SERI/TP-253-2476
UC Category: 59c
DE85000527

What Do Hourly Performance Data on a Building Tell Us

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November 1984

Presented at the American Solar Energy Society
Ninth National Passive Solar Conference
Columbus, Ohio
24-26 September 1984

Prepared under Task No. 3733.10
FTP No. 468

Solar Energy Research Institute
A Division of Midwest Research Institute

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Prepared for the
U.S. Department of Energy
Contract No. DE-AC02-83CH10093

Printed in the United States of America
Available from:
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price:
Microfiche A01
Printed Copy A02

PROJECT SUMMARY

Project Title:

Extrapolation of Long-Term Building Performance Based on Short-Term Measured Data

Performing Institution:

Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80401

Project Manager:

Kris Subbarao, (303) 231-1056

Project Objectives:

Predictions of building performance based only on a calculational method are seldom accurate, but performance assessment based on long-term monitoring is not only costly and time-consuming, but is subjected to the variability of weather and building operation. Furthermore, cause and effect relationships are sometimes unclear. The objective of the task is to develop (1) the building element vector analysis (BEVA) method in which short-term measurements of a building can determine long-term performance, especially of a multizone building, and (2) a methodology for performing laboratory or test cell measurements on certain passive components and extrapolating the results to performance of real buildings.

Project Status:

The methodology for performing laboratory or test cell measurements on certain passive components has been completed. Methods to extrapolate the results to performance in real buildings have been established.

The BEVA method has been applied to data for a multizone building from the Class B program to derive building parameters from short-term (one week) data. These parameters serve as inputs to an hourly simulation for the subsequent period. Predictions for the following week agree well with measured data. Obviously, quantities such as heat exchange with ground and variations of solar gains over a season cannot be determined by short-term measurements; they have been incorporated through calculations. Efforts to predict long-term performance are under way.

One important issue that needs to be refined is the uncertainties in the parameter estimation. It is intuitively plausible that an increase in the loss coefficient can be nearly compensated for by an increase in solar gain and an appropriate solar energy storage-release mechanism. One can devise tests such as introducing heat input so that these uncertainties are reduced. Such tests may even be more important than continued monitoring under normal operation of the building. Once the building parameters have been determined with an acceptable level of uncertainty, they can be used to determine performance of the building under normal operation.

Plans and Objectives for FY 1985:

Initiate efforts to identify the necessary tests to be performed on a building to reduce uncertainties in the parameter estimation.

Major Publications Related to Project:

"BEVA (Building Element Vector Analysis): A New Hour-by-Hour Building Energy Simulation with System Parameters as Inputs," by K. Subbarao, SERI/TR-254-2195, submitted to Journal of Solar Energy Engineering.

"A Balanced Measurement/Calculation-Based Approach to Building Energy Analysis," by K. Subbarao and L. Flowers, presented at the American Council for an Energy Efficient Economy, Summer Study, Santa Cruz, CA, Aug. 1984.

"Solar Gains from Individual Building Components," by K. Subbarao and J. V. Anderson, SERI/TP-254-2300, accepted for publication in the Journal of Solar Energy Engineering.

Contract Number:

DE-AC02-83CH10093

Funding Source:

U.S. Department of Energy

FY 1985 Funding:

Undetermined

WHAT DO HOURLY PERFORMANCE DATA ON A BUILDING TELL US

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ABSTRACT

Hourly performance data on a building contain valuable information on the dynamics of the building and of the HVAC systems. Quantities such as the building loss coefficient, solar gains, and the net effect of thermal masses and their couplings are all contained in the data. In order to extract this information, a suitable analysis method is essential. A qualitative approach is to look at plots of variables such as inside temperature, auxiliary energy, etc. over selected periods such as a sequence of clear days or a sequence of cloudy days. Since several other quantities such as outdoor temperature, internal gains, and thermostat set points govern the building performance, the qualitative approach does not unambiguously establish cause and effect relationships; therefore it is of limited use. A quantitative approach that only uses the total auxiliary energy, average temperatures, average solar radiation, etc., over a month or over the season dilutes the dynamical information through the time-averaging process. If, on the other hand, a detailed simulation such as DOE2.1 is to be used, the nonavailability of the detailed inputs makes it difficult to extract the dynamical information. It is thus clear that time-averaging as well as the requirement of component/subcomponent level inputs should be avoided. In other words, an hourly simulation that accepts whole building (or zone) level inputs is needed. In this article, an hourly simulation called BEVA (Building Element Vector Analysis) is outlined that accepts whole building (or zone) level inputs. The number of these inputs is small, and they can be obtained from suitable short-term hourly performance data. An illustrative application of the method for a passive residential building is given. In order that BEVA be a design tool (and thereby also provide a natural framework to account for differences in design and actual performance), it is pointed out that these parameters can be calculated from a building description, i.e., from component/subcomponent level inputs. Potential additional applications for BEVA include determining long-term performance from short-term performance data, as well as HVAC system diagnosis.

1. INTRODUCTION

Hourly data on temperatures, solar radiation, energy usage, and humidity pertaining to a building contain much valuable information about the dynamics of the building and its space-conditioning equipment. A systematic method to obtain this information is of critical importance. Some of this information can be obtained qualitatively by plotting quantities such as indoor temperature and solar radiation as functions of time; typical values of indoor temperature swings, time of peak load, etc. can be visualized. A quantitative analysis is generally restricted to the study of total auxiliary energies, that is, to a comparison between measured values and those predicted by a design method. Much of the dynamical information is lost in this time-averaging process. One possible approach to a quantitative analysis of the hourly data is to compare the measured hourly quantities with those based on a first principles numerical simulation such as DOE 2.1. Since such a simulation requires a large number of inputs, not all of which are readily measured, as well as somewhat subjective assumptions such as distribution of solar radiation on various surfaces, it has been difficult to find a systematic way to reconcile the differences between measured and calculated performance of the building. Thus, a first principles numerical simulation, while useful for design and for parametric studies, is of limited utility for performance data analysis.

An alternative approach to the analysis of hourly performance data is to first construct a model of the building with a small number of parameters. The model can be thought of as a resistor-capacitor network with a small number of independent parameters. It is then subjected to the measured driving functions (ambient temperature, solar radiation, humidity, internal gains, etc.). The model parameters can be regressed by suitably minimizing the difference between calculated and measured hourly values. This method is reasonable for studying the building response to a different sequence of driving functions (in particular, to normalize the performance data for a chosen standard sequence of driving functions such as the typical meteorological year). However, without a method to directly calculate the building parameters from a building description, it is not useful for design and therefore for comparing and reconciling design and actual performance, or for studying consequences of design changes.

2. BEVA - A NEW HOURLY SIMULATION

To address the issues discussed in the introduction, we will use the concepts of "forward" and "inverse" processes. The calculation of building performance from a building description will be referred to as the forward process. The determination of a set of building parameters from performance data will be referred to as the inverse process. A first principles numerical simulation is suitable for the forward process but is ill-suited for the inverse process. The model for the inverse process must be chosen judiciously. Since regression can generally hide quite easily serious deficiencies in a model, one can construct a number of models, all of which are seemingly acceptable in terms of fitting short-term data. It is necessary to ensure that the model contains the essential physics to begin with. This is especially important for passive solar buildings because of the necessity to adequately treat storage and release of solar gains. We have performed such an analysis and arrived at a model called building element vector analysis (BEVA). This article highlights some aspects of the method. Additional details are given in Reference (1). BEVA is a reasonable model for each zone of a multizone building as long as there are no intrinsically nonlinear components (i.e., components with material properties and heat transfer characteristics that are strongly dependent on temperature) such as walls with phase-change materials. When such nonlinear components are present, the rest of the building can still be adequately represented by the BEVA method.

BEVA is an hourly simulation. A key aspect of the BEVA simulation is its suitability for both the forward and the inverse processes, in contrast to a first principles numerical simulation which is generally suitable only for the forward process. Figure 1 is a flowchart of a first principles numerical simulation, and Figure 2 is a BEVA simulation. In the BEVA method,

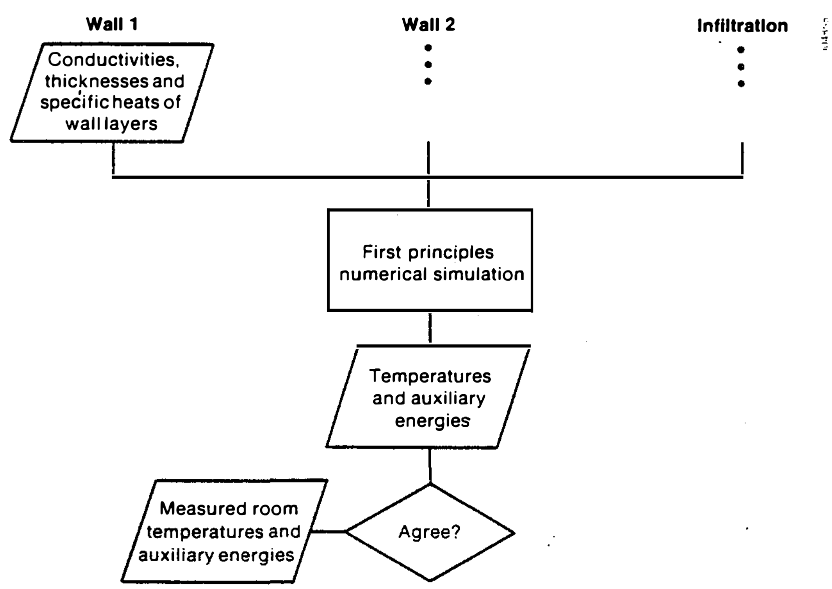

Fig. 1. Schematic Flowchart of Calculations of Room Temperatures and Loads Using a Mainframe Numerical Simulation

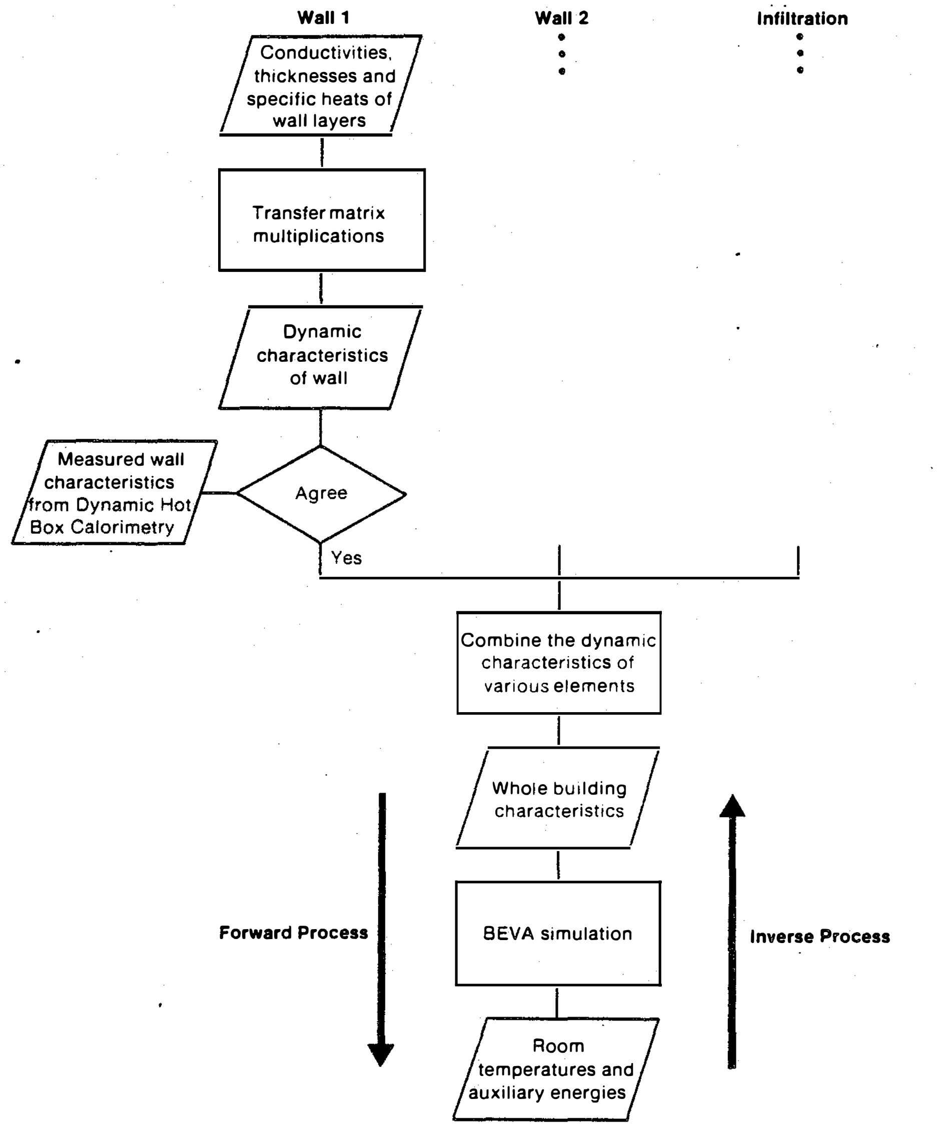

Fig. 2. Schematic Flowchart of Calculations of Room Temperatures and Loads Using the BEVA Simulation

wall layer properties are combined into wall characteristics. One can directly measure these wall characteristics in a dynamic hot box and use them as inputs to a BEVA simulation. The wall characteristics are then aggregated into zone characteristics. These zone parameters can be directly obtained from short-term performance data. Thus, the inputs to a BEVA simulation can be at the subcomponent level, the component level, or the zone level. Lower level inputs are aggregated into higher level inputs. Inputs at any level are accessible to measurement.

One of the parameters in the BEVA method is the loss coefficient, which is calculated in the usual manner. It can be determined experimentally by electrically heating the building to maintain a constant inside temperature when the outside temperature is relatively constant and solar gains have been minimized. It can also be regressed from dynamic data in the presence of varying solar gains and varying temperatures. A comparison between measured and calculated loss coefficients diagnoses possible problems in the design assumptions. Another parameter in the BEVA method is effective thermal mass coupled with inside air. Again, a comparison between calculated and regressed values is possible. There are additional parameters--a total of eight for a simple one-zone building--to account for the building response to all the driving functions of indoor and outdoor temperatures and solar radiation. These whole building parameters can be expressed in the form of two-dimensional vectors and can be obtained in the forward process by an element-by-element addition of individual vectors.

Short-term monitoring of a building can be thought of as determination of build ng level inputs to a BEVA simulation. Us ng these inputs with the BEVA simulat on

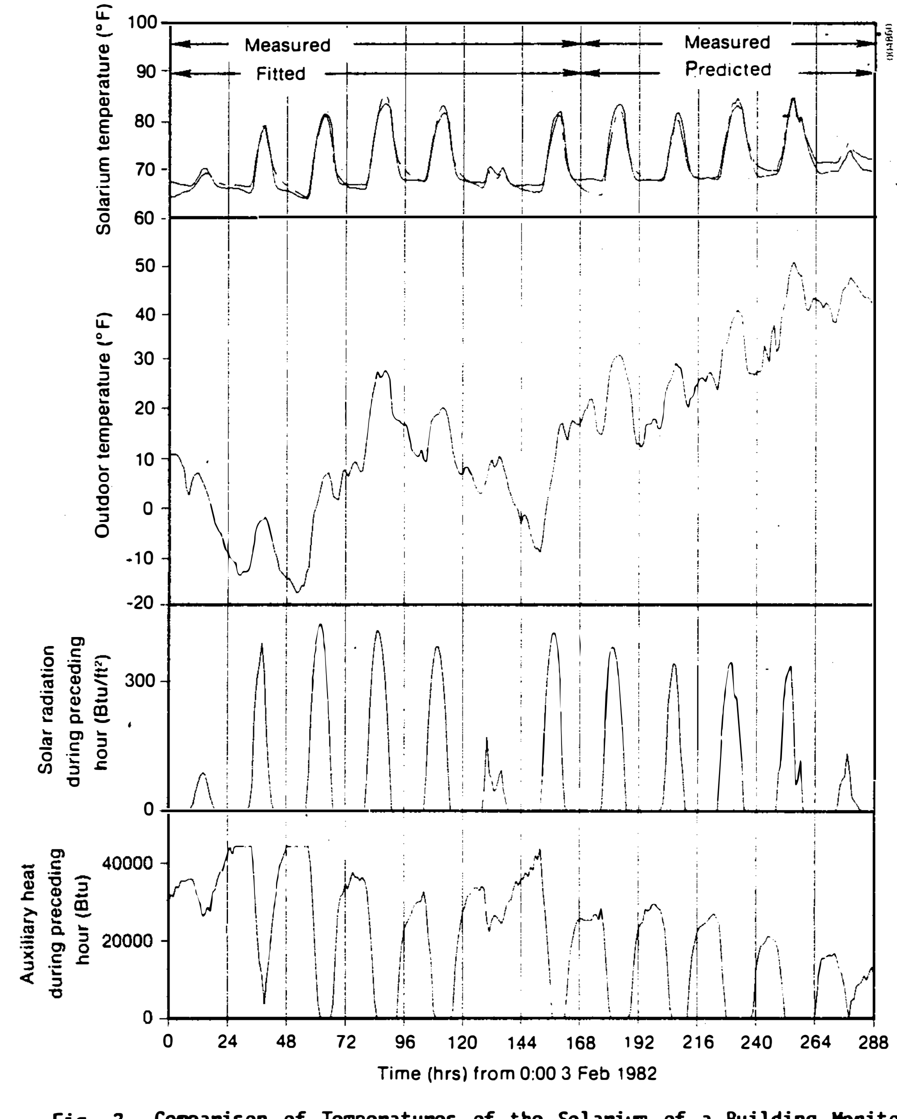

Fig. 3. Comparison of Temperatures of the Solarium of a Building Monitored Under the Class B Program. Data from the period February 3-9, 1982 are used to estimate system parameters by the inverse process; the measured vs. file temperatures for this period are shown. The estimated system parameters are used in the forward process to predict solarium temperatures: the measured vs. predicted temperatures for the period February 10-14, 1982 are shown.

(combined with calculated variations over a season of solar gains, infiltration, and heat exchange with ground--all of which are not accessible to short-term monitoring) gives long-term performance.

The BEVA method has been applied to a multizone residential passive solar building monitored under the SERI Class B program. Using short-term data (approximately one week), the building parameters were regressed. With these as inputs, the subsequent performance of the building was well predicted. Using performance data for the period February 3-9, 1982, the building vectors were obtained by regression. The resulting best fit for the zone temperature is given in Figure 3. These parameters were used to predict the temperature for the period February 10-14. The resulting values are also plotted in Figure 3 along with the outdoor temperature, solar radiation on a south vertical surface, and auxiliary energy for these periods. A thorough comparison of calculated and measured values of the parameters, as well as a determination of seasonal performance, are underway.

The uncertainties in the parameters estimated from the inverse process are sometimes quite large. Preliminary indications are that tests can be devised (such as subjecting the building to a heat input of a certain profile) that reduce the uncertainties to acceptable levels. Efforts are under way to determine the necessary tests so that short-term monitoring is fully developed into a tool for long-term performance estimation as well as for diagnostics.

3. REFERENCE

(1) Subbarao, K. BEVA (Building Element Vector Analysis): A New Hour-by-Hour Building Energy Simulation with System Parameters as Inputs, SERI/TR-254-2195, Solar Energy Research Institute, Golden, CO, (Mar. 1984). Reference to earlier works are given in this reference.