ESPRÊ 1.2: A MICROCOMPUTER PROGRAM FOR RESIDENTIAL HOURLY ENERGY USE ANALYSIS

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ABSTRACT-The theory and applications of a microcomputer program for simulation of hourly heating and cooling energies in a residential building are presented. Using TMY weather data, the program performs thermal balances on the building spaces and walls to establish the hourly loads; system simulations are carried out simultaneously to account for the interaction between loads and equipment behavior. Validation of the program is carried out with metered hourly energy use data for two unoccupied structures.

BACKGROUND

Building energy use analysis computer programs provide a means of estimating the effects of alternative building design methods and space conditioning systems on total energy use experienced at the residence and on the hourly energy use profile experienced by the utility. A number of building energy analysis computer programs have appeared over the past several decades; most have focussed on energy use in commercial buildings.

A brief review of simplified analysis methods was carried out as a part of an evaluation of residential building energy use estimating tools. Most simplified tools use steady-state heat transfer assumptions to arrive at estimates of monthly and annual heating and cooling energy use. Such procedures are often carried out manually. With the advent of relatively powerful and inexpensive microcomputers some of the simplified methods have been extended in their level of complexity and have been implemented in various forms for use on a microcomputer. Most of these programs focus on the building thermal loads analysis with no or only a secondary focus on equipment operation.

A microcomputer program, known as ESPRÊ (EPRI Simplified Program for Residential Energy) has been developed to provide a simple means of estimating seasonal, daily, and hourly average electrical energy use that explicitly takes into account the residential building design and system operating characteristics. The design of ESPRÊ was based on meeting the following objectives:

- The method should be capable of providing detailed hourly analysis of loads and energy use patterns.
- The model should use actual or typical weather data on an hourly basis rather than "compressed" or synthetic weather data.
- The method should allow the user to make trade-offs between the level of detail in the analysis and the computer running time.
- Typical residential structures and typical residential heating and cooling systems should be modeled.
- The program should be highly interactive and simple to use.

ESPRÊ APPLICATIONS

ESPRÊ was developed to provide a means to quickly and inexpensively study the impacts of both building design changes and equipment parameters on hourly electrical and gas energy use patterns. The program may be run over selected portions of the year or over an entire year in hourly time steps (requiring 3 minutes with a math coprocessor resident); it may also be run in an accelerated mode where the weather data are aggregated over a specified number of days, thereby requiring fewer energy balances.

Table 1 lists several modeled building configurations and heating/cooling system components. The building may be represented by one or two spaces (either or both may be conditioned) with an attic or cathedral ceiling and one of three types of foundations (basement, crawlspace, or slab). When the building is represented by two spaces the attic may be shared by the spaces or may be separate for each space. Either constant or weather-dependent infiltration may be modeled; natural ventilation cooling may also be simulated. Both sensible and latent internal loads may be specified. A building moisture balance is carried out each time step and a coil model is used to determine the hourly latent and sensible coil loads. Part load performance, under-capacity and central system duct losses are included. The user can specify time of day heating and/or cooling thermostat setpoints and can enable or disable the systems over portions of the year.

Table 1

MODELED BUILDING/SYSTEM CONFIGURATIONS

CONFIGURATION	OPTIONS
Number of living spaces	1 or 2 (side by side only)
Foundation types	Basement, crawlspace or slab
Attic	Separate by space or shared attic
Infiltration model	Constant or wind/temperature dependent
Internal loads	Sensible/latent, constant or variable
Space heating systems	None, electric resistance, heat pump, gas furnace or add-on heat pump
Space cooling systems	None or air conditioner
Controls	Time of day thermostat and system shutoff
	Window thermal management

The program is structured to take into account the dynamic response of the building to changing environmental and building use conditions. Either or both of the building spaces may be considered conditioned. An unconditioned (floating temperature) space might represent a sun space or a garage, for example. Thermal mass elements are located within each space, within the walls, ceilings and in the partition separating the two building spaces. The ability to model a two-space building allows the simulation of a simple passive solar structure; window thermal management and shading may be specified.

HVAC System Details

Heat pump capacity and compressor power are considered to vary linearly with outdoor temperatures using the ARI design conditions. Fan power is represented separately. Below the balance point resistance heat may be brought on line; an outdoor reset controls the enabling of a second stage resistance bank. Defrost is assumed to occur below a user specified outdoor temperature down to 17°F; the defrost net energy use, cycle time and cumulative compressor run time between cycles are user specified. Crankcase heater power and outdoor reset control may also be simulated.

The gas furnace model represents the furnace performance by a steady state efficiency and a cycle loss term. Pilot light gas energy use and circulation fan electrical energy use are represented separately. The model for an add-on heat pump is essentially a combination of the air-air heat pump and gas furnace models with control for switching the mode of operation based on the outdoor temperature.

Utility Related Features

Both block structured gas and electric rates can be specified to establish the net energy costs. Electric rates may be specified on a time of day and/or seasonal basis. Input specified non-HVAC month gas and electrical energies locate the positions in the block rates for the economic analysis.

User Features

The program was designed to take full advantages of the capabilities of current microcomputers. All input is menu-driven; a form of screen editing of input data is provided. All data are checked against high and low limits; in certain instances the user may override the limits (e.g., wall size) whereas in others the limits must be respected (e.g., month numbers).

Files may be saved. The program prevents the running of a file that has been modified without first determining if the file should be saved. DOS error messages are intercepted to prevent program aborts due to missing files or a printer that has not been turned on.

Only one disk is required to run the program. Since the thermal loads determination and system simulation are carried out simultaneously multiple passes or disk switching is not required.

Output may be saved in LOTUS compatible files for post processing. Although the program is written in compiled FORTRAN, extensive assembly routines have been developed to provide the screen functions and disk I/O operations carried out. For example, less time is required to perform a full years' analysis in hourly time steps and to output the results to a disk in LOTUS compatible format than is required by LOTUS to subsequently read the data in.

The computational time for an analysis depends upon the situation being simulated. Table 2 lists times required for an annual simulation in hourly time steps for two machine configurations: one with a resident math coprocessor (8087 chip) and the other without. (At the current cost of the chip relative to the total machine cost any serious user would be well advised to install the math coprocessor.) To simulate a full years' energy consumption in a two conditioned space building would require about 4 1/2 minutes. If the user were only interested in total annual energy use rather than in hourly profiles for specific days, the computational requirement can be reduced to about 1 minute.

Table 2

COMPUTATION TIME FOR ANNUAL SIMULATION IN HOURLY TIME STEPS (IBM-PC WITH HARD DISK)

CASE	WITH MATH CO-PROCESSOR	WITHOUT MATH CO-PROCESSOR
One Space Building, No Day Skips	3 min, 12 sec	71 min, 20 sec
Two Space Building, No Day Skips	4 min, 33 sec	82 min, 20 sec
One Space Building, 1 Day/Week Analysis	1 min, 43 sec	21 min, 37 sec
One Space Building, 1 Day/Month Analysis	56 sec	6 min, 46 sec

METHODS

Rather than adopting an existing program, ESPRÊ was developed afresh to meet the objectives listed earlier. The analysis methods selected represent a compromise between level of detail in the program and the requirements for a high level of computational speed.

The program is based on the room thermal balance method for establishing space conditioning loads. Thermal nodes are used to determine the dynamic heat flows associated with the walls, ceiling, internal mass elements, room air and partitions between adjoining spaces (see Table 3). Although solar heat gains to the exterior walls are calculated separately for each wall (and roof element) enclosing the building spaces, the walls are lumped (assumed to be the same temperature) in each space.

Table 3

THERMAL MASS ELEMENTS DEFINED IN ANALYSIS

NODE	1 SPACE BUILDING	2 SPACE BUILDING
Room Air	1	2
Interior Mass	1	2
Exterior Walls	1	2
Ceiling	1	2
Floor	0	0
Partition Between Spaces	0	1
Total	4	9

Ultimately, all the energy balance equations are written in linear form. To maximize the computational speed, those coefficients to the linear equations which are problem specific constants are calculated once during the program initialization phase and are saved. (All energy balances are solved simultaneously, including those describing interactions between the two building spaces.) In addition, the solar gain and building infiltration analyses can be expressed in terms of normalized hourly parameters which are primarily functions of the building location. Where feasible, these parameters are pre-calculated and included in the hourly weather data file.

A key to the computational speed of ESPRÊ lies in the structure of the weather data files. A weather data disk is prepared by preprocessing a TMY tape on a a mainframe computer. The disk contains 366 (256 byte) records of data consisting of the following information:

- record 1: city name and weather station data; and
- records 2-66: 256 bytes of data containing hourly values for outdoor drybulb temperature, outdoor humidity ratio, normalized values of building infiltration corresponding to the hourly temperature and windspeed, values of transmitted solar flux through a 1 square foot single-pane window in 8 orientations, and values for diffuse and total solar radiation.

As noted, all the weather data values are in the form of 1 byte integers; that is, they are in the range of 0-255. This requires that scaling of the actual data be carried out as a part of the preprocessing step. The packing of the weather data into 1 byte integers allows a full year of hourly weather data to occupy less than 97K bytes of data on the disk. Hence, the ESPRÊ execution program and data files can reside on the weather data disk thereby obviating the need for switching disks during a run.

The preprocessing, which is carried out on the mainframe computer, eliminates the need for repetitive, time consuming, calculations associated with determining values for the sun vectors for establishing the distribution of diffuse and direct solar radiation. At present, weather data diskettes have been prepared for 27 locations through the United States.

Additional details on the methods and assumptions employed can be found elsewhere[1].

VALIDATION STUDIES

Validation studies have been carried out using metered data for an unoccupied test house in Columbus, Ohio[2] and for two unoccupied test cells at the NBS[3]. The Columbus house is a two-story, 2250 square foot north facing dwelling furnished with an uninsulated ducted electric furnace and an air conditioning system. The NBS test cells are 20 ft. x 20 ft. internal dimension one room houses with a slab foundation and an attic. Partial shading of the structures are provided by an attic floor overhang. Weather data (wind, temperature, humidity, and insolation) were measured on-site. Because of the carefully controlled experimental conditions and the well defined building and heating/cooling system characteristics the NBS test cells provided a particularly valuable data source for program validation.

Hourly weather sensible loads and energy use data were available for 3 day periods during both the winter and summer seasons. The validation exercise focussed on the match between the predicted and measured hourly energies and sensible loads. Figures 1 and 2 show the comparisons for NBS test house #1 (insulated lightweight wood frame) and test house #2 (uninsulated lightweight wood frame). By reference, model predictions from the new NBS building loads program (TARP--Thermal Analysis Research Program) are also shown.

The ESPRE calculated hourly heating energies and hourly sensible cooling loads are in good agreement with the metered data and in excellent agreement with the TARP predictions for each of the cases studied. As discussed in a recent paper by Sorrell[4] any constant error in the space heat loss would provide a larger percentage difference between predicted and measured results in the well insulated house #1. Sorrell obtained similar comparisons between metered data and data predicted by three mainframe programs (EMPS 2.1, TARP 84 and DOE 2.1B).

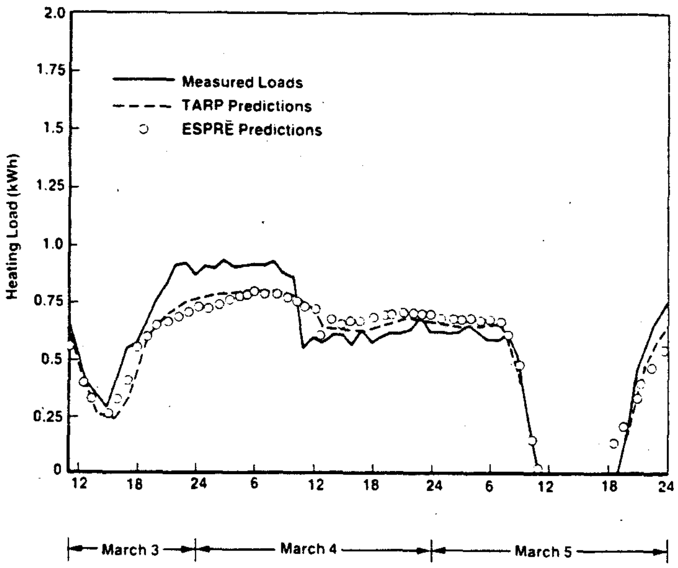

Fig. 1a. NBS House 1 Predicted and Measured Heating Loads

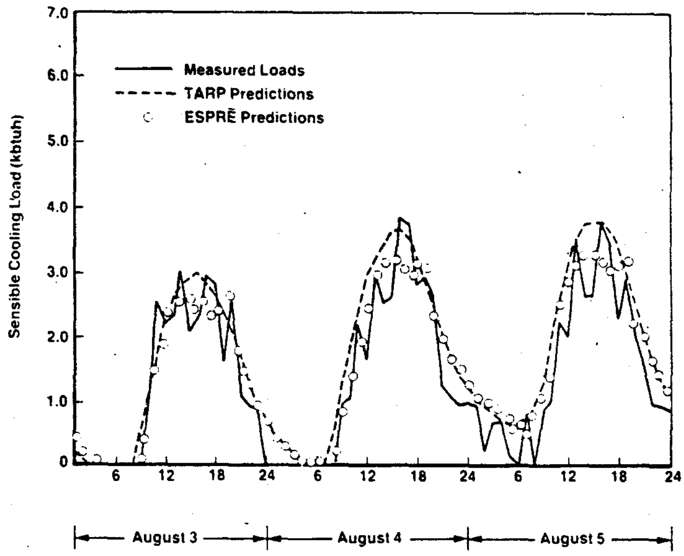

Fig. 1b. NBS House 1 Predicted and Measured Cooling Loads

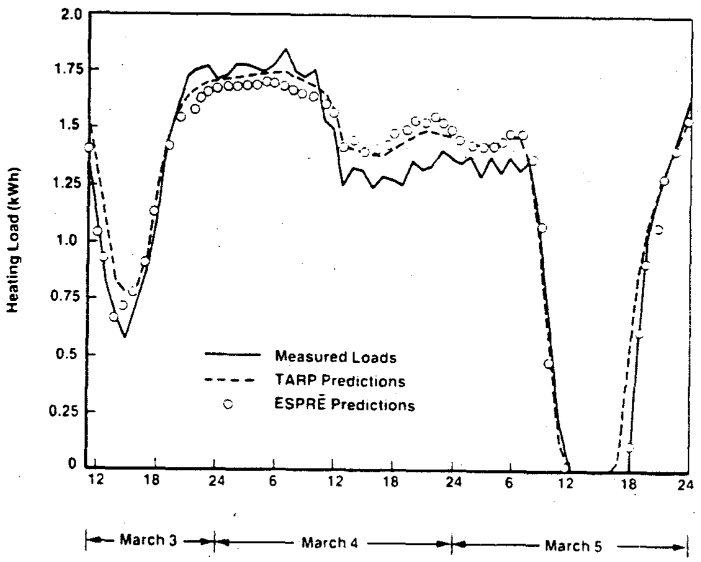

Fig. 2a. NBS House 2 Predicted and Measured Heating Loads

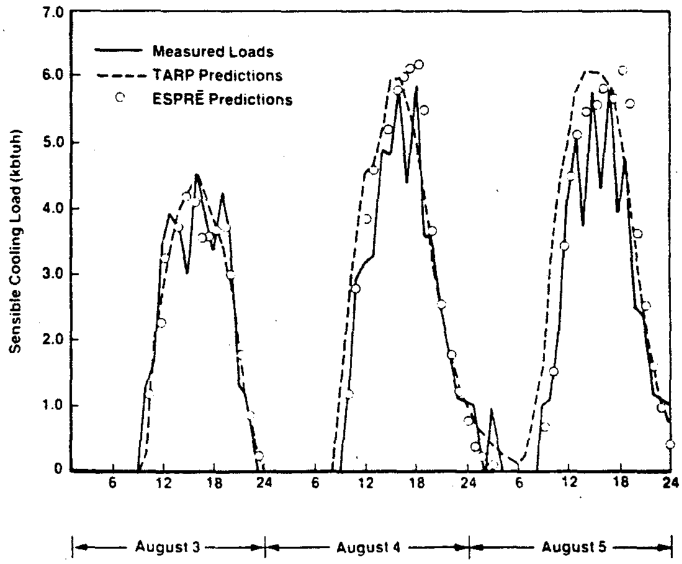

Fig. 2b. NBS House 2 Predicted and Measured Cooling Loads

The comparisons shown here as well as those shown elsewhere for the Columbus Ohio two story house[1] indicate that ESPRĒ has the capability of matching both the daily total energies and the hourly dynamic response of the building to changing conditions.

PROGRAM AVAILABILITY

The program is presently available on a pre-release basis for use on an IBM-PC or compatible microcomputer (it will execute properly on the AT series computers as well) using DOS 2.0 or higher.

A user's group (EMPS-ESPRĒ User's Group) has been formed to facilitate support in the use of the model. The group meets on a bi-annual basis.

An EMPS-ESPRĒ electronic bulletin board has also been established and is maintained for access by the program user. A purpose of the bulletin board is to facilitate information transfer between the user and the program author.

REFERENCES

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4. SORRELL, F.Y., LUCKENBACK, T.J. and PHELPS, T.L. 1958. "Validation of Hourly Building Energy Models for Residential Buildings," ASHRAE Transactions, Vol. 91, Pt. 2.