energy-effective windows

NBS SPECIAL PUBLICATION 512

Proceedings of a joint DOE (ERDA)/NBS Conference/Round table on energy-effective windows

U.S. DEPARTMENT OF COMMERCE/NATIONAL BUREAU OF STANDARDS

The search for knowledge
on the design and engineering of windows
in the cause of energy conservation

NBS SP 512

energy-effective windows

Proceedings of a joint DOE (ERDA)/NBS Conference/Round Table
on energy-effective windows
held in Washington, D.C., on April 13th, 1977

U.S. DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary

Sidney Harman, Under Secretary
Jordan J. Baruch, Assistant
Secretary for Science and Technology

National Bureau of Standards
Ernest Ambler, Director

Issued April 1978

The editors were Robert E. Fischer and Walter F. Wagner Jr.
with design supervision by Jan V. White
The technical coordinator was Heinz R. Trechsel

For more information, contact:
Heinz R. Trechsel
Center for Building Technology
National Engineering Laboratory
National Bureau of Standards
Washington, D.C. 20234

Library of Congress Catalog Card Number: 78-600034

National Bureau of Standards Special Publication 512
Nat. Bur. Stand. (U.S.) Spec. Publ. 512, 53 pages (Apr. 1978)
CODEN: XNBSAV

For Sale by the Superintendent of Documents
U.S. Government Printing Office, Washington, D.C. 20402

Stock No. 003-003-01929-1 - Price $2.20

☆ U.S. GOVERNMENT PRINTING OFFICE : 1978O—2

Contents

1

Introduction

A look back toward early research into window design, a look at the reasons for and objectives of this Conference/Round Table, and a look forward toward better life cycle/cost benefit analyses in the development of truly energy-effective windows.

By Maxine Savitz
Director
Division of Buildings and Community Systems
Office of Conservation and Solar Applications
Department of Energy

Energy loss through windows is estimated at about five per cent of total U.S. energy use. But, under certain conditions, windows can act as solar collectors—gaining energy over-all, rather than losing it. Furthermore windows can contribute significant amounts of daylight for work situations. Therefore . . .

From the standpoint of energy conservation, research needs to develop information, data and strategies to reduce the energy-wasting aspects of windows, while improving the energy-gaining aspects —in other words, to optimize the solar radiation and light available through windows.

Windows also serve a number of functions that are intimately tied to the quality of the built environment—to the psychological as well as the physical well-being and comfort of building occupants. These factors need to be considered so that efforts to optimize windows for energy conservation do not lead to an unwarranted and possibly counterproductive reduction in the quality of buildings.

Windows mean different things to different people:

☐ To the architect, they are a design element that not only permits creation of interesting and pleasant interior spaces, but are basic requirements in the modulation of building exteriors;

☐ To the builder and contractor, they represent a substantial cost and one of the building elements that can be a source of complaints from irate clients;

☐ To the building owner, windows are an initial cost factor, possibly a source of complaints from tenants, but also a source of additional income—since the windowed exterior zone is more valuable as rental space than the interior;

☐ To the occupant, windows can be a source of light, sunshine, fresh air, and a view to the outdoors. But they can be a cause of fading carpets and upholstery, damaging water leaks, and unpleasant drafts during cold weather.

☐ Finally, to the window and glass industries, they are a source of profit; and for the working public, they are a source of jobs for factory workers, sales representatives and installers.

Research on the heat loss through windows goes back many years

Back in the 1920's, ASHVE, the forerunner of ASHRAE, conducted the first systematic testing series on the air-leakage performance of windows, with tests on different types of windows under different conditions. These tests generated data that could be used in the sizing of heating plants. In the 1950's and early '60's, ASHRAE conducted investigations on the effects of solar radiation and the influence of various devices such as double glazing, shades, and drapes on the performance of the window. Again, this research related to the thermal performance, hence the sizing and energy use of heating and cooling equipment; but it was now also concerned with the conscious utilization of techniques to counteract adverse effects of weather and sunlight.

Despite this considerable research in the 1950s and 1960s, the low cost of the energy needed to provide indoor comfort offered little incentive for designers and owners to consider trade-offs between windows and heating and cooling systems. And design decisions based on human response to windows—their size, location, and shape; and the utilization of blinds and drapes—were left mostly to the intuition of building designers.

But when the price of oil escalated, and with it the cost of heating and cooling buildings, the potentially negative aspects of windows became a cause for concern, and began to receive significant attention. Several studies conducted in the first half of the 1970's indicated that approximately 33 per cent of all energy consumed in the U.S. is used to heat, cool and light the nation's buildings and homes. Roughly 15 per cent of that amount can be attributed to conduction radiation and air leakage losses through windows. Thus if we consider windows just on the basis of their negative heat loss and heat gain aspects, one can see that they account for about five per cent of total U.S. energy consumption!

It was not surprising, then, that the immediate reaction to this statistical evidence was the suggestion—and in some quarters, demand—that steps be taken to drastically reduce the number and size of windows being used in buildings. This attitude conflicted sharply with contemporary design philosophy stressing light, transparent walls that stemmed from the development of modern, lightweight curtain walls.

While preliminary evidence indicated that windows *are* a primary source of energy losses, it took into account only the negative physical aspects of windows such as conductive losses (winter) and gain (summer), radiation losses (winter), and solar gain (summer). That this evidence formed only part of the story became apparent in the summer of 1974 when Dr. Samuel Berman (who spoke at the conference reported here) presented a paper at a special American Physical Society seminar at Princeton University —demonstrating that actually more energy is available through daytime sunlight (in winter, Northern Hemisphere) than is lost by nighttime radiation to the sky. It was largely the results of Berman's paper that led to a number of extensive research activities: one of these being the interdisciplinary project conducted at the National Bureau of Standards, and another—the DOE (ERDA)-sponsored activities at the Lawrence Berkeley Laboratories. The latter involves refinement of work presented in Berman's 1974 study, and research on new product development designed to improve the energy efficiency of windows.

With this background in mind, and in response to requests from industry for an opportunity both to hear the latest research results and to be able to comment on Federal activities . . .

DOE (ERDA) and NBS agreed to co-sponsor a Conference/Round Table on Energy-Effective Windows

It was held on April 13, 1977 in the board room of the American Institute of Architects in Washington, D.C., and was attended by 29 participants and 42 auditors listed at the end of this publication. These conferees represented a wide segment of industry, design professionals, academia, researchers, government program managers, Federal agencies, and technical and consumer publications.

Objectives of the Conference/Round Table were to:

☐ Define the technology available now.

☐ Describe the research underway and the anticipated availability of improved technologies, and . . .

☐ Learn the needs of designers and industry.

The conference portion of the meeting comprised four papers: by Dr. Belinda Collins of the National Bureau of Standards (page 8); Dr. Samuel Berman of Lawrence Berkeley Laboratory (page 16); Architect Harwood Taylor (page 22); and David Button, manager of the technical advisory service of Pilkington Brothers, a leading British glass manufacturer (page 28).

The conference is one of several held to continue the dialogue between the Federal government and the private sector in order to develop and implement the best methods for more efficient use of energy in the built environment.

2

An overview of window research at NBS

An examination of research into the window-design strategies for energy-effective windows, the usefulness of controlled daylight and heat transfer through windows, the effect on human behavior of windows, (or the lack of them), window-management studies, and the life-cycle costs involved with all of the trade-offs.

By Belinda Lowenhaupt Collins

Center for Building Technology
National Bureau of Standards

This paper will describe some results from an interdisciplinary project in window research that has been in existence at the National Bureau of Standards (NBS) for about two years. Begun under NBS funding in FY75, it has had continuing NBS support, as well as additional funding by the Department of Housing and Urban Development (HUD) and the Department of Energy (DOE), formerly the Energy Research and Development Administration (ERDA) as part of the Building Energy Performance Standards program.

The major goals of the NBS window research project include evaluation of the design, use, and consequence of windows in buildings, in terms of thermal effects, life-cycle costs, and psychological requirements. In addition, the development of trade-offs is a critical element, particularly in areas of conflicting functions such as daylighting and natural ventilation (see Figure 1). For example, an assessment of the energy consequences of daylighting must include the balance between the heat gains and losses through the window in all seasons, as well as the fuel consumption associated with electrical lighting and air conditioning. For natural ventilation, the energy losses due to uncontrolled air. infiltration around an operable window must be weighed against the benefits of fresh air through the same window. In addition, noise and security problems must be studied.

An interdisciplinary approach was chosen for the window research project because of the variety and complexity of the issues

- EVALUATION OF STATE-OF-THE-ART DATA ON WINDOW PERFORMANCE
- DEVELOPMENT OF TRADE-OFFS BETWEEN CONFLICTING FUNCTIONS:
  - DAYLIGHT / ARTIFICIAL LIGHT
  - VENTILATION / INFILTRATION
  - SOLAR HEAT GAIN / CONDUCTIVE HEAT LOSSES
  - PSYCHOLOGICAL REQUIREMENTS / ENERGY REQUIREMENTS

Figure 1. Research approach

DESIRABLE:	UNDESIRABLE:
SUNSHINE	HEAT GAIN / HEAT LOSS
DAYLIGHT	GLARE
VENTILATION	AIR INFILTRATION
EGRESS / INGRESS	BREAKAGE / INFILTRATION
VIEW OUT	LOSS OF PRIVACY
CONTACT WITH OUTSIDE	NOISE
PSYCHOLOGICAL WELL-BEING	

Figure 2. Window functions

DISCIPLINE	FOCUS
ARCHITECTURAL	DESIGN STRATEGIES
THERMAL ENGINEERING	HEAT TRANSFER
PSYCHOLOGY	USER NEEDS
ECONOMICS	LIFE CYCLE COSTS

Figure 3. Window research project

WINDOW DESIGN STRATEGIES:
- SITE VARIABLES
- EXTERNAL APPENDAGES
- FRAME CONSTRUCTION
- GLAZING MATERIALS
- INTERNAL ACCESSORIES
- INTERIOR TREATMENT

Figure 4. Window design strategies—architectural approach

involved and because these issues often reach across disciplinary boundaries (see Figure 2). As shown in Figure 3, researchers from four different disciplines, each with different areas of responsibility, participated. For example, the architect identified different window design strategies for conserving energy in buildings. The thermal engineer calculated the daylight levels and the heat losses and gains associated with selected window designs, while the economist determined the life-cycle costs for the same designs. Finally, the psychologist dealt with human requirements for windows, as well as with behavior toward window management devices.

In the course of this paper, I shall describe briefly some of the issues and findings in each of the areas of research—beginning with the architectural research area. This effort provided a focus for the project by developing a framework for subsequent research as well as delineating selected design strategies.

The architect, S. Robert Hastings, was responsible for the identification of window design strategies that could save energy[1]

Several strategies were later selected for more detailed analysis. Hastings identified six groups of strategies that affect the energy-related performance of a window: site, exterior appendages, frame, glazing, internal accessories, and interior treatment (see Figure 4). Under the strategies, Hastings summarized some of the effects of windbreaks, ground surfaces, shade trees, and orientation to the sun and wind. Advantages and disadvantages of each strategy were reviewed. Under exterior appendages, Hastings reviewed roll blinds, sun screens, architectural projections, exterior shutters and awnings. Characteristics of operation, size, aspect ratio, weatherstripping, and thermal breaks were dealt with as frame strategies. The fourth strategy involved the glazing material: film coatings, multiple glazing, heat absorbing glass, reflective glass, reduced glazing, glass block, and thru-glass ventilators. The fifth strategy included interior accessories such as roll shades, venetian blinds, draperies, film shades and insulating shutters. The final set of strategies dealt with interior strategies: interior colors, fixture circuitry, task lighting, automatic switching, and thermal mass.

Hastings' work is a presentation of many of the strategies that can be used to save energy. In later portions of this paper, I will describe quantification of selected strategies, including examples of site, frame, glazing, interior accessories, and building interior strategies.

Before turning to the quantification of selected design strategies, consider some of the reasons for the use of windows in buildings:

Why bother with windows at all? What effect do they have on people? What functions do they perform for people in buildings?

In other words, what are the psychological requirements for windows? This effort began with a survey of the literature to determine the research that had been done on human requirements and attitudes toward windows.[2] Briefly, this survey evaluated the research on the reaction to spaces with and without windows. Although a rather negative response occurred in spaces without windows, this negative reaction seemed to be tempered by the dynamic qualities of the space. For example, you may not notice that you are in an essentially windowless space because of the activity occurring in it. Similarly, the absence of windows is not particularly noticeable in a department store or theatre. On the other hand, in a small office or hospital room, the reaction to a room without windows was found to be quite unfavorable. In the second portion of the survey, the qualities of windows desired by people in buildings were discussed. These included view out, sunshine, daylight, and a sense of spaciousness. This review of the available research indicated a number of gaps in the knowledge of human needs and expectations from windows.

One of the first research questions that arose was that of window size. How large should a window be to satisfy the user? The British Building Research Establishment (BRE) conducted several scale modeling studies which indicated a minimum acceptable size of about 20 per cent of the window wall. With this research in mind . . .

The Center for Building Technology (CBT) of NBS began a survey of attitudes toward the windows at the General Services Administration (GSA) Manchester Building (Norris Cotton Building)

These windows are particularly interesting because on most floors they are only about 10 per cent of the external wall. On the second floor they are somewhat larger, occupying about 20 per cent of the external wall. In addition, there is tinted glass and dark venetian blinds in each window. A survey of occupant attitudes to the environmental conditions at the GSA building in Manchester (including the windows) is currently being administered by Jacqueline Elder.

Still another research approach (used at BRE) involves the use of scale models or simulations, in which window parameters such as size and shape can be easily varied. Scale models are small replicas of a room in which the area can be changed. Subjects are asked to respond to different window configurations according to a predetermined criterion such as "minimum acceptable window size" or "optimal size." In conjunction with the Manchester project, we have begun a simulation study that will attempt to identify and quantify user needs related to window size and shape.

Another important research area centers on the ways in which people use windows and window accessories

In this area, we conducted a limited study to determine some of the factors that influence the use of the venetian blinds in the windows of several low-rise office buildings at NBS.[3] Six buildings were involved in the study. Each had a facade that faces north and one that faces south—providing an excellent opportunity to assess the effects of building orientation upon window use. Briefly, we photographed the buildings several times a day for a week. Then we went in over the weekend and moved one-third of the blinds to the top of the window and one-third to the bottom of the window and closed the slats; the last third were left unchanged, to serve as a control group. We then took additional photographs during the next week to determine the response to our treatment. Again, photographs were taken several times a day. The study was repeated three times —in October, February, and July.

The results of this study indicated that people responded rapidly to the experimental treatment. By the end of the first day about 80 per cent of the blinds had been moved. Many of these were returned to the position that they were in before our treatment. We also found a highly significant relationship between building orientation and venetian blind use.

User behaviors that require further research include use of windows and window accessories for both window management and daylight. How do people use adjustable shading devices such as shades and blinds? How and when do they open and close windows? When do they use daylight instead of electric light? Marketplace behaviors are still another area that requires research. For example, does the presence or absence of windows influence buying and renting of space and by how much? Does the size or placement of windows influence these behaviors? What about view quality—do people pay more for a "good" view? Answers to questions such as these are needed for developing input on psychological factors to a cost-benefit analysis. In addition, research is needed on the effects of windows upon people in still other areas such as safety, fire egress, noise, pollution, and privacy. There are psychological costs and benefits associated with each of these areas.

Thus, the approach taken by the psychologists has involved identification of human requirements through an examination of previous research, and the development of attitude surveys, simulation studies, and user behavior studies. Ideally, this latter area will include research on the use of window accessories as well as of the windows themselves.

Now that we have discussed some of the psychological needs for windows, and some of the research methods used for investigating and quantifying these needs, let us turn to . . .

The next area of study: the thermal properties of windows

In view of the urgent need to conserve nonrenewable energy resources, detailed quantification of the thermal properties and functions of windows is critical. Are windows responsible for considerable energy waste? Or, if properly used, can they, as Dr. Berman has indiciated, actually save more energy than they "waste"?

In order to research such questions, Dr. Tamami Kusuda, a mechanical engineer, developed a computer model for studying a number of parameters associated with windows in some detail. This program enables one to compare the thermal consequences of varying window size, orientation, resistance, and shading coefficient for a window in either an office module or a residential module (see Figure 5). It calculates the thermal properties of a window in a single room (which is assumed to have no heat transfer through the interior walls, ceiling or floor). In a specific application of the computer model, window size was varied from 0 to 75 per cent of the window wall for offices and 0 to 40 per cent for residences. For both offices and residences, the effects of four different types of operation upon the thermal performance of the window were examined for the variables noted earlier.[4] These were: external loads only; external and internal loads; external loads,

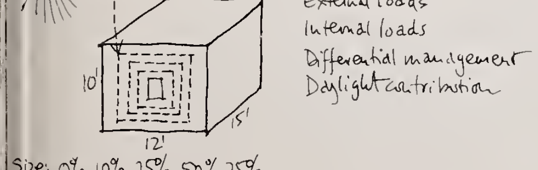

Figure 5. Effects of varying window parameters

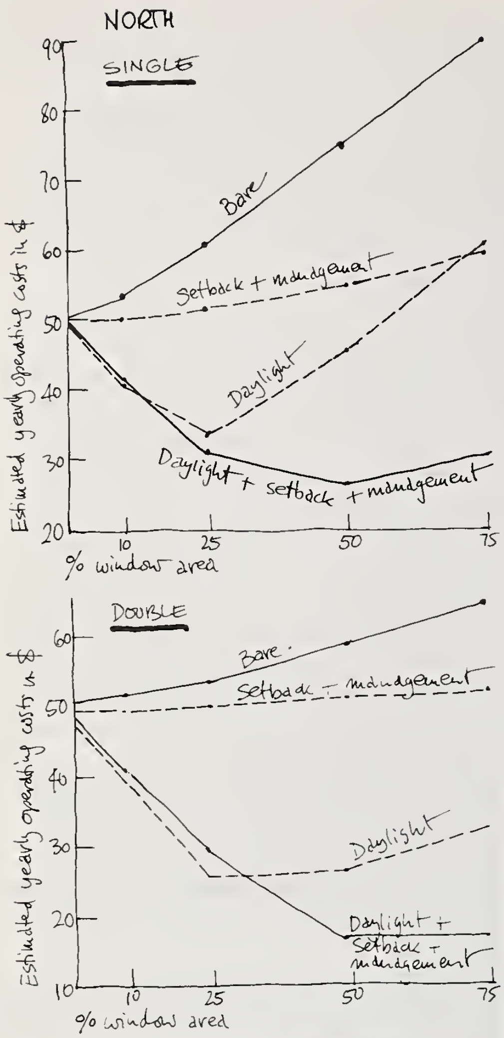

Figure 6. Effects of different types of operation on yearly energy costs (north orientation)

internal loads, and window management; external and internal loads, management, and daylight. Internal loads included loads generated by people, equipment, and lights, at a fixed rate of air leakage. Differential management was defined as the use of (wooden) thermal shutters during winter nights and venetian blinds during summer days. In the final type of operation daylight was substituted for electric light. Figures 6 and 7 present calculations for the four types of operation for north- and south-facing windows in a gas-heated, electrically-cooled office module. The top curve represents the effects of increasing window area upon estimated annual energy costs for both single and double glazing. As you can see, as window area increases so do energy costs, particularly for north-facing, single-glazed windows. Costs remain somewhat more level for south-facing double-glazed windows as shown in the second figure. The second set of curves in both figures demonstrates that selective window management causes estimated costs to remain about level with those for a solid wall for both north- and south-facing windows. The third pair of curves demonstrates that substituting daylight for artificial light lowers energy costs below those for a solid wall for some window areas. Finally, the last set of curves demonstrates that the lowest annual operating costs are obtained when both daylight and management are used, and that these occur for a window size of around 25 to 50 per cent of the window wall. (Life-cycle costs will be dealt with later in this paper.)

It should be pointed out that these results are tentative, based only upon a rather limited computer analysis, not upon physical measurements. The model assumes good management practices and proper utilization of daylight. Furthermore . . .

Experimental verification of the amount of daylight is essential along with actual measurement of the potential energy savings made possible through the use of daylight

We have begun a preliminary verification of some daylight predictions. The next graph presents some data obtained at NBS under several different sky conditions. As you can see, there is a fairly good agreement between the calculated and the observed data for the clear sky conditions (see Figure 8). You can also see, however, that there is a great deal more daylight on overcast days, and a great deal less on very cloudy days—indicating some of the problems involved with the accurate prediction and use of daylight.

Although these calculations are tentative and based upon a computer model, they do indicate some of the possibilities for saving energy by the careful design and operation of windows. Dr. Kusuda has also developed an hourly load computation program, NBSWD, that combines NBSLD (NBS Load Determination program), with the daylight routine used to generate these findings. Preliminary calculations from this program also indicate the possibility of saving energy through the use of daylight.

If nothing else, the computer calculations indicate the urgent need to verify the potential energy savings due to the use of daylighting and selective management. Although questions still remain about the extent to which people will use management devices and daylight, these calculations indicate the need first to develop devices that have energy conservation potential and second to inform homeowners and building operators of these possibilities.

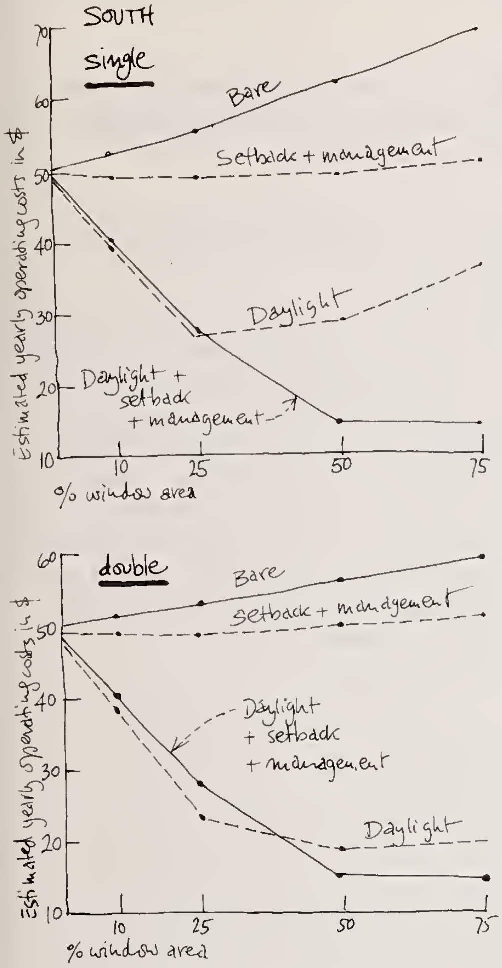

Figure 7. Effects of different types of operation on yearly energy costs (south orientation)

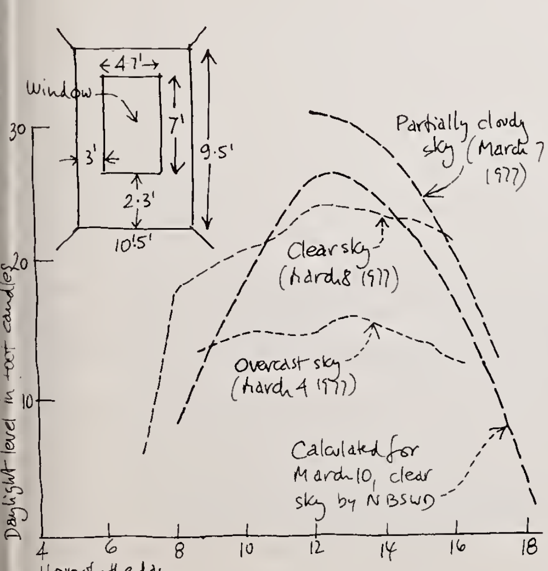

Figure 8. Measured vs. calculated daylight levels

In addition, the daylight calculations underline the importance of determining the amount of usable daylight and the potential savings in electric energy for lighting and cooling.

The economics portion of the project has included the development and application of a life-cycle cost model which includes the thermal model

The approach taken by Economists Rosalie Ruegg and Robert Chapman has been to balance the costs of windows against their benefits (see Figure 9). The easily quantifiable costs include: acquisition, maintenance, repair, and operation. Benefits include winter solar heat gain and daylight (as well as natural ventilation which we have not included in our model at this time.) Ideally, a comprehensive cost-benefit model would also include psychological costs such as loss of privacy, fear of falling, and benefits such as view out, light, spaciousness, and contact with the outside world. As yet, though, we have made little headway toward quantifying the psychological costs and benefits associated with windows.

A life-cycle cost model has, however, been developed which includes results from the thermal model. It compares the costs of windows and their accessories with those of a solid wall for a room over a twenty-five year lifetime. The economists have developed an interactive computer program which considers all window areas including zero window area for each orientation and determines:

1) the optimal window size and amount of glazing that will minimize life-cycle costs
2) the total savings/losses over a 25-year life cycle for that size
3) years to payback, and
4) minimum rate of fuel price escalation to just break even for different discount rates.

Selected application of the life-cycle cost model to a residential module in Washington, D.C., indicates that with only management, windows will increase life-cycle costs over the 25-year period.[5] (see Figure 10). (These calculations include the estimated annual energy costs for a residential module with both daylight and window management as calculated by Kusuda's model. See Figure 11.) With the addition of daylight, however, windows can save dollars in energy and life-cycle costs.

The economic life-cycle cost model has been run for both commercial and residential applications for nine different cities to assess the effect of different climates with five heating zones and four cooling zones.

In some instances a window will provide enough savings in energy to offset acquisition, maintenance, and repair costs. Thus, for a residential module in Washington, D.C., when daylight and management are used with single glazing on the south side there is a payback in four to five years.[6] Double glazing on the north side leads to payback in six to seven years for an 18-square-foot (12 per cent) window. When daylighting and management are used, all window sizes tend to have lower life-cycle costs than a comparable section of wall.

Note: These costs may be modified by less quantifiable psychological requirements. Thus, it may be possible to design and build an energy-efficient window that is not cost-effective, but which

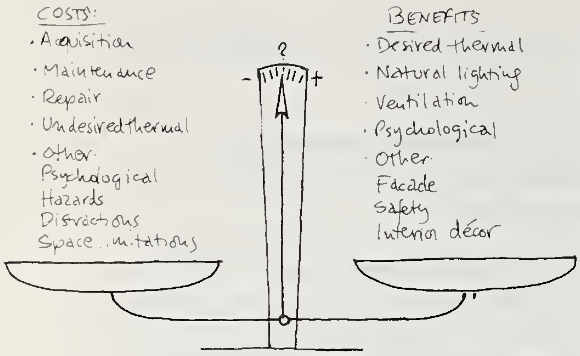

Figure 9. Economic cost/benefit evaluation

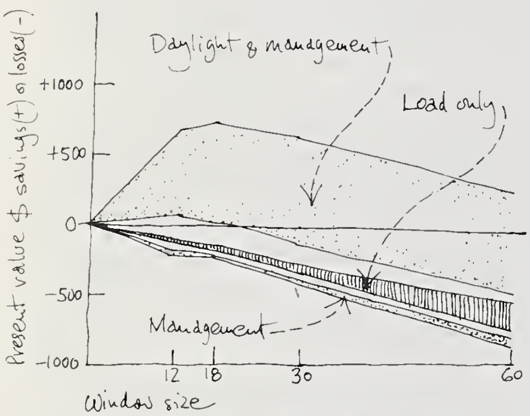

Figure 10. Savings or losses accruing to double-glazed windows over 25 years

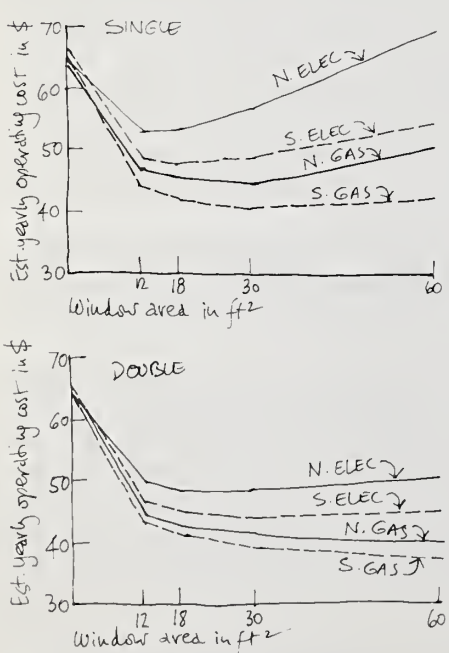

Figure 11. Annual energy costs for residential module with daylight and window management

provides a good view out or similar psychological benefit desired by the client. These benefits, however, should be weighed against the extra life-cycle costs of the window.

In conclusion:

The window project at NBS has begun the development of an integrated data base that considers thermal loads, daylight, human requirements, and life-cycle costs

We have identified elements of this data base, and developed computer models that compare both the thermal and life-cycle cost performance of different elements.

The project has pointed to the urgent need for further research in several areas of window performance. These include: 1) verification of the amount of daylight in existing buildings and determination of the potential energy savings associated with the use of daylight; 2) determination of the energy savings or costs through the use of natural ventilation with operable windows; 3) definition of user requirements and preferences for window size and shape in different building types; 4) investigation of patterns of use of windows and window accessories in different buildings; 5) development of a comprehensive cost-benefit analysis that weighs psychological, thermal and economic costs and benefits.

Bibliography

1. Hastings, S. R., and Crenshaw, R., *Window Design Strategies to Conserve Energy*. BSS 104, U.S. Department of Commerce, NBS, June 1977.
2. Collins, B. L., *Windows and People:* A literature survey. BSS 70, U.S. Department of Commerce, NBS, June 1975.
3. Rubin, A. I., Collins, B. L., and Tibbott, R. L., *Venetian Blind Use at NBS*. BSS in press.
4. Kusuda, T., and Collins, B. L., *Simplified Analysis of Thermal and Lighting Loads Associated with Windows: 2 Case Studies*. BSS 109, February 1978.
5. Ruegg, R. T., and Chapman, R., *An Economic Analysis of Windows*. NBS BSS in preparation.
6. Collins, B. L., Ruegg, R. T., Chapman, R., and Kusuda, T., *A New Look at Windows*. NBSIR 77-1388, January 1978.

3

DOE (ERDA)/LBL window research

A report on DOE (ERDA)/Lawrence Berkeley Laboratory research into 1) a wide spectrum of cost-effective window designs, 2) computational techniques that can quantify the results of alternate strategies, and 3) methods of management of windows by building occupants to maximize the benefits of good design.

By Samuel M. Berman

Program Leader, Energy Conservation for Windows and Lighting and Environmental Policy Analysis,

and Stephen E. Selkowitz

Technical Project Manager, Energy Efficient Windows and Lighting Systems Lawrence Berkeley Laboratory Berkeley, California

(Dr. Berman delivered the talk at the conference)

A surge of interest in designing energy efficient buildings has fueled a controversy over the proper role of windows in such buildings. Glass-sheathed skyscrapers are proclaimed by some to be energy efficient; while others promote minimal glazing or windowless buildings as true energy conserving design. In most buildings, windows do account for a disproportionate share of both peak HVAC loads and annual energy consumption. However, it is possible to minimize these adverse effects of windows, and in many instances demonstrate a net beneficial impact on energy consumption with the use of sensitive building design strategies, improved window products, and intelligent window management techniques. It is the intent of this research program to provide the necessary products and management options to allow the design professional to maximize the positive psychological and aesthetic impacts of windows within the context of an energy efficient building.

It has been estimated that 20 per cent of our nation's yearly energy production is consumed in the space conditioning of residential and commercial buildings (see Figure 1). Windows—because of their comparatively high thermal conductivity—permit heat losses and gains that account for 25 per cent of this yearly consumption, or an annual energy loss of 3.5 Quads, the equivalent of an average of 1.7 million barrels of oil per day. Because a large percentage of buildings in the U.S. use the simplest forms of windows—the single-glazed type—the potential for reducing these

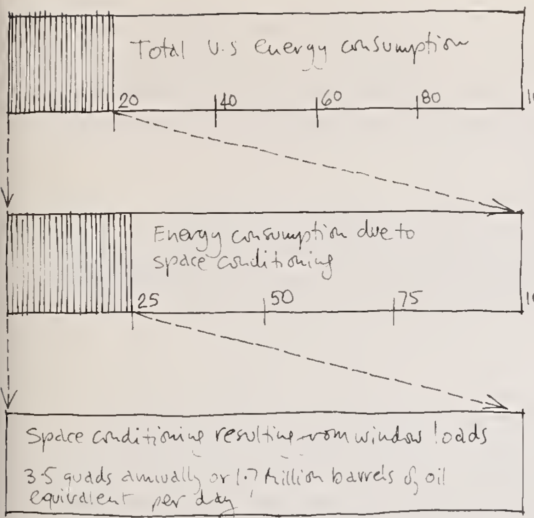

Figure 1. Energy consumption attributable to windows

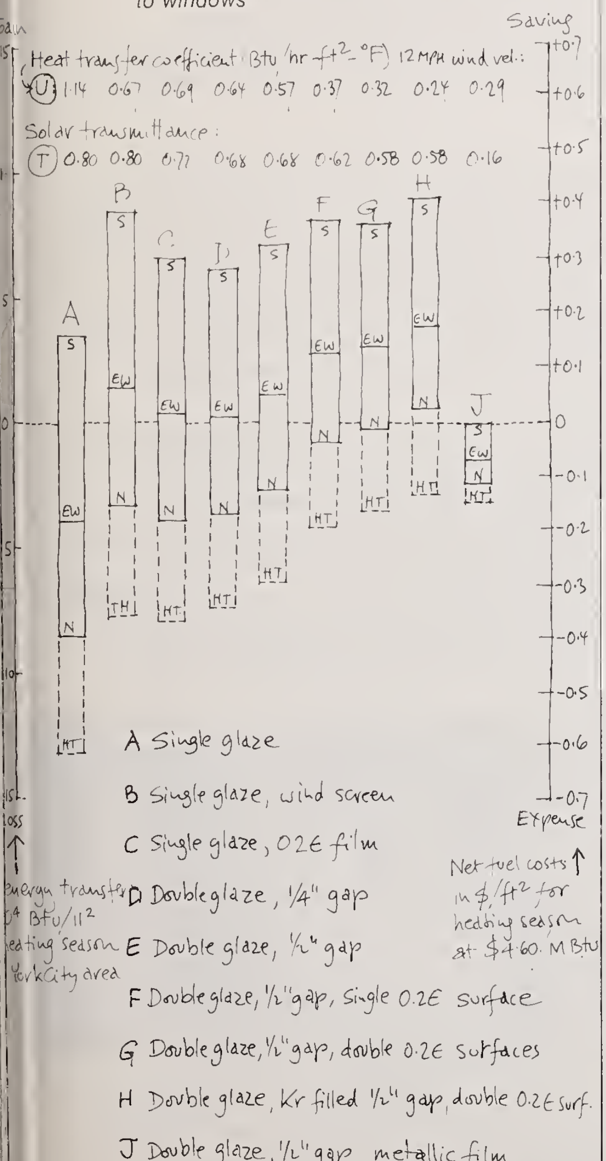

Figure 2. Effects of different window improvements on energy use and cost

heat losses and gains is very high. In the last few years, buildings designed to tight new energy performance specifications have demonstrated significant reductions in energy consumption based on intelligent use of existing products and design strategies. However, a large fraction of the total conservation potential has not yet been realized.

The DOE (ERDA)/LBL research program has as its goal a major reduction in the consumption of nonrenewable energy resources in buildings by optimizing the role and function of windows. To be successful in its entirety, it will require that: 1) a wide spectrum of cost-effective, new and existing energy efficient window products with desirable static and dynamic properties can be successfully developed and commercialized; 2) computational techniques, product data and well-developed building design strategies can be successfully merged in the hands of designers with other architectural programmatic directives and constraints; and 3) people who inhabit or work in the buildings so designed will successfully "manage" their immediate environment (i.e., pull shades, etc.) to the degree required to realize the projected energy savings.

To the extent that one or more of these premises is not fully realized, energy savings will fall short of their full potential but will still remain substantial in magnitude.

To assess priorities in more detail, the Windows Program has been divided into three major issue areas:

Issue 1. Windows as architectural components

Window units may be examined as isolated architectural components to study design features and thermal properties which will impact energy consumption:

A. Materials for improved thermal and radiant control. In the last 25 years, the choice of glazing materials for use in window units has been significantly expanded. A wide variety of tinted, reflective and insulated glazed units is available for specification by the architect. Additional development is recommended to expand the range of properties available with glazing units and to add capabilities of passive and/or active response of glass to changing environmental conditions. This will include alteration or modulation of transmission and absorption properties at a mechanical or molecular level. Other possibilities exist for improving the thermal performance of windows by reducing conductive and convective heat transfer. Increased energy efficiency can be achieved in this area for both new and retrofit applications. See Figure 2.

B. Window management control devices and strategies. Shading devices, both movable and static, are well-known elements for control of unwanted heat gains. Designers need to be made aware of the potential of external shading devices and need other methodologies and design tools to facilitate their use. Windows and window elements that function as dynamic mechanisms with either automatic or manual control and operation can be effectively utilized to manage incoming short-wave solar radiation, outgoing long-wave radiation, and conductive and convective heat losses and gains. See Figure 3.

C. Natural ventilation and infiltration. Undesired air infiltration through operable windows often results in large heating and cooling

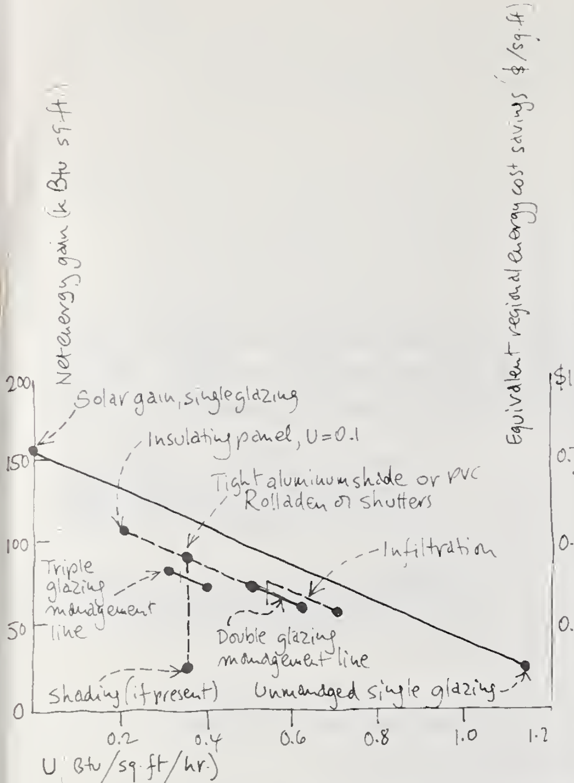

Figure 3. Heating season window management diagram fòr south-facing windows in New York City. (Energy gain is for entire heating season)

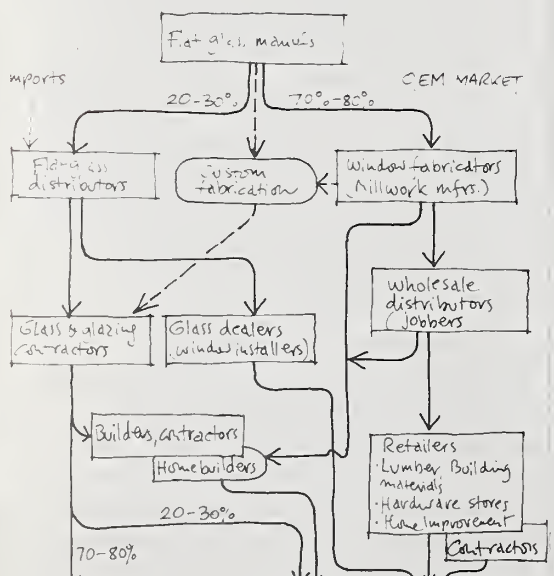

Figure 4. Structure of window and window glass industry

loads. However, trends in the use of sealed windows create a total dependence on building mechanical systems for climate control. Significant opportunities exist for the utilization of natural ventilation to reduce cooling loads. Additional analytical design work must be performed before the potential savings can be realized.

Issue 2. Integrated windows in an architectural context

Windows can be studied as isolated hardware components, but their role as energy consumers is related to their function as an integrated architectural element in a room, and as a component of the entire building.

A. Windows as room elements. Guidelines for the design of optimized window systems must be developed over a range of key parameters such as latitude, climate, orientation and building type. Recommendations for window type, size, placement and management will be derived. Optimization for combined thermal and illumination energy use may produce results which run counter to present conservation axioms which stress thermal performance only. Windows act as passive solar collector elements, and the relationship of window area, control of passive gains and room heat capacity deserves additional study.

B. Windows as building elements. The impact of windows on both peak heating and cooling loads and annual energy consumption for space heating and cooling must be assessed at the level of building operation. Instantaneous heat flux through a window may either offset a heating load or aggravate a cooling load, depending upon other building variables. Windows are key contributors to peak load conditions which are determinants of HVAC equipment size and cost.

A variety of design considerations and window parameters do not directly impact energy consumption but rather indirectly affect the acceptance of any new window product and therefore its successful use in a building. These include health and safety factors, physical integrity to wind and water, ease of maintenance and cleaning, and aesthetic and psychological factors. Any novel window design or components must provide acceptable performance with respect to these criteria, as well as conserving energy.

Issue 3. Data base

A qualitative and quantitative understanding of the glazing and window industry and the various end-use markets is essential to assist program management functions and to provide data for specific research projects.

A. Window system inventory. Data on the distribution of existing window designs and installed square footage as a function of building type, climatic zone and other relevent variables is essential to a better understanding of the chances of success of window retrofit options and estimations of window energy consumption.

B. Market data. Historical sales data can be merged with inventory data to assist in generating a current model of the impact of windows on building energy utilization. An understanding of the marketing structure of the industry and the key actors will be developed to assist commercialization efforts. See Figure 4.

C. Impact assessment. The energy and power impacts of

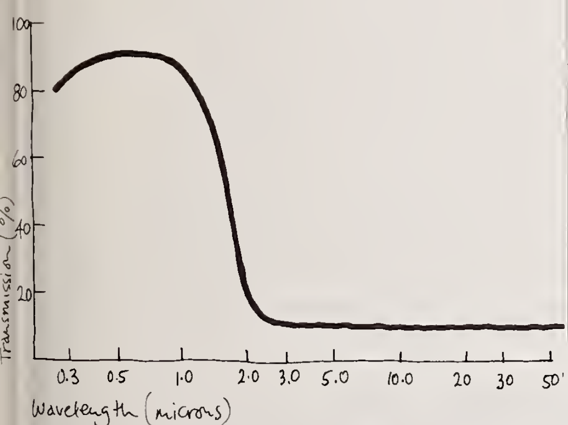

Figure 5. Measured transmission spectrum of heat mirror on mylar

Figure 6. Sun shedder window under development by Lawrence Berkeley Laboratory. (Contains a gel that clouds up when exposed to sun's rays, blocking summer sun. In winter sun passes through and thin film layer prevents reradiation of heat to outdoors)

various commercialization strategies, implementation scenarios, new products, and other research efforts will be determined with the use of models developed under this task.

A major study of windows and window management is under way as part of DOE's energy conservation research

The Consumer Products and Technology Branch activity is a major thrust of the Division of Buildings and Community Systems program in DOE, and includes research, development and demonstration activities in energy conservation that

- ☐ Accelerate the efforts of private industry
- ☐ Complement the efforts of private industry
- ☐ Foster the acceptance of energy saving technology
- ☐ Maximize the effectiveness of energy use
- ☐ Minimize adverse socio-economic and environmental impacts

The CPT Branch has established a decentralized management plan in several areas of its over-all program. The Lawrence Berkeley Laboratory (LBL) has been given the responsibility to plan and manage the DOE conservation activities in the area of Windows and Lighting Systems.

The majority of research dollars will be allocated to subcontractors in the private sector. However, LBL will continue to play an important and visible role. In order to function effectively in program planning, technical management and proposal review, it is essential that LBL have a concurrent in-house research program to demonstrate expertise and credibility to the private sector. LBL must also engage in certain research oriented background activities; that is, act as a clearinghouse and information center; organize meetings and conferences; serve a variety of troubleshooting functions; act as a catalyst to bring together diverse private sector actors; serve as a liaison to energy standards activities, solar reseach programs and related building sector energy conservation activities; and so on. There are additional activities which may occur in-house or be supported outside LBL, but which are designed to provide data that are vital to LBL's mandate to plan and direct the over-all research program: marketing studies; industry organization profiles; consumer attitudes; barriers and incentives to acceptance; cost/benefit studies; impact assessment studies; analytical and testing capabilities; etc.

The following projects are presently in progress or being negotiated:

Window analysis—computer codes

As part of our work to develop new window management options and determine optimal window design and size, we have begun development of a set of analytical tools to assess window performance. These will be useful both as design tools to analyze modes of heat transfer, etc., and as an assessment tool to predict conservation savings at various levels of market penetration.

Every promoter of a new window product or design makes claims concerning the potential impact of their device on energy consumption. These are based on their own choice of estimates

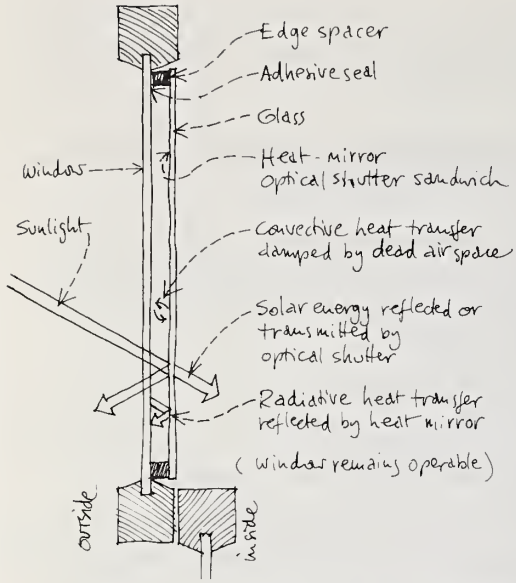

Figure 7. Proposed construction of window with optical shutter and heat mirror

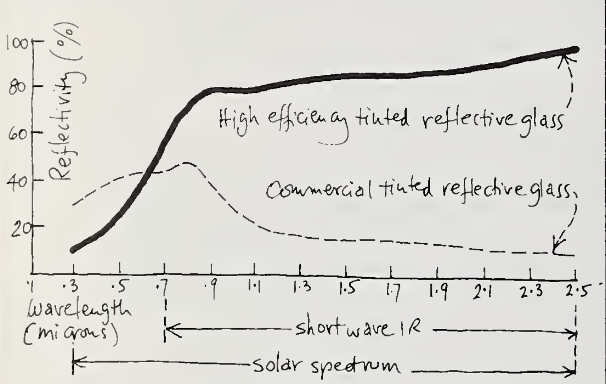

Figure 8. Spectral reflectivity of energy conserving windows

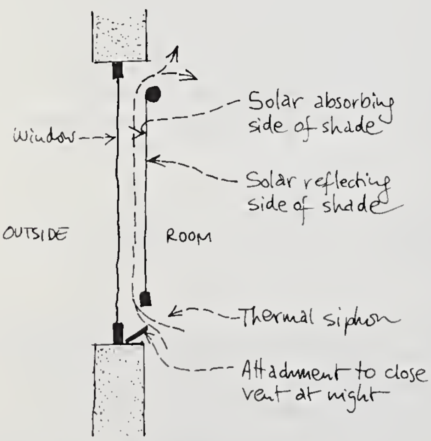

Figure 9. Dual shade for absorption or reflection of sun. (Heating season daytime configuration is shown. At night the shade closes off the lower vent. In summer the shade is reversed so reflecting side faces out)

from a body of literature on: energy use attributable to windows, the fraction of existing stock that might be affected, the potential reduction in consumption achievable per unit, etc. Thus there is no simple method of comparing the relative merit of proposed window innovations since the figures have not been derived by a common methodology relying on a uniform data base.

Since the proposers of new projects recognize these shortcomings, they generally propose the development of computer codes to correct the situation. However, the resultant computer programs may still be based on different data bases and engineering assumptions so that again there is no way of comparing results. Furthermore, there is a tremendous duplication of effort and expense to repeat the development of these codes.

To remedy this situation, our existing computer codes will be modified so that they might accept a variety of additional window designs, the input procedure simplified, and the entire package made available to other researchers in the field.

Heat mirror and optical shutter development

This project is a continuation of on-going work to optimize a retrofit window package which includes a heat mirror deposited on a plastic substrate and an optical shutter between glass layers. The shutter switches from a transparent state to a white translucent state at specified temperature and sun conditions. Prototypes of each have been produced and tested, and the second phase of this study would include optimization of the integrated package (heat mirror, optical shutter and edging system), selection of production equipment for full production of components, and tests of the completed package under installed conditions (see Figures 5, 6 and 7).

To improve the acceptance and utilization of such a retrofit product a commercialization plan will be developed. This will include extensive market research to assess the size and character of the market, a cost analysis of the final product, and evaluation and selection of plans for introduction to the market.

Weather resistant infrared radiation mirrors

In many buildings, undesired solar heat gain substantially increases cooling loads. Reflective and tinted glazing, and solar-control plastic films, provide desired control, but often at the expense of natural lighting. Approximately 45 per cent of incident solar radiation is received in the infrared portion of the spectrum (beyond the visible range) under average conditions (see Figure 8). This fraction of incident energy could be rejected without the loss of daylighting potential. This project supports the development of a glazing unit which contains an external film layer to reject short-wave IR. The film is applied and protected in such a manner that it will maintain its properties under prolonged exposure in an outdoor environment.

Innovative window designs with decreased thermal energy transport

Windows have been designed that incorporate convection and radiation suppression in dual-pane glazing units. The mechanism involved is controllable so that optical and thermal window properties may be changed in response to changing environmental conditions. Prototypes will be developed and tested in cooperation with potential manufacturers of such devices (see Figure 9).

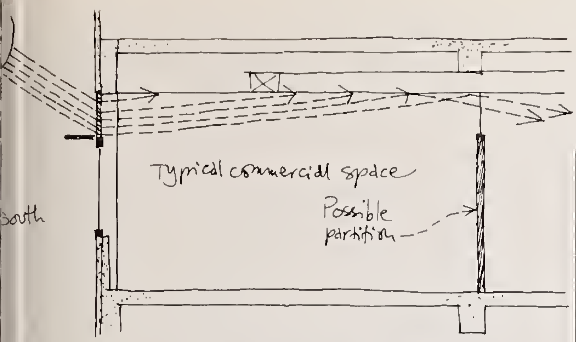

Figure 10. Use of silvered beam blind to project daylighting to interior

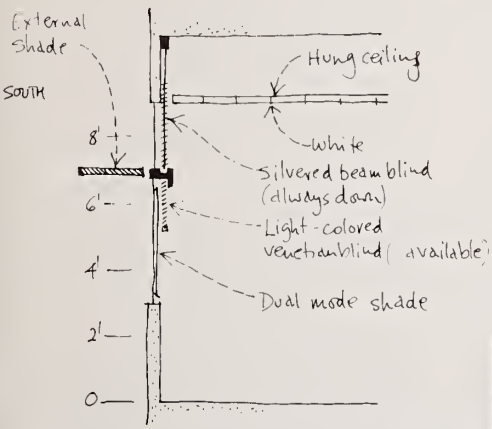

Figure 11. Wall section showing beam blind, vision window, and solar control options

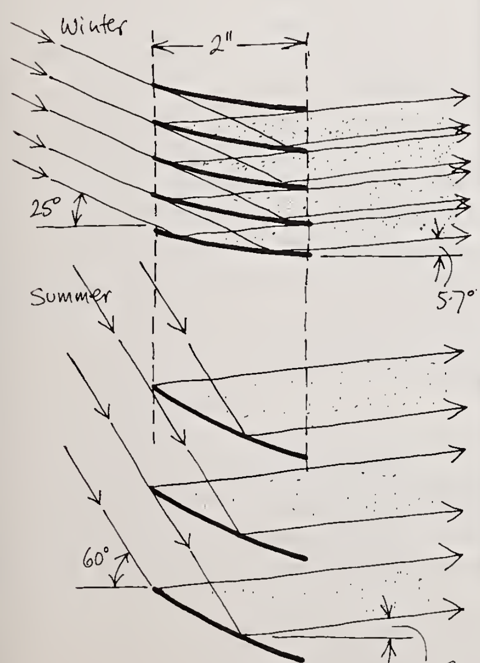

Figure 12. Seasonal beam blind configurations

Dual mode shades and blinds

A variety of shades and blinds are available to architects to assist in control of the microclimates in rooms. These have evolved to serve a sun-control function as well as to provide privacy and esthetic impact. This project will extend analysis to include design and testing of several novel shades and blinds which have been developed to control undesirable heat gains and losses. The advantage of such an approach is that the modified shades and blinds are extensions of state-of-the-art items that are accepted and used by both consumers and the design professions. The use of "managed" window systems (automatically and/or manually controlled) promises savings well in excess of those achieved by most static design solutions.

Window analysis—optimal window size

For each of several window designs developed in the preceding projects and for other common window design options, we will optimize window size as a function of combinations of glazing orientations, building envelope and internal characteristics, use patterns, comfort criteria and climate. We will identify and parameterize those variables upon which optimal size shows the greatest sensitivity to change.

Minimizing energy consumption through optimal window design may not always be economically viable. We will examine the change in life-cycle costs of optimal solutions under the influence of varying hardware cost and energy cost scenarios.

Recent attempts to formulate new building codes to promote energy conservation have often resulted in the simplistic directive to minimize glazed areas. The results of our studies to date indicate that these guidelines are often counterproductive. There presently exists no set of guidelines which treats this complex subject correctly, yet simply and concisely enough to be of practical use to legislators, code officials and architects. We will assemble and organize the relevant data from this study which might form the basis for a comprehensive manual on optimal window design.

Beam sunlighting

Daylighting techniques, for lighting perimeter zones near windows are well known. Natural illumination in the interior spaces of multi-story buildings has not yet been achieved. However, beam sunlight can be reflected from the tops of windows onto the white ceilings characteristic of most commercial buildings so as to penetrate to 30 to 40 feet into the space (see Figures 10, 11 and 12). It is then diffusely reflected by the ceiling to provide usable illumination in the space. Devices are being designed and tested to perform this function in a cost-effective manner. If they can be successfully integrated with artificial lighting systems, the energy and peak power savings will be substantial.

4

An architect's view of energy efficient windows

A pictorial guide to one architect's Age of Innocence, Age of Ignorance, and Age of Enlightenment when it comes to the use, the over-use, and the sensible use of glass in his office building designs.

By Harwood Taylor
Senior Vice President
3D/International
Houston, Texas

I have been very relieved to hear the other panelists describe some of the advantages of natural light, because I thought I would be the only one that would defend windows. I hold the philosophy that windows are essential.

I was also very frightened that it would be proven that my life up until now had been a horrible mistake—and I'm going to discuss some of those mistakes.

As I review our firm's designs in relation to energy conservation, I see that our philosophy can be divided into three stages:

1. I would describe the period from the beginning of my practice until the late 1960's as The Age of Innocence. We used single glazing glass, predominantly bronze or grey, to reduce sky glare; and we were very concerned with protecting the people in our buildings from direct sunlight. Various sun-shading devices were used, but for economy we relied on draperies and venetian blinds.

2. In the latter part of the 1960's, the glass industry made a fantastic step forward with the introduction of double-glazed insulated glass with metallic-reflective coatings. All of a sudden we were able to use glass and maintain comfort as never before. I would call this period from the late 1960's to 1973 The Age of Ignorance.

Like many architects, we exuberantly over-used glass because it made economic sense with cheap energy.

3. With the oil boycott in 1973—when, belatedly, our firm and most of the profession recognized the severity of the energy crisis—we entered what I hope will be The Age of Enlightenment; still utilizing high-performance glass and solar shading but with greater moderation than in our Age of Ignorance.

Before high-performance, high-efficiency glass, we concerned ourselves with shading devices, of course reducing the amount of glass. My practice is in a moderate climate, with mild winters—and air conditioning is the big problem. But then came the new glass—and The Age of Ignorance. The Campbell Center was designed prior to the energy crisis. This is a 100 per cent glass building. Actually, as originally conceived, it had projecting 45-degree bay windows, creating 60 per cent more window area. The client said: "Well, doesn't that cost money?" And I said: "Oh yes. We're increasing the perimeter and the exterior of the building by so much, and the cantilevers will cost so much. But it's all net rentable space, it would be a unique architectural environment, and the wonderful new glasses will make it practical." The client said: "If what you tell me is correct, let's go ahead and straighten out the cantilevers at the apex, pick up twice as much area, and save the glass." And that's how the building was designed. It shows how figures lie and liars figure.

At any rate, during our Age of Ignorance, we built a lot of 100 per cent glass buildings like this. The floor-to-floor height was slightly less than normal to utilize the maximum piece of glass that was available on the market. This reduction in height actually imposed some cost premiums rather than savings, as a result of structural and mechanical problems.

Figure 1. Campbell Center, Dallas. A 100 per cent vision-glass facade

Figure 2. Bryan Tower, Dallas. A 100 per cent vision-glass facade (drapery pocket at spandrel)

Bryan Tower—a 40-story building—also had a 100 per cent facade. We created big drapery pockets at the spandrel area, but even the area between the ceiling and floor above is 100 per cent vision glass (thereby admitting a maximum of heat into the building). With very efficient glass and lower energy costs, it made economic sense in those days—but this was one of the last 100 per cent glass buildings.

Even prior to 1973, we made very detailed analyses of the impact of glass on our energy costs, and our engineers used computer programs to tell us exactly how many dollars were involved in increasing the amount of glass, varying solar orientations, and using glass of varying efficiencies for esthetic effect. Obviously, if we were to design Bryan Tower today, we would utilize insulated spandrel glass instead of utilizing the drapery pockets; but at the time, it seemed a reasonable and rational decision.

From the late 1960's to 1973, most of our work was done for investment builders, who are extremely cost conscious—not only of first costs, but of operating costs. Our engineers started advising us of the impending energy crunch; but I'm afraid, at times, we treated their advice as "scare rumors." However, we gradually started modifying our designs by varying the amount of vision glass and insulated spandrel glass. Although the remaining photos all appear to be 100 per cent glass buildings, the area of vision glass varies from 35 per cent to 75 per cent. Because of the opacity of the new high-performance glass, a new esthetic was created—the new reflective glass appeared more like granite or marble than transparent glass, yet no transparency was lost. In Century Center we used a gold reflective glass in a sloping section to create an air-conditioned, four-story garden. Actually, the garden is partially air-conditioned and heat is exhausted through openings in the roof. With spot air-conditioning, we created a coffee area in the garden. From an energy standpoint, the reflective glass from the garden, shielding the transparent glass in the floors of the building overlooking the garden, made a very economical building and made good sense at the time.

The Transco Tower was for a

Figure 3. Century Center, San Antonio. Gold reflective glass on the sloping wall makes it possible to provide a people-occupied four-story garden

Figure 4. Transco Tower, Houston. Company moved out of a windowless building to this amply-windowed one.

company which moved out of a windowless building. Theirs was one of the few windowless buildings in Houston—and it was the greatest thing in the world for them to get into a building *with* windows. I'll guarantee that people *need* windows—how much or to what degrees of glass and view we're still trying to determine.

United Technologies Building is in Hartford, Connecticut. The developer saw an article in *Engineering News Record* on the 40-story Bryan Tower, and asked us to do a similar all-glass effort for them. We did, but we increased the insulated spandrel in response to the harsh winter conditions that were a little foreign to us Texas architects. It's a reasonably efficient building, but probably wouldn't be designed like this today. I would probably drop the window head down to seven feet instead of leaving it up at the ceiling. This building appears all glass—but it is approximately 65 per cent glass. Today we would probably reduce the vision glass under 50 per cent.

Lincoln Center in Tampa, Florida, is more recent—designed when we knew energy costs were going up. It looks like an all-glass building—the esthetics haven't changed particularly—but here we have an exactly 50-per cent glass building—half the facade being spandrel sections.

Century Center in Atlanta, again approximately 50 per cent vision glass—but appearing to be all glass. It's a very efficient glass that we're using.

Another building in Atlanta—Marietta Tower—was our last pre-depression building. In this building the deeper section is the spandrel section—the windows are only five feet deep yielding a 38 per cent glass building.

From 1968 to 1972 to 1977 we've gone from 160 per cent glass buildings (like the one with the crenelated facade would have been) to 100 per cent glass buildings to 80 per cent to 50 per cent. We now feel, and this is subjective, that we should use something between 30-35 per cent vision glass. That seems the minimum the market will accept.

We did a building for a major national company in which we raised the window sill to four feet, six inches, dropped the head to six feet, and sloped the glass outward to 45 degrees. This created a

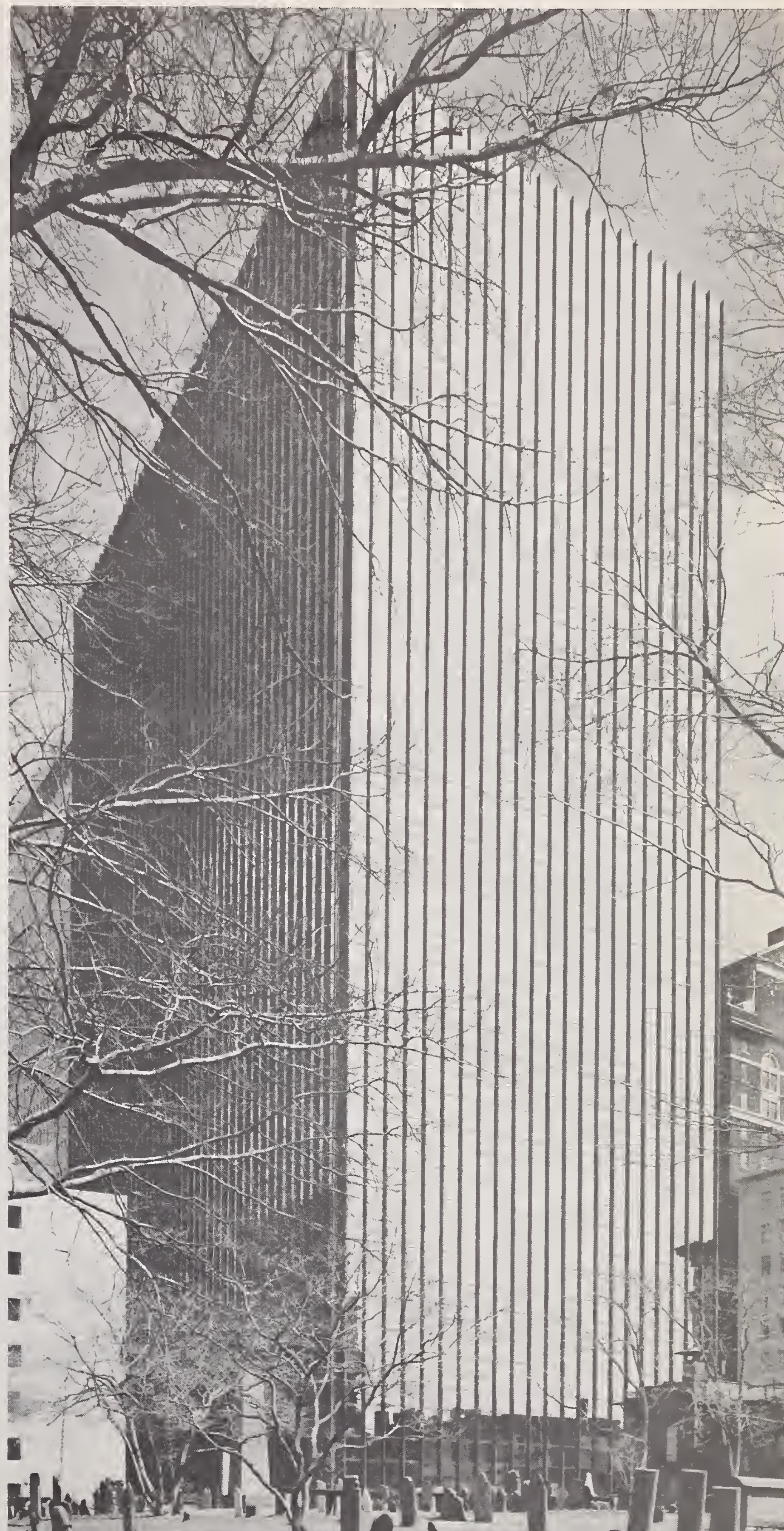

Figure 5. United Technologies Building, Hartford. Vision glass is about 65 per cent of the total. (Building designed before oil embargo.)

very, very efficient building. But the people hate it—just literally hate it. When they're sitting down at a desk, they can't see out. Personally, I like the sills not to exceed 30 inches—when a man is at his desk, if he doesn't see the horizon, he doesn't see out. Our compromise—instead of raising the sill heights—has been to lower the head heights to about seven feet. If it gets much lower than seven feet, we get into problems—again, psychological problems.

In the lateral direction, we feel that 50 per cent of the wall space must be in the window. In buildings where less than 50 per cent of the width of the space is vision glass, we have encountered stiff market resistance.

There are many, many variables to be considered. When considering the amount of glass to be used as a percentage, are you talking about a building with a 10,000-foot floor or a 30,000-foot floor? The aspect ratio of buildings is another consideration: I'm working on two 20-story suburban buildings in Houston now. One of them will house headquarters, and we are orienting both buildings with the long sides facing east and west. It is an additional expense, but at the location we have a beautiful dramatic view of the downtown skyline of Houston. Three apartment buildings and a number of office buildings have proven to me that people *do* want the view; they rent the buildings for the view, they will pay for it by the view. Sometimes it is necessary to orient the building in an east-west direction to achieve the view. We think that is practical and responsible with the high-performance glasses that are available today. And I hope we won't be legislated from making these judgments.

On a lot of buildings we ask the engineer: "Well, what will happen if the sill is to be 18 inches, 30 inches, 36 inches?" The numbers, when you start using efficient glass, are very, very small in proportion to the total energy used in the building. I would much rather drop five-foot candles of light out of the building than reduce the glass too much; or reduce fresh air requirements from 15 or 25 cfm of fresh air per person to 5 or 8 cfm. Before cutting down on vision glass area, I would rather look at a number of other aspects within the building: at lighting levels, fresh air, the type of air-conditioning system, fan

Figure 6. Lincoln Center, Tampa. Though this looks like a 100 per cent glass building, 50 per cent of the facade is spandrel area

Figure 7. Century Center, Atlanta. Another building with 50 per cent vision glass (high-performance type used)

horsepowers. There are a lot of ways we can save a certain amount of energy without reducing glass too much. I don't want to end up with buildings like the one I described with a four-foot, six-inch sill and a six-foot window head.

In our Age of Ignorance, before 1966, we utilized single-glazed conventional glasses judiciously with proper sun control as an operating and comfort necessity. With the advent of the high-performance glasses, we exuberantly designed the building (the bay window solution) from 160 per cent glass to 80-90 per cent glass. With the Age of Enlightenment, with the real energy crunch recognized by all, we are utilizing the high-performance glasses in the 30-50 per cent of our wall areas. Our firm believes that greater reduction in glass would have adverse psychological effects.

Figure 8. Marietta Tower, Atlanta. This building has more spandrel area than vision area (only 38 per cent of facade)

5

Window research in the United Kingdom and in Europe

The case for window area as a positive factor in saving energy through solar radiation and daylighting

By David A. Button

Manager, Technical Advisory Services, Flat Glass Division
Pilkington Brothers, Ltd.
St. Helens, England

The influence of the window on energy use is not just its effect on heat loss. Because glass is transparent to solar radiation, it allows useful heat *into* buildings. In the past, this effect of solar radiation has been largely ignored—but there are substantial and useful amounts of solar radiation available even during the heating season. For certain orientations of window, these gains can actually be *greater* than the conduction heat losses, and for other orientations the solar heat can offset a lot of the heat loss.

A further positive influence of windows is on the amount of energy needed for artificial lighting. As daylight is increased, so the period when electric lighting can be switched off is increased.

To maximize these advantages of solar heat and daylight, readily available automatic control mechanisms can be used. For the heating system, this may require individual room control. For the lighting system, photocell controls can be used (where occupants could not be relied upon) to switch off the lights when daylighting is adequate. Full controls are required to get substantial utilization of this free energy; and with such controls, the designer can vary his window area anywhere between the limits dictated at the lower end by psychological requirements and at the upper end by the need to maintain acceptable conditions in the summer.

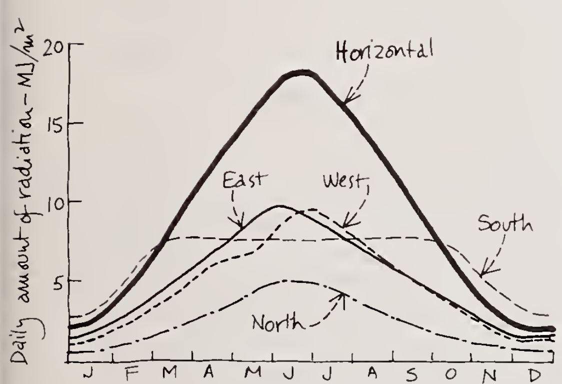

Figure 1. Daily amounts of radiation, direct plus sky diffuse, measured at Bracknell, England

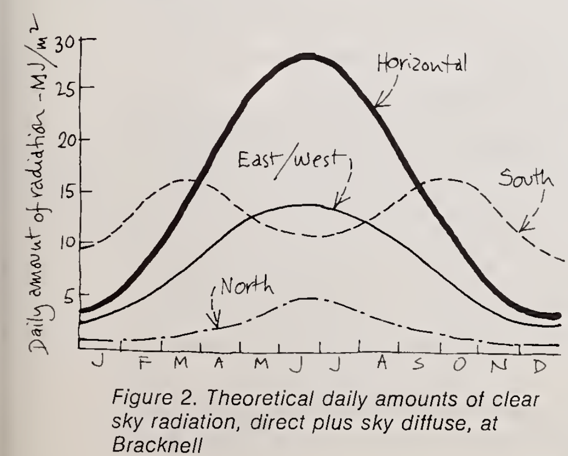

Figure 2. Theoretical daily amounts of clear sky radiation, direct plus sky diffuse, at Bracknell

The amount of energy consumed in buildings clearly justifies conservation measures

The environmental services in buildings consume about half of all the energy used in the United Kingdom, so the need to minimize energy wastage in buildings is self-evident. One third of the primary fuel used in the United Kingdom is used to generate electricity. Of this, 17 per cent is used in commercial buildings, and if at least 50 per cent of this is attributable to lighting (i.e., the lighting load plus the associated cooling and heating loads), it means that over three per cent of the primary fuel used in the United Kingdom is attributable to the artificial lighting of air-conditioned and heated commercial buildings. This inevitably raises the question as to whether lighting loads (as distinct from lighting levels) can be reduced without a lowering of environmental standards. Recent research has shown that this is indeed possible, and that considerable reduction in energy used for lighting is quite easily obtainable.

Windows do not just lose energy; they can gain energy through radiation. For most months, there is a net gain

Compared with the energy attributable to lighting, the energy attributable to heat transfer through the building envelope is small.

All external elements of a heated building lose heat by conduction, and generally speaking a low thermal transmittance (U-value) for the opaque wall sections is desirable. (Exceptions occur where deep offices have such high internal gains that refrigeration is necessary in winter—and good insulation is therefore a disadvantage.) With glazing, however, energy is not only lost by conduction but is also *gained* because glass is transparent to solar radiation. This effect has seldom been taken into account in the past because of lack of data on incident solar radiation. Designers have perhaps instinctively thought that the amount of solar energy available in the heating season was sufficiently small to be ignored. This, however, is not so.

Figure 1 shows the amounts of radiation measured at the Meteorological Office, Bracknell, England, averaged for the period 1967-73, for comparison with the theoretical amounts of radiation available under clear skies shown in Figure 2. The amount of radiation available in average weather conditions is a significant proportion of what would be obtained with clear skies, even during the U.K. winter! The amount of radiation on north-facing surfaces is, for instance, always higher than the clear sky values (because of the large proportion of diffuse energy with cloudy skies). In fact, the energy received on a north-facing surface in June is as high as 70 per cent of that incident on a south-facing surface. Other orientations also receive more radiation than might be expected. East- or west-facing surfaces receive about 60 per cent of the radiation that would be available on them annually for clear skies. South-facing surfaces receive 50 per cent of their clear-sky radiation. (By way of comparison, the sunshine hours recordings made simultaneously at Bracknell, using a Campbell-Stokes sunshine recorder, showed that the average annual availability of bright sunshine is only 31 per cent of the theoretical maximum. Because of the large amounts of diffuse radiation in the U.K., the sunshine-hours recordings therefore give a very pessimistic indication of the solar

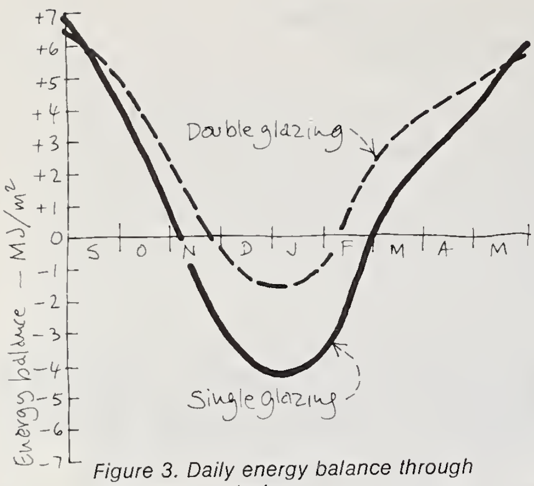

Figure 3. Daily energy balance through south-facing glazing

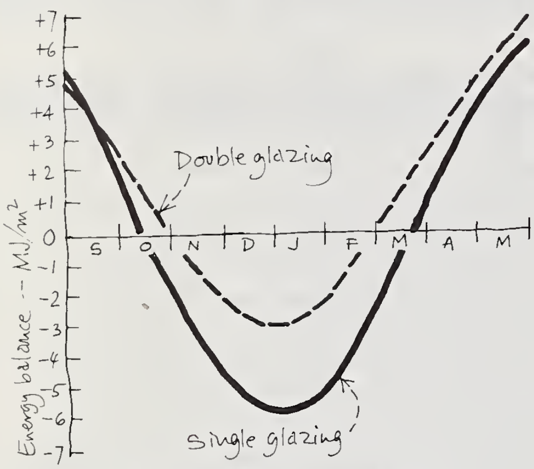

Figure 4. Daily energy balance through east-facing glazing

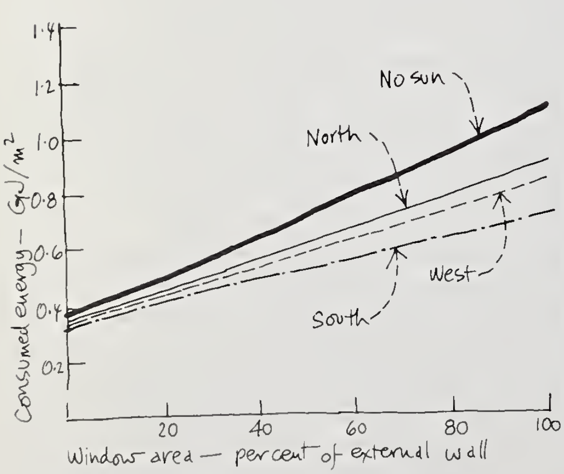

Figure 5. Annual consumption of energy attributable to heating. Single-glazed office, Kew, England

energy available. However, as demonstrated by the charts, the actual measured values of solar radiation show that there is indeed a considerable amount of useful energy available.)

It is a relatively simple matter to calculate the net exchange of energy through glazing, using Figure 1 to obtain the solar gains and using outside temperature data to obtain the conduction losses. When account has first been taken of the additional ground-reflected component of radiation, the net balances shown in Figures 3 and 4 are obtained (in these charts, only the months of the heating season are given). It can be seen that, for south-facing glazing in particular, the months when the energy balance is positive (when the average solar gains are greater than the average conduction losses) represent a large part of the heating season. Similar diagrams have been published for other orientations.

Sophisticated calculation on computers show that the influence of windows on heating requirements is far less than has been assumed

Figures 3 and 4 show merely the *balance* of the physical processes of energy exchange at the building envelope. The fortuitous solar gains that contribute to these balances will not necessarily be all useful. The gains can only be considered useful if, in their absence, additional heating energy would be required to maintain the design indoor temperature. The degree of usefulness of the solar gains will depend on a range of factors: time of year, geographical location, orientation, dimensions and thermal properties of the building, glazing area, pattern of occupancy, and other heat gains. The utilization of solar gains will vary from building to building and it is impossible to state a universal utilization coefficient.

A computer program has been developed which enables the two-way transfer of energy through glazing to be taken into account. The program uses average solar radiation data and average external temperatures to calculate the energy required for heating a building. The thermal properties, dimensions and orientation of the building are fed in as data to the program—which then calculates the heating requirement. It is obtained by calculating the heating requirement for each hour of an average day of each month in the heating season. The heat load for a day is then computed by integrating the hourly values; and the heat load for the whole heating season is computed by integrating the daily values. The program distinguishes between solar gains that are useful and not useful by rejecting all those solar gains which would elevate the inside temperature above the thermostat temperature. These solar gains are not regarded by the program as supplementing heating requirements.

The influence of solar gains can be seen in Figures 5 and 6. These have been obtained using the computer program for a 5- by 5-meter office module with one external wall. Thermal properties of the fabric, internal heat gains corresponding to 600-lux lighting, one occupant per 10 square meters, and a heating-system efficiency of 66 per cent were assumed. The graphs show the relation between the amount of glazing in the external wall and the annual heating-energy consumption for each square meter of floor area.

The top curve in each figure shows the energy consumption if no solar gains are taken into account; that is, the result of the

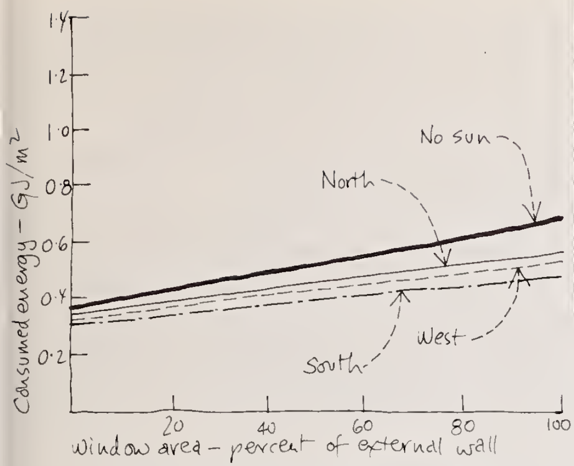

Figure 6. Annual consumption of energy attributable to heating. Double-glazed office, Kew

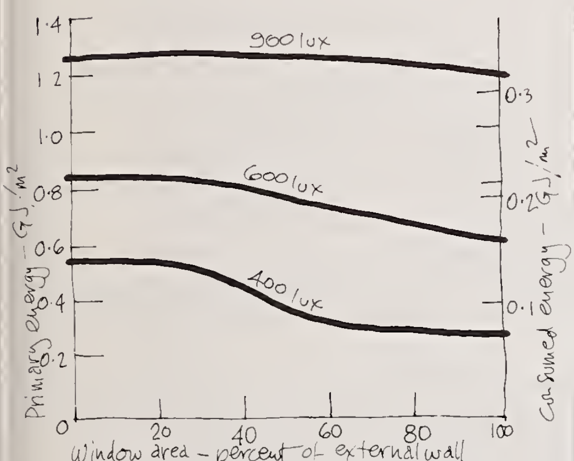

Figure 7. Annual consumption of energy attributable to lighting

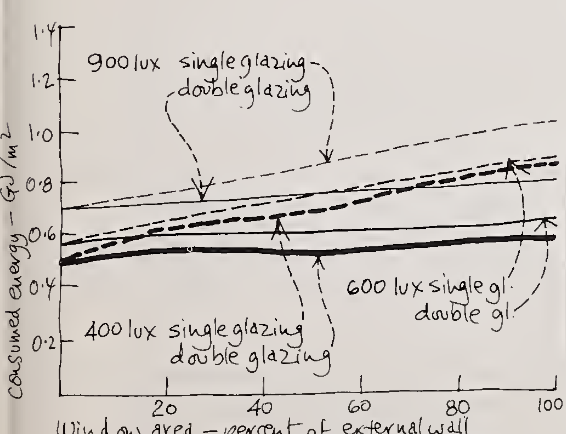

Figure 8. Annual consumption of energy attributable to heating and lighting. South-facing office, Kew

conventional calculation approach which treats glazing merely as a source of heat loss. The remaining curves show the situation when solar gains are considered on various building faces. These charts show clearly that when solar energy is taken into account the influence of windows on heating requirements is not as significant as is commonly supposed.

Windows can also save energy by reducing the artificial lighting requirement

The greater the amount of daylight admitted to an office, of course, the greater will be the number of hours when that office can be adequately lit without artificial lighting. The tendency to use artificial lighting for fewer hours in offices that have good natural lighting was observed even before the recent rapid rise in energy costs. Any energy analysis of the building envelope should therefore go beyond calculating heat losses and solar gains, and take account of the influence of windows on lighting requirements.

Figure 7 shows the influence of window area on lighting energy for the 5- by 5-meter office module considered above. The results have been obtained according to the Illuminating Engineering Society's Technical Report No. 4, which gives the number of hours per year that daylighting will exceed certain levels. The lower the design lighting level, the greater will be the number of hours when daylighting is sufficient to enable the lights to be switched off. This is shown in Figure 7, which illustrates that a design (artificial lighting) level of 400 lux provides far more potential for saving energy as window area increases than does a level of 900 lux. Figure 7 gives the energy consumption in both primary and consumed-energy terms because the two values are vastly different when electricity is the fuel.

The results of the computer program for obtaining the heating requirements have been combined in Figure 8 with the lighting energy values of Figure 7 to examine the influence of window area on total energy consumption.

Figure 8 shows that, with double glazing (solid lines d, e, and f), the energy consumption is almost completely unaffected by the area of window. With single glazing (dotted lines a, b, and c), there is a slight increase in consumed energy as window area increases. Certain simplifying assumptions were made in Figure 8 in that only one orientation (south-facing) was considered and the daily saving in artificial lighting due to daylight was taken to be constant throughout the year. However, these assumptions do not alter the general principles deduced from the analysis.

Taking into account primary energy demand, the case for window area (vs. more lighting usage) is strengthened

Generating and distributing electricity introduce considerable losses: the ratio of gross energy input to energy delivered to users is 3.82 in the U.K., compared with 1.09 for oil and 1.07 for natural gas. It is, therefore, important to examine the primary energy consumption of a building because it gives a better indication of the demand on national energy resources and—as fuel tariffs increasingly reflect resource costs—the primary energy consumption will increasingly give the most reliable indication of running costs.

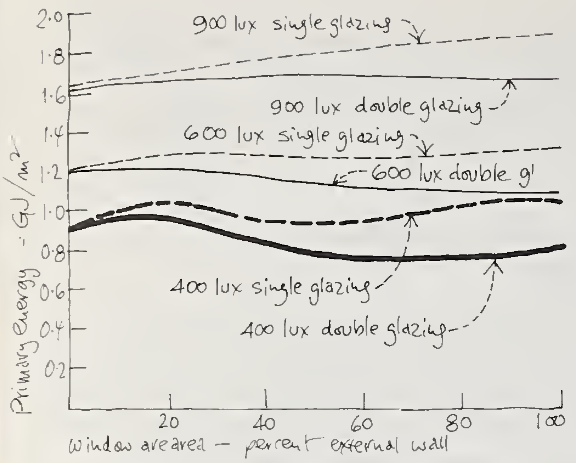

Figure 9. Annual consumption of primary energy attributable to heating and lighting. South-facing office, Kew

Office type (depth, lighting load)	Full Control	No photo-cell	No thermo-stat	No control
NOT AIR-CONDITIONED:				
Shallow, 30 W/m²	1.78	1.78	1.82	1.82
Shallow, 20 W/m²	1.28	1.40	1.34	1.45
Deep, 30 W/m²	1.70	1.70	1.72	1.72
Average:	1.59	1.63	1.63	1.66
Present value of extra running cost (£)*	–	0.22	0.22	0.39
AIR CONDITIONED:				
Shallow, 30 W/m²	2.58	2.58		
Shallow, 20 W/m²	1.96	2.12	n.a.	n.a.
Average	2.27	2.35		
Present value of extra running cost (£)*	–	0.44		

* Present value of annual cost after 10 years, discount rate = 10% p.a. assuming no real increase in fuel costs

Figure 10. Annual consumption of primary energy in office buildings with 32.6 per cent single glazing and U-value of opaque wall —1.0 W/m²K

Figure 9 shows the influence of the window on primary energy demand—and shows that increasing window area can in many cases *reduce* energy consumption. Even in those situations where increasing the window area causes increased consumption, the influence of window area is small compared with the influence that the installed lighting level has on total consumption.

In Figures 8 and 9, the benefit of increased artificial lighting levels in reducing the heating load has been taken into account. The results are for south-facing glazing, which gives the lowest energy demand. However, Figures 5 and 6 show that the increase in heating energy due to changing orientation is small compared with the total energy pattern of Figure 9. Thus, the trends observed in the curves of Figure 9 are applicable to all orientations.

Controls to shut down heating and lighting when "free" solar heating and daylighting are available are cost effective

Automatic controls that would save energy in buildings are not common practice at present, but are readily available as standard items or can be built up from standard components. They can be shown to be cost-effective, and their inclusion would represent a good economic decision by the building designer. The following analysis uses computer calculation to represent the complex annual energy balance of buildings, using such controls and with various values of aggregate thermal transmittance for the external walls.

Two types of control are considered. The first is a lighting switching system linked to a photoelectric cell which senses the outside daylight level and controls the artificial lighting so that it is switched off when daylight alone would provide the design illuminance. A typical photocell controlled system could be installed in an average office building for an additional cost of about £0.10 per square meter.

The second control considered is a simple thermostatic radiator valve for use in buildings that do not have air-conditioning. It enables individual radiators to respond to any incoming solar radiation so that they do not provide unneeded heat to a room being heated by the sun. In a typical heated office building, they could be installed for an average additional cost of about £0.20 per square meter of floor area. The fitting of further heating controls to a building with air-conditioning is not considered because such a building would normally be provided with a sophisticated control system.

Figure 10 shows the annual primary energy consumption of a range of office buildings. Four different degrees of control are compared:

1. *Full* con*trol*. This assumes that 90 per cent of the potentially useful solar heat and all the potentially useful daylight is used.

2. *No photocell*. This assumes that 90 per cent of useful solar heat is used, but only 20 per cent of useful daylight is used through the manual switching of lights.

3. *No thermostat*. This assumes that none of the useful solar heat is used in the heated buildings but all the daylight is used.

4. *N*o con*trol*. This assumes that none of the useful solar heat and only 20 per cent of the useful daylight is used.

Figure 10 shows that in non-air-conditioned buildings the

fficetype	Aggregate U-value of external walls (W/m²K) 2.5	3.0	3.5	4.0	4.5
OT AIR CONDITIONED					
hallow, 30 W/m²	1.79	1.70	1.67	1.65	1.65
hallow, 20 W/m²	1.28	1.25	1.24	1.25	1.30
eep, 30 W/m²	1.70	1.65	1.64	1.62	1.62
verage	1.59	1.53	1.52	1.51	1.52
IR CONDITIONED					
hallow, 30 W/m²	2.58	2.54	2.57	2.64	2.73
hallow, 20 W/m²	1.96	2.01	2.09	2.19	2.33
verage	2.27	2.28	2.33	2.42	2.53
eighted average	1.82	1.75	1.79	1.81	1.86

Figure 11. Annual consumption of primary energy in office buildings with full automatic control (GJ/m²)

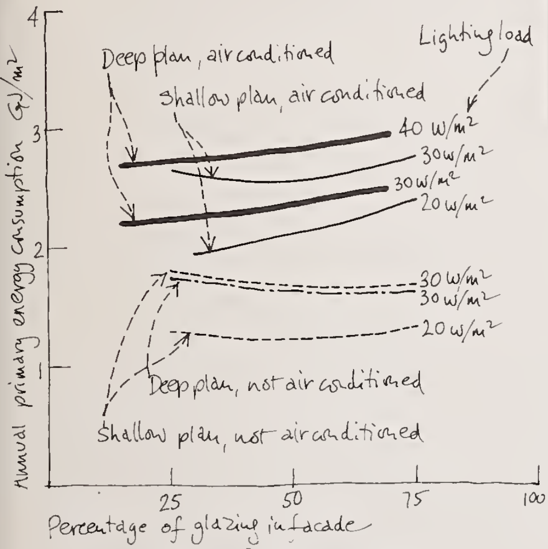

Figure 12. Annual primary energy consumption GJ/m²

All units in these graphs are on the metric system. In all cases, the result to be shown is clear. Those who wish to convert the figures to U.S. terms may use these conversion figures:

MJ/m² = 87.7 BTU/ft²
where MJ is megajoules (joules x 10^6), and m² is square meters

GJ/m² = 87.7 x 10^3 BTU/ft²
where GJ is gigajoules (joules x 10^9)

For U-value conversion:
W/m² x C = 5.68 x BTU/ft² x hr x F
where C is temperature difference in Celsius degrees, and F is temperature difference in Fahrenheit degrees

W/m² = 3.42 x BTU/ft² x hr

inclusion of both photocell control and thermostatic radiator valves would be economically justified. In air-conditioned buildings photocell control would be justified.

Figure 11 shows the influence of different aggregate U-values for the external walls of office, for the buildings listed in Figure 10. The range of U-values is from 2.5 W/m²K to 4.5 W/m²K, generated by varying the area of window (single-glazed) in an opaque wall of U-value 1.0 W/m²K. Deep and shallow offices with lighting loads of 20 W/m² and 30 W/m² have been studied, with certain classes omitted. For instance, deep buildings with lighting loads of 20 W/m² (giving about 400 lux) are not included because it is considered that deep offices would always have higher lighting loads than this. In addition, deep air-conditioned offices with a lighting load of 30 W/m² have been omitted, as they would invariably have an aggregate U-value of less than 2.5 W/m²K.

In Figure 11, values were computed assuming full photocell and thermostatic valve control, where applicable, as justified in Figure 10. Although results for individual cases may differ, the general trend —as observed from the weighted average results of all types—is that *energy consumption remains more or less constant* for a very wide range of aggregate U-values. A graph plotted from these results would not produce a steady increase in energy as U-value increases, but a very shallow curve with minimum energy use at about 30 W/m²K. As the table shows, the variation in energy use for different U-values is so small that it would be ill-advised to place any emphasis on an optimum U-value. Given the limits of accuracy relevant to building calculation and use, *one may safely conclude only that there is no real relation between U-value and the use of energy in buildings.*

Figure 12 shows the primary energy consumption in a non-air-conditioned shallow office building (dotted lines) in an office with a lighting load of 30 W/m² of floor area, and in another office with a lighting load of 20 W/m². It appears that the increased heat losses incurred by large windows tend to be counterbalanced by the useful solar heat gains and the savings in artificial lighting energy.

Figure 12 also shows a shallow air-conditioned building (dashed lines), again with lighting loads of 30 W/m² and 20 W/m². It shows that there is a slight increase in annual energy consumption—but only slight, because the solar heat gain in summer can be an energy penalty.

Conclusion: The effect of windows is not just negative, but positive —and energy savings can result from careful window design

The effect of the window on the indoor environment and on the energy consumption of buildings is very complex, and each design must be considered on its own because generalizations are not necessarily trustworthy. In buildings, the energy admitted by the glazing can make such an important contribution to the energy requirement of the building that to limit it in an inappropriate manner would not contribute to over-all energy conservation.

It is essential, therefore, that new building legislation for energy conservation and codes of building design should allow the window to be used as a passive solar collector, thus permitting the window's full potential for conservation to be realized.

The calculations given in this paper have been based upon U.K.

climate and practice. These concepts, however, are being investigated in all European countries and, at present, these positive aspects of the window are being considered by the European Economic Commission for inclusion in European directives. The National Research Council of Canada has also examined these concepts in its publication, "Net Annual Heat Loss Factor Method for Estimating Heat Requirements of Buildings."

Although climate does have an effect on the usefulness of these concepts, they are, nevertheless, effective in energy conservation in all climates. At this stage in the development of these concepts of window design it is essential that:

1. Designers be encouraged, and allowed, to use and experiment with them in new buildings.

2. In order to gain support for this action, these concepts should be given the widest possible promotion, and . . .

3. Research work should be carried out in all climates in order to refine the concepts so that precise design guides can be established.

6

The panel discussion at the Round Table

Highlights of the discussion among the panel members —and the questions raised by the participants.

Dr. Maxine Savitz, in opening the Conference/Round Table, made the startling statement that, "roughly five per cent of the nation's energy consumption is lost through windows"

"Because the heat losses and gains through windows are so very large—estimated at roughly 5 per cent of the nation's energy consumption, one could say that either this is a problem, or one could view it as an opportunity—asking one's self how can we utilize windows better and how can we develop better materials and better criteria for them.

"Today's meeting is planned as a dialogue between industry, government, and practitioners. And we hope that this dialogue can be an ongoing activity, so that together we can solve and record solutions that will help us respond creatively to the urgent need for large reductions in the energy expenditure attributable to windows in all types of buildings."

Co-moderator Richard N. Wright listed some of the issues he thought the Conference/Round Table should be addressing . . .

"The first issue we must concern ourselves with is, of course, users' needs.

"Another major category is our knowledge of the natural environment in which buildings have to work. One wonders, for example, how cognizant and concerned people are about the inadequacies in the completeness and accuracy of data on the amount of daylight we can expect for any particular building for any time of day and time of year.

"A third category is the identification of the physical characteristics of building components, materials and subsystems.

"A fourth category is our ability to predict the response of building components and subsystems to their environment.

"Finally, the last and perhaps the most difficult one: how can the building community be assisted in making full use of the available hardware and knowledge on windows that is now available? How can we achieve energy-effective windows by making better use of the knowledge we already have?"

Architect Harwood Taylor offered comments on his firm's use of high-performance glass, and glass in general—"I would much rather drop five footcandles of electric light, and save a heck of a lot more energy"

"We have tried to sell high-efficiency glasses in 99 per cent of our buildings, and we have succeeded in probably 85 per cent of them. We have one 20-story building in the Gulf states with about 50 per cent of the facade single-thickness glass. We tried and tried to get the owner to use high-efficiency glass, but he just would not do it. Now he recognizes the error of his ways, and two more buildings in the same complex are using high-performance glass.

"For interior spaces—even if there are partitioned offices, we try to get some daylight in—more for psychological effect than anything else.

"We have not used photoelectric cells to control our lights, as yet, but I think it certainly is the coming thing.

"For all practical purposes, we were doing 'task lighting' years ago. I don't think two per cent of our office buildings have modular lighting—and this was primarily an economic consideration, especially for a lot of investment builders. We put all of our lights on flexible pigtails, and tried to locate the lights over the desks."

After Belinda Collins described the NBS experiments on window management, she replied to a questioning architect . . .

Commented architect William Jarratt: "From some of your charts, I was beginning to get the impression that the more glass we use, the more fuel we save. I'm having difficulty understanding that one."

Replied Dr. Collins: "This is only true when the utilization of daylight is considered, substituting daylight for electric light. Window management helps improve the energy picture—that is, the use of thermal (wooden) shutters during winter nights and venetian blinds during summer days."

Not fully satisfied, Jarratt then asked, "With all that window management, couldn't the initial cost get to be much more than you would pay for the part of the wall that's now window?"

Collins' answer: "I should point out that most people, when they are building residential or commercial establishments, include these devices as part of the building design as an esthetic thing—apart from the energy conservation."

One panelist wondered what the glass companies were doing to improve their products, and another wondered if reflections from high-performance glass had caused any trouble. PPG's Bob McKinley replied:

"As soon as we get the go signal from the marketplace, we are ready to provide even higher performance than has been utilized to date. For example, how would mechanical engineers like to have a 1-inch-thick transparent insulating-window unit with a U-value in the 0.26 to 0.28 range? This does not require a research breakthrough. It is easy to provide by forming three insulating spaces with four lights of clear, thin float glass, in what I like to call a double-double or a quadruple-glazed unit. It is ready for use today in energy-conserving designs! Current architect/owner interest has encouraged us to improve the performance of our opaque spandrel glass panels, also. One with a U-value of 0.05 is immediately available.

"On the reflections matter, if we had reason to believe they were a problem, naturally we would be concerned. In reality, when we have investigated specific questions [similar to what the questioner had asked] we have discovered no justification for continuing concern. Perhaps this is more understandable when it is realized that glass reflectivity falls most often in the 5 to 50 per cent range, as compared with, say, 60-70 per cent for light-colored marble, masonry, concrete, porcelain or painted surfaces."

(One auditor, however, thought that the distinction should be made between the diffuse reflections from a material such as white concrete and the specular reflections from glass, and that the nature of glare should be defined.)

"The industry can provide both high- and low-reflectance glasses. Some architects ask for high; others ask for low. The designer usually wants to set a particular building apart from its neighbors, and, at the same time, reduce owning and operating costs. One low-reflection solution is to apply the metallic or metallic-oxide coating to the indoor air-space surface of tinted glass, thus reducing the light reflectance, while maintaining an effective level of heat reflectance."

Postal Service executive Alfred Maevis challenged the researchers to give him some simple rules to fix the thousands of buildings he already has . . .

"At the present time, those of us who own buildings are making seat-of-the-pants decisions. We just don't have information readily available, based on sound research or studies that give us answers. The Postal Service has something like 30,000 buildings. Some we own; some we lease, but we lease them for 20 or 30 years. Many of these buildings built 10 and 20 years ago don't even have any insulation. What do we do about this? What do we do with our windows? Do we put in storm windows? Do we just tear the windows out? I just hope the things we are talking about here get applied to the energy problem before we run out of it.

"I heard about the management of windows. But who really has time in his office to get up and down like a monkey opening and closing blinds and pulling drapes. I do it when it gets unbearable, but then it's probably too late. You pay a lot of money for staff men to do that all day long. You talk about elaborate devices—I worry about them. They generally don't seem to work, and they just make money for somebody else. Nobody is talking about retrofits, or about movable sash so we can shut down the air-conditioning system on a day when we could do without it.

"I heard about computer programs with models. Every time I do I get the shakes. Yet my paycheck comes out of the payroll system that is computerized. It works.

"I saw a life-cycle study up there. Positively fascinating! But only a Ph.D. will really look at that and worry. But I don't have Ph.D.'s on my staff—particularly when we get down to a 5,000-square-foot post office.

"Maybe I'm a voice in the wilderness or something. But do something for us. You've got to look at both ends of the iceberg!"

In her reply, NBS' Belinda Collins said the steps they were studying were simple and practical: "One of the reasons we took the approach we did at NBS was to identify some things that could be done easily, either in new construction, or as a retrofit measure. You could turn your lights off in your buildings and use daylight, for instance. That was the point in our developing the computer model that we did. As far as window management goes, the biggest savings we found were in the nighttime closing up of the window. You close the window blind at night, and open it up the next day. Then, too, staff at the Bureau has demonstrated the outstanding success of storm windows. What you are asking for is a set of guidelines to say what you should do and when."

"And they have to be understandable by the least-skilled we have," Maevis added.

But one of the panelists questioned: "And how are they enforced?"

Said Maevis, "You rely on good people. We can enforce it through budget control. Some poor guy out there gets a new air-conditioned building, well lit, and so forth. Now, we say, operate it at the same cost you did the old one. This could be amazing—could cut the energy costs way down across the board. But then it's difficult beyond this to get the next couple of per cent savings."

A fair energy standard for retrofit would be based upon economics —a reasonable Return On Investment—said ASHRAE committee member (and NBS staffer) Preston McNall

"Some of the philosophical aspects of writing a standard for retrofit of existing commercial buildings for energy conservation involve some agonizing choices. Ideally, you might say that old buildings ought to be as good as new ones. But then, one might argue that this isn't possible economically. On the other hand, you could say that the older the building, the worse it can be. There are a whole series of such decisions.

"I'm associated with the development of ASHRAE Standard 100.3 on retrofitting of commercial buildings, and presently our approach is to say that owners will have to undertake those retrofit measures that could reduce energy consumption, and are estimated to give a return on investment (ROI) of X per cent. The X on ROI would be different for the various retrofit categories, and for the different kinds of buildings. For example, the ROI might be 20 per cent for putting on storm windows. If such is the case, then the owner must do this. But this still might not cover all situations; there still are problems with the concept.

"What do you do about the old building that is so bad that nothing can be proved economically feasible? What do you do with buildings that have very limited economic life, say five years? Our current thinking is that if payback on a retrofit item occurs for such a building by its half life—in this case, two and a half years—the owner would have to do it because he would get twice his investment back in the five-year life.

"What do we do with that existing stock of buildings out there? It is a huge problem. How do we provide a better system of retrofit to save huge amounts of energy that we know is out there to save?"

David Smith—developer/builder/owner—argued that government agencies and lessees don't pay enough rent to cover the cost of providing energy-saving materials and devices.

"If I'm building a building for lease to the Postal Service, why don't they give me enough rent to cover the cost of putting in these energy-saving devices to start with? I'm caught in this situation with a shopping center I'm building—tenants want to lease for the least dollars per square foot. If I increase my rent, I'll price myself out of the market. Somebody has to educate the public that if they pay more money per square foot, the energy consumption will be less, and in the long run it is going to pay off for them.

"I find the same thing with single-family homes. We've investigated putting in triple-glazed windows, heat pumps, R-30 insulation in the ceiling, etc. The return on investment is very interesting—but I've got to have a salesman who can sell this to the homeowner; the prospect has to be convinced he should pay the additional initial cost. I think maybe the homeowner can be convinced. But I have my doubts about the commercial building market, and even some of the government agencies."

One panelist suggested the need for low-cost solutions for window retrofit in residences

Said David Quentzel of *Good Housekeeping Institute:* "We have millions of homes with tens of millions of windows, and I look forward to simple and relatively inexpensive answers—maybe some of them a short-term nature—that will enable the homeowner to do something. I'm not talking about retrofitting that involves pulling out an existing window and replacing it with another.

"Storm windows are a very effective system for reducing conductive heat loss or gain. But for solar heat gain in summer, could there be solutions as simple as utilization of reflective-coating materials in the form of roller shades, or some other variation?

"And how about casement windows? What can be done here to obtain the effective benefit of insulating glass without having to replace the windows? Is it possible to add on?

"It is one thing to recognize that the energy problem exists. But people need to be told about the availability of things that could be done. Of course, a number of things can be done with venetian blinds and drapes. But I'm talking about some of the insights we have acquired and that could now be translated into some pragmatic solutions via products that could be made available to the mass market."

NBS' Heinz Trechsel cited help the Bureau is giving Federal agencies for assisting people who live in low-income housing

"NBS has begun a fairly extensive study of all aspects of the retrofit problem at the very low end of the technology level. The retrofit strategy involves some rather elementary technology—because we are addressing ourselves to the type of housing that may have loose clapboards, broken window panes, etc.

"First of all, windows can be caulked and weatherstripped. Then the next step may be storm windows. Finally, the windows may be replaced, or even boarded up.

"But one of the big difficulties is developing a methodology for answering the question whether a *specific* window needs weatherstripping, a storm, or needs to be replaced—in contrast to answering the more general question of whether storm windows are effective in a particular climate."

Samuel Berman indicated how some of the product-type research the Lawrence Berkeley Laboratory is involved with could have retrofit application now

"We've been studying the use of plastic sheet to which a metallic coating can be applied that has about 80 per cent light transmission, but that rejects about 80-90 per cent of the radiation in the infrared range. The problem in the past has been that solar-control techniques have been effective, but often at the expense of natural lighting. This piece of plastic can be applied as a type of storm window on retrofit.

"The metallic coating we have been investigating also reflects long-wave radiation back into the room. Altogether, there is better than 50 per cent improvement in the over-all thermal performance of the window through this single product."

Window energy efficiencies can be greatly improved, said McKinley, by a line of retrofit products

"Many building owners want to improve the appearance and performance of existing office windows. A line of reliable retrofit window products is available that can improve U-values and shading coefficients more than 40 per cent. They can be installed without disturbing occupants, and without opening the building to the weather. The technique forms an insulating air space between the glass in the existing window and an additional factory-prepared light of glass and attached edge seal."

Engineer Fred Dubin suggested some inventive retrofit techniques for commercial buildings that require only low-cost materials and state-of-the-art technology

"There literally are hundreds of thousands of uninsulated concrete-block buildings in the country that are wasting huge amounts of energy. We have been looking at some schemes to treat these buildings with insulation on their exteriors—perhaps northwest and northeast exposures—to increase the U-value, rather than take advantage of thermal mass. But we could treat the south, southeast and southwest exposures differently to take advantage of solar heat.

We would do this by painting their surfaces black, and later glass could be added which would give a solar-wall effect. This could be cost-effective and improve the appearance of most of these buildings.

"We also are looking at a laminated shade—11 or 12 laminations of aluminized Mylar and nylon—that can be pulled down and act as a thermal barrier. It is reflective and it has air pockets to give a very high insulating value. This seems to me to be a very cost-effective way to treat existing windows."

Dubin also thought that atriums should be considered more carefully as energy savers in new buildings . . .

"When commercial office buildings are designed with skylit atriums, the inside walls benefit from a daylighted outlook, but they are not exposed to weather that would create energy losses. The atriums can be used functionally for people to circulate between offices and other spaces. And since people would only be spending short periods of time there, the atrium need not be kept as warm in winter or as cool in summer as the offices themselves, and the heating or cooling can be accomplished by means of return air from office spaces, improving over-all system operating efficiency."

. . . and he wondered whether better information was in the offing for determining how much energy is lost with HVAC terminal units located under windows

"Normally in calculating heat loss through glass, the engineer takes the U-value of glass, 1.13 for a single layer, and uses the temperature difference between assumed room-air temperature and outdoor-air temperature. But with an HVAC terminal under the window, the conditions are not what normally is assumed. First of all, there no longer is an interior layer of still air that acts as an insulator. Secondly, the temperature of the indoor air is not room-air temperature, but supply-air temperature. Both of these conditions increase the energy losses. I wonder if this has been quantified?"

Replied John Yellott: "This is being studied by the University of Florida. Further, the new edition of the ASHRAE Handbook of Fundamentals has quite an elaborate treatment of this subject. So it has been quantified, and there are numbers that can be used for the design of HVAC systems."

Engineer Jack Beech wondered whether the operable window was going to be reinvented—because it would affect how engineers design HVAC systems

Beech reminded the audience that the configuration of windows that will meet ASHRAE Standard 90-75 represents only a small portion of the entire energy expenditure in a building. And he warned that some of the energy simulation studies—showing energy balances taking into account useful solar gain and daylight to replace electric light—have dealt only with a single 12- by 15- by 10-foot-high module.

"But that's not how it is in real life," he said. "Real life is buildings with a million square feet and both interior and perimeter spaces. In New York," he said, "we pump ventilation air around with thousands of horsepower. We have ventilation air requirements, we have sealed windows, and the systems continue to operate without any involvement of the occupants themselves."

Environmental-systems engineer Gershon Meckler emphasized that the building had to be treated as a system . . .

"The key element in understanding the window problem," stated Meckler, "is to understand the energy relationship as the window impacts the energy relationship of the whole system. But it's not easy," he warned the group. "For example," he asked, "With under-the-window HVAC units, what is the impact on fans if there is an incremental increase or decrease in the square footage of glass? Very few people know that," opined Meckler. "It's not an easy trick to dissect and break apart energy usage and define what percentage of the energy can be assigned to the glass, and what percentage to the lights. Until that's done, until we understand this, we will be hamstrung on the ability to innovate.

"Fred Dubin says he would like to have a dynamic window that reacts to energy inputs or losses, and that heats or cools," Meckler continued. "The window would do its own heating or cooling automatically. That would be window management to his way of thinking. Well, as a matter of fact, 10 to 12 years ago we developed a vertical venetian blind for installation inside the building through which heated or cooled water could be circulated to counteract solar gain or heat losses. We found that we could circulate non-refrigerated water to absorb solar load. Also we could neutralize heat loss through low-temperature heating using the louvers and solar-heated water. Now it's these kinds of systems that we have to address ourselves to in order to make intelligent approaches to interrelating the mechanical systems with the windows."

Architect William Jarratt reminded the Round Table that a building wall is a system, too . . . and that appearance is just as important as function

Following up on Dubin's and Meckler's remarks, Jarratt raised the subject of geographical location: "In Michigan," he said, "there's no question of whether there will be double glazing and a heat source on the outside wall to offset the cold-wall effect. On the other hand, in San Francisco, most of the time double glazing is not used because of the favorable climate. With retrofit," he warned, "architects will be concerned about the appearance of devices such as insulating shutters. For example," he said, "when architects retrofit (which usually means restoration to them), they want to preserve some of the good things given to us in the past. Which means that maybe insulating shutters, in some cases, should look like they used to."

Scientist Berman urged the group to consider totally the benefits of daylight, and of ways to preclude unwanted light . . .

"There are a number of positive effects of daylight that are measurable," Berman stated. "For example, the direction of daylight can improve the clarity of objects that we look at. The patterning of daylight can add to the feeling of spaciousness. Of course, the level of electric lighting in the space can be reduced proportionately to the contribution of daylight. Such design elements as atriums can intercept infrared energy before it gets into the interior. And architectural/mechanical devices can be designed to 'beam' sunlight into interior spaces for daylighting. Light issuing into a room laterally from windows is of very good 'quality' because it minimizes veiling reflections (i.e., there is no mirror-image reflection back up into one's eyes) [see Berman's speech, page 16]."

Light is light, said engineer James Griffith, but the direction it comes from can make a lot of difference . . .

"Many of the comments and observations during the meeting," Griffith noted, "emphasized reduction in lighting input, which is an arbitrary move, particularly where visual performance is an important factor. When you start designing lighting, you have to have some criteria that approach the goal the facility is being designed for." Griffith pointed out that there are two basic types of tasks: 1) the simple tasks of seeing how to get around in a room, recognizing people, etc., and 2) work-type situations. "For the first type of task, conventional footcandle specifications are satisfactory," he said. "But for visual-performance situations, the designer needs to employ the concept of 'equivalent sphere illumination,' which is an index of the quality of light from the standpoint of veiling reflections—reflections that diminish the ease of seeing.

"When equivalent sphere illumination is used as the measure of quality of light for effective seeing," Griffith stated, "a footcandle of daylight [because of the direction it comes from through windows] can be three to four times as effective as footcandles from overhead lights. In addition, you are reducing the amount of electric energy needed.

"What this all means is that the lighting designer must look at the total system based upon the lighting conditions that can optimize the productivity of workers. When one uses life-cycle/cost benefit analysis in analyzing a system, one can account for all of the input energy, and also for the most critical energy resource we have, and that's human."

The control of the sun's daylight and infrared energy should be done actively rather than passively, said Bill Chapman

"It seems to me that our best opportunity for retrofit of existing buildings is to come in with some active control as contrasted with some passive system," said Chapman (the immediate past-president of ASHRAE). "Considerable savings can be demonstrated even with the simple system of turning lights on and off manually," noted Chapman, "but there are well-established control means that are far more sophisticated than that. We can actually measure the load of daylighting in summertime," he continued, "and determine when it's beneficial, and when it's detrimental."

Fred Dubin, looking into the future, thought that solar greenhouses had a lot of potential for residential, and even commercial, buildings

"I think that we are getting into a period when we need to grow more and more food, and the greenhouse would be a tremendous adjunct to an existing building," Dubin observed. "If it's designed properly, you can utilize the energy that the greenhouse captures because most of the time it has more than it can use for its own purposes. Certain kinds of combinations of both active, semi-active and passive systems could be used. One of the entries in a recent AIA competition was low-cost housing with greenhouses, designed by a group of young women students at the University of Colorado. It was a very cost-effective design, and added another dimension to the building."

Consultant architect Herb Swinburne experienced "a bit of deja vu" when he listened to a proposal for external solar controls . . .

Earlier, Fred Dubin remarked that a systems approach looking at cutting solar load and reducing heat loss caused by wind suggested that external fins and louvers could accomplish both, and in the long run be more effective than going to the various kinds of glazing. "In other words," he said, "clear, tinted glass for glare control, with external devices to control both wind and sun."

Following up on this remark, Swinburne said, "Why don't we look back to the '30's before we had all this air-conditioning. These external solar controls have already been done before—and in high rises. I refer you to Le Corbusier in the Mediterranean area, and to Oscar Niemeyer in South America. I don't think we need much research on that—it's all been done."

Effective utilization of daylight for office buildings may call for higher ceilings and shallower floors . . .

Floor-plan configuration of present-day office buildings is just the opposite of what would be good for effective daylighting, said architectural-engineering professor John Flynn. Buildings of the '30's and earlier—with interior courts—worked out very nicely. But in recent years, ceilings were lowered, and floor plans were made deeper.

Studies in the architectural engineering department at Penn State, described by professor Flynn, compared a squarish 1960's building with one that was long and narrow, and that had higher ceilings. The latter building was a daylighted design with sunscreens. While computer analysis of this building showed that it consumed only 37,000 BTU/sq ft/yr, the 1960's building with larger interior area and that was electrically lighted, consumed 70,000 BTU/sq ft/yr. Flynn said the daylighted building would not pass Standard 90-75 on the basis of over-all U-value, but it would qualify under Section 10 of 90-75, as Preston McNall pointed out during the discussion period.

Flynn said that he was not arguing for higher ceilings and narrower rooms, but observed that this would be a step to take to save energy. "Perhaps we should go back and look at the way daylighted buildings were built—narrow rooms, light wells—all of those things architects of a generation ago knew well."

Following up on professor Flynn's remark that the daylighted building did not meet the prescriptive portion of Standard 90-75, engineer Griffith was not so sure the optional provision encouraged innovation

Because the architect and engineer have to design first according to the prescriptive portion of ASHRAE Standard 90-75 to get a budget, and then redesign if they wish not to follow certain of the prescriptive requirements, he thought this was inhibiting to innovation. "They're doing a lot more planning design work than the designer who decides to conform to the prescriptive parts," Griffith said. "I think you're going to find this to be counter-productive to energy conservation, rather than productive."

South-facing, triple-glazed windows in a super-insulated house can supply a third of the heating energy, a computer study at the Small Homes Council showed, reported professor Rudy Jones

Because Illinois architects and home builders were disturbed about a proposed legislative move to cut down sizes of windows to save energy, the Small Homes Council at the University of Illinois designed a house with triple-glazed windows on the south exposure, with overhangs to cut out unwanted summer sun, and with extra-heavy insulation in ceilings and floors. A computer study, using a modified version of the NBS load-calculation program, showed that the sun contributed at least one-third of the heating energy required; another third came from internal gains—so only one-third needed to be supplied by the heating system of the house.

The researchers were skeptical about such favorable results, Jones said, so they replaced the south-facing glass with an insulated wall. The results this time showed much higher energy consumption because the south-facing windows on a sunny, cold day could have contributed a significant number of BTU/sq ft/day. With the windowed scheme, there could be fairly rapid payback if the heating source is electricity, Jones said.

"One slight problem is that there might be periods in the spring or fall when there is more energy than we'd like, and we would prefer to have some additional screening on the lower part of the windows —which, incidentally, makes me think that perhaps venetian blinds are designed upside down. They ought to come up from the bottom, because usually it's the lower part of the window that you want to cut out from getting solar heat during the summer."

Windows might not be high-tech, but compared to other methods for capturing solar heat, the cost is much less—the point was made by Stephen Selkowitz of LBL

"Studies have shown," said Selkowitz, "that the cost of a solar heating system that provides between 50-80 per cent of the building's needs may cost from $5,000 to $15,000. On the other hand, by placing windows in a house where they may capture the sun, between 10 and 50 per cent of the heating load might be recovered, depending upon the climate. The ballpark figure that we have been talking about is about 30 per cent.

"This is hardly a new idea," Selkowitz stated. "Research people have pointed out that as long ago as 1947, a paper by F. W. Hutchinson went into an analysis of this problem, and what the effects were of latitude and other variables. From this study, one can see very quickly where in the United States, and under what climatic conditions, insulated windows for solar heat recovery are practical.

Selkowitz remarked that regulatory officials in California have become aware of the potential because the glass restrictions first included in the California state regulations have been modified to allow more south-facing windows, when they are double-glazed, than was permitted in earlier drafts. But one area, he acknowledged, that needs research is the amount of mass in the house—so that heating is not instantaneous, but also so that overheating does not occur.

With governmental and land-planning requirements being what they are, it is not always possible to have a good south exposure, noted Harmony Home's Smith. "You'll find many, many subdivisions," said Smith, "that have no windows whatsoever on the ends of the houses—simply because of the location and land-planning requirements brought about by regulation. In one project I inspected, trying to select two houses to build under the National Association of Home Builders' conservation program, only two lots in the whole subdivision would allow a good south exposure.

"In research, we can talk about south exposures and the like, but when you get out there building the houses, it's a different world! There are not many times when you can go out on extremely large blocks and change the windows to meet some of the requirements that are being mentioned here today. The point is that we have to deal with the building regulatory system, and this is a problem in building codes, zoning, and so on."

Co-moderator Wright wondered about the status of standards for window properties, in the context of energy standards as a whole

Rudy Jones felt that one of the biggest problems with respect to applying the performance concept to building components was having a source for impartial evaluation. He felt that it was fairly well known that ASHRAE, ASTM and American Refrigeration Institute all were working on different aspects of standards and tests for solar-heating panels.

One of the editors said that there was "a great need to develop test methods for so-called 'window-management' devices such as shades, blinds, draperies, shutters. What exactly are the thermal properties of each one of these so that the homeowner can know exactly what he or she is getting, and what effect it will have when he puts it on his house?"

While the thermal and daylighting properties of windows figure prominently in the energy equation, what about the psychological aspects?

For an answer on this, Round Table moderator Wright turned to Mary Powers of *The Ladies Home Journal:* "When we heard there was the possibility of regulation affecting the size of windows, we set out to survey attitudes that homeowners, men and women, had on the possibility of window sizes being determined by legislation. The reaction—though it was from people who are very worried about the energy crisis and the cost of energy—was very emotional. They talked in terms of wanting more, rather than less, if they were to make a change in the amount of window space in a new home, or if they were to refurbish or change their present home. They became upset at the thought that they might be denied the freedom of choice, and there was much grumbling about government interference in their private lives.

"We then asked them, what about a commercial building? What about offices, hospitals, libraries, churches—the whole gamut? They replied that if any buildings should be regulated, then it would have to be government buildings. Some did feel that office buildings could do with smaller windows—but it turned out that these respondents were often the people who were not working in office buildings.

"Then we asked them what they would do to save energy, inasmuch as they had demonstrated their concern about the problem (and at that time everybody was talking about windows being the big energy-loss sources). They said that it didn't have to be so . . . that loss could be controlled by draperies, and by how the heating was used. . . .

"They also demonstrated a fairly high level of knowledgeability about the various devices available, though they didn't use technical terms. We found that people were aware of double glazing, even though they might not have referred to it this way. So I would suggest that we not underestimate the consumer out there. In fact, we found that they have been practicing window management, though they didn't know it, for years and years and years!"

Engineer Griffith echoed the view that more reliance should be placed on the people who use buildings, and the professionals who design them

Griffith cited the example of his first-grade teacher who told him he should sit so that the light from the window came from the left side. "After 40 years of research, I can say she was right," he said. "The only difference is, I know now why she was right, but she knew back then by practice."

A similar point could be made about energy-conservation standards related to lighting, he argued. "A requirement that the lighting take only so many watts per square foot is no insurance that there will be adequate illumination. In fact it has absolutely no basis for either performance or conservation," Griffith emphasized. "What I'm saying is—leave the problem to an architect who is trained to design, based upon performance. If we approached the energy problem that way, rather than the way we're doing it, we'd be far ahead of the game."

Glass manufacturer Don Vild thought more emphasis in research should be put on how the amount of glass in a building affects worker productivity . . .

"While there is technology available regarding characteristics of building components, and how a building will perform in terms of energy usage, very little is known about the effects of building design on the output of occupants. For example, what is the reduction in productivity if windows are eliminated? I suggest one of the main research thrusts might be just this area. Clearly, if the energy input is reduced 20 per cent by using small windows, while the worker output is reduced 25 per cent, the building is not energy efficient!"

Dr. Wright wondered whether the free market would support energy-effective windows. Dr. Berman thought not . . .

"The free market is not going to do very much," said Berman. "Discussing this with people who are experts on economic incentives, you hear two points of view: 1) Though people may be ready, they are waiting because they 'know' the government is going to subsidize—'so why insulate when I know I'll get a 50 per cent subsidy if I wait?' 2) You've got to scare the pants off people before they'll move on window construction . . . an enormous tax or a statement that you've got to cut back on energy consumption by 25 per cent, or else!"

. . . but Earl Swanson of Andersen Windows thought otherwise:

"I believe there has been a strong increase in the awareness of the problem on the part of the public. . . . I think it is on a very sharp curve. But I'm not enough of an economist to know what time interval occurs between acute awareness and action. I suppose there is a delay because people by nature are inclined to 'put it off' until something ignites their action." Swanson placed some of the blame on poor communications: "I think that we have failed to make known to others in our own industry all of the new ideas, all of the new techniques, all of the new materials that are available today. We've done a great job of *providing* materials, techniques, architectural know-how, and mechanical engineering know-how, but we haven't done a good job of communicating. With improved engineering and improved merchandising, I think that the demand situation and the supply situation will mesh to a greater extent than they do now. My reaction is that we're doing a better job than has been reflected here so far."

Maybe the homeowner would respond faster if the banks made it easier for him to borrow the money at low interest, commented Eberhard

"One bank association said that most of their members really cannot afford to extend a loan to the private homeowner because the cost of the paperwork involved in handling the loan, changing the mortgage, and so on. But not all lenders feel this way. The president of a savings and loan association in Des Moines, Iowa, said that they're going to let people open up their mortgages for $800. They are not going to raise the interest rate, not going to rewrite the mortgage. They are just going to add the increment to their payments —$1.50/month, whatever it is, for the remaining life of the mortgage. They see it as a sound investment—because if people can't afford to pay the cost of energy, they won't be able to pay off their mortgages. If they can convince the rest of their industry that that's the practical thing to do, I think the response of people in the marketplace will be much faster."

Architects can respond in energy cost-effective ways, said William Jarratt—and he illustrated by citing his office's approach to task lighting . . .

"In my own office we have developed a computer program that allows us to determine the most effective locations in the ceiling for lighting fixtures, depending upon furniture locations. We can take different patterns of lighting fixture layouts and plot the equivalent sphere illumination levels at the desks throughout a space. Through this procedure we can come up with the least watts per square foot for a desired performance level. The computer program has been elaborated so that it also can take into account daylight contribution."

The corporate owner can innovate right now, remarked IBM's Robert Howe . . .

"Corporations need incentives, just as anyone needs incentives, to innovate. But companies such as ours, and operations as large as the Postal Service, ought to be able to risk a little something for innovation. First of all we can draw on our own past experiences and our resources in the form of knowledgeable people. Secondly, we can hire good architects and engineers to come up with innovative ideas that have a better than even chance of being successful. Of course, the difficult problem we have with human factors and window management can only be solved by having each on-site supervisor or manager given the responsibility to get the job done.

Payback (return on investment) can look pretty good right now for some types of retrofit, and with some energy sources, said builder Smith, when asked what rate of return a homeowner would expect

To make retrofit investment attractive to the homeowner, the return on investment would have to be somewhere above 10 per cent, Smith replied. Studies with power companies have shown, said Smith, that payback on such retrofit as thermal insulation, triple glazing, and heat pump can get as high as 33-39 per cent. "If you talk to the homeowner and tell him that investment in energy conservation is going to give him more money than what he can get invested in a bank, he will accept that. Payback has to be less than seven years for the homeowner to be interested."

Scientist Selkowitz urged designers to study the total dimensions of the window problem to get the most energy-effective solution:

"Someone earlier," said Selkowitz, "addressed the problem from the point of view of 'starting with a hole in the wall.' That's important. We have to look at what's on the inside of the building and what's on the outside. So many buildings have all four facades identical. Why? Shouldn't the south wall be different from the east, the west, or the north?"

Then there's the question of whether the application calls for solar heat and light, or just light. Selkowitz said, "The question was asked, 'If you use reflective glass for solar control, what happens to your winter heat gain?' It was pointed out that in today's office buildings, heating is not a major problem because of the large interior space and internal heat gains, but the natural lighting question is still important. If we have glass chosen for solar exclusion that admits only 10 to 16 per cent of the daylight, what have we done to the lighting possibilities? I think we need to spend more time looking at the integrated effects to come up with a proper design."

The homeowner needs help, Preston McNall agreed, in getting some tangible information on just what he'll save by retrofitting . . .

"What we need is a data bank so that the homeowner can go out and look at his window, check the newspaper to see what his fuel rates are, and then have the answer as to what he could save on that window per year if he did this, that, or the other thing."

But the biggest problem is communication, communication, communication . . .

Said Griffith, "I would say there are people sitting around this table who have known for 25 or 30 years that windows were cost-effective in energy conservation. Unfortunately, they're *the ones* who know it. I think the biggest problem is taking the knowledge we have at hand and disseminating it." Acknowledged builder Smith: "There is a tremendous amount of research going on that I wasn't aware of as far as windows are concerned. There is a lack of communication of this research to the people who are selecting windows and putting them in homes—I'm referring to residential builders."

Warned solar expert John Yellott, "Before any further research is undertaken, a careful study should be made of the literature to make sure somebody hasn't done it 20 years ago. For example, Don Vild, who's sitting here today, did a lot of research 20 years ago on glass characteristics at the former ASHRAE laboratory in Cleveland."

In summing up his impressions of the Round Table, and proposing actions to be taken, DOE's Dr. Kurt Riegel saw needs for . . .

1) Design procedures leading directly to energy-effective windows; 2) the compilation of data on window performance and management to support these design procedures; 3) the development of test methods for the evaluation of window systems; 4) advances in window systems hardware and software. What is needed, said Riegel, are guides on window systems and components that give simple, practical step-by-step instructions for designers and builders so that energy-conservation opportunities offered by good windows and window systems can be realized.

He proposed that the private and public sectors move vigorously, and in concert, to eliminate the information barrier. Specifically he indicated three areas for cooperative work: 1) Dissemination of information to the practitioner; 2) simplified calculation methods to supplement computer models and to act as a bridge between the researcher and the user in the field; 3) the development of reliable and effective active controls for windows to make window management practical. Research and development such as the work at Lawrence Berkeley Laboratory on thermally-activated optical shutters is in the direction of the latter, he said.

Lastly, Riegel stated, this meeting should be followed by others to more sharply focus on individual technical issues, and to get the word out to practitioners. He reminded the assembled group that DOE has an active window and energy conservation research program which is discussed in, "Consumer Products and Technology Branch Program Plan." He indicated that the program is being currently funded at $400,000 annually, and that many individual projects are carried out through private-sector subcontractors.

7

Summary and conclusions

Recapitulation of major research issues that surfaced during the discussions.

By Richard N. Wright
Director
Center for Building Technology
National Bureau of Standards

Testimony at the Round Table made amply clear that people like windows. A *Ladies Home Journal* survey, it was reported, showed that homeowners would prefer more rather than fewer windows. And architect Harwood Taylor found that office workers objected to windows that at the top were less than 7 feet from the floor, and at the bottom were higher than 3 feet from the floor.

But what about energy performance? Can windows take in more energy as passive solar collectors and light sources than they lose in air leakage and thermal conduction? What is known and what needs to be learned about the performance of windows, and how can designers use this knowledge to achieve useful, safe and economical buildings?

As mentioned in the beginning, objectives of the Conference/ Round Table were to: 1) define the technology available now, 2) describe the research under way and the anticipated availability of improved technologies, and 3) learn the needs of designers and industry.

The four speakers addressed themselves to the first two objectives. Panelists and auditors offered suggestions, raised questions, and expressed concerns. In her paper, Dr. Belinda Collins of NBS reported on studies at the Bureau on human requirements and window management capabilities, over-all design concepts, thermal performance and economic implications. Dr. Samuel Berman of Lawrence Berkeley Laboratory reviewed their current window research dealing with concepts for, and performance of, new window materials and components. David Button of Pilkington Glass discussed techniques for making windows positive factors in saving energy through solar radiation and daylighting. Architect Harwood Taylor of 3D/International told how a leading design firm has responded to energy concerns by utilizing high-performance glasses to achieve energy-effective designs, while still providing building exteriors that are pleasing to look at and interiors that are pleasing to look out of.

A lively dialogue developed between building users and building product suppliers. The discussions clearly indicated that life-cycle benefit/cost information must be made explicit to potential beneficiaries if a number of energy-conserving technologies are to become significant factors in building design and operation.

The discussion periods—following the papers and during the Round Table segment of the meeting—pointed to the needs for research and investigation in the following areas:

1) Convincing empirical documentation of the energy effectiveness of windows including aspects of heating, air conditioning, lighting, and window management;

2) The broad interactions between land planning, building orientation, building shape, building mass, mechanical equipment and systems, and the energy efficiency of windows;

3) Systems for distributing heat from the sunny sides of buildings to exterior zones not receiving sun. Thermal storage for storing heat at times of over-supply, and for releasing it when needed;

4) Human tolerance to variation in temperature and light. Human willingness to provide window management—i.e., active control of window shading devices (drapes, blinds, louvers, etc.) and thermal insulating devices (e.g., shutters).

In closing, I wish to thank all those who made this roundtable conference possible:

- ☐ The speakers for their illuminating and interesting presentations;
- ☐ The participants and auditors for contributing the lively dialogue which sharpened the focus on the issues;
- ☐ Arthur Goldman and his staff for handling the administrative details to such great satisfaction;
- ☐ Heinz R. Trechsel for his leadership in initiating, organizing, and conducting the Round Table; and
- ☐ Finally, all the many researchers whose work was discussed, and whose efforts made it possible to discuss the energy related performance of windows in rational terms.

List of Participants

Co-moderators

Maxine Savitz, Ph.D., *Director, Division of Building and Community Systems, Department of Energy*

Richard N. Wright, Ph.D., *Director, Center for Building Technology, National Bureau of Standards*

Speakers

Samuel M. Berman, Ph.D., *Program Leader, Energy Conservation for Windows and Lighting and Energy and Environmental Policy Analysis, Lawrence Berkeley Laboratory*

David A. Button, *Manager, Technical Advisory Service, Flat Glass Division, Pilkington Brothers, Limited*

Belinda Collins, Ph.D., *Research Psychologist, Center for Building Technology, National Bureau of Standards*

Harwood Taylor, FAIA, *Senior Vice President, 3D/International*

Participants

Jack Beech, *Vice President and Chief Mechanical Engineer, Joseph R. Loring & Associates, Consulting Engineers*

John Cable, *Chief, Architectural and Engineering Systems Branch, Division of Buildings and Community Systems, Department of Energy*

William P. Chapman, *Vice President, Operations, Johnson Controls*

Kenneth L. Credle, *Project Manager, Energy, Division of Energy, Building Technology and Standards, Department of Housing and Urban Development*

Fred S. Dubin, *President, Dubin-Mindell-Bloome Associates, Consulting Engineers*

John P. Eberhard, *Chairman, AIA Research Corporation*

John E. Flynn, *Professor of Architectural Engineering, The Pennsylvania State University*

James W. Griffith, *K-G Associates, Consulting Engineers*

Robert H. Howe, *President, Real Estate and Construction Division, International Business Machines Corporation*

William R. Jarratt, AIA, *Vice President and Director of Architecture, Smith, Hinchman and Grylls Associates, Inc., Architects and Engineers*

Rudyard A. Jones, *Director, Small Home Council—Building Research Council, and Research Professor of Architecture, University of Illinois*

Otis M. Mader, *Vice President, Corporate Marketing, Aluminum Company of America*

Robert W. McKinley, *Manager, Technical Services, Glass Division, PPG Industries, Inc.*

Preston E. McNall, Ph.D., *Chief, Building Environment Division, Center for Building Technology, National Bureau of Standards*

Gershon Meckler, *President, Gershon Meckler Associates*

Kurt W. Riegel, Ph.D., *Chief, Consumer Products and Technology Branch, Division of Building and Community Systems, Department of Energy*

Stephen E. Selkowitz, *Technical Project Manager, Energy Efficient Windows and Lighting Systems, Lawrence Berkeley Laboratory*

David C. Smith, *President, Harmony Hall Development Corporation*

Earl C. Swanson, *Chairman of the Board, Andersen Corporation*

Herbert H. Swinburne, *Consultant in Architecture, Planning and Building Research*

Heinz R. Trechsel, AIA, *Chief, Rehabilitation Technology Program, Environmental Design Research Division, Center for Building Technology, National Bureau of Standards*

Donald J. Vild, *Assistant Director of Research, Libby-Owens-Ford Company*

John I. Yellott, *Professor of Architecture, Arizona State University; and President, Engineering Associates, Inc.*

Auditors

Frank Anton, *Professional Builder*
Phil Bender, *Ford Motor Company, Glass Division*
Thomas Casberg, *Department of Defense*
David Dildine, *AIA Journal*
S. Porter Driscoll, *Center for Building Technology, NBS*
John A. Earl, *United States Air Force*
Robert E. Fischer, *Architectural Record*
Oscar Glasberg, *Glass Digest*
Robert J. Griffin, *Department of Energy*
Jack Healy, *Army Corps of Engineers*
Casper Hegner, *Veterans Administration*
Vincent Hennessy, *U.S. Postal Service*
Forrest Higgs, *Journal of Building and Energy and University of Texas*
Bryan Hodgson, *National Geographic*
Madeleine S. Jacobs, *National Bureau of Standards*
Eileen Leubecker, *Better Homes & Gardens*
James Long, *United States Navy*
Alfred C. Maevis, *U.S. Postal Service*
Will Mehlhorn, *House & Garden*
Colonel James F. Miley, *Department of Defense*
James A. Murphy, *Progressive Architecture*
Fred Nelson, *Sunset Magazine*
James Newbrey, *Glass Division, PPG Industries*
Peter R. Orser, *Libby-Owens-Ford Company*
Elise Platt, *Housing*
Mary E. Powers, *Ladies Home Journal*
David Quentzel, *The Good Housekeeping Institute*
Noel J. Raufaste, Jr., *Center for Building Technology, NBS*
Susan Schraub, *House Beautiful*
Edward R. Sczesny, *Guardian Industries*
B. K. Shaddock, *ASG Industries, Inc.*
Kenneth R. Sheets, *U.S. News & World Report*
Jack E. Snell, *Institute for Applied Technology, NBS*
Roger D. Spenser, *PPG Industries, Inc.*
Harry E. Thompson, *Center for Building Technology, NBS*
Janice Tuchman, *Engineering News-Record*
Gary Wells, *General Services Administration*
Wesley Wise, *Multi-Housing News*
Jerry Wulf, *Andersen Corporation*
Herman York, *Woman's Day*

NBS-114A (REV. 11-77)

U.S. DEPT. OF COMM. **BIBLIOGRAPHIC DATA SHEET**	1. PUBLICATION OR REPORT NO. NBS SP 512	2. Gov't Accession No.	3. Recipient's Accession No.
4. TITLE AND SUBTITLE Energy-Effective Windows Proceedings of a joint DOE/NBS Conference/Round Table on Energy Effective Windows held in Washington, D.C. on April 13, 1977			5. Publication Date April 1978 6. Performing Organization Code
7. AUTHOR(S) Heinz R. Trechsel, Technical Coordinator			8. Performing Organ. Report No.
9. PERFORMING ORGANIZATION NAME AND ADDRESS NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234			10. Project/Task/Work Unit No. 4656520 11. Contract/Grant No.
12. Sponsoring Organization Name and Complete Address *(Street, City, State, ZIP)* Department of Energy Division of Building and Community Systems 20 Massachusetts Avenue Washington, D.C. 20545			13. Type of Report & Period Covered Final 14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

Library of Congress Catalog Card Number: 78-600034

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

On April 13, 1977, a Joint DOE/NBS Conference/Round table was held on Energy-Effective Windows. The conference was attended by 30 participants and speakers and auditors representing all major interests in window industry, government, academia, professions and the media. The procedings of the conference contain:

° An introduction to Window Research and its significance to Energy Conservation in Buildings by Dr. Maxine Savitz;
° An Overview of Window Research at NBS by Dr. Belinda L. Collins;
° DOE/LBL Window Research by Dr. Samuel M. Berman;
° An Architect's View of Energy-Effective Windows by Harwood Taylor, AIA;
° Window Research in the United Kingdom and in Europe by David A. Button;
° Summary of the Discussion by Panel Members;
° Summary and Conclusions by Dr. Richard N. Wright; and
° A List of participants and auditors.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Daylighting; energy conservation; glass; thermal performance; windows

18. AVAILABILITY [X] Unlimited	19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
[ ] For Official Distribution. Do Not Release to NTIS	UNCLASSIFIED	53
[ ] For Sale by the Superintendent of Documents U.S. Government Printing Office, Washington, D.C. 20402 Stock No. 003-003-01929-1	20. SECURITY CLASS (THIS PAGE)	22. Price
[ ] Order From National Technical Information Service (NTIS) Springfield, Virginia 22151	UNCLASSIFIED	$2.20

NBS TECHNICAL PUBLICATIONS

PERIODICALS

JOURNAL OF RESEARCH—The Journal of Research of the National Bureau of Standards reports NBS research and development in those disciplines of the physical and engineering sciences in which the Bureau is active. These include physics, chemistry, engineering, mathematics, and computer sciences. Papers cover a broad range of subjects, with major emphasis on measurement methodology, and the basic technology underlying standardization. Also included from time to time are survey articles on topics closely related to the Bureau's technical and scientific programs. As a special service to subscribers each issue contains complete citations to all recent NBS publications in NBS and non-NBS media. Issued six times a year. Annual subscription: domestic $17.00; foreign $21.25. Single copy, $3.00 domestic; $3.75 foreign.

Note: The Journal was formerly published in two sections: Section A "Physics and Chemistry" and Section B "Mathematical Sciences."

DIMENSIONS/NBS

This monthly magazine is published to inform scientists, engineers, businessmen, industry, teachers, students, and consumers of the latest advances in science and technology, with primary emphasis on the work at NBS. The magazine highlights and reviews such issues as energy research, fire protection, building technology, metric conversion, pollution abatement, health and safety, and consumer product performance. In addition, it reports the results of Bureau programs in measurement standards and techniques, properties of matter and materials, engineering standards and services, instrumentation, and automatic data processing.

Annual subscription: Domestic, $12.50; Foreign $15.65.

NONPERIODICALS

Monographs—Major contributions to the technical literature on various subjects related to the Bureau's scientific and technical activities.

Handbooks—Recommended codes of engineering and industrial practice (including safety codes) developed in cooperation with interested industries, professional organizations, and regulatory bodies.

Special Publications—Include proceedings of conferences sponsored by NBS, NBS annual reports, and other special publications appropriate to this grouping such as wall charts, pocket cards, and bibliographies.

Applied Mathematics Series—Mathematical tables, manuals, and studies of special interest to physicists, engineers, chemists, biologists, mathematicians, computer programmers, and others engaged in scientific and technical work.

National Standard Reference Data Series—Provides quantitative data on the physical and chemical properties of materials, compiled from the world's literature and critically evaluated. Developed under a world-wide program coordinated by NBS. Program under authority of National Standard Data Act (Public Law 90-396).

NOTE: At present the principal publication outlet for these data is the Journal of Physical and Chemical Reference Data (JPCRD) published quarterly for NBS by the American Chemical Society (ACS) and the American Institute of Physics (AIP). Subscriptions, reprints, and supplements available from ACS, 1155 Sixteenth St. N.W., Wash., D.C. 20056.

Building Science Series—Disseminates technical information developed at the Bureau on building materials, components, systems, and whole structures. The series presents research results, test methods, and performance criteria related to the structural and environmental functions and the durability and safety characteristics of building elements and systems.

Technical Notes—Studies or reports which are complete in themselves but restrictive in their treatment of a subject. Analogous to monographs but not so comprehensive in scope or definitive in treatment of the subject area. Often serve as a vehicle for final reports of work performed at NBS under the sponsorship of other government agencies.

Voluntary Product Standards—Developed under procedures published by the Department of Commerce in Part 10, Title 15, of the Code of Federal Regulations. The purpose of the standards is to establish nationally recognized requirements for products, and to provide all concerned interests with a basis for common understanding of the characteristics of the products. NBS administers this program as a supplement to the activities of the private sector standardizing organizations.

Consumer Information Series—Practical information, based on NBS research and experience, covering areas of interest to the consumer. Easily understandable language and illustrations provide useful background knowledge for shopping in today's technological marketplace.

Order **above** *NBS publications from: Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.*

Order **following** *NBS publications—NBSIR's and FIPS from the National Technical Information Services, Springfield, Va. 22161.*

Federal Information Processing Standards Publications (FIPS PUB)—Publications in this series collectively constitute the Federal Information Processing Standards Register. Register serves as the official source of information in the Federal Government regarding standards issued by NBS pursuant to the Federal Property and Administrative Services Act of 1949 as amended, Public Law 89-306 (79 Stat. 1127), and as implemented by Executive Order 11717 (38 FR 12315, dated May 11, 1973) and Part 6 of Title 15 CFR (Code of Federal Regulations).

NBS Interagency Reports (NBSIR)—A special series of interim or final reports on work performed by NBS for outside sponsors (both government and non-government). In general, initial distribution is handled by the sponsor; public distribution is by the National Technical Information Services (Springfield, Va. 22161) in paper copy or microfiche form.

BIBLIOGRAPHIC SUBSCRIPTION SERVICES

The following current-awareness and literature-survey bibliographies are issued periodically by the Bureau:

Cryogenic Data Center Current Awareness Service. A literature survey issued biweekly. Annual subscription: Domestic, $25.00; Foreign, $30.00.

Liquified Natural Gas. A literature survey issued quarterly. Annual subscription: $20.00.

Superconducting Devices and Materials. A literature survey issued quarterly. Annual subscription: $30.00. Send subscription orders and remittances for the preceding bibliographic services to National Bureau of Standards, Cryogenic Data Center (275.02) Boulder, Colorado 80302.

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
Washington, D.C. 20234

OFFICIAL BUSINESS

Penalty for Private Use, $300

POSTAGE AND FEES PAID
U.S. DEPARTMENT OF COMMERCE
COM-215

U.S.MAIL

SPECIAL FOURTH-CLASS RATE
BOOK