Photovoltaics in Architecture: Thermal Simulation of High Rise Commercial Buildings Using Photovoltaic Glazed Windows

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INTRODUCTION

The Need for Energy Conservation

Despite the reduction in the per capita energy use and the steady increase in the GNP in America, the consequences of future energy shortages and the increases in energy costs (Kraushaar and Ristinen, 1998) can be seen in the recent blackouts in America's northeastern and pacific northwestern states . In Texas, the energy consumption was predicted to surpass their production of energy in 1993 (Sloan, 1995). On a national level, once this trend affects all states, who will supplement the energy needs of America and who will control the energy distribution and costs.

To answer these questions, we must give immediate attention to preparing for possible increased energy shortages, while maintaining a stable economic and social structure for future generations. In this `section a discussion of the impacts of solar energy (photovoltaics) on government policies, deregulation of the utility industry, building construction, the energy use of commercial buildings, and social acceptance is presented.

Government Policy and Support

With governmental concerns over accelerating energy conservation, research of Building Integrated Photovoltaic (BIPV) systems has been congressionally mandated in the United States (Ashley, 1992). Additionally, major government demonstration programs using BIPV systems have been initiated in Austria, Germany, Switzerland and the Netherlands (Schoen & Blum, 1994).

With efforts to significantly increase the use of a clean and renewable resource, in 1994 President Clinton announced the Million Solar Roofs Initiative for the United States. Working with businesses and communities, the U.S. Department of Energy will coordinate the installation of solar panels on one million new roofs by the year 2010. The President's program targets: 1) electric utilities and energy service organizations, 2) PV manufactures and PV infrastructure organizations, 3) community, city and corporate personnel, 4) community development organizations, 5) residential and commercial real-estate developers, 6) architects and energy consultants, and 7) local and regional financial institutions (UPG, 1997).

Another program by the Department of Energy promotes partnerships between the public and private sectors to lead to sustainable utility photovoltaic markets (UPG, 1997). Entitled the building Technology Experience to Accelerate Markets in Utility Photovoltaics, TEAM-UP funds ventures that develop sustainable markets and opportunities for PV applications. It also funds programs that take advantage of business opportunities with PV technologies and supports the expansion of utility PV markets through collective market actions or pre-commercial installations. With continued support from the government and increased public awareness, the use of photovoltaic systems is expected to increase and expand into new applications.

Deregulation of the Utility Industry

The Public Utility Regulatory Policies Act of 1978 (PURPA) and the 1992 Energy Policy Act (EPACT) increased competition in the electric generation industry. PURPA requires utility companies with a need for more electricity to receive bids from alternative suppliers, while EPACT extends the scope of non-utility producers by creating a new class of suppliers that are permitted to sell power in wholesale markets. EPACT also requires the owners of transmission facilities to provide independent suppliers with open access to the electric grid to transmit power to wholesale utility customers. In 1992 Congress passed the Energy Policy Act to deregulate the sale of electricity to promote competition among power sellers and to create lower electric rates (King, 1996). With a shift from large, central power plants to smaller generating facilities, a restructured electricity industry is now poised to offer significant opportunities for the increased deployment of renewable energy using integrated photovoltaic systems (Brown et al., 1999).

Building Integrated Photovoltaics

When considering BIPV systems, it is now possible for an owner to use BIPV systems to provide some or all of the building's energy. As a power supplier, the owner can sell the electric energy produced by the PV system to the tenants of his or her building. Conventional or other renewable sources of electricity could then be used to provide the electricity not provided by the BIPV system. Conversely, this concept may not apply to all building management structures, and therefore, more research is required to develop feasible financial solutions for building owners and management groups. Projected to affect up to 70 % of a building's electric demand when designed for their optimal energy production, research of BIPV systems has been aimed at integrating photovoltaic elements directly into the roofs and walls of commercial buildings (Ashley, 1992).

To offset our predicted energy shortage, we can provide electric energy at the point of demand using BIPV systems. Converting sunlight into electricity, these systems integrate with the energy use and structure of buildings as weathering skin, sun shading, and roof and window systems. Because they provide a viable alternative and renewable method for generating electric energy, BIPV systems can improve and secure our economic growth by reducing our dependence on non-renewable energy.

While roof mounted modules have been tested and used intensively, as seen in the solar roof programs around the world, efforts to integrate PV into facades have been hampered by several unsolved problems in the module design and the cost of wiring and framing (Bendel et al., 1994). Nonetheless, several demonstration projects are investigating PV as cladding and glazing for facades . In the United States, Advanced Photovoltaic Systems (APS) company integrated PV skylights and semi transparent curtain walls into their new manufacturing facility in Fairfield, California. In Germany, the Bavarian Environment Ministry uses amorphous silicon modules in the non-window areas of the facades (Strong, 1994). In Japan, a prototype PV façade has been installed by Sanyo in a building for the Tsukasa Electric Industry Company.

Energy Use of Commercial Building

Among commercial buildings, one of the most significant energy users has been the tall building. Typically a sealed enclosure without operable windows, tall buildings are usually oriented to match the prevailing street layout, and therefore, may not have an optimal solar orientation. To maintain a comfortable environment for the building's occupants, in southern climates, tall buildings depend on the use of mechanical cooling to compensate for heat gain from the sun or heat and humidity gains in ventilation air.

To offset the existing drain on non-renewable energy, commercial buildings will eventually have to increase their use of renewable energies and energy conserving technologies. Although current applications are few, photovoltaic systems are potentially one of the most useful of the renewable energy technologies. According to Kiss et al., (1995), photovoltaic systems using glass substrates, as compared to flexible photovoltaic modules using stainless steel substrates, are the most available photovoltaic products that can be immediately integrated into current building systems.

Societal Impacts

Despite the known benefits of photovoltaic systems, architects, builders and developers are still reluctant to use photovoltaic systems as integral building elements (Goethe, 1994). Their reluctance is due to a lack of understanding about the economic and aesthetic aspects of BIPV systems. For example: Are photovoltaic systems economical and how will they look? Therefore, to address economic and aesthetic concerns, we must define the economic and environmental benefits of photovoltaic building products for the public and building community. In addition, we must understand what factors, such as aesthetics, will influence their acceptance (Kiss and Kinkead, 1996).

Finally, if society continues to demand architects to design in climates where ambient conditions are inhospitable, reducing energy consumption becomes paramount due to the continuous need for mechanical cooling and heating. Furthermore, if architects continue to seek new forms of architecture that are independent of the climate and orientation, renewable energy conservation methods must be utilized to provide as much renewable energy that is financially viable to operate such buildings. Thus, to improve the building's sustainability, an economic and psychological analysis of photovoltaic glazing in commercial buildings will lead to a better understanding of their potential to save energy and social acceptance.

In the following section, this paper reviews issues surrounding the design of photovoltaic glazing, their installation and maintenance in buildings, and how they affect owing and operation costs of commercial buildings. In addition, a review of the state of the art energy simulation software is discussed, as well as methods for predicting the photovoltaic system's thermal and electrical performance. In the following section, the review of literature discusses the effects of windows on people and the measurement tools that are used to determine the level of human satisfaction

METHODOLOGY

Introduction

This study targets high-rise buildings within densely populated urban centers in the United States. Within each census region (Northeast, Midwest, South, West) a typical city was selected. To insure that the selected sites had the appropriate characteristics of a downtown district within large urban centers, each selected city had a population greater than one million people, based on 1992 US Census Data. Furthermore, in census regions where more than one city met the selection criterion, the city with the largest population was chosen (Figure 1).

Census Region:	City:
South	Houston
West	Los Angeles
Northeast	New York
Midwest	Detroit

Figure 1. Selected Sites for Each Census Region
The sites selected contained human population greater than >million. In census regions where more than one city met selection criteria, the one with the largest population was selected.

Using a typical high rise building and city block, this study used a forty-story building surrounded by buildings one-half its height. Because of their density and grid layout, general characteristics of the city block, as observed from maps, are: small-building footprints, multi-lane roadways with off-street parking and setbacks for pedestrian sidewalks. To determine the dimensions of the typical city block mentioned above, downtown Houston was used as a basis for all four cities. After review of the appropriate maps and building sites, this study used a building footprint of one hundred by one hundred feet square, six-lane roadways with off street parking and a twenty feet setback for pedestrian sidewalks (Figure 2 and Figure 3).

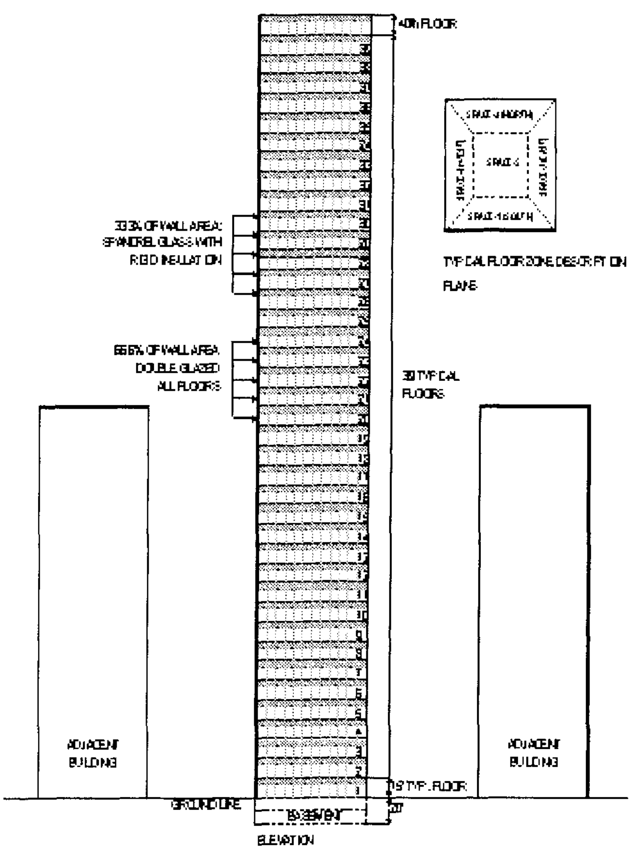


Figure 2. Typical High Rise Building in downtown-city block
The figure shows a 40-story high-rise building within a typical city block and the surrounding buildings that are 20 stories high. The distance between each building is 100 feet and accounts for off-street parking. The building contains 33% spandrel glass and 66% vision glass with a floor to floor height of 15 feet. Each floor has five zones with the basement being a single independent zone.

To determine the building's height, a survey of high-rise structures within each downtown business district was conducted. In general, various data were available regarding historical and prominent buildings within each downtown area. However, very little comprehensive data existed for Houston, regarding the building's sizes. Detroit, no statistical data was available for review regarding its high-rise buildings. Nonetheless, using the compiled data, representing mainly Los Angeles and New York, the average height of high-rise buildings was determined to be 42 stories. Thus, a 40-story building was used in this study. After a survey of the photographs of the selected cities, the surrounding buildings in this study were set at one half the height of the 40-story high-rise building discussed earlier.

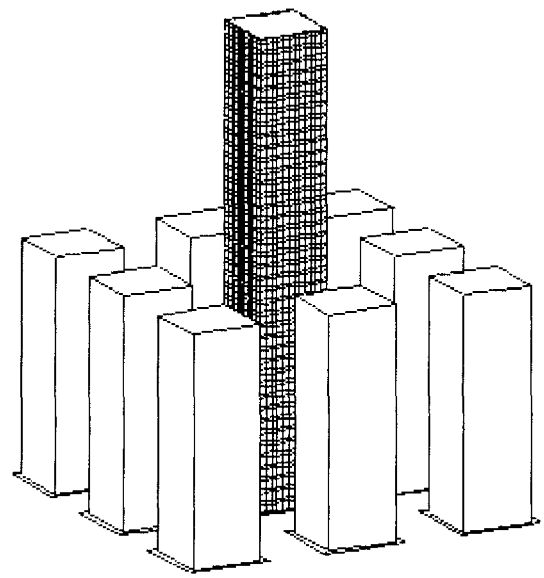


Figure 3. Three Dimensional Model of Prototype Building
The figure, shows the spatial relationship of the prototype building and its surrounding buildings. Based on visual analysis of photographs of the selected sites, all buildings are 100' x 100' in length and width. The surrounding buildings are 20 stories tall. The middle building is 40 stories tall.

In general, the building is a steel frame structure with four-inch concrete floors and roof, a fifteen feet floor-to-floor height, and ten feet ceilings. The curtain wall is 100% glass, with typical floors containing five vertical feet of spandrel glass and ten feet of windows. The interior of the building has suspended acoustic tile and ceilings typical partitions for the interior spaces, and recessed fluorescent lights. Occupancy of the building was determined using 100 square feet per person for perimeter spaces and 200 square feet per person for core areas.

Energy Simulation

As a reference point, the sample2.inp file, distributed with the DOE 2.1e software (LBL, 1980a and LBL, 1980b) was used to develop the input files used in this study. Before modification, the file was simulated using weather data for Houston, Texas and the output was examined for reliable results. The input file was then modified to increase the building's gross energy intensity to be comparable to those of area cities in Austin, Texas. Figure 4 shows the building input file as seen by DOE-2.

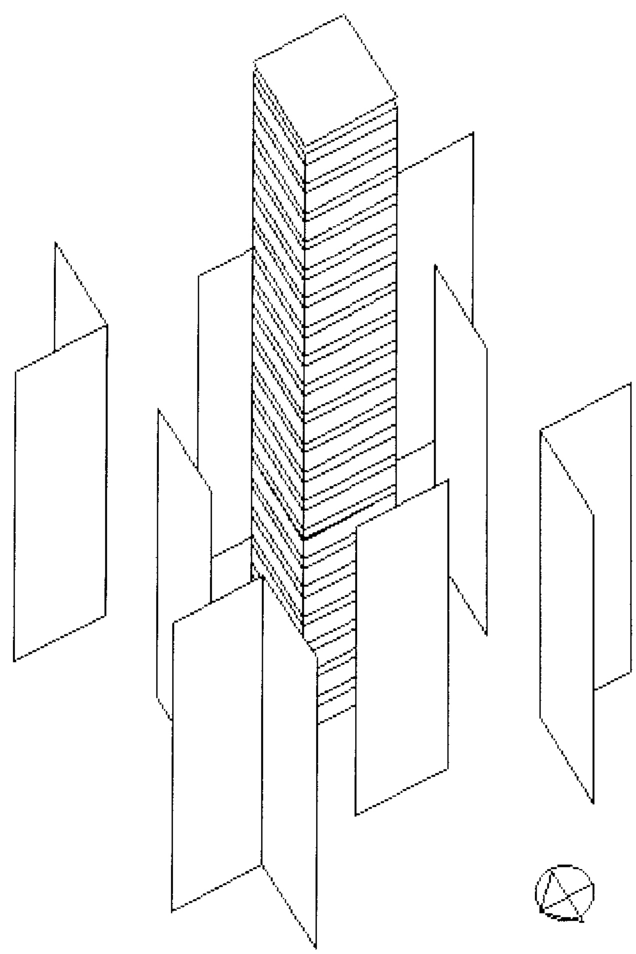


Figure 4. Draw BDL Model of Prototype Building
The figure represents how DOE 2.1E sees the geometry of the building. Due to software constraints which sets limits on the number times a command can be used (LBL, 1993) in an input file, the building input defined the 40 story building using 20 double height floors and ceiling spaces. In addition, the surrounding buildings were defined using only the facades that would affect the shading of the building. In general, corner buildings required the definition of two adjacent facades that were closest to the building while the other buildings, on the North, South, East, and West axis, were only defined with the innermost façade to the center building.

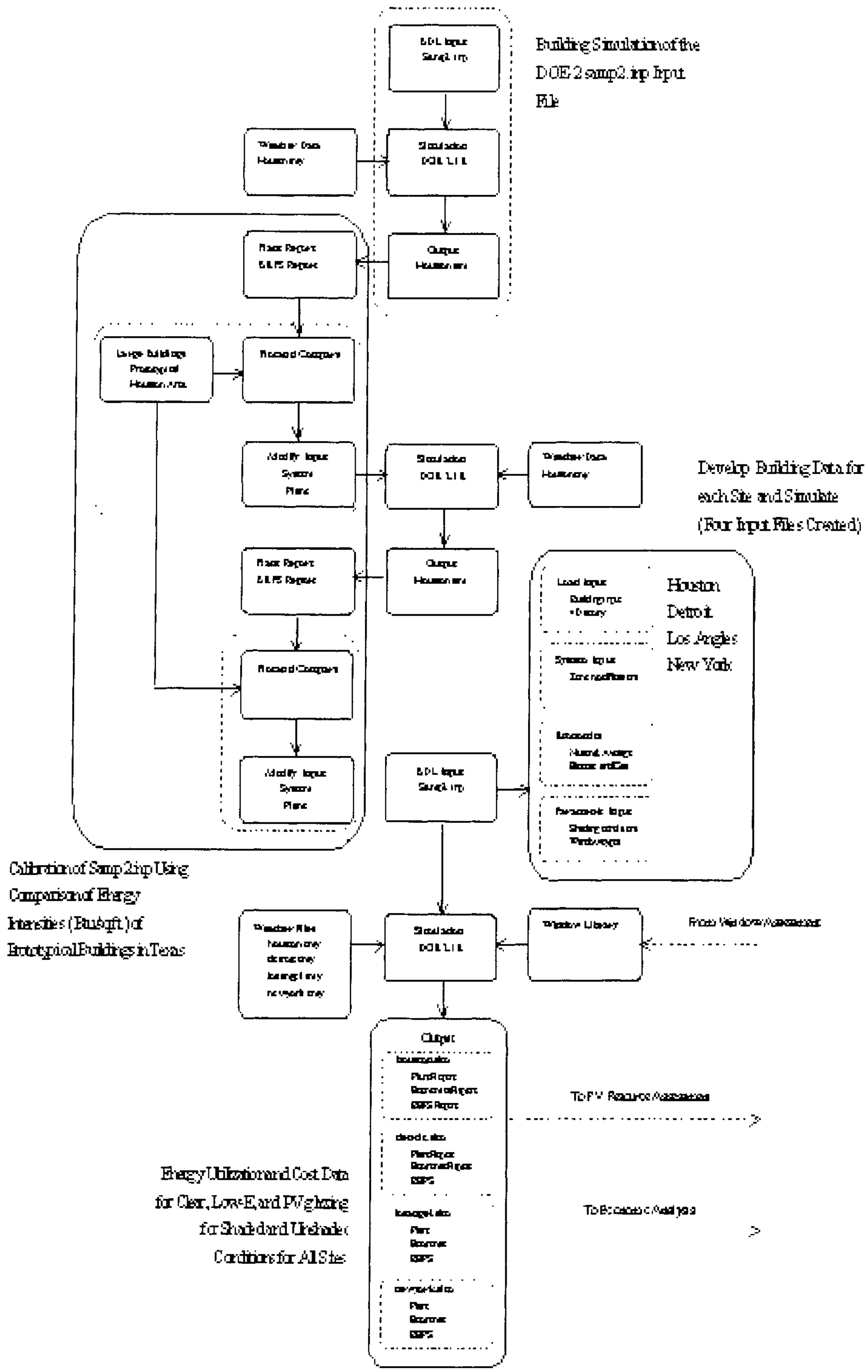


Figure 5. Methodology: Energy Analysis
The figure represents the methods used to conduct the energy analysis in this study. Major components of this part the study are the simulation of the samp2.inp file of DOE-2, the calibration the DOE-2 input file, and the final energy simulation. As shown above, the data produced was used by the PV Resource Assessment and the Economic Analysis Method described earlier.

Using the typical city block defined earlier, the input file was again modified using data of the prototype building, a national average electric and gas cost, and weather data of the selected sites. Each file used the parametric input command to vary window types and shading conditions. In summary, each file produced outputs for six conditions, which represents shaded and unshaded condition for clear, low-e and photovoltaic glazing.

Last, a window library entry was created for the three window types using Window 4.1 (LBL, 1997) and added to the existing DOE-2 window library file. Due to the effect of the location of the solar film on the window's performance, two window types were created for the Low E and photovoltaic windows. In total, the file contained five window entries. For the output data, the plant summary (PS-A), building energy performance (BEPS) and energy costs summaries (ES-D) were reported. However, for this analysis, only the BEPS and PS-A reports were plotted and analyzed for all conditions (Figure 5).

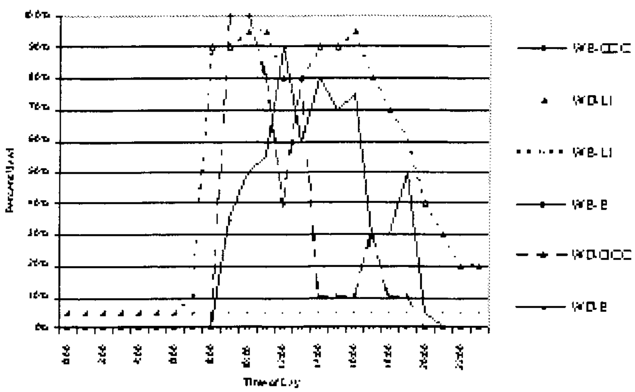


Figure 6. Building Schedules for DOE2 Sample File
The diagram shows the occupancy (OCC), lighting (LI), and equipment (E) schedules for the weekday (WD) and weekend days (WE)

RESULTS

In this study, the DOE-2 energy simulation evaluated the reduction in electricity and the heating and cooling reduction due to the effects of the glazing type. Using the calculated window properties and PV resource assessment values, the energy consumption was determined for each site for the shaded and non-shaded conditions. In addition to the simulation results, this section discusses the DOE-2 input file and its modification.

DOE-2 Sample Input File

The DOE 2.1E programs provide several sample-input files of various types of buildings. For this study, the samp2.inp was used as a basis for developing the case study input file. In general, the DOE-2 input file is a 31-story office building with a steel frame, curtain walls, double-glazed tinted windows, and built-up roofing. In the samp2.inp file, the FLOOR-MULTIPLIER command is used to define a plenum zone and five zone models for each floor. The spaces are 13 feet floor to floor with 9 feet ceiling heights. In SYSTEMS, a single variable-air-volume system serves the entire building. This system has cooling and heating design temperatures of 78 degrees and 70 degrees respectively in the samp2.inp file. The PLANT input uses a chilled water storage system to provide cooling while taking advantage of low nighttime rates. Last, in the ECONOMIC input, uniform rates for gas and electricity are used with a nominal flat rate for electric demand charge. To evaluate the reliability of the input file, the building schedules in the LOAD input were plotted and the BEPS reports from a test energy simulation were tabulated. A plot of the samp2.inp building schedules for lighting, equipment and occupancy are presented in Figure 6 and the tabulated results from the BEPS's report are in Table 1 In this plot, it is evident that the building is almost completely shutdown during unoccupied periods. As a result, the samp2.inp produced an unreasonable low energy use that is not characteristic of typical high-rise commercial buildings in the case study locations.

DOE-2 Sample Input File Modifications

The low unreasonably low energy use of the samp2.inp file made it necessary to increase the gross energy-intensity and energy consumption of the building to reflect that of comparable buildings as shown in Figure 7. The buildings in these tables were selected from the LoanSTAR database at Texas A&M University (Turner et al., 1998) at Texas A&M University based on their gross square footage and building characteristics. In general, these buildings represent mid-rise buildings with 8 to 20 floors and low-rise buildings with 3 to 8 floors. Overall, the low-rise buildings had the larger square footages while the mid-rise buildings had the smaller square footages. In summary, Table 2 shows that there is a 55 kBtu/sq.ft difference between the original samp2.inp file and the national average energy intensity of 100 kBtu/sq.ft in commercial buildings (EIA, 1992). Additionally, there is a 105 kBtu/sq.ft difference between the sample file run for Houston, Texas and the average energy intensity of the LoanSTAR buildings in Austin, Texas. Because of this difference, the energy consumption of the building was increased using the modifications discussed in the following paragraphs.

In the LOADS portion of the samp2.inp file, the building description and windows were the only areas of major modification. The SYSTEMS and ECONOMICS descriptions were only modified to reflect changes in the LOADS input and average energy costs, while the PLANT description required no modifications.

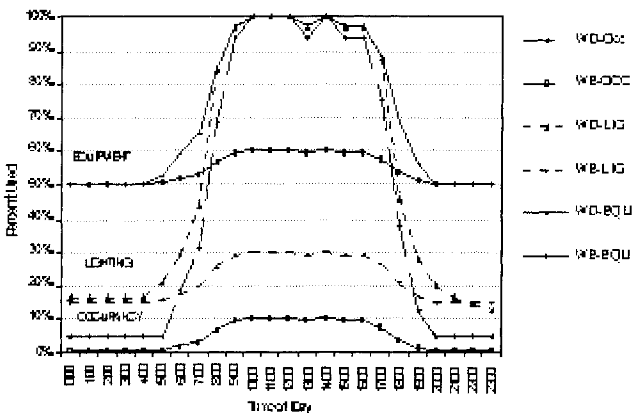


Figure 7. Building Schedules for the Texas Department of Health The diagram shows the occupancy (OCC), lighting (LI), and equipment (E) schedules for the weekday (WD) and weekend days (WE)

In LOADS because the input was written for Chicago, Illinois, the atmospheric moisture and turbidity values were removed. In addition, the occupancy, lighting and equipment schedules of the samp2.inp file were modified to be more representative of the monitoring pool of the Texas LoanStAR program (Turner, 1998) (Table 1). Using these data, the weekday and weekend schedules for occupancy, lighting and equipment were modified. The window-shading schedule that simulated the use of blinds in the windows was deleted and removed from the SET-DEFAULT for the windows.

In the SYSTEMS portion of the input file, the temperatures for the heating schedule were changed from their various inputs to a constant 72 degrees Fahrenheit in order to reflect continuous building operation, which is typical of office buildings in the LoanSTAR database. Likewise, the temperatures for the cooling schedules were changed to a constant 75 degrees Fahrenheit. The temperatures for the weekend set back schedules were also changed from 90 degrees Fahrenheit (summer) and 55 degrees Fahrenheit (winter) to constant summer and winter set points. Likewise, the fan schedules were also modified to provide constant operation of the fans. The heating schedules for the weekday and weekend were set to a constant temperature of 72 degrees Fahrenheit and the cooling were set to a constant temperature of 75 degrees Fahrenheit. The cooling coil set point schedule, in all areas, was set to a constant temperature of 55 degrees Fahrenheit. Note that this could also be accomplished by setting a COOL-SET-TEMP of 55 degrees. The design heating and cooling temperatures were also adjusted to be 72 and 75 degrees respectively from 78 and 70 degrees. ZONE-AIR was set to an OA-CHANGE of 0.25, as compared to OA-CFM/PER of 20. In addition, the damper position is set to be open constantly. Last, humidification was eliminated. The results of all these changes yielded an energy intensity of 156,029 MMBtu/sq.ft, as shown in Table 2. The modified DOE-2 samp2.inp file is included in the Appendix.

Table 1. Comparison of Gross Energy Consumption

Site	Size (sq.ft.)	Electric (kWh)	Heating (MMBtu)	Cooling (MMBtu)	Total (MMBtu)
S.F. Austin	470,000	17,301,615	11,520[1]	27,195	99,314
W.B. Travis	491,000	8,469,987	12,098[1]	35,220	76,217
L.B. Johnson	308,000	12,423,650	7,591[1]	45,434	95,441
Capitol Building	282,499	6,964,998	14,202[2]	30,568	33,334.37
Capitol Extension	592,781	3,368,989	14,931[2]	46,469	59,954
Texas Dept. Of Health	298,700	6,823,603	13,022[2]	22,652	61,968
DOE 2 Sample Building	640,000	6,287,719	1,894	5,460	22,808
DOE ADJUSTED	640,000	18,781,878	25,443	10,332	99,858

1 There is a single gas meter for the S.F. Austin, W.B. Travis, and L.B. Johnson that used 31.270 MMBtu per year. Total usage was divided by the total square footage proportioned to each building.
2 Steam used for heating was assumed 80% efficient.

Table 2. Comparison of Gross Energy Intensity for Selected Sites

Site	Size (sq.ft.)	Electric (Btu/sq.ft)	Heating (Btu/sq.ft)	Cooling (Btu/sq.ft)	Total (Btu/sq.ft)
S.F. Austin	470,000	129,232	24,639	16,452	170,324
W.B. Travis	491,000	58,858	24,639	20,395	103,894
L.B. Johnson	308,080	137,614	24,639	41,950	204,204
Capitol Building	282,499	84,122	62,840	50,896	197,859
Capitol Extension	592,781	48,171	31,485	22,289	101,945
Texas Dept. Of Health	298,700	77,967	75,418	21,568	174,954
DOE 2	640,000	33,521[1]	2,960[2]	8,532[3]	45,013
DOE ADJUSTED	640,000	100,130	39,754	16,143	156,029
National Average	—	—	—	—	100,000

1 Electricity consumption includes the DOE-2 BEPS totals for area lights, miscellaneous equipment, heat rejection, pumps and miscellaneous, vent fans, and domestic hot water.
2 Heating is the sum of electricity and natural gas for space heating.
3 Cooling energy is the electricity used for space cooling.

Table 3. Energy Cost Data for Commercial Users

Source	Service Description	Electricity (kWh)	Demand (kW)	Gas
Estimated Prices[1]	———	$0.734000		$5.18 (mcf)
Detroit[2]	Primary Supply Service	$0.028100	$14.25	
Los Angeles[3]	General Service A2, Rate A	$0.021810	$13.20	
Houston[4]	Large General Services	$0.025496		
New York[5]	General Commercial, Large	$0.054250	$19.27	0.489 (therm)
Average Costs		**$0.032402**	**$15.57**	**$5.18**

1 Source: Energy User News (1998).
2 Source: Detroit Edison (1997). Energy Choices, 1997 Detroit Edison, Detroit, MI
3 Source: Department of Water and Power, City of Los Angeles (1997).
4 Source: Houston Lighting and Power Company (1995).
5 This data was obtain in 1997 through interview with Kelvin Colvin, an employee of Consolidated Edison of New York.

The DOE-2 ECONOMICS input reflects the simplest calculation possible and was modified to use uniform rates for both electricity and gas. In the input file, the fixed monthly rate and rate limitation were deleted and the national average electric and gas charges were used instead, remaining constant for each case study (Table 3). In addition, the peak demand charge was deleted. Only, a flat rate for the electric demand of the building was used. In summary, the comparison of energy use between the modified prototype building and comparison buildings from the LoanSTAR database are shown below.

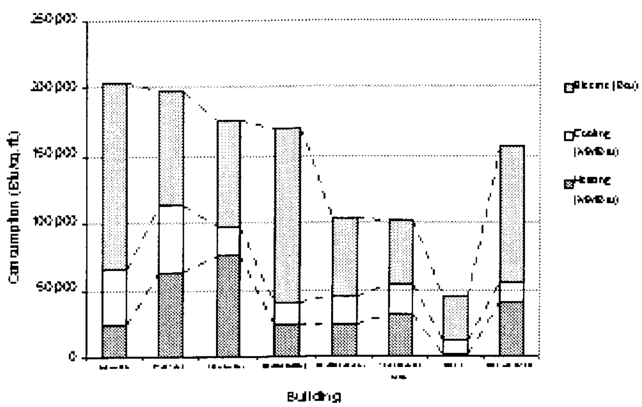
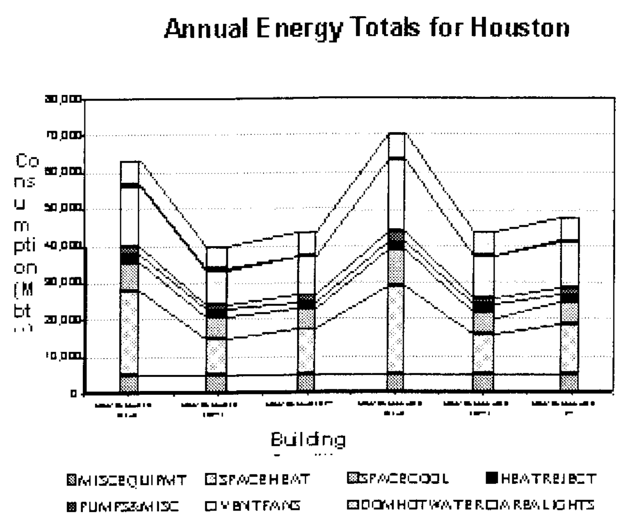


Figure 8. Comparison of Annual Energy Consumption

The figure is a comparison of annual energy consumption for the buildings chosen from the LoanSTAR database and the DOE-2 case study building using the Houston TMY weather file (Energy Soft, 1994).



The figure shows the annual energy consumption for the three window treatments for the shaded and non-shaded effect in Houston. The legend is read by associating, from left to right, the first entry of the upOper row in the legend entry with the bottom division in the figure. This association should be repeated for all legend entries reading from left to right and for the figure reading from bottom to top. The Appendix contains the BEPS results used to produce this figure.

In Figure 8, the electric energy, cooling and heating energy are shown. In summary, the energy performance of the unmodified DOE-2 samp2.inp file was unreasonably low and therefore produced results that were not applicable to a typical high-rise commercial building. After modification, the adjusted DOE-2 file shows consumption that has moved to a level comparable to LoanSTAR buildings that were representative of typical buildings in the four census regions.

SIMULATION RESULTS

After development of the modified DOE-2 input file, the weather and site data were changed and the prototype building was simulated for the selected sites. Figure 9 shows the results of the energy consumption by category from the DOE-2 BEPS report based only on the glazing performance. In this figure, the shaded and unshaded conditions for Houston are plotted for single-pane clear, double-pane Low-E and double-pane PV glazing. In all, the results show that the buildings using single-pane, clear glazing were the most consumptive for the shaded and unshaded conditions. The Low-E and PV glazed buildings showed similar results for the shaded and unshaded cases. The PV glazing shows a slightly higher consumption that the Low-E because the PV electricity production is not factored into the result shown in Figure 9.

An analysis of Figure 10 and Figure 11 shows the annual building energy use and the simulated PV electricity production. In this figure, it is evident that the electricity produced by the PV makes the building slightly less consumptive than the Low-E.

In Figure 12 the shaded and unshaded cases are shown with and without the PV production. Overall, the data shows that buildings in Houston, Los Angeles, and New York have about the same reduction in energy consumption, despite the production of the photovoltaic glazing. In addition, an analysis of Figure 12 shows that the unshaded performance with PV production is the same as the shaded condition with no PV. Detroit on the other hand shows that there is a linear decrease in consumption between cases and that the shading of the building has a larger effect on the energy consumption than in other cases.

In summary, in this study, the DOE-2 samp2.inp file produced unreasonably low results mainly due operation and temperature schedules, which completely shuts down the building during unoccupied periods. However, the energy use of the building increased to levels comparable to buildings from the LoanSTAR database after modification of the samp2.inp file. The results, which are based the modified DOE.2 samp2.inp file, shows that buildings using single pane clear glazing were the most consumptive for both conditions and that Low -E and PV glazed buildings perform similarly. In review of the electric production for all conditions, the electricity produce by the PV made the building slightly less consumptive than Low-E. Overall, the buildings in unshaded conditioning perform similar to buildings that are unshaded, which do not use PV.

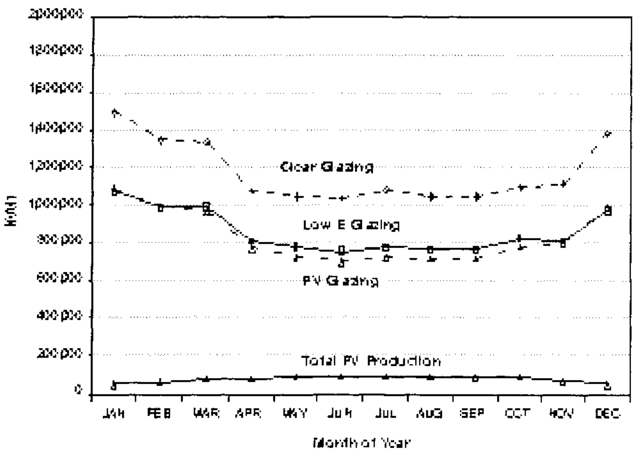


Figure 10. Shaded Monthly Electric for Houston

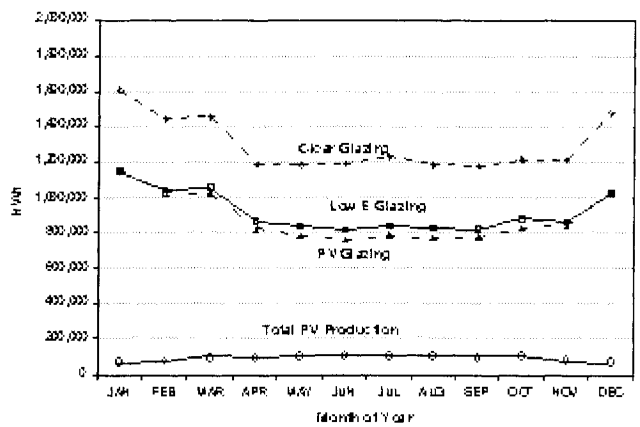


Figure 11. Unshaded Monthly Electric for Houston

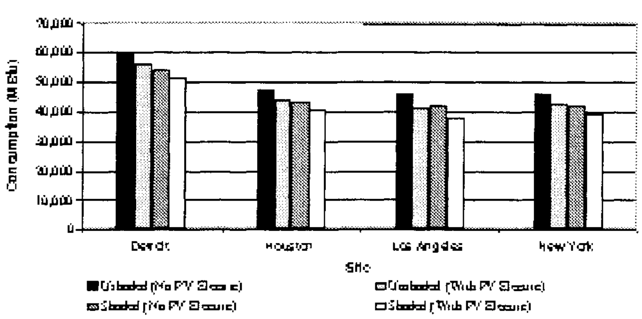


Figure 12. Annual Energy Consumption

The figure shows the shaded and unshaded results of the PV glazing for all sites. In summary, the first column is the building's energy use for the unshaded condition and does not consider the electricity production of the PV glazing, while the second column includes the PV electricity production. The third column is the building energy use for the shaded condition that does not consider the electricity production of the PV glazing, while the fourth column does factor in the PV electricity production. This format is used for each city's grouping.

CONCLUSION

In this study, the DOE-2 samp2.inp file produced unreasonably low results mainly due to the operation and temperature schedules, which completely shut down the building during unoccupied periods. After modification of the samp2.inp file, the energy use of the building increased to levels comparable to buildings from the LoanSTAR database. Based on the modified DOE.2 samp2.inp file, results show that buildings using single pane clear glazing were most consumptive for both conditions. In addition, this study also shows that Low-E and PV glazed buildings perform similarly, which agrees with current research (EIA, 1992) .

The electricity produced by the PV glazing made the building slightly less consumptive than buildings using Low-E glazing. Overall, Ashley (1992) states that BIPV systems can supply up to 70% of the electric demand of the building. In this study, the mostly vertical PV glazing, with no shading effects of surrounding buildings, met 21% of the electricity needs of the building, while the PV glazing that considered shading from surrounding buildings satisfied 14% of the electric needs of the building. Thus, the shading by surrounding buildings reduced the electricity production of the PV glazing by 34%.

Future Work

There are several obstacles preventing the widespread adoption of solar photovoltaics as a power source on buildings in the world today. Listed by priority, these obstacles are 1) public awareness, 2) system costs, and 3) code requirements. Although the congress of the United States has mandated research in the area of Photovoltaics, the application of these systems has been minimal. Whether influenced by Corporate forces that want maintain their monopoly on fossil fuels as the major provider of electricity or the lack of relevant research that would facilitate the immediate application of photovoltaics, the reasons for this condition is unknown. In 1993, a general survey of the building community (Kiss, 1993) indicated that the results of such research - or lack thereof - is reaching the relevant professions in a slow and controlled manner. Consequently, we must answer the question of the building community in the areas of thermal analysis, life cycle costs and energy costs of buildings using PV glazing. Specifically, these concerns are about market incentives, safety and liability, reliability, maintenance, thermal and physical characteristics of PV's.

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