CHAPTER 2
THEORIES

2.1 Daylight Design in Atrium Building

The atrium or enclosed courtyard forms a key element in many recent building designs. One of the perceived advantages of the atrium is that it is seen as bringing natural light into the core of a building.

A previous paper (Littlefair and Aizlewood, 1998) describes current guidance on daylighting of atrium buildings. This can be summarized as follows:

- Atrium shape is a key parameter. A deep, narrow atrium will be poorly lit. Splaying the atrium, so that the top is wider than the bottom, will give more daylight potential.
- High reflectance in the atrium, particularly at the higher levels, will boost inter-reflected light. This can be achieved by reducing the glazing or aperture area in the walls towards the top of the atrium, or by using reflective glazing in these areas.
- Glazing areas need to be chosen with care to admit enough daylight without excessive solar heat gain.
- Planting can be attractive, but many plants require high illuminances (Baker et al., 1993). To avoid excessive supplementary electric lighting, it is best to choose those plants which can survive at lower light levels.
- Internal obstructions, such as walkways, cleaning cradles, glazing bars and structural members can significantly reduce the daylight available in the atrium. Measurements in real atria (Littlefair and Aizlewood, 1998) suggest that half or more light can be blocked. The effective transmittance depends on the angle of view. Areas toward the top of the atrium tend to be more affected than the base.
- Getting light into spaces adjoining the atrium can be difficult.
- Solar shading of spaces adjoining the atrium need to be considered if glare is an issue, as it is in offices. Blinds or baffles will be needed if sunlight can reach these spaces through the atrium.

- Effective control of electric lighting in an atrium is essential if the full benefits of daylight are to be realized. Since building occupants do not expect to have control over the lighting in an atrium, automatic (photoelectric) control is often the best.

2.2 Prediction Techniques

Predicting the distribution of daylight levels in an atrium and its adjoining spaces can be difficult. Three techniques can be used:

- Model studies
- Computer simulation
- Analytical formulae

In scale model studies (Littlefair, 1993), it is possible to assess the visual impact of the system as well as to measure the light admitted. To check whether enough daylight reaches the interior and that there are no gloomy areas, an overcast sky study in an artificial sky is the easiest. To assess solar shading or glare protection, the real sun or heliodon can be used with a sun dial, and assessment made visually, coupled with internal luminance measurements if required.

For the model used in daylight measurements, the following guidelines need to be followed (in order of importance):

- The entire building surface must be present.
- Access is needed inside the model for measurement and visualization.
- Reflectance must be correct. Often models are too light colored, which can be a big source of error.
- The model should be light-tight.
- External obstructions should be modeled accurately, both in (scale) size and reflectance.
- Window details such as atrium roof structure should be modeled if possible.
- The scale of the model needs to be chosen with care. A very big or very small model is hard to test 1:40 is a good compromise.

- Plan measurement positions in advance (not too many).

Some computer programs can calculate the daylight factor at the base of an atrium. Most use the "point-to-point" or "radiosity" algorithm. All modeled surfaces are divided into a number of elements, assumed perfectly accurate and quick to compute. To model complex spaces with significant specular reflection, "ray tracing" programs have been developed. One such program is RADIANCE (Ward, 1994). This technique requires far more computer power than a radiosity calculation, but in principle should be more accurate since surface may be diffuse, specular or of any semi-specular nature.

Measurements in an atrium model by BRE were compared with RADIANCE's predictions (Aizlewood et al., 1997). For the sky component at the base of the atrium, there was complete agreement between the predictions and the measurements. However, RADIANCE underestimated the reflected light in deep, high reflectance atria. Although the relative error is not large, this is a matter of some concern because there is no clear explanation for it (Aizlewood et al., 1997).

The other way to estimate daylight in an atrium is to use an analytical formula. This is considered in detail in the next section.

2.3 Formulae to Predict Daylight in Atria

Many authors have produced formulae or diagrams to predict the daylight factor within atria. Usually these are based on the scale model measurements or computer simulations. Aizlewood (1995) has reviewed them in detail.

The British standard code of practice for daylighting (1992) uses the average daylight factor DF_{av} (Littlefair, 1988: Lynes, 1979) as a way to judge a daylit space. The daylight factor is the ratio of internal illuminance to external horizontal unobstructed illuminance; DF_{av} is the average over the atrium base. If an atrium is to look well daylit, then DF_{av} should be 5% or more.

The average daylight factor on the base of the atrium can be calculated using the following formula (Littlefair, 1998):

$$DF_{av} = \frac{w \cdot T_g \cdot T_f \cdot \theta}{A \cdot (1 - R^2)} \tag{2.1}$$

and the average daylight factor over all the atrium surfaces (Lynes, 1979) is given by

$$DF_{avs} = \frac{w \cdot T_g \cdot T_f \cdot \theta}{2 \cdot A \cdot (1 - R)} \tag{2.2}$$

where w is the area of the atrium roof aperture (m^2). T_g is the diffuse visible transmittance of the glazing, corrected for dirt on the glazing. Provision must be made for cleaning the atrium glazing. T_f is a factor to allow for light blocked by the atrium roof structure. θ is the angle of visible sky in degrees, measured as shown in Fig. 2.1. For a completely unobstructed horizontal roof this gives θ as 180°. In fact, 200° would be a better approximation here. A is the total area of the atrium surfaces: roof, floor, walls and windows (m^2). If the atrium sides are open, they should be included in A by adding in the area of imaginary atrium walls. R is the average reflectance of these surfaces. For many atria, R is fairly low. Even if the atrium wells are white (reflectance 0.8), the roof and side glazing (reflectance 0.15 single, 0.3 double) will reduce the average. If the atrium sides are open, their reflectance is taken to be 0. Typical average values of R are 0.3 to 0.4.

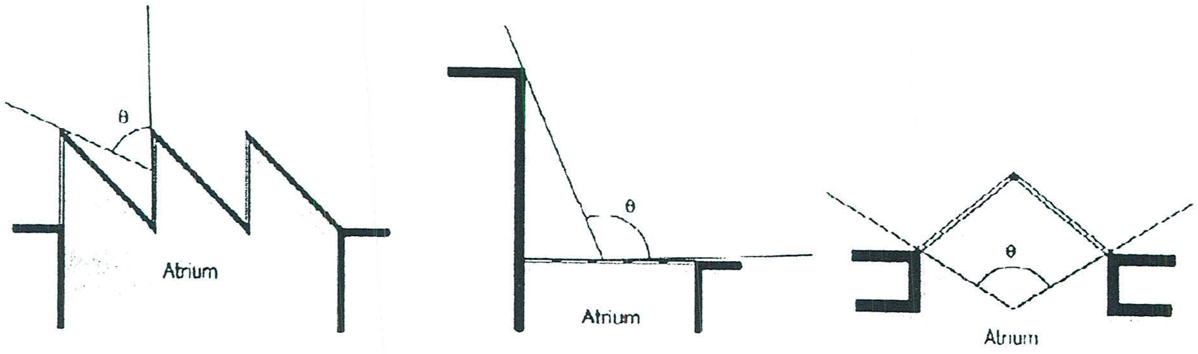

Figure 2.1 θ is the angle of visible sky (in degrees) viewed in a vertical section from the centre of the atrium roof aperture.

These equations are most accurate for fairly shallow atria (width at least half their height). If an atrium has both roof and side glazing, the average daylight factor due to each is calculated separately, then the two are added together.

The advantage of the average daylight factor is that it can give a single number which summarizes the overall daylit appearance of the atrium. However, it does not give information about the detailed distribution of light which is also important.

The daylight factor on the walls of the atrium is of particular interest because it is related to the amount of light entering adjoining spaces.

The contribution from the atrium to the average daylight factor DF_{sav} in the adjoining space is then given by (Littlefair and Aizlewood, 1998):

$$DF_{sav} = \frac{2 \cdot A_w \cdot T_s \cdot DF_v}{A_s \cdot (1 - R_s^2)} \qquad (2.3)$$

where A_w is the net area of the glazing between the space and the atrium (m^2). T_s is the diffuse visible transmittance of this glazing. For clean clear single glass, a value of 0.8 can be used; for double glazing 0.65; for no glazing 1.0. A_s is the total area (m^2) of the room surface: ceiling, floor, walls and window, including those of the atrium. R_s is the average reflectance of the room. A typical value is 0.5 for a light colored space.

Often an adjoining room would also be lit from outside of the building. The average daylight factor from each set of glazing can simply be added together.

The average daylight factor measures the amount of daylight in the adjoining space. However, the distribution of this light is also very important. Light from an atrium may not go very far into an adjoining space. The depth to which daylight penetrates into an adjoining space can be roughly estimated using the no skyline (Littlefair, 1991). The skyline divides those areas of the working plane that can receive direct skylight from those that cannot receive any. Areas beyond the no-skyline will generally look gloomy (Lynes, 1979), and supplementary electric lighting will be required. Figure 2.2 shows typically no skyline in an atrium building.

The penetration of daylight into the adjoining space can be improved by:

- Increasing the head height of the apertures between the adjoining spaces and the atrium
- Higher reflectance both in the atrium and the adjoining spaces to increase the amount of reflected light
- Innovative glazing systems (Littlefair, 1996), such as light scoops and shelves, can distribute light from the atrium into adjoining spaces, particularly with splayed atrium walls, where the top floors are set back. They can also decrease the contrast between the very bright areas next to the atrium and the darker areas further in.
- Changing the roof profile to admit more light from the side.

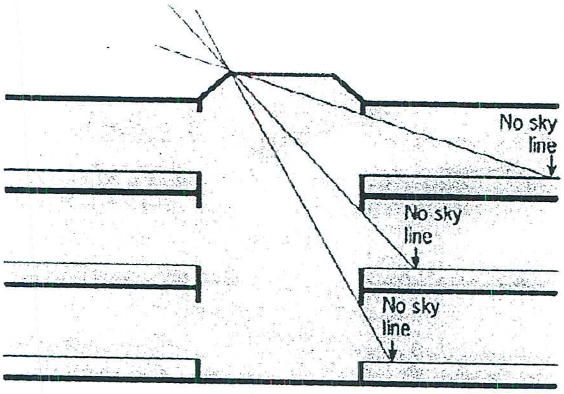

Figure 2.2 No skyline in an atrium building

Previous works suggest that the behavior of light in atrium spaces depends mainly on the configuration of the atria and can be expressed in terms of the Well index. The Well index is similar to the cavity ratio in interior electric lighting calculations and has been applied to daylighting performance methods to evaluate the well efficacy of the skylighted space. The well index is used to describe the shape of the atrium that represents the relationship between the light admitting area and the surface of the atrium.

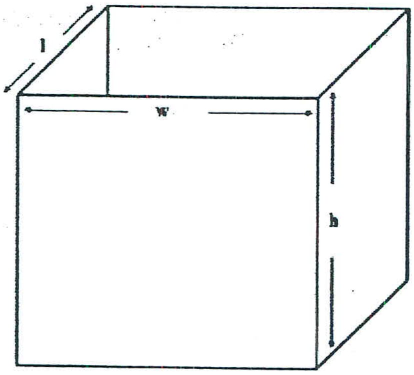

Figure 2.3 WI definitions.

$$\mathrm{WI} = \frac{h(w+l)}{2wl} \quad \text{(Rectangular atrium)} \tag{2.4}$$

$$\mathrm{WI} = \frac{h}{w} \quad \text{(Square atrium)} \tag{2.5}$$