DEVELOPMENT OF REVISED ENERGY STANDARDS FOR TEXAS BUILDINGS: PRELIMINARY RESULTS

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ABSTRACT

In 1977, the State of Texas published a two-part Energy Conservation Manual to aid designers, builders, and contractors in the design of energy-efficient state buildings. Under the sponsorship of the Governor's Energy Management Center, the Center for Energy Studies (CES) at The University of Texas at Austin is revising and updating the nonresidential building portion of the Energy Conservation Manual.

The proposed revision is a Texas-specific adaptation of ASHRAE Standard 90.1P ("Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings"). These modifications include editorial changes, such as deletion of criteria that do not apply to Texas climates, as well as improved envelope criteria and the addition of HVAC systems performance criteria.

This paper documents the approach taken in the development of the revised Texas standards. Preliminary results are presented for the new envelope calculation procedures that will be included in the compliance software. This software will parallel that provided for the envelope and lighting sections in the ASHRAE Standard and will ultimately extend the standard to include a performance-based approach for HVAC systems and whole-building Energy Targets.

Residential Buildings and Part 2: Apartment and Nonresidential Buildings)[1], published by the State of Texas, was one of the State's initial efforts to respond to the energy crisis. This document, which was intended to aid designers, builders, and contractors in the design of more energy-efficient State buildings, has served as the energy standard for new State of Texas buildings for the past 10 years. The manual provides criteria for the building envelope and for mechanical, lighting, service water heating systems, and equipment. The envelope guidelines and criteria are unique, but the mechanical, lighting, and service water heating systems and equipment criteria are very nearly the same as those of ASHRAE Standard 90-75[2] published in 1975.

At the request of the Governor's Energy Management Center, the Center for Energy Studies at The University of Texas at Austin is revising the State's Energy Conservation Manual. The objective of this revision is to provide up-to-date criteria reflecting recent progress in energy-efficient building design and in the structure and format of building energy standards. Because of the extensive research and extended public review that have gone into its development, CES is using ASHRAE Standard 90.1P ("Energy Efficient Design of New Buildings except Low-Rise Residential Buildings")[3] as the basis of the new State standards.

The modifications for this Texas adaptation fall into two categories. In the first category are editorial changes, such as the deletion of criteria in 90.1P that do not apply in Texas climates. Moreover, criteria of particular importance to Texas climates are being reexamined and strengthened where appropriate. The changes in the second category are more substantive and include changes to improve the reliability of the envelope calculation procedures and criteria, the addition of performance criteria for HVAC systems, and the addition of a whole-building energy target alternative. These changes are based on results from recent research at CES. None of the changes will modify the procedural approach and innovative features in 90.1P.

The CES research effort is focusing on two areas: improvement in the reliability of the building envelope criteria, and an extension of the ASHRAE work to provide performance criteria for HVAC systems. The equipment criteria will remain the same as those in ASHRAE 90.1P to avoid difficulty in meeting a separate set of State criteria.

modified approach that will allow more flexibility in building and system design. This approach will be incorporated in the State's Energy Conservation Manual in two steps. The first will involve the modification of the ASHRAE Standard 90.1P envelope criteria and compliance equations. Whereas the present ASHRAE 90.1P equations are based on a national climatic data base, the Texas-specific equations will be applied to an expanded set of exclusively Texas locations. These improved equations will provide more reliable results for Texas but will not affect the structure or format of the calculation and compliance procedures. The second step will add an HVAC system performance path to Section 9 (HVAC Systems) and will provide a whole building energy target alternative to the Building Energy Cost Budget Method of Section 13 of ASHRAE 90.1P.

ASHRAE STANDARD 90.1P

ASHRAE Standard 90.1P for new, nonresidential buildings forms the basis of the Texas building energy standard. Standard 90.1P covers buildings, or portions of buildings, that provide facilities for human occupancy and that use energy primarily to provide human comfort, except single and multifamily residential buildings of three stories or fewer. Building areas intended primarily for industrial or commerical processes are exempt from this standard.

Figure 1 illustrates the compliance procedures in Standard 90.1P. Several alternative procedures may be used. The same compliance paths will be available in the proposed Texas standard. Compliance requires that a set of Basic Requirements be met whichever path is elected. These Basic Requirements are a set of general energy efficiency guidelines and/or calculation procedures for the building envelope; energy distribution systems; heating, ventilating, air conditioning, service water heating, lighting, and energy management systems and equipment; and auxiliary equipment. In addition, a proposed design must comply with a set of either Prescriptive, Performance, or Building Energy Cost Budget criteria. These criteria are the heart of the compliance procedures.

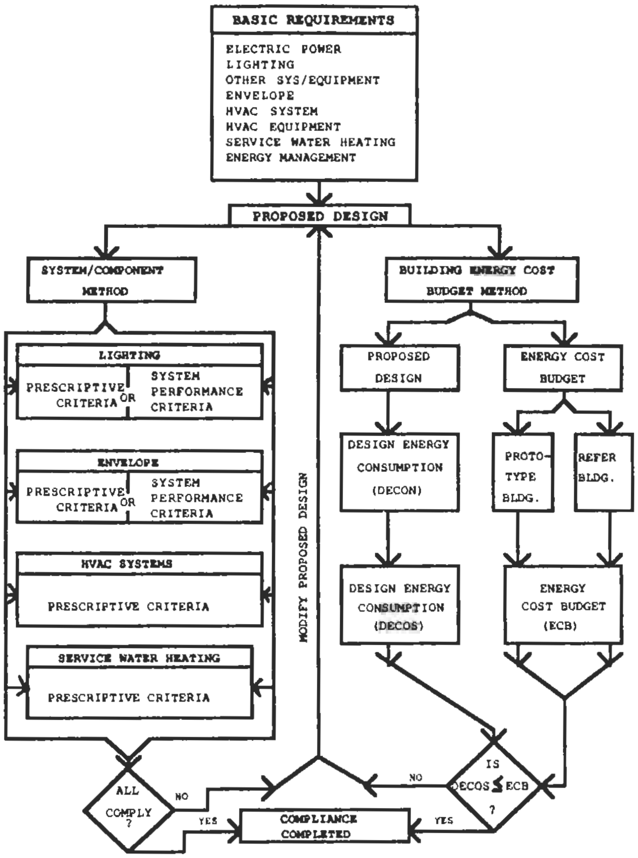

Figure 1 Alternative Methods of Achieving Compliance

BASIC REQUIREMENTS

Compliance with Standard 90.1P requires compliance with the Basic Requirements set forth in each of the following Sections:

1. Electric Power
2. Lighting
3. Other Systems/Equipment
4. Envelope
5. HVAC System
6. HVAC Equipment
7. Service Water Heating
8. Energy Management

Criteria are established for the electrical distribution system, transformers, electric motors, and for consideration of heat recovery potential. Criterial are also established for interior and exterior lighting, including maximum allowable lighting power for the building as a whole, and minimum ballast efficiencies. Credits are given for lighting power controls and daylighting. Daylighting credit is given for the reduction in electric lighting energy resulting from automatic controls in zones adjacent to windows or skylights. The control credit takes the form of an increased lighting power density allowance.

The envelope Basic Requirements specify a calculation procedure for determining the thermal resistance of opaque walls and fenestration that takes into account thermal bridging. They also specify procedures for determining gross envelope areas, shading coefficients, and air leakage, and provide for the daylighting credits.

The Basic Requirements in sections on HVAC systems and equipment specify load calculation procedures, zoning requirements, and system control requirements. Piping and duct insulation R-values, and materials and construction requirements are also presented. Minimum efficiencies for heating and cooling equipment are specified. Minimum equipment efficiencies and insulation requirements are specified in the service water heating section, as are control and water conservation requirements.

PRESCRIPTIVE CRITERIA

The Prescriptive Criteria may be elected when designers wish to minimize the effort required to demonstrate compliance. Prescriptive criteria are available for lighting, envelope, HVAC, and service water heating systems designs.

The prescriptive path in the lighting section provides procedures for determining the Interior Lighting Power allowance for illumination systems installed in new buildings. This method prescribes a maximum allowable Unit Lighting Power Density by building type. The procedure provides no recognition of the specific configuration of spaces or of activities in the building (however, these factors are considered in the Performance Criteria described below). Minimum recommended luminary and ballast efficiencies are also specified.

An Alternate Component Packages (ACP) procedure is used for the envelope Prescriptive Criteria. The ACPs are precalculated prescriptive requirements for a set of selected envelope component configurations. Standard 90.1P has ACPs for 30 U.S. climate zones. The configurations include a base case and two or three cases of perimeter daylighting with varying glazing types. Thermal mass considerations are also built into the ACP tables. Using these tables, a maximum allowable percent fenestration and maximum allowable U-value for opaque wall assemblies are specified. The Texas adaptation of Standard 90.1P will maintain this procedure, providing ACP tables for Texas locations.

In the HVAC systems and equipment sections, the prescriptive path specifies design criteria for system sizing, zone and economizer controls, fan and pumping system design, and temperature reset controls. Minimum efficiences are specified for heating and cooling equipment. Similarly, minimum efficiencies are specified for electric and gas water heating equipment in the service water heating section. In addition, economic evaluations of heat pump, heat recovery, and solar water heating are required.

PERFORMANCE CRITERIA

Standard 90.1P currently provides Performance Criteria only for lighting and for the envelope. CES is developing performance alternative HVAC systems in the Texas adaptation of the standard. The performance path can be used when innovative designs are to be considered or when increased flexibility is desired. The Performance Criteria for lighting include a system performance procedure for determining an Interior Lighting Power Allowance for each space in the building. This procedure can also provide a basis for estimating the lighting heat gain (or energy use) of individual rooms, spaces, or areas, and for the whole building. The procedure used is the Unit Power Density procedure, which is based on the activity in (or function of) each building space or lighting zone.

The Performance Criteria for the building envelope specify roof, floor, and exterior wall criteria as a function internal load, orientation, and climate. The exterior wall criteria were developed from an extensive series of computer simulations; heating and cooling criteria are given for each wall orientation. These criteria represent limits on cumulative annual heating and cooling energy flux through the wall attributable to transmission and solar gain. These criteria accommodate variations in internal load and wall heat capacity. The building envelope performance procedure is based on work initiated under ASHRAE Special Project 41[4] and continued through the development of 90.1P.

A set of microcomputer-based software packages has been developed to aid in determining building-specific envelope and lighting criteria and to demonstrate compliance with these criteria. An envelope design is in compliance if the sum of the calculated wall heating and cooling compliance values, for all orientations of the proposed design, does not exceed the sum of the corresponding wall heating and cooling criteria for all orientations combined.

BUILDING ENERGY COST BUDGET METHOD

The Building Energy Cost Budget path is more complex, and more flexible, than either the Prescriptive or Performance paths. It may be used to check compliance when the proposed design fails to meet either (or both of) the Prescriptive or Performance Criteria of the Standard. Or it may be used in lieu of the Prescriptive or Performance Criteria. The method might be used for an unusual or particularly innovative design. This method allows greatest design flexibility while still providing building energy efficiencies consistent with the other compliance paths. It uses the unit cost of energy rather than energy in specifying criteria. This approach lets the cost represent the value of a fuel to society to avoid difficulty in directly comparing the value of different energy sources. This path provides an opportunity for the designer to evaluate and take credit for innovative conservation designs, materials, and equipment -- including load management strategies -- that cannot be evaluated in the other compliance paths.

Demonstrating compliance under the Building Energy Cost Budget Method requires detailed analyses of the proposed design, referred to as the Design Energy Consumption (DECON); an estimate of annual energy cost for the proposed design, referred to as the Design Energy Cost (DECOS); and comparison with an Energy Cost Budget (ECB) (see Figure 1). Compliance is achieved when the estimated annual DECOS is not greater than the annual ECB. The ECB, which is determined through calculation of the monthly energy use and energy cost of a prototypical building, is the highest allowable annual energy cost budget for a specific building design and location. It is a numerical target for annual energy cost and is intended to assure neutrality with respect to choices of HVAC system type, architectural design, fuel choice, etc., by providing a reliable, repeatable budget. For a given building size and type, the ECB will vary only with climate, the number of stories, and the simulation tool used.

ADAPTING STANDARD 90.1P FOR TEXAS STATE BUILDINGS

MODIFICATIONS TO ASHRAE 90.1P

ASHRAE Standard 90.1P has been revised and adapted for use as the Texas State Buildings Energy Standard. This process began by editing Standard 90.1P to remove criteria not applicable to Texas and to identify provisions that should be reevaluated because of climate or building practices specific to Texas. Most of the changes made to date are editorial in nature. However, some changes have been made to strengthen the provisions in areas of particular importance in Texas or to improve the reliability of the results for Texas buildings.

One of the key modifications that has been made to adapt 90.1P for Texas was to replace the 90.1P regression equations used for the heating and cooling criteria in the Envelope Performance path with equations specifically developed for Texas locations. The 90.1P equations are based on a national data base that includes results of analyses of building envelope performance in several locations with climates quite different from that of Texas and in relatively few Texas locations. The Texas-specific equations are based on the same analysis procedures used in developing the ASHRAE 90.1P equations, but in this case they are applied to six Texas climates. The revised equations also use a simpler and more physically intuitive form. They provide a higher level of confidence in the results for Texas buildings.

ADDITIONS TO ASHRAE 90.1P

The first addition to ASHRAE 90.1P will be an HVAC performance procedure. The purpose of this procedure is to provide a means of evaluating the impact of system selection and control characteristics on the energy required to maintain comfort in a particular building, with its own set of functions, schedules, and climate factors. This procedure is based on work initiated during the development of ASHRAE 90.1P and continuing at CES under this project.

The Texas-specific envelope correlation and HAVC system performance criteria will also play a role in the development of the whole-building Energy Target performance alternative that is being added to the Texas standards. This new approach, based on the initial ASHRAE Special Project 52 work[5], is a procedure which estimates an annual energy use for each functional space (zone) in the building and then sums the results to obtain an annual whole-building target. The target process begins with an estimate of annual heating and cooling loads for each function in a building (office, circulation, conference, food preparation, etc.) adjusted for operating schedule, sums the function loads to zone loads, applies HVAC systems performance multipliers and then equipment efficiency multipliers to obtain an estimate of a whole-building energy target. Sets of space load, schedules, and HVAC system factors are being developed for 10 space function types. The targets procedure will provide an alternative to using the 90.1P Section 13, the Building Energy Cost Budget Method.

RESEARCH RESULTS

DEVELOPMENT OF TEXAS-SPECIFIC ANNUAL HEATING AND COOLING LOAD CORRELATIONS

The ASHRAE 90.1P envelope criteria and compliance equations are based on regression analyses using the results of a large number of DOE-2.1 runs. The ASHRAE locations included three in Texas: Houston, Fort Worth, and El Paso. The Texas-specific correlations were developed using the results for these three sites and, using the same basic analysis procedures, for three additional sites: Amarillo, Austin, and Brownsville. These results were then examined to define the correlation between annual heating and cooling loads, internal loads, and two composite building envelope characteristics, the effective aperture and the overall thermal transmittance. The intent was to determine the form of the correlation equations by examining the variation in loads, for a range of Texas climates, as a function of these fundamental parameters.

Preliminary simulations indicate that these parameters include all of the envelope characteristics that significantly affect annual heating and cooling loads in a given climate. Envelope thermal mass also has a minor effect on the annual loads for the type of building and range of parameters considered in this study. The ASHRAE 90.1P procedure for correcting for thermal mass will be used to deal with this second-order effect in the Texas standards. The envelope correlation equations developed are not intended to be a general design or load-prediction procedure, but rather are a means of identifying the variation in annual heating and cooling loads over a realistic range of envelope design parameters.

SIMULATIONS FOR SIX TEXAS CLIMATES

A set of DOE-2.1 building energy analysis computer program input files for a 5-zone office building module was used for the simulations run for this study. These input files were the same as those used in the ASHRAE Special Project 41 and Standard 90.1P development process. The module included a core zone and four perimeter zones facing the four compass points. Ranges for internal loads, effective apertures, and overall loss coefficients were selected to represent typical office building construction and operation for a middle floor in a multistory building. A number of parametric runs were then made, using DOE-2.1 and Test Meteorlogical Year weather data files for the six Texas cities.

Annual heating and cooling coil loads for a single-zone reheat system were determined for each of the four perimeter zones. In each of these cases the internal loads (lights, equipment, and people) of 0.5, 2.3, and 4.1 W/ft^2-°F were used, overall loss coefficients of 0.119, 0.287, and 0.592 Btu/h-ft^2-°F were used, and effective apertures (window-to-wall ratio times Shading Coefficient) were varied over 0, 0.18, 0.36, and 0.60.

SIMULATION RESULTS

The results of these simulations can be expressed in graphical or equation form. The equation form is most easily used in the compliance software; however, the graphical format best illustrates the linear nature of the results. For each building zone, in each of the six climates considered, there are 18 (3 X 3 permutations for each of the 3 envelope parameters for heating and cooling) plots of load versus envelope parameter. Figures 2-4 show a representative set of these plots. They show the variation in the west zone annual cooling load in Houston versus the overall loss coefficient (U_{oc}), with the internal load (W) as a parameter, for effective aperture (EA) values of 0, 0.18, and 0.36, respectively. Note the clear linearity over the range of envelope characteristics examined for this office building module. For an effective aperture of 0 (Figure 2) the cooling load is nearly independent of, but increases slightly with, U_{oc}; variation is greatest for low values of internal load. Thus with no solar gains and high internal loads, the cooling load is virtually independent of the overall loss coefficient. In contrast, for low internal loads, an increasing loss coefficient results in increased cooling loads, illustrating the slight effect of outside ambient conditions. Figures 3 and 4 show the effect of increasing solar gains on these

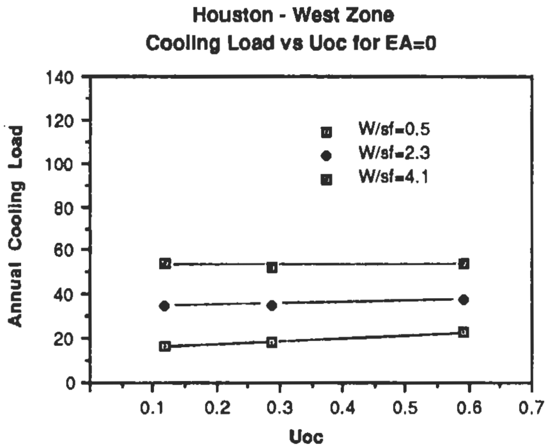

Figure 2 Cooling Load Correlations for Houston, West Zone; Load Versus U_{oc} Plot for EA = 0

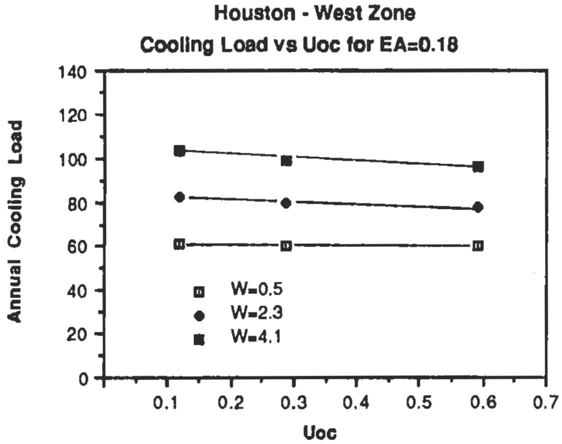

Figure 3 Cooling Load Correlations for Houston, West Zone; Load Versus U_{oc} Plot for EA = 0.18

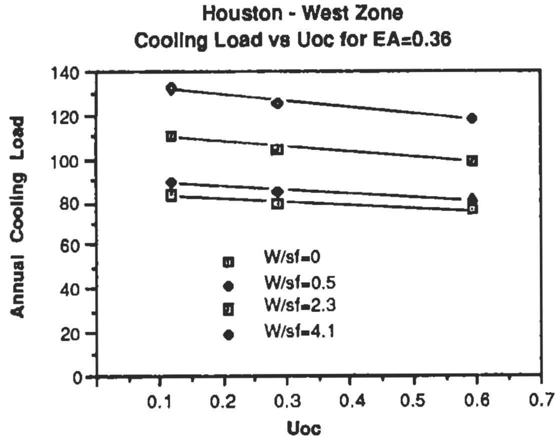

Figure 4 Cooling Load Correlations for Houston, West Zone; Load Versus U_{oc} Plot for EA = 0.36

patterns. As the solar gain increases, the cooling load now decreases with overall loss coefficient, becoming increasingly dependent at high effective apertures. Thus the increased envelope loss coefficient becomes a means of dissipating the high internal and solar gains.

In addition, note that the correlations show a relationship between the slope of each load/envelope parameter curve and the other two parameters. Figure 5 shows the dependence of the slope of the cooling-load-versus-loss coefficient (CL/U_{oc}) curves with the internal gain (W), with effective aperture (EA) plotted as a parameter. Figure 6 shows the same relationship, but with the independent variable and parameter (W and EA) reversed. There is remarkable linearity, except for an unrealistically high value of effective aperture (EA = 0.6) when the west zone is overloaded with excessive solar gain.

Because of the plethora of data, only one representative set is presented here. Consistent and similar relationships were observed for all other cases, although zone and climate differences were evident.

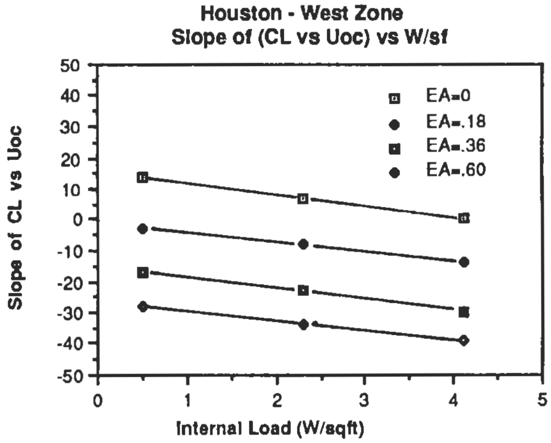

Figure 5 Slope of Cooling Load Versus U_{oc} Curve, Expressed as a Function of Internal Load for Houston, West Zone

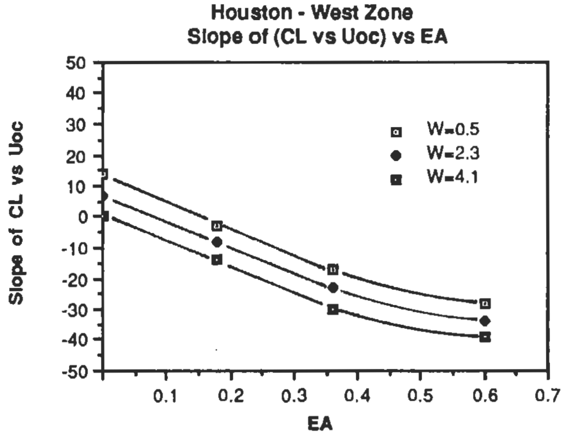

Figure 6 Slope of Cooling Load Versus U_{oc}, Expressed as a Function of Effective Aperture for Houston, West Zone

CORRELATIONS

Linear relationships similar to those shown were observed for both heating and cooling loads for all zones in all climates. This suggests a form for the correlation of annual heating and cooling load with the three envelope parameters. Thus the correlation equations for the Texas climates were expressed in the following form:

$$CL(\text{or } HL) = a_0 + a_1(W) + a_2(U_{oc}) + a_3(EA) + a_4(W \times U_{oc}) + a_5(W \times EA) + a_6(U_{oc} \times EA) + a_7(W \times U_{oc} \times EA)$$

A representative set of correlation coefficients for annual cooling and heating coil loads is given in Table 1 for Houston.

A comparison of DOE-2 simulated results and results using the correlation equations is shown in Figure 7 for the west zone in Houston. The cooling loads correlate with less scatter than do the heating loads. The reason is that the heating loads are very small (note magnitudes). This same pattern was observed for all zones in all climates, with the most strongly solar-driven zones exhibiting the greatest scatter for heating loads and the least scatter for cooling loads.

SCHEDULE FACTORS

To test results for space functions other than a typical office module, the operating schedule was varied. The correlations shown in Figures 2-7 were developed for a standard 60 h/wk operating schedule (12 h/day, weekdays only). Two alternate schedules were simulated for Houston and Amarillo to span the range of expected continuity in schedules. The intent was to determine if there is a reasonably simple relationship between schedule and load. Obviously, annual cooling loads will increase as the hours of operation increase. The question is, will the increase be a simple function of the number of hours of operation, or will the time of day and climate introduce nonlinear effects? If there is a simple, linear relationship, scheduled effects can be accommodated with a single factor.

Table 1 Loads Regression Coefficient Table For Houston, Texas

a0 thru a7 are the regression coefficients for the loads model to be incorporated into the Texas version of the ASHRAE 90.1P compliance computer program. There is a set for each combination of city, zone, and load type (heating or cooling).

CITY=HOUSTON

		COEFFICIENTS (INDEPENDENT VARIABLE)							
ZONE	LOAD	a0 (CONS)	a1 (WSQFT)	a2 (UOC)	a3 (EA)	a4 (W*U)	a5 (W*E)	a6 (U*E)	a7 (W*U*E)
NORTH	COOL	13.54	11.13	9.04	105.79	-4.12	3.30	-35.26	0.29
	HEAT	1.30	-0.52	25.76	-5.98	-2.79	1.09	-13.15	1.75
SOUTH	COOL	11.35	11.14	11.67	250.59	-3.42	5.06	-68.86	-2.21
	HEAT	1.22	-0.49	20.40	-6.53	-1.93	1.42	-23.41	2.10
EAST	COOL	10.58	11.08	14.79	271.51	-3.40	5.49	-75.12	-1.50
	HEAT	1.30	-0.49	21.37	-6.53	-2.16	1.37	-23.58	2.37
WEST	COOL	11.51	11.06	12.17	205.07	-3.62	5.12	-58.23	-1.04
	HEAT	1.27	-0.50	23.77	-6.82	-2.49	1.38	-21.70	2.30

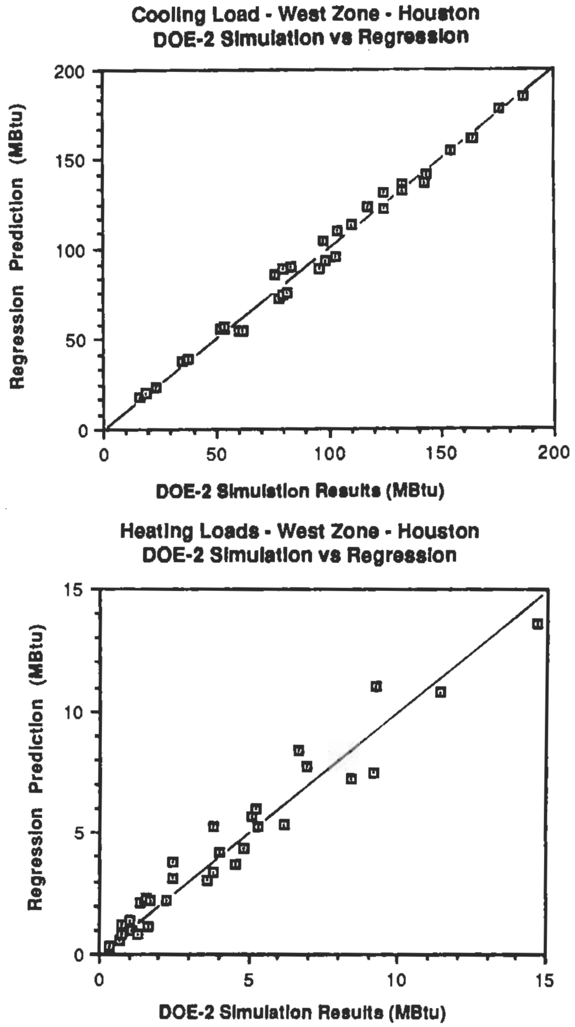

Figure 7 Annual Cooling and Heating Load Regressions for Houston, West Zone

The first schedule tested was 84 h/wk, operating for 12 h/day, repeating for 7 days of the week. This schedule maintains an overnight shutdown, but eliminates the long weekend shutdown. The second alternative was also an 84 h/wk schedule, but it started on Monday morning and continued nonstop at a constant value for 84 consecutive hours. Thus the two schedules had the same number of operating hours, but those hours were spread differently over the week.

Although the schedule factors are not yet final, the preliminary simulation results for Houston shown in Figure 8 illustrate the effects of the three alternative schedules on the annual

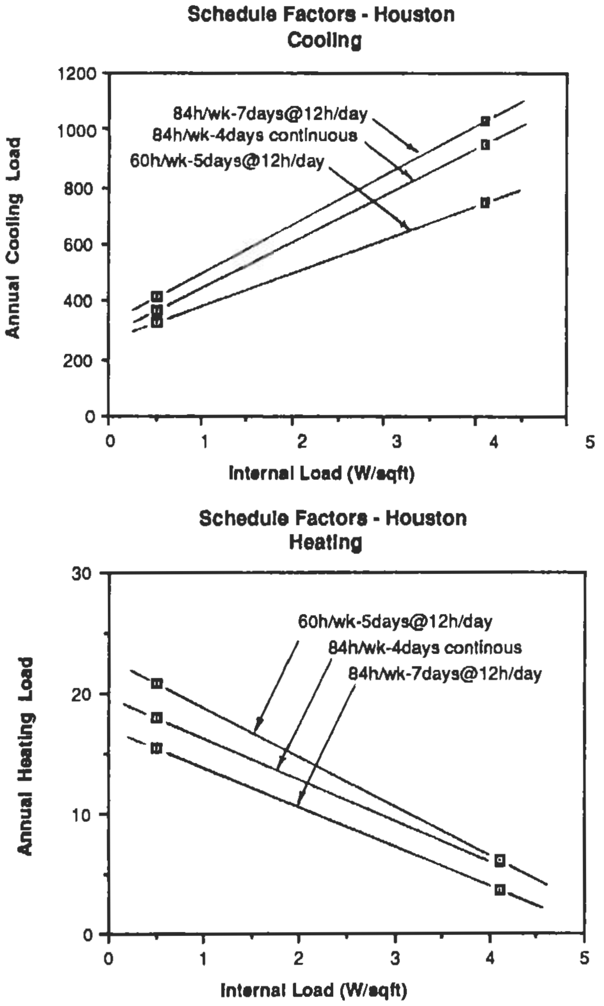

Figure 8 Operating Schedule Factors for Houston, Texas, Expressed as a Function of Internal Loads

coil loads. (Similar results were found for Amarillo.) These results are consistent over the range of internal loads (0.5–4.1 W/ft²) examined in this study. As expected, the longer operating hours (84 h/wk vs. 60 h/wk) result in higher cooling loads and lower heating loads. These results show a linear variation with internal load, but the slopes of these curves differ somewhat. This difference indicates the effect of pick-up loads and leads to the conclusion that a different type of schedule factor may be required to represent the effect of the different operating schedules. It is expected that the schedules will be characterized by an operating h/wk term and a term that relates to the shutdown pattern.

DEVELOPMENT OF HVAC SYSTEMS CORRELATION

One of the tasks remaining in the development of the current ASHRAE 90.1P standard is the incorporation of systems performance criteria comparable to those in the envelope and lighting sections. Performance criteria are needed to make the standard more flexible. CES has been developing an approach that may provide such a path in the Texas State buildings standard. Research is underway to develop a set of quantifiable performance criteria for HVAC systems that would allow the comparison of various system and control operations for a particular building, schedule, and location. The approach being considered is a modification of the System Performance Factor approach suggested by Tao[6] and considered during the development of Standard 90.1P. In the proposed approach, a series of standard system factors would be developed from DOE-2.1 simulations and a procedure provided for developing custom system performance factors from the consideration of a limited number (5 to 10) of daily load profiles. This work is still in the development stage.

The first step in developing the systems performance procedure is to devise a means of selecting a limited number of daily (24 hourly) sets of load and weather data that provide an adequate range of conditions over which to test systems performance. The daily energy use derived for each of these profiles must bear a definable relationship to annual energy use. CES has been examining daily loads from DOE-2.1 simulations with summary climate parameters. Results for Houston and Amarillo show that zone cooling loads correlate well with a combination of the daily average temperature and total solar on a vertical surface at the zone orientation. Addition of the daily average wet-bulb temperature as a parameter does little to improve the correlation.

The loads, daily average temperature and solar correlations are being used to select a set of 10 daily profiles for each of the six Texas climates under study. The next step is to use these daily profiles to drive a series of simple microcomputer-based system simulations. The system simulation output, along with equipment part-load curves for the selected system components, will then be used to estimate daily energy use for heating and cooling. The daily energy use and daily climate summary parameters will be used to estimate annual energy use, thus providing a system-level performance approach.

This approach has several advantages. One is that a single set of daily load profiles can be used to examine a number of system and control options. Another is that the extent of this analysis is sufficient to provide some insight into the performance, but is not overwhelming. A final advantage is that the procedure is manageable on a microcomputer and is thus accessible to all designers.

CONCLUSIONS

Because this study is not yet complete, few conclusions can be drawn. However, the following significant observations can be made.

1. ASHRAE Standard 90.1P, adapted for application to commercial buildings in Texas, clearly forms the basis for revised Texas Building Energy Standards that will guide the energy

efficient design of buildings in Texas for many years to come.

2. The annual heating and cooling load correlations developed in this project for six Texas climates provide a simple, and physically intuitive, means of defining building envelope performance criteria in the new Texas State buildings standard. Operating schedules are simply accommodated by a schedule factor.

3. Preliminary analysis indicates that correlations can be developed from which to generate quantitative HVAC systems performance criteria for use in the new standard.

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