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# Digital and Color Energy Maps for Graphic Display of Hourly Data

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## PROJECT SUMMARY

**Project Title:**

Building Diagnostics

**Performing Institution:**

Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80401

**Project Manager:**

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**Project Objectives:**

Hourly data are available from several sources (weather tapes, building simulations, and monitoring programs), but often only a small fraction of the useful information is extracted from such data. The objective of this project is to enhance the use of hourly data by developing concise methods for display so that recognizable patterns will be revealed to the user. Interpretation of hourly results allows cause-and-effect analysis and facilitates diagnosis and design.

**Project Status:**

Energy maps have been developed based on time-of-day by time-of-year plots of up to 8760 hourly values. Digital energy maps can be generated by standard computer terminals and printers. In order to further increase the compactness of energy maps we have employed computer-generated color graphics. Hourly values are indicated by hue and intensity. Current versions of color energy maps are approximately 10 times more compact than digital energy maps (and approximately 100 to 1000 times more compact than typical numerical printouts).

Energy maps are of interest to users of hourly data from calculations or measurements. This user group is likely to expand dramatically with the advent of increasingly powerful microcomputers.

A potential problem in the application of this research is a lack of standards for microcomputer graphics, a situation that is likely to be partially resolved in the near future.

**Plans and Objectives for FY 1985:**

Research will continue on the development of methods for displaying dynamics of building performance for a range of variables. Additional applications for energy maps will be investigated including systems analysis of advanced concepts and analysis of data from monitored buildings.

Educational applications will be investigated based on an accumulated set of typical patterns observed in energy maps and development of a systematic procedure for scanning and interpreting energy maps.

**Major Publications Related to Project:**

"Energy Maps for Graphic Display of Hourly Data," SERI/TP-253-2461, August 1984.

**Contract Number:**

DE-AC02-83CH10093

**Funding Source:**

U.S. Department of Energy

**FY 1985 Funding:**

Undetermined

# DIGITAL AND COLOR ENERGY MAPS FOR GRAPHIC DISPLAY OF HOURLY DATA*

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## ABSTRACT

In this paper we discuss the display of hourly data. We review existing methods based on contour plots, design-day graphs, and three-dimensional surfaces; note the relationships; and describe the possibilities for extending and combining existing methods. Problems with using typical weather days are discussed, and new methods based on sequential days are described, including "energy maps." Examples of color** energy maps are given for three versions of a four-zone commercial building, and patterns of energy use are noted and interpreted. In this paper, the display of hourly data is discussed primarily in terms of simulation results, but the approach is equally applicable to measured data from monitored buildings or any source of hourly data.

## BACKGROUND

Output from design tools is often limited to monthly and annual totals. Only a few methods have been developed for displaying long-term hourly data, and most of these have been used for educational purposes rather than as design tools.

Olgyay [1] developed contour plots of average monthly bioclimatic conditions for 12 typical days as shown in Fig. 1. Reynolds [2] developed similar contour plots for a wide range of environmental variables including temperature, humidity, sky cover, precipitation, wind, and horizontal insolation. Reynolds also extended the method by including additional weather variability. Contour plots emphasize annual patterns of time-of-day by time-of-year data, but are based on a limited number of typical days.

Milne [3] developed the SOLAR-5 computer program to generate three-dimensional surfaces of building heating and cooling loads as shown in Fig. 2. Hourly values for components of heat loss and gain, calculated by simplified ASHRAE algorithms, are plotted for 12 typical days. The development of SOLAR-5 pioneered the use of computer graphics in building energy analysis. These three-dimensional surfaces provide a very graphic display of the overall data set but are difficult to use quantitatively.

Hart, Kurtz, and Whiddon [4] developed the Energy Graphics method, which involves seasonal

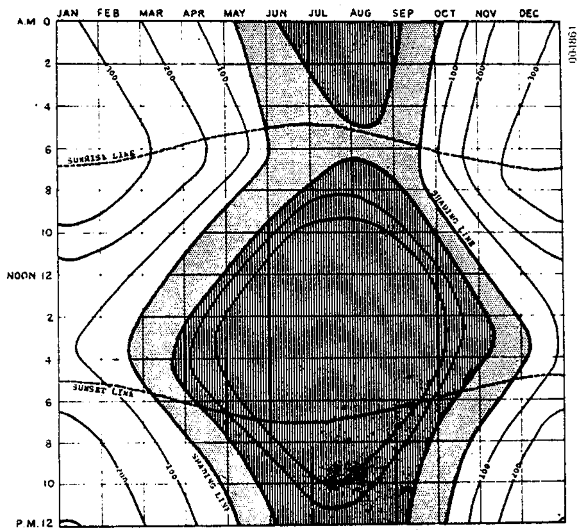


**Figure 1. Contour plot climatic needs (Olgyay 1963).**

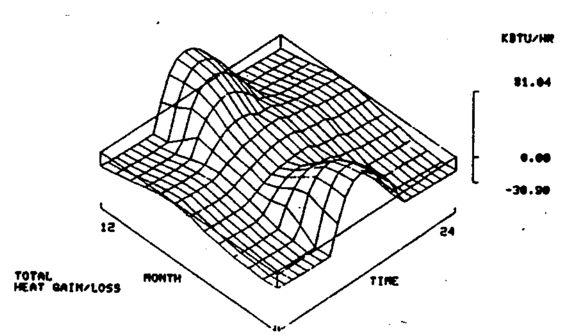


**Figure 2. Three-dimensional surface generated by SOLAR-5 (Milne 1979).**

* Most of the information in this paper will also be included in a paper to be presented at the Ninth National Passive Solar Conference.

** Because it is impossible to print color in these proceedings, the energy maps are rendered in black and white with reduced resolution and some loss of detail.

design-day graphs of heat gains and losses as shown in Fig. 3. Energy Graphics was originally developed as a manual method based on simple calculations for nonresidential buildings. Computerized versions have since been implemented to make the method less tedious. Design-day graphs are quantitative but typically are used to provide results for only a few days.

In spite of differences in appearance, these methods are closely related as shown in Fig. 4. In form, contour plots by Olgyay and Reynolds are a "top-view" projection of a three-dimensional surface such as that generated by Milne's SOLAR-5 program. The design-day graphs of Energy Graphics are equivalent to sections cut through the same three-dimensional surface.

### METHODS BASED ON SEQUENTIAL WEATHER DAYS

All of the methods described in the previous section depend on 12 or fewer representative weather days for the year. We have investigated using a large number of days in seasonal weather sequences. This approach has a number of potential advantages, depending on the number of sequential days used:

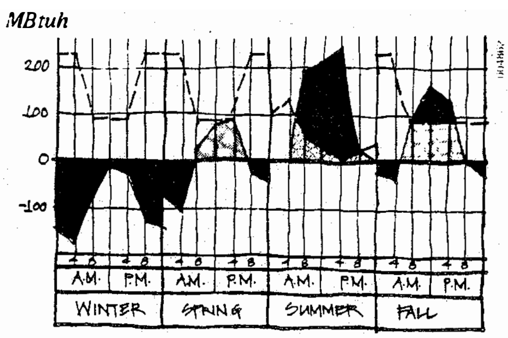


**Figure 3. Energy Graphics seasonal design-days (Hart, Kurtz, and Whiddon 1980).**

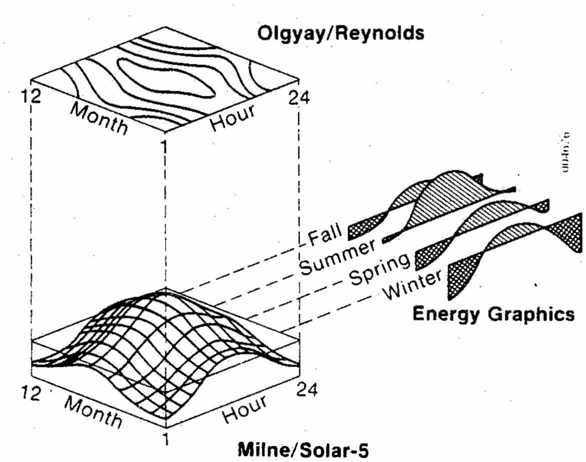


**Figure 4. Relationship of contour plot, design-day graphs, and three-dimensional surface.**

- a wide range of good, average, and poor days are included for different environmental variables and combinations,
- the importance of different day types is indicated by frequency of occurrence,
- multiday weather sequences and operational sequences are included,
- peak demand in addition to heating and cooling energy is indicated, and
- results are applicable for a full range of building designs.

Using more complete weather data requires the ability to display a larger quantity of data. We have developed methods to display hourly data compactly to increase the number of days that can be displayed on a single page.

#### Contour Plots

We first attempted to display hourly data for sequential days as contour plots similar to Olgyay's. Each month is represented by a sequence of days from the TMY weather tape [6]. The results for outdoor temperatures in February are shown in Fig. 5. Upon inspection we find that contour plots are not a satisfactory method for displaying this type of sequential data. Contour plots are suitable for average monthly days because the seasonal variation is a smooth function from one month to the next month (i.e., horizontally in Fig. 1). For sequential days, however, values for a particular time of day may vary erratically from one day to the next. There is, of course, a probability that the values at a given time of day will be similar from day to day, and this is the

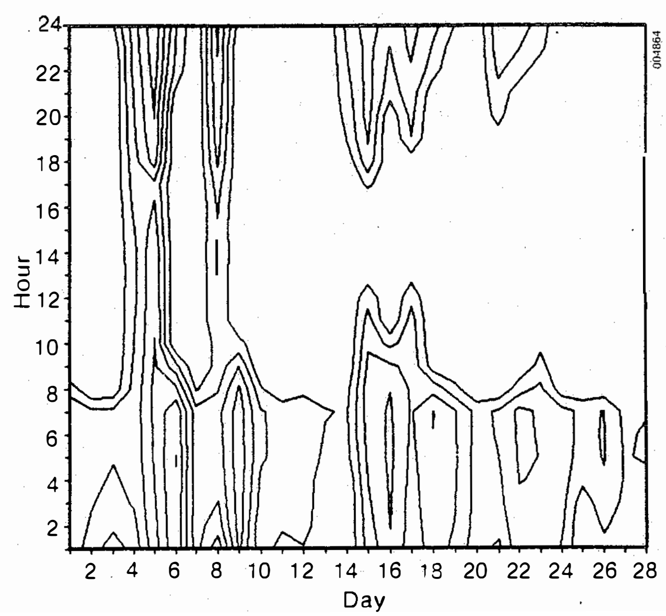


**Figure 5. Contour plot of hourly outdoor temperatures in February.**

basis for arranging data in the time-of-day by time-of-year format. In Fig. 5, the contours between days are the result of curve-fitting data that are discontinuous from day to day. Contour plots are less than ideal because they emphasize rates of change and only indirectly indicate magnitudes.

### Digital EMAPs

To avoid the problems of contour plots, we have developed energy maps (EMAPs) based on time-of-day by time-of-year plots of hourly data. One approach is to produce digital EMAPs by printing single-digit values for each hour as shown in Fig. 6. Single-digit resolution is generally adequate when values for many hours are to be scanned. Greater resolution in printouts is typically unused. By eliminating the insignificant figures, we are able to display information much more compactly. Digital EMAPs are approximately 10 to 100 times more compact than typical numerical printouts. An advantage of this method is that output can be produced on any alpha-numeric computer terminal or printer. In fact, this has proven to be a useful way to format numerical results.

```
 Heating Load in Zone 1     Cooling Load in Zone 1
Hour:                      Hour:                      Day:
1                      24  1                      24
------511---------------   -------------111--------    1
----111821111122---11111   ------------------------    2
1111111822222221-----111   ------------------------    3
1111111821-------------1   -------------123--------    4
1111111821-------------1   -------------121--------    5
1211111822222222-----111   ------------------------    6
1111111821------------11   -------------11---------    7
1111111832222222--122333   ------------------------    8
3333333943211-------2222   -------------133--------    9
222222293111------------   --------------13--------   10   January
111111282121---------122   -------------122--------   11
2223333932221------12333   --------------22--------   12
33333339321--------12222   ------------------------   13
222222282111----------11   -------------133--------   14
2222222821------------22   -------------123--------   15
2233333932222------12333   --------------23--------   16
3333333931111---------12   -------------133--------   17
222222282111----------12   -------------133--------   18
2222222832111-12----1111   ------------------------   19
11111118221---12----1111   ------------------------   20

------62111-111-------11   ------------------------    1
1111111711--------------   -----------11245--------    2
---111721---------------   ------------1221--------    3
-1111--71---------------   -----------12232--------    4
------511111111-------11   ------------------------    5
1111116-----------------   ----------122211--------    6
-11111171---------------   ----------122333--------    7
----11-6----------------   ------------------------    8
111111171---------------   ----------111211--------    9
-1111115----------------   ----------111342--------   10   April
--112116----------------   ----------111344--------   11
-------4----------------   ---------1222321--------   12
-------3----------------   ---------1212355-1------   13
-------3----------------   ---------1112354--------   14
-------1----------------   --------12222343--------   15
-------3----------------   --------------11--------   16
-----1161---------------   ----------112333--------   17
-------1----------------   ---------1222211--------   18
---111-4----------------   ----------112345-1------   19
-------3----------------   ---------1112345--------   20

------------------------   -------222233212--------    1
------------------------   --------12323345--------    2
------------------------   -------2222224561521----    3
------------------------   -------222222356121-----    4
------------------------   -------222233355-22-----    5
------------------------   -------122223333--------    6
------------------------   -------2222234572641----    7
------------------------   -------322322222--------    8
------------------------   -------122222456131-----    9
------------------------   -------122322324-21-----   10   July
------------------------   -------122222333--------   11
------------------------   --------11122222--------   12
-------21---------------   -------------111--------   13
------------------------   --------11221111--------   14
------------------------   --------12113345-21-----   15
------------------------   -------222333334--------   16
------------------------   -------222223456-1------   17
------------------------   -------322222345--------   18
------------------------   -------112222354--------   19
------------------------   --------12233455--------   20
```

**Figure 6. Digital energy maps of zone heating and cooling loads.**

### Color EMAPs

To further increase the compactness of EMAPs we used computer-generated color graphics. In color EMAPs, hourly values are indicated by hue and intensity according to the given scales. Different portions of the color spectrum allow multiple variables to be shown on a single plot (e.g., heating and cooling loads). As color was impossible to show in these proceedings, Figs. 7 through 9 are black and white renditions of color EMAPs. Current versions of color EMAPs are approximately 10 times more compact than digital EMAPs (and approximately 100 to 1000 times more compact than typical numerical printouts). The graphic nature of color EMAPs is an important advantage because it facilitates pattern recognition and interpretation by the user.

A number of color EMAPs have been generated to illustrate the method. The plots shown in Figures 7 through 9 are based on hourly results of computer simulations using the SERIRES code with TMY weather data for Denver, Colo. A simplified building model was used, and the results are intended only to illustrate the EMAP approach. Assumptions are listed in Table 1. The building configuration is shown in Figure 10 and includes four office modules oriented to the West, South, East, and North.

The EMAPs for Building 1 (with 1/2-in. drywall on interior surfaces and 24-h thermostat settings) as shown in Fig. 7 can be interpreted as follows:

- Heating loads are nearly identical from zone to zone because the lightweight interior surfaces provide little thermal storage.
- Cooling loads are high in the south zone in winter because of solar gains.

**Table 1. Assumptions for Office Modules**

| | |
|---|---|
| Floor area | 100 $ft^2$ |
| Interior surface area | 400 $ft^2$ |
| Window area | 50 $ft^2$ |
| Glazing type | double |
| Infiltration/ventilation | 0.5 ACH |
| Electric lighting | 0.5 $W/ft^2$ |
| Thermostat setback | 50°F |
| Thermostat setup | 120°F |

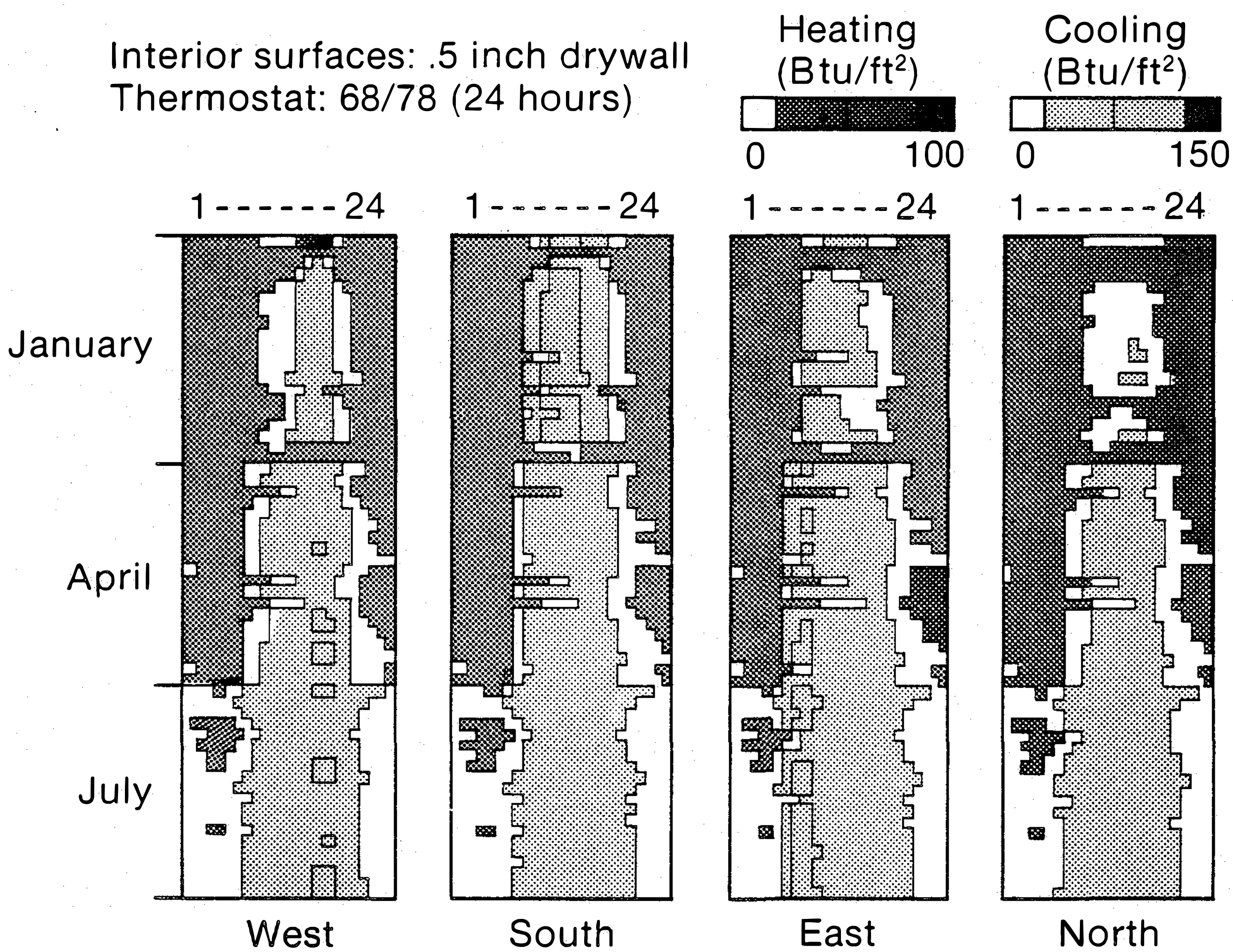


**Figure 7. Color energy maps of zone heating and cooling loads for Building 1.**

- Peak cooling loads occur in summer in the west zone during afternoon hours and in the east zone during morning hours.
- The absence of cooling peaks in the west zone on some days may be due to cloudy afternoons in the Denver climate.

The EMAPs for Building 2 (with 1/2-in. drywall on interior surfaces and 8 a.m. to 5 p.m. thermostat settings) as shown in Fig. 8 can be interpreted as follows:

- Heating loads do not begin until later in the day because the heating thermostat is set back to 50°F at 5:00 p.m.
- Peak heating loads occur at 8:00 a.m. because of the morning start-up when the heating thermostat is set up to 68°F.
- Peak cooling loads occur at 8:00 a.m. in the east zone when the cooling system is turned on.

The EMAPs for Building 3 (with 2-in. concrete on interior surfaces and 8 a.m. to 5 p.m. thermostat settings) as shown in Fig. 9 can be interpreted as follows:

- Neither heating nor cooling loads occur during nighttime hours because of the combination of the thermostat schedule and massive interior surfaces.
- Heating and cooling loads seldom occur on the same day, indicating that the heavyweight interior surfaces provide a significant amount of diurnal thermal storage.
- Heating load peaks are large because of morning start-up and the extent of recovery required when heavyweight interior surfaces have cooled overnight.
- Cooling load peaks are small because of the heavyweight interior surfaces.

## DISCUSSION

As demonstrated by the examples in the previous section, the use of EMAPs is a multistep process.

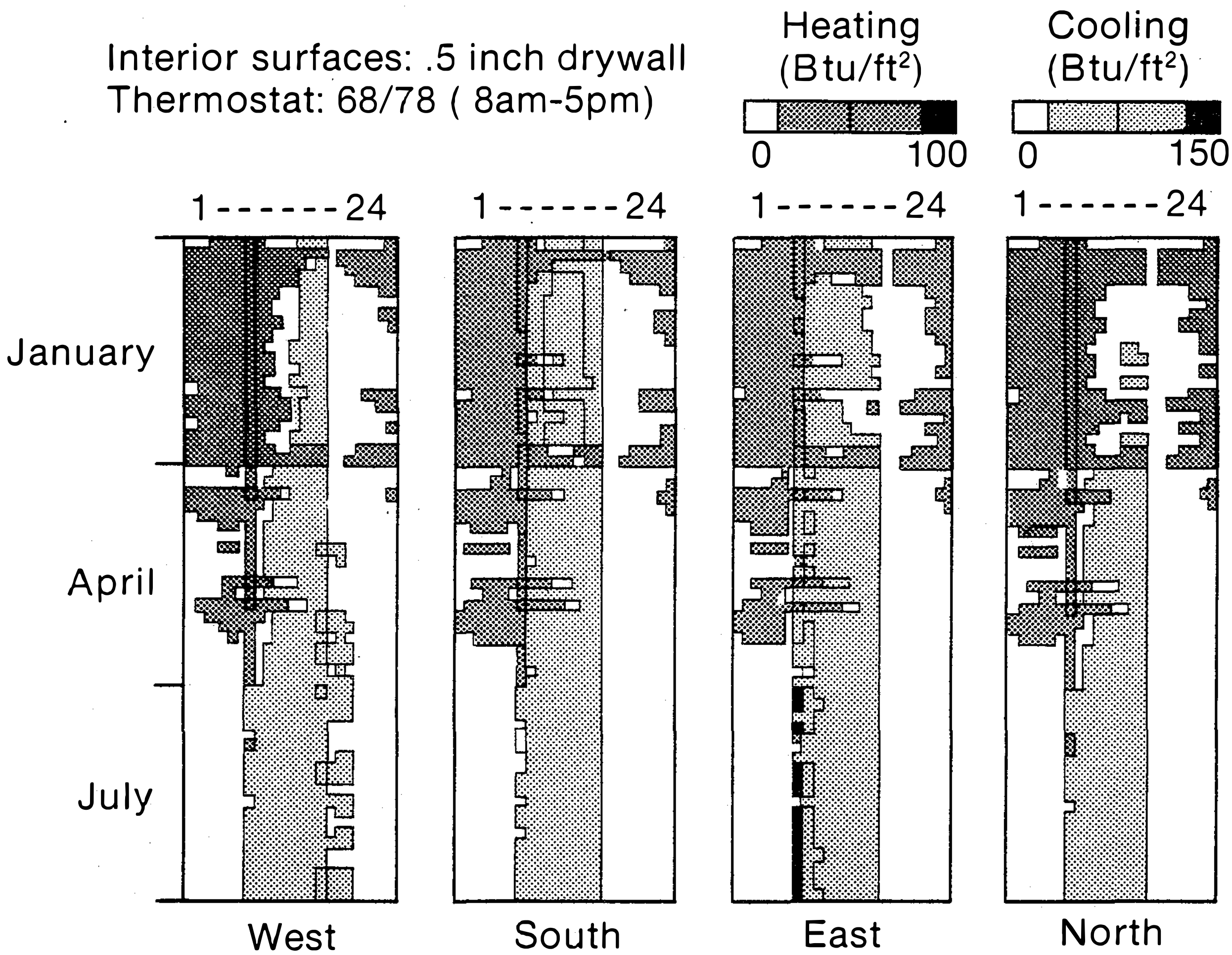


**Figure 8. Color energy maps of zone heating and cooling loads for Building 2.**

A single EMAP does not provide the final answer, rather information is provided at each step as the design evolves. An advantage of EMAPs is that the user has detailed information for choosing design options, and this information is specific to the building and the combination of strategies already in place.

The energy use patterns displayed in EMAPs are not necessarily surprising; in many cases, they correspond to conventional wisdom regarding building performance. The advantage of the method is the availability of detailed information in an accessible form. Interpretation of the data depends on the user. For users new to a particular building type or application, basic patterns will be educational. For researchers and experienced designers, more subtle patterns will be of interest. EMAPs will make obvious what might otherwise be overlooked (e.g., morning start-up heating loads in passive commercial buildings).

## CONCLUSIONS

The following conclusions can be stated:

- Time-of-day by time-of-year formats have been developed previously but are limited by the use of 12 or fewer representative weather days.
- Contour plots are suitable for seasonal data based on typical days; they are not suitable for data based on multiday weather sequences because the data are discontinuous from day to day.
- Hourly simulation results for multiday weather sequences can be formatted as EMAPs to show patterns of energy use and provide guidance for design or optimization.
- Color EMAPs can be generated using computer graphics to display a large amount of information in a very compact form.

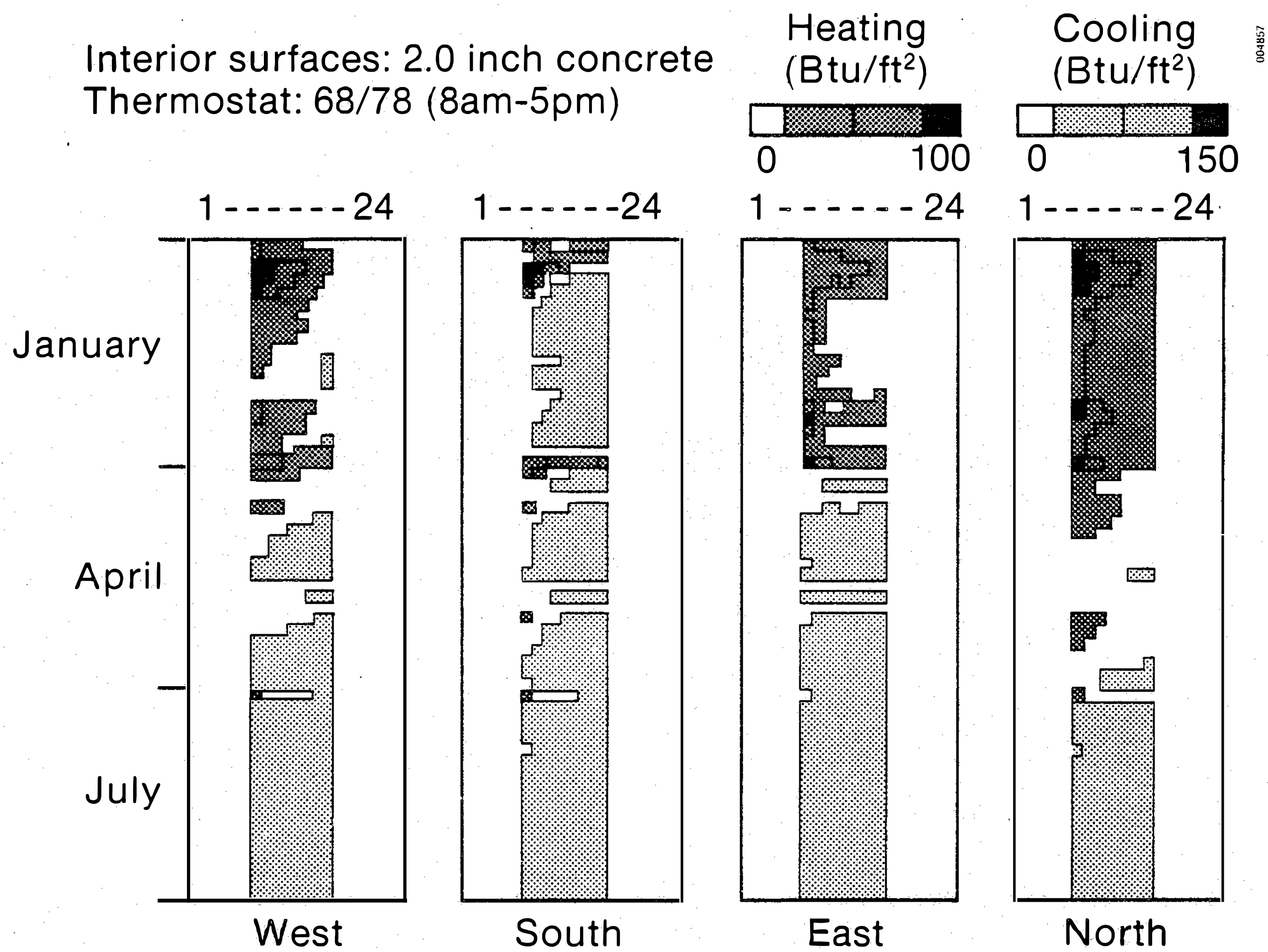


Figure 9. Color energy maps of zone heating and cooling loads for Building 3.

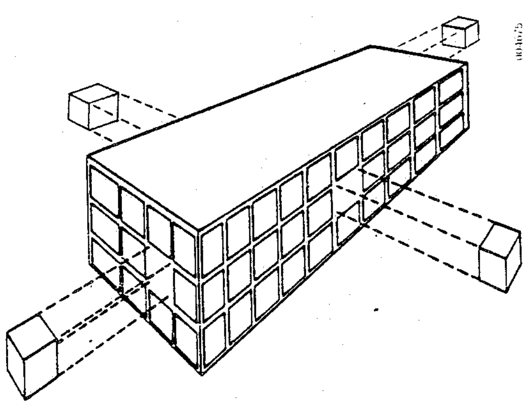

Figure 10. Building configuration with office modules oriented to West, South, East, and North.

## FUTURE WORK

EMAPs are not limited to heating and cooling loads as used in the analysis of this report. EMAPs may be generated for any variable of interest including a wide range of environmental driving forces and building responses. Environmental driving forces include: dry bulb and wet bulb temperatures, solar radiation, windspeed, etc. Building responses include: energy fluxes, comfort conditions, daylighting levels, HVAC system energy flows, etc. Potential effectiveness for strategies such as evaporative cooling and night ventilation will be indicated by comparing building load EMAPs with appropriate environmental EMAPs.

EMAPs can be generated for other data sources, not necessarily based on computer simulations. For environmental variables, hourly weather data are available on computer tapes in several forms; e.g., TMY, WYEC, SOLMET. For building responses, EMAPs may be generated to display patterns in measured data from monitored buildings.

EMAPs can be based on differences between two variables. For instance, EMAPs can be used to indicate hour-by-hour discrepancies between simulation results and measured data. EMAPs can also be based on coincidence among variables. For instance, EMAPs can be used to display the match between available daylight and the lighting load.

## ACKNOWLEDGMENTS

I wish to thank Karen Zuelke for her assistance in the early stages of this project. This work was sponsored by the U.S. Department of Energy, Division of Passive and Hybrid Solar Heat Technologies.

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