

Development of a Simplified and Manual Energy Calculation Procedure for Residences

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ABSTRACT

A simplified calculation procedure was developed for an energy performance design system (EPDS), which can be used to predict annual heating and cooling energy consumptions of residences. The simplified procedure is an interactive computer program. A manual procedure was also developed which focuses on the performance of low-energy houses. The goal was to provide builders and designers with a procedure to evaluate the energy performance of houses while still at the design stage. The purpose of this paper is to present an overview of the approach used in development of this simplified procedure including assumptions, methodology, capabilities, and limitations.

The basis for the thermal calculations was an experimentally validated, transient analysis computer program. Whole-house interactions were modeled with this hourly program. Individual components were analyzed using the appropriate subroutines from the hourly program and a simplified technique using balance-point temperatures. The individual results were generalized by correlating those values to heating and cooling degree-days plus other relevant variables.

The simplified procedure was checked against 108 comparative test cases that covered three house sizes, four constructions, 11 climates, various thermostat set points, and different family sizes. The overall agreement between the hourly computer program and EPDS was remarkably good given the degree of simplification, but its strength lies in the ability to determine the relative performance of alternate features.

INTRODUCTION

Interest in predicting residential energy consumption has risen for several reasons. Some states have energy requirements that must be met prior to issuing a building permit. Also, the consumer is more energy conscience because of increased utility rates. Finally, designers need the ability to evaluate alternative design options.

Sophisticated computer programs are available to analyze houses but they are too complex and expensive to effectively use on every house design. Conversely, simple procedures, like the degree-day formula for heating and equivalent-full-load hours for cooling, do not adequately account for all the variables and conditions that can arise. Therefore, the need exists for simplified energy calculation procedures that are easy and inexpensive to use,

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simple to understand, accurate, and have sufficient capabilities to account for major design options.

A simplified calculation procedure has been developed to predict residential energy consumption. Initially, a manual procedure was developed that concentrated on the performance of energy-efficient homes. Since then, an interactive computer program has been developed that contains many additional features. Collectively, these procedures have been identified as the energy performance design system (EPDS). Since the interactive computer program encompasses all of the manual procedure capabilities plus significant other advantages, this paper will focus on just the computer program.

TECHNICAL OBJECTIVE

A simplified energy calculation procedure could take one of many forms. EPDS employs a correlation technique. Energy factors were calculated with a sophisticated computer program that performs hourly heat balances for an entire year. These energy factors are then correlated in EPDS to simple independent variables such as degree-days to characterize the weather, R-values to represent the materials, and balance points to typify the house construction. This paper describes the approach used in developing the various energy factors and their correlations, including assumptions, methodologies, advantages, limitations, and accuracy. Since this is an overview paper, specific technical details are provided in companion papers.

BACKGROUND

The basis for EPDS was a sophisticated, transient-energy-analysis computer program,¹ that uses response factors and a heat-balance approach on hourly intervals to predict the conditioned space loads for an entire year. Initial development of the hourly program can be traced to subroutines from ASHRAE² and to three existing computerized design tools.^{3,4,5} Many changes and improvements have since been incorporated into the hourly program as the result of an extensive five-year research program, which was undertaken to develop a detailed program specifically tailored to model residences.

The first step in development of the hourly computer program was to assemble an extensive data base of material properties for all the construction materials that typically go into residences, e.g., wood, shingles, insulation, drywall, concrete, soil, etc.⁶ Material properties of interest were thermal conductivity, specific heat, and density. Particular interest focused on property changes caused by temperature and moisture. From basic material properties, the research investigated single components of a structure.

An attic model was developed and verified through measurements obtained in the newly constructed thermal research facility.^{7,8,9,10} The model accounts for ventilation through pitched roofs and insulation compression at the eaves. The wall model was developed from measurements made in a calibrated hot box.^{11,12,13} Numerous tests were completed to verify the response-factor technique for composite constructions, including parallel paths, sheathings and massiveness. Other component models developed include a two dimensional, finite-difference model for below-grade heat losses,¹⁴ development of correction factors to model the radiative exchange of internal partitions, development of a thermostat model that includes switch differentials, development of an air-infiltration model,^{15,16} and development of a new window model.¹⁷ Each of these components received individual validation checks against either measured data collected on site or against measured data reported in the literature.

Extensive validation of the hourly program was completed prior to the development of EPDS. Measured data from three unoccupied test houses in Granville, Ohio, provided an experimental validation base. The three houses were identical in construction except for the insulation levels, Tab. 1. Each ranch-style house has the same 1361 square foot (126.4 m²) plan with 170 square feet (15.8 m²) of glazing, which consists of thermopane windows with storms and thermopane sliding-glass doors. All three houses face south with a single-car

garage attached to the west side. There is a full basement under the center of each house with vented crawlspaces at both ends.

Heating was supplied by electric resistance forced-air furnaces, which were accurately monitored by Watt-hour meters. Cooling was measured calorimetrically via a chilled water loop to individual coils in each furnace. The cooling energy was monitored by measuring a temperature rise in the water across the coil along with a mass flow rate of water through the coil. Air infiltration rates were measured using the tracer gas technique. Weather conditions were monitored by a complete weather station located at the test site. Each house was fully instrumented with 200-300 data channels, which were tied into an on-site computer for data manipulation and local storage.

Heating and cooling data for two-and-one-half to three months from each season were used on an hourly basis for program validations. Overall results indicated the hourly program accuracy was plus or minus 13%, Fig. 1. This level of accuracy was considered very good for two reasons. First, the hourly model was capable of addressing all the unique features of a residence. Second, the accuracy covers a broad range of insulation levels. Test home A, which is heavily insulated, uses very little energy, so that a plus or minus 13% difference in energy prediction is a small value. On the other extreme, the uninsulated house, C, uses approximately three times as much energy. The plus or minus 13 percent difference was investigated and a significant portion was attributed to the ceiling-film coefficients. Heat gains in the uninsulated house were dominated by the ceiling. Since air films represent the major thermal resistance, knowing them precisely would improve the modeling. The intermediate house, B, was predicted to within plus or minus 6%. Based on these results, the program was considered appropriate for modeling residences and generalizing their thermal performance to other climates.

TECHNICAL APPROACH

The technical approach used in the development of EPDS was a correlation technique. Simply, energy factors were calculated using either the hourly program itself or its appropriate subroutines with a balance-point procedure. Energy factors are the net heating and cooling energy per unit area for each component. These energy factors were then correlated to the independent variables, e.g., degree-days, R-values, and house balance points. The form of the correlations was regression equations. Separate equations were developed for heating and cooling. A detailed explanation of this approach will be reviewed in the following sections.

PROCEDURES AND METHODS

In the development of EPDS, numerous assumptions and approximations were made. These were necessary to develop a simplified procedure. Also, new approaches and techniques were developed. Since it would be prohibitive to review each one in detail, only the most significant will be presented. Those presented are concerned with developing the energy factors, correlating them, and determining their accuracy.

Development of Energy Factors

Two procedures were used to develop the various energy factors. The most straightforward method was to use the hourly computer program and step through a series of computer runs, changing one variable at a time to determine the net energy impact. Thermostat factors were checked this way because they depend upon detailed whole-house interactions. It was expensive and time consuming to use this approach. Considering all the options that needed to be investigated, a second method was developed. This method was called the balance point procedure. It uses the hourly program's subroutines to model individual components and the house balance point to account for interactions.

Balance Point Procedure. The purpose of this procedure was to decouple the hourly program's subroutines but still account for interactions. There are three steps in this procedure: modeling of the exterior surface conditions,

modeling of the component heat flux, and modeling of the interior surface conditions.

Modeling of the exterior surface conditions was done using the hourly program's air-film subroutine. It uses hourly weather conditions (temperature, solar radiation, and wind) and performs an energy balance at the exterior surface to determine the exterior surface temperature. This accounts for orientation and surface properties (roughness and absorptivity) in a manner consistent with the hourly program.

Modeling of component heat fluxes was accomplished using the hourly program's appropriate subroutines. All opaque surfaces, i.e., ceilings, walls, doors, and floors, use the response-factor technique. Windows were modeled using the fundamental equations for solar and conductive heat transfer. Air infiltration was modeled using hourly values of temperature, wind speed, and an effective leakage area. Below-grade heat loss through basements, crawlspaces, and slabs-on-grade were modeled using a two-dimensional finite-difference routine. In each case, the component heat flux was modeled for EPDS the same way as it was in the hourly computer program. This modeling approach provided a direct linkage between EPDS and the hourly program, which was a unique attribute of this simplified procedure.

The most significant assumptions with the balance-point procedure were in modeling the interior surface temperatures. The hourly program couples the component heat flux, interior surface temperature, film coefficients, and interior air temperatures together in a matrix. Accounting for these interactions in the balance-point procedure required three simplifying assumptions.

First, a constant interior air temperature of 73°F (22.8°C) was assumed for the entire year. This was chosen as the average of 68-78°F (20-25.6°C) thermostat set points. The influence of various thermostat set points was incorporated into EPDS through thermostat factors. These factors will be described in detail later.

The second assumption was that all interior surfaces radiate to the constant 73°F (22.8°C) set point. This was done by using a combined interior-film coefficient that accounted for both radiation and convection. In actuality, each surface radiates to other surfaces that may not be at the inside air temperature. However, in order to separate one component from the rest of the house, this simplifying assumption was necessary. This assumption, in turn, was based on the fact that interior surface temperatures approach the indoor air temperature because interior partitions and intermediate floors reduce radiative heat exchanges between various exterior sections of the envelope. These interior walls and floors are also warmer than exterior walls. In addition, radiative heat components from the people, lights, and appliances all tend to raise interior surface temperatures.

This approximation is most tenuous in considering the radiative exchange between walls and windows. The interior surface temperature of windows is definitely much lower than 73°F (22.8°C) during the winter. However, in this analysis, the overall window area was small relative to the interior partitions, ceilings, and floors, which makes direct radiation exchange with all exterior surfaces minimal. These assumptions were considered realistic for an actual house and probably more accurate than assuming the house to be a single space in which all surfaces of the house envelope can see each other.

The third assumption was to differentiate between heating and cooling in a house each hour of the year on the basis of the house balance-point temperature. The balance-point temperature, or balance point, is the outdoor air dry-bulb temperature at which the thermal load on the house is zero because, on a daily average, the internal and solar heat gains just equal or balance the conductive and air-infiltration losses. Therefore, if the outdoor air temperature is above the house balance point, the house is cooling. Conversely, if the outdoor air temperature is below the house balance point, the house is heating. This allows a simple determination of whether a house is

heating or cooling depending upon the outdoor air temperature. It is critical to know whether a house is heating or cooling so that the influence of a particular component can be attributed to the proper load on a house.

Balance points can be determined using two different techniques. The most accurate is to plot daily heating and cooling loads against the daily outdoor air temperature. Fig. 2 shows typical results of such an analysis using the hourly computer program. The other technique is to calculate balance points directly using daily average solar radiation, internal heat gains, and air-infiltration rates. This is the approach used in EPDS. Balance points depend on five major variables: solar loads, internal heat gains, conductive heat losses, air-infiltration losses, and the thermostat set point. Changing any variable can alter the house balance point. Balance points are calculated in EPDS using the following equation.

$$\text{Balance Point} = \text{Thermostat Set Point} - \left[\frac{\text{Solar} + \text{Internals}}{\text{Conduction} + \text{Infiltration}} \right] \quad (1)$$

This equation was checked by comparing its results to those obtained from the hourly computer program. The average difference between the two procedures was less than 2° F (1.1°C) for any house design. This was excellent agreement and justified using the equation in EPDS.

The balance-point procedure provides a method for decoupling a subroutine from the hourly program and to still account for whole-house interactions. The next step in determining the energy factors was to actually perform the component calculations. Those steps are presented in the next section.

Calculating Component Loads. The procedure used to calculate component loads was a multi-step process. First, the hourly heat flux through the component was calculated. The hourly heat flux could either add to or subtract from the net loads depending on the outdoor weather conditions. Next, the house load was determined to be either heating or cooling depending on the balance point and outdoor dry-bulb temperature. This introduces four possible combinations, Fig. 3. A component heat loss adds to the net heating load if the house is heating but subtracts if the house is cooling. Similarly, a component heat gain adds to the net cooling load if the house is cooling but subtracts if the house is heating. Thus, two net loads are being accumulated for each component, one for heating and another for cooling. This procedure is repeated every hour, and the net loads are accumulated for an entire year. In EPDS, two regression equations were developed, one for the net heating and another for the net cooling. The energy consumptions derived from this procedure were divided by the appropriate areas and the resulting energy factors were expressed in kWh per unit area.

Analyzing Individual Components. Although the basic procedure has been presented for calculating component loads, there were important points worth noting for selected components.

Ceilings were modeled using hourly wind speeds to calculate various ventilation rates through the attic. Also, the convective portion of the interior surface film coefficient changed with the direction of heat flow. Floors had the film coefficient change in a similar procedure.

The energy factors for walls and doors are an average of four orientations: N, S, E, and W. The difference between various orientations was solar loads. This averaging was done to simplify the input descriptions so that just a total area is entered into EPDS. The impact of this assumption was small, and it will be reviewed in a following section.

Windows were modeled as clear glass, with no screens, and with a fixed interior-shading coefficient of 0.75. Eight orientations are available (N, NE, E, SE, S, SW, W, and NW) for single, double, and triple glazings. Overhang options are available from 0 to 10 ft (3m). One shutter option is provided,

which consists of an R-5 (RSI-0.9) insulation that covers the window at night during the heating season.

Air infiltration was modeled using hourly values for temperature and wind speed. The model was derived from tracer-gas measurements in the three test homes and blower-door or pressurization tests in 57 other homes. An "effective leakage area" was calculated and used in the analysis to characterize the relative air-tightness levels that could be expected.^{18,19}

Air infiltration characteristics were given special attention when various levels were prescribed. Five levels were investigated. The leakiest condition, Level 5, represented an average of one air change per hour. One air change means that the total house volume of air is changed or replaced with outdoor air in one hour. Level 4 represents three-fourths of an air change each hour, and Level 3 corresponds to half an air change. These are average values over the course of a year. Hourly values can be higher or lower depending upon the particular weather conditions at that instant. Level 2 represented an average of one quarter an air change. At this point an additional one quarter air change was introduced through an air-to-air heat exchanger. Level 1 represented an average infiltration rate less than 0.1 air changes an hour with half an air change introduced through a heat exchanger.

Internal loads were modeled to represent family options of two, four, or six people and corresponding levels of lights and appliances. The total heat release was approximately 6040 kWh for the family of two, 8900 kWh for the family of four, and 11,540 kWh for the family of six.^{20,21,22} Although it was recognized that differences of 200 to 300% values in these could arise as a result of family lifestyles, they were considered typical and sufficient for design purposes.²³

The basic energy factors for all components were developed assuming a constant 73°F (22.8°C) indoor air temperature. Adjustments to the energy factors' subtotals are made to account for thermostat set points ranging from 65°F (18.3°C) to 80°F (26.7°C). These adjustments are made in two steps. First, conduction terms use a ratio of degree-days. The ratio is degree-days at the house balance point, which corresponds to the new thermostat set point divided by the degree-days at the house balance point, which corresponds to a 73°F (22.8°C) set point. The second step adjusts solar and internal gains. These gains use a ratio of hours. In this case, the ratio is hours below the house balance point, which corresponds to the new thermostat set point divided by the hours below the house balance point, which corresponds to a 73°F (22.8°C) set point. The same procedure is used for heating and cooling adjustments. These adjustments were checked using the entire hourly computer program.

Analyzing the air-distribution losses introduced further assumptions.²⁴ Specifically, the ducts were assumed to be in different locations, e.g., attic, crawlspace, or basement. In order to simplify the analysis, the temperatures in these locations were calculated without including any duct losses. This was necessary to simplify the calculations but it was a conservative assumption. These space temperatures were calculated at hourly intervals for a full year using the hourly computer program. This was necessary because the duct losses depend on a combination of insulation levels plus the type, size, and run time of the heating and cooling equipment.

Modeling of the heating and air conditioning equipment varied depending upon the particular item being modeled. Gas and oil furnaces are modeled using annual fuel utilization efficiencies (AFUE). The AFUE is a user input. Electric furnaces were assumed to be 100% efficient.

Manufacturers' data were consulted for heat pumps and air conditioners. Temperature-dependent performance data were used to derive seasonal coefficients of performance (SCOP) for heat pumps and seasonal energy efficiency ratios (SEER) for air conditioners. A significant research project was completed that modified the performance of air conditioners relative to latent loads on a residence.²⁵ The basic SEER was derived assuming an indoor

humidity level fixed at 50%. Latent loads for the air conditioning were calculated using a moisture-balance model that accounts for air infiltration, internal heat generation from people, and condensate removal through the air conditioner. This approach accounts for removal of various quantities of moisture from the conditioned space, depending upon the specific cooling-coil performance, which has a significant impact on the actual energy consumed. The net effect was to increase energy consumption in humid climates and reduce energy consumption in dry climates.

Characterizing Climates

In order for EPDS to be applicable in various climatic regions, it was essential to generalize. The approach was to select a broad spectrum of climates in which to perform detailed calculations and then correlate the results to selected weather parameters. First, the climates under study were restricted to the 48 contiguous states. They were characterized by plotting their cooling degree-days against their heating degree-days, Fig. 4. The basis for the hourly weather data were test reference year (TRY) weather tapes.²⁶ Each regression equation was developed using the seasonal degree-days obtained from these same tapes. However, to characterize the long-term weather conditions for each of the 319 locations in EPDS, 30 to 40 year average heating and cooling degree-days from NOAA were used.²⁷

The points tend to define a distinct relationship in that an upper boundary is formed. This boundary represents the maximum cooling degree-days for any given heating degree-days. Therefore, any city located on the boundary would use more energy than any city directly below it. This is because their heating energy requirements would be similar; however, cooling energy requirements decrease as one moves down from the boundary. As a check to the existence and shape of the boundary, data for 3039 NOAA locations were plotted, and the same shape was confirmed.²⁸

Once the boundary concept was defined, a procedure to characterize the climate began to emerge. The procedure started by analyzing five cities that fell on the boundary--Bismarck, Minneapolis, St. Louis, Ft. Worth, and Miami. These five cities were selected to characterize the boundary by identifying the two end points and locating three interior points to define curvature. These five cities were then used in all the component analyses. Further characterization of the climates was necessary for whole-house analyses, so five more cities were selected that formed an imaginary line parallel to the boundary. This process was repeated further from the boundary until a total of 20 cities were selected. In total, these 20 cities represented a complete cross section of climatic conditions that exist across the country.

Correlation Equations

Correlations in the interactive program were regression equations. A summary of the variables for each correlation is presented in Tab. 2. Collectively, EPDS has approximately 400 different equations. In order to achieve improved correlations, the regression equations include second- and higher-order terms as well as cross products. The number of terms in each equation range from 7 to 30. A feature of the correlation equations was the ability to interpolate between various options. For example, doors were analyzed at specific R-values, and the correlation equation can be used to determine the performance of doors at any R-value. Specific details on the development of the correlations can be found in references 10, 14, 16, 17, 24, and 25.

Setting An Energy Target

The purpose of an energy target was to provide an achievable energy-conservation goal. The calculation procedure subsequently developed can be used independently of the target. One can elect to do better than the target or decide not to meet it. The utility of the target is to serve as a yardstick to measure the relative energy performance of houses at the design stage.

As defined in EPDS, the energy target refers to the energy lost or gained at the envelope of the house. This definition avoids any difficulty relative to heating- and cooling-equipment selections and efficiencies plus differences in local fuel rates. The basic problem in setting an energy target was to establish what level of energy consumption was considered energy efficient. The term energy efficient is a relative concept and has no meaning until a base or reference is established. As a starting point, HUD-MPS was considered minimum energy-efficient construction.²⁹ The absolute best would be a house that did not use any energy to heat or cool, but this was considered too extreme. Somewhere between these two levels of construction is a realistic target. The approach used in EPDS was to define a specific construction for each component of the house, Tab. 3. Since each component of a house is considered in the specifications, this is a balanced approach.

Many variables influence an energy target. Some are under direct control of the contractor, for example, insulation levels, window sizes, number of glazings, orientation, air-infiltration controls, and the basic house size and shape. Each of these variables were specified in developing the energy targets. Other variables influence the actual energy performance of a house but are outside the control of the contractor. Specifically, the size of the family and their lifestyle plus the heating and cooling thermostat set points are unknown at the design stage. Since these factors are important and affect the house's energy consumption, a typical family of four was assumed along with heating and cooling set points of 68° F (20° C) and 78° F (25.6° C) in the development of the energy targets. Location or weather conditions was the last major variable considered in setting the energy targets. The energy target is calculated in EPDS for each house analyzed using the target specifications and that particular city's weather data. This ensures a realistic and house-specific energy target.

Design Loads

In addition to predicting energy consumptions, EPDS also calculates heating and cooling design loads. This was done for two reasons. First, design loads are essential for sizing of heating and cooling equipment. As houses become more energy efficient, general rules of thumb for sizing the equipment no longer apply. By including this feature in EPDS, there was a complete and consistent approach to designing a house and selecting the appropriate equipment size. The second reason for adding the design-load capability was that the duct-loss calculations were improved when the equipment size was known.

The basis for the design load calculations was the ASHRAE simplified procedure.¹⁰ There was one notable exception to this procedure and that dealt with the design latent loads. Instead of assuming a 30% factor for humid climates and a 20% factor for dry climates, the latent load was calculated. A moisture balance was completed using design conditions on weather, air-infiltration rates, latent loads from occupants, and condensate removal by the air conditioner. The model solves for the peak indoor humidity level, which in turn is used to calculate the design latent load. This was considered a substantial enhancement to the design-load capabilities.

Validation Of The Simplified Procedure

Numerous assumptions had been made in the development of EPDS, which raised a question as to its overall accuracy. The best way to answer this question was to compare it to the hourly computer program for a variety of houses and locations. However, it must be pointed out that this is not an absolute validation. This type of validation is not any better than the original hourly computer program. It does not ensure that actual houses will exhibit the predicted performance. In fact, actual houses could exhibit quite dissimilar performance because of occupant lifestyles, thermostat settings, differences in yearly weather patterns, and other variables not accounted for in the procedure, such as night setback of the thermostat and natural ventilation.

Validation of EPDS was completed at three levels: individual regressions, comparisons of predicted annual loads, and a check on the relative performance between homes. First, each regression equation was checked against the original data. Using standard statistical packages, the regressions were evaluated for goodness of fit by inspecting the correlation coefficient, using F-tests to confirm the significance of variables, and finally, reviewing the residuals to check for consistency.

The second level of validation was to check the annual loads for 108 test cases. This was a check on the heating and cooling loads before they were adjusted by the heating and cooling equipment factors. Results from this check are presented in Fig. 5. Perfect agreement would have all the points lie on the diagonal line.

Finally, the relative performance of four houses was investigated in eleven different climates. Differences between various levels of energy conservation features were determined with both the hourly computer program and EPDS. As the energy conservation features increased, consistent trends in energy consumption were predicted by both programs.

DISCUSSION OF RESULTS

The distinguishing feature of EPDS was the development and use of precalculated energy factors. Their development introduced certain simplifications that makes them easy to use. However, it also introduced certain limitations and advantages that affect the accuracy and sensitivity of the analysis.

Simplifications

In the development of precalculated energy factors, numerous assumptions were made that subsequently affected the results. The analysis of walls assumed constant framing factors of 17% for 16 in. (0.41 m) on-center spacings, 15% for 24 in. (0.61 m) on centers, and 9% for the band joists. The framing factors changed with stud spacing, but they may not represent all houses. Similarly, the band-joist percentage was based on a fixed ceiling height. Lower or higher ceilings will have different framing factors, but EPDS cannot distinguish between these types of construction.

In the analysis of ceilings, the precalculated factors account for compression of the insulation at the eaves in certain constructions. The results also depend on roof pitch, type of shingles, color, and orientation. Again, typical conditions were used in the development of these factors, but they do not represent all possible combinations.

Windows were another instance in which simplifications had to be made. The approach was to model the major parameters and then use interpolation schemes to determine intermediate values. For example, analyses were completed for eight orientations, three window heights, four latitudes, and six overhang depths. Other window variables include shutter strategies and screens, the use of which changes with seasons and are not under the contractor's control or even known at the design stage. Therefore, they are not options. Drapes, on the other hand, were included in the analysis, but only as a constant shading coefficient of 0.75.

Weather was another variable that can have a dramatic influence on the energy performance of houses. NOAA long-term degree-days were used as representative values; however, the weather encountered in any particular year may exhibit substantial differences.

The end result of all these simplifications was simplified calculation procedures that were easy to use and still substantially accurate. Those construction options that can be changed at the design stage were allowed to vary, but those variables not under control of the builder were modeled as typical values to simplify the calculation procedure.

Sensitivity

During the development of EPDS, the sensitivity of selected variables was investigated. Particular attention was devoted to walls as a representative component of the house envelope. The sensitivity of wall performance to balance point and insulation level is presented in Fig. 6. Three cities, Minneapolis, St. Louis, and Dallas, were investigated at two insulation levels, R-19 (RSI-3.3) and R-60 (RSI-10.6). The R-19 (RSI-3.3) walls exhibit almost the same curvature or sensitivity as the R-60 (RSI-10.6) walls. In each city the energy use decreased with lower balance points, the warmer climates showing a larger percentage of decrease. Therefore, accounting for the dependence of balance points by location was essential in the development of the energy factors.

Another sensitivity of walls was solar loads at different orientations. Using the R-19 (RSI-3.3) wall and assuming a 55°F (12.8°C) balance point, the effect of orientation was investigated. The results are presented in Fig. 7 which shows that the average difference for any city between the high and low values was 5 to 15%. However, for simplification purposes, the N, S, E, and W wall-orientation energy factors were averaged in each city for representation in EPDS.

Recognizing the changes in degree-days with base temperature was important in improving the correlations for energy factors. Changing the base temperature produces different results depending upon the particular location involved. This is most easily demonstrated by plotting heating degree-days to various bases, Fig. 8. Changing the degree base temperature from 65°F (18.3°C) to 55°F (12.8°C) in Bismarck reduced the length of the heating season by 27%. However, the same shift in San Diego essentially eliminates the entire heating season. Since EPDS uses degree-days in each city that correspond to the balance point of the house, this sensitivity is incorporated into every calculation.

Internal loads were also investigated. In northern cities, they help to offset predominantly heating loads but in southern cities increase the predominant cooling loads. In climates that are moderate the influence is negligible and a small change can switch the effect from a benefit to a liability. The net effect of internal loads was observed to depend on how they were modeled. Internal loads convect and radiate heat to the surrounding air and surfaces. Changing the fraction of convection and radiation caused the net effect of internal loads to change. The radiative portions used in EPDS were 70% for people, 90% for incandescent lights, and 100% for appliances.^{31, 32}

Accuracy

The question of accuracy could relate to how well EPDS predicts actual performance. The procedures in EPDS were not intended to predict actual performance because of the difficulty in modeling family lifestyles and the weather. The strength of EPDS is to predict relative performance under identical conditions in the design stage. For example, EPDS can accurately predict the change in performance between two house designs if all other variables are held constant. This strength arises from the use of the hourly computer program's subroutines in modeling individual components. However, to compare an EPDS prediction to an actual house, differences can arise primarily as a result of differences between the assumptions made in EPDS and the actual circumstances. Specifically, differences can easily arise in family lifestyles, weather, thermostat set points, window management, heating and cooling equipment efficiencies, plus workmanship items that affect air infiltration levels. Therefore, the comparisons that were presented between EPDS and the hourly computer program appear to be very good and justify using EPDS as a design tool.

Limitations

Since EPDS was based on precalculated factors, certain limitations were built into the analysis. The features under control of the contractor include

the type of house and construction options. EPDS limits the contractor to evaluations of conventional housing that excludes passive-solar and underground house designs. Other features were outside the control of the contractor, so they were fixed in the calculation procedure, e.g., family lifestyle, weather, thermostat usage and settings, natural ventilation, and window treatments with shades and screens. Typical values were chosen for each of these items in order for the calculations to be completed and to produce reasonable results.

Advantages

There are six unique and distinct advantages of EPDS.

1. It is easy to use. Only three types of input are required: surface areas, construction options, and HVAC equipment. An extensive library of construction options (ceilings, walls, floors, basements, crawlspaces, slabs, etc.) has been prepared which correspond to the precalculated energy factors. A description of the house is entered as surface areas of the various components.
2. It is user friendly. The interactive computer program steps the user through the calculation process. It responds immediately to any incorrect input so that the problem can be corrected before any calculations are made. Numerous prompts and help commands are available at each step to assist the user if necessary.
3. There are hundreds of options. Many combinations can be used in the design of homes, and EPDS provides a broad spectrum of construction features and HVAC equipment from which to choose.
4. It allows for quick redesigns. One distinct feature of EPDS is the ability to quickly evaluate options at the design stage. Orientations can be changed in one simple command. City locations are changed as easily. Individual components can be compared directly, or their impact on the total house design can be evaluated.
5. It is a generalized procedure. The procedure has weather data for 319 locations across the U.S., which allows one to evaluate almost any particular site.
6. It has been validated. The entire procedure was derived from an extensive and sophisticated computer program that was validated at both the component level and with full-scale houses.

CONCLUSIONS

An overview of the approach used in developing EPDS has been presented. The two most critical parts were the development of a procedure to quickly analyze the thermal performance of numerous individual components and the development of a correlation procedure to generalize the results to any city or climate.

Analyzing the thermal performance of a specific house in one city with the hourly computer program was straightforward, but it was unwieldy for modeling numerous components. Instead, the balance-point concept was introduced because it accounted for whole-house interactions in a simple procedure that significantly reduced the computer time. The end product was the formation of precalculated energy factors that were easy to use in EPDS. Every major feature in the design of conventional houses was evaluated. Hundreds of options were developed for the contractor or builder to select from. Those items that the contractor cannot control, but still influence the energy consumptions, were included in the procedure as typical values.

Using the balance-point concept did simplify analyzing individual components by accounting for whole-house interactions, but it also introduced some limitations and approximations. The sensitivity of walls to balance points was shown to be very critical. Solar loads, internal heat gains, internal partitions, and film coefficients were all built into the balance

points as part of the simplification, but were necessary to develop the procedure.

The accuracy of EPDS was checked against a validated computer program and the results were remarkably good given the level of simplification. The strength of EPDS is to calculate relative comparisons under identical operating conditions. Predictions of actual performance are too difficult because they depend heavily upon family lifestyle and weather, which cannot be predicted at the design stage.

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TABLE 1
Description Of Three Test Homes Insulation Levels
Test Houses Insulation R-Values

<u>Component</u>	<u>A</u>		<u>B</u>		<u>C</u>	
	<u>R</u>	<u>(RSI)</u>	<u>R</u>	<u>(RSI)</u>	<u>R</u>	<u>(RSI)</u>
Ceilings	38	(6.7)	19	(3.3)	0	(0)
Walls	19	(3.3)	11	(1.9)	0	(0)
Floors	19	(3.3)	11	(1.9)	0	(0)

TABLE 2
Correlation Variables

<u>Component</u>	<u>Independent Variables</u>
Ceiling	HDD, CDD, BP, U
Walls	HDD, CDD, BP, U
Doors	HDD, CDD, BP, U
Floors	HDD, CDD, BP, U
Windows	HDD, CDD, NP, SOLAR, LAT
Overhangs	HGT, OVHG
Shutters	HCL, NP
Below Grade	HCL, CCL, R
Infiltration	HCL, CCL, BP, VOL
Internals	HDD, CDD, BP, CTR, LAT, H10, H20, R202, FAM
Thermostat	HDD, CDD, HSP, HH, CSP, FAM
Ducts	HCL, CCL, HTD, U, OVERSZ, ANNHLD, ANNCLD, DAREA
Htg. Equip.	HCL, AFUE, COP
Clg. Equip.	EER, ACHAA, SLKWH, HRHRS, CSP, VOL, LEK

<u>Variable</u>	<u>Description</u>	<u>Variable</u>	<u>Description</u>
ACHAA	Air changes per hour in an air-to-air heat exchanger	HDD	Heating degree-days
AFUE	Annual fuel utilization efficiency	HGT	Window height
ANNCLD	Annual cooling load	HTD	Heating set point minus htg. bal. pt.
ANNHLD	Annual heating load	HRHRS	Humidity ratio hours
BP	Balance point of the house	HSP	Heating set point
CCL	Cooling climate locator (CDD55)	LAT	Latitude
CDD	Cooling degree-day	LEK	Leakiness
COP	Coefficient of performance	NP	Number of panes
CSP	Cooling set point	OVERSZ	Oversizing of furnace (% of design load)
CTR	Cooling to total ratio (CCL/(HCL+CCL))	OVHG	Overhang length
DAREA	Duct area	R	R-value
EER	Energy efficiency ratio	R202	(H20/HDD65)**2
FAM	Family size	SOLAR	Solar radiation on a hor. surface - annual
FLR	Floor area	SLKWH	Sensible cooling load
HH	Heating hours	U	U-value
H10	HDD65-HDD55	VOL	Volume of house
H20	HDD65-HDD45		
HCL	Heating climate locator (HDD55)		

TABLE 3
Energy Target Specifications

<u>Specifications</u>	<u>Component</u>
R-38 (RSI-6.7)	Ceilings
R-30 (RSI-5.3)	Walls
R-10 (RSI-1.8)	Doors
R-8 (RSI-1.4)	Slabs
R-19 (RSI-3.3)	Crawlspaces with insulated walls
R-11 (RSI-1.9)	Unconditioned basement with insulated walls
R-19 (RSI-3.3)	Conditioned basement with insulated walls
R-30 (RSI-5.3)	Floor over vented crawlspace or basement
R-8 (RSI-1.4)	Ducts
Triple glz.	Windows limited to 10% of the floor area uniformly distributed on all four orientations with two foot overhangs and no shutter option
Level 2	Air infiltration
Family 4	Family size
68°F (20°C)	Heating set point
78°F (25.6°C)	Cooling set point

		HOUSE LOADS	
		HEATING	COOLING
COMPONENT LOADS	HEATING	ADD TO NET HEATING (+)	SUBTRACT FROM NET COOLING (-)
	COOLING	SUBTRACT FROM NET HEATING (-)	ADD TO NET COOLING (+)

Figure 3. Calculating net component loads

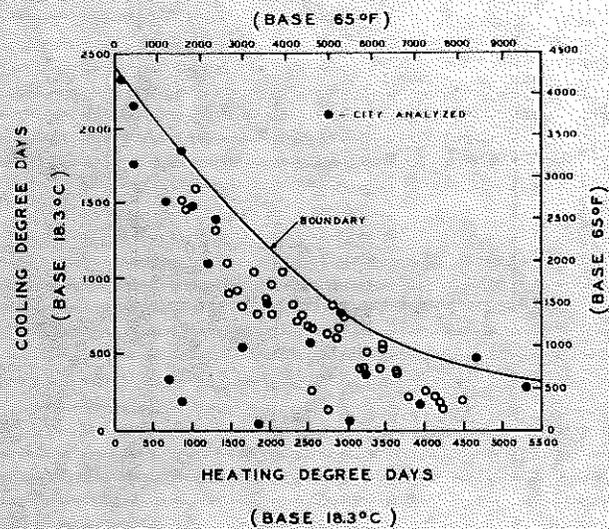


Figure 4. "TRY" weather data

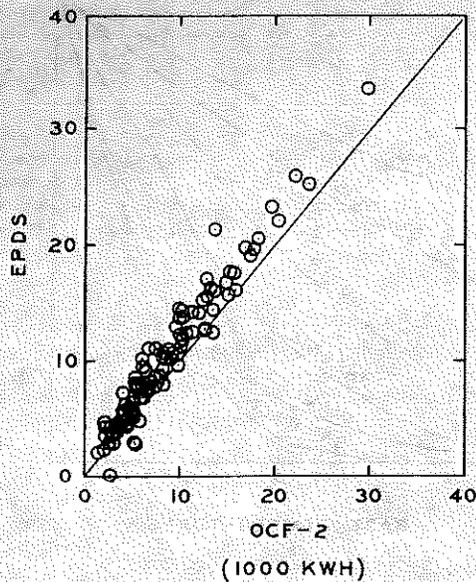


Figure 5. Accuracy check on total loads

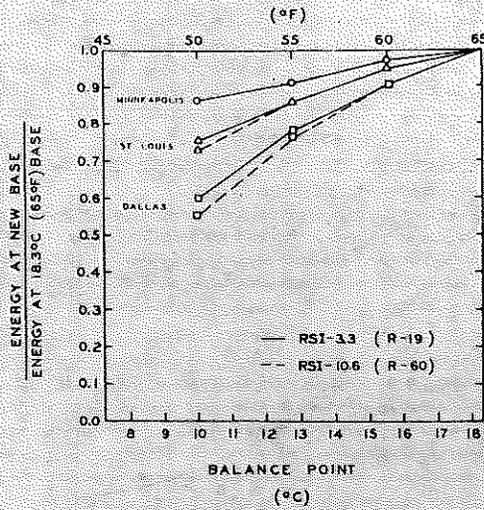


Figure 6. Sensitivity of balance points on wall performance

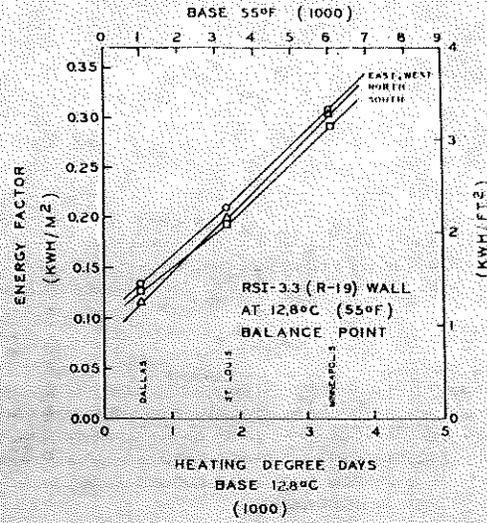


Figure 7. Sensitivity of orientation on wall performance

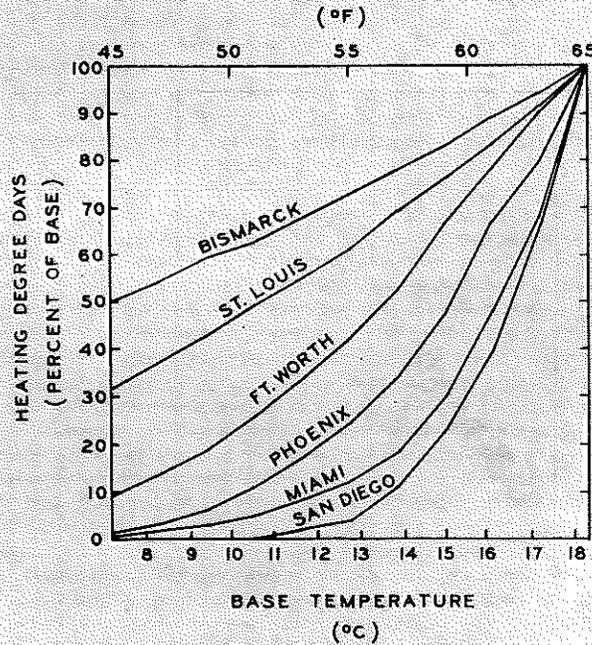


Figure 8. Sensitivity of degree days to base temperature

Discussion

H. F. Wu, Architecture Resch. Lab., University of Michigan, Ann Arbor: Is there any application for passive solar components and any future consideration?

McBride: Presently, there is not any application for passive solar components in EPDS. Future plans call for passive solar to be integrated into EPDS but a specific time table has not been developed.

J. W. Mitchell, Univ. of Wisconsin, Madison: Even though you have many combinations of walls, roof, etc., available, a user may attempt to extrapolate outside the range of the correlation. Do you allow extrapolation? Could you comment on why you chose a correlation approach rather than a more realistic approach, such as TC 4.7?

M. F. McBride: Extrapolation within EPDS is not permitted; however, interpolation is permitted. The initial development of EPDS was a manual that presented graphs to use in conjunction with a simplified hand calculation procedure. Each graph was generated by using the detailed, hourly simulation program, OCF-2. Development and validation of OCF-2 required several years of extensive research and it was desired to incorporate that work into EPDS. Correlations were determined to be the best method.