of a full year. It is proposed that this second method offers a true measure of solar access because it accounts for the totality of illumination (light from the sun and the sky over a period of a full year) and presents it as a definite, numerical value.

The cumulative light energy over a period of a full year is called the *total annual irradiation* which has units of Watt-hours per m^2 (per year). It has a visual equivalent called the total annual illumination which has units of lux-hours (per year). Equating solar access with total annual irradiation (or illumination) is consistent with the prevailing experience of daylight where the sky and sun together interact with the urban form to create the luminous environment. Daylight, as noted, is subject to enormous variation, and 'snapshot' evaluations (i.e. shading patterns on particular day) reveal little about the prevailing conditions. Thus a period of a full year is needed to account for the hour-by-hour, day-by-day and seasonal variability that sky and sun conditions are subject to. Any shorter period would introduce biases and be unrepresentative.

How then can we begin to investigate solar access (defined as total annual irradiation) in urban settings? In principle, it would be a straightforward matter to measure the total annual irradiation (or illumination) at an actual location by recording the incident irradiance (or illuminance) over a complete 12-month period. The total (annual) irradiation is simply the integral over time of all the measured irradiances. Of course, in practice maintaining a single recording instrument over a full year would be a costly as well as lengthy exercise. Also, a large number of locations would need to be measured to gain any insight into how the solar access is related to the urban form. Furthermore, it is preferable to have the predictions of total annual irradiation founded on reference meteorological datasets, which would allow for meaningful comparison between examples. At first sight, physical modelling using one of the latest generation sky simulator domes (SSDs) seems capable of delivering predictions of total annual illumination. Here, a scale model of an urban setting could be 'wired-up' with illuminance metres and the brightness pattern of the SSD could be generated from a reference meteorological dataset. The 4000 or so daylight hours of the year could, in principle, be modelled fairly swiftly using 'accelerated days'. However, SSDs were discovered to be inherently subject to parallax errors (Mardaljevic, 2002a) and the rapid changing of lamp output to mimic 'accelerated days' is considered problematic due to calibration and stability issues. Physical modelling is therefore not considered a practical method for predicting total annual irradiation. Computer simulation offers a far more effective, reliable and consistent approach to predict and investigate total annual irradiation than physical measurements in either real or scale model settings. A computer-based method to predict total annual irradiation in arbitrarily complex urban settings has recently been developed by the author (Mardaljevic and Rylatt, 2003). The design goals for the new approach are as follows:

- **To accurately predict the total annual incident irradiation/ illumination on surfaces (e.g. ground, building) based on hourly meteorological data. To provide facility to compute any temporal or source component of total annual irradiation, for example seasonal, direct sun only**
- **To include the contributions of realistic sky patterns as well as radiation from the sun**
- **To account for shading of and inter-reflections between buildings**
- **To present results as images**
- **To extract geometrical information from the images to allow for quantitative assessment of the surface area associated with each pixel**

These aims have been realised in a simulation approach that uses the state-of-the-art rendering and data visualization techniques. The new approach is called *Irradiation mapping for Complex Urban Environments* or ICUE.[4] The ICUE approach is currently implemented in software on a UNIX workstation as an 'expert-user' tool for proof-of-concept, demonstration and research. The ICUE simulation system is a suite of programs and scripts to initiate, process and view irradiation images. The underlying numerical 'engine' for ICUE is the rigorously validated (UNIX) *Radiance* lighting simulation system (Ward, 1998). The theoretical basis for ICUE is derived from the work carried out by the author on lighting simulation, validation and data analysis/visualization (Mardaljevic, 1995; 1997; 2001; 2002b).

The data requirements for the ICUE simulation are a three-dimensional (3D) model of the urban setting (i.e. building geometry and surface reflectivities) and a meteorological dataset for that locale. If the surface reflectivities are not known, then typical values for building materials should be assumed. A series of example results using the ICUE approach are given in the next section. For the remainder of this chapter, solar access will be taken to mean either the total annual irradiation or the total annual illumination depending on the context.