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Empirical Validation of Building Analysis Simulation Programs: A Status Report

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EMPIRICAL VALIDATION OF BUILDING ENERGY ANALYSIS SIMULATION PROGRAMS: A STATUS REPORT

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ABSTRACT

Under the auspices of the DOE Passive/Hybrid Solar Division Class A Monitoring and Validation Program, SERI has engaged in several areas of research in fiscal year 1982. This research has included: (A) development of a validation methodology, (B) development of a performance monitoring methodology designed to meet the specific data needs for validation of analysis/design tools, (C) construction and monitoring of a 1,000-ft^2 multizone skin-load-dominated test facility, (D) construction and monitoring of a two-zone test cell, and (E) sample validation studies using the DOE-2.1, BLAST-3.0, and SERIRES-1.0 computer programs. This paper reports on the status of these activities and briefly describes the validation methodology and the Class A data acquisition capabilities at SERI.

INTRODUCTION

The Class A, B, and C performance monitoring programs were initiated in 1979 because of the demand from researchers and industry for passive and hybrid building performance data at various levels of detail [1]. Class A monitoring was defined to provide detailed data (on the order of 200 channels per building) under controlled conditions at a few sites for algorithm development and validation of building energy analysis simulation programs. Class B was to provide limited detail (about 20 channels per building) in approximately 100-200 occupied buildings for field testing of passive/hybrid designs and statistical evaluation of simplified design tools. Class C was to provide utility bill data and a survey of occupant reactions.

SERI's involvement in the validation of building energy analysis simulations (BEAS) resulted from two comparative studies conducted in 1980 and 1981 [2,3]. These studies showed significant disagreement between four state-of-the-art simulations: DOE-2.1, BLAST-3.0, DEROB-4.0, and SUNCAT-2.4 when given equivalent input for a simple, direct-gain building with a high and low mass parametric option (Fig. 1). These studies indicated the need for high quality controlled validation data and a validation methodology. SERI assumed responsibility for defining the data acquisition criteria for validation, developing a validation methodology, and constructing a Class A data collection facility. Los Alamos National Laboratory was assigned the role of coordinating the Class A Program which included SERI, the National Bureau of Standards, several universities, and several subcontractors.

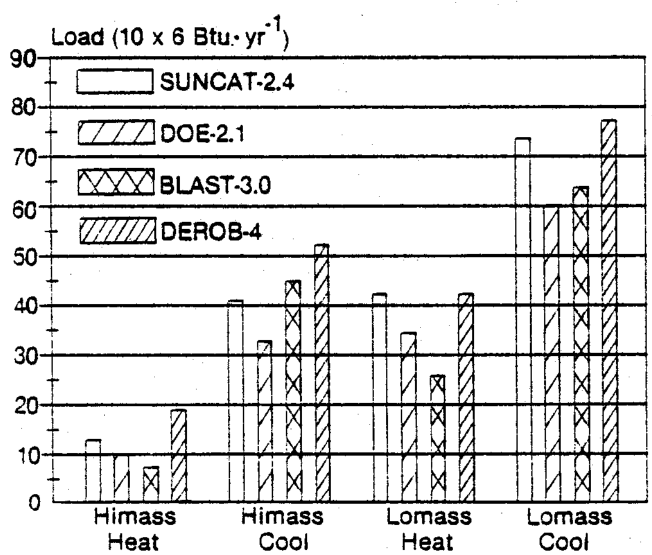

Figure 1. Phase II Comparative Study: Albuquerque

VALIDATION METHODOLOGY

The overall validation methodology uses three different kinds of tests: (1) Analytical Verification, (2) Empirical Validation, and (3) Code-to-Code comparisons. The advantages and disadvantages of these three techniques are shown in Table 1.

The need for these three tests has been described in detail elsewhere [4,5] and only a brief discussion will be possible here.

Each comparison between measured and calculated performance represents a single data point in an immense N-dimensional parameter space. We are constrained to establishing a very few data points within this space. Yet we must somehow be assured that the results at these points are not coincidental and are representative of the validity of the simulation elsewhere in the parameter space. The analytical and comparative techniques are used to minimize the uncertainty of the extrapolations we must make around the limited number of Class A empirical data points it is possible to sample. These extrapolations are classified in Table 2.

Table 1. Validation Techniques

Technique	Advantages	Disadvantages
A. Comparative Relative test of model and solution process	• No input uncertainty • Any level of complexity • Inexpensive • Quick: Many comparisons possible	• No truth standard
B. Analytical Test of numerical solution	• No input uncertainty • Exact truth standard given the simplicity of the model • Inexpensive	• No test of model • Limited to cases for which analytical solutions can be derived
C. Empirical Test of model and solution process	• Approximate truth standard within accuracy of data acquisition system • Any level of complexity	• Measurement involves some degree of input uncertainty • Detailed measurements of high quality are expensive and time consuming • A limited number of data sites are economically practical

Table 2. Types of Extrapolation

Obtainable Data Points	Extrapolation
1. A few climates	Many climates
2. Short-term (e.g., monthly) total energy usage	Long-term (e.g., yearly) total energy usage
3. Short-term (hourly) temperatures and/or flux	Long-term (yearly) total energy usage
4. A few buildings representing a few sets of variable mixes	Many buildings representing many sets of variable mixes
5. Small-scale, simple test cells and buildings	Large-scale complex buildings

Figure 2 shows the process by which we use the analytical empirical and comparative techniques together. The first step is to run the code against the analytical test cases. This checks the numerical solution of major heat transfer models in the code. If a discrepancy occurs, the source of the difference must be corrected before any further validation is done. The next step is to run the code against Class A empirical validation data and to correct discrepancies. A quantified definition of these discrepancies has been proposed by LANL [6]. SERI and several other Class A sites are currently collecting these data. The data along with site handbooks will be archived at LANL. The third step involves checking the code against several prevalidated building energy analysis simulations (BEAS) in a number of comparative studies. If the code passes all three steps, it can be considered validated for the range of climates and building types represented by these studies. The prevalidated BEAS will have successfully passed steps one and two and will have shown substantial agreement for all the comparative study cases. These comparative study cases will, to the extent possible, use Class B data. SERI is currently prevalidating the DOE, BLAST, and SERIRES programs as part of its Class A empirical validation project.

DATA COLLECTION METHODOLOGY

There are many levels of validation depending on the degree of control exercised over the possible sources of error in a simulation. These error sources consist of seven types, divided into two groups:

External Error Types

1. Differences between the actual weather surrounding the building and the statistical weather input used with the BEAS.
2. Differences between the actual effect of occupant behavior and those effects assumed by the user.
3. User error in deriving building input files.

4. Differences between the actual thermal and physical properties of the building and those input by the user (generally from ASHRAE handbook values).

Internal Error Types

5. Differences between the actual thermal transfer mechanisms taking place in the "real building" and the simplified model of those mechanisms in the simulation.
6. Errors or inaccuracies in the numerical solution of the models.
7. Coding errors.

At the most basic level, the actual long-term energy usage of a building is compared to that calculated by the computer program with no attempt to eliminate sources of discrepancy. This level is similar to how the BEAS would actually be used in practice and is therefore favored by many representatives of the building industry. However, it is difficult to interpret the results of this kind of validation exercise because all possible error sources are simultaneously operative. Even if good agreement is obtained between measured and calculated performance, the possibility of offsetting errors prevents drawing conclusions about the accuracy of the method of calculation. More informative levels of validation are achieved by controlling or eliminating various combinations of error types. At the most detailed level, all known sources of error are controlled to identify and quantify unknown error sources. This is the approach taken in Class A data acquisition for validation.

Detailed meteorological and microclimate measurements are taken at the site to eliminate error type #1. The buildings are kept unoccupied to eliminate error type #2. Input files are derived independently by several experienced users and then cross-checked until collective agreement is reached to control error #3. Thermophysical properties are directly measured through destructive and nondestructive testing to control error #4. Once all external error types have been controlled, it is possible to isolate internal errors.

To validate the key thermodynamic models which comprise error types 5 and 6, data of two different kinds need to be acquired. First, data must be taken to define the overall building energy performance. This overall system level includes zone air and globe temperature data and (if temperature controlled) auxiliary energy measurements. These data summarize building energy performance. Energy transport mechanisms are summarized in Table 3. Where this is not possible due to limitations in the state of the art of measurement, or where no acceptable models exist for a mechanism, the mechanism may be physically suppressed as was done in our test cell for ground coupling. This two-level approach allows the identification of those mechanism inaccuracies that lead to system level errors.

To ensure that all major transport mechanisms are monitored, we provide for internal consistency

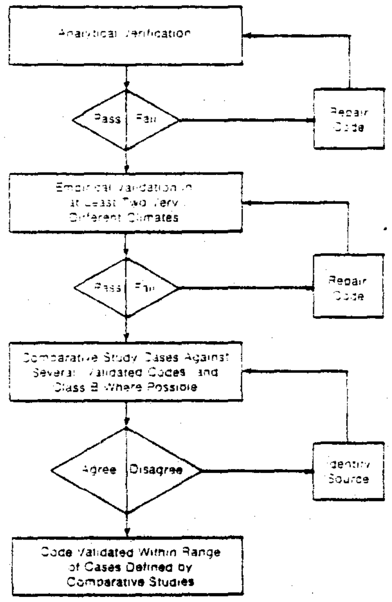

Figure 2. Validation Method

Table 3. Energy Transport Mechanisms

I. CONDUCTION: Measure Temperatures and Conduction Fluxes
   - A. Structural elements
     1. Skin and interzonal opaque walls
     2. Glazings
   - B. Ground coupling

II. CONVECTION: Tracer Gas, Special Experiments
   - A. Film coefficients
     1. Inside surfaces: free convection
     2. Outside surfaces: forced convection
   - B. Air motion
     1. Infiltration
     2. Zone to zone
        - a. Natural convection through doorways
        - b. Natural convection through cracks
     3. Stratification

III. RADIATION: Measure Radiant Fluxes
   - A. Infrared surface coupling
     1. Internal surfaces
     2. External surfaces (sky temperature)
   - B. Solar
     1. External absorption
     2. Glazing transmission and absorption
     3. Internal absorption

checks. Failure to achieve closure on the measured heat balance $Q_{in} = Q_{out} + Q_{stored}$ can be attributed only to faulty data or to important mechanisms not represented in the measurements.

SERI CLASS A DATA FACILITY

The SERI Class A validation facility consists of two structures: a 1,000-ft^2 residence and a 120-ft^2 two-zone test cell. These two structures are instrumented with approximately 500 sensors to achieve the degree of experimental control discussed in the previous section. The sensors include type J thermocouples, heat flux transducers, hall effect watt-hour meters, Kip & Zonen and Eppley pyranometers, and an Eppley pyrheliometer. Wind speed, direction, and humidity are also measured.

Details of the house and the test cell are provided in two handbooks [7,8]. Figures 3a and 3b show the plan and south elevation of the house. The cell and the house were designed to be complementary to each other and to other Class A facilities. The approach in the cell was to supress all difficult mechanisms. These included ground coupling, interzonal and cavity convection, stratification, and infiltration. The house was operated in a more realistic fashion, and attempts were made to measure such difficult transport paths as ground coupling via a crawlspace and multizone infiltration. The crawlspace configuration was chosen to complement the floor slab configuration at NBS. For multizone infiltration, a project was initiated to develop an apparatus capable of continuous multizone infiltration monitoring [9]. A prototype of this apparatus was produced and has been collecting data since April 1982. Table 4 shows the measurement approach taken for various mechanisms in the house and the cell.

Both the house and the cell were monitored through a number of configurational changes in the Winter and Spring of 1982. In the case of the house this consisted of a number of conservation and solar retrofits including: (A) insulation blown into walls and attic, (B) batt insulation on foundation walls in crawlspace, (C) storm windows, (D) caulking and weatherstripping, (E) orientation of largest glazed areas to south, and (F) addition of thermal mass to south-facing rooms. These retrofits reduced the effective crack area as measured by a blower door from approximately 200 to 50 $in.^2$ (see Fig. 4).

Data from the house and the cell are currently being reduced and analyzed. Results from this work will appear in our annual report, which is scheduled for completion in December 1982.

VALIDATION STUDIES

Figure 5 shows preliminary results from the validation study. Temperatures measured in the northwest (kitchen) zone of the SERI test house have been plotted along with the temperatures calculated by the BLAST-3.0 and SERIRES-1.0 computer programs for the period from April 21 to April 26. The two computer programs agree closely with each other but show a considerable absolute difference from the measured data. However, the shape of the measured and calculated curves are quite similar, with the calculated temperatures being about 9°F (5°C) warmer than the calculated curves.

The differences may be explained mainly by the fact that these runs were made prior to reduction of the data for internal heat generation from equipment. Manufacturers' specifications were used to estimate internal heat generation in Zone 1 at 1 kW (3,143 Btuh). Data that became available too late for inclusion in this publication indicated actual internal heat closer to 0.6 kW (1885 Btuh). Thus, approximately 0.4 kW (1,200 Btuh) less energy was actually introduced into the zone than was assumed in the computer simulatons. This would, of course, cause the calculated temperatures to be higher than the measured temperatures.

Subsequent runs will be made using measured data for internal heat generation, infiltration, and thermophysical properties of the building for all four zones. We expect that the discrepancies will diminish when this is done and that remaining differences will reflect true differences between the models and the experiment. Additionally, predicted versus measured auxiliary energy usage will be analyzed. The results from this work will appear in our annual report scheduled for completion by December 1982.

CONCLUSIONS

1. A methodology has been developed by which any building energy analysis simulation may be systematically validated.
2. Class A data acquisition criteria have been defined to meet validation needs for skin-load-dominated buildings.
3. The SERI and NBS Class A data sites are in place and ready to produce archivable validation data in FY 1983.

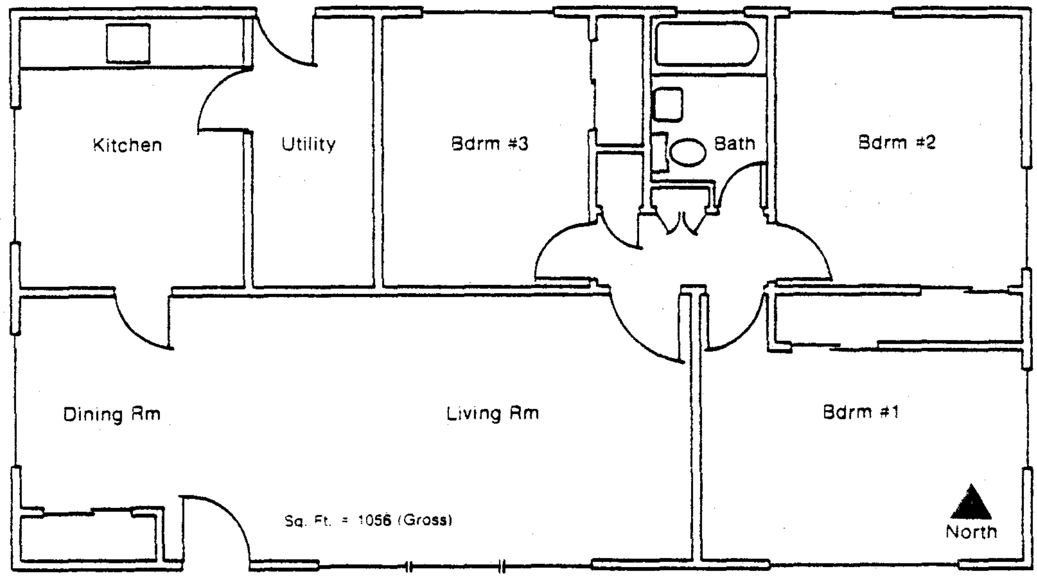

Figure 3a. Validation Test Residence: Floor Plan

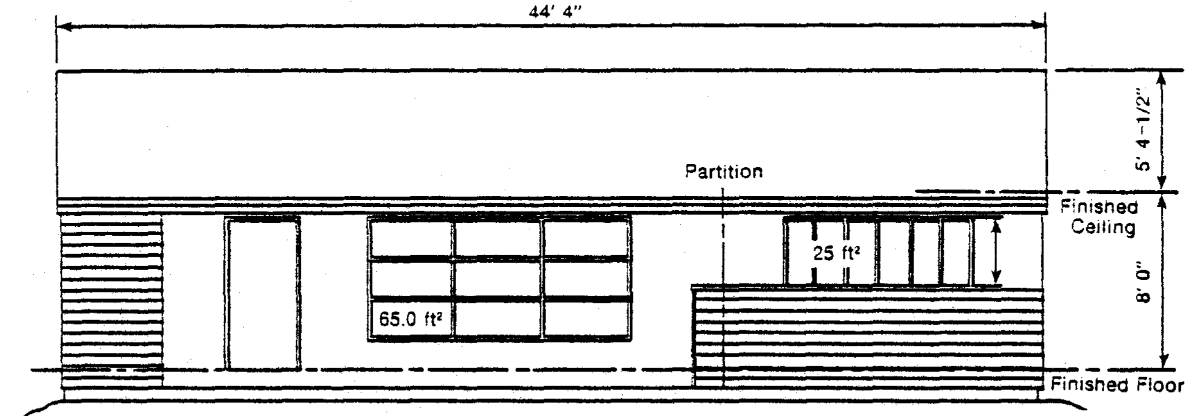

Figure 3b. Validation Test Residence: South Elevation

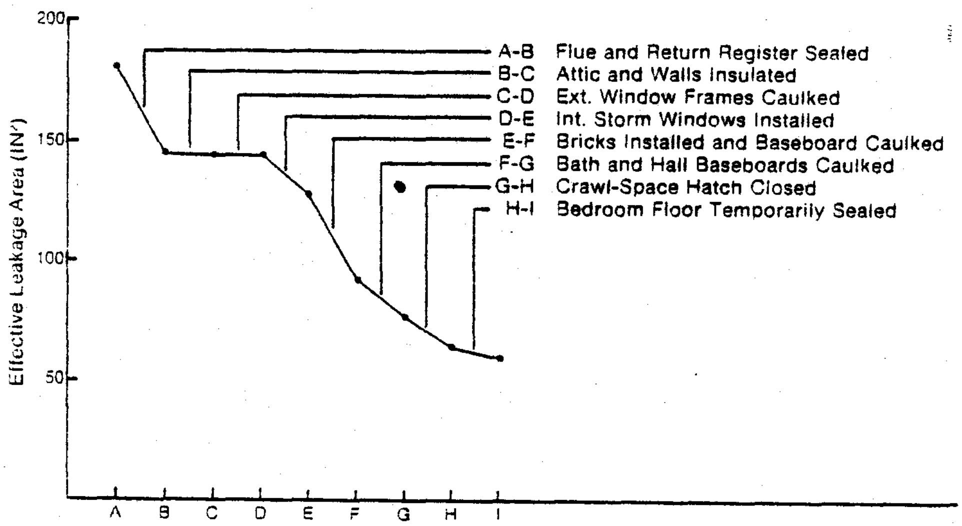

Figure 4. Blower-Door Results for SERI Retrofit House

Table 4. Measurement Approaches

		Measurement Approach	
Mechanism	Code Approach	Test Cell	House
Building-Related Processes			
1. Wall Conduction			
a. Basic assumption	a. One-dimensional flow	a. Insulate edges where possible to ensure one-dimensional flow	a. One-dimensional flow assumed
b. Wall conductivities	b. Inputs, constants	b. Measurements to directly determine U_{wall}, U_{layer}	b. Same as cell
c. Mass storage	c. Not directly available; can be computed from	c. Compute from temperature data, ~10 rakes in mass.	c. Compute from temperature data, ~2 locations per zone
d. Ground coupling	d. One-dimensional flow to ground temperature, neglecting edge effects	d. Eliminate entirely	d. Study in detail, flux and temperature at ~10 locations
2. Boundary Conditions			
a. Interior surfaces	a. Varied approaches from h_{tot} = const. (e.g., SANCAT) to explicit IR + convection correlations (e.g., DEROB)	a. Measure h_{conv} separately; define effective interior temperature, and compute infrared flux (Q_{IR})	a. Measure films only on glazing, same techniques as for cell
b. Exterior surfaces	b. Varied approaches, from constant (SUNCAT) or wind-driven only or wind and sky infrared.	b. Measure Q_{IR}^{sky} T_{ground}; deduce h_{conv} on average.	b. Same as cell
3. Zone-Related Effects			
a. Zone mixing	a. Always isothermal	a. Destratify to force zone to be isothermal	a. Destratify continually (FY 1982); study destratification in FY 1983.
b. Interzonal advection and conduction	b. Uncertain, approximate algorithms for advection; wall conduction included	b. Measure conduction directly; advection minimized by careful caulking	b. Measure conduction; closed doors between cells (FY 1982). Study natural advection in FY 1983.
c. Occupancy effects	c. Schedules input, major uncertainty	c. None	c. None
d. Furnishings	d. Neglected or approximate	d. None	d. Unfurnished
e. Internal humidity	e. Latent heat usually included	e. Not measured	e. Not measured
4. System Effects			
a. Heating systems	a. Set points: ramp	a. Measure $\dot{Q}_{heater}$ with electrical inputs of known efficiency, η = 1.0; small deadband	a. Electric heaters, to be computer-controlled for night setback at night.
b. Night ventilation	b. Schedule or constraint for $\dot{V}_{night}$; volume flow $\dot{V}$ is input	b. None	b. Measure $\dot{V}_{once}$ by tracer decay.
Environment-Related Processes			
1. Solar Radiation			
a. Descriptive inputs	a. Need I_{beam}, G_H	a. Measure I_{beam}, G_H directly	a. Same as cell
b. Tilted surface irradiance	b. Various models, mostly isotropic or anisotropic	b. Exterior: measure south irradiance broken into south sky and ground diffuse components Internal: floor, north wall, east wall	b. External: same as cell Internal: measure vertical transmitted, each orientation; and floor and mid-wall irradiance in living room
c. Glazing transmissions	c. Beam transmission calculated from input index of refraction and extinction coefficient diffuse transmission = some input or default constant	c. Measure beam and diffuse transmission directly; extract best fit index of refraction and extinction coefficient from data. Done only occasionally.	c. Same as cell, for the south glass only, before and after storm glazings.
d. Ground reflections	d. Input α_{GR}	d. Measure α_{GR} continuously; $\alpha_{GR}^{Eff.}$ once	d. α_{GR} is some as for cell, use cell data
e. Solar glazing back losses	e. Calculatable from various models, or input constant (SUNCAT)	e. Measure cell albedo directly for clear, cloudy conditions	e. No albedo measurements
2. Wind	a. Input velocity, direction; assume same value for film calculation and infiltration model, very uncertain	a. Measure at two heights at ~100 yards from cell; uncertain microscale problems - Average $h_{convection}$ to be calculated. - Reduce effects by tight construction	a. Same as cell
3. Other: humidity, pressure	a. Inputs used for air heat capacity, latent loads	a. Adequate direct measure	a. Same as cell
4. Precipitation	a. No impact on thermal models	a. Field site observation, plus α_{GR} data affects	a. Same as cell

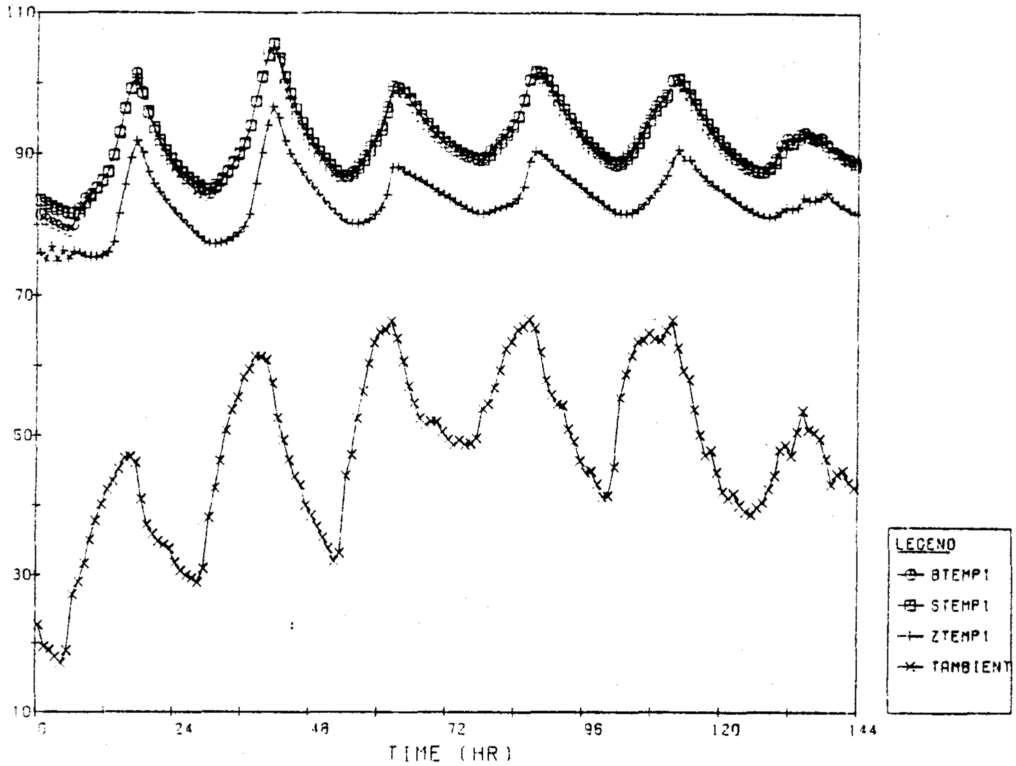

Figure 5. Zone 1 Temperature from Apr. 21 to Apr. 26, 1982

4. The data bank and methodology should be expanded to include mechanical systems so that commercial buildings can be included in the validation activity.
5. The Class A program should continue as a coordinated multilab effort for at least three more years. Only in this way will industry gain confidence in innovative building design options and associated analysis/design tools.

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