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DESIGN TOOLS FOR PASSIVE SOLAR APPLICATIONS

by
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ABSTRACT

Examples of passive solar design tools are given, categorized as either **evaluation** tools or **guidance** tools. A trend toward microcomputer-based tools is noted; however, these are usually developed for use by engineers rather than architects. The need for more instructive tools targeted specifically to designers is emphasized.

INTRODUCTION

By **passive solar design,** we mean intentionally including solar thermal, daylighting or natural cooling benefits during the design process. Such attention to these issues may not result in a design which is significantly different than would have resulted otherwise, but most often a modified design will emerge. Major architectural changes, such as orientation or building shape, may be made; or less dramatic modifications may emerge such as relocating windows, use of different internal materials, or the size of overhangs outside windows. In any case the incorporation of the passive solar elements must be integrated into the design process. Few designers are driven totally by thermal or energy issues and most pay only very secondary attention to them.

Passive solar techniques usually integrate the solar collection, storage, and distribution elements into the architecture of the building. Typically, these elements serve multiple functions; often the passive solar function is secondary to the main function. Windows provide view, emergency egress, ambiance and external skin in addition to their passive roles of solar heat collection, daylighting, and natural ventilation. Sunspaces or atria provide additional building space, possibly an area for growing plants, and architectural excitement in addition to thermal or daylighting roles. Building structure and contents will store heat.

For all these reasons, passive solar design tools must be carefully devised so as to fit comfortably into the design process and thus be accepted by designers. A key issue which has had a major influence on the development of design tools is that architects have traditionally abdicated the major responsibility for thermal design of a building to engineers to be done after the major architectural design is complete. Design tools have tended to be quantitative and laborious rather than the graphic and simple type of tool that would be most likely to be used by an architect. The widescale availability of computers may or may not change this depending on the perspective of the computer programmers. One can only report on trends and the trend is for computer-based design tools to appear which are ever more complex, numerical, and comprehensive rather than more user friendly, graphical and instructive.

However, passive solar design is inherently within the domain of the designer. This is so because it is the architecture of the building which determines its passive solar effectiveness. These features must be incorporated during the preliminary or schematic design phase rather than being "retrofit" onto the design at a later phase, such as design development. If the passive solar design tool is a thermal analysis done only after the building is designed, then there is little hope that the results will have a major effect on the design. The most one could hope for is for some minor tuning of the window design or other elements.

CATEGORIES OF DESIGN TOOLS

We separate design tools into two major categories, **evaluation** tools and **guidance** tools. A good example of an evaluation tool is an energy analysis computer program. A description of the building and the local climate is fed into the program. The analysis produces an estimate of monthly and annual energy use and perhaps hourly profiles of temperatures or requirements for heating or cooling. The results may be very informative but they do not provide any direct

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guidance as to how the design might be changed to achieve an improvement. Such guidance may come from the experience or intuition of the analyst or by brute-force re-running the program in order to accumulate results which show the sensitivity of the design to parametric changes. Other examples of evaluation tools are the solar load ratio method or the unutilizability method which employ correlations (derived from hourly simulations) to estimate performance on a monthly basis. Increasingly, these techniques have come to be equated with "passive solar design tools". The way such tools are usually used to aid design is to use them iteratively as shown in Figure 1. The key point to be made is that the time when the tool is used is **after** a design step has taken place. The tool is used to evaluate the consequences of the design decision. Corrections may then be made if the result is not satisfactory. This process may be iterated until a satisfactory result is obtained. Using an evaluation tool as a design tool can be effective but it is not very efficient. Too often an evaluation tool may only be used to document the consequences of the design and no iteration takes place.

The second category of design tool is called a **guidance** tool. The key point is that the tool provides recommendations **prior** to a design step being taken. This is shown schematically in Figure 2. The most widely used guidance tools are rules of thumb. Most such rules evolve through experience and are quite general. While they are very useful, they usually do not account for variations in climate from place to place and therefore cannot properly reflect the key aspects of climatic design. Such variations are particularly important to passive solar heating, and to a lesser extent, to natural cooling. They are least important to daylighting. Rules of thumb are most useful very early in the design process but, being very simple, do not take into account issues which should have a major impact on the design, such as the internal heat characteristics of a commercial building.

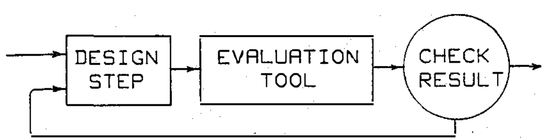

Fig. 1. Schematic of the use of an **evaluation** tool. The tool is used after a design step. The feedback path indicates an iteration, based on the evaluation tool results.

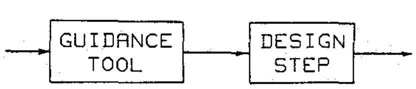

Fig. 2. Schematic of the use of a **guidance** tool. The tool is used prior to a design step based on design objectives or constraints.

A good guidance tool should factor in information about the local climate and the architectural program of the building. Based on this information, it should provide recommendations as to the next appropriate design direction.

In practice, both guidance and evaluation design tools can be used effectively during the design process. Ideally, one would use a guidance tool prior to each design step, and after the step use an evaluation tool to verify that the desired result was indeed obtained. If the guidance tools are effective, then there should be little, if any, need to iterate as the design evolves. The design will proceed quickly and the result will be a building well adapted to its intended use and climate; in short, a comfortable and economical building with low operating costs. A comprehensive evaluation tool may still need to be employed at the conclusion of design to assure that the predicted performance is satisfactory or perhaps to satisfy regulatory compliance where required. Note, however, that such a final evaluation does not guarantee that the energy design is optimum. It only provides a set of numbers without any indication that a better set may not have been obtained, perhaps at a lower first cost.

EXAMPLES OF DESIGN TOOLS

Architects and other designers have traditionally used a variety of design tools which have been quite effective. A classic is the sun chart which shows sun location (altitude and azimuth) for different times of day and different seasons. A different chart is needed for each latitude but this is no problem because the designer working in only one location needs only one chart. Overlays can be used to develop shadow patterns which are very helpful in designing shading devices carefully tuned to particular building facades and desired sun penetration characteristics. This has been carried to a fine art in the design of exterior louvers for buildings in South America and Australia. The effect of neighboring buildings or vegetation can also be assessed. In the hands of a trained user, a sun chart is both a guidance tool and an evaluation tool.

Besides the sun chart, a wide variety of sun shading tools have been developed. An excellent example of a guidance tool has been developed by Shaviv[1], which indicates the exact shape of overhangs in order to achieve a desired seasonal shading characteristic. Another example is the use of a light and a model to track shadow patterns outside and inside a building. A simple graphical "sundial" can be placed on a tilting table next to the model in order to simplify setting the table angle to simulate any time of day in any season. Scale models are also used very effectively for daylighting design since accurate results can be obtained if shape and color are faithfully reproduced. Light levels and light quality measured in the model properly simulate full scale.

Many other handy design tools have evolved over many decades to assist designers in accounting for passive effects. Natural ventilation can be predicted using simple equations based on pressure coefficients measured in wind tunnel tests. Many other simple algorithms have been developed and are documented in the literature, especially the publications of ASHRAE, and for daylighting, IES.

THERMAL DESIGN TOOLS

Strong interest in thermal design tools was sparked in the early 1970's by the energy crisis leading to major attention being focused toward the prediction of expected energy savings from the use of passive solar heating techniques. This intense interest spawned the development first of simulation techniques and subsequently of simplified methods such as the solar load ratio technique. The order of use of design tools and the order of evolution of these tools is exactly opposite as shown in Figure 3. The simple tools evolve from more complex models. However, during design, simple tools are used first followed by the use of more complex tools.

An example of this process is the development of the design tools presented in the book **Passive Solar Heating Analysis,** published by ASHRAE[2]. Guidelines, which appear early in the book, are intended to start the designer onto the right initial course. Recommended conservation and solar design parameters are given for 216 locations in the U.S. and Southern Canada, which lead immediately to recommendations for conservation levels and passive solar collection area. The guidelines are based on weather conditions of each location. These guidelines are most useful at the very beginning stages of the design, the pre-design or programming phase, when all that is known is the building floor area and location.

The next part of the book presents the annual calculation method (sometimes called the LCR, or Load Collector Ratio method) by which an

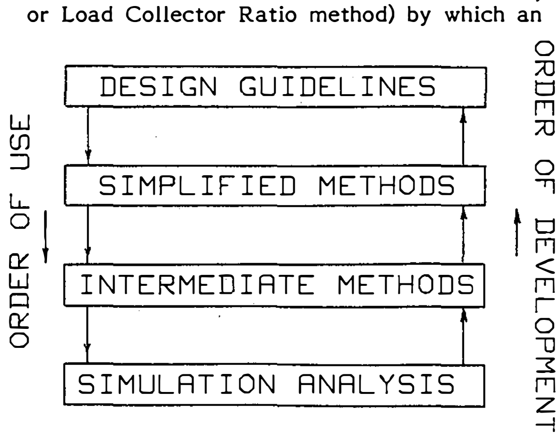

Fig. 3. Schematic showing the relationship between various levels of design tools.

annual auxiliary heat estimate can be made on a one-page worksheet based on selected conservation levels and passive solar design choices. This simple calculation is made possible by the inclusion of performance tables for each of the 216 locations giving solar savings fractions for each of several values of load collection ratio and each of 94 passive solar design options. This method is most useful in schematic design when estimates are needed quickly and great accuracy is not required. The important point is that design decisions which effect building loss coefficient and passive solar type and area are faithfully reflected in the analysis.

The final (and most complex) procedure in the ASHRAE book is the monthly solar load ratio method. This calculation which also leads to an estimate of annual auxiliary heat, has the advantage in that additional details of the design can be accounted for, such as shading characteristics, which change from month to month. However, the analysis is much more complex than the annual method although worksheets are provided to aid the process. This procedure is intended to be used during design development.

The hierarchy of design tools in the preceding paragraphs is evident and carefully structured to mesh with the phases of the design process. It is instructive to note that the development of these same tools is also a hierarchy, but in just the opposite order in the manner outlined previously on Figure 3. The annual method tables were derived from the solar load ratio correlations using monthly weather data from each locality. The guideline values were derived from the annual results using a procedure for balancing conservation and solar strategies against one another at the same time they are balanced against the present value of future heating costs. The guidelines, although simplest to use, were the hardest and last to be developed.

THERMAL COMFORT

The single-minded focus on annual energy savings which pervaded the early design tool development effort led to many passive buildings with less than adequate comfort. In fact, the single most often cited complaint in the Class B monitoring program of 335 passive solar residences was overheating, often on winter or swing-season days.[3] Less common was summer overheating, except for sunspaces which were designed with excessive east, west, and overhead glazing and inadequate natural ventilation openings.

The major cause of winter overheating is inadequate mass for storage of daytime direct gain solar heat. Two types of design tools were developed to address this problem. The first were simple simulation programs devised for use on programable calculators such as the

TEANET program. A reasonable simulation of a single day could be performed with this program in a half-hour or less. These programs were subsequently modified to run on microcomputers much more easily and quickly.

The second design tool to evolve for estimating temperature swings in direct gain buildings was the diurnal heat capacity method.[4] With the aid of appropriate tables, this method can be easily carried out by hand. It is based on a harmonic or frequency analysis of the penetration of a thermal wave into a wall or floor. The result is a diurnal heat capacity which quantifies the heat storage capability of a particular wall or floor construction during a repeating daily series. By analyzing only the diurnal (daily) frequency, accurate estimates of temperature swing can be made.

TAILORING DESIGN TOOLS TO THE USER

One lesson which has been reinforced repeatedly is that design tools must be tailored to a particular user. No single design tool can hope to fit every need. There are two major ways of dividing up design tools, by user category and by phase of design. Division by phase of design has already been discussed above in the example of the ASHRAE book. There are at least four main user categories, 1) architects, 2) engineers, 3) builders, and 4) do-it-yourselfers. Each group thinks differently, works differently, is driven by different motivations and speaks a different language. Their tools must be different.

Up to now, the main thrust of design tool development has been for engineers. The book cited earlier, **Passive Solar Heating Analysis** which evolved from the three volume series **Passive Solar Design Handbook**, is a good example of design tools targeted to engineers. Although usable by other designers, the language, level of detail, and format are tailored to the engineering community. It is no coincidence that the book was developed and published in coordination with ASHRAE, an engineering society.

The needs of architects, builders, and do-it-yourselfers have been widely recognized and discussed. Many books have been written for these audiences and many seminars and short courses given, but few true modern design tools have evolved. It is an area needing attention and one of the reasons that acceptance of passive solar strategies has not been faster and more widespread. Despite the considerable evidence compiled, including the detailed performance monitoring of more than 100 residential and 23 commercial buildings which have generally been very successful, considerable resistance remains, principally among architects and builders. Providing good design tools may be one of the best ways of overcoming this resistance.

BUILDER GUIDELINES

Design tools to meet the needs of builders are being developed. One such effort is an outgrowth of the 1983 Showcase of Solar Homes conducted in Santa Fe and Albuquerque, New Mexico. This program was devised by a builder and was developed by an advisory committee with the technical assistance of a local electric utility and the Los Alamos National Laboratory.[5] Since the committee developed performance criteria, a method of evaluation was necessary. The resulting 18-page package which was distributed to the builders consists of four sections, as follows:

1) **Target Levels:** These are specific numeric values for **conservation** (expressed as a maximum level of building net loss coefficient, in Btu/°F-day), for **auxiliary heat** (expressed as a maximum, also given in Btu/°F-day after accounting for the savings due to passive solar), and for **comfort** (expressed as a maximum clear winter day temperature swing).

2) **Guidelines:** These are recommended levels of insulation, solar glazing area, and thermal mass. The purpose of the guidelines is not to be prescriptive but rather to aid the builder in selecting values which will result in meeting the target levels established.

3) **Worksheets:** The longest part of the workbook is a set of fill-in-the-blank worksheets. These result in performance estimates which can be compared directly against the target levels. If the target levels are exceeded, then corrective remedies are suggested. The worksheets use no formulas and almost no new nomenclature and can be filled out in less than an hour.

4) **Reference Tables:** Needed for the worksheets.

The analysis methods behind the worksheets are the solar load ratio method (annual calculation, with the aid of an abridged table for the specific locality) and the diurnal heat capacity method.

As a design tool, the workbook combines guidance tools (the guidelines) and an evaluation tool (the worksheets). This structure provides the builder with a very flexible format for thermal design. It is performance based rather than prescriptive.

A more recent evolution of these builder guidelines is a nationwide program conducted by Los Alamos, in conjunction with the National Association of Home Builders and the Passive Solar Industries Council. A pilot workshop was held in Raleigh, North Carolina, in October, 1985. The New Mexico format was modified to include target levels, guidelines, and a worksheet for summer cooling. Feedback from the builders is now being included in modifications of the workbooks. The future plan for the project is to develop a microcomputer program to produce the workbook for any locality. Input data for this program would consist of the monthly weather norms for the particular location. The program will print out a complete workbook which could then be reproduced and distributed to builders. The project could be implemented in each locality by a local NAHB Chapter, a utility company or municipal or civic group.

COMPUTER BASED DESIGN TOOLS

Since the advent of powerful and readily available microcomputers, there has been a strong interest in design tool programs. Many such programs are convenient implementations of manual tools. For example, there are at least ten commercially available software packages which implement monthly solar load ratio calculations on one or more of the most popular microcomputers. Other programs are designed to facilitate sun angle and shadow pattern calculations and ASHRAE procedures.

A major survey of design tools was conducted by Burt Hill Kosar Rittleman Associates, under the aegis of the International Energy Agency (IEA) Solar Heating and Cooling Program, Task VIII on Passive and Hybrid Solar Energy Buildings.[6] Although a few manual methods are included, the survey emphasizes computer-based design tools. The survey includes programs from 12 countries, however, 118 of the total of 159 programs are from the U.S. Sixteen programmable calculator programs are described although the survey concluded that now these are largely being replaced by microcomputer techniques.

The IEA survey breaks down design tools by different categories: country, machine type, application (heating, cooling, lighting, hot water, miscellaneous), calculation method, phase of the design process, building type, and intended user. One hundred of the programs were for microcomputers and 59 for mainframe computers.

Major findings of the IEA survey are as follows:

- There are several design tools available for calculating the savings due to the use of daylighting. Most of the design tools for daylighting calculations were developed between 1982-1984; some of the most recent activity is in this field.
- Fewer simplified design tools are available for calculating cooling energy requirements than for heating. There are many design tools for cooling calculations which require micro or mainframe computers.
- Very few design tools are available for use on microcomputers or programmable calculators for the calculation of miscellaneous loads.
- Many more design tools exist for calculating energy requirements for small buildings than for large buildings.
- The majority of design tools for active solar energy systems use the F-Chart method. A considerable number of design tools use the component-based simulation method.
- There is a need for simplified methods for active solar energy systems calculations for heating, cooling, and DHW for large commercial buildings.
- The solar load ratio and thermal network method are the most commonly-used algorithms for a passive solar energy systems.
- There is a need for simplified design tools for calculating the performance of passive solar systems for commercial buildings.
- The weather data required for the mainframe computer-based design tools in most cases is hourly data. During 1982-84, a few microcomputer-based design tools have been developed which use statistically processed condensed weather data. This condensed data is created from the hour-by-hour weather data by the design tool developers.
- During 1982-84, a few microcomputer-based design tools have been developed for commercial buildings. Some of these design tools perform hour-by-hour simulation for multi-zoned buildings with a variety of HVAC system types.
- The design tools developed prior to 1982 tended to use operating systems which restricted them to a few types of microcomputers. Very few design tools had been developed for CP/M operating system. Thus, the issue of design tool portability was a very serious one. However, during 1982-84, most of the new design tools were developed for use with CP/M and/or MS-DOS operating systems. These design tools can usually be used on a wide variety of computers which support these operating systems.
- While most microcomputer design tools were developed using BASIC language, a few were developed using USCD PASCAL, or FORTRAN 77.
- Very little information is available on validation except for some government-sponsored design tools. Some of these

design tools have been validated against a simulation program, a few have been validated with actual building data. In most cases, validation of any scientific significance did not exist.

It appears that a large (but indeterminant) number of design tools do not have a significant users group outside the author or developer's own organization.

CURRENT TRENDS

Many new computer-based design tools have been recently released or are in development. Some are microcomputer implementations of mainframe programs. In one notable example is the program PC-DOE™ which allows a microcomputer user to run the DOE-2.1C program on a microcomputer. While an annual calculation takes many hours to complete, this may be more convenient and practical for a design or engineering firm than doing the same calculation on a mainframe computer.

Another major trend is toward graphical input and output. An example is the evolution of the hourly simulation program CALPAS3™ into CALPAS4™. The older program uses a traditional and cumbersome batch input file and the results are listings of numbers. The newer version will have a graphic inputter which utilizes the arrow keys on the keyboard to draw a building on the screen and will have plots or bar graphs as options in the output.[7] The increasing use of computer aided design (CAD) by the design community will probably evolve into the coupling of these programs with thermal or daylighting analysis programs.

The author is in the process of developing a new microcomputer-based design tool called Energy Signatures. A preliminary paper describing this method is presented in these proceedings. The method is based on the use of hourly profiles of energy delivered to a building from a large selection of available design strategies. The method is a **guidance** tool which will assist the designer in sizing an optimum set of strategies to match a desired building architectural program in a designated climate. It is targeted to architects for use during schematic design.

CONCLUSIONS

Design tools are an at intermediate stage of developement. Some traditional simple tools, such as sun charts, are still widely and effectively used. The trend is toward computer-based evaluation tools targeted to the engineering community. However, there is also a major, but largely unfulfilled, need for guidance tools specifically targeted to the design community.

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