An Automated Tool for Evaluating Compliance and Providing Assistance with Building Energy Standards During Design

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Abstract

In an effort to encourage the maximum cost-effective level of energy efficiency in new building design, energy-efficiency standards have become more location-specific and performance-based. As a result, standards often provide more than one path for ensuring and demonstrating that a design complies, but at the cost of increased complexity. In addition, the burden of remedying a noncompliant design rests on the designers' knowledge and experience, with only general guidance provided by the standards.

As part of efforts in the U.S. Department of Energy's (DOE's) Advanced Energy Design and Operation Technologies (AEDOT) project, a team at DOE's Pacific Northwest Laboratory is developing a computer program known as the Energy Standards Intelligent Design Tool (ES-IDT). The ES-IDT is one component of a prototype computer-based building design environment. It performs automatic compliance checking for parts of *ASHRAE/IES Standard 90.1-1989* and provides designers assistance in bringing noncomplying designs into compliance. This paper describes the ES-IDT, the functions it provides, and how it is integrated into the design process via the AEDOT prototype building design environment.

Introduction

The energy consumption of commercial buildings far exceeds the level possible using energy-conscious design and currently available, cost-effective technologies. Studies conducted in the 1980s [Stoops 84] [Deringer 82] [NAHB 87] involving the redesign of existing buildings showed that energy savings of 30% to 60% were readily achievable. In an attempt to encourage the maximum cost-effective level of energy efficiency in new buildings and capture these potential savings, existing energy-efficiency standards have become more stringent.

To tighten requirements to increase energy efficiency, while ensuring that these requirements are reasonable and cost-effective, standard-setting bodies have made energy standards more climate-responsive and more location-specific. In some cases, they have provided more than one compliance procedure. Standards are becoming increasingly performance-based to give designers flexibility in satisfying energy requirements and to encourage innovation. Designs are no longer constrained by specific prescriptive requirements; compliance with energy standards can be achieved by many different designs that satisfy a specified energy performance level.

ASHRAE/IES Standard 90.1-1989 [ASHRAE 89], set by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. and the Illuminating Engineering Society, is a prime example of such a standard. It provides two primary paths for compliance: a system/component method and a building energy cost budget method. While the system/component method is largely prescriptive, it is complicated by dual paths for evaluating lighting and building envelope compliance. The building energy cost budget method is a performance-based compliance approach that provides designers greater flexibility in satisfying the requirements of the standard. In both cases, the standard provides location-specific requirements. For example, for wall and fenestration requirements, the standard includes tables of alternative component packages for 38 different climate types. The net result is a more responsive standard, but one that is rather complex.

Energy-efficiency standards provide benchmarks against which designers can evaluate their designs; however, compliance checking is often tedious. When a design does not comply, the burden of selecting appropriate changes to bring it into compliance falls entirely on the designer, as current standards fail to provide project-specific recommendations for improving energy-inefficient designs. New computer-based methods, however, provide opportunities to lift some of this burden, freeing designers to concentrate on the more creative aspects of building design.

Automated Compliance Evaluation

One such computer-based tool, called the Energy Standards Intelligent Design Tool (ES-IDT), has been developed at the U.S. Department of Energy's Pacific Northwest Laboratory. This tool automatically evaluates a building design for compliance with sections of *ASHRAE/IES Standard 90.1-1989* (Standard 90.1). At present, the ES-IDT is not intended to provide a complete evaluation, but is simply a prototype that demonstrates some of the advanced capabilities that will appear in automated energy and design tools of the future. Although subsequent versions of this tool may provide more comprehensive coverage of Standard 90.1, the current ES-IDT focuses on only two of its eight compliance categories. These categories include electric power, lighting, other systems/equipment, envelope, HVAC system, HVAC equipment, service water heating, and energy management. The ES-IDT evaluates two of these, lighting and envelope. Specifically, compliance evaluation is performed for the following areas: lighting power, lighting controls, fluorescent light ballasts, and fenestration.

Lighting Power

To achieve compliance with Standard 90.1, the total connected lighting power (CLP) for all of the enclosed (interior) spaces of the building must be less than the interior lighting power allowance (ILPA). The CLP is usually calculated by summing the rated power (in watts) of all luminaires in the building, although Standard 90.1 permits significant credits if automatic lighting control devices are used. For example, if the total lighting power for 10 office spaces is 2000 W, the CLP can be reduced to 1700 W if occupancy-sensing control devices are used in those spaces. Credits can range from 10% to 40%, depending on the type of automatic control used.[1]

The ILPA can be determined by two methods: the prescriptive method or the system performance method. In the prescriptive method, the ILPA is the product of the unit lighting power allowance

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[1] Table 6-3 of Standard 90.1 lists various automatic control devices and their associated power adjustment factors.

(ULPA) and the gross lighted area (GLA). The ULPA depends on the building type and gross floor area, and generally ranges from 0.2 to 3.3 watts per square foot.[2]

$$\mathrm{ILPA} = \mathrm{ULPA} \times \mathrm{GLA} \tag{1}$$

In the system performance method, the ILPA is the sum of the lighting power budgets (LPBs) for each of the building spaces.

$$\mathrm{ILPA} = \sum_{i=1}^{n} \mathrm{LPB}_i \tag{2}$$

where n = number of spaces in the building.

The LPB for each space is determined by

$$\mathrm{LPB}_i = A_i \times \mathrm{UPD}_i \times \mathrm{AF}_i \tag{3}$$

where A_i is the area of space i, UPD_i is the unit power density for space i, and AF_i is space i's area factor. The UPD varies with the activities planned for the space. At one extreme, the UPD for garage parking is 0.2 W/ft^2, while merchandise areas in retail establishments, at the other extreme, have a UPD of 5.6 W/ft^2. The area factor permits a higher LPB for spaces that have unusually high ceilings. AF is normally close to 1.0, but can reach 1.8 or more for small spaces that have ceiling heights greater than 25 feet.[3]

In general, the prescriptive method is used to determine the ILPA for building designs in which less than 80% of the spaces have been defined. It provides a means for estimating the lighting power allowance while still in the conceptual design stages. At later stages in the design process, when most if not all of the spaces and activities are defined, the system performance method is preferred. Regardless of the current state of design, however, compliance is achieved so long as the building's CLP is less than *either* the prescriptive-based ILPA *or* the system performance-based ILPA.

The ES-IDT automatically calculates the building design's CLP and its ILPA using both the prescriptive and system-performance methods. The CLP is determined by adding the wattage of all luminaires that appear in the building floor plan; the ILPA is calculated from equations (1) and (2). A comparison of these two numbers immediately indicates whether the design complies with respect to lighting power.

Lighting Controls

Standard 90.1 requires that "each space enclosed by walls or ceiling-height partitions shall be provided with controls that, together or singly, are capable of turning off all the lights within that

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[2] The prescriptive unit lighting power allowance (ULPA) for various building types can be found in Table 6-5 of Standard 90.1. Values for ULPAs are given in W/ft^2.

[3] The area factor can be determined from either Figure 6-1 of Standard 90.1 or from

$$\mathrm{AF} = 0.2 + 0.8(1.0 / 0.9^n)$$

where $n = \{[10.21(\text{Ceiling Height} - 2.5)]/(\text{Room Area})^{0.5}\} - 1.0$

space." Furthermore, it prescribes a minimum number of lighting controls, depending on the number of task locations, the use of automatic controls, and the total lighting power of the luminaires used in the space. The conditions for determining the minimum number of controls can be paraphrased as follows:[4]

1. Each space has 1+N "control points," where N = the number of task locations in the space.
2. The space must have a control for every control point, unless automatic controls are used, in which case the automatic control can be applied to two or possibly three control points.
3. The minimum number of controls shall not be less than one for each 1500 W of connected lighting power in the space, regardless of the number of controls determined by Condition 2.

Given a space in the building floor plan, the ES-IDT automatically determines the minimum number of controls required by that space and checks if the designer has specified a sufficient number of controls to meet this requirement. The tool determines the number of control points, checks for automatic controls, and calculates the CLP by adding the wattage of all luminaires in the space. If the space fails to comply, the ES-IDT notifies the designer and provides an opportunity to correct the condition. The ES-IDT can also be set to an "automatic" mode, in which case the computer will automatically adjust the number of controls so that a noncomplying space satisfies the requirements of Standard 90.1.

Fluorescent Light Ballasts

If fluorescent lights are used in the building, their ballasts must meet or exceed the minimum ballast efficacy factor (BEF) specified in Standard 90.1. These minimums vary, depending on the size of the luminaire, the number of lamps, and the nominal power input.[5] The BEF is calculated by

`BEF = ballast factor/power input.` (4)

The ballast factor is associated with a specific manufacturer's ballast and, in this equation, is expressed as a percentage, where `0 < ballast factor < 100`. The power input refers to the total wattage of the fluorescent lamps serviced by the ballast.

The ES-IDT examines the fluorescent luminaires in each space to determine their ballast factors and power inputs. If the resultant BEF fails to meet the minimum efficacy factors prescribed by Standard 90.1, the tool notifies the designer of the noncomplying space.

Fenestration

Standard 90.1 places an upper limit on the permitted area of fenestration, relative to a building's overall exterior wall area. This limit is called the maximum allowable percent fenestration (MAPF) and is dependent on several parameters, including

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[4] A complete description of the requirements for compliance is given in Section 6.4.2 of Standard 90.1.

[5] The listing of fluorescent ballast efficacy factors (BEFs) is given in Table 6-4 of Standard 90.1.

1. *internal load density*, which is the sum of the lighting power density, the equipment power density, and the occupant load adjustment
2. *external shading projection factor*, which is the ratio of the projection depth to the projection height[6]
3. *shading coefficient* of the fenestration, including internal, integral, and external shading devices
4. the use of *perimeter daylighting*
5. *thermal transmittance* of the fenestration assembly.

The values of these parameters are used to find the appropriate MAPF in Standard 90.1's alternative component package (ACP) tables. There are 38 different ACP tables corresponding to climatic differences at various geographic locations. The manual calculations required to determine the MAPF can be time-consuming; fortunately, the ES-IDT performs them automatically. First, the ACP tables are automatically loaded into the ES-IDT during initialization. After calculating the values for the relevant parameters, the ES-IDT finds the MAPF using the appropriate ACP table. It then calculates the actual fenestration percentage and compares it to the MAPF to evaluate compliance with Standard 90.1. If the building fails to comply, the designer is notified of the situation.

So far, we have described no characteristic of the ES-IDT that is remarkable: the tool has only calculated the Standard-prescribed requirements and limits, and compared the actual conditions to the prescribed conditions. What distinguishes the ES-IDT from other computer-based compliance evaluation tools are two important features: its integration with the design process and its ability to offer design assistance.

Design Integration

Most computer-based energy tools appear as stand-alone software packages. To use them, a designer must first suspend other design activities, prepare a special data set for the software, execute the program, and receive the results. The degree to which these results impact the design is dependent on the designer's ability to interpret the data and apply knowledge to effect beneficial changes to the design. This exercise can be time-consuming and expensive. Unless a building owner has stipulated energy efficiency as a design directive, or codes require the use of such tools, architects and engineers generally ignore these software products.

In contrast, if energy tools were more closely integrated with the design process, and if they contained expertise that could assist the designer in making design decisions, they would more likely be used. This is precisely the goal of the U.S. Department of Energy's Advanced Energy Design and Operation Technologies (AEDOT) project. The project is intended to reduce the energy consumption of the U.S. building stock by placing advanced energy tools into the hands of architects, engineers, and operators [Brambley 91][Brambley 88].

The ES-IDT is one component of the first AEDOT prototype, which combines computer-aided drafting tools, databases, and other intelligent energy and design tools into an integrated system. The prototype is based on the *Intelligent Computer Aided Design System* (ICADS), which is a general design framework and a set of tools developed at the California Polytechnic State University [Pohl 88] [Pohl 89] [Pohl 91]. AEDOT Prototype 1 is nearing completion, and

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[6] The projection height is the sum of the height of the fenestration and the distance from the top of the fenestration to the bottom of the external shading projection.

contains tools produced by the Pacific Northwest Laboratory and other AEDOT collaborators: the California Polytechnic State University, the University of Oregon, and the Lawrence Berkeley Laboratory.

In AEDOT Prototype 1, energy tools such as the ES-IDT monitor the development of a building design as it is drawn on a computer-aided drafting system. Information about every wall, door, and window that is placed in the drawing is made available to any tool that has been "watching" the designer's progress. These tools process this information in the "background" and provide signals to the designer indicating their current status and recommendations. In some cases, the tools may make changes directly to the design during the course of their operation.

The ES-IDT, along with other tools in AEDOT Prototype 1, offers three important benefits of design integration:

1. The designer is not required to suspend design activities to execute the ES-IDT. The tool performs its function concurrently with other design activities.

2. The designer is not required to prepare input specifically for the ES-IDT. It extracts required information from the computer-aided drafting tool while the design is being developed.

3. The ES-IDT provides project-specific suggestions for remedying noncompliance with Standard 90.1. The tool offers an opportunity for the designer to act on these suggestions, or, in some cases, implements changes to the design automatically.

This third benefit leads to a second important feature of the ES-IDT: its ability to provide energy assistance during the design process. Tools within the AEDOT Prototype 1 contain knowledge of their domain as well as knowledge of the design process. The ES-IDT, for example, not only knows the requirements of Standard 90.1, but also knows how to effect changes to the design to meet those requirements.

Design Assistance

The ES-IDT operates concurrently with other design activities, monitoring the progress of the design and constantly evaluating the design for compliance with Standard 90.1. The results of its activity are simply stated by the color of the ES-IDT icon: green when the design complies or red when the design fails to comply.

The designer may continue regardless of the color of the icon. An experienced designer may understand the reasons for the noncompliance situation and know that the situation will "correct itself" as the design develops. An inexperienced designer may wish to find out exactly why the design is out of compliance and may "click" on the icon to obtain more information. This action will bring forward the Compliance Categories window, which lists the eight categories covered in Standard 90.1 (see Figure 1). Because the ES-IDT is intended as demonstration software, six of these eight categories shown in Figure 1 are inactive. The remaining two categories, Lighting and Envelope, will be displayed on the screen in red or green, indicating the compliance status of the design with respect to these two compliance categories. If the ES-IDT has not received sufficient information from the computer-aided drafting tool to determine compliance, then these categories will be displayed in gray, indicating an unknown compliance condition.

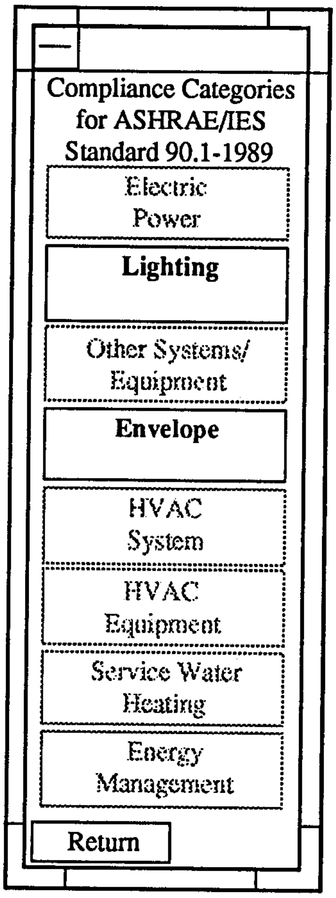
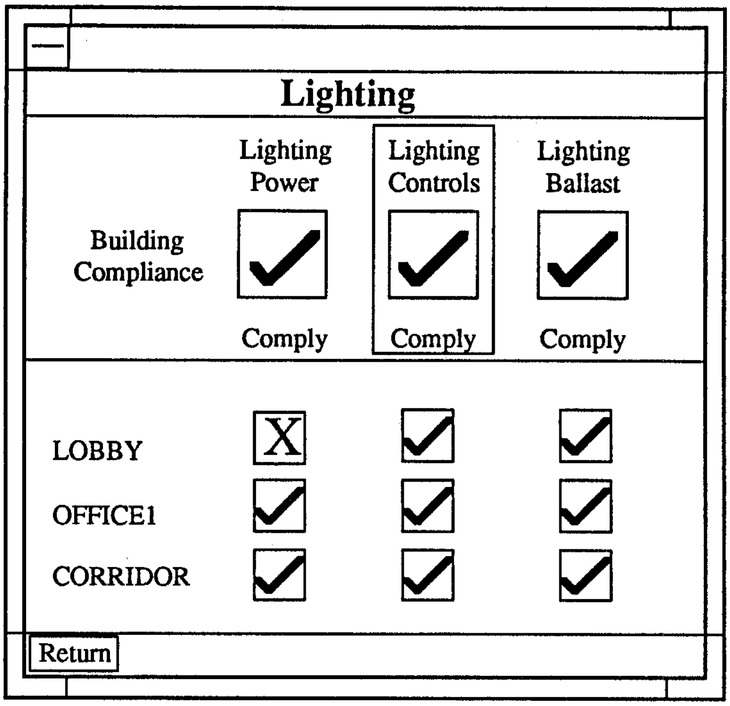


Figure 1. The Compliance Categories window will display the Lighting and Envelope categories in green or red, depending on their compliance or noncompliance status, respectively. The remaining six categories are currently inactive.

The Compliance Categories window immediately indicates whether compliance problems exist in the building's lighting subsystem, envelope subsystem, or both. The designer may click on either of these categories to get further information. In the case of lighting, the next window provides information about the building's compliance status with respect to the three lighting compliance subcategories: lighting power, lighting controls, and fluorescent ballasts (see Figure 2).

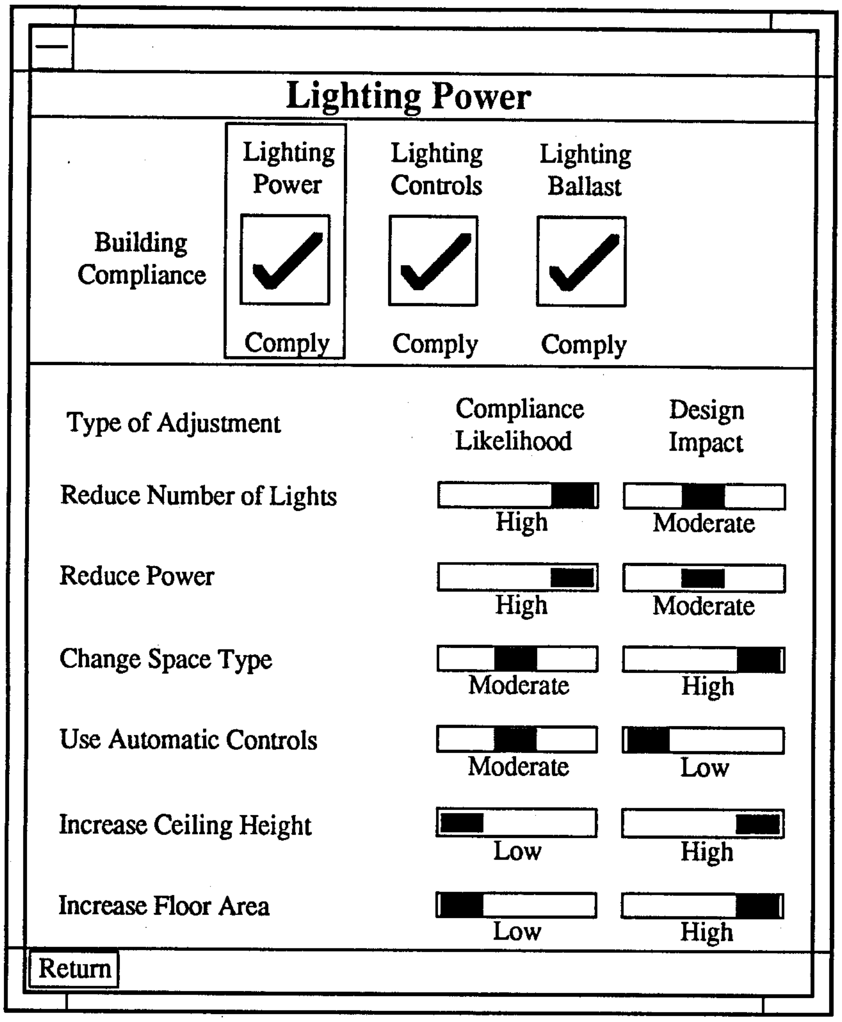


	Lighting Power	Lighting Controls	Lighting Ballast
Building Compliance	✓ Comply	✓ Comply	✓ Comply
LOBBY	☒	☑	☑
OFFICE1	☑	☑	☑
CORRIDOR	☑	☑	☑

Figure 2. The Lighting Compliance subcategory window indicates design compliance with respect to lighting power, lighting controls, and fluorescent ballasts.

At this level of detail, the ES-IDT not only indicates the categories for the overall building, but also shows how the individual spaces contribute to the compliance status. For example, notice that it is possible for a space to exceed its recommended power allowance while the building as a whole still complies.

Based on this information, the designer may proceed to a Remedies window to fix a noncompliance in one of the subcategories. If the designer clicked on the Lighting Power icon, for example, the Lighting Power Remedies window appears, as shown in Figure 3. This window provides five options for correcting the noncompliance situation. The ES-IDT associates information with each of the options to help the designer make a selection. For each option, the ES-IDT rates the likelihood that executing this option will have an impact on the compliance situation and the potential effects on the design. Ideally, the designer would prefer to choose an option that has a high probability of bringing the design into compliance with minimal impact on other spatial, functional or aesthetic decisions.



Lighting Power

	Lighting Power	Lighting Controls	Lighting Ballast
Building Compliance	☑ Comply	☑ Comply	☑ Comply

Type of Adjustment	Compliance Likelihood	Design Impact
Reduce Number of Lights	High	Moderate
Reduce Power	High	Moderate
Change Space Type	Moderate	High
Use Automatic Controls	Moderate	Low
Increase Ceiling Height	Low	High
Increase Floor Area	Low	High

Figure 3. The Lighting Power Remedies window provides five options for bringing the building design closer to compliance with respect to lighting power.

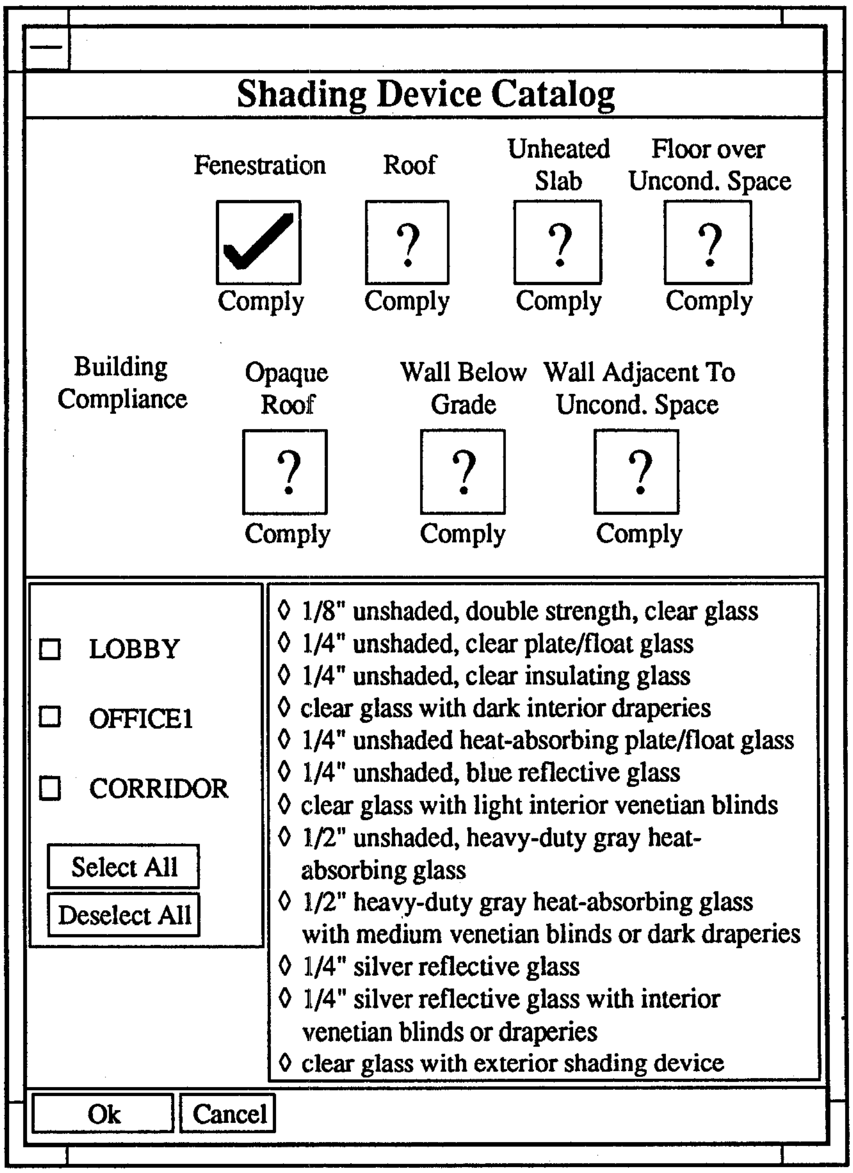
In general, each option uses one of four methods for assisting the architect in bringing a noncomplying design back into compliance: design suggestion, catalog selection, manual design modification, and automatic design modification.

Design Suggestion

At the simplest level, the ES-IDT will recommend specific design changes to improve the energy efficiency of the building design. The designer may choose to act on these recommendations by updating the design using the appropriate tool. As shown in Figure 3, lighting power noncompliance can be improved by following the recommendation to "Reduce Number of Lights" in the building. When selecting this option, the ES-IDT first explains why the building is out of compliance and how reducing the number of lights may help. It then provides the steps necessary to pursue this course of action: return to the drawing tool and delete some of the luminaires that appear in the reflected ceiling plan.

Catalog Selection

The ES-IDT also allows the designer to make design changes while using the energy tool itself. For example, the tool provides a catalog of shading devices that can be applied to the building fenestration. Selection of one of these catalog items changes the overall building shading coefficient, which may increase (or decrease) the building's MAPF. Figure 4 illustrates a catalog of shading devices.



Shading Device Catalog

Fenestration ✓ Comply
Roof ? Comply
Unheated Slab ? Comply
Floor over Uncond. Space ? Comply

Building Compliance
Opaque Roof ? Comply
Wall Below Grade ? Comply
Wall Adjacent To Uncond. Space ? Comply

☐ LOBBY
☐ OFFICE1
☐ CORRIDOR

Select All
Deselect All

◊ 1/8" unshaded, double strength, clear glass
◊ 1/4" unshaded, clear plate/float glass
◊ 1/4" unshaded, clear insulating glass
◊ clear glass with dark interior draperies
◊ 1/4" unshaded heat-absorbing plate/float glass
◊ 1/4" unshaded, blue reflective glass
◊ clear glass with light interior venetian blinds
◊ 1/2" unshaded, heavy-duty gray heat-absorbing glass
◊ 1/2" heavy-duty gray heat-absorbing glass with medium venetian blinds or dark draperies
◊ 1/4" silver reflective glass
◊ 1/4" silver reflective glass with interior venetian blinds or draperies
◊ clear glass with exterior shading device

Ok
Cancel

Figure 4. The Shading Device Catalog window allows the designer to select from among various shading devices for fenestration.

Manual Design Modification

The ES-IDT provides other tools in addition to the catalog selection for making direct design changes. For certain remedial options, the ES-IDT will present a window that allows the designer to change the values of various design parameters in an effort to bring a noncomplying building back into compliance. In Figure 5, for example, the ES-IDT has notified the designer that the building is noncompliant because its fenestration area exceeds the MAPF. The screen allows the designer to make changes to the window head and sill heights, the projection depth, and the projection height. Modifying any of these parameters will have an effect on the fenestration compliance evaluation. By modifying the various parameters, the designer can explore the effect of window and projection configuration on compliance with Standard 90.1.

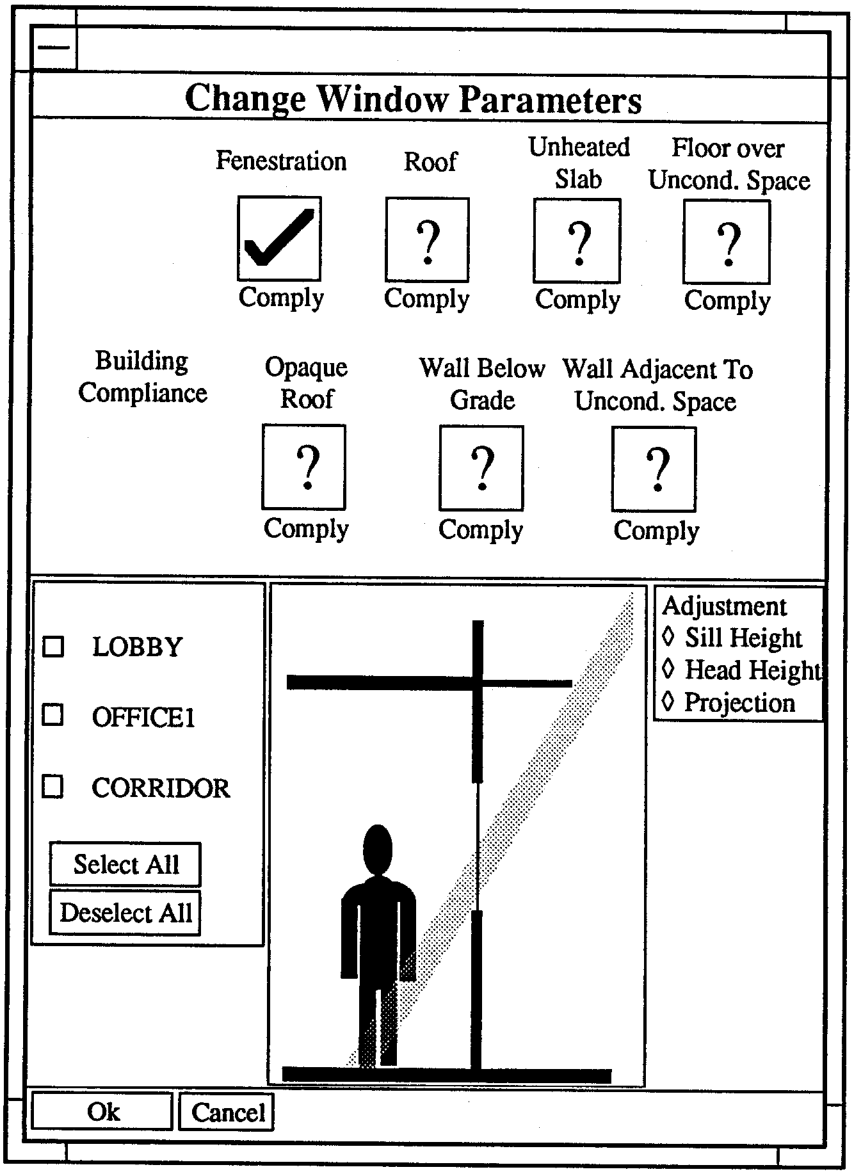


Figure 5. The designer may change various window parameters to increase or decrease the fenestration percentage.

Automatic Design Modification

One other option for design assistance is to allow the ES-IDT to make design changes automatically. Whenever the building fails to comply with Standard 90.1, the computer may modify the design based on its knowledge about remediation of noncompliance situations. In the ES-IDT, this approach is used only in one area: lighting controls. If the number of controls within a space is insufficient according to Standard 90.1, the ES-IDT will automatically increase the number of controls in the space until compliance is achieved. Automatic performance is controlled by a mode switch that the designer may turn on or off for automatic or manual operation.

Summary

Energy standards have become more stringent in an effort to improve energy efficiency in buildings. Despite the increased benefits of these standards, they have also become more complex, requiring tedious calculation and increasing the difficulty of using standards during design. The Energy Standards Intelligent Design Tool is a computer-based tool designed to alleviate the tedium of using energy standards. The ES-IDT not only evaluates building designs for compliance with the ASHRAE/IES Standard 90.1, but offers additional benefits of design integration and design assistance.

The ES-IDT is one component of the first prototype of the Advanced Energy Design and Operation Technologies Project, whose goal is to increase the energy efficiency of the U.S. building stock by emphasizing energy concerns during building design and operation. The AEDOT project is a testbed for advanced technologies, such as artificial intelligence, knowledge representation, analysis, interpretation and visualization. The use of the ES-IDT in AEDOT Prototype 1 provides architects and engineers a tool to ensure energy standards compliance as an integral part of the design process.

Acknowledgements

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