ENERGY ASSESSMENT PROCESS FOR GENERIC MULTISTORY ATRIUM TYPES

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ABSTRACT

In addition to the environment that atriums provide, the daylight admitted into such spaces can be utilized to displace part of the electric lighting load during the daylight periods. While within the atrium itself only the lighting required for circulation or plant growth is displaced, the surrounding perimeter spaces (which are often offices) can also benefit from available daylight that can supplement electric task lighting. If the electric lighting system can be either turned off or dimmed when daylight is available, energy savings can be achieved.

Several prototype atrium configurations within a "standard" building are addressed to study the analysis process for daylighting energy performance. Multi-story atriums of the three-sided, square, and linear types are considered, as are warming and cooling functions for the atrium. The analysis process involves using detailed computer simulations to generate simplified design algorithms. The procedure for incorporating these atrium design strategies into the ENERCALC prediction model developed at Texas A&M University is described along with the rationale and format of the results.

INTRODUCTION

Atrium designs are typically used to address several specific issues concerning aesthetics, thermal conditioning, and lighting. From the viewpoint of aesthetics, atriums are utilized to set mood, define space and provide an environment for growing plants. Thermally, atriums can be used to supplement heating needs or provide breezeways to help with ventilation and cooling. This is a climate sensitive function and must be approached carefully to avoid overheating in the hot and humid climates. The thermal nature of the building must be evaluated along with the climate to determine which approach is to be used for the atrium design. Some of the interactions that must be considered are graphically depicted in the network in Figure 1 [Saxon 1983]. The lighting benefits of an atrium include the general public circulation spaces (e.g., hotel registration desk, cocktail lounge, and leisure space) but can also include lighting of perimeter spaces adjacent to the atrium, such as corridors and offices. This paper describes the procedure for developing algorithms for assessing the daylighting and thermal impacts in both the atrium space and the perimeter spaces.

The illumination criterion for general public circulation space is not very demanding. According to the American IES (Illuminating Engineering Society) Standards, 5 to 20 fc (50 to 200 lux) is sufficient [Stein, Reynolds, and McGuinness 1986]. Most spaces within an atrium, especially those which sustain plant life, will easily meet or surpass 100 percent of this lighting requirement during daytime hours through the use of daylighting. Office spaces, however, require illumination levels of 20 to 100 fc (500 to 1000 lux). It is common to find offices located around the perimeter of atrium spaces. These offices can utilize part of the atrium light to offset some of the office lighting task for significant annual energy savings. Therefore, it is critical to have reliable methods for estimating daylighting contributions not only to the atrium space itself but also to the perimeter office space [Arasteh, Johnson, Selkowitz, and Connel 1985].

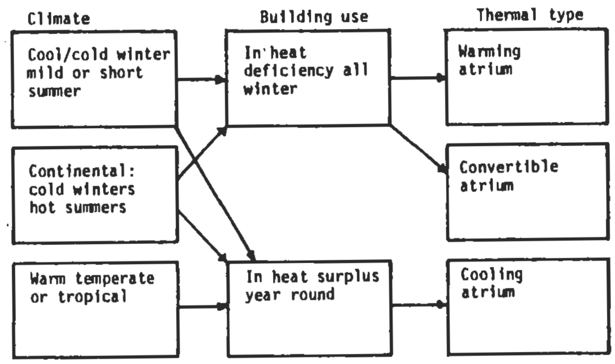

Fig. 1 Atrium Thermal Type Selection [Saxon 1983]

BACKGROUND

Previous work has been directed at predicting daylighting levels within the atrium space by modeling the atrium as a light well [Aaronson 1982, Windheim and Daly 1983, Navvab and Selkowitz 1984]. Some of this previous research produced contour lines of daylight illumination levels both on the atrium floor and on the atrium walls. These results provide a valuable starting point for extending the illumination prediction model beyond the atrium space into the surrounding office spaces.

More recent work at Texas A&M University is targeted at extending the prediction of lighting levels into spaces adjacent to atriums [Boyer and Degelman 1985]. Methods used to measure daylighting levels within the atriums and the correlation between measurements

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and predictive algorithms are described in several publications [Molinelli and Kim 1986, Kim and Boyer 1987, and Kim 1987].

Parallel efforts in the area of algorithm development for annual energy simulation in buildings have also been conducted at Texas A&M University under DOE (Department of Energy) sponsorship, resulting in the development of the ENERCALC computer program [Degelman 1980]. This model includes the prediction of annual energy savings due to daylighting received from vertical windows. The basis of the daylighting level calculations in ENERCALC is an efficacy equation which converts the thermal radiation into luminous flux, after which the interior levels are predicted by a Coefficient of Utilization (CU) method developed by the IES [Libbey-Owens Ford 1976]. This model would be the basis for estimating annual energy savings once the new atrium daylighting algorithms have been incorporated.

DAYLIGHT PREDICTION METHODOLOGIES

The daylight prediction methodologies that are available can be classified into three categories: (1) Daylight availability (exterior horizontal and vertical surfaces), (2) Daylight penetration (function of glazing, structural configuration, and effective transmissivity), and (3) Daylight distribution (that falling on the work surface within the occupied space).

A widely known resource for daylight availability data is the SERI (Solar Energy Research Institute) publication [Robbins and Hunter 1982], which gives illuminance and sunlight probability data for 230 selected U.S. cities. These data are broken into global and diffuse components and are tabulated for clear and overcast skies and for horizontal and vertical surfaces. A second method for estimating available daylight is to apply the efficacy concept, whereby a constant ratio of luminous to thermal flux is assumed to exist for energy received from the sun. Solar radiation models, which are in widespread use, can therefore be used as a predictor of daylight availability. This concept is described in Stein, Reynolds, McGuinness [1986, pp 923-924], and supporting data for this method has been derived by other researchers [Gillette, Pierpoint, and Treado 1982; Treado and Gillette 1982; and also Gillette and Treado 1985]. Values for luminous efficacy are usually expressed in units of lumens per watt.

Daylight penetration may at first be thought of as merely the glazing transmissivity value; however, the glazing support system on atrium covers adds a great deal of shading to the incoming light. Systems such as trusses, space frames, waffle grids, etc. dictate very different light penetration patterns when the light is admitted to the atrium space [Navvab and Selkowitz 1984]. Generally speaking, the models which treat the problem of daylight penetration utilize an overall value known as effective transmissivity, or transmission efficiency. When multiplied by the incoming light flux, this value adjusts the source to an average amount admitted to the atrium space.

Once light has been admitted to the space, a daylight distribution model must be applied to determine the amount of light ultimately utilized on the work plane. Several models have been employed to estimate this distribution. The IES Lumen model [Libbey-Owens Ford 1976] utilizes a Coefficient of Utilization (CU) to estimate the fraction of light which penetrates the space to varying depths. An alternative method is known as the Flux Transfer Daylight Factor (FDF) method which expresses the internal illuminance as a percentage of the external illuminance normal to the aperture surface [Robbins, Carlisle, Hunter and Wortman 1987]. This method should not be confused with the traditional Daylight Factor (DF) method which deals with only diffuse sky contributions.

The above three steps will remain as the key procedures to be followed in the derived prediction models developed in this work.

GENERIC ATRIUM TYPES

The three generic atriums to be used in this study have been described by Kim [1987], representing the three-sided, four-sided, and the linear atriums. These are generally regarded as prototypical for multistory buildings using atriums, and are illustrated in Fig. 2. Several correlations have already been made between daylight level measurements obtained in buildings and in models. The model measurements will be extended with the generic atriums so additional data can be generated to validate the numerical model. The main concept here is the "clip-on module" (see Fig. 3), which is a model of a "standard" furnished room that can be moved to any horizontal or vertical position on the walls of a multistory atrium. The plans and sections in Fig. 4 indicate the positions of interest where the majority of station points will be located.

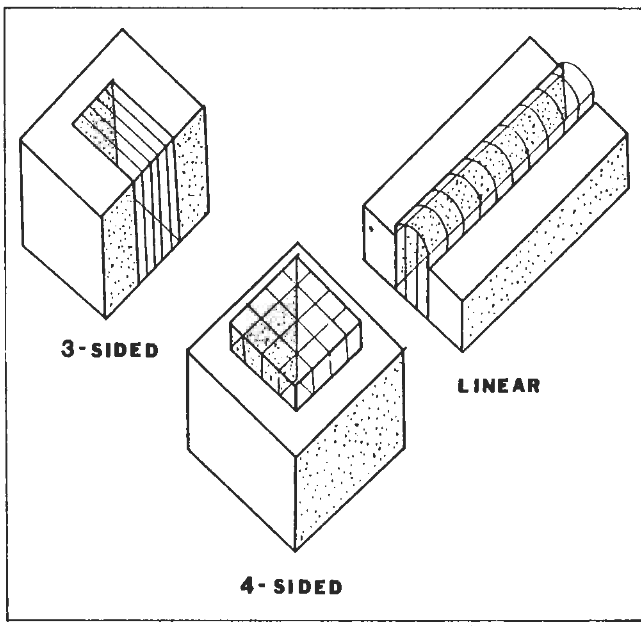

Fig. 2 Generic Forms of Atrium Buildings [Kim 1987]

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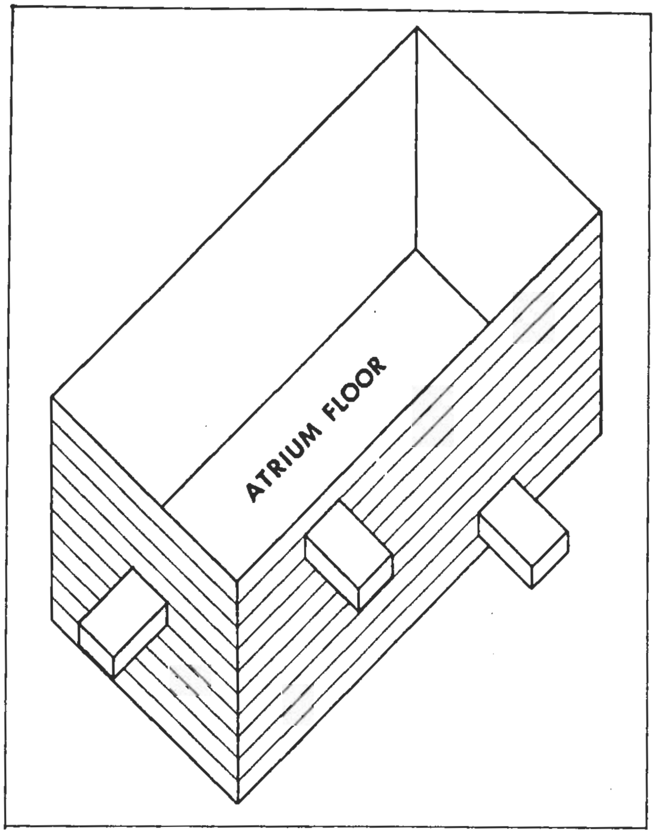

Fig. 3 Clip-On Office Module Concept for Daylight Model Study [Kim 1987]

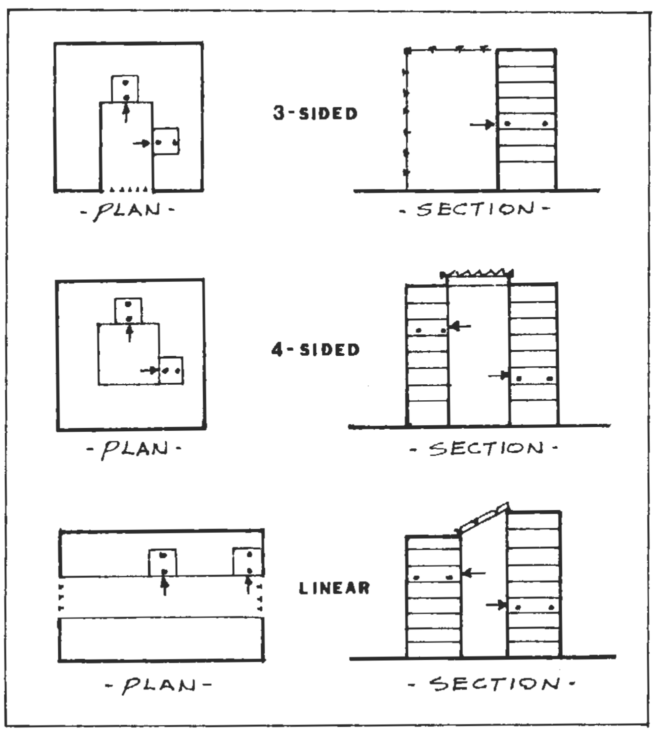

Fig. 4 Typical Measurement Locations for Offices Adjoining Atriums

ENERGY SAVINGS PREDICTION MODEL

At present, the prediction algorithms for daylight levels throughout an atrium space have been developed for the generic atrium. The next step is to extend the algorithms to the adjacent space: such as perimeter offices. After correlations have been made between the lighting levels in the clip-on office module and detailed computer algorithms, then the algorithms will be incorporated into the existing ENERCALC energy simulation model. The model will then be exercized using a variety of atrium design scenarios to assess the impact on annual energy consumed for lighting, space heating, and space cooling. The detailed simulations will be executed for a logical range of design variations so that simplified algorithms can be derived from the results. In this manner, a set of streamlined algorithms, nomographs, or charts will eventually be developed for implementation in the form of a design manual. Some preliminary work on this area has been documented by Boyer [1981, 1986].

Essentially, the overall algorithm encompasses the two functions depicted in Fig. 5 which shows the forms for deriving (1) daylight illumination in a space and (2) annual energy savings for lighting and cooling. The second part of this algorithm is a detailed annualized simulation of the total building performance in a specified climate, and not just an evaluation of lighting alone. As such, it entails many facets of the building envelope, mechanical system, and controls that are outside the normal realm of daylighting. These conditions, however, are highly critical to an accurate expression of annual energy usage and must be included. Several available energy simulation computer programs could conceivably handle this part of the model formulation.

The development of the algorithm entails four parts:

1. Available illumination can be obtained from the SERI data base [Robbins and Hunter 1982]. However, since there are a finite number of cities within the data base, an attempt will be made to determine the dependability of the efficacy concept. If this concept can be applied universally, then the more prevalent thermal radiation modeling can be carried out, and conversions can be made to luminous values within the simulation model on an hourly basis. Preliminary tests to compare the SERI values to those derived from efficacy calculations in the ENERCALC model are shown in Fig. 6 for March and September for Austin, TX. A large group of the cities in the SERI data base will be evaluated before final conclusions can be made on applying this concept, especially for vertical surfaces.

2. The second step in the algorithm involves the transmission efficiency of the atrium cover and wall fenestration system. Glazing transmissivities are routinely published by the glazing manufacturers. However, atrium enclosure systems can vary significantly, and these are much less documented. About 14 atrium covers have been examined by Navvab and Selkowitz [1984], including roof monitors, single-barrel

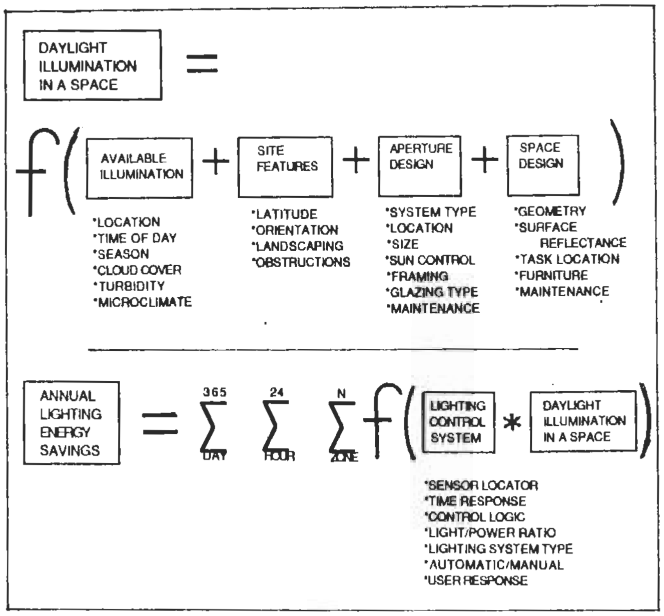

Fig. 5 Algorithm Forms for Energy Assessment in Atriums

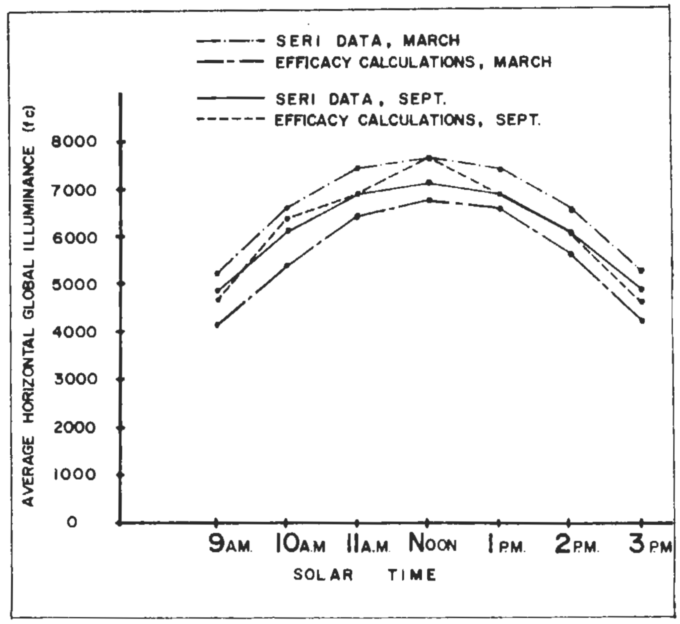

Fig. 6 Comparison of Illuminance Derived From Efficacy Calculations to the Illuminance From the SERI Data Base (Austin: Mar & Sept)

vaults, A-frames, pyramids, and flat clear glazings. Results indicate that "system transmittances" range from around 30 percent for the monitor type roof to about 90 percent for the A-frame type roof. Presumably, the light transmissivity of tinted glazings could be simply multiplied by these system transmittances to obtain an overall "atrium cover transmissivity". These measured ranges currently appear to be applicable, but a more comprehensive list would have to be developed as backup data for the design guide.

3. The next step in the algorithm is to determine the daylight illumination levels within the atrium space -- both at the atrium floor level and on the atrium walls at each story level. This part of the model has had extensive development under the current NSF research project [Royer and Degelman 1985] in the form of actual building measurements and model testing under an artificial sky. Algorithms developed for the three generic atriums for floor and wall daylight contributions have been documented in Kim's dissertation [1987]. These models will continue to be confirmed as the remainder of the project progresses toward its final conclusion.

4. Step 4 will be to predict the daylight penetrating into the perimeter office space and falling on the work plane. The atrium windows, room geometry, room furnishings, and room color are the prime determinants to the amount of inter-reflections that account for the level of usable daylight within the space. The CU (Coefficient of Utilization) and the FDF (Flux Transfer Daylight Factor) models will both be used as candidates for this application. Final selection of the model for this calculation will be based on its ability to perform consistently and on its clarity and ease of application in a simplified algorithm. (See Fig. 7.)

OPTIMIZATION APPLICATIONS

Use of atrium daylight is acknowledged as contributing to the saving of electrical lighting energy. Indiscriminate designs, however , can result in "more than sufficient" light causing glare problems and the likelihood that the atrium will increase (rather than decrease) the overall building energy use due to the creation of excessive heating and/or cooling loads over the annual period. The strategy behind atrium design, therefore, calls for an optimization process whereby the glazing sizes, tints, and orientations can be varied in such a way as to bring about a minimum life-cycle cost. It is only through the use of reliable algorithms that the annualized energy results of an atrium can be properly evaluated. The algorithms being developed under this research project are intended to contribute to the base of analysis tools that makes this type of design and evaluation possible.

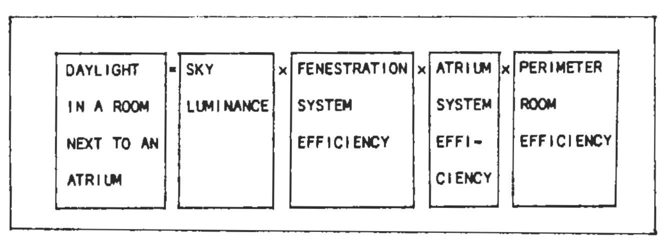

Fig. 7 Coefficient of Utilization (CU) Approach

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