ENVELOPE DESIGN IMPLICATIONS OF ASHRAE STANDARD 90.1P: A CASE STUDY VIEW

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ABSTRACT

ASHRAE issued a first public-review draft of Standard 90.1P, Energy Efficient Design of New Non-Residential Buildings and High-Rise Residential Buildings in July 1985. A second public-review draft is scheduled to be issued in mid-1986. Standard 90.1P is substantially different in structure and content from the existing Standard, especially in those sections dealing with the building envelope. In this paper, the envelope compliance procedure in Standard 90.1P is examined and an example building, modified for two different climates, is used to illustrate the impact of the proposed standard.

INTRODUCTION

The envelope requirements of proposed ASHRAE Standard 90.1P constitute a substantial departure in structure and content from previous versions of Standard 90. The proposed Standard deals with a number of building attributes that were previously not considered and thus requires additional inputs to describe a proposed design. The procedure for compliance analyses used in the Standard recognizes that building envelopes can interact with internal loads in a complex manner. In 90.1P, electric lighting and other internal loads, thermal mass, automatic daylighting controls, solar loads, glazing characteristics and orientation, and exterior shading are all taken into account in determining envelope compliance.

BACKGROUND

In 1982 a research project was initiated to develop recommendations for updating ANSI/ASHRAE/IES Standard 90A-1980. The project, supported by the U.S. Department of Energy (DOE), came to be known as SP41 (ASHRAE Special Project 41). The project was managed by Pacific Northwest Laboratory (PNL) in cooperation with ASHRAE, with research performed by PNL, Lawrence Berkeley Laboratory (LBL), the National Bureau of Standards (NBS), and a number of engineering and architectural firms from across the country.

Energy simulations of test modules representing more than 2000 different combinations of envelope characteristics, internal load ranges, and climatic conditions were performed at LBL using DOE-2.1B.[1] Multiple regression analysis, performed on the resulting heating and cooling coil loads, was used to develop simple algebraic expressions that describe the effect of envelope, internal-load, and climate parameters. These expressions form a simplified model of building heating and cooling loads in perimeter zones, and this model has become the basis for the envelope compliance methodology.

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1 Sullivan, R.; Nozaki, S.; Johnson, R.; and Selkowitz, S. 1985. "Commercial Building Energy Performance Analysis Using Multiple Regression." ASHRAE Transactions 1985, V.91, Pt.2.

As part of the SP41 research, testing was performed on the recommended changes to the Standard. Simulations were performed on ten different test buildings in 8 locations using DOE-2.1B in order to determine energy and cost impacts. [2] In 1984, ASHRAE organized the Special Standing Project Committee 90R (SSPC 90R) to revise and update Standard 90 using the SP41 Recommendations as a starting point. In the spring of 1985, PNL conducted additional limited testing on the draft Standard 90.1P in support of the SSPC 90R's development work using five of the existing test buildings in six different climates. The case study presented in this paper has been drawn from this latest testing.

THE ENVELOPE COMPLIANCE METHODOLOGY

The proposed Standard establishes three different compliance paths for building envelopes: prescriptive, systems performance, and building energy. The prescriptive path uses tables of acceptable component packages (ACP's), which are combinations of building and envelope characteristics that are in compliance. The system performance path requires the user to input certain building descriptors into a mathematical model of building energy loads in order to demonstrate that acceptable levels of building loads will result. The building energy path requires computer simulations of both the proposed design and a similar design modified to comply with one of the other compliance paths.

The systems performance path forms the basis for the other two paths and is the primary focus of this paper. Of the three compliance paths, the building energy path provides the greatest flexibility. The system performance path offers a high degree of flexibility, however, the designer must deal with an interactive model in order to determine compliance.

The regression model developed by SP41 and later refined by SSPC 90R was used in defining required performance levels, called heating and cooling criteria, and is also used to determine compliance. The heating and cooling criteria are measures of annual cumulative space conditioning loads derived from DOE-2 simulations of perimeter zones in a simplified building with a specific size and configuration. For purposes of using the Standard, the criteria should be thought of as dimensionless measures of acceptable annual cumulative building heating and cooling loads.

In order to comply, the calculated heating and cooling loads that are both heated and cooled must be less than or equal to the sum of the heating and cooling criteria. This allows flexibility in tradeoffs between heating and cooling loads to meet specific project goals. Buildings that are heated only or cooled only must meet the single criterion.

In previous versions of Standard 90, the designer could determine envelope compliance without regard to the power level of electric lighting and other internal loads. In Standard 90.1P, in addition to climate parameters, internal load levels (W/ft^2 of lighting and equipment) define the required performance levels for a given building and location.

Figures 1 and 2 illustrate the heating and cooling criteria for a range of building internal loads under the system performance path. The five vertical bars correspond with the levels of internal loads (electric lights plus zone equipment) that were used for the five test buildings. The lowest internal load levels were for the apartment building and for the warehouse. Progressively higher levels were used for the medium-sized office building, the branch bank, and the anchor retail store test buildings. Internal load level is the basis by which the proposed envelope compliance procedure differentiates between building types.

Heating and cooling criteria are adjusted for internal loads up to 2.5 W/ft^2 (27 W/m^2), above which the criteria become fixed. This cap on the adjustment for internal loads was imposed by the SSPC 90R to ensure that buildings with high internal loads effectively control energy consumption. Points of inflection at 2.5 W/ft^2 (27 W/m^2) are seen in subsequent graphs as a result of this feature of the criteria.

The envelope compliance procedure constrains space conditioning loads to levels considered appropriate by the SSPC 90R for the given climate and building internal load. By comparing Figures 1 and 2, the impact of climate variation on the heating and cooling criteria can be seen. Houston and Milwaukee were the hottest and coldest climates, respectively, that were tested.

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2 Jones, J.W. 1983. "Special Project 41: Development of Recommendations to Upgrade ASHRAE Standard 90A-1980, 'Energy Conservation in New Building Design'". ASHRAE Journal, October, pp.30-36.

DESIGN IMPLICATIONS

In order to illustrate the nature of the envelope compliance procedure, and its impact on the design of actual buildings, a series of design tradeoffs have been examined. Pairs of important design parameters were simultaneously adjusted for the branch bank test building. One parameter was adjusted across the range of possible values, while solving for the value of the other parameter that yields minimal compliance with 90.1P. This approach was felt to be the most illuminating, given the inherent difficult in illustrating the behavior of an interdependent model. The building was modified for both Houston and Milwaukee to illustrate the role that climate plays in these tradeoffs.

The branch bank building (Figure 3) has a floor area of 2500 ft^2 and is used for typical banking and office functions by its 19 occupants. The building is single story with a floor-to-roof height of 16 feet. Its construction is slab-on-grade with brick veneer on wood frame walls. Square in plan, the bank has large north and south-facing glass areas that are partially shaded by roof overhangs. The average power density is 2.2 W/ft^2 (23.8 W/m^2) for lighting and 0.5 W/ft^2 (5.4 W/m^2) for zone equipment, giving the building relatively high internal loads.

Table 1 summarizes the building configuration. The characteristics shown in this table are required inputs for determining compliance using the system performance path. Table 2 shows the building assemblies that were used in the testing work to define minimally compliant configurations for the two locations. Because the system performance path is performance based, there are a large number of different minimally compliant configurations that could have been used to test the Proposed Standard. Configurations complying with Standard 90A-1980, which were used in previous testing, have been included for purposes of comparison.

Figures 4 and 5 illustrate the maximum window-wall ratio that would result in compliance for a range of levels of internal loads (lights plus zone equipment). This has been done by increasing the window-wall ratio by the same percentage for each orientation, while leaving all other parameters unchanged. The configuration that was used in the testing work is shown on each graph. The graphs illustrate some of the alternatives that a designer could consider in designing the bank to minimum compliance with 90.1P. Such a graph can not be developed without using a specific building configuration as the basis, due to the interaction between variables in the regression model on which the procedure is based.

Note that in the hot climate, where the dominant load is cooling, less glass is permitted as internal loads increase, while in the cold climate, where significant excess heat is lost through the glazing, more glass is permitted as internal loads increase. This suggests that if a highly glazed exterior is desired in a hot climate, low shading coefficient, low internal loads or some combination will be necessary in order to comply. In northern climates, high window-wall ratios may be restricted to building types having sufficient excess heat to offset the loss. These comparisons, and others that will follow, were conducted under the assumption that no interior shading was present. The impact of this strategy is examined later in a set of comparisons.

These two graphs, as well as the others in this paper, are based on the different building assemblies that were selected for compliance in the two locations (see Table 2). Therefore, comparisons cannot be made between the two graphs on an absolute-number basis. In addition, each graph or set of graphs has been defined based on a specific building configuration. Thus, caution must be exercised to avoid overly broad interpretations of the results.

Figure 6 illustrates the maximum wall U-values for Houston and Milwaukee that result in compliance for a range of different window-wall ratios, assuming the test configurations listed in Table 2. U-values for low-mass walls (walls having heat capacities lower than 10 $Btu/ft^2 \cdot °F$ (204.4 $KJ/m^2 \cdot °C$)) are constrained in the proposed Standard by a minimum U-value that varies with climate. The walls in the bank exceed the minimum heat capacity requirement and not constrained by this requirement.

As would be expected, the results are very different for the two climates. Relatively high conductances can be used in each location, but only if compensated for by additional changes, such as reduced glazing area. The design tradeoffs necessary to bring a building with high conductance walls into compliance in a cold climate would be very restricting. These tradeoffs might be acceptable in a building type where windows are not required, such as a warehouse. In either climate, only modest flexibility for increased window-wall ratio can be gained by increasing the wall thermal resistance beyond standard practice levels.

Figure 7 illustrates the maximum window-wall ratios that would result in compliance using the full range of shading coefficients available with reflective glazing. Single reflective was used in Houston, and double reflective was used in Milwaukee. Examination of product literature from several manufacturers has revealed that the performance characteristics within each glass type are quite similar and that within specific limits a nearly continuous range of shading coefficients are available.

The line for Milwaukee is to the left of the line for Houston, and has a significantly steeper slope. In hot climates reflective glazing is sufficiently effective in reducing loads to permit the use of high window-wall ratios. Reflective glazing is far less effective in allowing high window-wall ratios in cold climates, and by extension from the previous set of graphs, this is particularly true for buildings in cold climates with low levels of internal loads. Standard 90.1P will constrain large glass areas more in cold climates than in hot, even when additional glazing layers are considered. In cold climates for buildings with relatively high internal loads, lower shading coefficients permit marginally more glass to be used, but designers will probably find that this is not a highly productive tradeoff.

Figures 8 and 9 illustrate the same relationship as in Figure 7, although in this case, automatic daylighting controls and several different types of glazing have been used. For Houston the graphs have been generated using single reflective, single tinted, and double tinted glazing, while in Milwaukee double reflective, double tinted, and high-performance (low emissivity) glazing were used.

The daylighting provisions in the envelope compliance procedure are intended to offer sufficient flexibility in the design of fenestration (window-wall ratios, interior shading, fixed overhangs and glass shading coefficients) to permit effective daylighting solutions. Note that in this example, a satisfactory daylighting solution was not possible for the configuration as tested in Houston without the use of double glazing; single tinted fell just short of compliance and the use of reflective glazing would have decreased visible transmittance by 35% from the glazing selected, significantly diminishing the benefits of daylighting.

A comparison of Figures 8 and 9 to Figure 7 reveals that the addition of automatic daylighting controls permit more glass and higher shading coefficients, although the allowance has a greater impact in Houston than in Milwaukee. The addition of a glazing layer permits shading coefficient to be raised and window area to be increased, both generally beneficial for daylighting. This effect is modest in the case of Houston for double glazing but quite dramatic for Milwaukee and high-performance glazing.

The motivation for pursuing daylighting strategies normally will not stem from the need to comply with the standard, but rather will grow from a more basic design or client goal. The relevant question then becomes how is this design goal constrained by the proposed Standard. The graphs suggest that sufficient glass area and adequate shading coefficients is permitted to allow effective daylighting solutions. The automatic daylighting control allowance permits the use of moderately higher shading coefficients necessary for letting light into the building, which in a similar non-daylit building would likely contribute to excessive cooling loads.

In Figures 10 and 11, tradeoffs between permitted window-wall ratios and glass shading coefficients are shown for the bank with interior shading devices in Houston and Milwaukee. These graphs illustrate the importance of interior shading devices relative to other design tradeoffs a designer would encounter for glazing and interior shading devices. In this case, unshaded windows with single tinted glazing in Houston and double tinted glazing in Milwaukee are compared with the same glazing with light venetian blinds and light roller shades. As is clear from the graphs, the compliance procedure offers considerably increased flexibility for designs that employ these devices in hot climates. Many building types, such as office buildings, routinely use these devices while others, such as warehouses rarely do. These differences need to be kept in mind when assessing the implications of 90.1P for the design of different building types in different locations.

CONCLUSION

Standard 90.1P will undergo at least one more revision as a result of comments received during the public review period that ended in October 1985. It appears highly probable that, while equations will be modified, the nature and structure of the envelope compliance procedure will remain unchanged. The use of Standard 90.1P, when adopted, will require modest changes in both buildings and designers. Following are several key attributes of the envelope compliance procedure for Standard 90.1P as established through detailed assessment of its impacts.

- **RESPONSIVENESS** Each building will be treated individually based upon its unique combination of envelope characteristics and internal loads. While Standard 90 has always accounted for climate in its building envelope requirements, the extent of climate responsiveness has been substantially expanded in 90.1P. Buildings that under previous versions of Standard 90 were required to conform to identical envelope thermal requirements will be constrained in different ways depending on climate and internal loads. More regional variation may be observed in the buildings that result.

- **PASSIVE BUILDING FEATURES** Standard 90.1P accounts for a number of building features, including thermal mass, fixed overhangs, and daylighting that have been advanced by proponents of climate-responsive and passive solar design. These features have been implemented conservatively in 90.1P. Acknowledgement of the contribution of these building features should encourage their use on a more routine basis by a wider community.

- **FLEXIBILITY** While testing has indicated that 90.1P is somewhat more stringent in terms of energy performance than 90A-1980, designers are likely to find a wider range of design solutions complying under 90.1P. This has been the rationale behind development of the performance-oriented approaches in 90.1P.

- **COMPLIANCE PROCESS** Designers may find it particularly advantageous to perform a compliance check early in the design process. They are likely to find that using the procedure is a highly instructive process that is most valuable early in the schematic design process. It is dangerous to make an isolated envelope decisions based on prior experience with the Standard without having examined the decision in light of its interaction with other building characteristics.

  It is expected that most users will use a personal computer to conduct the compliance check. With this approach, the time required to check compliance is no longer than that required for Standard 90A-1980. The procedure is lengthy if performed by hand.

  The envelope section of 90.1P gives indication of being an accurate and flexible procedure that is based on an up-to-date understanding of how buildings use energy.

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TABLE 1

Building Configuration

All Locations	North	South	East	West
Wall Orientation Factor	0.22	0.29	0.29	0.20
Window-Wall Ratio	0.58	0.60	0.05	0.20
Overhang Shading Factor	0.21	0.14	0.25	0.00
Heat Capacity of Walls	10.0	10.0	10.0	10.0

Average Power Density (W/ft^2)	90A-1980	90.1P
Electric Lighting	2.09	2.20
Zone Equipment	0.50	0.50

TABLE 2

Building Assemblies

Roof U-Value Btu/(h•ft^2•^{o}F) (W/(m^2•K))	90A-1980	90.1P	90.1P (Daylit)
Houston	0.062 (0.352)	0.093 (0.528)	0.093 (0.528)
Milwaukee	0.062 (0.352)	0.042 (0.239)	0.042 (0.239)

Opaque Wall U-Value Btu/(h•ft^2•^{o}F) (W/m^2•K)	90A-1980	90.1P	90.1P (Daylit)
Houston	0.403 (2.289)	0.296 (1.681)	0.296 (1.681)
Milwaukee	0.227 (1.289)	0.111 (0.630)	0.111 (0.630)

Glazing Characteristics		90A-1980	90.1P	90.1P (Daylit)
Houston	Panes	1	1	2
	Shading Coefficient	0.69	0.46	0.73
	Visible Transmission	0.50	0.30	0.76
Milwaukee	Panes	2	2	3
	Shading Coefficient	0.81	0.35	0.66
	Visible Transmission	0.80	0.27	0.69

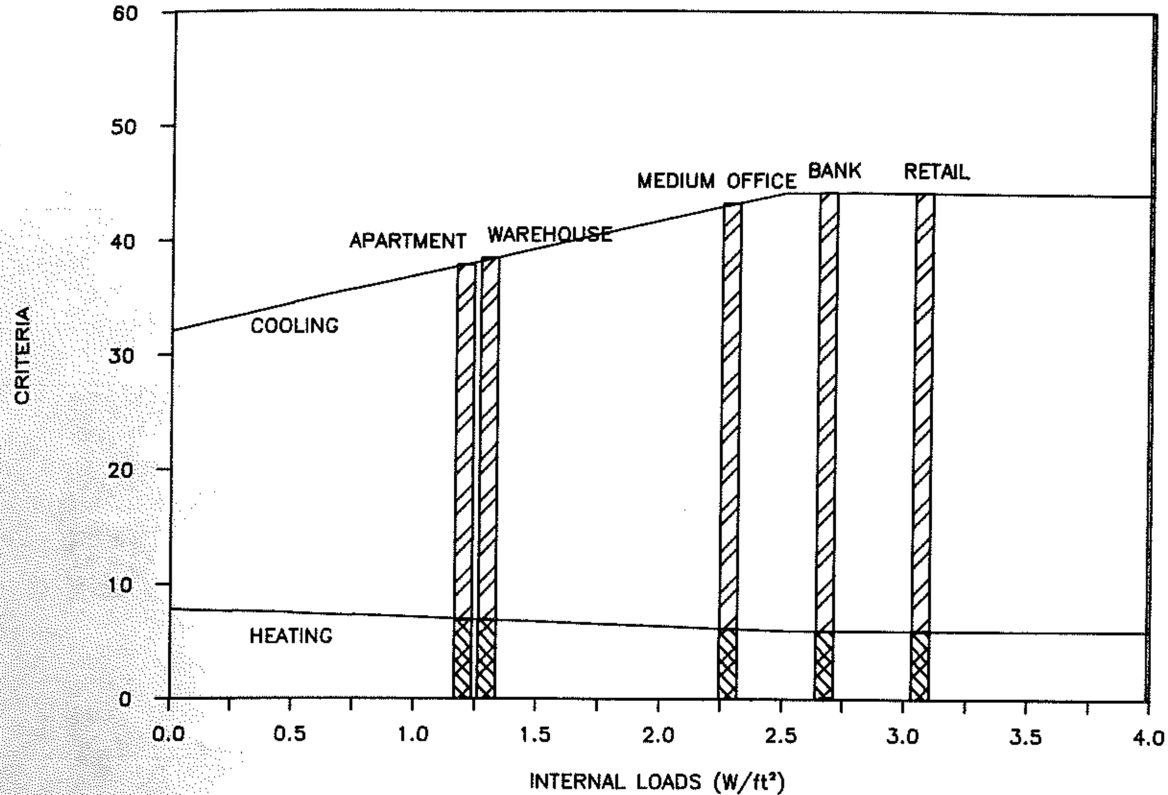

Figure 1. Heating and cooling criteria vs. internal loads for buildings in Houston

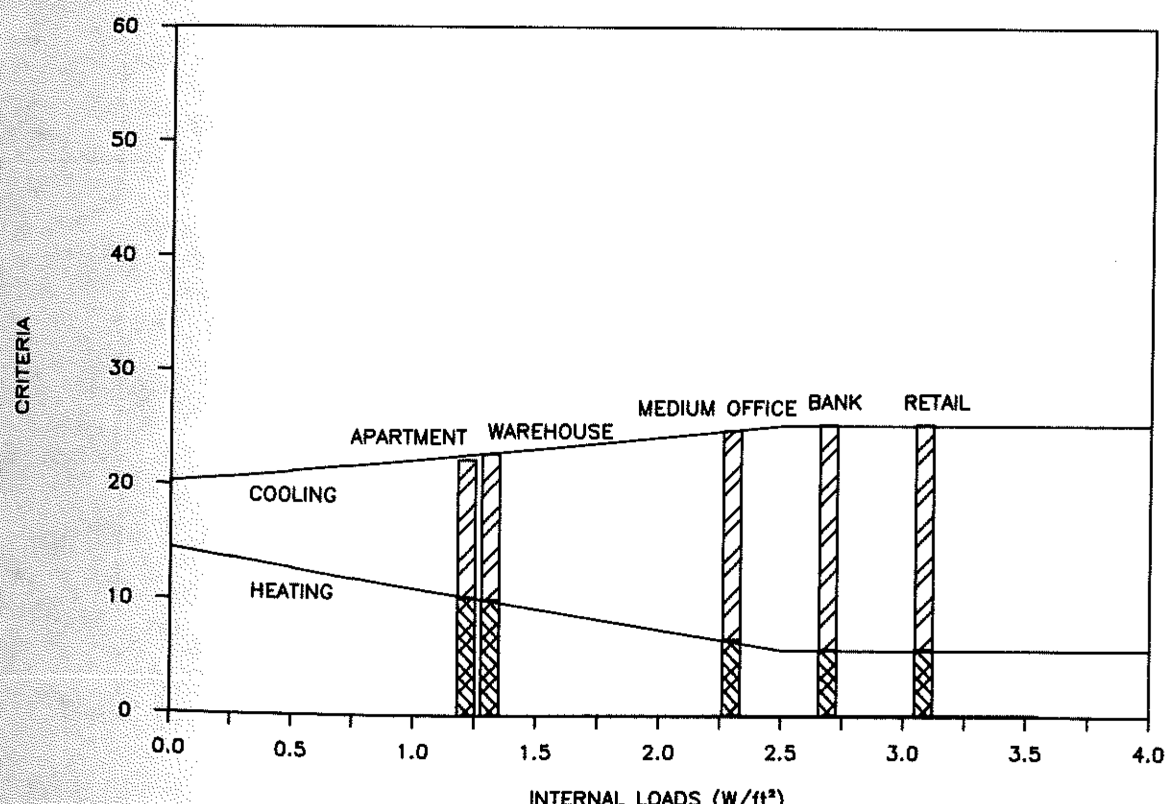

Figure 2. Heating and cooling criteria vs. internal loads for building in Milwaukee

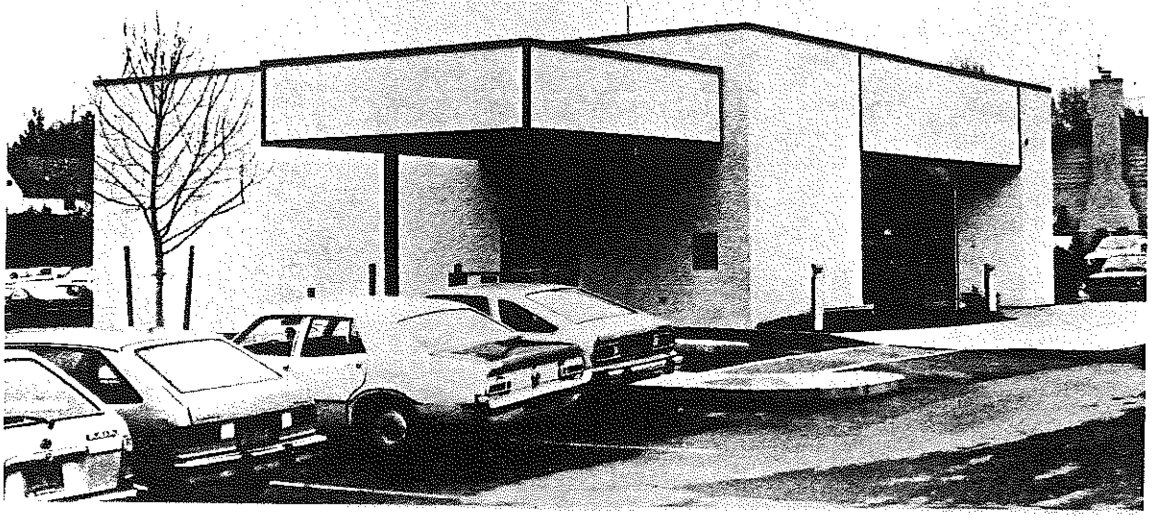

Figure 3. Branch bank

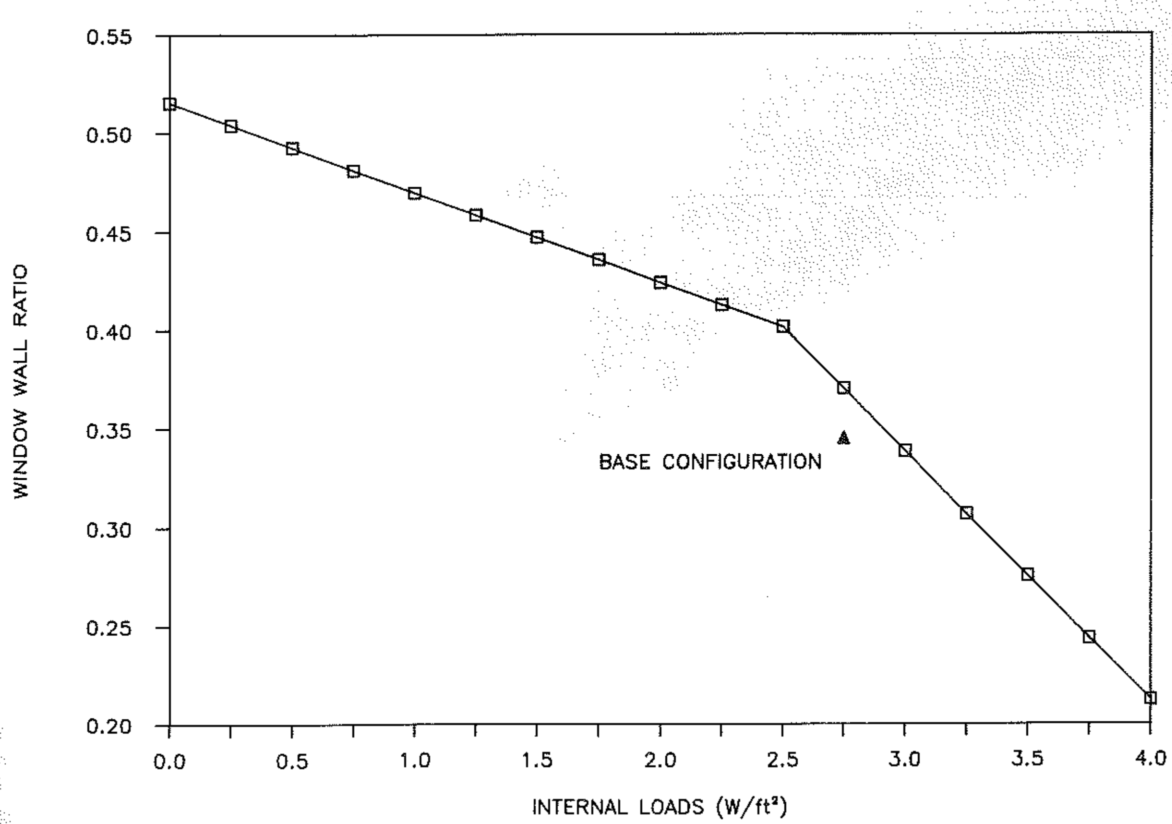

Figure 4. Window-wall ratio vs. internal loads for branch bank in Houston

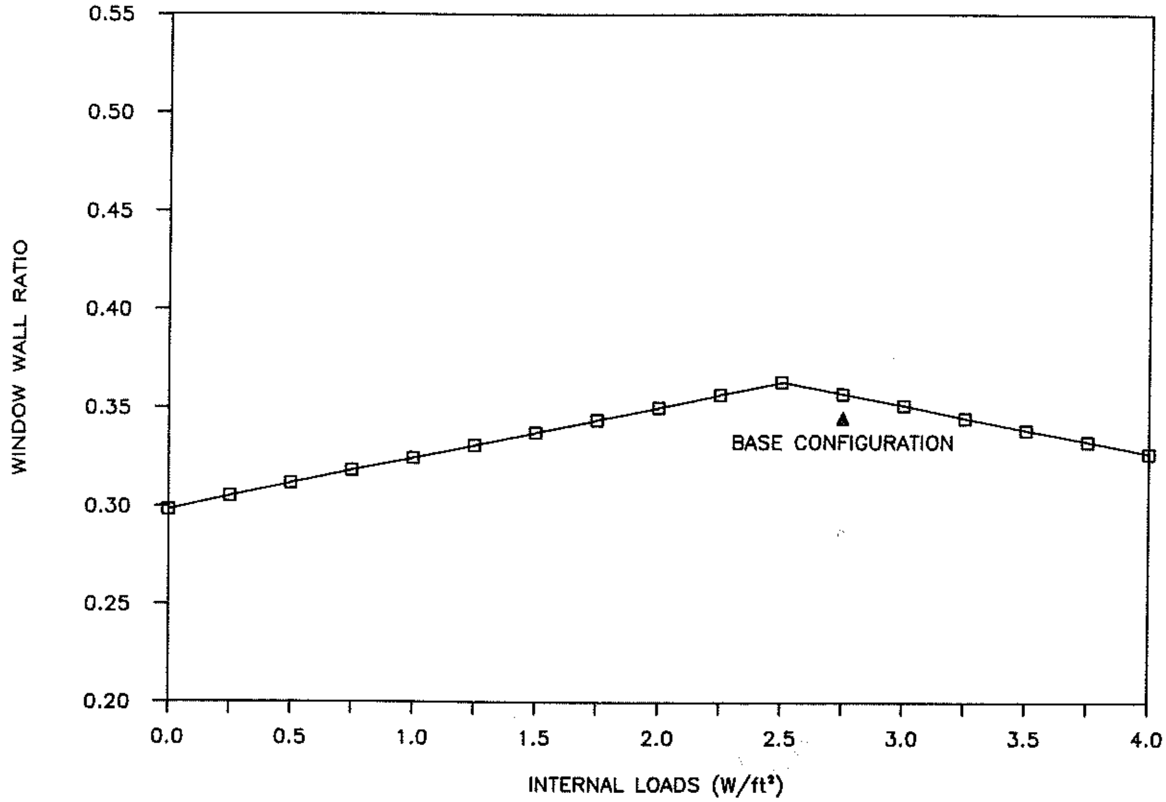

Figure 5. Window-wall ratio vs. internal loads for branch bank in Milwaukee

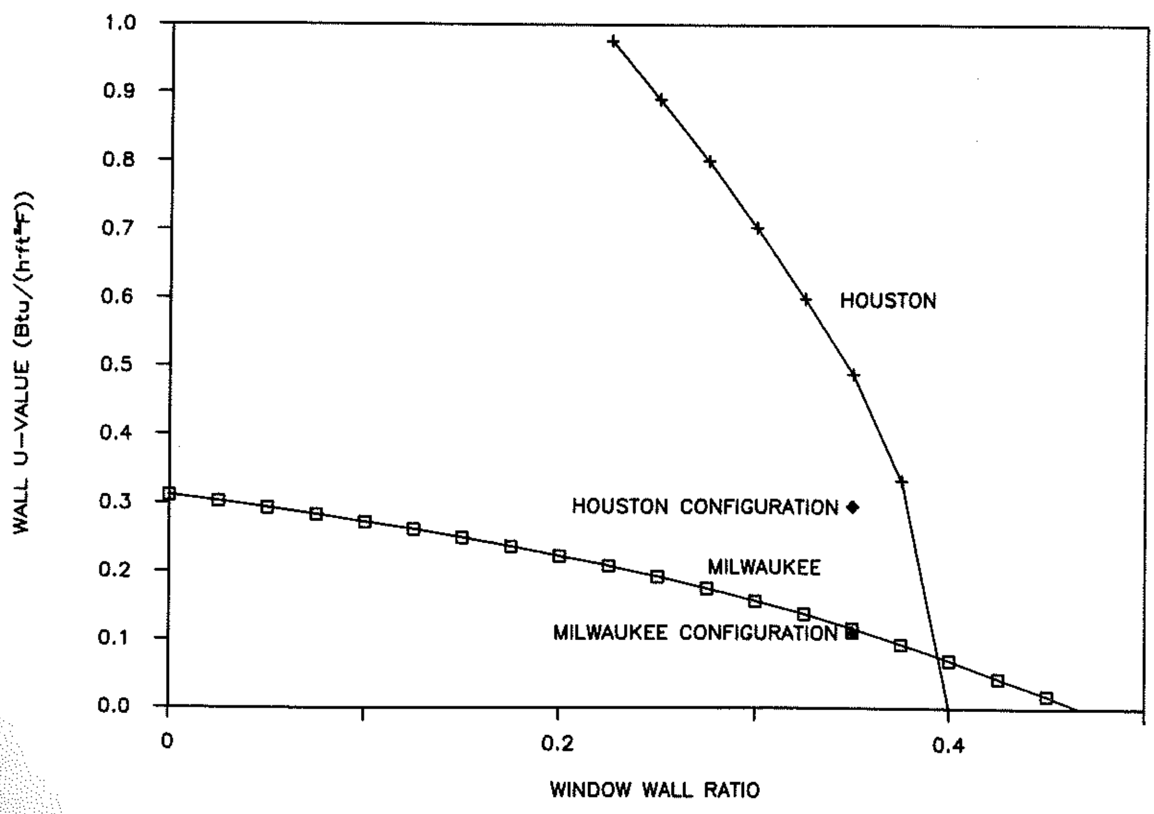

Figure 6. Exterior wall U-value vs. window-wall ratio

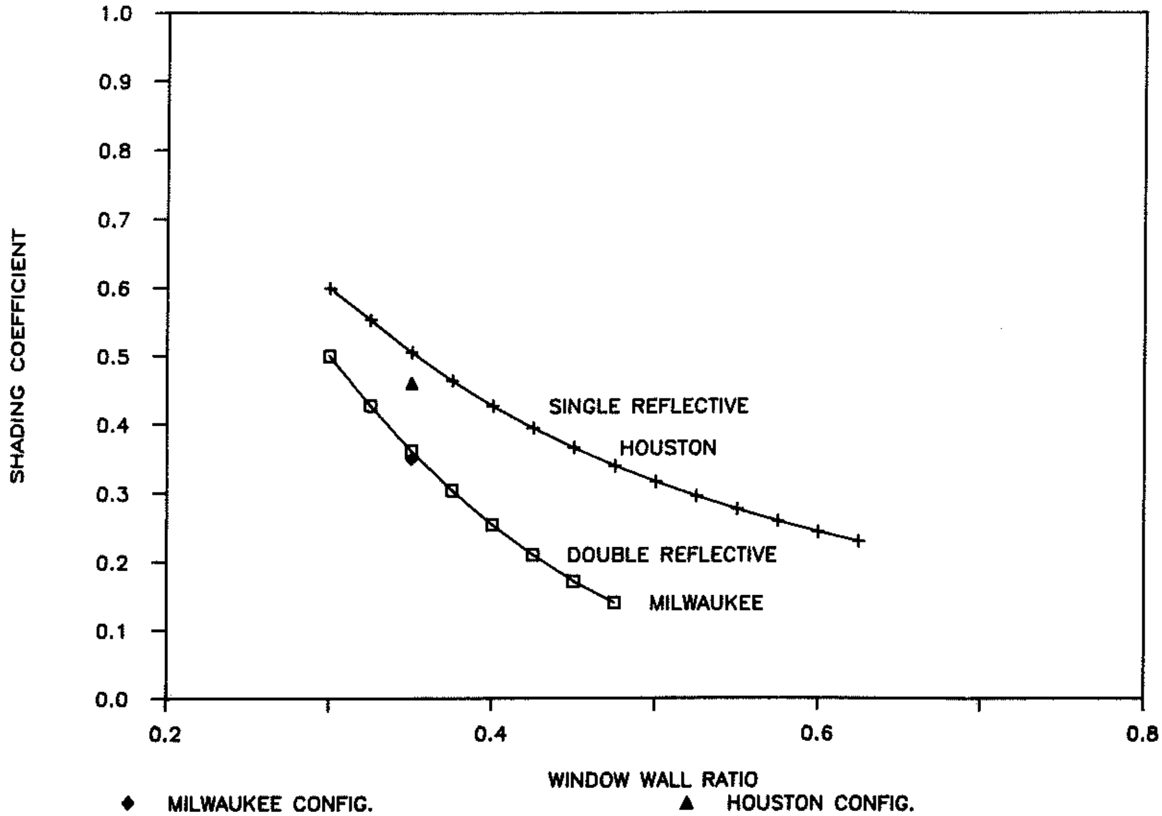

Figure 7. Glazing shading coefficient vs. window-wall ratio

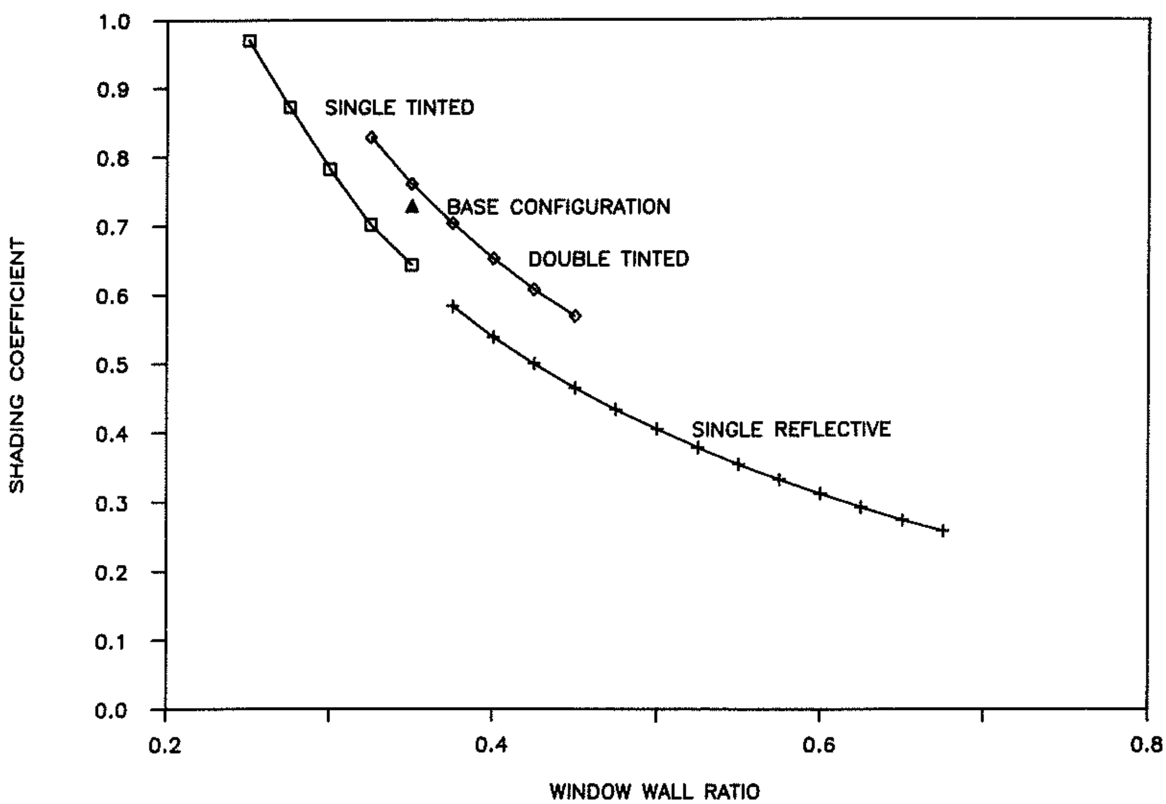

Figure 8. Glazing shading coefficient vs. window-wall ratio in Houston

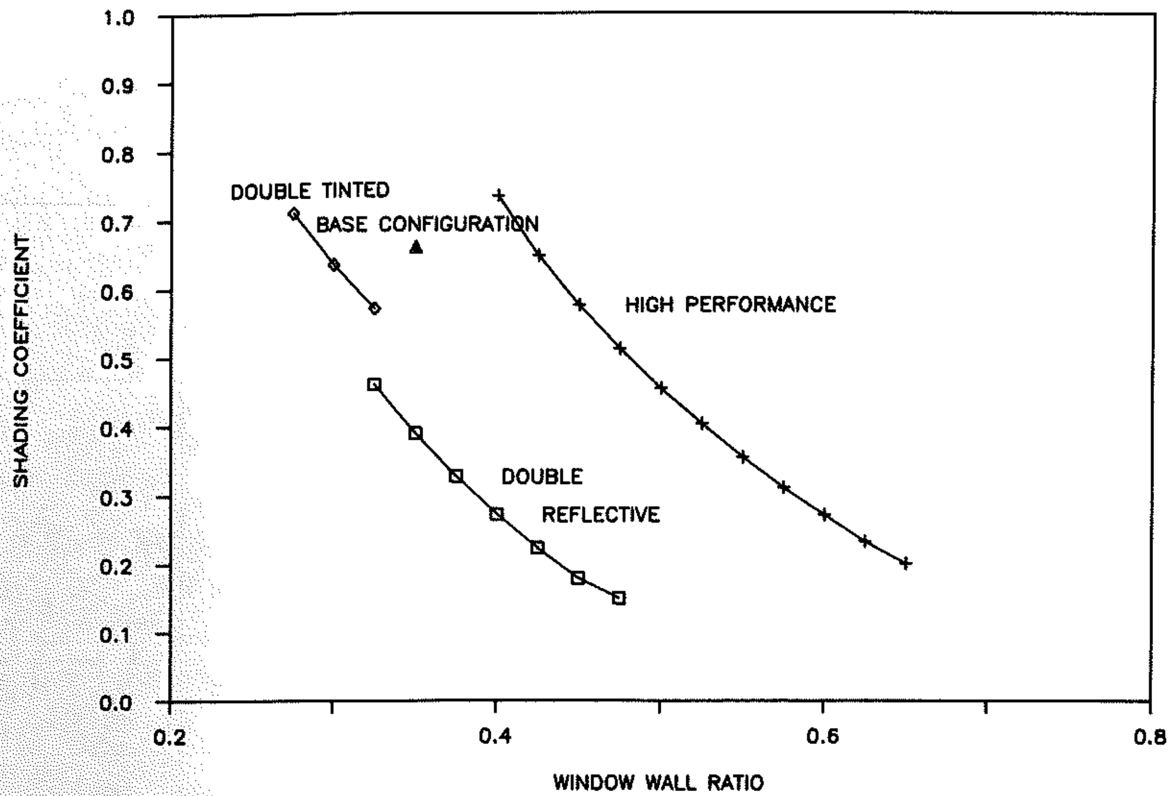

Figure 9. Glazing shading coefficient vs. window-wall ratio in Milwaukee

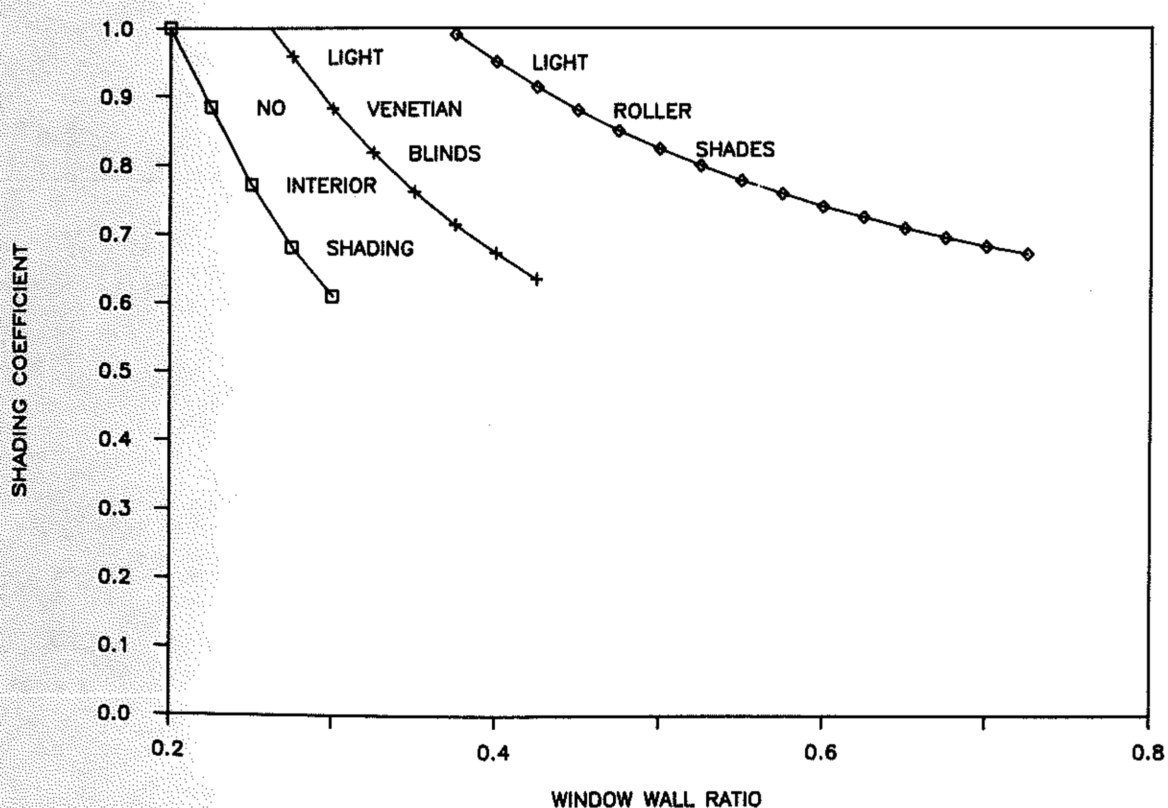

Figure 10. Glazing shading coefficient vs. window-wall ratio for internal shading devices in Houston

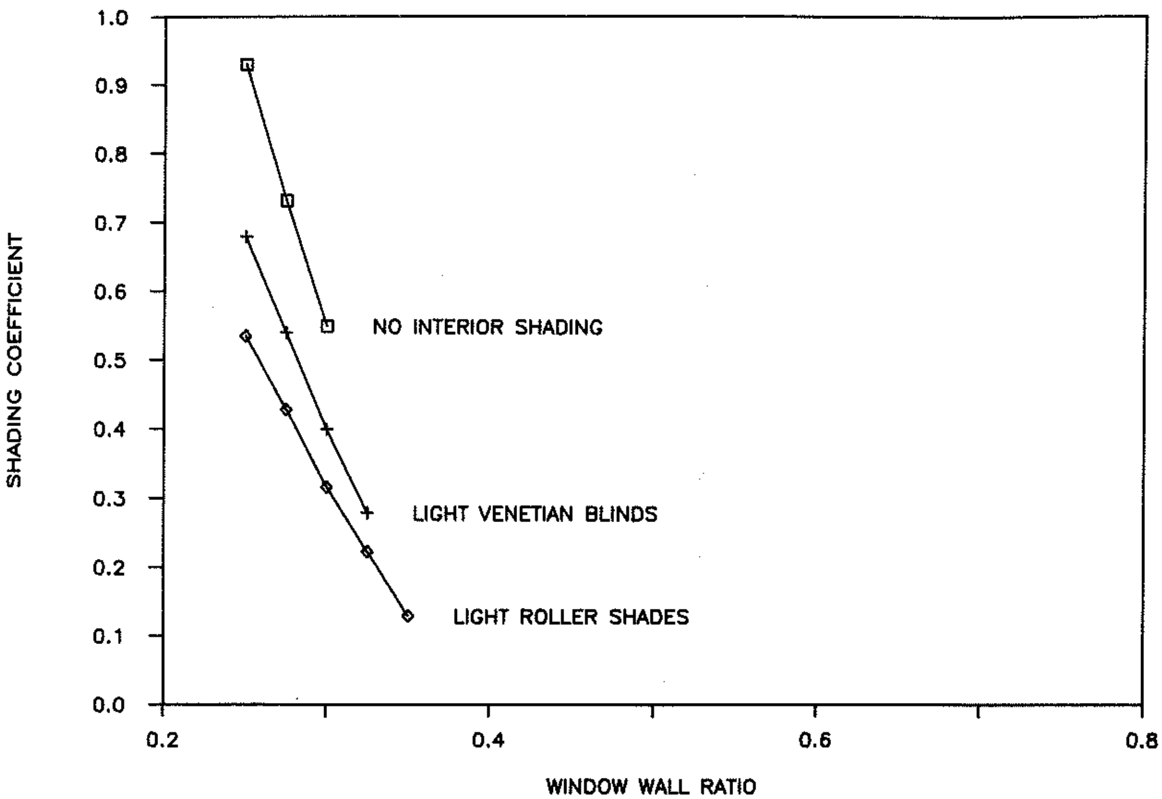

Figure 11. Glazing shading coefficient vs. window-wall ratio for internal shading devices in Milwaukee