing. Nevertheless, even this minimal amount of venting lowered peak temperatures 10°F below the unvented PG. It also appeared to reduce humidity and condensation problems.

CONSERVATION DESIGN ISSUES

When designing the installation details of a protective glazing system, the following factors must be considered: the existing condition of the window and its surround, the effect on the aesthetics of the window and the building, the appropriate materials to use, the venting of the interspace and the ease with which the system can be maintained. The owner should be aware of the present condition of the stained glass of the windows to be covered. Carefully examine the leaded glass, supporting frame, and window surround for signs of deterioration. Special care should be given to areas of unstable paint or severely deflected lead matrices. These conditions should be monitored after installation of PG to ensure that the deterioration is not accelerated. PG cannot fix existing problems, it merely covers them up.

There are aesthetic as well as structural elements to this aspect of the design. The individual merits of the different glazing materials are described above. Use framing materials that complement the existing materials of the building. Avoid, where possible, large sheets of plastic (that will deflect) or glass (that will reflect), both distracting to the architectural aesthetic of the building. Do not use dissimilar metals that may encourage galvanic corrosion. Electrically isolate such metals when their pairing cannot be avoided. This will inhibit galvanic corrosion. When securing new framing materials to the existing building fabric, consider and allow for the coefficients of expansion of the different materials to avoid damage as the elements experience the heating/cooling cycle. If polycarbonate is used a glazing material, use a deep rebate frame to allow for its high rate of expansion. Silicone is the only caulk that will adhere well to polycarbonate. Silicones that release acetic or other organic acids while curing must not be used in the presence of leaded windows.

While wood can be used to fabricate frames to hold protective glazing, metal is usually more appropriate. A much larger section must be used with wood, which may obscure part of the stained glass window. Aluminum is the current metal of choice. In strong salt conditions (such as near the ocean) special coatings or alloys should be specified so that the aluminum does not corrode. All fasteners should be nonferrous. The protective glazing framework should be attached to the surround of the window and be securely anchored. The PG frame work should only be attached to the existing frame of the stained glass it is to protect after careful investigation has determined that the original frame can support the additional weight. If plastic is used as a glazing material it must be placed into an adequate frame. It should never be screwed onto the existing wood frame.

A common mistake on many PG projects is the application of the secondary glazing "piggy-backed" onto the existing single-glazed ventilator sections. If operable vents are desired, a custom double-glazed ventilator must be fabricated to accommodate the stained glass and the protective glazing. While aluminum, double-glazed ventilators are readily available, they are more appropriate for new installations for which the large size of the sections can be accounted for during the design process. For historic restoration projects, bronze or steel ventilators are more appropriate. The narrow profiles available in these metals will accommodate the historic glass without altering the original panel size thereby obviating the loss of historic glass.

Wire screens are often a good option to the protective glazing materials covered in Section III, and are gaining favor, particularly in Europe. Wire screens can be inexpensive and quite effective in the prevention of vandalism and impact damage to stained glass windows. They allow for the periodic rinsing of the windows from the exterior with a hose. Screens also provide a degree of security from unauthorized entry to the building. The parameters to consider when designing this type of system are: the material of the screen; the size of the wire and the mesh; and the method of attachment to the building.

The least expensive material is galvanized wire but it should be avoided for churches due to the high maintenance required to preventing rusting. Copper or bronze may also be used to fabricate screens but are more expensive than galvanized. Copper, if left unpainted, can also result in staining of the building particularly light-colored stones. The longest-lasting material needing the least maintenance is stainless steel which is also the most expensive. Whichever material is used, it should be painted, blackened or stained to a dark color. The screens will then minimally interfere with the appreciation of the stained glass and building from the exterior.

A possible negative result of installing wire screens to protect stained glass windows is the shadow of the wire through the screen. This type of protection may not be suitable for very transparent, lightly tinted stained glass windows. It can be quite effective for heavily painted antique glass, textured glass or opalescent glass windows. Dr. Jütte, Department for the Care of Ancient Buildings, The Netherlands and others in Europe, have studied the problem. To minimize the shadow effect, the consensus opinion recommends the use of the smallest gauge wire that can maintain rigidity over the given span. The size of the mesh, or spacing between the wires, should be quite small, one quarter of an inch or less. The screen is deemed acceptable if it allows the transmission of 95 % of the available light through the stained glass.

The screens should be placed relatively close to the stained glass. Individual screens should be made for each panel in the lancets and the tracery. The smaller panels allow for a lighter gauge material to be used and facilitate required repairs and maintenance. Existing ventilators can be used by creating a cage into which the window can open, or by fixing individual screens to each ventilator. Care should be given to the choice of fasteners. In general, they should be nonferrous and compatible with the other metals and materials found in the system.

All stained glass and their window frames need regular maintenance to ensure a long serviceable life. The PG system should be designed to allow for periodic maintenance work to the frames. The applied frames used to support the PG should cover as little of the original frame as possible. It is a misconception that covering all of the wood of a frame with PG will obviate the need for constant maintenance of the wood. The enemies of wood and its painted surface are ultra-violet radiation, heat, and the movement of water through the wood. These factors are rarely negated by the application of PG, and are often made more destructive when the PG is incorrectly applied.

Most windows in the United States do not have to be protected from anything other than vandalism. The most stable, albeit most expensive protective glazing system is an isothermal one. This system ensures that the temperature on both sides of the historic glass are similar. An excellent combination of cost-effectiveness, protection against vandals and allowance for the proper micro-environment can be provided by the use of laminated glass vented externally. If absolute protection from vandals is needed, laminated glass is the material of choice in all but the most extreme cases. Mausoleums for instance, where security is often a much greater issue than aesthetics, may warrant polycarbonates. As in all endeavors, the careful consideration of all existing conditions and needs will result in the most appropriate application.

SECTION V: ADDENDUM

PRELIMINARY ANALYSIS OF TEMPERATURE DATA ON STAINED GLASS WINDOWS WITH PROTECTIVE GLAZING

Written by

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March, 1996

Preliminary Analysis of Temperature Data on Stained Glass Windows With Protective Glazing

Wayne E. Simon, Ph D

Introduction

The National Park Service Protective Glazing Study conducted by Inspired Partnerships has provided a unique opportunity for the quantitative analysis of the effect of protective glazing. Dataloggers were installed in windows with protective glazing at St. John U. C. C. in Evanston. Only a small portion of the available data has been analyzed. Preliminary analysis has concentrated on data from two similar windows with the same geometry, both with protective glazing, but one with venting. This gives a direct measure of the effect of venting.

Analysis

The first requirement of this analysis was the calculation of the solar input (insolation) for any location on the earth, any date, any time, and any orientation (elevation and azimuth) of the surface receiving the solar input. Exact calculations would require orbital mechanics, but a good approximation was found which was programmed in the HP keystroke language and had an associated writeup of the equations. These equations were then programmed in Visual Basic as an Excel function. It is listed as "radvmod" in the appendix. The first check was to compare calculations of the Excel function with calculations with the keystroke program on an HP calculator. After correcting several errors in the writeup of the equations, satisfactory agreement was obtained. The second check was to compare the Excel function, listed in the appendix as "radv", output with tables of solar insolation accepted in the field. Comparisons were made with data in tables from "Solar Heating and Cooling", Jan F. Krieder and Frank Kreith (Ref. 1). Figures 1 through 3 present comparisons on March 21 at 40 deg N Lat, for vertical, 40 deg inclination, and horizontal surfaces. Very good agreement is shown.

Figures 4 through 6 the same comparisons for June 21. The vertical surface comparison, Figure 4, is quite interesting. An E-W wall in summer does not receive direct sunlight for some time after sunrise or for some time before sunset. The tables in Ref I include ground reflection, so some insolation occurs before the wall gets direct sun. This is shown graphically in Figure 4, since the approximate calculation does not include ground reflection. Figures 5 and 6 show that the calculation is a little high in midday, but is still quite acceptable.

The calculations for September 21 are the same as those for March 21, so the comparisons are not repeated for September.

Figures 7 through 9 present results for December 21, the most southward travel of the sun. Calculations are just slightly below the table values for a vertical wall. Calculations for the inclined and horizontal surfaces are not quite as good, as much as

14 per cent low at noon, but are still acceptable. Fortunately, the primary interest in this application is in the vertical surface.

The second requirement of this analysis is a solution for the coupled differential equations of the heat transfer in the window and cover. Some of the solar input is reflected from the cover, some is adsorbed by the cover, another portion is absorbed by the lead came and the glass of the window, with the remainder adsorbed by the interior structure.

The first step in satisfying the second requirement is to evaluate the physical processes in as complete a manner as possible. First, some of the solar input is reflected from the cover. Reflection from a transparent medium is a function of the refractive index and the angle of incidence of the solar input. The Handbook of Chemistry and Physics (Ref. 2) gives a table on p. 2437 for reflection for a refractive index of 1.55 (appropriate for both glass and Lexan). Figure 10 shows that a simple exponential equation is a good representation of the results calculated using Fresnel's formula. Note that the solar input has a constantly changing angle with respect to the cover, so an equation is required**.**

Second, an estimate of the solar energy adsorbed by the Lexan is required. *A* phone call to GE Plastics Structured Products Technical Sales produced a fax of a test report on the exposure of UV-coated and uncoated Lexan to the sun (Ref. 3). Figure 11 presents the data from the fax and an equation which is a reasonable fit to the data. An extrapolation of the data on uncoated Lexan to 14 years (exposure time of these covers), accounting for reflection, gave a value of 0.20 for adsorption of the solar input by the cover. A rough check of transmission with a light meter was consistent with this value, setting one of the constants in the equations.

Third, an estimate of the solar energy adsorbed by the stained glass is required. First, from the average length in one square foot of the window, about 20% of the area is covered by lead, adsorbing essentially all of the solar input. A rough check of transmission through several samples of medium density stained glass gave an average of about 25% transmission. The effect of reflection and the complete adsorption of the lead are approximately in balance, so 75% was taken for the adsorption of the stained glass. Note that light meter measurements on individual windows would be desirable. Two thermal inertia constants were computed, based of the mass and specific heat of one square foot of the Lexan cover (0.55 BTU/deg F) and one square foot of the window (0.36 BTU/deg F). Other constants required were determined by the geometry of the windows (thickness of air space, window area, vent area in and out, vertical distance between the vent areas), the properties of air, and the gravitational constant. Average atmospheric pressure was given by weather reports for O'Hare Airport (Ref. 4).

With the best estimates or determination of the constants complete, the next step is to select the heat transfer equations to be applied to the components of the window and cover system. First, the heat transfer from the interior to the stained glass window is driven by natural convection. The flow velocity across the window is a function of the temperature difference between the window and the interior. Marks "Mechanical Engineers' Handbook (Ref. 5, p 374) gives an expression for natural convection for a vertical surface over one foot high (Eq. 1).

$$U_{is} = 0.27 \cdot \sqrt[4]{|T_i - T_s|} \quad \mathbf{(1)}$$

U_{is} = *natural convection heat transfer ~ BTU / ft² / hr / deg F*
T_i = *inside temperature ~ deg F*
T_s = *stained glass window temperature ~ deg F*
$|T_i - T_s|$ = *absolute value of the temperature difference ~ deg F*

Then the heat transfer from the room to one square foot of the window is given by Equation 2.

$$Q_{is} = U_{is} \cdot (T_i - T_s) \quad (2)$$

Q_{is} = *heat transfer ~ BTU / ft² / hr*

Note that the equation is written in terms of heat transfer to the window. That is, if 7,' the interior temperature, is hotter than 7, the window temperature, the window is gaining heat from the interior. If the window temperature is hotter than the interior temperature, the window is losing heat to the interior.

The next step is the heat transfer from the window to the air space to the cover. Since the thermal inertia of the air in one square foot of air space is very small, the heat flow across the air space can be assumed to be quasi-steady. That is, the temperature of the air space is approximately equal to the average temperature of the window and the cover. Small transient deviations may be produced by venting. "Heat Loss Through -Stained Glass Windows", by Wayne Simon (Ref. 6) presents the variation in resistance factor for enclosed air spaces for depths up to three quarters of an inch, and states that the resistance is constant for larger depths. As a convenience for this program, this data has been fitted with an exponential equation, Figure 12, so that the program constant can be just the depth of the air space. Now the heat transfer from the window to the cover is, except for the effect of venting, equal to the heat transfer from the window to the air space and to the heat transfer from the air space to the cover. From Figure 12, Equation 3, for R_{sc} the resistance to heat flow from the stained glass window to the cover, can be written.

$$R_{sc} = 0.83 \bullet (1-e^{6.1Da})$$

D_a = *air space depth ~ in* (3)

Then, since the U-factor is just the reciprocal of the R-factor,

$$U_{sc} = \frac{1}{R_{sc}}$$

And

$$Q_{sc} = (T_s - T_c) \cdot U_{sc}$$

Q_{sc} = *heat from s to c ~ BTU / ft² / hr*

Therefor, the heat transfer from the air space to the stained glass window can be written:

$$Q_{as} = 2 \bullet (T_a - T_s) \bullet U_{sc} \qquad (6)$$

The last input to the stained glass window is the portion of the solar radiation adsorbed by the window, this is given in Equation 7.

RAD_s = *(solar insolation)* (1 – *refl)* (1 – cover *adsorb) (window adsorb)* (7)

Then the differential equation for the temperature of the window can be written:

$$\frac{dT_s}{dt} = \frac{Q_{as} + Q_{cs} + RAD_s}{TM_s} \qquad (8)$$

$$TM^s = thermal\ mass\ of\ window \sim BTU / ft^2 / \deg F \qquad (9)$$

The next task is to develop the differential equation for the temperature of the air space. The first two terms are simple, since the heat transfer to the air space is just the negative of the heat transfer from the window and the cover to the air space, as shown in Equations 9 and 10.

$$Q_{sa} = -Q_{as}\ 2 \bullet (T_s - T_a) \bullet U_{sc} \qquad (9)$$

$$Q_{ca} = -Q_{cs}\ 2 \bullet (T_c - T_a) \bullet U_{sc} \qquad (10)$$

The nest step is to develop the equation for the effect of venting When the air in the air space is hotter (or colder) than the outside air, the difference in density creates a buoyancy force which, if venting area is provided at the top and the bottom of the air space, causes a flow of air. Marks Handbook (Ref. 5, p 1120) gives an equation for the draft (pressure difference) as a function of height (vertical distance between inlet and outlet vent area), ambient pressure, outside temperature, and the air space temperature. Converting to the units of this work, it is given as Equation 11

$$D = 0.0188 \cdot P \cdot H \cdot \left(\frac{1}{T_o + 460} - \frac{1}{T_a + 460} \right) \qquad (11)$$

$$D = draft \sim \frac{lb}{ft^2}$$

$$P = ambient\ \ pressu \sim \frac{lb}{ft^2}$$

$$H = vertical\ \ distance\ \ between\ \ inlet\ \ and\ \ outlet \sim ft$$

$$T_o = ambient\ \ temperature \sim \deg F$$

$$T_s = air\ \ space\ \ temperature \sim \deg F$$

Note that the quantity “460” added to the temperatures converts to an absolute temperature scale, degrees Rankine. Now the steady state flow through the air space represents a balance between the draft and the pressure loss due to flow. For the usual case, where the area of the vents is much smaller than the flow area through the air space, the loss can be evaluated as a fraction of the dynamic pressure through the inlet and outlet, as given in Equation (12).

$$D = \eta \cdot \frac{\rho}{2 \cdot G} \cdot (V_i^2 + V_o^2) \tag{12}$$

$$\eta = loss \ \ ratio$$
$$\rho = density \sim \frac{lb}{ft^3}$$
$$G = gravitational \ \ acceleation \sim \frac{ft}{\sec^2}$$
$$V_i = vent \ \ inlet \ \ velocity \sim \frac{ft}{\sec}$$
$$V_o = vent \ \ outlet \ \ velocity \sim \frac{ft}{\sec}$$

Using mass conservation to express vent velocity ratio in terms of vent area ratio, Equation 13 can be developed.

$$V_i = \frac{D}{|D|} \cdot \sqrt{\frac{|D|}{\eta \cdot \frac{\rho}{G} \cdot (1 + \frac{A_i^2}{A_o^2})}} \tag{13}$$

Note that, in order to compute correctly if the air space temperature is colder than the outside air, the sign of D has been moved outside the square root. This could occur in an air conditioned building with small solar input. The rate of heat loss (or gain) due to the vent flow can now be computed with Equation 14.

$$Q_{vent} = \frac{3600 \cdot \rho \cdot A_i \cdot V_i \cdot (T_o - T_a)}{A_{sgw}} \tag{14}$$

$$Q_{vent} = venting \ \ heat \ \ loss \sim BTU \ / \ ft^2 \ / \ hr$$
$$A_{sgw} = area \ \ of \ \ stained \ \ glass \ \ window \sim ft^2$$

Now the differential equation for the temperature of the air space can be written as Equation 15.

PROTECTIVE GLAZING CASE STUDY #1

-

Berry Memorial United Methodist Church (1909), Chicago, Illinois

WINDOW: Opalescent art glass & painted glass (1909)
WINDOW ORIENTATION: South
WINDOW VALUE: Moderate
VANDALISM/SECURITY RISK: High
YEAR PG WAS INSTALLED: 1970s
PG SQUARE FOOTAGE: 125
PG COST OF INSTALLATION: Unknown
PG COST PER SQUARE FOOT: Unknown
PG MATERIALS: Plastic sheets & aluminum channels

PG INSTALLATION REASONS: Although the church does not have any records as to why the PG was installed, the windows were probably covered due to general concerns regarding energy and glass protection.

PG INSTALLATION METHOD: The PG was installed in large sheets over the wood window frame and screwed into the outer molding around the perimeter. An aluminum grid subframe with snap-in stops was screwed into the window frame and sill for additional support and caulked with silicone. The PG created a deep 4½" airspace around most of the window, while hopper ventilators were piggybacked (flush) so that they could continue to operate.

WINDOW CONDITIONS:

The PG had hazed and yellowed so extensively that it was impossible to evaluate the condition of the art glass prior to removal of the PG. Upon removal of the PG in September of *1995,* it became apparent that the painted sections of the window were plated and a number of the outer plates were broken from vandalism. The window frame was also in seriously deteriorated condition. The plated art glass could not have been broken with the PG in place, therefore the window was vandalized prior to PG installation.

PG REMOVAL/ALTERATION REASONS:

The aesthetics of the badly hazed PG, as well as the disruptive frame, have bothered the church for many years. The yellow glazing is also muting the color of the window to the interior of the church.

FINAL RESULTS:

[The existing PG was reinstalled.] Test results revealed that sound transmission through the window remained the same, with or without PG. However, with the PG temporarily removed, the daylight more than doubled from 17 footcandles to 36 footcandles. The surface temperature of the art glass dropped approximately 12°F during the test. Unfortunately, due to the advanced state of deterioration, and the need for full restoration, the existing PG had to e reinstalled since neither the project or church budget could cover the restoration costs. This proves to be a prime example of the challenges owners will face once the decision is made to remove PG. Stained glass stewards should e prepared to face serious window deterioration problems upon removing PG that has been in place for a number)f years. Window conditions may reveal that restoration projects and PG removal must be placed on hold while the funds are raised to restore the stained glass properly. As an initial test, owners should remove several PG panels around the building, ideally on different elevations, to determine the condition of the window frame and art glass in he interspace. Serious deterioration could undermine the window's structure and the church or synagogue may need to leave problematic PG in place or temporarily pull the stained glass for safe storage until proper restoration is feasible **(see Case Study #1 photos also Figs. C16 in Appendix A).**

$$\frac{dT_a}{dt} = \frac{Q_{sa} + Q_{ca} + Q_{vent}}{TM_a} \tag{15}$$

$$TM_a = thermal\ \ mass\ \ of\ \ air \sim BTU\ /\ ft^2\ /\ \deg\ F$$

The last step is to develop the differential equation for the temperature of the cover. Reference 6 presented a table of R-Factor for the exterior of a building as a function of wind speed. For this program, wind speed is a variable, so an equation is required. Figure 13 presents a comparison of Equation 16 with the data from Reference 6.

$$R_{oc} = \frac{0.68}{(1 + 0.2 \cdot V)} \tag{16}$$

$$V = wind\ \ speed \sim mph$$

Again, since the U-factor is just the reciprocal of the R-factor,

$$U_{oc} = \frac{1}{R_{oc}} \tag{17}$$

And

$$Q_{oc} = (T_o - T_c) \cdot U_{oc} \tag{18}$$

$$Q_{oc} = heat\ \ from\ \ outside\ \ to\ \ cover \sim BTU\ /\ ft^2\ /\ hr$$

The heat transfer from the air space to the cover, $Q_{ac'}$ has already been developed in Equation 10, so the remaining term, the portion of the solar radiation adsorbed by the cover, is given by Equation (19).

$$RAD_c = (solar\ insolation) \bullet (1\text{-}refl) \bullet (cover\ adsorb) \tag{19}$$

Now the differential equation for the temperature of the cover can be written as Equation 20

$$\frac{dT_c}{dt} = \frac{Q_{ac} + Q_{oc} + RAD_c}{TM_c} \tag{20}$$

$$TM_c = thermal\ \ mass\ \ of\ \ cover \sim BTU\ /\ ft^2\ /\ \deg\ F$$

Note that the three differential equations, (8,15, and 20) are not independent. Each temperature appears in the differential equation of the others, making this a coupled set of differential equations. The solution is obtained by a very fine time scale simultaneous integration (12 second interval) with ten repetitions of the complete integration. This Excel function is listed in the appendix as “Tinteg”.

The temperature time histories of the components then depend on the natural convection from the window to the interior of the building, the mixed conduction/convection between the window and the air space and between the air space and the cover, the forced convection from the cover to the exterior atmosphere, and, for the case of venting, the removal of heat from the air space by buoyancy driven convection. In actuality, the temperatures also vary with vertical and horizontal location in the window and cover. In order to simplify the analysis, it is assumed the temperature at all locations in the window and cover is uniform. Another way of stating this restriction is that the analysis calculates the space averaged window, airspace, and cover temperatures.

The third requirement for the analysis is a knowledge of the local weather. First, the heat transfer from the cover to the outside atmosphere varies by a factor of four as the wind speed varies from 0 to 15 mph, a very modest wind. For this purpose, data for O'Hare airport was obtained from the National Climactic Data Center. No direct measurement of solar insolation was found, but the weather descriptions were used to adjust the variation in transmission through the atmosphere (cloud cover, fog, blowing snow, etc.).

First, the data was searched to find a day as clear as possible. January 26. 1996 had a little fog in the morning, but was otherwise clear. This made possible a test of the program with minimum ambiguity. January 27 was added as an example of a day with much smaller solar input. Figure 14 compares the measured air space temperature of two similar windows in the same wall, differing only in venting. One is sealed, the other has 0.147 square inch vents at the top and bottom of the cover. The effect of venting is not large, but the peak temperatures are significantly reduced. This probably indicates that the vent area is on the small side. Larger vent areas will be investigated with the computer model.

Figure 15 makes the same comparison for the measurements of humidity. The vented window has significantly lower humidity during solar insolation, even though the humidity levels were fairly low in both windows. The equations for humidity have not yet been included in the computer model, so the effect of larger vent areas on humidity cannot yet be computed.

Figure 16 compares measured and calculated air space temperatures for the unvented window. Figure 17 presents the adjusted air transmission factor which was used to compute the calculated temperature. No independent measure of the solar insolation was available, so the magnitude of the dips in the transmission factor have been determined by the measured air space temperature. The location in time of the dips is consistent with the weather reports. Figure 18 presents the measured wind speed at O'Hare airport, which is also a vital part of the calculation through its effect on exterior heat transfer.

Comparison of measured and calculated air space temperatures for the vented window is given in Figure 19. Note that the adjusted air transmission factor is that of Figure 17 and, of course, the measured wind speed is that of Figure 18. The agreement is not quite as good as that for the unvented window. This may indicate that significant vertical variation in the air space temperature may occur with venting.

Figure 20 presents the computed effect of increasing the vent area. It is seen that the vent area of the-test was too small to provide significant reduction of temperature from that of an unvented window.

Conclusions and Recommendations

Preliminary analysis of the data is quite encouraging. The only missing factor is an independent measurement of solar insolation. The humidity calculations can be added to the program at a later time. A real test of the humidity calculations will require data from the southeast region, where air conditioned interiors and a hot humid exterior atmosphere create real humidity problems. Finally, for a reliable prediction of the effect of protective glazing on stained glass windows, the computed results must be compared with measured data for several different installations. The installations should be chosen with consideration of the locations for which the National Climactic Data Center has detailed weather records.

References

1. Kreider, Jan F. and Kreith, Frank, “Solar Heating and Cooling”, McGraw-Hill, 1975

2. Hodgman, Charles D. (editor), “Handbook of Chemistry and Physics” Thirty-Second Edition, Chemical Rubber Publishing Co., 1950

3. Personal Communication from Lillian Barker, Technical Sales, GE Plastics Structured Products, Pittsfield, Ma., May, 1996.

4. Weather Reports for O’Hare airport, November, 1995 through February, 1996, U.S. Department of Commerce, National Climactic Data Center, Asheville, Md

5. Marks, Lionel S. (editor), Mechanical Engineers’ Handbook, McGraw-Hill Book Co., Fifth Edition, 1951

6. Simon, Wayne E., “Heat Loss Through Stained Glass Windows”, Stained Glass, Summer, 1981

Figure 1 - Solar Insolation in BTU/sq ft/hr
(March 21, 40 deg N Lat, Vertical E-W Wall)

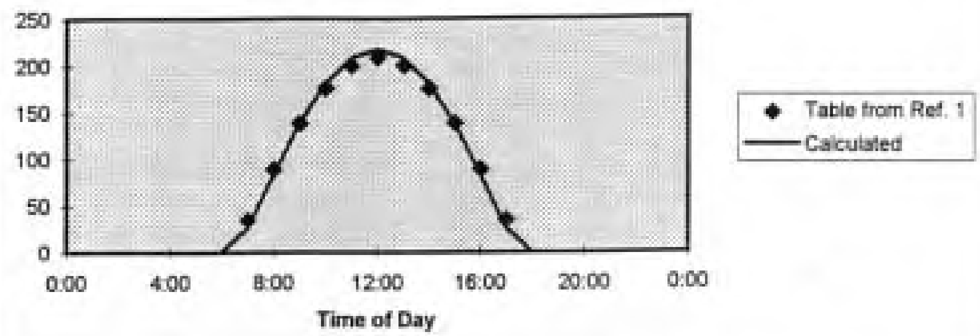


Figure 2 - Solar Insolation in BTU/sq ft/hr
(March 21, 40 deg N Lat, E-W wall at 40 deg Inclination)

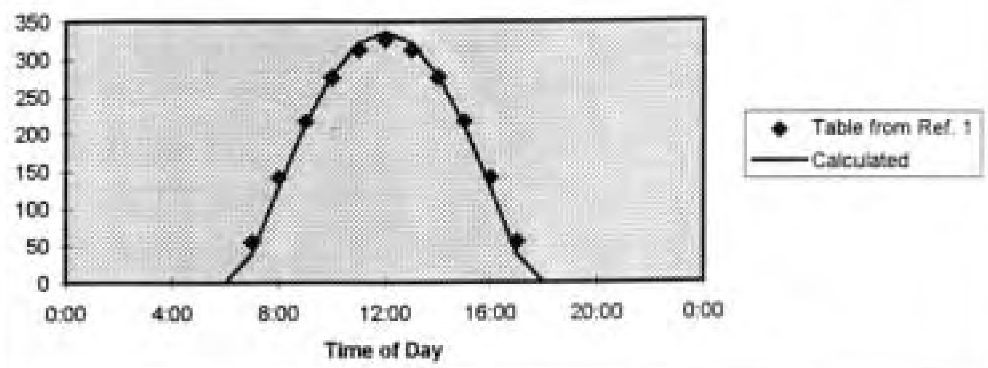


Figure 3 - Solar Insolation in BTU/sq ft/hr
(March 21. 40 deg N Lat, Horizontal Surface)

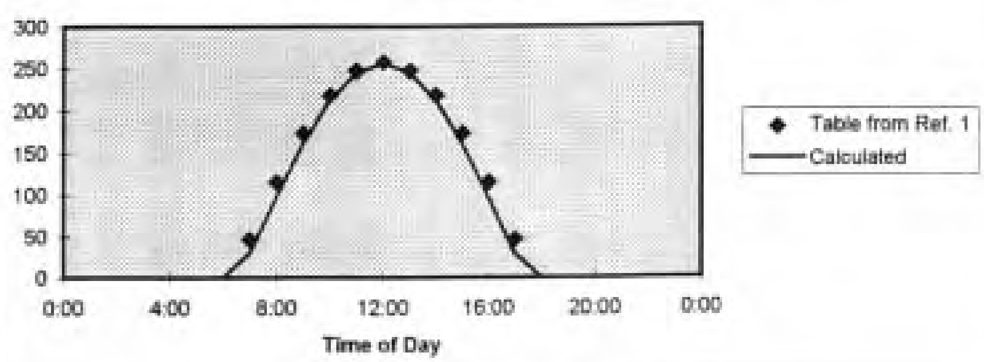


Figure 4 - Solar Insolation in BTU/sq ft/hr (June 21, 40 deg N Lat, Vertical E-W Wall)

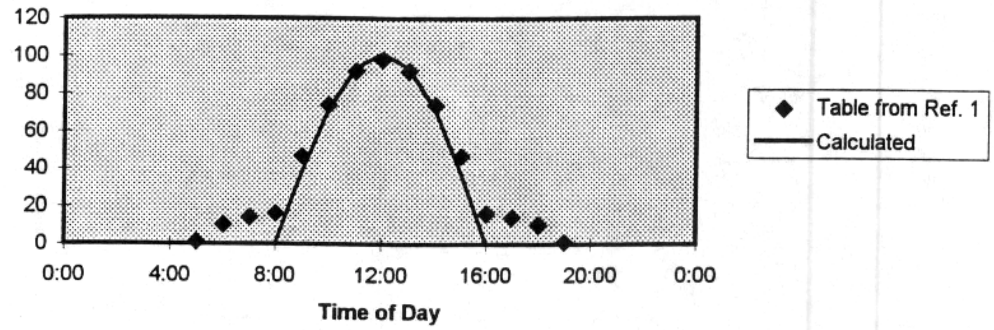


Figure 5 - Solar Insolation in BTU/sq ft/hr (June 21, 40 deg N Lat, E-W Wall at 40 deg Inclination)

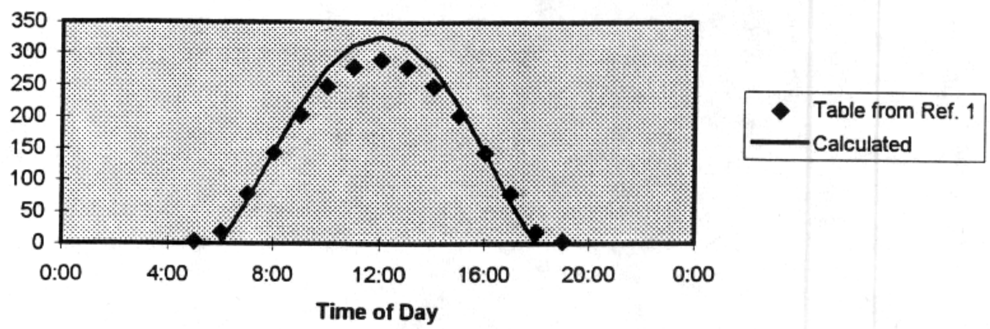


Figure 6 - Solar Insolation in BTU/sq ft/hr (June 21, 40 deg N Lat, Horizontal Surface)

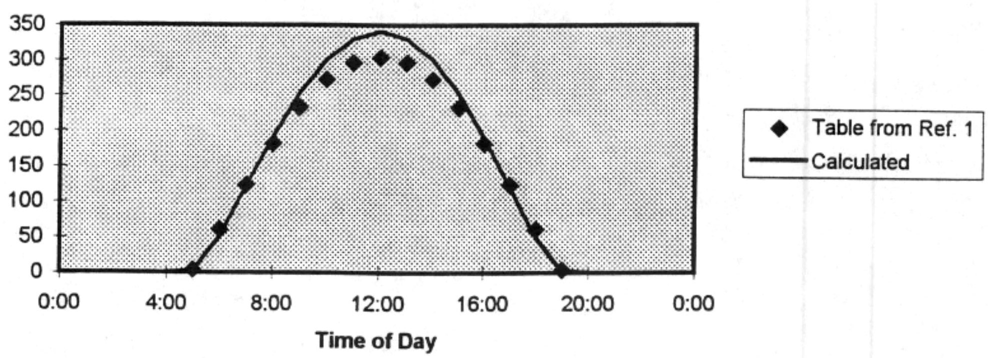


Figure 7 - Solar Insolation in BTU/sq ft/hr
(December 21, 40 deg N Lat, Vertical E-W Wall)

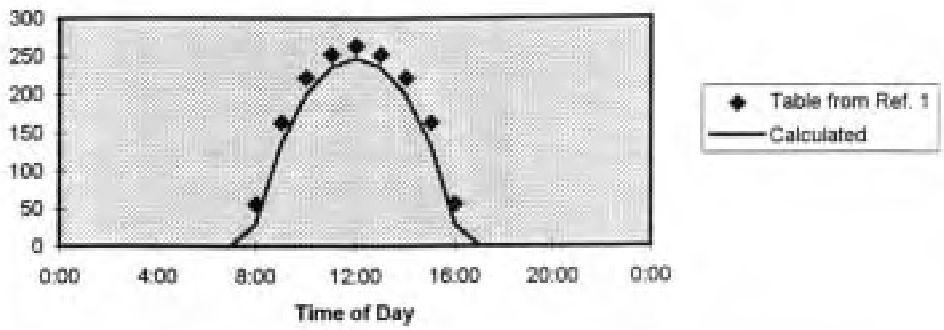


Figure 8 - Solar Insolation in BTU/sq ft/hr
(Decenber 21, 40 deg N Lat, E-W Wall at 40 deg Inclination

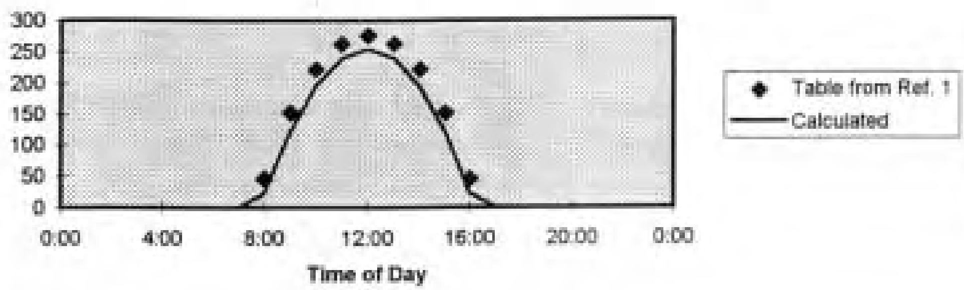


Figure 9 - Solar Insolation in BTU/sq ft/hr
(December 21, 40 deg N Lat, Horizontal Surface)

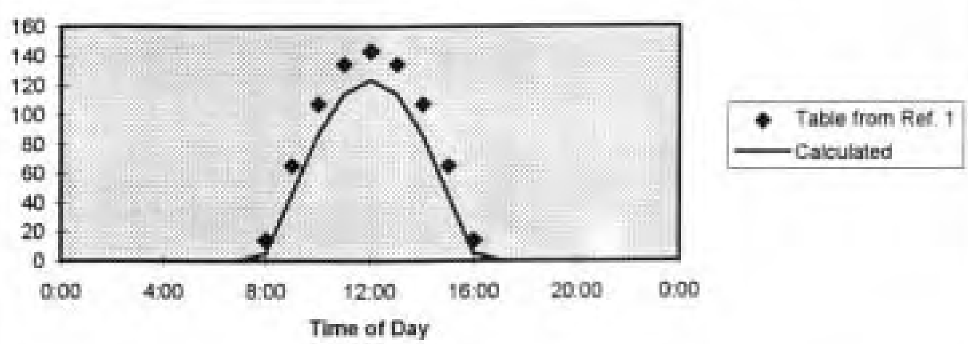


Figure 10 - Reflection from Transparent Medium With Refractive Index of 1.55 (Glass or Lexan)

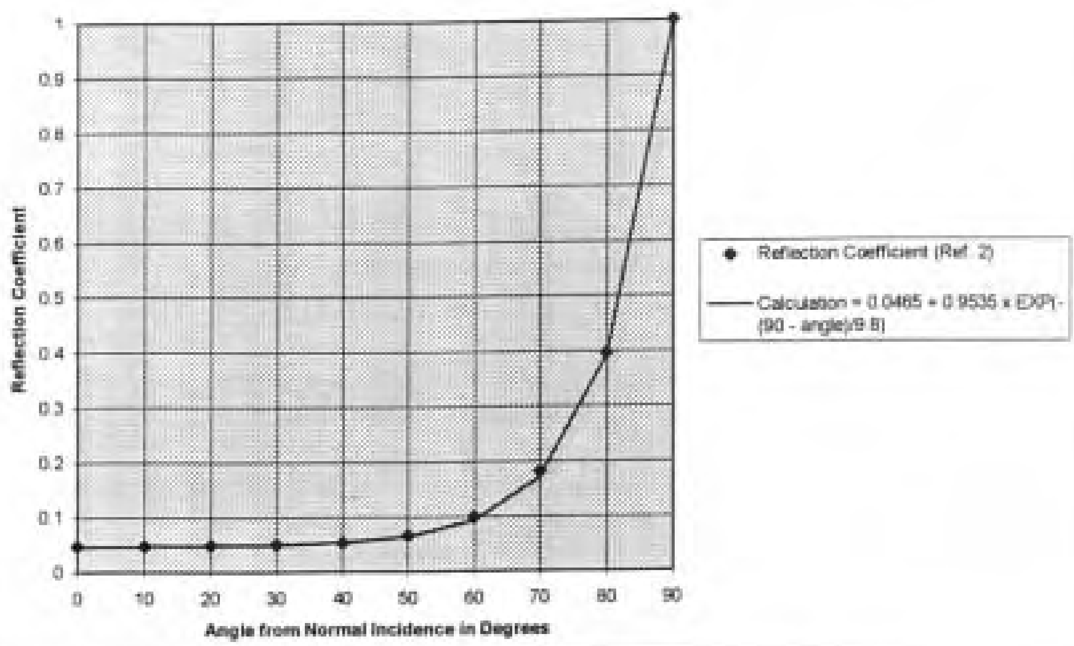


Figure 11 - Transmission of Uncoated Lexan (Data from fax from GE Plastics, Ref. 3)

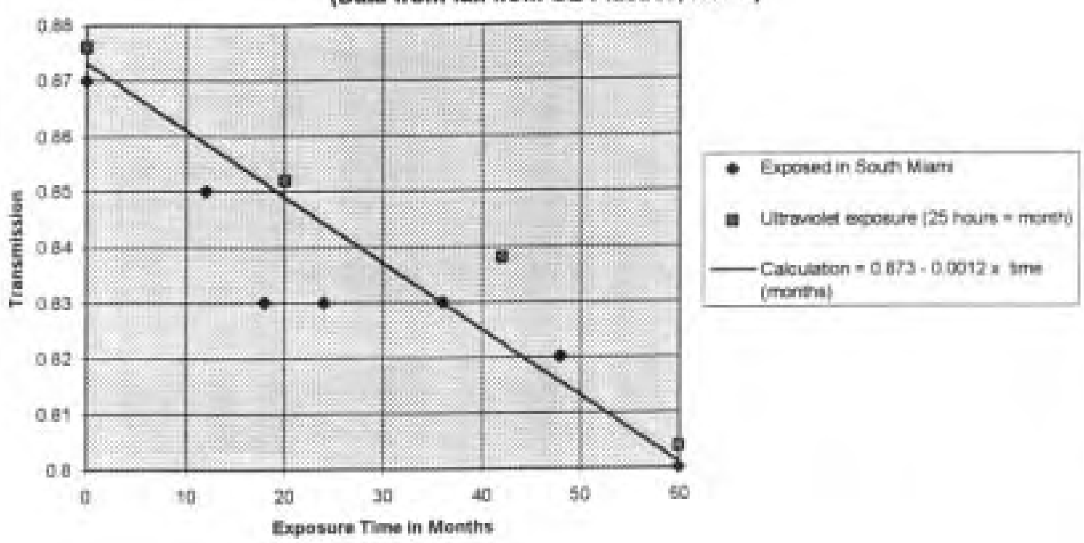


Figure 12 - R-Factor for Enclosed Air Space

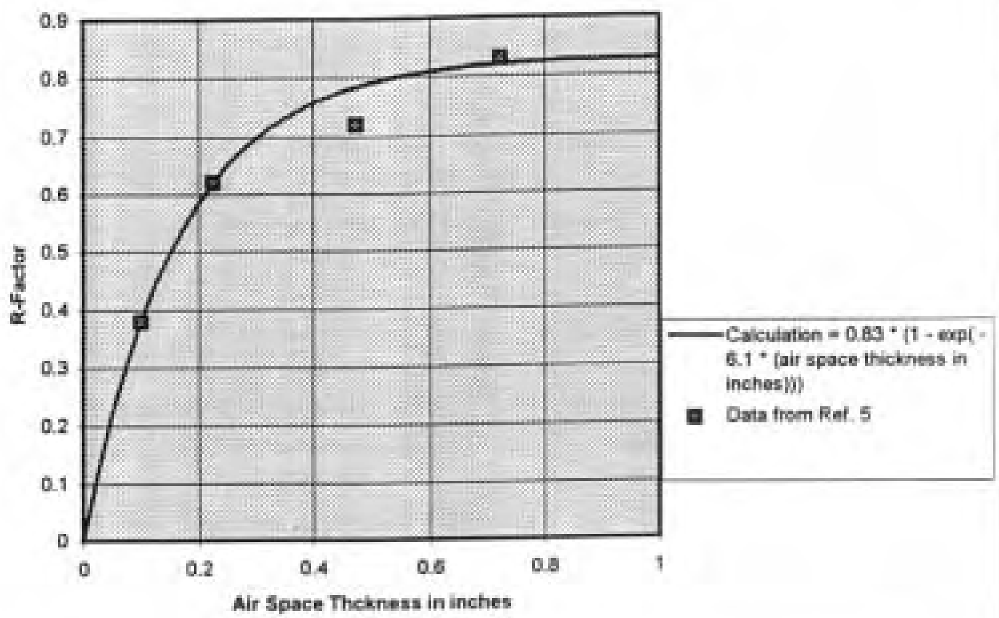


Figure 13 - R-Factor for Building Exterior

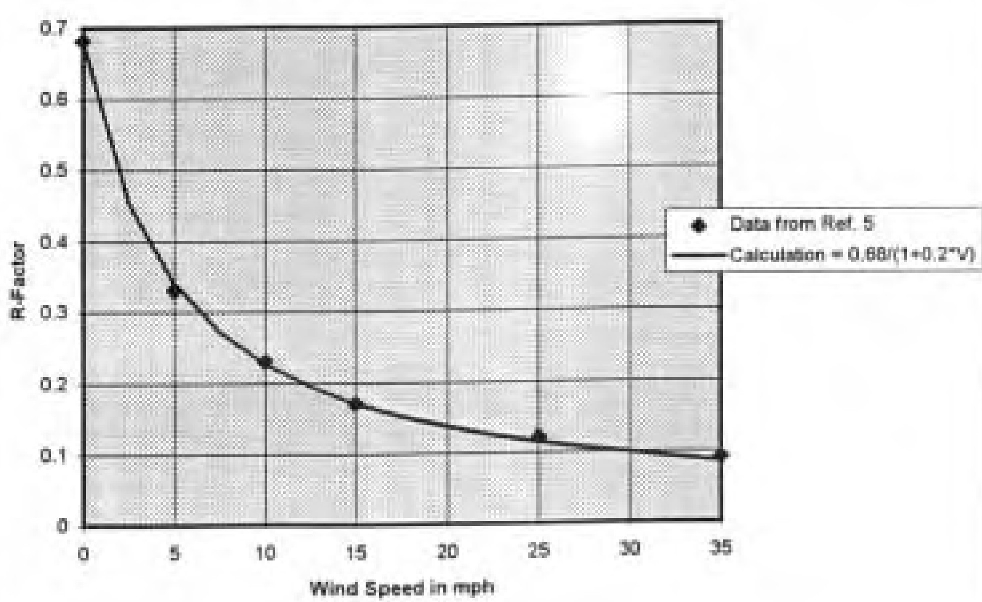


Figure 14 - Measured Air Space Temperature (unvented and vented)

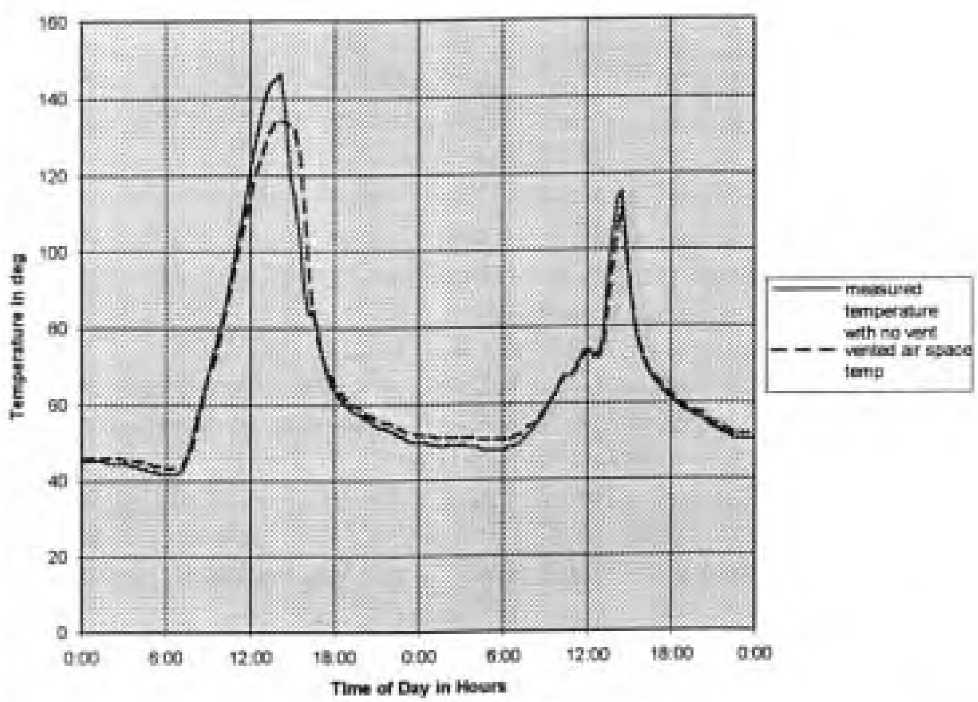


Figure 15 - Measured Air Space Humidity (unvented and vented)

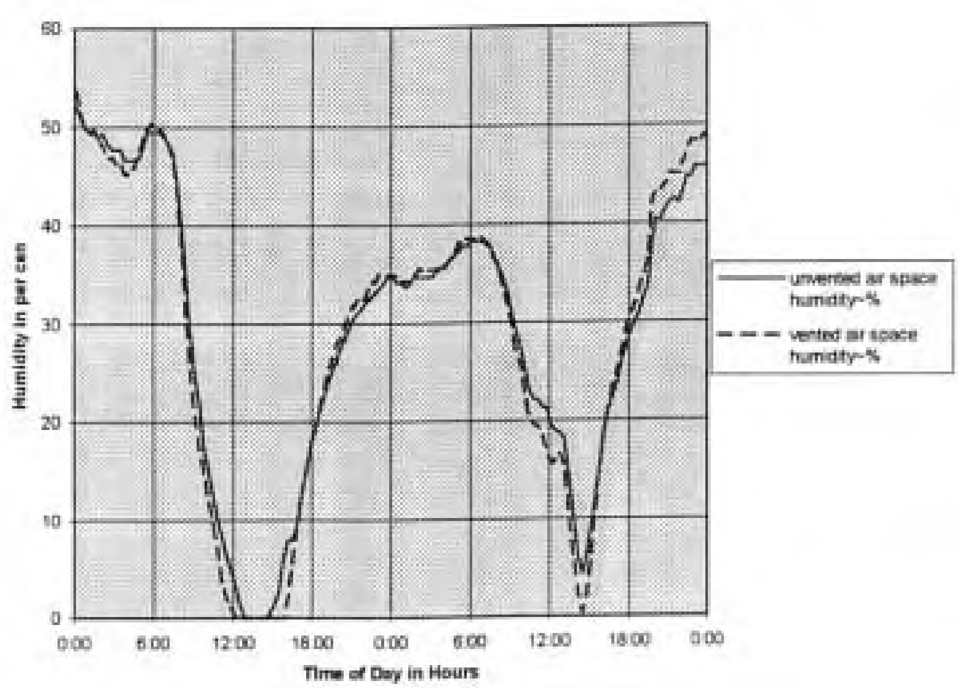


Figure 16 - Measured and Calculated Air Space Temperature (unvented)

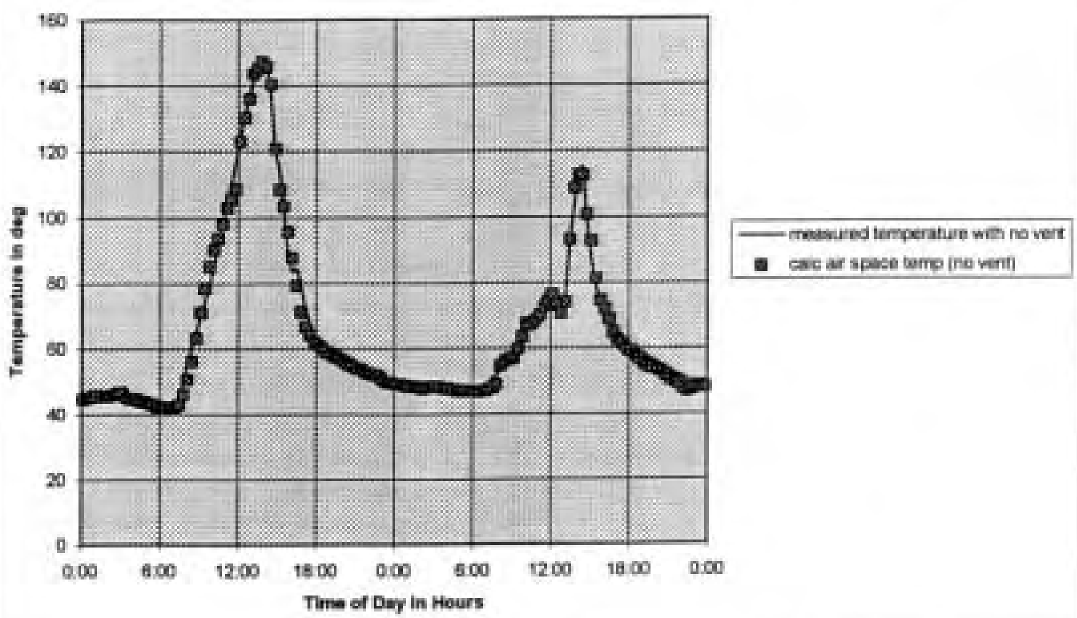


Figure 17 - Adjusted Air Transmission Factor

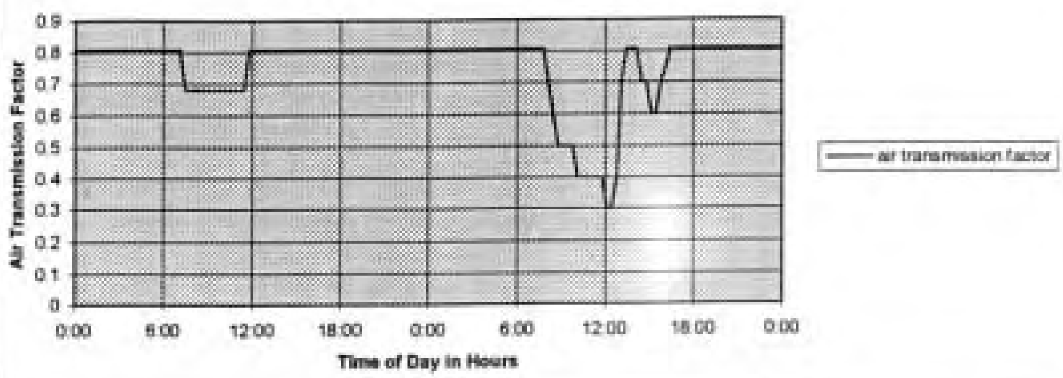


Figure 18 - Measured Wind Speed at O'Hare Airport

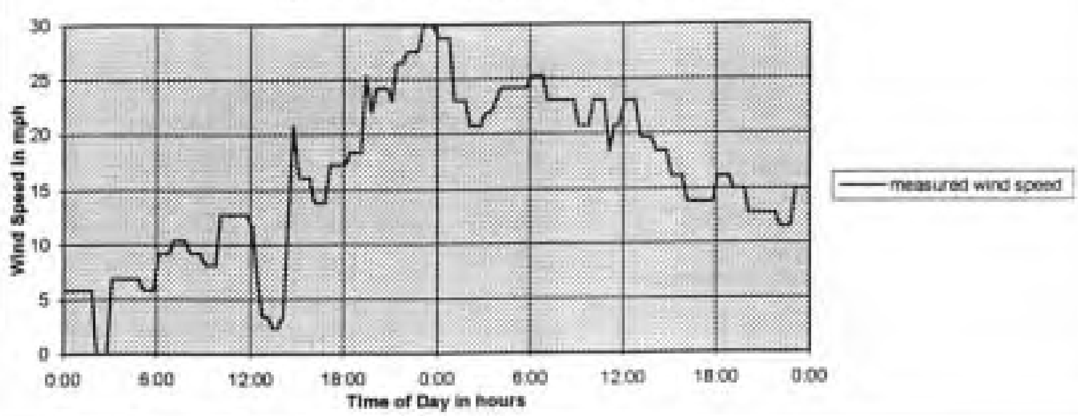


Figure 19 - Measured and Calculated Air Space Temperature (0.147 sq in vent)

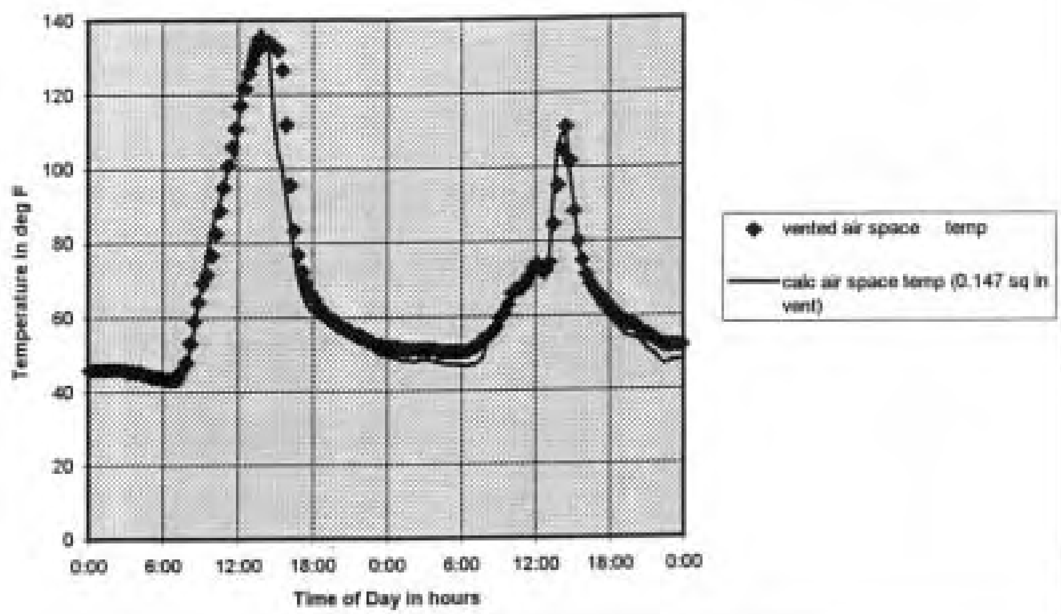
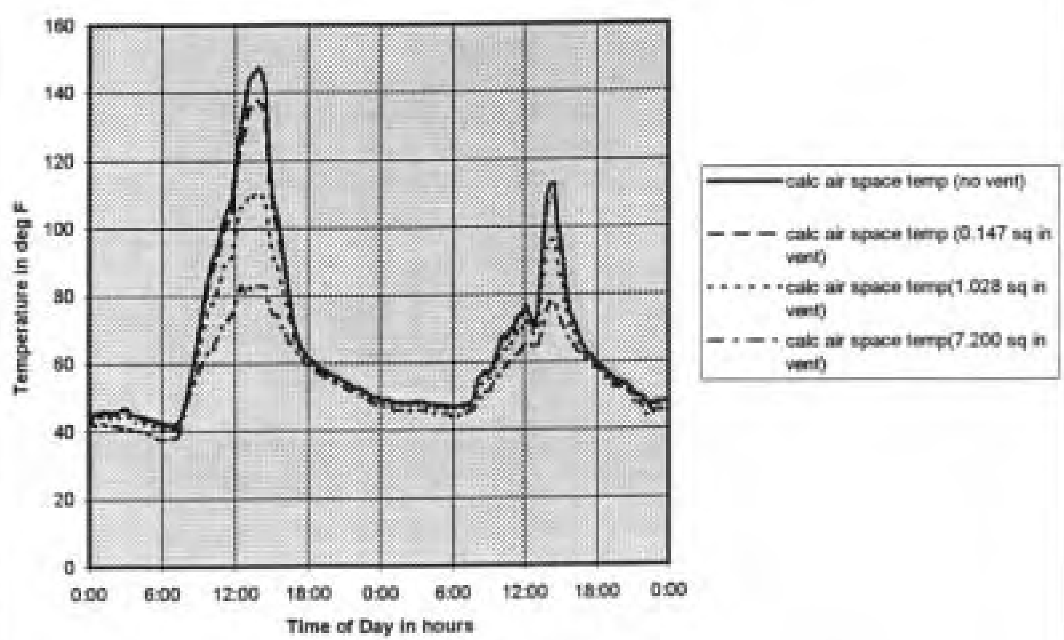


Figure 20 - Calculated Effect of Vent Ares



SECTION VI

CASE STUDIES

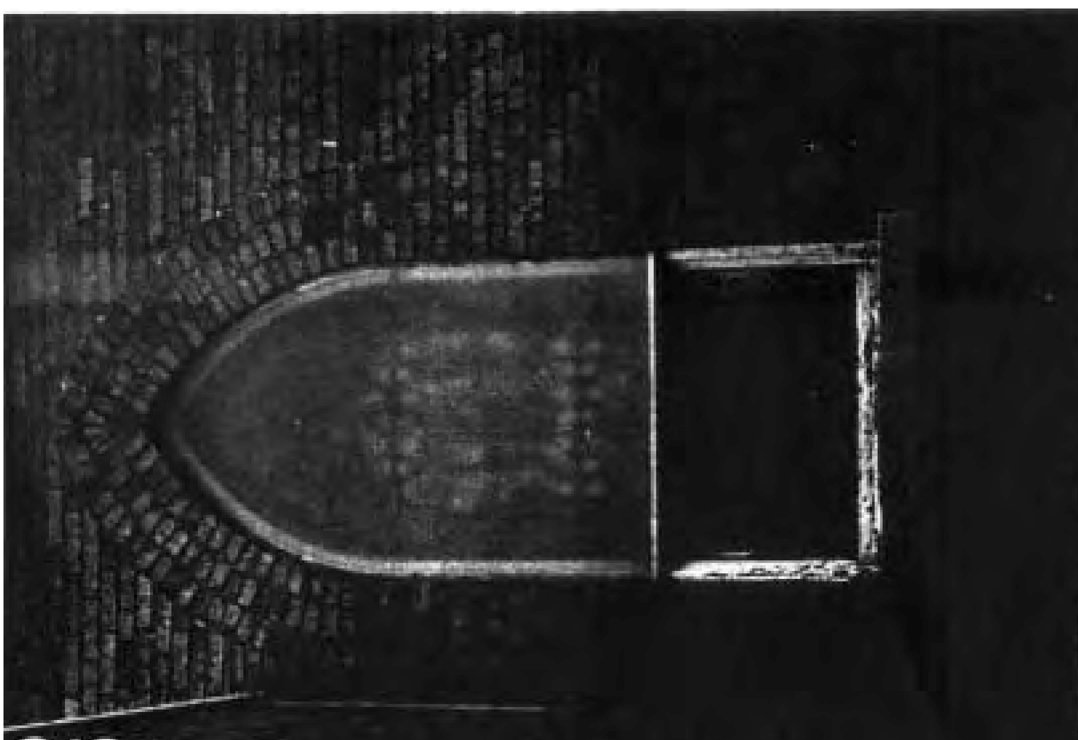
Written by

Neal A. Vogel
Project Director

March, 1996

The aluminum grid and yellowed glazing ruins this art glass window.

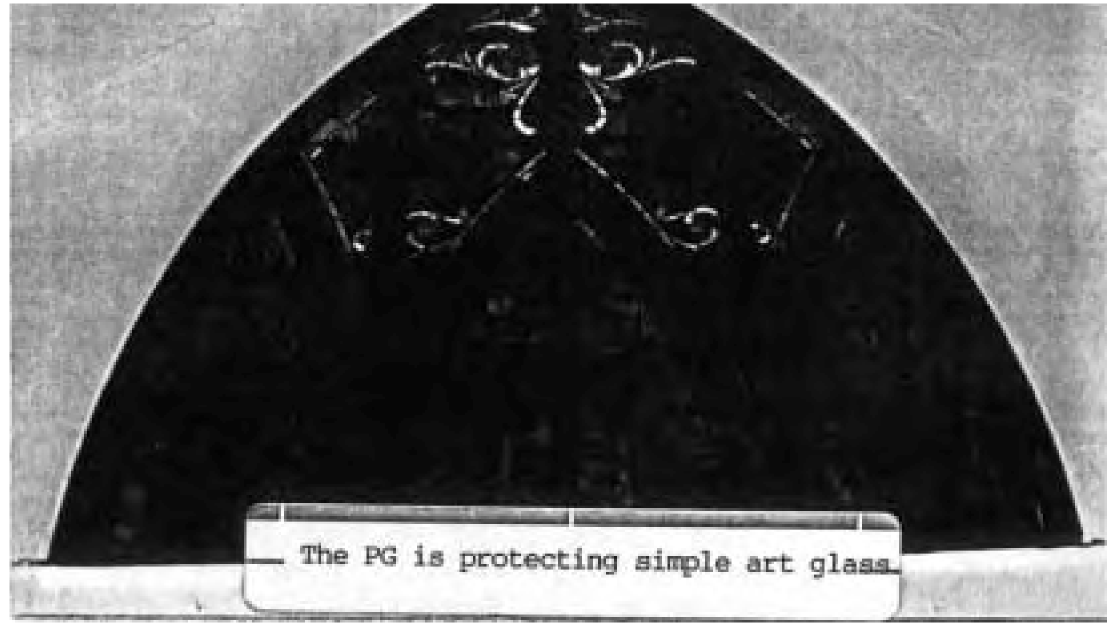
Poor flashing details at the roof are allowing the wood sill to rot.



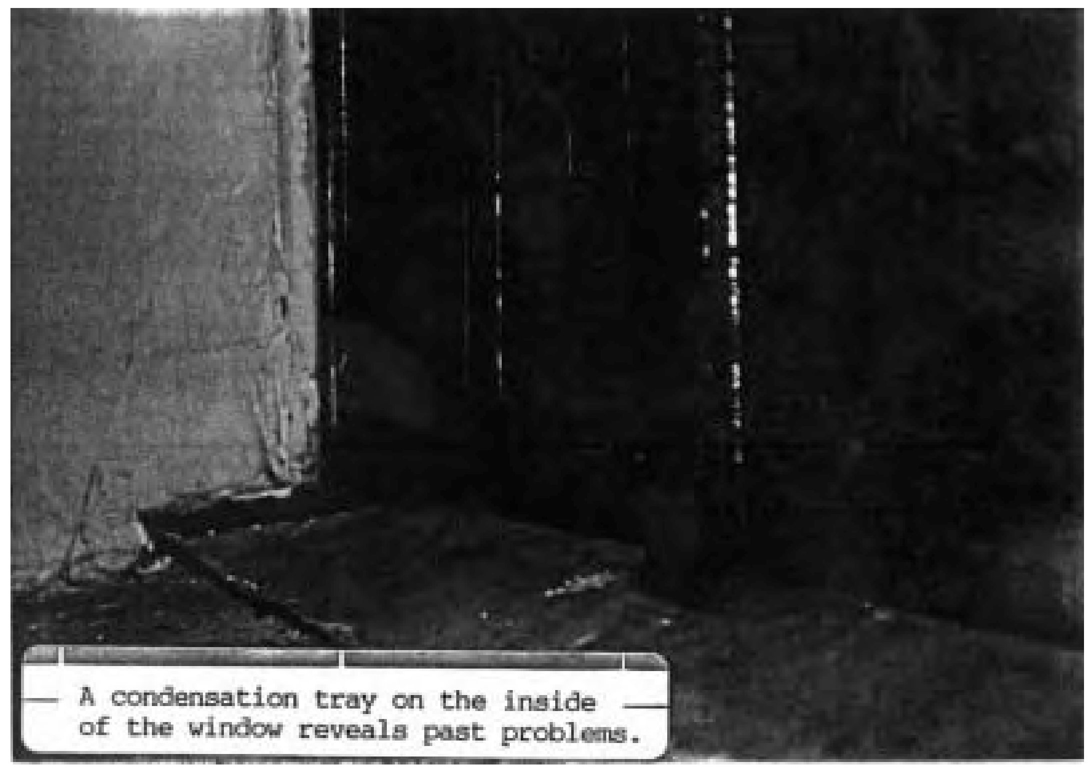
This window no longer reads as an apeture in the wall.

C16.c

The roof membrane should never be flashed into a PG system.



The PG is protecting simple art glass.



A condensation tray on the inside of the window reveals past problems.

PROTECTIVE GLAZING CASE STUDY #2

Covenant United Methodist Church (1911), Evanston, Illinois

WINDOWS: 1911 Amber Art Glass
WINDOW ORIENTATION: West
WINDOW VALUE: Low
VANDALISM/SECURITY RISK: Low
YEAR PG WAS INSTALLED: 1985
PG SQUARE FOOTAGE: 1,000 (all windows)
PG INSTALLATION COST: $27,000
PG COST PER SQUARE FOOT: $27
PG MATERIAL: *Lexan*® & anodized aluminum

PG INSTALLATION REASONS: *The PG was installed due to energy concerns, but the church discovered that there was not a significant change in their heating bills.*

PG INSTALLATION METHOD: The PG was installed in large sheets over the wood window frame and screwed into the outer molding around the perimeter. A subframe of anodized aluminum with snap-in stops was screwed into the window frame and sill for additional support and caulked with silicone. The PG created a deep 5½" interspace around most of the window, while center-pivot ventilators were piggybacked (flush) so that they could operate.

WINDOW CONDITIONS:

Three art glass windows were investigated upon removal of the PG in September, 1995. Most of the windows still have the original leading. The interspace was soiled and dirt had collected on the outer face of the art glass. It was also apparent that condensation had caused the leads to oxidize in the interspace and that white lead carbonate had collected on the surface of the cames and wood sill. The original waterproofing on the art glass windows was missing in areas, but the art glass did not show any deformation. The paint on the wood window frame was sun-faded and chalking in areas. The PG was generally sturdy and showed no apparent signs of failure, except for several bowed pieces on the large south window; however, all of the PG has badly hazed.

PG REMOVAL/ALTERATION REASONS:

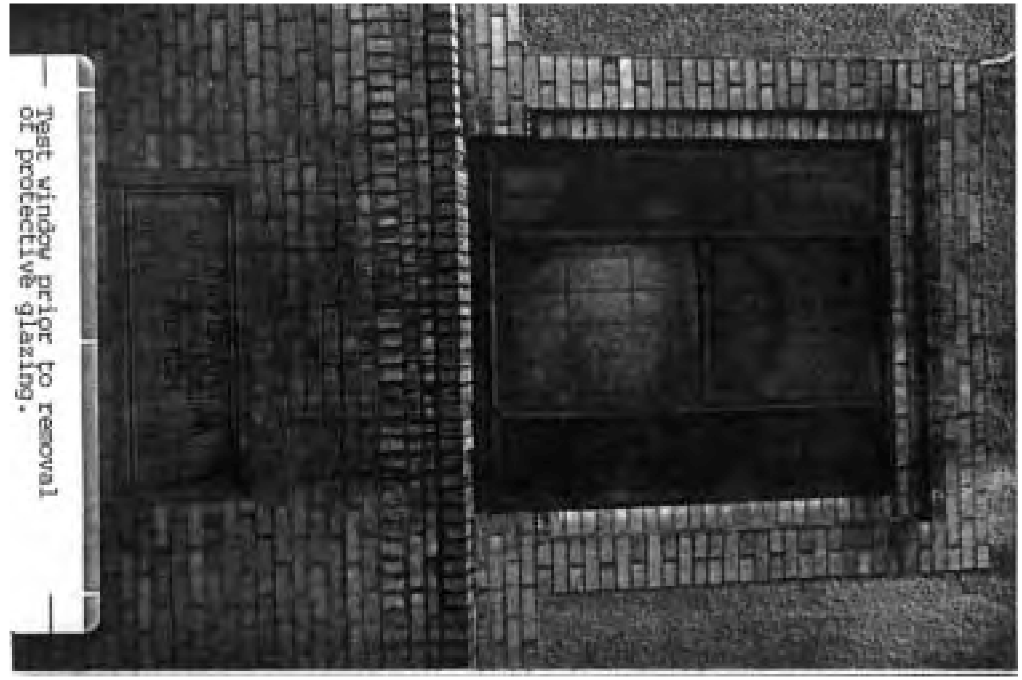
The aesthetics of the PG has bothered the church since it hazed over several years after installation. The church scale, massing and aesthetics compliment its middle to upper-middle income two-story residential community. As noted by the pastor, Reverend Nick Mitrovich, the hazy PG *"gives the building an industrial appearance."* Vandalism is never non-existent, but it is very low in this area and the church is not overly concerned about the simple art glass windows of readily-available amber glass. Architecturally, the hazy PG ruins the depth and color of the windows, one of the most important features of the eclectic Prairie School/Tudor Gothic design. As for the energy concerns, the church noted that the PG has not shown any significant savings. **Inspired Partnerships** discovered that although the sanctuary was separately zoned, the church was not setting the thermostat back during unoccupied periods. Moreover, the boiler was not operating properly and required some adjustments and repairs.

FINAL RESULTS:

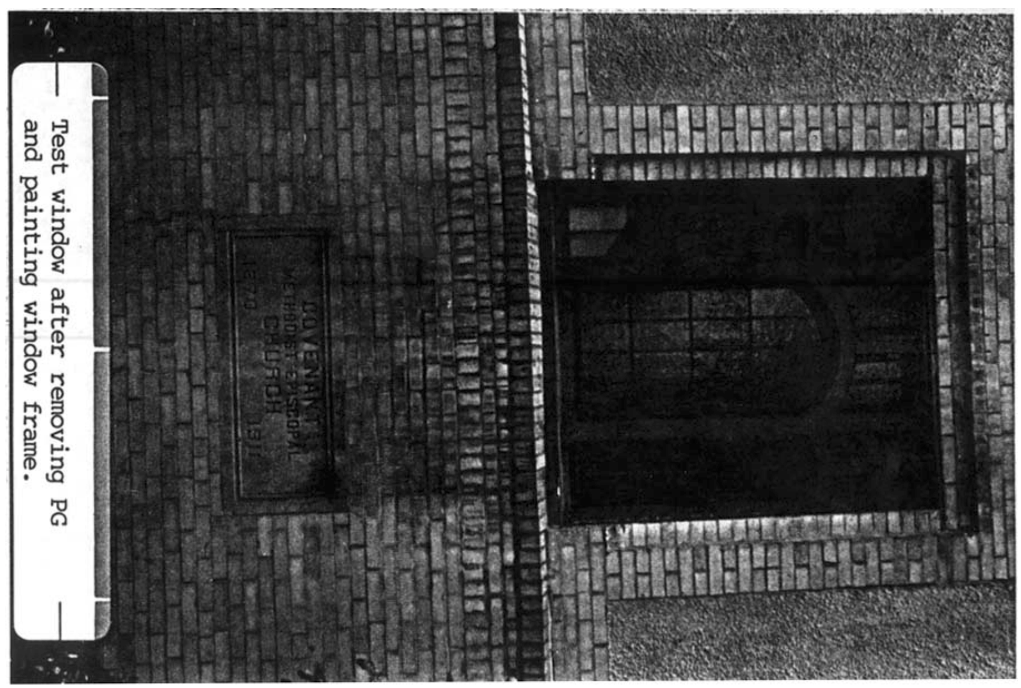
[The existing PG was removed.] The church regrets installing the PG ten years ago, and intends to remove it from all of the windows. Unfortunately, removal could cost $25,000 or more, money which could have been used for ongoing window maintenance. Test results after removal indicated that sound transmission increased about 14% but is still a negligible 70 to 90 decibels from passing trucks. The surface temperature of the glass only dropped four degrees. However, daylight through the art glass increased between 40% to 80% depending on window orientation! Aesthetically, the bland red and tan brick walls are greatly improved by the PG-less recessed window and blood-red trim (which would be even better if painted the original evergreen color). Although very simple, these windows repeat the design of the louvered vents of the tower and are the most prominent architectural features on the building **(see Case Study #2 photos also Figs. C14 in Appendix A).**

CASE STUDY #1

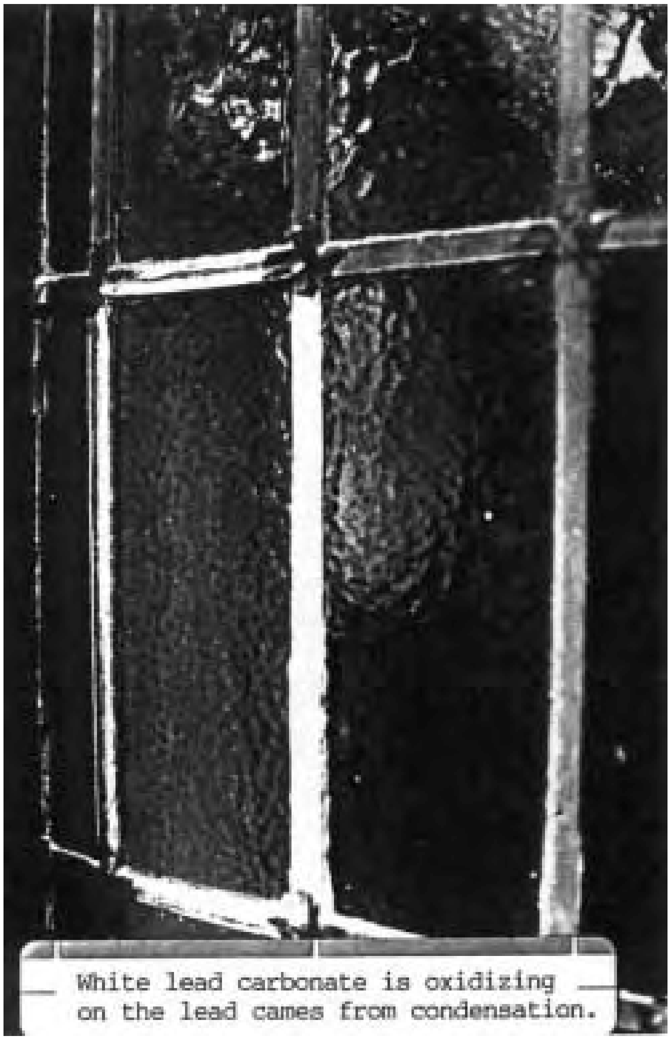
Powdered lead carbonate from condensation caused by PG.



Test window prior to removal of protective glazing.

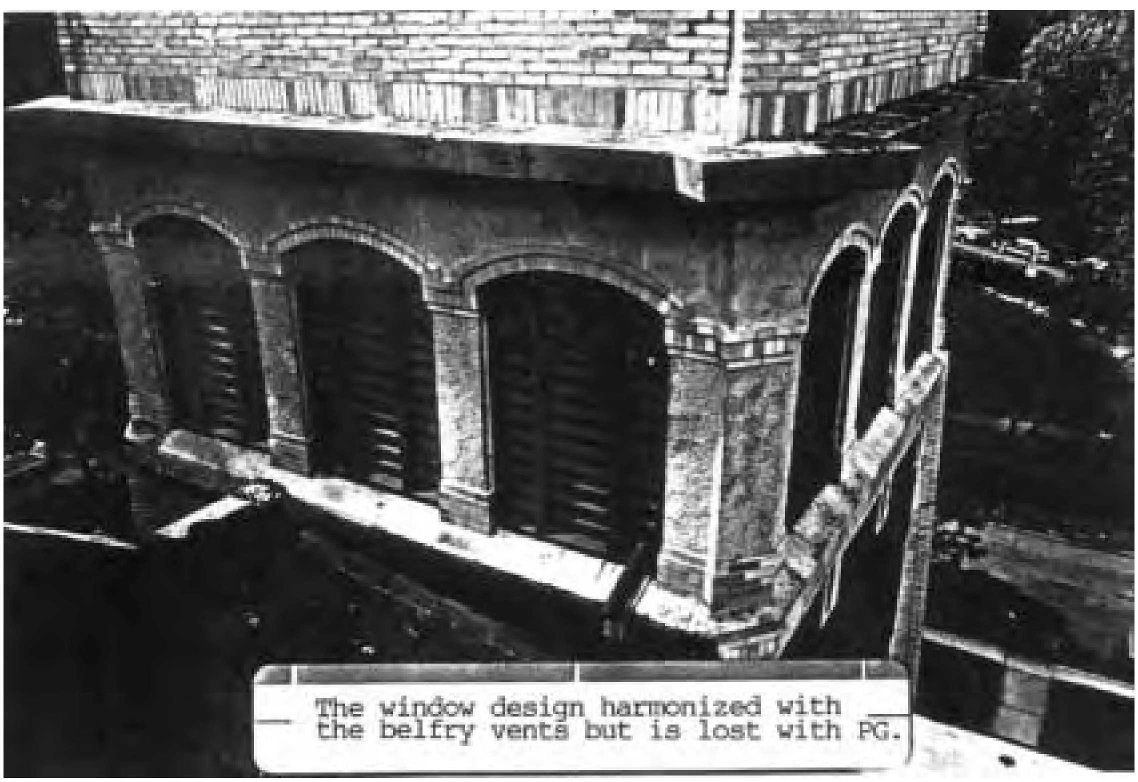


Test window after removing PG and painting window frame.



White lead carbonate is oxidizing on the lead cames from condensation.

Refurbishing this window cost $250.



The window design harmonized with the belfry vents but is lost with PG.

PROTECTIVE GLAZING CASE STUDY #3

First Lutheran Church of Logan Square (1906), Chicago, Illinois

WINDOW: 1906 "catalog" opalescent art glass & painted glass
WINDOW ORIENTATION: South
WINDOW VALUE: Low
VANDALISM/SECURITY RISK: High
YEAR PG WAS INSTALLED: Ca. 1980
PG SQUARE FOOTAGE: 1,100 (all windows)
PG INSTALLATION COST: Unknown
PG COST PER SQUARE FOOT: Unknown
PG MATERIALS: 1/4" float glass, and acrylic & steel framing

PG INSTALLATION REASONS: Changing demographics and higher vandalism called for installation of PG. According to church trustee, Mr. Bob Straeder, *"several years ago they threw a brick through our window which had a note attached that simply said…legalize drugs."*

PG INSTALLATION METHOD: The PG is float glass installed against an outer stop within the original window frame. The glass was secured with wood moldings nailed into the frame and glazing putty. The PG was set about ½" away from the art glass.

WINDOW CONDITIONS:

The door transom art glass window was investigated upon removal of the PG in December, 1995. The interspace was dirty and most of the original sealants and glazing putty were exhausted. The leaded panels had previously deformed and were braced with flat saddle bars that were soldered onto the window. These were poorly attached and the panels were deforming again, as evident when they were pulled to be flattened and repaired for this case study project. Vandalism continues to be a problem in this commercial, light-industrial Chicago neighborhood and several glass storms have been broken over time.

PG REMOVAL/ALTERATION REASONS:

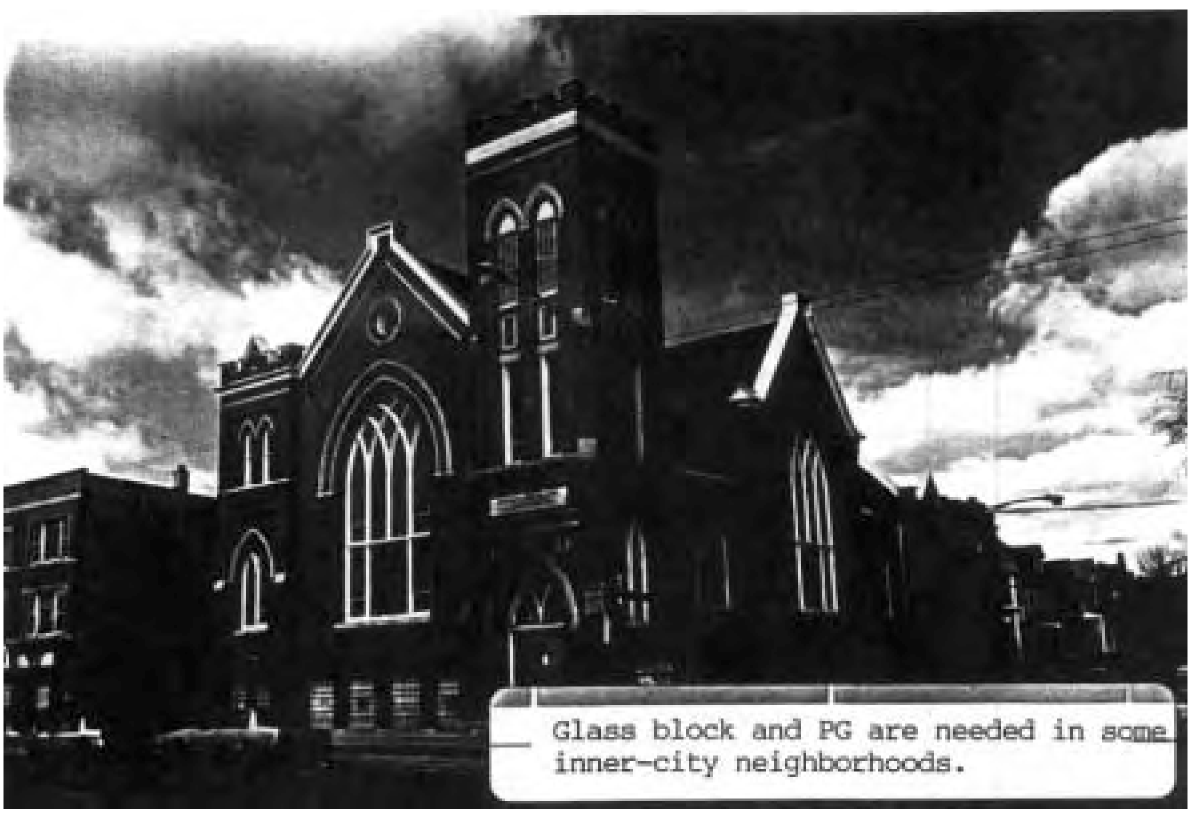
Given the <u>proven</u> high vandalism in the area, PG is required. The church wanted to repair several broken storm glass panels and improve the appearance of the building. Condensation problems have been observed at the church on several occasions and the poorly-fired painted glass is losing paint. Much of this paint loss may have been caused by window leaks before the PG was installed. The transom over the front door was selected as a place to begin --with the intention of additional entrance improvements and other window repairs as capital funds are available. Two of the three arched panels require replacement; one was badly broken and the other (which had been replaced with acrylic) had badly yellowed. The planned PG program is to repair all broken glass to discourage further vandalism, and to vent the windows to the interior.

FINAL RESULTS:

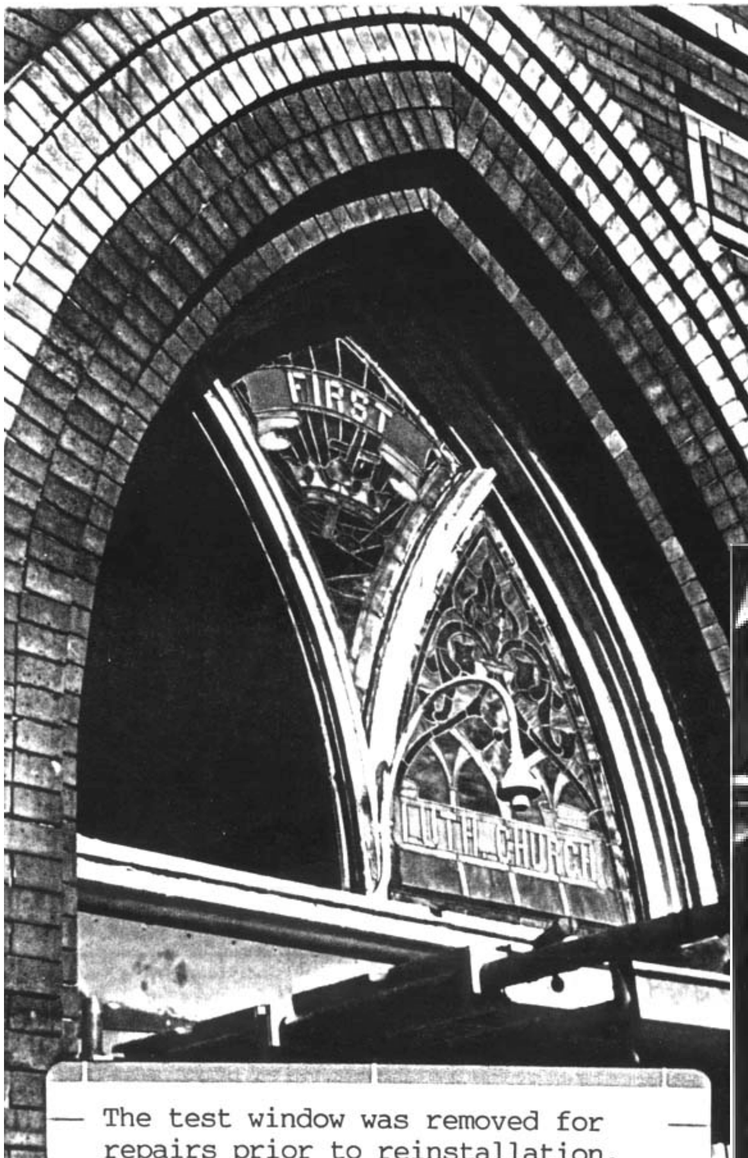
[The existing PG was replaced and vented.] Test results during temporary removal indicated that sound transmission only increased a few decibels despite the window location approximately 15 feet from a heavily traveled Chicago street. The alterations were completed on an overcast day so the surface temperature of the window could not be measured. Daylight only increased from 8 footcandles to 10 footcandles due to cloudy skies dirty glass PG. This case study endorsed the single best reason to use PG: when <u>real</u> vandalism threats are present. It also further revealed that PG systems, like any other building components must be maintained and should be included in on-going window and trim maintenance **(see Case Study #3 photos, also Figs. C23 in Appendix A).**

Test window had broken and yellowed panels in the transom.

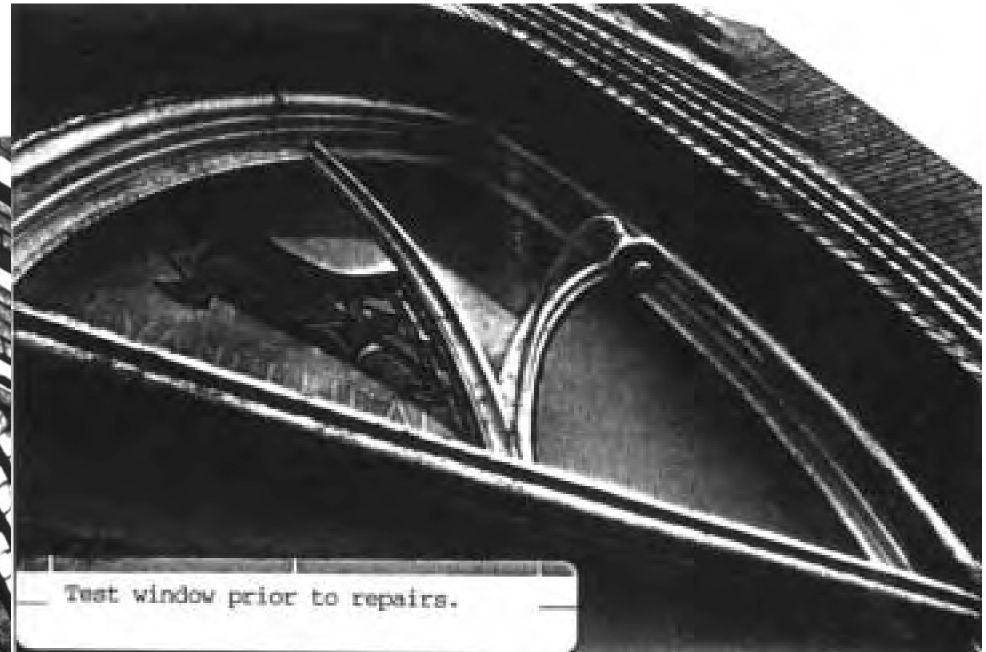
Test window after replacing PG with glass but prior to refurbishing doors.



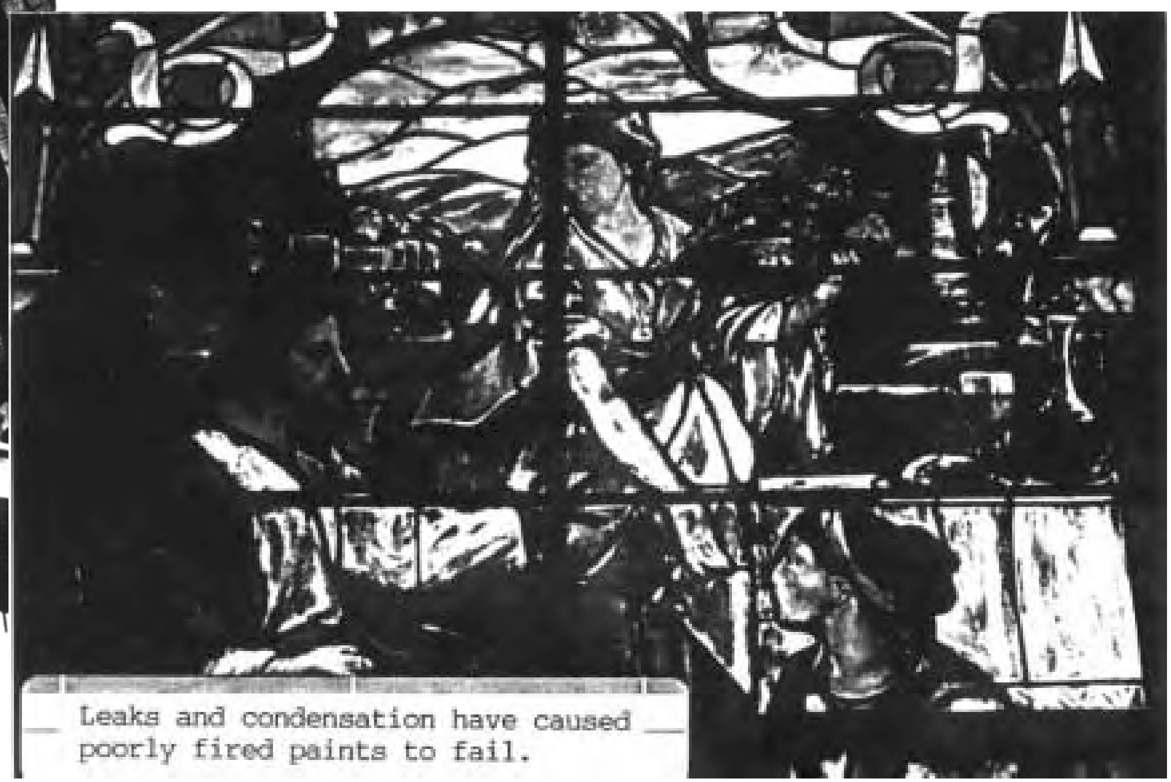
Glass block and PG are needed in some inner-city neighborhoods.



The test window was removed for repairs prior to reinstallation.



Test window prior to repairs.



Leaks and condensation have caused poorly fired paints to fail.

PROTECTIVE GLAZING CASE STUDY #4

First Presbyterian Church of Lake Forest (1886), Lake Forest, Illinois

WINDOW: 1886 opalescent Art Glass by McCully & Miles
WINDOW ORIENTATION: East
WINDOW VALUE: High
VANDALISM/SECURITY RISK: Low
YEAR PG WAS INSTALLED: 1979
PG SQUARE FOOTAGE: 230
PG INSTALLATION COST: $3,000
PG COST PER SQUARE FOOT: $13
PG MATERIALS: Polycarbonate & aluminum channels

PG INSTALLATION REASONS: The original "Cross & Crown" window was blocked from view on the interior by a pipe organ installed in 1974 and sealed off with insulation and a drywall partition. Apparently, there was no desire to restore the window several years later when it was covered with PG. In speculation, the PG was apparently installed to address concerns regarding possible leaks in the wall cavity which could not be viewed on the interior due to the drywall partition. Lake Forest has very low vandalism.

PG INSTALLATION METHOD: The PG is a polycarbonate, probably *Lexan*® which was installed against an outer stop within the original window frame. The PG was secured with aluminum channels nailed into the frame and caulked with clear silicone. The PG was set about 3" away from the art glass.

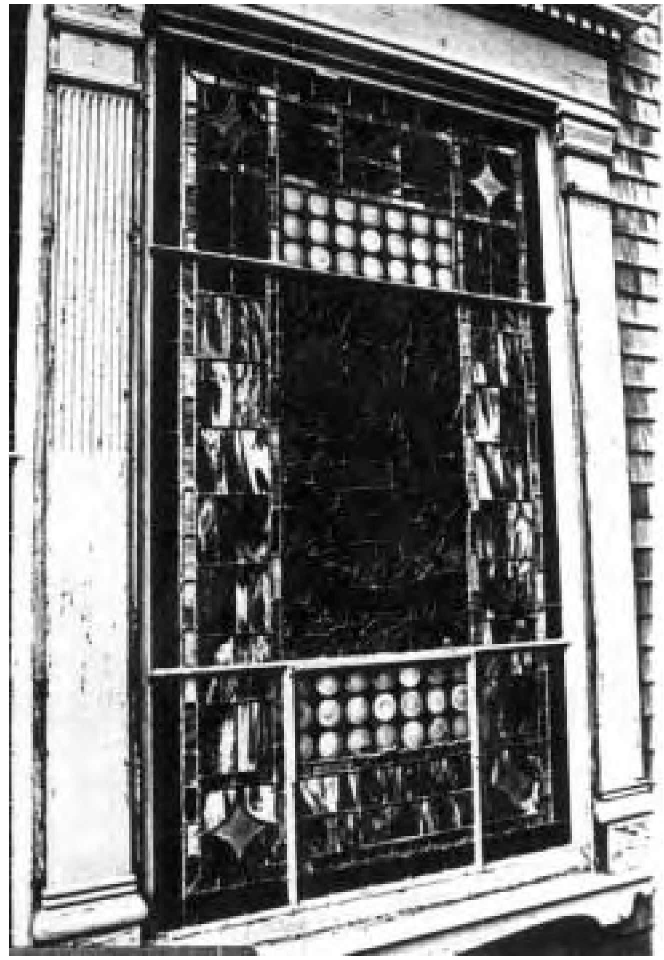
WINDOW CONDITIONS:

The art glass window was investigated upon removal of the PG in September, 1995. Most of the original sealants, glazing putty, and art glass leading were exhausted. The leaded panels were deformed near the bottom despite repairs performed during the 1940s and early 1970s. The window frame had deteriorated along the wood sill where moisture could pond against the caulked PG. The paint on the exterior frame was chalked and faded behind the PG. An access hole had to be cut into the drywall to inspect the window from the interior. The inside surface of the glass was filthy, indicating condensation, and was attracting and holding dirt against the glass. The PG had not been repaired since its installation and was still securely attached to the window frame; the silicone was holding up extremely well (as typical) and was difficult to remove. The PG had badly hazed.

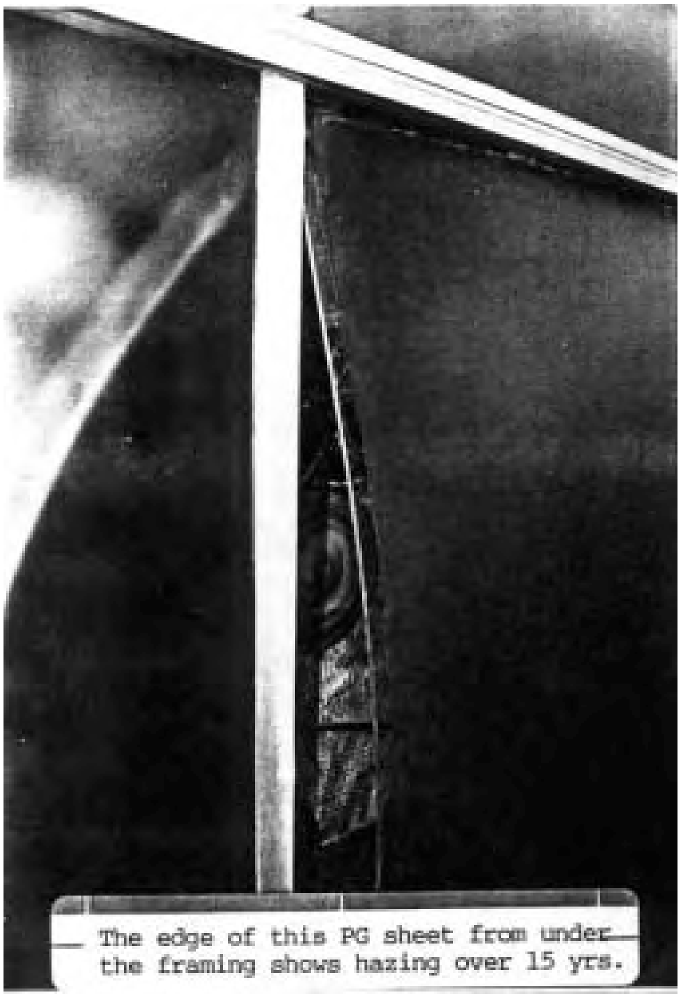
PG REMOVAL/ALTERATION REASONS:

The church is in the process of planning a phased restoration program for all of the stained glass windows. Several PG panels were initially removed to determine the priority for the Cross & Crown window in relation to other stained glass in the church. Due to the advanced deterioration of this window, it was determined to be the first priority. The remaining PG was removed and a 45 foot lift was rented to obtain accurate bids on removal and restoration of the art glass. Once the window was viwed without the hazed PG and grid, a decision was made not to install new PG. The opalescent glass not only adds color, it harmonizes with the texture of the wood shingles.

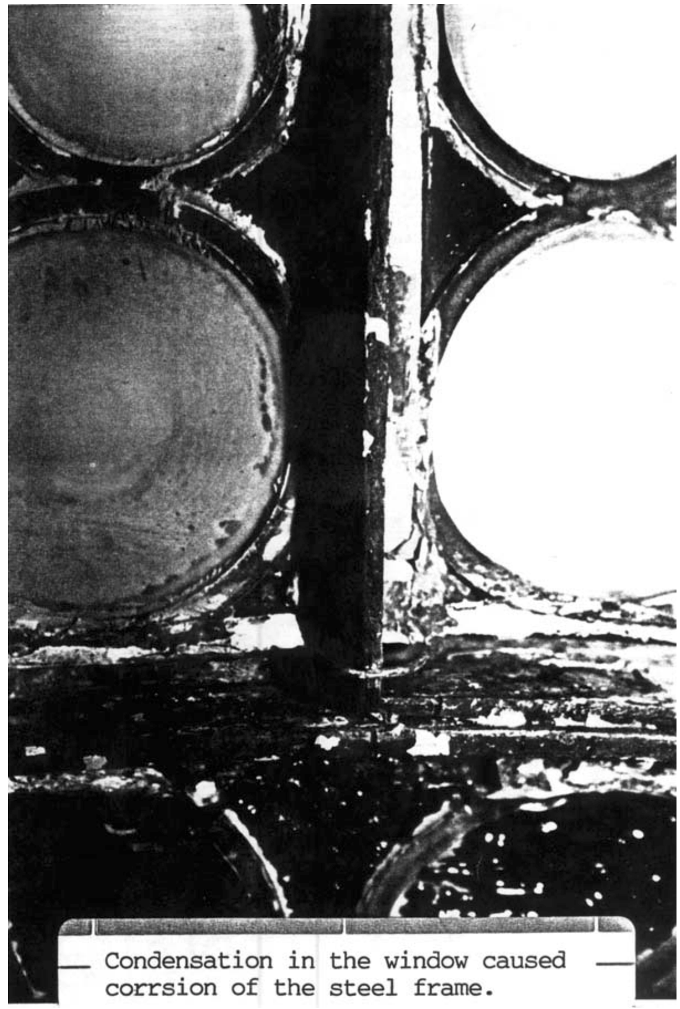
FINAL RESULTS:
[The existing PG was removed and the window will be totally restored.] Light, sound and temperature testing was not possible since the interior wall was not accessed until all of the PG had been removed. The art glass has been removed for restoration and will be reinstalled this spring for a contracted price of $48,500. Removal of the existing PG added about $2,000 to the project cost, while not reinstalling PG will save about $5,000. The church intends to backlight the window, possibly with neon, since it can no longer be viewed on the interior. This case study reveals that PG is used to defer restoration costs for even wealthy congregations who have other building priorities. It also clearly shows the importance of color and texture to a building's architecture -- which is lost when art glass is covered with PG **(see Case Study #4 photos).**



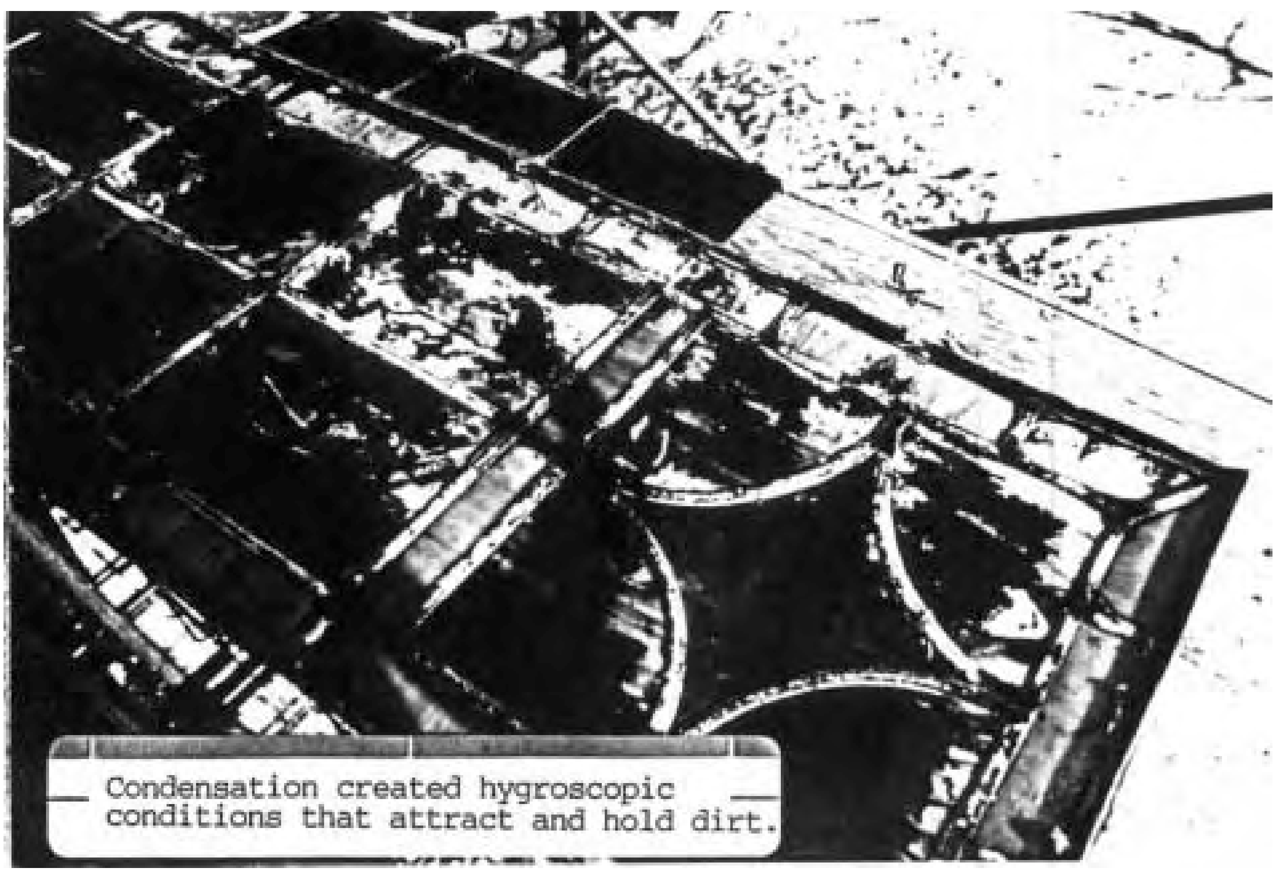
—Removal of the hazed PG revealed the --brightly colored class behind.



The edge of this PG sheet from under the framing shows hazing over 15 yrs.



Condensation in the window caused corrsion of the steel frame.



Condensation created hygroscopic conditions that attract and hold dirt.

PROTECTIVE GLAZING CASE STUDY #*5*

Holy Trinity Lutheran Church (1922), Chicago, Illinois

WINDOW: 1922 "catalog" opalescent art glass
WINDOW ORIENTATION: South, East & West
WINDOW VALUE: Low
VANDALISM/SECURITY: Moderate
YEAR PG WAS INSTALLED: 1980/1995
PG COST OF INSTALLATION: $3,800 (choir window)
PG SQUARE FOOTAGE: 160 (choir window)
PG COST PER SQUARE FOOT: $24
PG MATERIALS: Polycarbonate (1980), *Tuffex XL*® (1995) & aluminum channels

PG INSTALLATION REASONS: The church did not record why the PG was installed in 1980, but believes it was added to lower energy costs and protect the windows. The church had the PG replaced over the choir window in *1995* due to the badly yellowed PG (from 1980) with the intention of replacing all of the earlier PG. The contractor strongly promoted additional PG to "weather-seal" the window.

PG INSTALLATION METHOD: The 1980 PG was installed against the outer window frame and secured with screws and clear silicone. The PG was set about 4" away from the art glass. Aluminum subframing was used to divide the large sheets of plastic glazing horizontally. The 1995 PG was installed with screws and thin brown-anodized aluminum channels, and also caulked with clear silicone.

WINDOW CONDITIONS:

Most of the original sealants and glazing putty were exhausted. The leaded panels had minor deformation but are in fair condition overall. The window frames need painting and sealants and (as typical) there was considerable water damage to the wood sill where moisture could pond against the caulked PG. The 1980 PG had not been repaired since its installation and was still securely attached to the window frame, but had badly yellowed over the past 15 years. The 1995 PG over the south choir window was bowing and failing miserably after only two months.

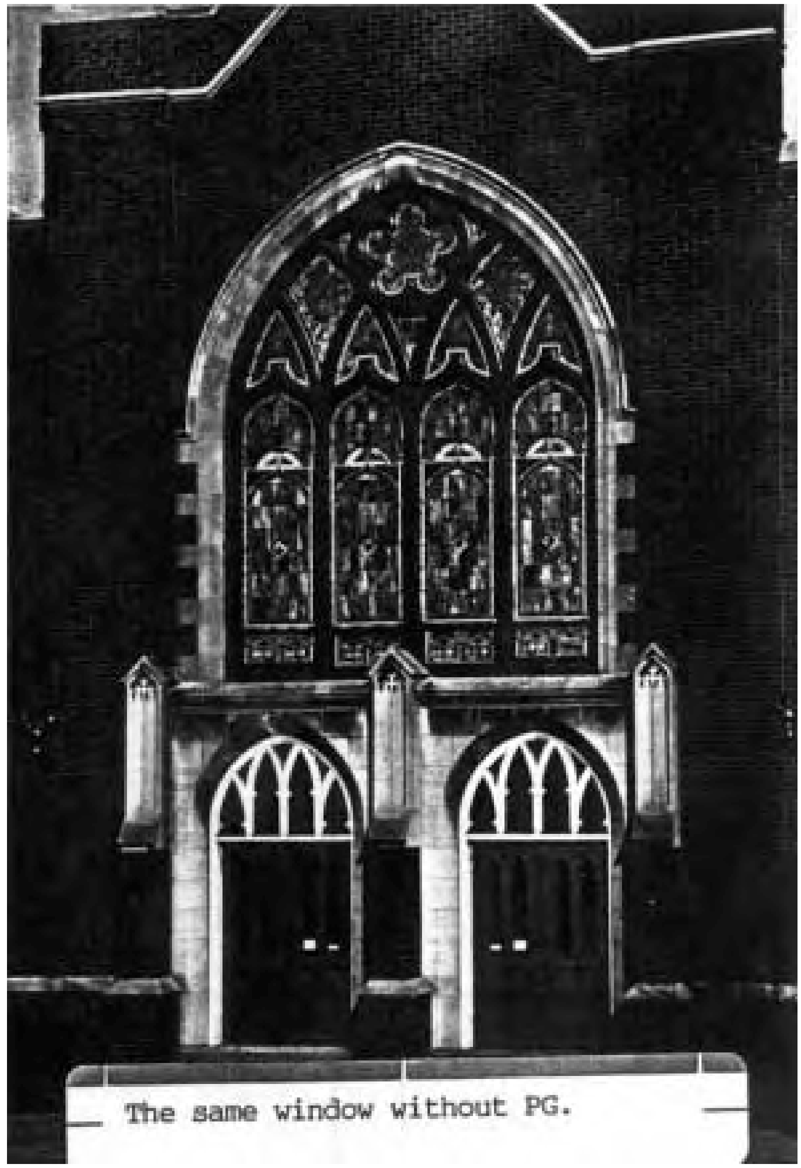
PG REMOVAL/ALTERATION REASONS:

Soon after the new PG was installed over the choir window in the spring of 1995, it began to bow badly. Based on recommendations from Inspired Partnerships, the church elected to remove all of the PG from the windows and refurbish the waterproofing, sealants and painted frames. The art glass is still in good condition and should not require total restoration for another 12 - 15 years. A contractor from the church removed all the remaining PG and caulked the windows for the cost of materials only. Minor art glass repairs are still needed and the church intends to refurbish the wood frames in the spring. The church is located in a relatively stable inner-city neighborhood near Wrigley Field in Chicago and has not had any security or vandalism problems to date.

FINAL RESULTS:

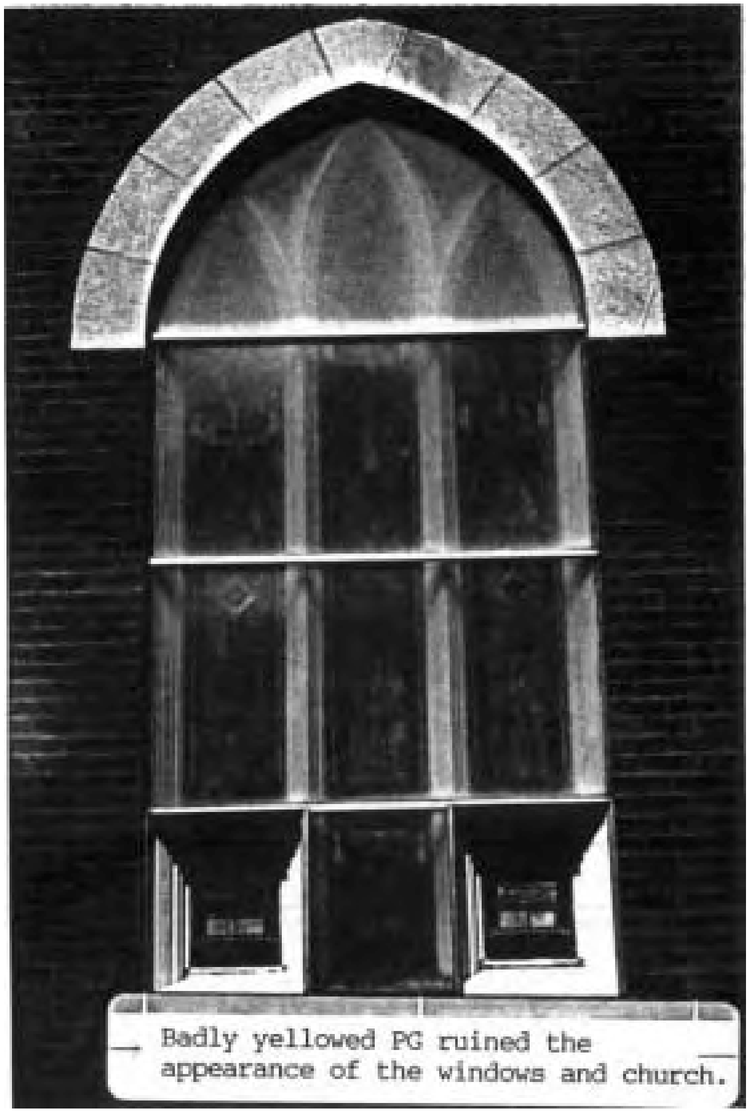
[The existing PG was removed.] Light, sound and temperature testing was not possible since the church did not notify Inspired Partnerships prior to removing the PG. The church had a few minor window leaks when the PG was first removed which have been corrected with new sealants. The church will save approximately $18,000 for not replacing all of the yellowed PG that was removed. This case study reveals that PG becomes an additional maintenance cost, in addition to window maintenance. Many glazing contractors are counting on a steady flow of business from plastic PG materials clouding over, prompting replacement. Churches that are not likely to have serious vandalism problems stand to benefit from removing the PG altogether and spending the money on window maintenance. Holy Trinity is yet another example of how opalescent glass adds color and architectural character to otherwise bland brick walls **(see Case Study #5 photos and CS in Appendix A).**

A 1995 PG installation was installed improperly and failed within months.

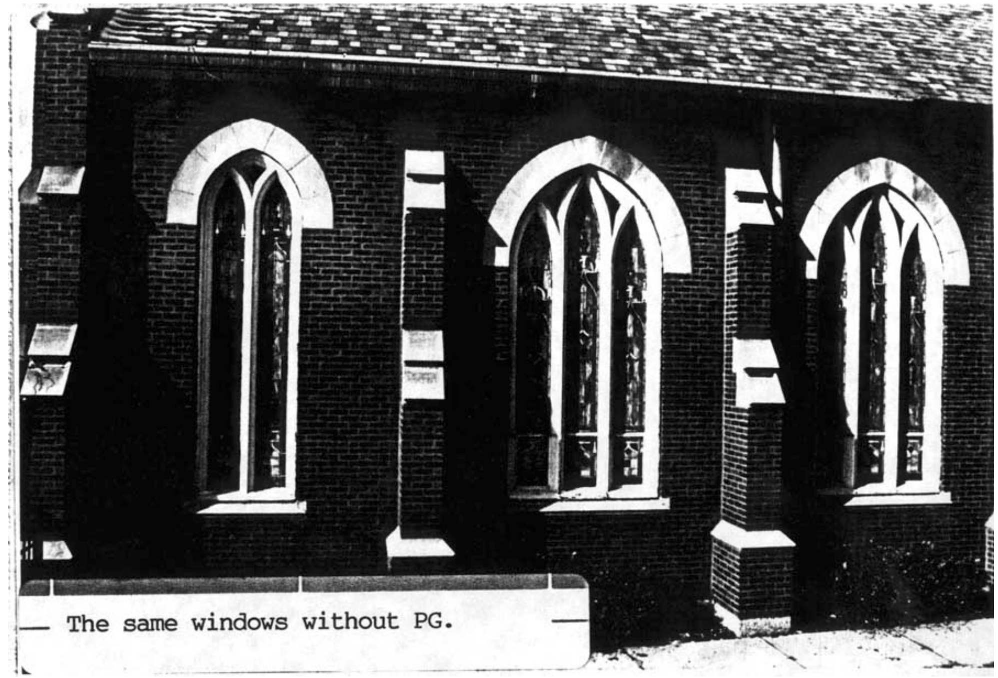


The same window without PG.

OPalescent art glass adds a lot of color & character to simple churches.



Badly yellowed PG ruined the appearance of the windows and church.



The same windows without PG.

PG typically causes condensation that gets trapped on the sill causing rot.

PROTECTIVE GLAZING CASE STUDY #6

Hyde Park Union Church (1906), Chicago, Illinois

WINDOW: 1995 rose stained glass window by Willet Studios
WINDOW ORIENTATION: East
WINDOW VALUE: High
VANDALISM/SECURITY RISK: Low
PG AGE: 1987
PG SQUARE FOOTAGE: 200 (rose window)
PG INSTALLATION COST: $1,960 (rose window)
PG COST PER SQUARE FOOT: $10
PG MATERIALS: *Lexan*® & aluminum

PG INSTALLATION REASONS: The PG was installed to "protect" the rose window as directed and paid for by a descendent of the original rose window stained glass donor.

PG INSTALLATION METHOD: The PG was installed against the outer window frame and secured with screws and clear silicone. The PG was set about 3" away from the stained glass. The large sheets of PG were divided up into 16 sections by a grid of aluminum channels.

WINDOW CONDITIONS:

The stained glass has been flattened and braced as recent as the 1980s and was in good condition overall. However, the original 1906 window frame was in seriously deteriorated condition. Upon removal of the PG, it was discovered that the contractor "repaired" the frame with fiberglass cloth, bondo, paint and caulk before installing the PG less than ten years ago. The wood frame laminations were rotting and separating, particularly from six o'clock to 9 o'clock (as typical). The PG was hazed and the framing was weak and buckling badly.

PG REMOVAL/ALTERATION REASONS:

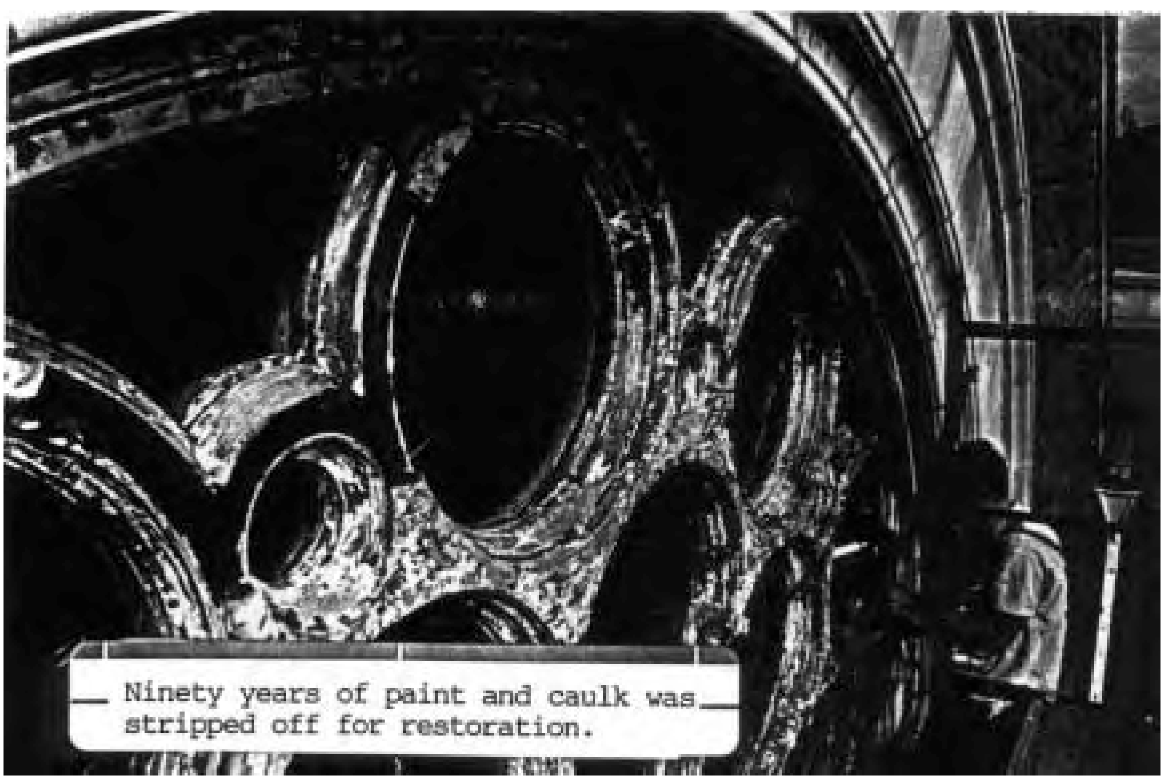
The PG was investigated to determine why it was failing and whether it was necessary. The church was concerned about liability and the loose PG falling and injuring someone. Upon further investigation, it became readily apparent that the entire rose window frame was weak and flexing within the stone surround. Water infiltration over the years and previous poor repairs had contributed to the separation of the wood laminations and rot. The entire PG was removed for a full evaluation and the church decided to have the stained glass removed to restore the wood window frame. The church believes the PG caused condensation and heat-build up that contributed to the deterioration of the wood frame. The church sets the sanctuary thermostat back and is also convinced that there is no significant energy savings from PG over the rose window. Finally, given the window's height (over 30 feet above grade), and the church location in Hyde Park near the University of Chicago, the vandalism risk was determined to be relatively low.

FINAL RESULTS:

[The existing PG was removed and the window will be totally restored.] Test results indicate that the increase in sound transmission is negligible; probably because the rose window is over 30 feet above street level. Daylight only increased about 8% through the relatively dark red, blue, purple and green stained glass. The surface temperature of the glass dropped 11°F within a few minutes after the PG was removed. The frame is partially restored and the stained glass has been reinstalled at the close of this study; the exterior frame will be restored in spring of 1996. The church does not intend to reinstall any PG which will save about $8,000 (if properly installed within the tracery). The total cost of restoration will be approximately $45,000. Hyde Park Union is an excellent example of how PG is too often used to defer badly needed restoration; the rose window was dangerously close to collapse prior to restoration **(see Case Study #6 photos and C4 in Appendix A).**

All the stained glass was removed

Prior to covering the window with PG the studio made repairs with bondo!

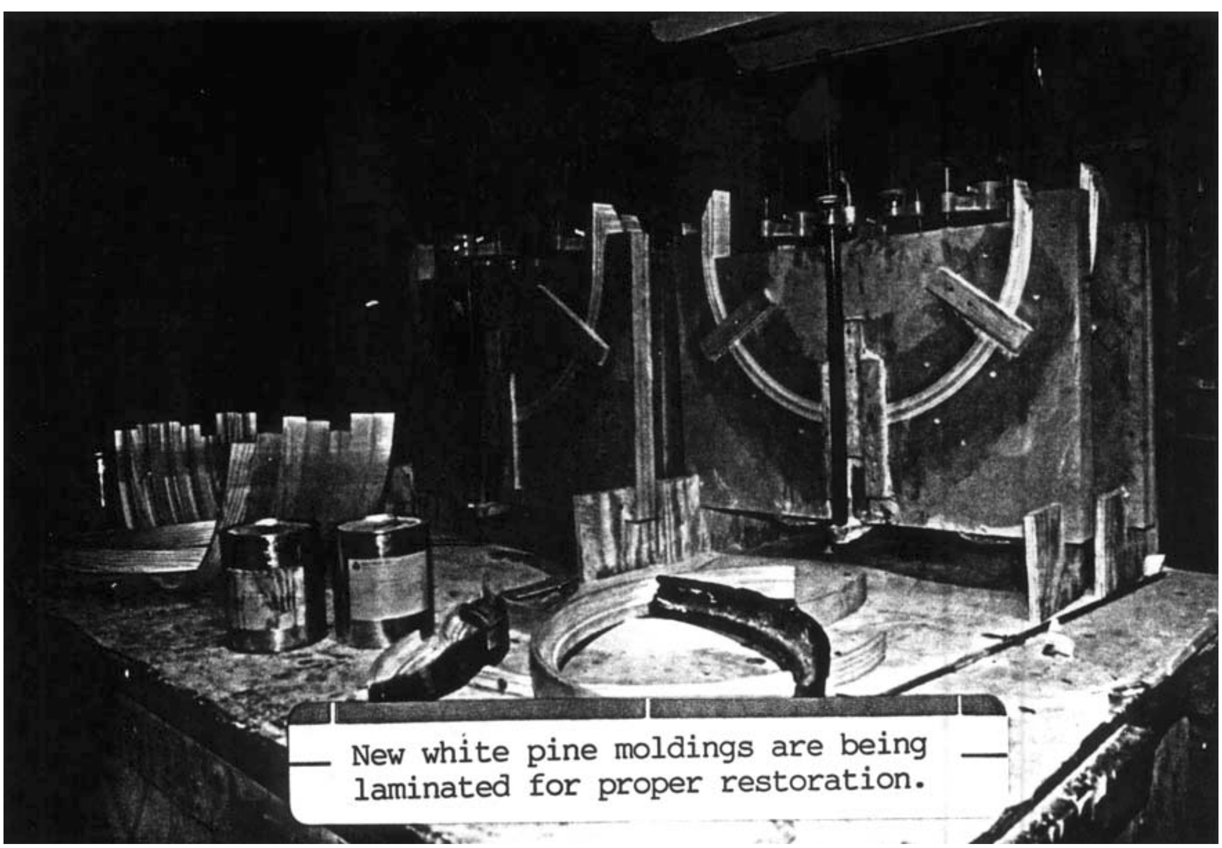


Ninety years of paint and caulk was stripped off for restoration.

CASE STUDY #6

The window flexed nearly 7" in the center from rotted, weak joinery.

Many sections of the rose window had rotted requiring replacment.



New white pine moldings are being laminated for proper restoration.

PROTECTIVE GLAZING CASE STUDY #7

Lake View Presbyterian Church (1888), Chicago, Illinois

WINDOW: 1888 "catalog" art glass
WINDOW ORIENTATION: South
WINDOW VALUE: Low
VANDALISM/SECURITY RISK: Moderate
YEAR PG WAS INSTALLED: 1970s
PG SQUARE FOOTAGE: 80
PG INSTALLATION COST: Unknown
PG COST PER SQUARE FOOT: Unknown
PG MATERIALS: *Lexan*® & aluminum moldings

PG INSTALLATION REASONS: The PG was presumably installed to "protect" the art glass, although the church cannot recall specific reasons.

PG INSTALLATION METHOD: The PG was installed about 2½" away from the stained glass and secured against the outer window frame with screws and clear silicone. It was divided into a six-section grid by aluminum moldings with snap-in beads. The interspace was not ventilated. PG was piggybacked onto upper ventilators.

WINDOW CONDITIONS:

The art glass has been repaired several times over the past 110 years, but has never been releaded. The case study window has folded along the bottom 1" border and all of the original putty and sealants for the window are exhausted. Upon removal of the PG, the outer face of the art glass was covered with dirt; probably caused by the hygroscopic attraction of condensation. In particular, it was observed that the glass jewels in the window had heavier concentrations of dirt on the top side. This indicated that dirt was settling without any air flow in the window. If the window had been ventilated, the updraft of warm rising air would theoretically caused heavier dirt deposits on the underside of the jewels. The wood frame was deteriorated, particularly the outer molding and sill.

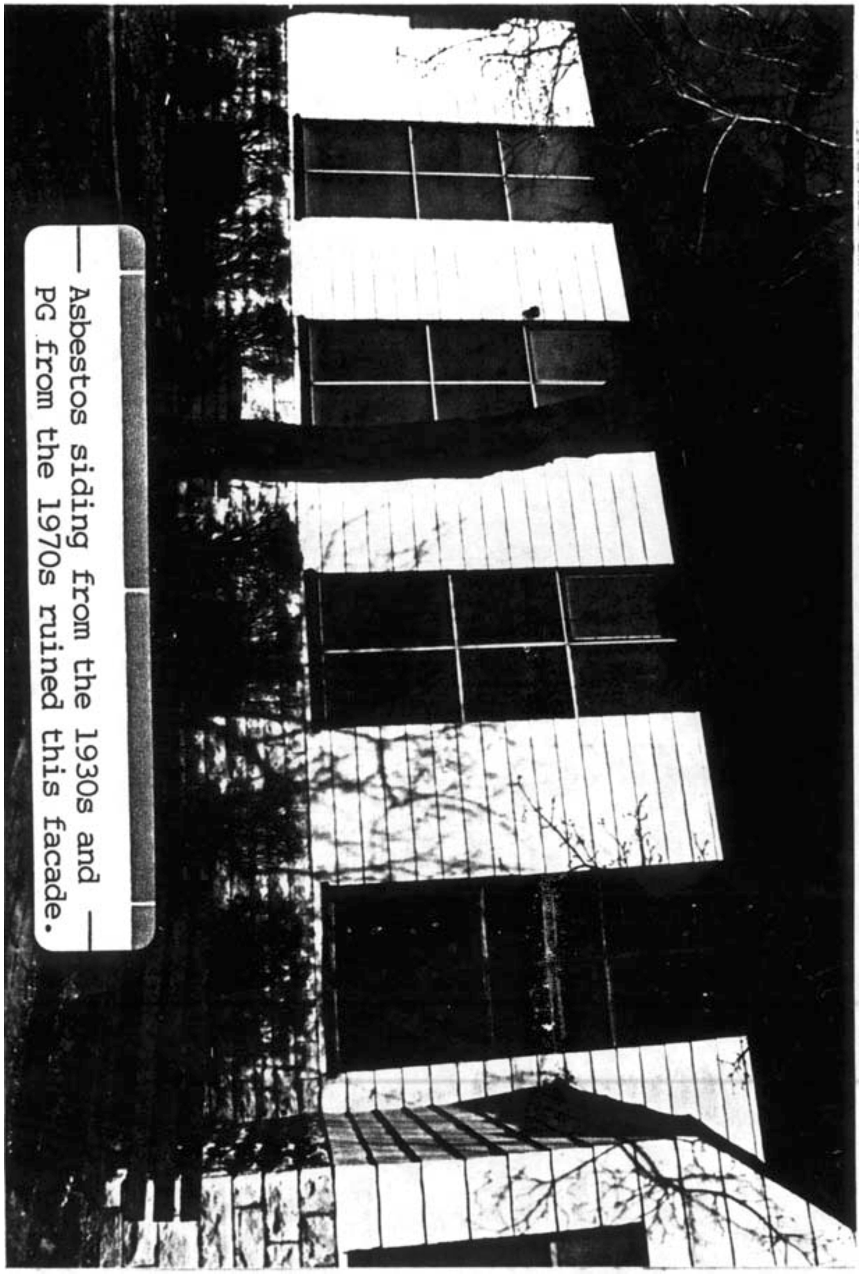
PG REMOVAL/ALTERATION REASONS:

This church was selected due to its historic and architectural value, which has been ruined by modern materials. Designed by Burnham & Root, the 1886 wood-shingle church once had a very quaint, rural character rarely found due to Chicago's revised fire codes by the early 20th century. However, composite siding and asphalt shingles added in the 1930s, and PG added in the 1970s, smothered the warm colors and delicate textures of the historic materials. The church wants to inspire a exterior restoration and removing the PG is a step in that direction.

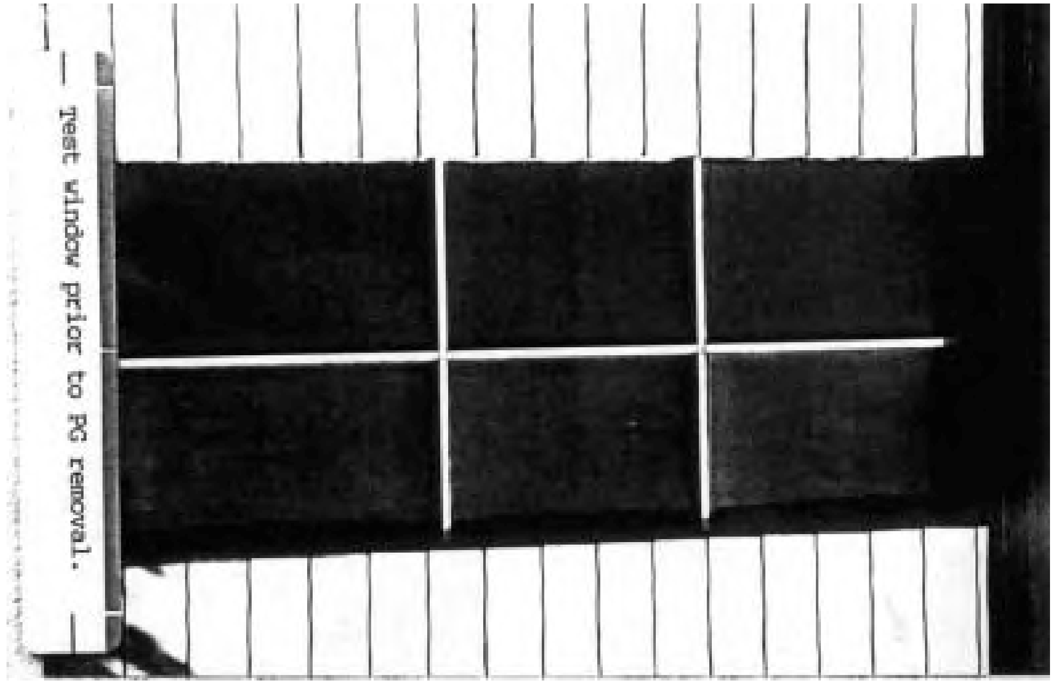
FINAL RESULTS:

[The existing PG was removed and the art glass was waterproofed.] Test results indicate that sound transmission only increased two decibels, despite the window's close proximity to a major Chicago thoroughfare with bus traffic. Daylight only increased one footcandle despite the badly hazed PG since the window was so dirty. Cleaning the outer surface of the art glass doubled the daylight through the window, and restored a *"luster and sparkle"* [to the art glass] *"not seen in years"* The surface temperature of the glass dropped 13°F within a few minutes after the PG was removed. The church hopes to continue PG removal soon, and strip off the composite siding in the next few years.
(see Case Study #7 photos and C8 in Appendix A).

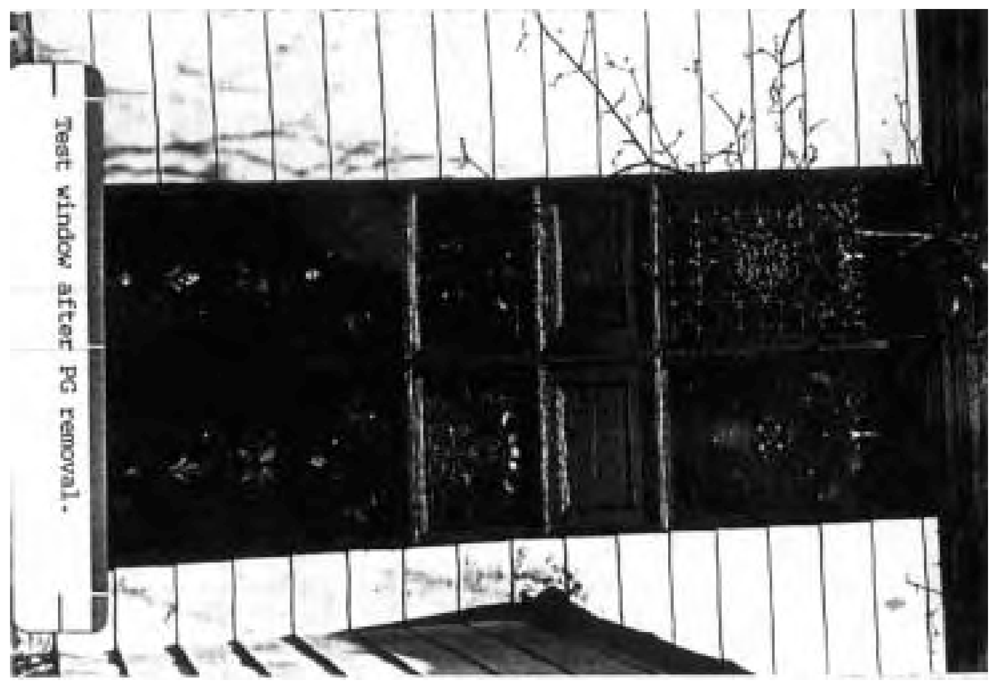
CASE STUDY #7



Asbestos siding from the 1930s and PG from the 1970s ruined this facade.



Test window prior to PG removal.



Test window after PG removal.

This view compares two windows with and without PG.

PG removal restored luster and sparkle not seen in years.

Test window after partial removal but prior to cleaning.

PG has been removed from the center lancet for maintenance and alteration.

Extremely valuable windows like this Tiffany generally call for PG.

Prior to removal the existing plastic unvented PG was causing condensation.

Levere Temple (1929), Evanston, Illinois

WINDOW: 1929 plated opalescent Tiffany
WINDOW ORIENTATION: East
WINDOW VALUE: Irreplaceable
VANDALISM/SECURITY RISK: Low
YEAR PG WAS INSTALLED: 1985
PG SQUARE FOOTAGE: 150
PG INSTALLATION COST: Unknown
PG COST PER SQUARE FOOT: Unknown
PG MATERIALS: *Lexan*® & aluminum t-bars

PG INSTALLATION REASONS: The PG was installed to "protect" the valuable plated opalescent glass and artistry of the renown Louis C. Tiffany Studios.

PG INSTALLATION METHOD: The PG was installed about 3/4" away from the stained glass and secured against the limestone with masonry anchors and latex caulk. The PG was subdivided into three sections in each lancet by aluminum t-bars that were keyed into the limestone. The interspace was not ventilated; however, the stained glass window is set into the opening with wood blocks which may allow some interior air/moisture into the interspace.

WINDOW CONDITIONS:

The stained glass remains in excellent condition at this time, even though the window has not been restored since its installation 67 years ago. These conditions are certainly attributable in part to the exceptional quality of Tiffany windows. The window shows no deformation and has remained generally waterproof. This was the only fully-plated window included among the ten case study windows.

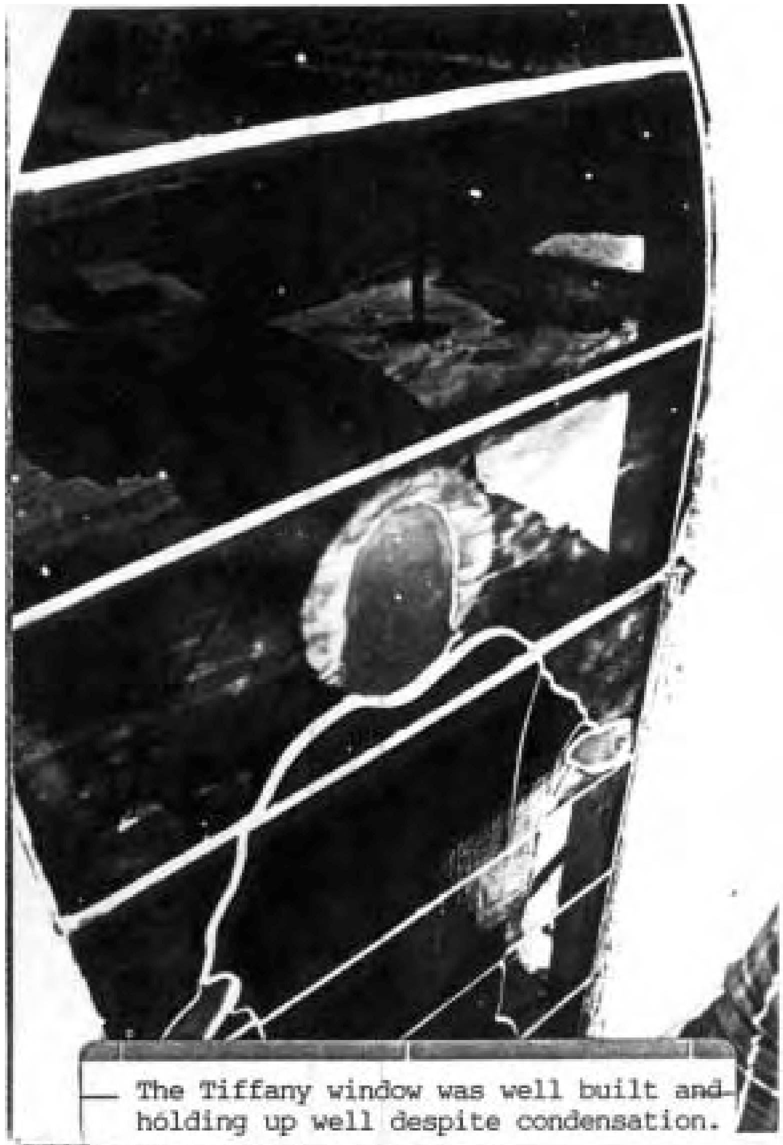
PG REMOVAL/ALTERATION REASONS:

The lexan, as typical, has clouded over, but the window was included in this study due to concerns over extreme condensation problems in the interspace observed on many clear mornings. Even though the window was in excellent condition, the PG has only been in place for a relatively short time and there was a prevailing concern to investigate the condition before any serious problems developed. Levere Temple is located in an upper income neighborhood and adjacent to Northwestern University. Nevertheless, the plated Tiffany window is extremely valuable necessitating protection from any possible vandalism or storm damage. The *Lexan*® was removed in December, 1995 from the center lancet only and replaced with '4" laminated glass that was set further away (1") from the stained glass. The two lower corners and apex of the lancet arch were cropped ¼" to allow for external air flow across the window.

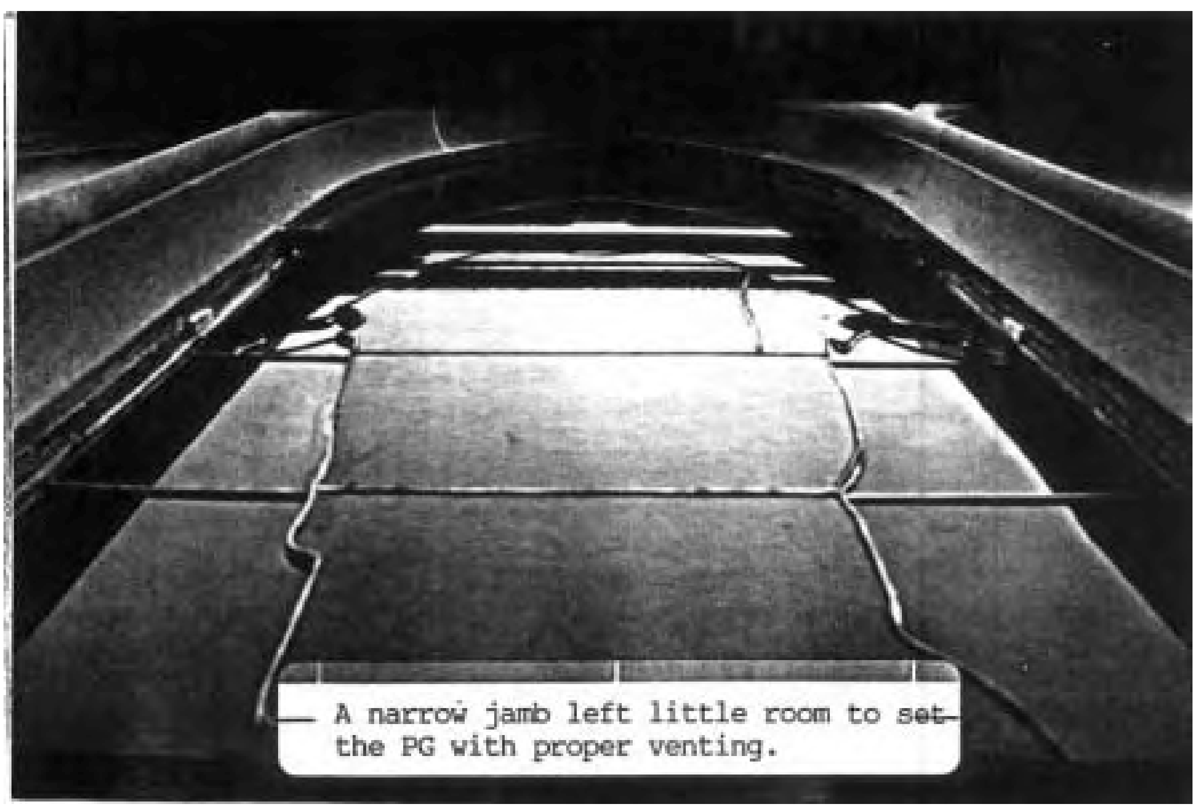
FINAL RESULTS:

[The existing PG was replaced with ¼" laminated glass and vented.] Test results indicate that sound transmission was unaffected through the heavily plated window. Daylight only increased one footcandle, also due to the numerous layers of opalescent glass in the plated window. The surface temperature of the glass only dropped a few degrees after the PG was removed. However, the laminated glass allows the window's intense colors to be seen from the outside as well. More importantly, <u>no condensation has been observed since the replacement with ventilated PG</u> **(see Case Study #8 photos and C7 in Appendix A).**

Sealants had been applied poorly on the existing PG.



The Tiffany window was well built and holding up well despite condensation.



A narrow jamb left little room to set the PG with proper venting.

PROTECTIVE GLAZING CASE STUDY #9

St. John United Church of Christ (1910), Evanston, Illinois

WINDOW: 1913 painted & opalescent glass
WINDOW ORIENTATION: South
WINDOW VALUE: Medium
VANDALISM/SECURITY RISK: Low
YEAR PG WAS INSTALLED: 1982
PG SQUARE FOOTAGE: 94
PG INSTALLATION COST: $1,974
PG COST PER SQUARE FOOT: $21
PG MATERIALS: *Lexan*® & wood moldings

PG INSTALLATION REASONS: The PG was apparently installed to prevent deterioration of the painted glass. The church could not afford total restoration of the windows.

PG INSTALLATION METHOD: The PG was installed about 5" away from the stained glass and secured against an outer wood stop with ½" wood moldings and clear silicone caulk. The interspace was not ventilated.

WINDOW CONDITIONS:

The painted glass, probably made in Chicago, was poorly fired and the paint is failing all around the lead came where the original waterproofing first failed. The window was resecured to the saddlebars in 1982 and there is only slight deformation around the borders at this time. The horizontal wood mullion is badly deteriorated from moisture ponding on the sill.

PG REMOVAL/ALTERATION REASONS:

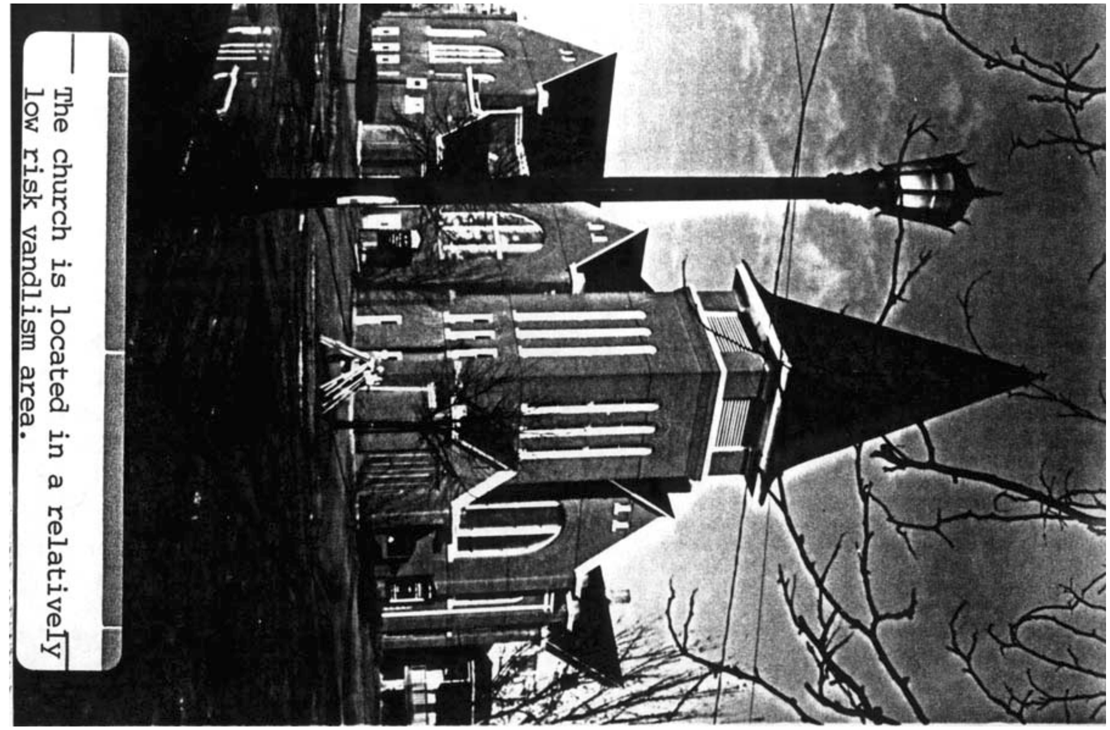
This window was included in the study to alleviate the deterioration of the painted glass which may be exacerbated by condensation from unvented PG. The window is one of two that were monitored by data loggers over a period of one year. The existing PG was vented twice, doubling the ventilation the second time, and the new PG was installed with vents to monitor the effect on the data loggers. New PG was required since the church cannot afford to restore the windows or properly waterproof the glass *in situ* to prevent the glass paints from deteriorating further. The *Lexan*® has clouded over and is an eyesore today. The church is located in a relatively low risk residential neighborhood of a Chicago suburb; however, the window was constructed with large pieces of painted glass that would be difficult to match. Therefore, the church elected to replace the plastic material with ¼" laminated glass.

FINAL RESULTS:

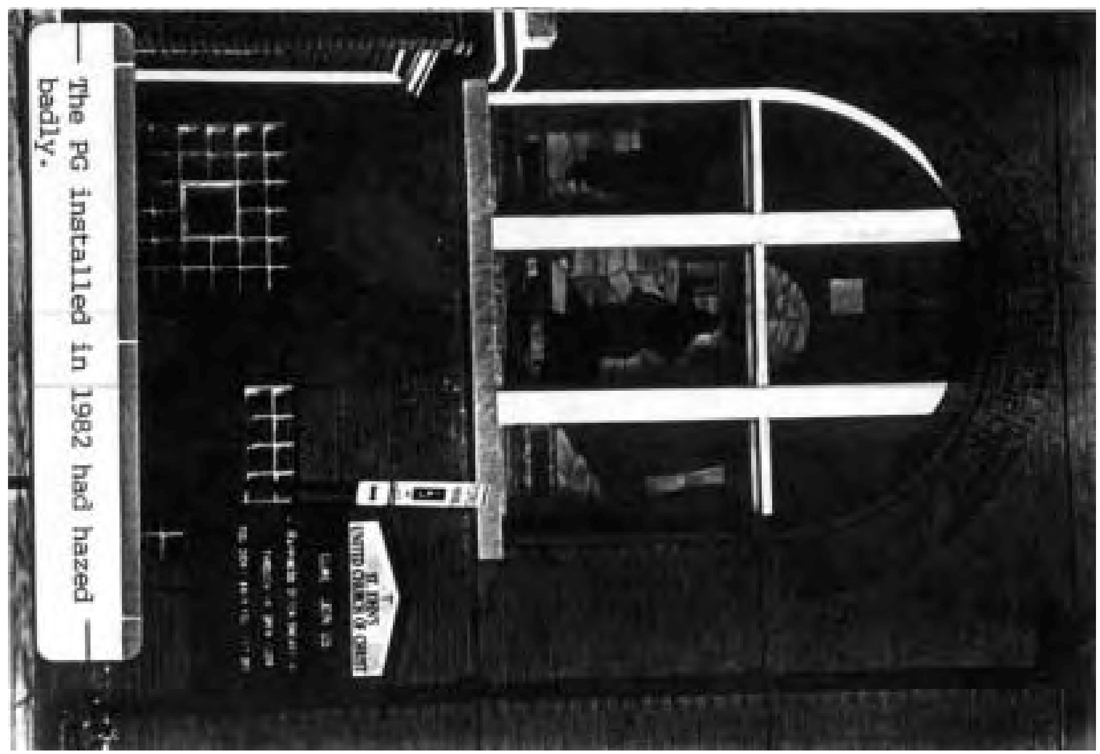
[The existing PG was removed, the frame repaired, and vented ¼" laminated glass was installed.] Test results indicate that sound transmission was unaffected while daylight doubled! The surface temperature of the glass only dropped a few degrees after the PG was removed. As with many of the other case study windows, removing the PG revealed serious deterioration of the window frame and the need for wood repairs. These rotting conditions would have eventually jeopardized the structural integrity of the frame and caused the window to collapse. Once again this proves that PG is a barrier to maintenance. The new laminated glass allows the window's opalescent colors to be seen from the outside as well **(see Case Study #9 photos and C3 in Appendix A).**

CASE STUDY #9

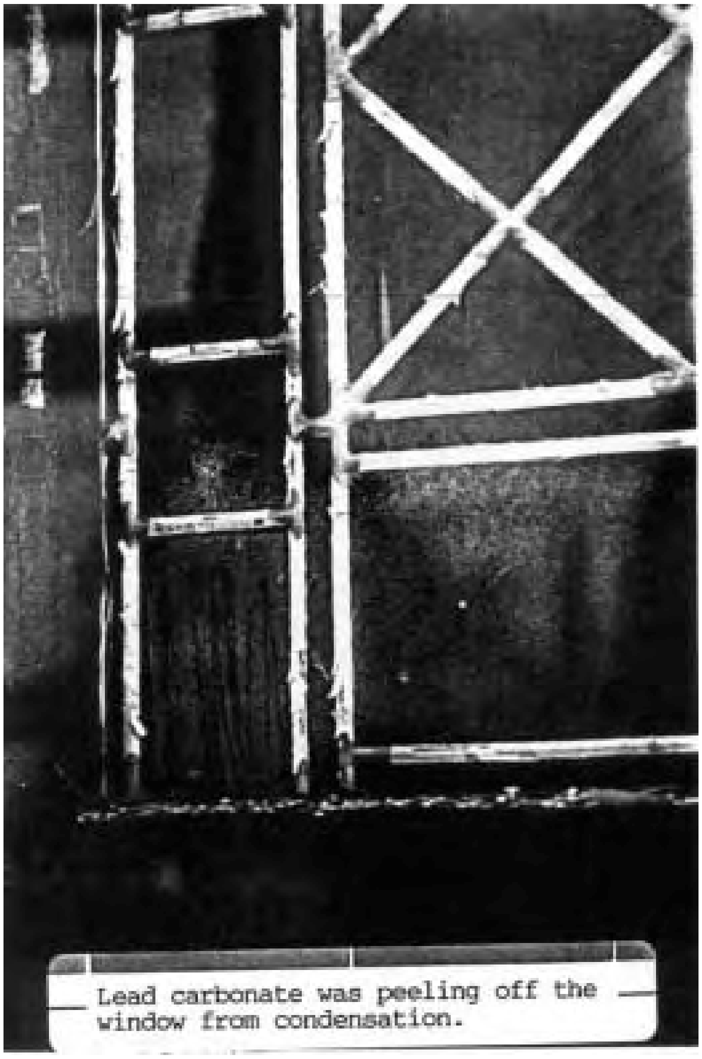
Condensation was occuring in the interspace causing the sill to rot.



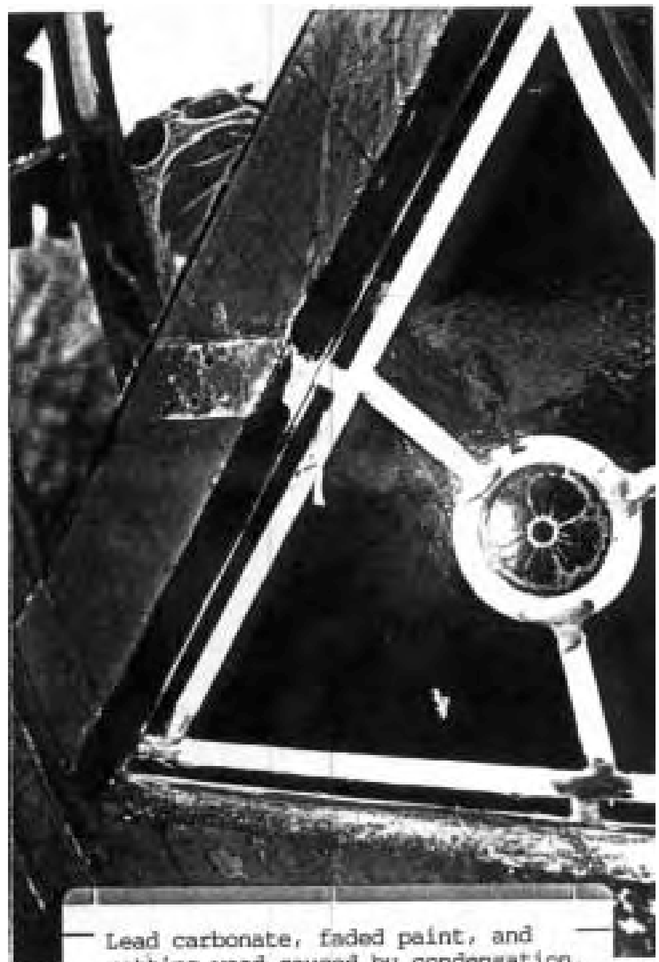
The church is located in a relatively low risk vandlism area.



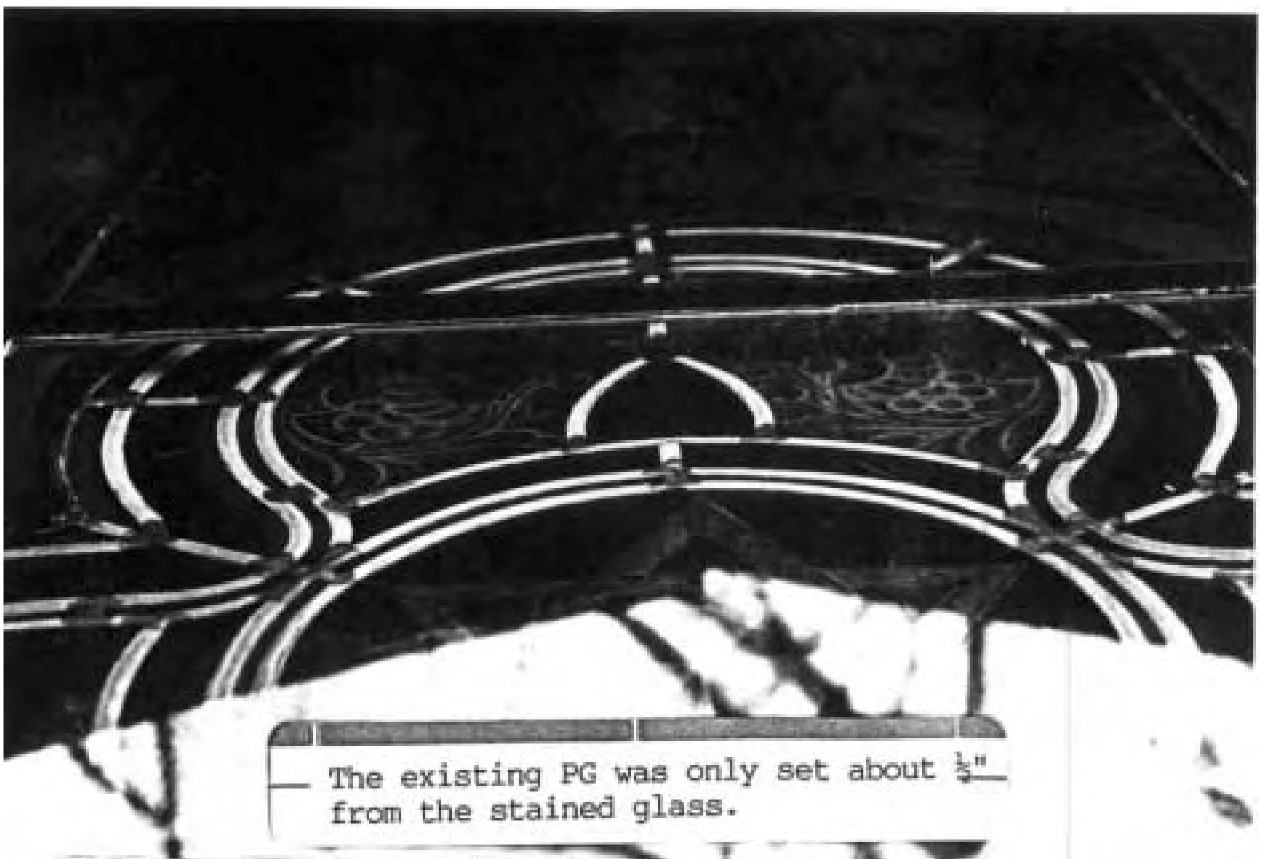
The PG installed in 1982 had hazed badly.



Lead carbonate was peeling off the window from condensation.



Lead carbonate, faded paint, and rotting wood caused by condensation.



The existing PG was only set about ½" from the stained glass.

"AFTER"

PHOTO

HERE

PHOTO OF

ROTTING WOOD

HERE

PROTECTIVE GLAZING CASE STUDY #10

Trinity Episcopal Church (1882), Wheaton, Illinois

WINDOW: 1882 painted antique glass; W.H. Wells Co. (Chicago)
WINDOW ORIENTATION: East
WINDOW VALUE: High
VANDALISM/SECURITY RISK: Low
YEAR PG WAS INSTALLED: 1974
PG SQUARE FOOTAGE: 160
PG INSTALLATION COST: Unknown
PG COST PER SQUARE FOOT: Unknown
PG MATERIALS: ¼" float glass & aluminum T-bars

PG INSTALLATION REASONS: The PG was reportedly installed for the general protection of the windows. The church undertook partial restoration of the east rose and arched window in 1974, at the time of the PG installation.

PG INSTALLATION METHOD: The PG was installed about ½" away from the stained glass and secured against the outer wood frame with points and caulk. The PG was also supported with aluminum T-bars; the T-bars lined up with the arched lancets in the Gothic arched window, but were set in a rectilinear grid over the curvilinear rose window and tracery. The T-bars were then screwed into the wood sash and window frame and the entire glazing was caulked. The interspace was not vented.

WINDOW CONDITIONS:

The painted glass, made in Chicago, was well fired and in excellent condition overall. However, the lead cames are deteriorating in a peculiar manner. The new leading from 1974 is peeling or delaminating in thin white sheets and thread-like fibers. This appears to be caused by the deterioration of Japan driers in the putty and applied coatings on the came, which is removing a surface layer of oxidized lead. This condition is likely caused by condensation in the unvented interspace; prevalent among similar window installations facing east. The wood sash and frame is also deteriorating from excess moisture in the interspace. It was not possible to renew the paint and sealants on this window without removing the PG. The glass PG has held up well and is in excellent condition.
PG REMOVAL/ALTERATION REASONS:

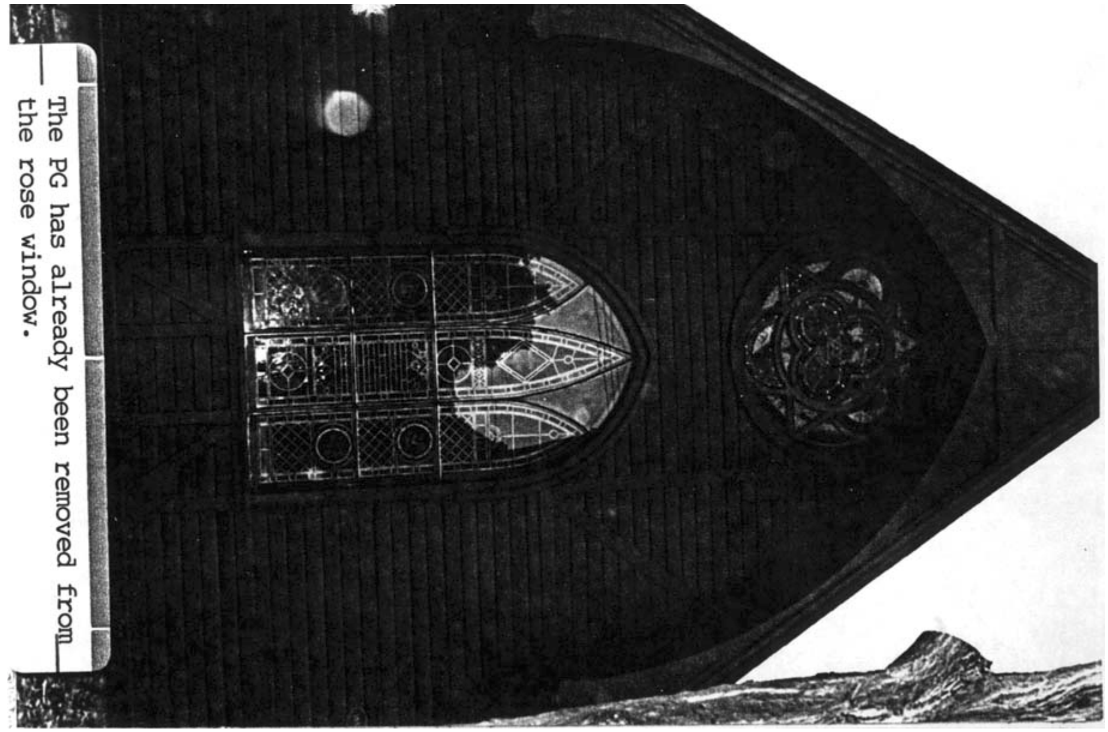
This window was included in the study to evaluate the oxidation of the lead cames. Only the new lead cames from 1974 are oxidizing while the original leading is so exhausted it could not be recemented. The church is preparing to restore the 1882 chapel and decided to address the unusual deterioration of the east windows. The PG grid which broke up the rose window tracery was undesirable and the church has elected to leave the PG off of the rose window after restoration. Although the church is located in a relatively low risk commercial area in terms of vandalism, there are security concerns. Therefore, the existing PG will be reinstalled on the lower arched window after the window has been cleaned and waterproofed. Methods of reinstalling the glass in a separate frame to perform ongoing maintenance will be evaluated and the re-installation will be vented.

FINAL RESULTS:

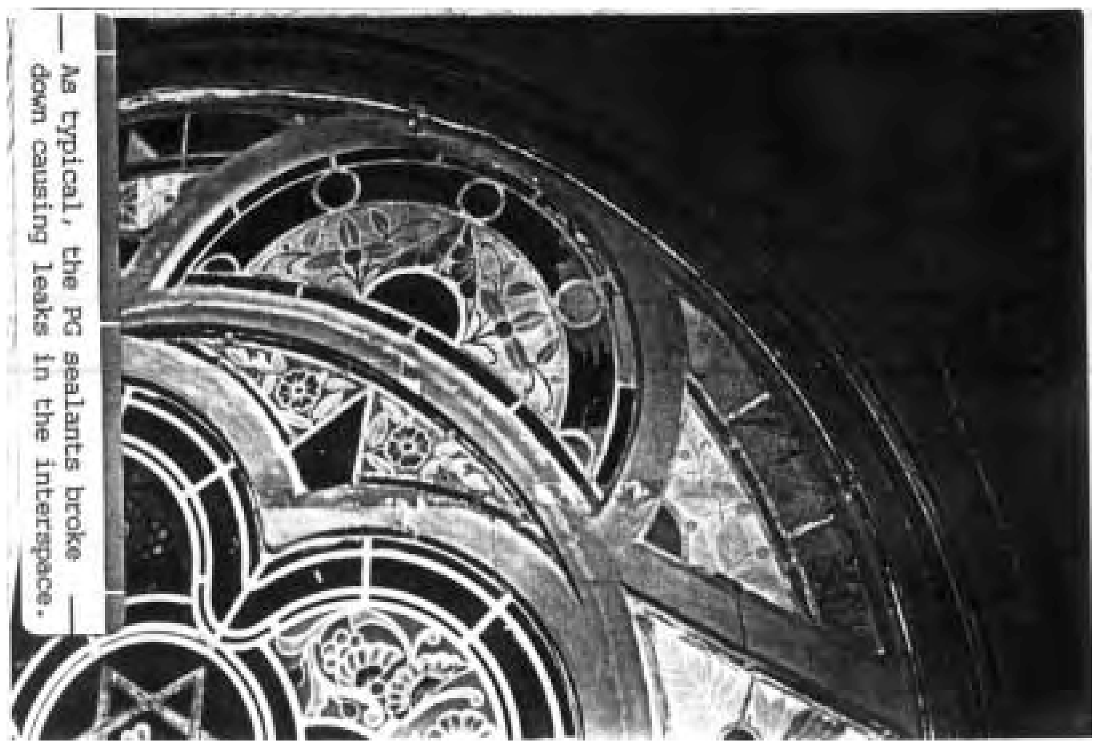
[The existing PG was **removed from the rose window which will be restored; the existing PG on the lower arched window will be reinstalled with venting].** Test results indicate that sound transmission increased a few decibels while daylight was unaffected by removal of the clear, clean glass. Overcast skies prevented any testing of the surface temperature of the glass. As with many of the other case study windows, removing the PG revealed more deterioration of the window <u>frame</u> then the stained glass. These rotting conditions would have eventually jeopardized the structural integrity of the frame and possibly caused the window to collapse. Once again this proves that <u>PG is a barrier to maintenance</u> **(see Case Study #10 photos and C25 in Appendix A).**

CASE STUDY #10

White lead carbonate from oxidation can be seen prior to cleaning.



The PG has already been removed from the rose window.



As typical, the PG sealants broke down causing leaks in the interspace.

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