DAYLIGHT ANALYSIS WITH MICROCOMPUTERS FOR SCHOOL BUILDINGS IN A HOT, HUMID CLIMATE

John Leaver, Assistant Professor, School of Architecture, Louisiana State University
Troy McQueen, Associate Professor, Department of Construction, Louisiana State University

ABSTRACT

Daylighting and other passive energy technologies are critical issues that should be considered in the early stages of building planning and architectural design. Both new design and retrofit of existing buildings benefit greatly by use of microcomputer-generated models, especially as they relate to building studies in zones of extreme climate. The hot, humid environment of Louisiana poses unique problems and calls for creative solutions.

The use of microcomputers as analytical tools to develop suggestions for optimizing the amount of energy consumed for lighting and climatic comfort is illustrated. The effective use of daylighting can, as might be expected, produce net energy savings in most school buildings.

INTRODUCTION

The existing stock of elementary schools in Louisiana contains buildings constructed prior to the era of energy conscious building design. The energy analysis conducted under this study, along with published research, indicates a potential of 30 to 45 percent energy savings by applying daylighting strategies to this building type. Electric lighting, one of the more significant energy consumers, exhibits a double-edged effect on the thermal environment. Coupled with a hot, humid climate, electric lighting increases cooling needs. This paper examines several characteristic school configurations in Louisiana, using microcomputers as analytical tools to develop suggestions for optimizing the amount of energy consumed for both lighting and climatic comfort. Envelope studies will feature daylighting and window design strategies that impact on the reduced use of electricity and the optimal use of daylighting. The measure of the available lighting, both natural and artificial, for classrooms and offices forms an important criteria for the success of analytical strategies.

To test these strategies, a microcomputer version of DOE-2 is used with reasonable success to establish an image of thermal behavior in buildings. PC-DOE exhibits parallel features compared to its mainframe parent and appears to be a comprehensive tool. Additional manual techniques such as the Daylight Factor and additional daylighting software DAYLITE are used to determine the effectiveness of daylighting and envelope strategies. These tools, used in close collaboration, illustrate the potential effectiveness of retrofit strategies for characteristic school buildings.

PREVIOUS WORK LEADING TO DAYLIGHT DIRECTION

An earlier study was initiated to delineate the potential for various energy conservation strategies by considering characteristic buildings and systems found in schools within a hot, humid climatic zone, South Louisiana. [13] The effects of the use of daylighting upon the exterior building envelope was to be considered as part of a set of appropriate retrofit strategies for this building type. Studies conducted by other investigations were used as a foundation for the development of an energy analysis methodology. [7,9] The initial intent of this study was to discover a simplified analysis procedure for retrofit energy conservation measures. Also, it would be considerably useful to have an available, easy to use tool for use in the early phases of building design.

Schools in hot-humid climates have a deceptive thermal behavior. Initially this building type would appear to react similar to an office building with heavy internal loads. While because of scheduling variations during peak cooling loads, such as the summer months and the late afternoons, these internal gains have little opportunity to add to the hot-humid condition and drive the energy consumption higher. Building configuration and compactness play a significant role in the effect the envelope has on the balance between internal and external loads.

The sensitivity of the skin was exposed by studies decreasing infiltration rates, increasing wall insulation, and adding double-pane glazing. Each strategy caused an increase in the cooling load, demonstrating the importance of the envelope as a means of dissipating the internal gains during moderate climatic conditions.

Schools in this climate spend a major portion of the energy bill on electrical costs. Although cooling loads form a large part of the expense, electric lighting contributes heavily to these charges both at a consumed rate and for peak demand. In comparing characteristic existing school buildings (A. a sprawling campus plan with double loaded corridors, with B. a compact square plan with no windows), it can be established that the sprawling campus plan with large apertures for daylighting consumes approximately half the energy of a comparable sized school with no exterior window penetration. (Energy use index for Building A. 99,465 BTU/SQFT/YEAR; Building B. 193,851 BTU/SQFT/YEAR). In others words, careful consideration of daylighting couples with a sufficient investigation of the buildings' envelopes as related to daylighting should be undertaken.

Proceedings of the Fourth Symposium on Improving Building Systems in Hot and Humid Climates, Houston, TX, September 15-16, 1987

A study of existing schools with the thought of applying a thorough daylight/fenestration examination in order to reduce energy consumption, while maintaining both visual and thermal comfort, is the purpose of this study.

METHODOLOGY

An hourly energy analysis program, DOE-2 (a microcomputer version), was used as the tool for thermal energy modeling. Establishing a base case building became the initial priority. Daylight studies have been carried on using several complementary methodologies. Initial readings were taken on site, under different sky conditions and of selected characteristic classrooms. Models were constructed to simulate the existing condition in order that various retrofit strategies could be tested to establish their daylighting potentials. Finally, a computer program (Daylite), was used to verify the model results and allowed for multiple iterative studies with subtle variation of envelope manipulation. Initial computer simulations based on the existing school condition were undertaken to establish a comparative energy consumption value with 10 percent of both heating and cooling loads. These values were compared with actual energy consumption values obtained over the past three-year period. This simulation established the elements that contributed most to energy consumed. Because of the important influence of electrical energy used by lighting, strategies to decrease the electric lighting levels and manipulate the envelope were studied. Numerous single variable parametric simulations were undertaken dealing with the following envelope elements: electric lighting levels, shading coefficient, size of window apertures, shading strategies, glass transmittance values and number of glass panes. Each element was considered in a range of values to test the singular effect of this element. While energy simulations were continuing, corresponding daylighting models were under study to determine the lighting effects. After the preliminary energy and daylighting analysis, the changing of two and three parameters continued with the goal of determining the optimal size and dimension of these parameters for both comfort and minimal energy consumed.

CASE STUDY EXAMPLE:
McKinley Middle Magnet School

Public operated middle schools were considered first because of the number of existing schools in the local city/parish region. East Baton Rouge Parish (city-county) public school system has more than 100

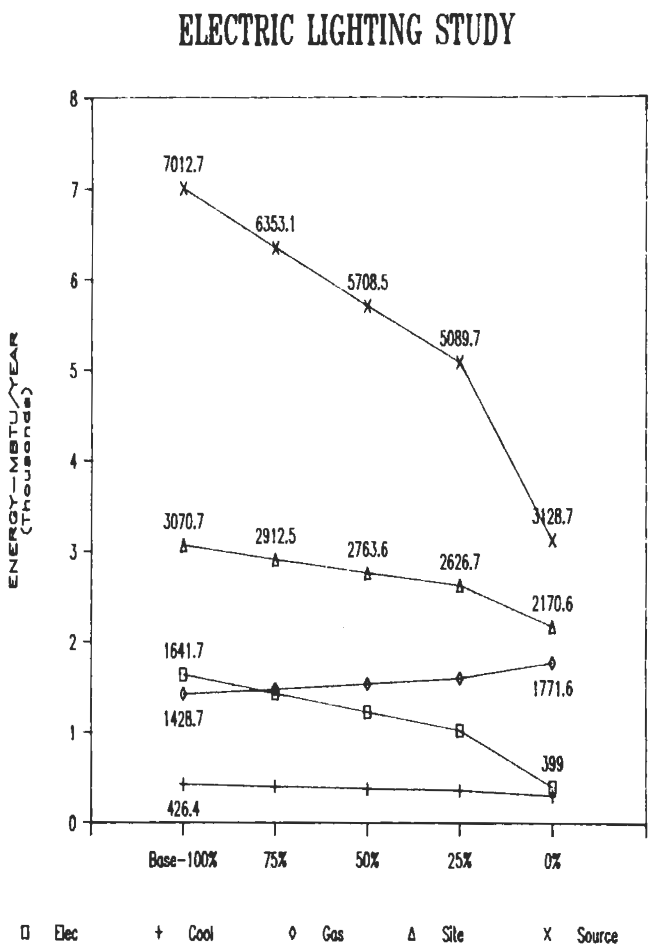

Figure 1. Electric Lighting Study

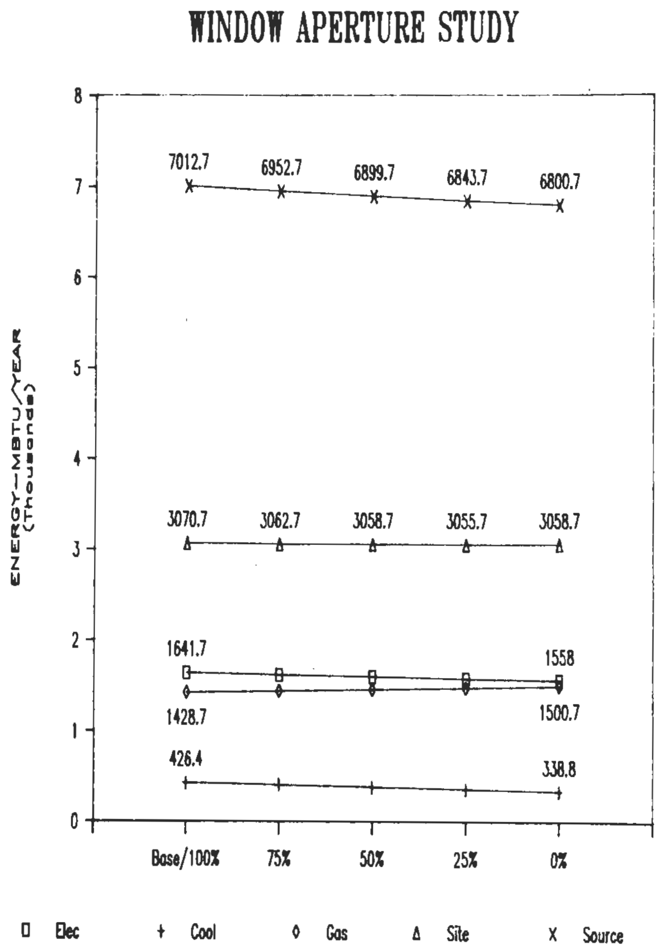

Figure 2. Window Aperture Study

school complexes. There are 19 high schools and 67 elementary schools. Of the 14 middle schools, McKinley Middle Magnet is a central city complex built in the early 1950s and has many characteristics of schools built in that decade. The earlier use of this structure was for a high school. When the facility was outgrown by student population, a new high school was built nearby and the facility became a middle school. The student population is about 1400. The classroom buildings are typical double-loaded corridor structures of two stories height. The structural frame is reinforced concrete and internal portions are hollow clay tile. The typical exterior wall is approximately 70 percent glazing.

Site planning for energy conservation was obviously not a major consideration during the building design phases. Orientation of these buildings, not air-conditioned initially, was a purely an aesthetic concern. While the building was originally considered to be naturally ventilated, the southwestern exposure coincides with a maximum daily peak load during the months requiring cooling. Daylighting may have been a part of the preliminary design consideration, but its use has not been maximized in the present configuration. Little or no insulation was placed in the roof and wall elements of the structure.

The campus type plan was modeled in three separate pieces to simulate the existing plant conditions. Although this school primarily uses a two pipe fan coil system, it also has a Direct expansion unit for the office and several unit heaters in the gym, cafeteria, and shop. Each building was divided into several zones to establish a thermal link between the internal and external loads.

The initial simulation illustrates the significant impact that electric lighting plays, as it utilizes 40 percent of the energy consumed at the site and it simulates higher cooling demands and aids in heating required for thermal comfort. The overall building loads range from approximately 10,000 MBTU's for cooling to 4,000 MBTU's for heating. The building element, in order of cooling impact, are glass solar (1316 MBTU's), occupants (1140 MBTU's), walls (1037 MBTU's), and the thermal effect of electric lights (876 MBTU's). The glass solar (381 MBTU's) and lights (335 MBTU's) contribute to a savings in heating energy as the conduction in the glass (739 MBTU's) and the walls (735 MBTU's) are the greatest consumers of heating required. The importance of peak demands cannot be underestimated as

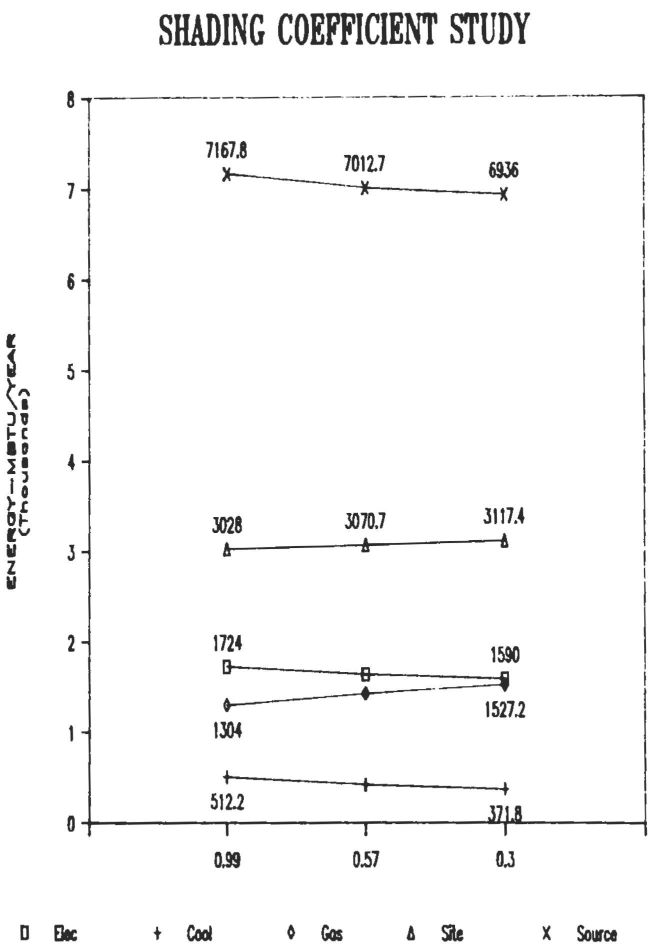

Figure 3. Shading Coefficient Study

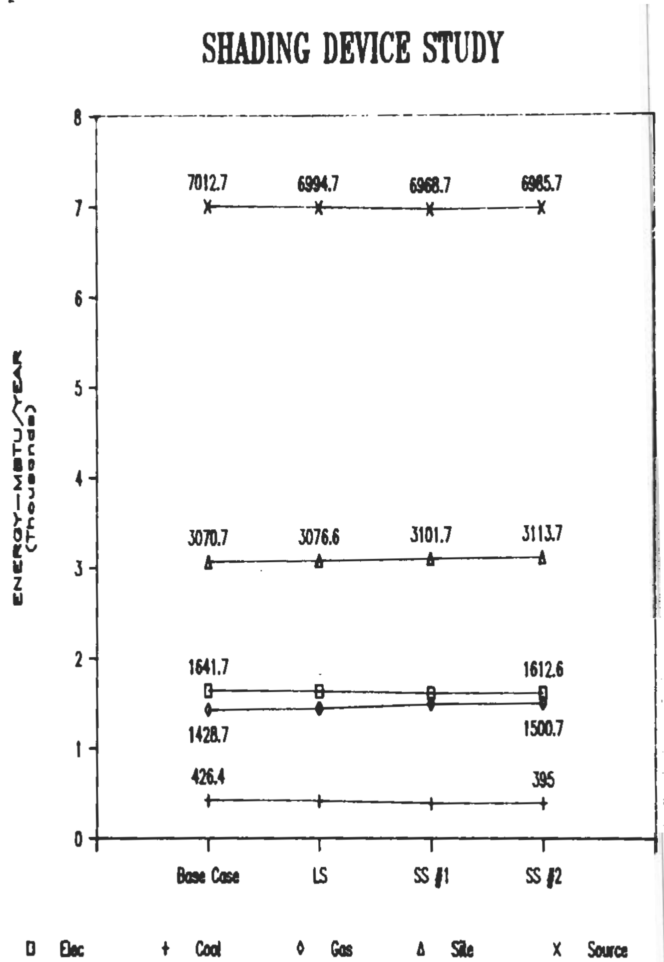

Figure 4. Shading Device Study

Proceedings of the Fourth Symposium on Improving Building Systems in Hot and Humid Climates, Houston, TX, September 15-16, 1987

demonstrated by the fact that 20 percent of the yearly total energy cost is paid in peak demand charges. The greatest peak demand users are occupants (1053 MBTU's), the thermal impact for lighting (530 MBTU's), glass solar (339 MBTU's), and the conduction of the walls (312 MBTU's). Reducing electric lighting and studying strategies to deal with the fenestration will impact the energy used to reduce these demands.

Calculation of the existing daylighting condition was first approximated by using the daylight factor method based on several typical classroom conditions. The exterior aperture being approximately 70 percent of the total wall surface yielded sufficient lighting (50 FC) for nearly all year round. On clear days the worst condition tested was approximately 39 FC and on the overcast sky 57 FC. Model tests on an overcast day with 540 FC available demonstrate a range from 30 FC at room center to 110 FC next to the glass, thus suggesting, that on such a dark sky condition 50 percent of the classroom has sufficient light comfort. The graphs illustrate the single parametric runs that were generated from decreasing the electrical lighting in the classrooms; varying the shading coefficient; reducing the window aperture; and studying various shading strategies. Decreasing the electric lighting from the existing condition to 70 percent, 50 percent, and finally to no lighting produces the most significant energy savings. It is interesting to note that as the electrical demand drops the heating demand is steadily increasing twice as fast as the cooling is decreasing (Fig. 1).

Shading coefficient studies indicate that by closing off the existing daylighting an energy benefit is gained. Even though that heating demand is rising at a faster rate than the electrical demand, the source energy take approximately 3x the electric energy to produce the necessary power for the electrical demand (Fig. 2). Light studies indicate a 55 percent reduction in available daylight by applying a .30 shading coefficient value. Approximately half of the room is sufficiently daylight, therefore, suggesting that a 50 percent delamping strategy would maintain necessary lighting levels.

The reduction of the window aperture from 75 percent, 50 percent, to no windows indicates a decrease in both electric and heating demands, which ultimately illustrates a savings in site and source energy (Fig. 3). Model studies indicate the available daylighting based on an overcast day is decreased by 30 percent for a 25 percent reduction

DOUBLE VARIABLE RUNS

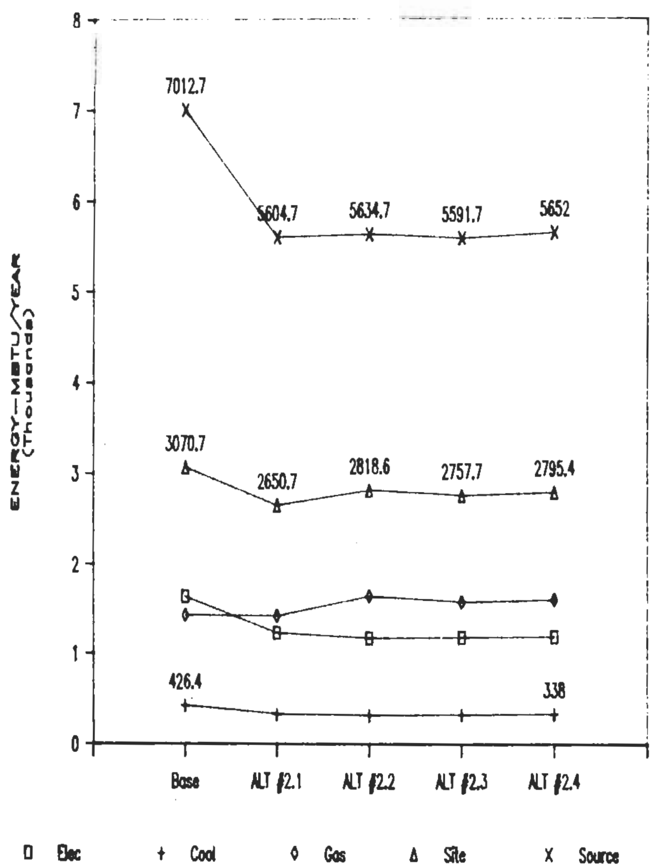

Figure 5. Double Variable Runs

TRIPLE VARIABLE RUNS

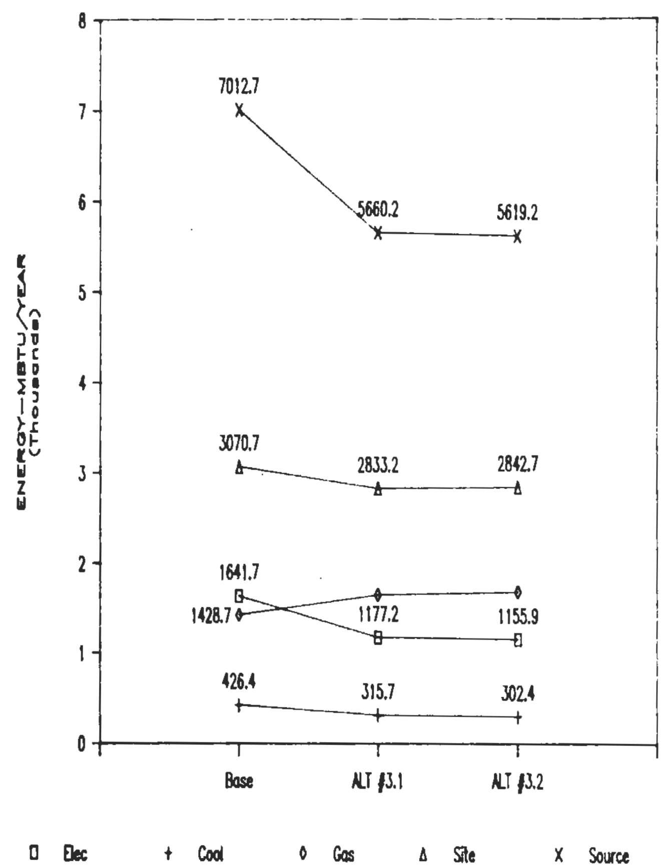

Figure 6. Triple Variable Runs

in aperture and 50 percent for a 50 percent reduction in vertical window size.

Shading strategies studied include a two foot lightshelf at two feet below the window head, (Fig. 4, LS). Four two foot deep horizontal overhangs that do not allow any direct light into the classrooms (Fig. 4, SS#1); and an eight foot overhang to shade the windows with a sun angle above 45 degrees (Fig. 4, SS#2), As noted in the graph, a slight savings is gained by the lightshelf approach, but this should exhibit excellent daylighting consequences. Although when models tested under overcast skies showed no appreciable difference from the existing condition, the study of the four horizontal overhangs reduced lighting at the window by 70 percent, at the center by 40 percent, and at the back of the classroom by 17 percent. A sixty percent reduction in available daylighting under similar conditions was exhibited by the computer model. Additional data for thermal and daylight conditions needs to be obtained for various shading strategies.

Reducing each variable, size, dimension, or effect--thereby simulating a means of reducing the external effect of the sun and temperature--and simultaneously interacting with the internal loads, demonstrated that each approach reduced total source energy consumption. Typically a savings of energy was registered for electrical energy and cooling; however, heating energy increases in most cases. To produce positive effects in both realms careful attention must be paid to scheduling of shading devices.

Multiple parametal changes were conducted by reducing the lighting levels by fifty percent in each case studies plus varying an additional parameter such as window aperture, shading coefficient, or shading device. Each of these approaches allowed a fifty percent reduction or more in the amount of artifical light for at least seventy percent of the school year. Figure illustrates the results from these double parametric runs. These strategies all include a fifty percent reduction in electric lighting and the other variable parameters are as follows: Alt #2.1 adding two panes of glass; Alt #2.2 reducing the shading coefficient from 0.57 to 0.30; Alt #2.3 reducing the window aperture by fifty per cent floor to ceiling; and Alt #2.4 applying the shading device with four horizontal two feet deep overhangs. Each of these strategies have relatively a similar overall effect in energy consumption, with the reduction in the window aperture being the most effective. Closer examination would suggest that more significant energy savings could be realized if the heating loads would also be reduced. Thus, attention to the suns orientation and allowing its benefits to be used in the winter season and blocking it during the summer season would enhance energy savings.

Additional thermal studies were performed by changing three variables (Figure 6) Alt #3.1 represented a fifty percent electric lighting reduction, a two foot lightshelf and a shading coefficient reduction to 0.30; Alt #3.2 demonstrated a fifty percent lighting reduction, a series of four horizontal two foot overhangs and a shading coefficient of 0.30. For Alt #3.2, the largest cooling load decrease was registered; however, the highest heating load increase was also generated. Additional daylighting studies must be conducted to determine the relative effect of these approaches.

Further studies need to be conducted to pinpoint which strategy will be most effective in reducing thermal loads and balancing visual comfort.

CONCLUSION

From this study good evidence has been uncovered to substantiate the claim that daylighting plays vital role in school design in reducing the electric lighting and cooling loads. In the test case electric lighting was reduced and visual comfort was maintained at appropriate illumination levels. Depending on the school's configuration, window sizes, fenestration condition, and electric lighting levels, daylight can guarantee an energy savings almost any school.

The use of the parametric run graphs give a good indication of the effects of single variables on the energy consumption. These graphs can predict the effect of a strategy on the building under study and can give direction to multiple parametric studies. In the case of the McKinley Middle School further study should tailor the variables to the specific conditions, so that a savings in cooling energy would also register as savings in heating.

Additional studies are continuing on the multiple effects of fenestration design, window aperture scheduling, glass type, and lighting conditions in hot-humid climates. Study of schools of different configuration, lighting, and aperture conditions are under way, leading to a broader understanding of issues involved with daylighting and window/fenestration design.

REFERENCE

1. lawrence Berkeley Laboratory. 1981. DOE-2 Reference Manuals. Lawrence Berkeley Laboratory Reports LBL-8705, -8706, and -8707.

2. Diamond, S.C., and Hunn, B.D. 1981. "Comparison of DOE-2 Computer Program Simulations to Metered Date for Seven Commercial Buildings." ASHRAE Transactions, Vol. 87, Pt. 1.

3. Kerrisk, J.F., Schnurr, N.M., Moore, J.E., and Hunn, B.D. 1981. "The Custom Weighting Factor Method for Thermal Load Calculations in the DOE-2 Computer Program". ASHRAE Transactions, Vol. 87, Pt.2.

4. Wagner, B.S. 1984. "Comparisons of Predicted and Measured Energy Use in Occupied Buildings". ASHRAE Transactions, Vol. 90, Pt. 2.

5. Alereza, Taghi and Hovander, Leonard. "Computer Modeling: A Micro Evaluation". ASHRAE Journal, December 1985, pp. 34-38.

6. CA Systems International, Inc. 1985. "Introducing DOE-2.1B on your office PC".

7. Arasteh, D., Johnson, R., Selkowitz, S. and Connell, D. 1986. "Cooling Energy and Cost Savings with Daylighting in a Hot and Humid Climate". Sun World 10 (4):104.

8. Gates, Steve, and Joe Wilcox. 1984. "Daylighting Analysis for Classrooms Using DOE-2.1B". Energy and Buildings 6:331-34.

9. Johnson, R., Sullivan, R., Selkowitz, S. Nozaki, S., conner, C., and Arasteh, D. 1984. "Glazing Energy Performance and Design Optimization with Daylighting". Energy and Buildings 6:305-17.

10. Steven Terncey, Larry Beckle, Claude Robbins, Robert Busch, Kitt McCord. 1985. "The Design of Energy-Responsive Commercial Buildings". New York: John Wiley & Sons.

11. Issac Turiel, Richard Boschen, Mark Seedall, and mark Levine. 1986. "Simplified Energy Analysis Methodology for Commercial Buildings". Energy and Buildings 6:67-83.

12. Carl H. Jordan. 1980. "Building Envelope Studies -- California Projects". ASHRAE Journal (March): 42-46.

13. Troy McQueen and John Leaver. 1986. "Microcomputer Energy Analysis Studies of Selected Building Types in a Hot, Humid Climatic Zone". Third Annual Symposium on Improving Building Energy Efficiency in Hot Humid Climates, November.