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ABSTRACT

Energy Mapping and Analysis Procedures (EMAPs) were developed to consicely display large amounts of hourly data. Energy Maps are generated using computer graphics to map hourly values into a time-of-day by time-of-year format. This approach has several advantages: (1) complete hourly data for several months or an entire year can be compactly displayed, (2) the graphic format reveals daily patterns, day-to-day variations, and seasonal trends, and (3) the same method can be used for a wide range of variable types. In this paper we introduce a monochromatic version of Energy Maps for use with typical microcomputers and printers. Procedures for using and interpreting Energy Maps are suggested and demonstrated. Energy Maps based on measured data are presented for solar radiation, outdoor temperature, building heating energy use, and indoor temperatures.

INTRODUCTION

Energy Maps are approximately 100 to 1000 times more compact than typical numerical printouts. The number of data points able to be displayed on a single page is maximized to provide direct access to as complete a set of data as possible. The user is presented with hourly data that can be scanned for details specific to a particular climate, building, energy system, etc. Energy Maps avoid the difficulties associated with using a limited number of design days to represent long-term weather.

The graphic nature of Energy Maps encourages user interaction with the data. A wide range of detail is displayed, and pattern recognition and interpretation can occur at several levels. For beginners or experts new to a particular building type or location the basic patterns are educational. For users with additional expertise more subtle patterns will be of interest. A user typically recognizes a range of patterns, some of which are readily interpreted and others that challenge the intuition. Causes for specific patterns can often be found by using the Energy Maps to compare other variables and to observe coincidental effects. In any case, Energy Maps will make obvious what might otherwise be overlooked (e.g., morning start-up heating loads in passive commercial buildings).

Energy Maps can be generated for any hourly variable of interest. Environmental driving forces, for example, include: dry-bulb and wet-bulb temperatures, solar radiation, and windspeed and direction. Building responses include: energy fluxes, comfort conditions, heating and cooling loads, HVAC system operation, and daylighting levels.

Energy Maps can display predicted or measured values. Environmental data can be from Typical Meteorological Year (TMY) weather tapes or from on-site measurements for a specific time period. Building response data can be from computer simulations or measured data from monitored buildings.

BACKGROUND

We have developed several types of Energy Maps for use on different forms of computer hardware. Color Energy Maps and digital Energy Maps are described in a previous paper[1], and monochromatic Energy Maps are presented in this paper. Each type is the result of a tradeoff between display characteristics and hardware requirements.

Color Energy Maps are excellent for displaying detailed data because the human eye can discern many more colors than shades of grey. Hourly values can be indicated by hue and intensity, and multiple variables can be shown on the same plot by using separate portions of the color spectrum. The required display hardware (approximately 16 simultaneously displayed colors with resolution of 320 x 200 pixels or better) has recently become available as an option on the IBM personal computer. Hardcopy of display images can be produced by color inkjet printers, but the inability to inexpensively photocopy color images indicates the need for a noncolor version of Energy Maps.

Digital Energy Maps are a simple noncolor type of display with hourly values indicated by single digits printed in a time-of-day by time-of-year format. No special hardware is required other than a standard computer terminal or printer. Digital Energy Maps are a useful format for storing and previewing numerical data, but they are not nearly as compact and graphic as color Energy Maps.

Monochromatic Energy Maps are a graphic form that can be used with typical microcomputers and printers. Monochromatic Energy Maps are not as flexible as color Energy Maps but are a significant improvement over digital Energy Maps and can be reproduced on standard photocopiers.

In summary, color Energy Maps have superior display characteristics, monochromatic Energy Maps can be used with widely available microcomputer hardware, and digital Energy Maps are available for numerical display. In fact, a single user might well use all three types: color Energy Maps for analysis and presentations, monochromatic Energy Maps when color hardware is unavailable and for printable copies, and digital Energy Maps for previewing and storing data.

METHODOLOGY

To illustrate the use of Energy Maps we have generated a number of examples and applied a multistep procedure for interpretation. Energy Maps provide information in a very detailed form. Our experience shows that patterns continue to be observed as additional time is spent inspecting Energy Maps and that different patterns are detected depending on the user. This indicates that a methodical procedure for interpreting Energy Maps may be beneficial.

When examining individual Energy Maps, the following procedure is suggested:

- Scan from top to bottom (1 a.m. to midnight) to detect
  - what diurnal patterns are typical
  - what time of day effects occur
  - whether changes are abrupt or gradual
- Scan from left to right (seasonally) to determine
  - if patterns are repeated day after day
  - if there are short-term weather sequences (5 to 10 days)
  - what the seasonal trends are.

When examining a set of Energy Maps for a particular building, the following procedure is suggested:

1. Observe patterns in environmental Energy Maps
2. Observe patterns in building Energy Maps
3. Make note of familiar patterns
4. Develop hypothesis for unexpected patterns
5. Reexamine Energy Maps to test hypothesis
6. Repeat previous steps to investigate additional patterns.

At step 5 it is especially useful to compare Energy Maps for different variables to observe coincident effects that may indicate cause-and-effect.

RESULTS

Figures 1 through 5 show monochromatic Energy Maps for solar radiation, outdoor temperatures, heating energy use, and indoor temperatures. The data are from a passive solar residence in Golden, Colorado (site DMD in the Class B monitoring program[2]). The 1982-1983 heating season results are shown for December, January, February, and April. March is not shown because of missing data.

Figure 1 shows solar radiation incident on a south-facing vertical surface. Clear days show the expected patterns centered about noon. Partly cloudy days and entirely cloudy days are evident. Extended sunny periods are seen from December 28 to January 3 and from February 20 to 26. An extended cloudy period is seen from April 15 to 30, perhaps combined with the effect of low incidence angles because of large solar altitude angles. Increasing length of day is apparent as the year progresses from December to April.

Figure 2 shows outdoor dry-bulb temperatures below 55°F (heating degree-hours to base 55°F). Areas in dark print indicate lower temperatures. Daytime warming is seen as a light horizintal band. Alternating mild and cold weather sequences are seen as light and dark vertical bands. For example, a very cold period from December 23 to 31 is followed by a mild period from January 1 to 13. The first part of April is surprisingly cold, and the last part of April is seasonably mild.

Figure 3 shows heating energy use for site DMD. Heating energy is used only rarely in the middle of the day. On some days heating begins during the evening but typically ends, or is significantly reduced, at about 11 pm, followed by gradually increased heating during the early morning hours. At the end of night-time heating (at about 8 a.m.), high heating rates occur for several hours.

Figure 4 shows indoor temperatures below 70°F (degree-hours of underheating). Low indoor temperatures occur regularly at night between midnight and 8 or 10 a.m. Cooldown typically begins during the evening and ends abruptly the following morning but not at precisely the same time each day. Low indoor temperatures are experienced during the entire day on a few occasions.

Figure 5 shows indoor temperatures above 70°F (degree-hours of overheating). Indoor temperatures rise above 70°F during late morning, reaching maximum values during late afternoon and persisting until after midnight on some days. Overheating tends to occur during 4 to 9 consecutive days.

DISCUSSION

In this section we compare Energy Maps for different variables and use coincident patterns to infer cause-and-effect relationships. Several patterns in the Energy Map of heating energy use warrant further explanation: daily heating patterns and the surprisingly large heating loads during the first part of April.

The most notable feature of the daily heating pattern is the high rate of energy use at the end of the heating cycle. This peak heating is probably because of the morning start-up heating after a night setback of the thermostat. The Class B building description does not specify whether or not thermostat setback was used, but we can refer to the Energy Map

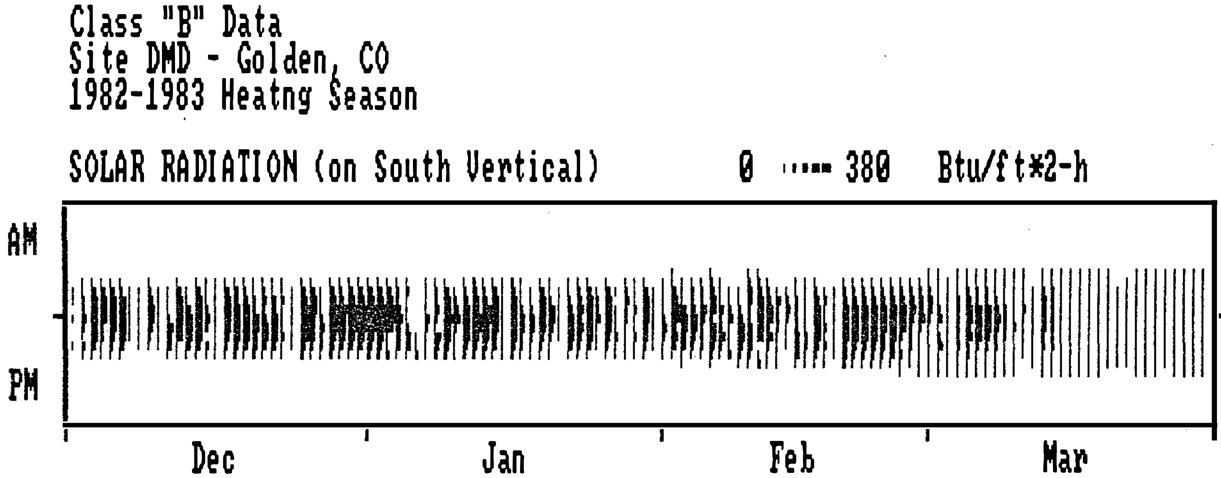

Figure 1. Energy Map of Solar Radiation at Site DMD in Golden, Colorado.

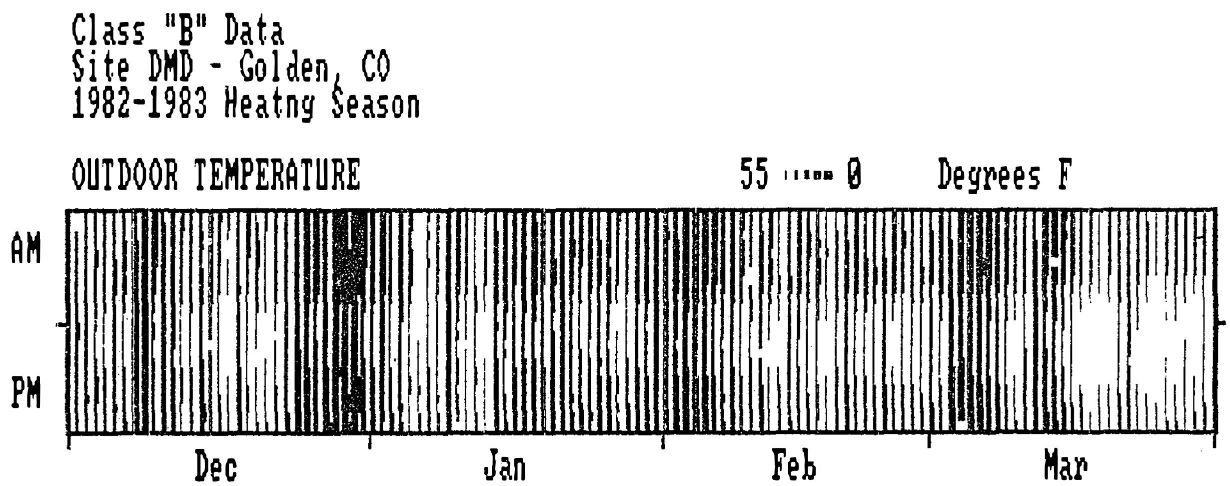

Figure 2. Energy Map of Outdoor Temperature at Site DMD in Golden, Colorado.

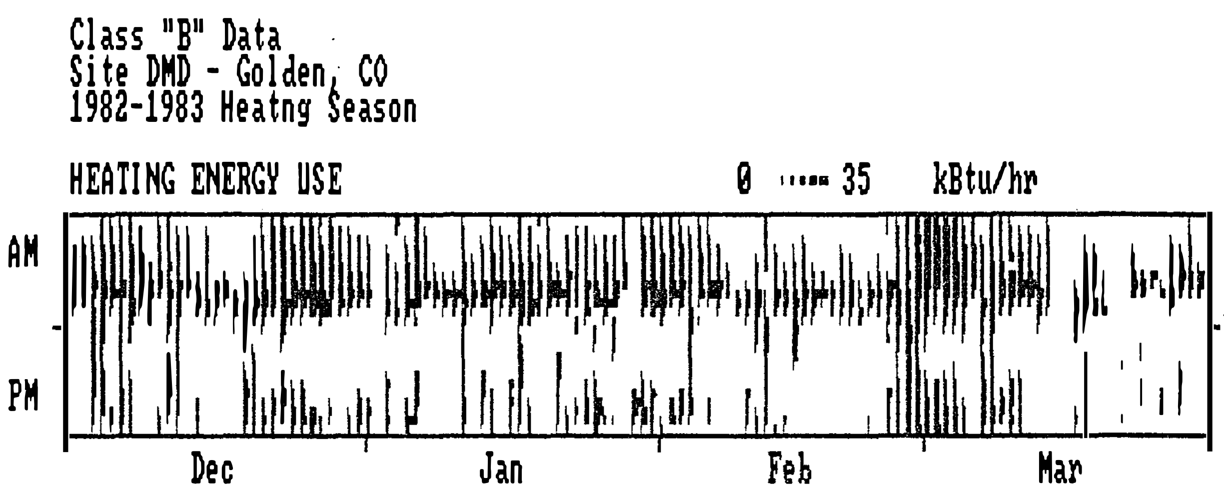

Figure 3. Energy Map of Heating Energy Use for Site DMD in Golden, Colorado.

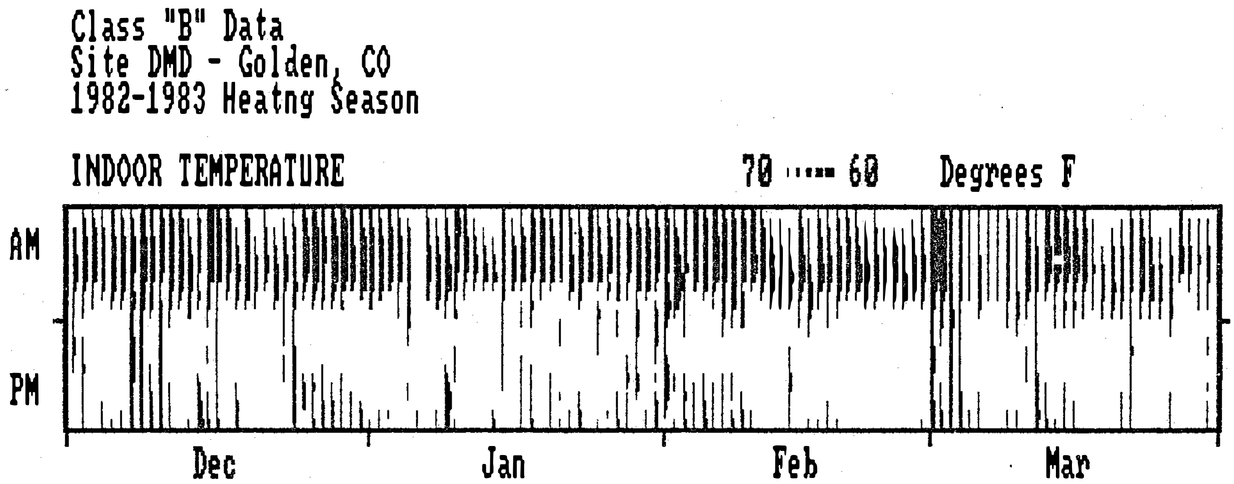

Figure 4. Energy Map of Indoor Temperature Below 70°F for Site DMD in Golden, Colorado.

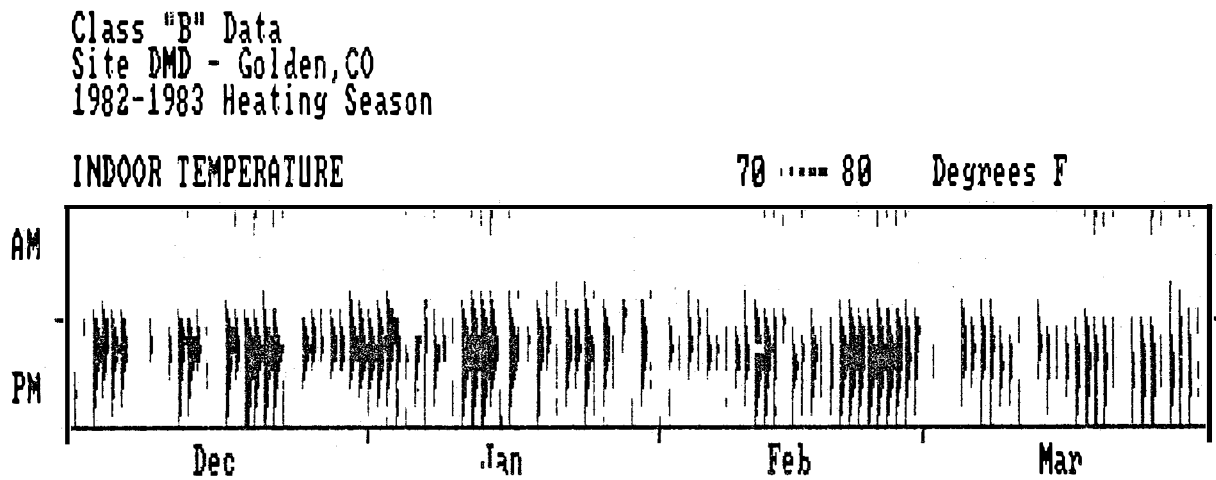

Figure 5. Energy Map of Indoor Temperature Above 70°F for Site DMD in Golden, Colorado.

of indoor temperature to check this hypothesis. Figure 4 shows that the indoor temperature does drop at night, and the abrupt end of the low temperature period in the morning is also consistant with a thermostat set-up at that time. The abrupt end of heating at about 11 pm on some days (see Energy Map of heating energy use) indicates the beginning of the setback period. The morning start-up does not occur at precisely the same time each day, probably indicating manual operation of the thermostat.

Heating energy use during the first part of April is surprisingly high, especially when compared with the last part of February. There are several possible explanations that can be investigated by referring to other Energy Maps. The outdoor temperature Energy Map shows that the first part of April was remarkably cold and the last part of February was quite warm. The solar radiation Energy Map shows more incident solar radiation during the first part of April than during the remainder of the month but less incident solar radiation than during the last part of February. In April the days are longer, but the levels of solar radiation are reduced during some hours because of the large incidence angles. The Energy Map of indoor temperatures below 70°F shows relatively warm night-time temperatures, indicating less thermostat setback. The Energy Map of indoor temperatures above 70°F shows that relatively high temperatures coincide with heating energy use, indicating higher thermostat settings.

CONCLUSIONS

Monochromatic Energy Maps have been developed and can be used much like color Energy Maps to reveal patterns in hourly data. The monochromatic version can be used with typical microcomputers and printers.

Procedures for using Energy Maps have been developed and demonstrated with measured data from a passive solar residence. Scanning of Energy Maps produces recognizable patterns of diurnal cycles, day-to-day variations, and seasonal trends.

In interpreting patterns for a particular building it is useful to compare Energy Maps of different variables, including heating energy use, outdoor temperatures, solar radiation, and indoor temperatures. Coincident patterns can often be observed and used to infer cause-and-effect.

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